Running head: WAIST-TO-HIP RATIO

The Functional Significance of Waist-to-hip Ratio

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Submitted in partial fulfilment of degree of Doctor of Philosophy, Clinical Psychology

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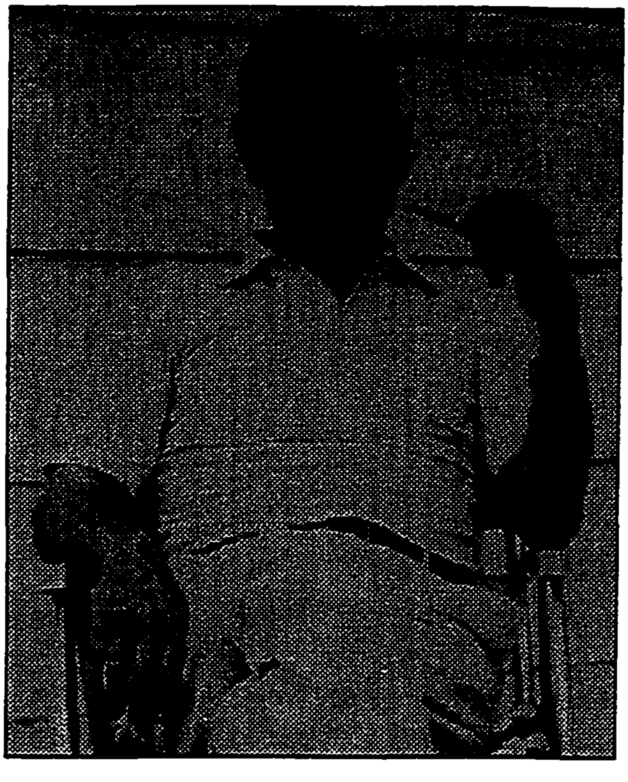
Acknowledgements

Thanks to everyone who has invested in me.

Dedication



In memory of Roy Dixon Butler

15 November 1919 – 6 February 2002

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Abstract

Waist-to-hip ratio (WHR) may be important and highly visible "honest advertisement" of general and reproductive health and, hence, physical attractiveness. Research shows that men and women aged 18-86 agree on what constitutes attractive WHRs: .7 for women and .9 for men. However, stimuli used in previous studies confound weight with WHR because the line drawings or photographs are altered to yield a range of WHRs and the actual body mass index (BMI) is not available. The purpose of the present study was to compare the predictive power of WHR and BMI in explaining the variance in attractiveness judgements. Unretouched photographs of men and women that varied by WHR and BMI were rated by men and women on several dimensions (masculine, feminine, good-looking, sexy, intelligent, interested in having children, capable of having children, age, weight, weight category, attractiveness for marriage, attractiveness for brief casual sex) and ranked according to global preference. Results showed that photographs of WHRs of .7 for females and only .8 for males were seen as most attractive. However, ratings of attractiveness were largely determined by BMI of the person pictured, although WHR was a sole predictor of age estimates and masculinity ratings. People with high BMIs were generally seen as less attractive and less intelligent. Raters, particularly women, were quite accurate at estimating the weight of people pictured. Ratings were largely consistent across rater characteristics, including sex, and ratings (pictures presented in random order one at a time) and rankings (pictures presented in random order simultaneously). Self-report anthropometric measurements were also found to be fairly reliable. These results suggest that BMI, not WHR, may be the best predictor of judgements of physical attractiveness.

The Functional Significance of Waist-to-hip Ratio

What makes people attractive? Many would reply that judgements of physical beauty and attractiveness are purely subjective and that the quality of beauty is elusive and fleeting, as manifested in centuries of poetry, prose, verse, and art. Although most are sure whether or not they find someone attractive, people are often hard-pressed to precisely describe just what balance of characteristics determined their opinion. Perhaps idiosyncratic notions are more romantic because they seem mysterious. Some might argue that uncovering how people make attractiveness judgements devalues the whole endeavour.

Henss (1995) suggests that this notion of ever-changing standards of beauty has "seriously hampered. . . scientific progress" (p.479). He cites high concordance and cross-cultural similarity of judgements of facial attractiveness to counter more romantic ideas of fleeting and subjective standards. Other physical features that have been investigated in relation to attractiveness include facial symmetry (e.g., Gangestad, Thornhill, & Yeo, 1994; Montgomerie, 2000), how well a face approximates a hypothetical average (e.g., Jones & Hill, 1993), and similarity to oneself (Feingold, 1990). Although facial features are an indication of parasite resistance and quality of growth, they convey less information about current reproductive health or capacity. Reproductive status is arguably a more pressing concern, the ability to reproduce viable offspring having been the blind ambition of organisms as long as they have existed (Dawkins, 1989). Thus, bodily, rather than facial, attractiveness may be more salient in helping people to form judgements of attractiveness (Furnham, Tan, & McManus, 1997). The current work will discuss how recent evidence suggests that men and women often use the same parameters in deciding whether they find someone attractive. Furthermore, as detailed below, such parameters are not ends in themselves, but seem to yield a wealth of information about health and reproductive status.

In contrast to work using solely facial judgements, the current work will examine an equally observable characteristic that seems to better account for variations in men and women's choices of desirable figures: waist-to-hip ratio (WHR). This work aims to clarify the role this information may play in shaping people's attractiveness judgements, as well as the meaning people extract from differences in this dimension. What is the normative distribution of WHRs in men and women? When we address problems in methodology, will the present results replicate previous findings? Can people detect these differences in WHR?

The Mechanics of WHR

To obtain WHR, a person's waist and hip girths are measured, and the former is divided by the latter, yielding a ratio that captures the relative amount of upper- and lower-body accumulations and intra- versus extra-abdominal fat (Singh, 1993a). Hips are always measured at the widest point, but the location of waist measurements differs slightly across investigations. The midpoint of the iliac crest and the lowest rib seems a popular choice (e.g., Davis & Cerullo, 1996; Lapidus, Bengtsson, Hällström, & Björntorp, 1989; Singh, 1993a), as do measures of the waist at the level of the umbilicus (e.g., Bell, Summerson, Spangler, & Konen, 1998; Laws, King, Haskell, & Reaven, 1993; Ravaja, Keltikangas-Järvinen, & Viikari, 1998; Zaadstra et al., 1993) and at the narrowest point (e.g., Joiner, Vohs, & Schmidt, 2000; Lippa, 1983; Radke-Sharpe, Whitney-Saltiel, & Rodin, 1990; Räikkönen, Hautanen, & Keltikangas-Järvinen, 1994).

If the narrowest point is not evident as in the case of morbidly obese individuals, some researchers (e.g., Keller, Chintapalli, & Lancaster, 1999) use the iliac crest-rib midpoint.

In most investigations, waist and hip measurements are taken by experimenters. However, a few investigators have allowed their experimental participants to measure their own WHRs using standardized measuring tapes and diagrammed instructions (e.g., Joiner, Vohs, & Schmidt, 2000; Marmot et al.,1998; Radke-Sharpe, Whitney-Saltiel, & Rodin, 1990; Singh et al., 1999). Radke-Sharpe et al. report that women's self-reported measurements are reliable and valid, creating valid WHR estimates for people who are not morbidly obese (i.e., they are able to determine the narrowest part of their torso as their waist). The reliability and validity of men's self-measurement has yet to be reported.

WHR has been called "the most parsimonious measure of bodily physical attractiveness" (Furnham et al., 1997, p.539). WHR is also the most widely known method for determining body fat distribution (Keller, Chintapalli, & Lancaster, 1999). Uncorrelated with overall body weight (Singh & Luis, 1995), this proportion is stable over time and enjoys high correlations with direct measures of intra-abdominal, subcutaneous fat, and deep abdominal fat (Singh, 1993b). Singh considers WHR the most valid measure of health in the epidemiological realm for women. WHR research has been conducted on two main fronts, which are detailed below. The first is epidemiological quantification in relation to health risks, with relative physical attractiveness constituting the second area of interest. Secondly, health-related work has identified diseases with which a relatively high WHR is associated, a normative distribution of WHR, and cutoffs above which WHR is considered a health risk.

A discussion of the development and measurement of WHR will afford a better understanding of the implications of research linking WHR to health, attraction, and reproduction. The main difference between the appearance of adult male and female bodies is their fat distribution (Singh, 1993b). Boys and girls have similar WHRs and body shapes. Women's "gynoid" distribution is formed by fat accumulating on the hips, buttocks, and thighs, also known as the gluteofemoral region. Men's "android" carriage is due to fat deposits in more central locations, "intra-abdominally," and the upper body, including the shoulders, abdomen, and nape of the neck. These distributions and how the body uses these deposits are under the hormonal control of estrogens in women and testosterone in men. These steroid hormones stimulate fat deposition in the appropriate areas and inhibit fat accumulation in the areas appropriate for the opposite sex. Compared to the rest of the body, lipoprotein lipase activity is two to four times higher in the abdominal area, with four times the number of glucocorticoid receptors in intra-abdominal fat (Thakore, Richards, Reznek, Martin, & Dinan, 1997). In addition, central fat is a reflection of greater visceral fat, which has a richer blood supply and the aforementioned greater concentration of glucocorticoid receptors, making it particularly responsive to circulating cortisol, which triggers increases in visceral fat size (Epel et al., 2000). Thus, steroid release affects fat deposition. Disorders with elevated glucocorticoids include endocrine disorders like obesity, Cushing's syndrome, and severe recurrent depression (Epel et al., 2000; Thakore et al., 1997).

Men's and women's WHR measurements form a bimodal and generally non-overlapping distribution between the sexes (Singh, 1995a). This dimorphism is unique to humans among primates. The gynoid and android patterns exist in all climates and societies. Without pathology or artificial means, fat distribution is difficult to change through, for example, dieting (Tovée, Mason, Emery, McCluskey, & Cohen-Tovée, 1997; Zaadstra et al., 1993). However, women's WHRs become more masculine after menopause (Singh, 1993b), unless estrogen is replaced artificially. In a sample of postmenopausal women, Laws et al (1993) found that WHR averaged a masculine .9 (SD = .081), with a range of .687 to 1.105. Also, as men age, their production of testosterone declines, encouraging abdominal accumulations of adipose tissue (Singh, 1995a). Men and women with certain medical conditions that affect neuroendocrine regulation or production (e.g., hypogonadism, Klinefelter's syndrome, advanced cirrhosis) develop the opposite-sex distribution, as do male and female transsexuals on hormone therapy. In an investigation of lesbian women, self-described "butch" women had relatively higher WHRs, along with higher saliva testosterone, more reported gender-atypical behaviour as children, and less desire to have children (Singh, Vidaurri, Zambarano, & Dabbs, 1999). Finally, WHR has a heritability of .50 (Epel et al., 2000), which suggests a moderate degree of genetic influence.

Normatively speaking, the literature paints a fairly consistent picture of WHRs, but information on the shape of distributions is often lacking (see Table 1 for a summary). Davis and Cerullo (1996) report healthy premenopausal women having WHRs lower than .8 and their male counterparts' WHRs ranging from .85 to .95. WHRs for reproductive age women ranged between .67 and .80 (Lanska, Lanska, Hartz, & Rimm, 1985) and, for reproductive age men, between .85 - .95 (Jones, Hunt, Brown, & Norgan, 1986). An aggregate of three studies, including one from the early 1940s, depicts the WHR of healthy premenopausal women as ranging from .67 to .80, with two studies of men also ranging from .85 to .95 (Singh, 1993b). Lippa (1983) reports a mean WHR of .86 for his 39 male participants and .75 for his 47 female participants. Seventy-seven women aged 21 to 50 averaged .75 (Radke-Sharpe, Whitney-Saltiel, & Rodin, 1990). A sample of 64 healthy, middle-aged men who were lean or moderately obese had an average WHR of .92 (Räikkönen, Hautanen, & Keltikangas-Järvinen, 1994). Three hundred healthy middle-aged women had an average WHR of .8, with a range of .53 to 1.44 (Horsten, Wamala, Vingerhoets, & Orth-Gomer, 1997).

Another 535 healthy premenopausal women had an average WHR of .77, narrowly ranging from .76 to .78 (Simkin-Silverman et al., 1995). Although women were randomly selected from a voter's list, a seemingly "representative" choice of sampling method, it was limited to "selected zip codes" in a county in Pennsylvania, perhaps curtailing its reflection of the general population. Also, participants' ages were limited to 44-50 years because the study evaluated an intervention to lower postmenopausal cardiovascular risks.

Particularly telling are results by Marmot et al. (1998) because they used the MIDUS sample, a U.S. nationally representative noninstitutionalized sample of people aged 25 to 74 who have telephones. Their obtained mean WHRs were .83 for women and .96 for men. In a sample of men and women with Type 2 (non-insulin dependent) diabetes mellitus, average WHRs were .96 and .90, respectively (Bell et al., 1998). In this last case, perhaps the relatively high averages could be attributed to the sample's health condition, or it may reflect that people with high WHRs are at greater risk for diabetes.

In Australia, WHRs of greater than .9 for men and .8 in women are considered "undesirable" in terms of health risk (Sharpe & Hills, 1998). People who exceed these figures are considered "centrally obese." Their sample of chronically mentally ill patients, for whom obesity is two to four times more likely than the general population, had an average WHR of .99 (SD = .1) for males and .95 (SD = .06) for females.

Although Keller, Chintapalli, and Lancaster (1999) claim that different ethnic groups have different body fat distributions, their sample of Mexican American women had an average WHR of .88, with a range of .75 to 1.10 and standard deviation of .07. While this figure is somewhat high relative to other figures, the sample consisted entirely of women scheduled for abdominal CT scans for gynecological or renal diagnosis. Such health factors, as we will see, may be linked to higher WHRs, possibly supporting the idea that WHR is an "honest advertisement" of physical health.

In addition, Singh and Luis (1995) are somewhat critical of what they call the "western consensus that obese women are considered attractive by [Black North Americans] and. . . societies from nonwestern developing countries" (p.51). They report that WHR attractiveness to Indonesians and Black Americans is consistent with previous findings based on Caucasian samples, that normal weight figures with feminine WHRs are considered the most attractive, healthy, and youthful. However, actual samples of Black Americans (female M = .75, male M = .84) and Mexican Americans (female M = .84, male M = .94) are statistically higher than Caucasians (female M = .73, male M = .82), though the difference between the Black American and Caucasian sample seems hardly worth mentioning in the practical sense. It has yet to be determined whether people can reliably detect a .02 difference in WHR.

In summary, epidemiological research has established protocols for measuring WHR and includes an number of reports of normative proportions from across cultures. Men and women show sex-typed body shapes. An opposite-sex fat distribution (i.e., a curvy shape in men and a tubular shape in women) is associated with a number of conditions in which reproductive hormones are functioning poorly.

WHR as an Indicator of Health and Obesity

Studies of the health risks associated with higher WHR often focus on cardiovascular disease, but also include mental disorders and even venture into the domain of personality. Body location of adipose tissue has been reported as a risk factor for coronary heart disease in men and women, Type 2 (non-insulin dependent) diabetes, elevated cholesterol (very low density and low density lipoproteins), apoprotein, insulin resistance, and hypertension (Keller, Chintapalli, & Lancaster, 1999). Other reported risks of high WHR include susceptibility to cardiac arrhythmia, higher risk of breast cancer, lower chance of conception (Davis & Cerullo, 1996), higher risk of infectious respiratory and abdominal disease (Lapidus et al., 1989), and higher rates of mortality (Marmot et al., 1998). Milligan et al. (1997) found a positive association, especially in women, between WHR and total cholesterol, which was also negatively associated with fitness.

Simkin-Silverman et al. (1995), mentioned above, implemented a dietary and exercise intervention with premenopausal women, aiming to reduce their risk of postmenopausal coronary heart disease. The treatment group showed significant decreases in total cholesterol (low-density lipids), triglycerides, weight, blood pressure, serum glucose, and WHR. However, the reduction in WHR only averaged .008, with a range of .012 to .004. Although waist and hip circumferences were measured to the nearest .1 cm, a .008 difference translates into a loss of .8 cm at the waist. While this might be statistically significant, one wonders whether such a small decrease would be discernable or whether the measurements were so reliable that such a small difference could be detected. In addition, as also mentioned above, the range of WHRs of this sample seems remarkably narrow (.76 to .78), so a lack of variability may have adversely affected statistical procedures. Thus, this study is not very informative regarding the link between WHR and physical health.

As reviewed by Räikkönen, Hautanen, and Keltikangas-Järvinen (1994), older reports stated that generalized obesity (measured with BMI) is associated with high blood pressure, high plasma triglycerides, and, paradoxically, overall good health and social adaptation. Abdominal obesity (measured with WHR) had a more dire prognosis, including risk of high blood pressure, high plasma lipids and fibrinogen, poor perceived health, and low socioeconomic status. Psychosocial variables associated with abdominal obesity included frequent work absence, psychosomatic and psychiatric disease, as well as frequent antidepressant, anxiolytic, and stimulant use. However, recent work reviewed by Räikkönen et al. indicates that abdominal and generalized obesity may operate similarly, both being associated with tension, anxiety, anger, pessimism, depression, low self-esteem, and low social support.

In a group of Type 2 (non-insulin dependent) diabetics, women showed significant associations between WHR and negative mood, defined as higher perceived stress and moods with less joy, contentment, vigour, and affection and more depression, anxiety, guilt, and hostility (Räikkönen, Hautanen, & Keltikangas-Järvinen, 1994).

Interestingly, stress was associated with BMI, again only for women. Bell, Summerson, Spangler, and Konen (1998) also report previous research showing associations in men between WHR and depression, anxiety, social support, and Type A personality, while women had WHR associations with depression and stress.

Laws et al., (1993) reported a significant association between WHR, BMI, alcohol, smoking, fasting plasma glucose, and high-density lipid cholesterol. However, the addition of triglyceride levels to the regression equation reduced the influence of WHR and BMI to nonsignificance, suggesting that plasma triglyceride levels mediate the effects of WHR and BMI on cholesterol. Other lifestyle variables found to correlate positively with WHR include accident proneness, mental disorder, antidepressant and tranquilizer use, and the use of alcohol and cigarettes (Lapidus et al., 1989). High WHR women were of average social class and education, but, despite these advantages, were more likely to be housewives, be physically and mentally ill more often, with more behaviour problems and accidents. Greater WHR in men was linked to low socioeconomic status and more mental and physical health problems.

A few investigations in primates have focused on the effects of social status on body proportions. Female macaque monkeys show greater abdominal adipose accumulation as their social status decreases (Shively, Clarkson, Miller, & Weingard, 1987). Female primates subjected to stress also show more abdominal adipose tissue (Lapidus et al., 1989).

In humans, Marmot et al. (1998) report a "social gradient" effect of WHR, self-reported physical health, and psychological well-being on health. This means that people with the lowest educational level (less than high school graduation) are the worst off health-wise, but that each successive level (high school graduate < some college < college/university graduate) has progressively better health. Joiner, Vohs, and Schmidt (2000) used a longitudinal design to provide evidence suggesting a temporal precedence of social rejection in WHR changes. Where Singh (e.g., 1993a) suggests that women with low WHRs receive better treatment from others, Joiner et al suggest that bodily changes occur *after* differential social treatment. They measured social esteem of a peer, and then documented increases in WHRs of women over the following two weeks. Were Singh's causal hypotheses true, the women's WHRs would remain stable over the two weeks.

In addition, WHR was significantly correlated with indices of physical aggression and anger, physical illness, and cigarette use (Joiner et al, 2000). However, when their measures were factor analyzed, WHR loaded on neither factors of emotional nor physical wellness, suggesting that, contrary to Singh, WHR may signify something considerably more general or quite different altogether. Joiner and colleagues also equate a low WHR with health in men and women based solely on Singh's investigation of females.

Lapidus and colleagues (1989) also noted differential personality profiles in people with high BMIs versus people with high WHRs. The former group tends to be less achievement-oriented, less aggressive, and less dominant, but more sociable. The latter group scores higher on affiliation and extraversion. The authors suggested that a high WHR and its accompanying extraverted personality is associated with a sensation-seeking lifestyle, which is more stressful and includes being accident-prone and heavy smoking and drinking. Feelings of frustration and strain arising from these behaviours are proposed to results in hypothalamic-pituitary-adrenal axis activity, which feeds back on itself and increases one's risk for physical and mental illness. This sample was randomly selected from Sweden, but the results may not generalize to the present North American population not only due to location, but also because the information was collected in 1968-1969.

On the other hand, Davis and Cerullo (1996), using a more recent sample, reported an *inverse* association between extraversion and WHR. They cited literature linking positive affectivity to resiliency, but equate extraversion (i.e., sociability and gregariousness) with "zest for life" and positive emotionality. They then suggested that introversion (which they equate with negative emotionality) contributes to stress and, thus, abdominal fat accumulation. Firstly, they are mistaken in using terms such as extraversion and positive emotionality interchangeably (e.g., Myers, 2001). Whether one is gregarious is a separate concept from whether one experiences positive affect. Secondly, the direction of causation might run the opposite way. For instance, might not women with attractive bodies come to behave more gregariously because they elicit more positive responses from others?

In the mental health realm, three studies have examined the relationship between WHR and depression, along with social support, cynicism, and stress. Looking at healthy middle-aged (ages 31-65) Swedish women, Horsten et al. (1997) assessed the relationship between high-density cholesterol and depression, as well as measuring WHR. They were unable to detect an association between depressive symptoms and WHR and suggested that their analysis lacked power. However, this is an unlikely explanation, as their sample included 300 participants.

The second depression and stress study, also Scandinavian, examined healthy middle-aged (ages 30-55) Finnish men (Räikkönen, Hautanen, & Keltikangas-Järvinen, 1994). Interestingly, the association between WHR and depression and stress varied depending on the weight status of the men. In lean men (BMIs below the median), higher WHR was associated with high stress. In moderately obese men, higher WHR was linked to low levels of stress and depressive symptoms. These results mesh with others suggesting that cardiovascular risk prediction may differ depending on the degree of generalized obesity. These results also suggest that WHR and BMI vary independently.

Thirdly, Haukkala and Uutela (2000), also from Scandinavia, found that education moderated the relationship between cynical distrust and obesity. Thus, in women with higher education, cynical distrust was unrelated to WHR and BMI. However, among women with lower education, those with more hostility had higher WHRs and BMIs compared to those with less hostility. Depression in men and women was also related to WHR after age and education were controlled for.

Ravaja, Keltikangas-Järvinen, and Viikari (1998) prospectively measured WHR and social support over three years, reporting a negative association between the two variables. Although less predictive for girls and women, the relationship was independent of depression and hostility, suggesting that increased social support may buffer people, especially men, from abdominal fat and coronary risk. This may suggest that a lack of social support may eventually be expressed physically in an increase in one's WHR. However, were causation to run the other direction (people with low, more desirable WHRs have higher social support), perhaps people with high WHR are experiencing rejection because others find them less attractive.

Some studies have investigated the relationship between body fat distribution and peoples' concerns about weight. Radke-Sharpe, Whitney-Saltiel, and Rodin (1990) hypothesized that women with lower, more favourable WHRs would express greater body dissatisfaction and disordered eating than women with higher, less favourable WHRs. Indeed, their results bear this pattern out. At first glance, such a finding strikes one as counterintuitive. How could women with more favourable WHRs be more concerned and dissatisfied with their bodies? Shouldn't women with less desirable WHRs be more upset? However, the authors also found that women with more gynoid distributions also felt that being at the "right" weight was more central to their sense of self. Perhaps this provides a clue to the low-WHR preoccupation with weight: women with low WHRs may have more at stake. Thus, they may be more fearful of losing their privileged status and worry about their weight. Nonetheless, WHR is relatively resistant to change artificially, outside of hormone treatments. Thus, one might imagine that the stress of worrying about one's weight might only serve to increase a woman's WHR, assuming that stress creates hormonal dysregulation, which is reflected in a higher, less favourable WHR.

Two works found interactions between WHR and other factors. Firstly, Joiner, Schmidt, and Singh (1994) discovered an interaction among WHR, depression, and gender. This study is the only one of the three addressing weight concerns and WHR that included men. The authors reasoned that a low WHR should be dissatisfying to men because such a fat distribution is feminine and that a high WHR should be dissatisfying to women because that distribution is masculine. Regarding how the depression connection would play out, the authors considered negative cognitive distortion (i.e., unrealistically negative self-evaluation) and so-called "depressive realism" (i.e., idea that depressed people see the world more accurately), opting for the latter in their hypotheses. Indeed, depressed men and women with respective preferred WHRs expressed less body dissatisfaction than depressed men and women with non-preferred WHRs. The authors stated that this supports depressive realism because the depressed group have attractive WHRs and "correctly" seem unconcerned about that fact. In addition, nondepressed men with masculine WHRs also expressed less body dissatisfaction than nondepressed men with more feminine WHRs. Perhaps we could label this reflects "non-depressive realism; this result runs contrary to their hypothesis of depressive realism because nondepressed men were also realistic. Lastly, regarding nondepressed women, those with feminine WHRs expressed more dissatisfaction than their high-WHR female counterparts. This finding is consistent with Radke-Sharpe, Whitney-Saltiel, and Rodin (1990). Again, we are left to ponder the apparent illogic of the finding for low-WHR women. Why do supposedly more physically attractive women seem to fret more than less physically attractive women?

The work of Davis and Cerullo (1996) may clarify the situation, as they found an interaction between overall body weight and WHR. They found differential associations between WHR and weight and body image concerns, depending on overall body size (BMI). Young women with small bodies and high WHRs had greater concerns about their weight and body images than small-bodied, low-WHR women. However, obese women with low WHRs were more concerned about their bodies than obese women with high WHRs. Using BMI to split the sample may account for the conflicting results described above. Small-bodied, low WHR women should be satisfied with their bodies, given information about health risk and, as we shall see, physical attractiveness. Perhaps obese women with high WHRs appear unconcerned about changing their bodies because, even if they lose weight, they will not achieve a low WHR. The low-WHR overweight women, on the other hand, may feel that, if they could just lose a few pounds, they could be quite attractive, which may express itself as higher body dissatisfaction than their high-WHR peers. Small-bodied, high-WHR women may be unaware that WHR is quite stable within-subjects, perhaps wondering whether they could achieve an “ideal” shape. While this is one possible explanation, it is obviously cumbersome and requires several assumptions. In addition, there is no logical reason why high WHR women are more in tune with the biological workings of their body shape than low WHR women.

However, Epel et al. (2000) demonstrated that lean women with high WHRs show higher cortisol reactivity to novel stress as well as continued reactivity in the face of familiar, predictable stressors, compared to obese women with low and high WHRs and lean women with low WHRs. Obese women with high WHRs showed greater reactivity to a novel stress, but seemed to adapt in repeated trials. Furthermore, on-line cognitive and psychological measures during the stressful task showed that high WHR women (lean or obese) adopted a defeatist attitude incorporating greater perceived threat, less effort, and poorer performance. In addition, lean high WHR women showed greater pessimism, negative affect, and passive coping.

This investigation is an important advance because Epel et al. carefully screened participants, used repeated trials of induced stress, and compared lean women with obese women. This allowed them to examine the effects of novel versus familiar stress and to parcel out the confounding effects of obesity on WHR. They stated that being lean and having a high WHR is especially risky because it is associated with early death and concluded that lean high WHR women experience greater life stress and reactivity to stress. This chronic damage culminates in disease. In addition, this greater reactivity to stress may explain why the lean high WHR women in Davis and Cerullo's sample appear more dissatisfied with their bodies: they are generally threatened by stress, less able to cope, and may be less satisfied with many aspects of their lives.

What Can WHR Predict?

Largely based on the work of Devendra Singh (e.g., 1993b, 1994a, 1995a), WHR has been transformed from a banal indicator of obesity and ill cardiac health into "what men and women look for" and "what women should realize men want." Singh has also aimed to develop a programme of research to refute ideas that judgements of physical attraction are merely personal preference, cavalier superficiality, cultural idiosyncrasy, or attempts to coerce women into unnatural shapes through the media. Rather, the preferred WHR shows considerable temporal and cultural consistency and may be a robust indicator of reproductive health or ability in men and women.

WHR and female attractiveness. A common criticism of contemporary media is its perceived objectification and devaluation of women (e.g., Mazur, 1986; Puhl & Boland, 2001). The fashion and pornography industries often bear the brunt of such comments, with critics insisting that men are finding increasingly emaciated women attractive and that women are "dying to be thin" to meet such impossibly lank standards. Throughout his work, Singh denies that men and women find gaunt women attractive and asserts that WHR, as a pivotal standard of beauty, has literally not budged one inch.

Most work on female physical attractiveness suggested that women thought that men were more attracted to thin women, when men really preferred figures of more normal size (Singh, 1993b). This, in and of itself, should be enough to counter the suggestion of social pressure to slim down (cf. Garner, Garfinkel, Schwartz, & Thompson, 1980; Mazur, 1986). Interestingly, when body shape is considered, men find normal weight women more attractive than underweight women (Singh, 1993a, 1994a, 1995b; Singh & Young, 1995) and men and women generally agree on what constitutes an attractive woman (Henss, 2000; Singh, 1993b, 1994b; Singh & Luis, 1995; Tassinary & Hansen, 1998). This seems to hold across generations, as cohorts of men and women up to age 86 produced similar ratings of attractiveness (Singh, 1993b). North Americans of Caucasian, Black, and Hispanic descent as well as Indonesians consistently rate normal weight figures with low WHRs (.6, .7 or .8) as more attractive than under- or overweight figures and figures with higher WHRs. Attractiveness judgements are unrelated to one's own body satisfaction and BMI (Puhl & Boland, 2001) and male raters' BMI (Singh, 1993a). However, Tovée, Emery, and Cohen-Tovée (2000) reported that women with anorexia and bulimia found a significantly lower BMI more attractive. Although non-eating disordered controls were very accurate in estimating photographs' BMIs compared to eating disordered women, non-eating disordered womens' estimates of photographs' BMIs also increased as their own BMIs decreased. Even when analyzed separately, it seems that eating disordered women's and control women's judgements formed a continuum showing the same inverse relationship between pictured BMI and personal BMI.

Interestingly, compared to same-age men, college-age and older (age 30-78) women still sometimes find underweight women more attractive than normal weight women (Singh, 1993b; Tassinary & Hansen, 1998). In one sample of women, heavier women with low WHRs were seen as more attractive than thin figures, but this study lacked normal-weight choices (Singh, 1994c). Henss (1995) found that a female underweight figure was seen as more attractive. He also found that, while overweight male figures were seen as less attractive compared to their under- and normal-weight counterparts, under- and normal-weight figures received similar ratings. Henss' findings are notable because he sampled both men and women's attractiveness judgements, using the same stimuli, but slightly different dependent variables and analyses than Singh. However, because all of these authors used line drawings as stimuli, there is no indication of what actual weights would constitute "underweight," "normal," and "overweight."

Attraction to low WHR is not limited to physical dimensions, but apparently spills over into assumed personality and reproductive characteristics. Men rate low-WHR female figures as more attractive (Henss, 2000), healthier, sexier, more desirous of children, more capable of having children (Singh, 1993a), more feminine, and more desirable for short- and long-term relationships (Singh, 1995b; Singh & Young, 1995). Men and women rate low-WHR women as more capable reproductively (Singh, 1993b), more youthful, healthier (Singh & Luis, 1995), and more desirable for long-term relationships (Singh, 1994b). Lest one imagine that "the grass is always greener," attractive figures are also rated less kind and understanding, and more conceited, vain, egotistic, unfaithful, and likely to divorce (Singh & Young, 1995). Henss (1995) reported that more attractive figures were also rated as less emotionally stable, family-oriented, agreeable, and conscientious compared to less attractive figures. Women reported more jealousy of hypothetical photographed female rivals with lower WHRs (Dijkstra & Buunk, 2001). Men and women also found low-WHR females more socially dominant and attractive.

Many feel that the Western standard of female beauty has changed considerably in the last hundred years (e.g, Garner et al., 1980; Mazur, 1986). The media's image of woman is said to have promoted an increasingly thin, tubular ideal. Demonstration of this transformation consists mainly of unrelenting citation of two studies (Singh, 1993a). Garner et al. (1980) state that Playboy models' average weight had decreased from 1960 to 1978. Similarly, Mazur (1986) found that Miss America contestants, as a group, were taller and weighed less in 1985 than they did in 1940. These results are often interpreted as a signal that the feminine ideal is becoming progressively thinner and tubular, and that women feel mounting pressure to attain this shape.

Interestingly, among Playboy centrefolds, absolute weights have not changed, while waists have increased (Mazur, 1986). Miss Americas over two decades have seen a gradual decrease in weight, but these comparisons used national norms as baseline. Given recent news reports of medical concern about increasing rates of obesity in the general population (e.g., Wingert, Weingarten, Cooper, & Gatland, 2000, July 3), one wonders whether comparison to a healthier (i.e., leaner) standard might have yielded different conclusions. Nonetheless, WHR remains remarkably constant (.68 - .72) over twenty years' worth of Playboy centrefolds and Miss America pageant winners (Singh, 1993a, 1994a) and consistent with everyday men and women's judgements of attractiveness, health, and desirability mentioned above. Six hundred fashion and glamour models were compared to normal and eating-disordered women (Tovée et al., 1997). The models' WHRs were .7 where normal womens' were .74. Anorexic and bulimic women had decidedly unusual WHRs of .36 and 1.05, respectively. Far from being "stick insects," the models were curvaceous, but generally taller, which may lend the impression of being more tubular. Even Twiggy, the English 1960s fashion model often labelled the distant ancestor of 1990s "heroin chic" had a WHR of .73 (Singh, 1993a). The Barbie doll, were she human, would have a decidedly non-tubular WHR of .54 (Etcoff, 1999).

Puhl and Boland (2001) insisted that the cultural ideal is variable and is based on thinness. They pointed out that Playboy centrefolds are 15% lighter for their heights than expected. Their results suggested an interaction between WHR and weight, and that male and females agree on attractiveness. In general, the underweight photographs of either WHR (.72 or .86) were preferred to normal and overweight photographs by male and female raters. The normal weight condition showed an interaction, such that females viewing the WHR of .86 gave higher attractiveness ratings than females viewing the .72 WHR or males viewing either WHR. Underweight figures with a WHR of .86 and overweight figures of WHR .72 were seen as significantly less fecund. However, Puhl and Boland's stimuli (shown in Figure 1) may explain these unusual findings. They used computer generated line drawings in which WHR was held constant, but weight and breadth were manipulated. Although based on two actual women with WHRs of .72 and .86 and BMIs of 22.6 and 21.31, the under- and over-weight stimuli were created by alternately shrinking and stretching the images by 20%. Thus, an objective measure of the weights of these new figures is unavailable. Also, a visual inspection of their stimuli suggests that their weight categories contain disparate stimuli. Specifically, the underweight photograph derived from one women appears to be closer to the same weight as the normal weight photograph derived from the other. Similarly, the normal weight photograph from the one woman appears to be a more similar weight as the overweight photograph derived from the other. The two overweight photographs do not appear to weigh the same. These discrepancies might account for differences in attractiveness and fecundity ratings.

Puhl and Boland concluded that their results supported a sociocultural view of feminine beauty. However, their results suggested that men and women have similar standards, and most studies of female attractiveness still suggest that normal weight figures are preferred. Although weight seems to have a had a more profound effect on ratings, they highlight that their .86 figure was seen as more attractive, which supposedly confirms that the feminine ideal is becoming more tubular. Thus, they are assigning greater importance to WHR than may be warranted by their analyses and ignoring the confound of weight in their participants' judgements. On the whole, the lack of parity between the two sets of stimuli severely curtail one's ability to draw firm conclusions about their results, let alone provide evidence to refute other researchers' claims. The only safe conclusion to be based on this work is that weight may be more influential in judgements of attractiveness than WHR, but this may be an artifact of improper experimental control of body weight.

As mentioned above, Mazur (1986) found a drop in average weight over time in Miss America contestants. He and others use such information to argue that such a change creates an increasingly impossible standard for what men consider attractive, such that "life imitates art" and society, specifically men, dictate what is considered beautiful. Discussion on this popular notion falls outside the scope of the current work.[1]

In clothing and art since ancient Greece, the main method for a woman to boost her attractiveness has been to accentuate or impose a petite waist, using corsets, belts, girdles, surgical rib removal, bustles, hoops and other assorted contraptions (Singh, 1993a). Women in cultures that use scarification and tattooing as ornaments tend to position markings to emphasize their stomachs (Singh & Bronstad, 1997). This tendency increases as a function of pathogen prevalence. As the risk of disease within a given cultural group increases, women's stomachs are increasingly highlighted by tattoos and scarring. Bloated abdomen is one symptom of parasite infection (Furnham, Dias, & McClelland, 1998). This suggests that the stomach may be an important marker of female mate quality in such groups.

So far, we have determined that differences in WHR are linked to variations in physical and mental health, sex hormone levels, self-perception, and judgements of

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[1] Several pieces of information argue against the "life imitates art" explanation. Firstly, Miss America contests, an endeavour driven by women's preferences and consumer behaviour, have seen a decrease in average weight of contestants. This event is entered by women, largely judged by women, and, most importantly, marketed to women. Secondly, the average weight of Playboy centrefolds has not changed and waist girths have actually increased (Garner et al., 1980). This magazine is marketed to men. The argument that life imitates art relies on the mistaken assumption that supply can dictate demand. This runs contrary to the most fundamental principle of consumer behaviour: the consumer is the driving force. Thus, is it not reasonable to propose that women prefer to consume magazines and television shows that portray a thinner "ideal" than media that men prefer? In addition, the "life imitates art" position implies that a large group of people has developed a deliberate consensus that they have also agreed to propagandize. This assumes not only high degree of collusion but also an extraordinary ability to persuade, for which evidence is forthcoming. Lastly, the sociological explanation also ignores that ideas must originate from somewhere, so if society is merely a machine for perpetuating the status quo, innovation must arise from elsewhere.

physical attractiveness, health, youth, and desirability of a potential mate. But how can we be sure that other features are not of equal or greater importance in influencing these characteristics? What of those who claim to be attracted to other physical features such as breasts or legs? Singh argues that the special power of WHR over other physical characteristics can be demonstrated by the significant correlation between WHR and men's attractiveness ratings. This alone seems somewhat intuitively unsatisfying. However, because women's attractiveness supposedly signals a potential mate's reproductive quality, men should preferentially attend to physical features linked to reproductive ability (Singh & Young, 1995). Markers of stored fat such as body size, breasts, and buttocks, interpreted as "famine insurance" against menstrual irregularities and malnourished pregnancies, are assumed to be attractive to men. However, overall body size will play a peripheral role because the use of stored fat depends on its location, such that low-WHR distributions in women are associated with more successful conception (Zaadstra et al., 1993) and pregnancy (Singh & Young, 1995).

In addition, breast size does not seem to affect conception or pregnancy success, so may not signal reproductive capacity (Furnham, Dias, & McClelland, 1998; Singh & Young, 1995). Although some evidence points to male preference for larger breasts, their appeal to male and female raters women seems to depend on an accompanying low WHR for a figure to be considered a more attractive short- or long-term mate. Women with high WHRs and higher overall body weight are not considered more attractive if they have large breasts, where women with low WHRs and, to a lesser extent, low overall body weight are. Thus, large breasts may accentuate an already attractive WHR, but do not make a woman attractive in and of themselves.

When WHR is held constant (at an "attractive" .7), figures with large hips are rated as less attractive, feminine, healthy, and desirable as short- or long-term mates, although they were considered more kind and understanding and older if they also had large breasts (Singh & Young, 1995). However, figures with large hips necessarily have larger waists if WHR is held constant, making them identical to the overweight figures used in other investigations that were judged less preferable than normal weight figures. Thus, overall body weight may confound these latter results. Nonetheless, those who are attracted to breasts and legs do not seem to be drawn to entirely inconsequential features, but are, in reality, attracted to WHRs, but with extracurricular interests that may further enhance their judgements of attractiveness. Buttock size and shape have yet to be scientifically considered (Singh & Young, 1995), but breast symmetry, although not shape and nipple placement, has been investigated (Singh, 1995b). Not surprisingly, female figures with the requisite low WHR and symmetrical breasts received higher ratings of attractiveness and youthfulness compared to figures with high WHRs or asymmetrical breasts.

WHR and male attractiveness. While normative data on male WHR is reasonably prevalent due to research on health risk, as yet, only two studies have tried to ascertain the most physically attractive male WHR. Women, aged 18-69, judged normal weight male figures with WHRs of .9 or 1.0 as more attractive than under- or overweight figures with WHRs of .7, .8, .9, and 1.0 (Singh, 1995a). The normal weight figure with WHR = .9 was deemed even more attractive than the normal weight figure with WHR = 1.0. Unfortunately, the raters were composed solely of women, so we cannot make a direct comparison of male and female ratings of male figures. However, relying on reasonable correspondence between the sexes in judging female attractiveness (e.g., Singh & Luis, 1995; Tassinary & Hansen, 1998), we might argue that men and women would find similar male WHRs attractive.

Figures were not considered attractive unless they also seemed healthy, but the appearance of strength, power, or the qualities of kindness or understanding did not seem to increase attractiveness judgements (Singh, 1995a). Singh explains this finding by appealing to the aforementioned "dark side of beauty:" that beautiful people are thought to be self-centred and mean. An alternate explanation emerges if one interprets kindness and understanding as salient concerns for long-term pairings (the so-called "good dad" qualities), where physical attractiveness is supposedly more important for short-term pairings (the so-called "good genes" qualities). Long-term considerations like strength and power to protect the woman or kindness may only surface once the short-term concern of attractiveness has been met. However, WHR, as we have learned, does inform about health. Cues about parenting seem to be screened later, perhaps because determining parental quality requires a fair investment of time and energy. As Singh (1993b) suggests, WHR may serve as a "first-pass" attractiveness mechanism by which people quickly determine whether other characteristics are worth investigating. Work on breast preferences among men and financial status among women exemplify this pattern – the second feature only makes the person attractive if they also have an attractive WHR.

Maisey, Vale, Cornelissen, and Tovée (1999) had female undergraduates rate photographs of males. Waist-to-chest ratio was the primary predictor of attractiveness (56% of variance explained), followed by BMI (13% of variance explained). WHR was not a significant predictor. Women found men with "inverted triangle" torsos most attractive, presumably because a strong upper body denotes physical strength or dominance.

Given the salient role of financial and social status as one of the characteristics that women across cultures seek (Buss, 1989), testing its influence relative to WHR is prudent to elucidate the function, if any, of WHR in men. Not surprisingly, women find male figures with high (more masculine) WHRs and high status occupations and incomes preferable to male figures with high WHRs and less stellar financial success (Singh, 1995a). However, high financial status does not seem to increase the attractiveness of low WHR men. This pattern held whether participants considered short- or long-term pairing. The astute reader will find this pattern of results reminiscent of that found for women's WHRs and breast size: a desirable WHR seems to be a minimum requirement for attractiveness, with other desirable features adding to the attractiveness once WHR is evaluated. Although men with higher shoulder-to-hip ratios were seen as more threatening romantic rivals, men with high WHRs were seen as more attractive, and more physically and socially dominant (Dijkstra & Buunk, 2001).

~~*The functional significance of WHR.* At the heart of any explanation informed by~~ evolutionary theory lies a description of a feature's possible function (Dawkins, 1989). If an organism must invest time or energy into the development or maintenance of a characteristic, it most likely serves a purpose. If the feature served no function or served it poorly, organisms who conserve their investments for alternate or more efficient use will eventually preponderate in the population. Genetic strains that waste energy die out. Lines that use their energy efficiently proliferate. (Gould (1993) counters with his notion of "exaptation," such that a characteristic that once served a function may still exist, though no longer apparently useful, but most have dismissed this alternate explanation (e.g., Dennett, 1995).)

To speak of the function of WHR may be somewhat misleading. As discussed above, WHR seems to develop based on endocrine and, possibly, heritability factors. Stress and disease may compromise WHR by dysregulating the endocrine system. In this sense, WHR is a byproduct of other factors. However, people's ancestors who were able to discriminate among different WHRs presumably had an advantage over people who could not. Children of those who could tell the difference and happened to prefer a gynoid distribution in women and an android distribution in men may have been at a relative advantage reproductively. Those who either could not discriminate or did not strive to mate with preferred-WHR may have had less reproductive success. Thus, WHR may have no "function," although it seems to have considerable "functional significance." Some may argue that people flaunt their WHRs in order to attract a mate, similar to a peacock displaying his tail, in which case "function" may, indeed, be an appropriate term.

In summary, WHR seems to convey important direct information about endocrine functioning and indirect information about overall physical and reproductive health. Studies on risk for various diseases from the medical community seem to converge with studies from the psychological literature on attractiveness. Furthermore, results involving men and women seem to follow a similar pattern. Other measures of bodily proportions seem not to be able to account for the pattern of findings explained by WHR.

Unanswered Questions About WHR

While work on WHR spans the epidemiological and psychological literature, this area of inquiry is relatively young and its findings are not immune to criticism. For instance, all but two studies that measured actual people (as opposed to presenting altered photographs whose real proportions were unknown) are from outside the psychological literature. Some might consider this a weakness in the psychological literature, but we can also interpret health-related findings as converging evidence to support the findings originating from psychology. One missing piece of the normative puzzle is the distribution of WHRs in the general population. While many have reported means and standard deviations, this yields a rather vague and ageless picture. Other issues that remain unresolved include methodological and analytic concerns as well as criticisms of stimuli, as follows.

Henss (1995) and Furnham et al. (1997) criticize Singh for having participants rank figures, which limits one to less powerful nonparametric analyses and allows participants to easily ascertain the independent variable, as they see all of the figures at once in consecutive order. To this end, Henss presented only one female and one male figure to his sample, thus creating a between-subjects design. He also used factor analysis of a broader list of characteristics to determine attractiveness and personality outcomes. This study mainly replicated Singh's findings, except that underweight figures were seen as more attractive than normal weight figures. Puhl and Boland (2001) also suggest that Singh's composite attractiveness ratings are based on the highest and lowest extremes, which would tend to inflate effects. Like Henss, their solution was to use a between-subjects design.

Furnham's group (1997) felt that a within-subjects design would allow "more rational judgements," but still compensates by not showing participants all the figures at once or in any particular order. They replicated Singh's findings, including that normal weight figures were seen as more attractive than their underweight counterparts. While male and female overweight figures were seen as the least attractive, only overweight males were seen as unhealthy, perhaps because women's plumpness may come in handy during pregnancy. Furnham, Tan, and McManus (1997) also tested men and women's metaperceptions of body shape. In other words, they asked men what they thought women preferred and women what they thought men preferred. Their aim here was to compare these results based on fat distribution (WHR) to previous findings suggesting that women believed that men preferred thinner figures, based on overall body size (BMI). They found no differences between participants' own judgements and what they perceived as the opposite sex's judgements.

In addition to methodological concerns, problems with stimuli have been noted. In addition to concerns raised in reference to Puhl and Boland (2001) in Figure 1, Tassinary and Hansen (1998) pointed out that nearly all WHR studies of female attractiveness have used the same stimulus materials. Although Lippa (1983) used a different set of line drawings, these yielded peculiarly shaped figures, none of which are particularly appealing (see Figure 2). Tassinary and Hansen successfully replicated the effect with new contour line drawings. However, they also note that the widely used stimuli only range from .7 to 1.0 (see Figure 3). In addition, they seem to have presented their figures in either rectangular or hexagonal boxes, which may have altered apparent proportions. Henss (2000) commented that their choice of line drawings is ironic, especially because he finds their versions less pleasing and more artificial than Singh's.

In addition, all but a few studies of female WHR attractiveness have used line drawings, not photographs of actual women. The two criticisms on restricted range and artificiality of stimuli can be at least partially addressed if we refer to Study Two by Singh (1994a, see Figure 4). The stimulus was a photograph of an actual woman from the midriff to the knees (perhaps to control for extraneous factors such as facial attractiveness, breast size, and social status cues) with the waist graphically altered to include WHRs of .6, .7, .8, and .9. This investigation found that men aged 18-22 found the .6 figure more attractive, and healthier, and least in need of weight loss than the other WHRs. Interestingly, as in other studies, the least attractive figure was judged to be the most intelligent, kind, understanding, and faithful. However, one wonders whether the clothing in the photos, although held constant, may have affected judgements, both because of its rakish style and because the belt partially obscures the hips. Furthermore, one could argue that the woman in the picture probably does not represent a normal weight individual. As we have learned, underweight figures consistently receive lower attractiveness ratings than normal weight figures. Finally, the photos were retouched to yield the range of WHRs, which introduces a confound with apparent BMI, discussed further below.

Henss (e.g., 2000) has avidly campaigned for the use of high quality colour photographs of women in more naturalistic poses wearing swimsuits or more typical clothing. However, his sets also embody the problem of BMI confound. Because the figures were altered using computer software, the actual BMI of the figure, which was unavailable to begin with, was altered along with WHR. Henss also noted that the digital manipulations affected the apparent height of the females pictured. Using this stimuli which is considerably more pleasing to view, Henss (2000) found that WHR was related only to male and female ratings of "attractiveness," but not to ratings of "motherliness-agreeableness," "extraversion-positive affect," "self-assurance-career orientation," "fashion plate," "figure," or "health-youthfulness."

Another feature of the line drawings is that, for Singh's (1995a) male figures and Tassinary and Hansen's (1998) female figures, the waist is held constant, but hips are enlarged to achieve the various WHRs. Singh's (e.g., 1994c) female line drawings and photographs present constant hips with altered waists. Both procedures may introduce a confound: perhaps higher WHR figures appear heavier than their lower-WHR counterparts. Thus, both apparent body weight and WHR are being manipulated. Puhl and Boland's (2001) stimuli (shown in Figure 1) are a prime example. This is exactly the point made by Tovée and Cornelissen (1999) in evaluating stimuli used by Yu and Shepard (1998) and Tovée, Reinhardt, Emery, and Cornelissen (1998): adjustments in pictured WHR also inflate BMI. As the findings demonstrate, heavier-than-normal figures have always been rated as less attractive than same-WHR normal weight drawings.

However, Tassinary and Hansen replicated Singh's effect with opposite manipulations: the former added hip size, the latter added waist size. In the study using photographs where the waist was altered, the .6 figure, which probably looked the most underweight, was judged most attractive, despite other findings suggesting that underweight figures are seen as less attractive than normal weight figures. While some evidence suggests that this confound may not produce profound differences, caution is recommended, especially at this early stage of investigation. Henss (1995) and Furnham, Tan, and McManus (1997) come to a similar conclusion, the former noting that Singh's male figures are "particularly heavy and massy." Although not commenting on the female figures in the photographic stimuli, they also advocate the use of more naturalistic stimuli.

Furnham, Lavancy, and McClelland (2001) found that facial attractiveness, not WHR, predicted male ratings of female figures' attractiveness, sexiness, health, and fertility. Their results suggest that WHR is a primary informer of whether a women is pregnant. However, their stimuli used retouched photographs and are subject to the confound with unavailable BMI as discussed above. Results may differ when unretouched photos of various people are used because these will avoid a weight confound.

In summary, major problems interpreting the research conducted to date arise from the stimuli employed. Many investigations have relied on the same set of line drawings. Also, the vast majority of stimuli consist of drawings or photographs that have been altered to yield a variety of WHRs. The difficulty with this approach is that once the alterations are made, weight categories tend to overlap such that, for example, the underweight figure with a WHR of 1.0 looks heavier than the normal weight figure with a WHR of .7. Moreover, some researchers alter the waist and some the hips, which further compromises comparisons across studies. Also, when drawings or magazine photographs are used, there is no way to determine the person's actual WHR or BMI. This problem is further compounded when the figures are retouched. Methodological concerns have also been raised, as a number of studies collected rankings, which relegates one to using nonparametric analyses.

BMI as a Determinant of Attractiveness

Body mass index (BMI) is considered the "most satisfactory index to date to define [generalized] obesity" (Neggers, Stitt, & Roseman, 1989, p.123, brackets in original). Weight in kilograms is divided by height in metres squared. An adult is considered to be obese when the BMI is ≥ 27.8 kg/m^2 for males and ≥ 27.3 kg/m^2 for females, which are the 85th percentiles for each sex. BMI is negatively associated with socioeconomic status and education (Lapidus et al., 1989). However, WHR (which reflects fat distribution) is better than BMI at predicting risk of disease (Neggers, Stitt, & Roseman, 1989) and fertility (Wass, Waldenstrom, Rössner, & Hellberg, 1997; Zaadstra et al., 1993). WHR is also a true indicator of androgenicity, osestrogenicity, and reproductive potential (Furnham, Tan, & McManus, 1997).

Not all researchers agree that WHR is the strongest determinant of physical attractiveness. Hume and Montgomerie (2001) report that facial attractiveness was best predicted by BMI and past health problems. As mentioned above in reference to male attractiveness, Maisey et al. (1999) found that BMI was a better predictor of female ratings, although waist-to-chest ratio was an even better predictor. Tovée and Cornelissen (2001) found that BMI was a better predictor of female attractiveness than other shape cues like WHR. This held for both anterior and lateral profile views of the female figures.

Tovée, Maisey, Emery, and Cornelissen (1999) pitted WHR and BMI against each other in explaining variance in men's ratings of colour pictures of women. Their 50 female figures represented five BMI categories: emaciated (below 15), underweight (15-19), "normal" (in the healthy not normative sense, 20-24), overweight (25-30), and obese (over 30). Because their regression analysis found a larger effect size for BMI (73.7%) than WHR (2.3%), they concluded that BMI is a much more reasonable candidate for the honest advertisement underlying men's attractiveness judgements. They also cite the curvilinear relationship between BMI and attractiveness ratings, saying that BMI is sensitive to the fact that emaciated women are amenorrheic and, so, infertile. They correctly point out that previously used stimuli have two main problems: they generally use rather unrealistic line drawings and their manipulations of these stimuli add a weight confound. They also point out an overlap in Tassinary and Hansen's stimuli, such that the weight categories overlap.

One concern with the Tovée et al. investigation lies with the stimuli used. Firstly, these authors did not control for breast size, which has shown to affect attractiveness ratings in specific ways. Secondly, while the range of BMI was quite broad, WHR ranged from .68 to .98. In addition, only 19 images were used in the main analysis, the selection criteria and representativeness (i.e., WHR and BMI ranges) for which is unclear (a figure caption suggests that the range of WHR in rated pictures ranged from .70 to .83). This restriction in range and low sample size would severely compromise the regression analysis with which the authors buttress a main assertion: that BMI accounts for an extraordinary 73.7% of the variance, while WHR only accounts for a mere 2.3%.

However, despite the above results, the theoretical rationale for BMI as a primary determinant of attractiveness is not as well developed as that for WHR. BMI lacks an underlying physiological mechanism that fluctuates both with reproductive status and weight in both men and women. Similarly, BMI supporters would be hard pressed to explain several findings above, including WHR being a better predictor of disease, consistency of "ideals" over time, and interactions of WHR with males' financial status or females' breast size. Interestingly, the preferred BMI of 18-19 falls in their descriptive category of "underweight," which seems to run contrary to their claim that reproductive health and attractiveness are associated with a healthy weight. Furthermore, since very few women fall in the "normal" category, apparently their narrative of what is desirable leads one to conclude that overweight women are more plentiful and desirable, which directly contradicts their findings. Lastly, their weight categories differ somewhat from those used by others; Neggers et al. (1989) report "obese" BMIs as the 85th percentile or 27.3 kg/m^2 for males.

Interim Summary

As is common in a relatively young area of research, methodological improvements and further replication would be welcome. In addition, there are a number of theoretical possibilities that have yet to be ruled out. For instance, a fair amount of evidence suggests that WHR is related to ratings of attractiveness and health, as well as risk factors for health and reproductive success. In that case, we can probably rule out the possibility that WHR is attractive just for its own sake. Tassinary and Hansen (1998) would have us believe otherwise, concluding that the ability to judge WHR is probably ontogenetic and likely a "dimensionless number with . . . highly circumscribed explanatory or predictive efficacy" (p.155). However, this conclusion ignores aforementioned epidemiological research clearly demonstrating a relationship between WHR and health risk and hormonal status.

A convincing rationale exists to propose that WHR holds signal value as an "honest advertisement" of someone's quality as a potential mate. The initial criteria for determining whether a union will bear children is whether the potential mate is of the opposite sex. Perhaps WHR is a long-range advertisement or "billboard" in this sense because both men and women seem to use it and agree on its significance in terms of attractiveness. Men and women's WHRs also form a bi-modal, mostly non-overlapping distribution. Some have also noted that WHR can be determined from any angle (Singh, 1993b). As yet, no one has tested whether people can determine someone's sex from a picture of their WHR or at what distance.

So WHR reflects level of physiological functioning such that it advertises lower risk of cardiovascular and other diseases. But most with heart disease fail to develop many symptoms or impairments until their fifties or sixties, plenty of time to reproduce even in Pleistocene-era terms. Similarly, if stress leads to neuroendocrine dysregulation after one has had children, such a mechanism should not be selected against. However, stop to consider the other health conditions associated with high WHR: diabetes, neuroendocrine and sex hormone problems, and, most damaging, decreased success of conception and pregnancy, the *coup de grâce* of personal deficits in the immediate and evolutionary senses. As we have learned, infertile and postmenopausal women exhibit more masculine WHRs and infertile men with conditions like Klinefelter's syndrome show more feminine WHRs. To propose that men and women attach the same functional significance to WHR is a more parsimonious explanation than suggesting WHR information is used differently depending on the sex of the perceiver. This also increases the possibility that men and women may compare mate value across targets, or even compare their own attractiveness to that of rivals.

In men, a low WHR may suggest abnormal gonadotrophic function, which may compromise fertility. However, in women, a high WHR has been empirically linked to lower rates of conception and successful pregnancy. Thus, people with WHRs that are atypical for their sex may be less attractive to potential mates. Postmenopausal women are one group for which reproduction is no longer possible. Thus, if WHR signals fecundity, one might expect that people would be able to separate WHRs of pre- and postmenopausal women. If one further considers that pregnant women are, for the purposes of mating, infertile for the time being, would one not expect that women relatively early (i.e., first trimester) in their pregnancies should exhibit higher-than-usual WHRs? The potential importance from a paternity certainty standpoint is obvious – the earlier people can detect that a woman is pregnant, the more energy men can devote to presently fertile women. There may be enough social implications stretching back into human history to suggest that men and women in the social group may reap advantage from early detection of a pregnancy. We may, then, hypothesize that WHR would increase when a woman becomes pregnant, aside from the obvious increase due to the size of the baby. Women with already-high WHRs may hold a devious advantage over women with usually low WHRs: might they be better able to hide their pregnancy from people with whom they are familiar, thus concealing paternity? As discussed above, people can detect minute differences (.1) in WHR on nearly identical figures. However, oral contraceptives mimic pregnancy hormonally – but are women's WHRs affected and, if so, how?

Some argue that BMI can better account for variance in attractiveness ratings. However, the theoretical rationale is relatively weak, as it can only predict a lack of fertility in severely underweight women. Furthermore, BMI does not provide a unifying explanation for the pattern of findings exhibited in the areas of health, consistency of "ideals" over time, and the effect of financial status in men or breast size in women.

The Present Study

The purpose of the present research is to replicate previous findings using more ecologically valid stimuli. The relative predictive power of BMI and WHR were compared using stimuli for which actual values are known. As broad a range of WHRs as possible was sought to avoid restriction of range. Not only does this yield normative data on WHR, but also various ratings related to attractiveness. Both men and women were recruited and anterior, posterior, and lateral views were collected, but only the anterior were shown to raters in the interests of limiting the length of the experimental session to about an hour. The present study also further investigated the reliability of self-report of waist and hip measurements.

The present study includes a number of relatively unexplored, yet potentially relevant, variables that are largely aimed at anticipating possible confounds with attractiveness ratings. These mainly relate to personal characteristics of raters that may affect mate value or mate selection. They include sexual orientation, age at sexual maturity, sociosexuality, body self-esteem, and intelligence. These variables have not yet been included in published investigations of physical attractiveness judgements.

Hypotheses and Exploratory Research Questions

Despite a large number of studies supporting WHR as an important determinant of attractiveness ratings, Toveé et al.'s recent investigations propose an alternative explanation. Therefore the primary purpose of the present study is to provide a direct test of competing hypotheses, using procedures that correct for past problems in stimuli and analyses.

We have grouped our hypotheses into three main areas: normative, theory-driven, and exploratory. The first deal with normative issues of body measurements:

1. The distribution of WHRs should show greater frequency around the preferred proportions and a truncated range (means of .7 in women and .9 in men, according to previous studies). Do actual distributions map onto the preferred distributions? If so, this would lend support for a process of stabilizing selection.

The second set is theory-driven hypotheses regarding perceptions of WHR:

2. As mentioned above, a main aim of the present work is to compare the predictive power of WHR and BMI. We hypothesize that WHR will explain a greater proportion of the variance in attractiveness judgements than BMI.

3. Although the present study includes a broader range of stimuli than previous investigations, we expect to replicate the following results:

   a) Female figures will be seen as increasingly attractive as their WHRs approach .7.

   b) Male figures will be seen as increasingly attractive as their WHRs approach .9.

c) Figures who are under- and overweight will be seen as less attractive than normal weight figures.

4. Are raters' perceptions accurate? How well can people assess weight and age based on our stimuli? Results showing that raters are accurate in assessing these characteristics could support an "honest advertisement" view of body shape.

5. Do raters agree on which photographs are most and least attractive? Results showing idiosyncratic judgements would support a "beauty is in the eye of the beholder" view of attractiveness judgements. Results in which ratings are consistent with each other could support an "honest advertisement" view.

6. Ratings of attractiveness are not expected to differ based on sex of participant or other personal characteristics. This is a null hypothesis, but has been shown in previous investigations. Significant differences between raters based on individual variation will serve to falsify an "honest advertisement" account of physical attractiveness. For statistical purposes, we predict differences in attractiveness judgements based sex and other personal characteristics.

The final set of research questions is exploratory in nature, as previous literature is lacking or unclear in these areas:

7. In keeping with the findings of Radke et al. (1990), Joiner et al. (1994), and Davis and Cerullo (1996) on body dissatisfaction and WHR, it is hypothesized that WHR will be related to physical attractiveness self-esteem, with sex of participant and BMI moderating the relationship. Men and women with more favourable WHRs (higher in men and lower in women) will show greater body self-esteem than participants with less favourable

WHRs, if their BMIs are in the normal-weight range. People with over- or under-weight BMIs will report lower body self-esteem.

8. Ratings of attractiveness are not expected to differ based on sexual orientation or sociosexuality, given previous findings that men and women show similar attractiveness ratings despite presumed differences in partner preference (e.g., Henss, 2000; Singh, 1993b; Tassinary & Hansen, 1998). In addition, findings from limited research on a lesbian sample did not show differences in attractiveness ratings based on "butch" or "femme" preferences (Singh et al., 1999). Significant differences based on sexual orientation and sociosexuality will refute an honest advertisement account of physical attractiveness.

9. a) Is body shape an honest advertisement of intellectual functioning? Results in which raters accurately estimate the intelligence of photographs will support this view.

b) Does intellectual functioning affect peoples' ratings of attractiveness?

c) What bodily proportions are seen as most and least intelligent?

10. How do global relative judgements of attractiveness compare to ratings of specific characteristics? This will allow some investigation into the effect of methodological differences across studies. Most previous research had participants rank a group of drawings, which were presented simultaneously. Our ratings were obtained when participants could only evaluate one photograph at a time. Conversely, they were able to compare all the stimuli before deciding their rankings.

11. Does sex pictured or sex of rater affect how quickly participants rate and rank the photographic trials? One might expect that women will take longer than men because

women are predisposed to be choosier of mates due to their greater investment in reproduction.

12. Are self-reported body measurements reliable?

13. What is the psychometric quality of the instruments used?

Method

Phase 1 – Prescreening and Stimulus Selection

Participants. Participants were male and female university students. The females were not currently pregnant. Students in Introductory Psychology classes received a bonus point toward their final grade for participating.

Two hundred and thirty-six participants were pre-screened to enable: (1) the collection of normative WHR data over a wider spectrum than might volunteer for a study on body shape, and (2) the selection of the appropriate range of WHRs while controlling for body weight, something that altering photographs does not allow. A prescreening questionnaire developed by the author (see Appendix A) was distributed, asking participants to provide the following information: if female, whether they have ever been or are pregnant; if currently pregnant, for how many weeks; personal and family history of correlates of cardiovascular and reproductive health; waist girth; hip girth; height; and body weight. These questions were included to assess body shape and determine whether respondents had conditions that might affect endocrine function and, therefore, WHR. From this pool, 20 males and 28 females were recalled and their measurements were confirmed. WHRs and BMIs for those appearing in stimulus photographs are shown in Tables 2 and 3.

All participants were asked to wear their favourite blue jeans and white T-shirt to appear in photographs. This allows control for the apparent age and status of the wearer while avoiding the trappings of providing a large number of variously-sized, clean leotards or the possibility of participants dropping out if asked to wear swimming apparel.

Materials.

1. Phase I Participant Information Sheet. Developed by the author, this measure (see Appendix B) collected the following information: age; sex; age at menarche if female; age at first nocturnal emission, shaving, and voice change if male; presence of artificial hormones (birth control or otherwise); and presence of a medical condition that might alter endocrine function. Women indicated whether they are currently pregnant and, if so, for how many weeks. This was followed by the Sociosexual Orientation Inventory (SOI), titled “Sexual Attitudes and Behaviour Survey”, the State Self-Esteem Inventory (SSEI), titled “Current Thoughts,” and the Shipley Institute for Living Scale (SILS), titled “Perceptual Processing Scale.” Finally, participants provided self-report waist and hip measurements, which were confirmed by an experimenter, who measured to the nearest .5 cm. The experimenter also collected height to the nearest .5 cm and weight to the nearest pound.
2. Sociosexual Orientation Inventory (SOI). Developed by Simpson and Gangestad (1991), the SOI measures individual differences in attitudes and behaviours associated with sociosexuality, or the willingness to engage in uncommitted sexual relations. The measure’s seven items have demonstrated divergent validity from sex drive or general

interest in sex. Psychometric analysis from this sample yielded a Cronbach's alpha of .86.

3. State Self-Esteem Inventory (SSEI), Appearance subscale. Developed by Heatherton and Polivy (1991), the SSEI measures short-lived or "state" changes in self-esteem related to physical attractiveness. Factor analysis confirms the presence of an appearance factor, composed of five items. This measure will be used to further explore the relationship between WHR and body dissatisfaction. Psychometric analysis for this sample yielded a Cronbach's alpha of .78.

4. The Shipley Institute of Living Scale (SILS). The SILS provides a short measure of intelligence that compares favourably to other adult measures of intelligence (Zachary, 1986). It yields four scores: Vocabulary, Abstraction, and total scores, as well as estimated IQ. The Vocabulary subscale consists of 40 items, in which participants are asked to circle one of four words that is synonymous with a target word, and the Abstraction subscale consists of 20 items, in which participants are asked to extend short sequences. It is highly reliable, with an internal consistency of .92, test-retest reliability of .78, and standard error of measurement of 6.6. The total score correlates .77 with Wechsler IQ.

Procedure. Participants completed the Phase 1 Participant Information Sheet. Anthropometric information was obtained through "guided self-report." In other words, participants took and recorded their own measurements in the laboratory, with direct access to instructions and the experimenter. The experimenter also collected this information to allow for tabulation of reliability coefficients. Where the two measurements conflicted, those obtained by the experimenter took precedence in analyses. Finally, participants were photographed with their T-shirts pinned back against a neutral background from three angles: posterior, lateral, and anterior. Only the latter view was presented to raters (as shown in Appendix C).

Phase 2 – Obtaining Judgements of Attractiveness

Participants. Sixty male and 78 female undergraduate students participated from the 236 who were prescreened. Those in Introductory Psychology classes received a bonus point toward their final grade for their participation.

Materials.

1. Photographs. Photographs obtained in Phase 1 were selected to represent the widest range of WHRs possible. Three weight groups were also represented for each level of WHR: underweight, normal weight, and overweight. Weight status (i.e., under-, normal-, or overweight) was determined using BMI, with the 15th and 85th percentiles comprising the cutoffs for underweight and overweight, respectively. The cutoffs were 21.99 and 30.17 for males and 20.26 and 28.37 for females, respectively. These cutoffs were chosen for two reasons: to remain consistent with previous research and to allow for contrasting of heterogeneous groups. WHR was separated at the 33rd and 67th percentiles to produce three groups in the same manner that two groups would be created using a median split.

This yielded eight body shape trials, based on the combination of the three WHR and BMI levels, with the exception of high WHR-low BMI because the prescreening did not garner anyone with these proportions. Please refer to Tables 2, 3, 4, and 5 for photograph and cell information. A total of 48 photographs were presented on a computer screen and mounted on index cards. Faces and upper torsos were obscured to control for facial attractiveness, protect anonymity and, in women, control for the effects of breast size (see Appendix C for sample stimuli).

Reliability information was obtained to assess homogeneity within trials (categories of photographs) on the dependent variables (as summarized in Table 6), with the exceptions of 3 trials because they consisted of only one photograph (male low WHR-high BMI, female low WHR-moderate BMI, female low WHR-high BMI). Results indicate that, except for one trial (male photographs with moderate WHRs and BMIs) on one dependent variable (masculinity rating), all average measure intraclass correlations were significant, ranging from .25 to .93. This suggests that the photographs in each trial are internally consistent. The one exception was not required because male photographs were grouped solely by WHR for analysis of masculinity.

2. Phase II Participant Information Sheet. This measure (see Appendix D) was developed by the author and asked participants to provide their age; sex; sexual orientation (on a 7-point Likert scale ranging from exclusively heterosexual to exclusively homosexual); age at menarche if female; age at first nocturnal emission, shaving, and voice change if male. This measure also includes the SOI, SSEI and SILS, as described above. Finally, participants reported their waist and hip measurements, followed by experimenter confirmation of these figures and collection of weight and height data.

3. Phase II Rating Sheet. This measure (see Appendix E) was developed by the author and asked participants to rate each target photograph on 10-point Likert scales on the following attributes: masculinity, femininity, good looks, sex appeal, intelligence, interest in having children someday, and capability of having children. Distributions of responses

contraindicate response bias. Raters then estimated the target's age and weight and, finally, on 10-point Likert scales, rated the target's attractiveness for marriage with children and a brief sexual encounter. Photographs were presented in random order, but were grouped for analysis by trial as established by WHR and BMI. This yielded eight body shape trials.

Procedure. Participants completed the Phase II Participant Information Sheet and a Phase II Rating Sheet for each photograph. Photographs of females and males were presented in separate segments on a computer screen, with participants rating opposite sex figures first, then same-sex figures. Secondly, participants placed the photographs mounted on index cards in rank order from most to least attractive. Participants' time to rate and time to rank male and female photographs were recorded to the nearest 30 seconds.

Results

Sample

One woman discontinued her participation in the rating phase of the study. Two women and three men indicated their sexual orientation was bisexual or homosexual. Unfortunately, due to lack of homo- and bisexual participants, these five participants had to be excluded from analyses of attractiveness ratings. Other demographic information for raters is presented in Table 7 (Physical proportions are reported for raters separately, as participants appearing in photographs were specifically selected for their body shape.) Age at sexual maturity was determined by age at menarche for women and the average of age at first nocturnal emission, voice change, and shaving for men.

Pre-analysis Issues

Overview of Analytic Strategy

The experimental design allows for two approaches to analysis: one that focuses on the photographic stimuli and one that examines the people who provided judgements of attractiveness. This affords the opportunity to determine how variations in the stimuli and individual differences among participants affected attractiveness judgements. Previous studies have concentrated largely on the former approach.

Outliers

The data were examined for missing values, univariate outliers, and multivariate outliers. Cases with missing data were excluded from corresponding analyses. Univariate outliers, defined as cases with z-scores of greater than ±3.29, were set closer to the mean until their z-score was less than ±3.29 (Tabachnick & Fidell, 1996). Multivariate outliers were tested for using Mahalanobis distance with a chi-square criterion. No multivariate outliers were found.

Assumptions

The following assumptions were tested: multivariate normality, linearity, homoscedasticity, homogeneity of variance-covariance matrices, multicollinearity, and singularity. As previously discussed, outliers have been managed to eliminate the possibility of violation of normality due to outliers. Detrended expected normal probability plots were also examined to protect against violation of this assumption (Tabachnick & Fidell, 1996).

All pairs of variables must be bivariate normal (Stevens, 1986). To this end, bivariate scatterplots were visually examined to ensure an elliptical shape. If the linearity assumption is violated, the overall shape of the plot will be curved, not rectangular. A violation of the assumption of homoscedasticity would show up in a residual plot as a band of plotted residuals becoming wider at larger predicted values. Visual examination of the residuals plots suggested that the assumptions of linearity and homoscedasticity were generally satisfied.

Correlations between measures were examined for multicollinearity and singularity. Tables 8a and 8b contain correlations for information provided by female and male participants who rated photographs, respectively. Multicollinearity occurs when a correlation between variables exceeds .90 (Tabachnick & Fidell, 1996). Ratings variables "good-looking" and "sexy" were correlated .90 ($p < .001$). However, collinearity diagnostics indicated that although the last root had a condition index greater than 30, there were no variance proportions greater than .50, thus, there is no multicollinearity (Tabachnick & Fidell, 1996, p.87). Singularity occurs when the correlation between variables is .99 or greater, indicating the variables are essentially identical. No singularity was found.

Analysis

Normative Data

The raw distributions for male and female WHR are shown in Figure 5. Previous research indicates that WHRs found most attractive by raters are .7 for women and between .9 and 1.0 for men. Both of the current distributions differ by about .05: these women average about .75 and these men average about .85. This is consistent with many of the studies of actual WHRs, as summarized in Table 1. One sample t-tests indicate that the current sample of females did not differ significantly from the so-called "preferred" proportion of .7. However, the males did, $t(79) = -8.48$, $p < .001$, compared to a test value of .9, which is the most liberal "masculine" value that has been produced by studies examining female preferences.

In terms of personal information, male raters had significantly higher body self-esteem (F (1,135) = 7.76, $p < .05$), sociosexuality summary scores (F (1,135) = 46.66, $p < .001$), and WHRs (F (1,135) = 148.29, $p < .001$). There were no sex differences in age, estimated WAIS IQ, or BMI.

Hypothesis 1. Significant kurtosis or a normal distribution would provide evidence of stabilizing selection. For males, the distribution of WHR showed a kurtosis of .45, with a standard error of kurtosis of .61. For females, kurtosis was .40 with a standard error of .54. Significance tests using a z criterion (Tabachnick & Fidell, 1996, p.72) showed neither distribution was kurtotic. However, significance tests of skewness showed that the female distribution was positively skewed, $z = 2.54$, $p < .05$ with a skewness of .67 and standard error of skewness of .27 (the male distribution showing skewness of .42 with a standard error of skewness of .31). In other words, female WHRs tended to be lower.

To summarize normative results, the current sample differs from those of previous investigations in that males show significantly curvier proportions. Male raters differed somewhat from female raters in BSE, sociosexuality, and, as expected, WHR. The properties of the current distribution do not suggest underlying stabilizing selection, although the female participants' distribution was positively skewed.

Theory-Driven Analyses

This set of analyses was grounded in previous research and provided a direct test of competing hypotheses: does WHR or BMI provide a better explanation for the current data? It also affords a picture of people's perception of different body shapes, whether these are accurate, and whether one's own characteristics affect one's perceptions. Where indicated, analyses included separate examination for male and female raters. As mentioned above, bisexual and homosexual judgements were excluded from analyses, except where indicated.

Hypothesis 2. Which provides a better account of the obtained data: WHR or BMI? Before proceeding with the analysis that follows, careful consideration was given to avoiding a large series of separate analyses by extracting a smaller number of factors from the various dependent variables. However, predictors turned out to be very specific for each variable and this area of research has yet to develop to the point that more general entities can be discerned. In lieu of reducing the number of variables, appropriate control for concerns such as Type I error were implemented as detailed below.

As a preview, the analysis used to answer this question employed a series of stepwise multiple regressions with WHR and BMI as independent variables, with separate analyses for male and female photographic trials. The 11 ratings and global ranking were examined separately as dependent variables (these results are summarized in Table 9). Following this, multiple regressions were conducted separately for each sex of rater to determine whether male and female observers use different information (WHR vs. BMI) to make attractiveness judgments (these results are summarized in Table 10).

Firstly, to compare the predictive power of these two variables, stepwise multiple regression was used with WHR and BMI as independent variables, with separate analyses for male and female photographic trials and for the 11 ratings and global ranking as dependent variables (results are summarized in Table 9). WHR was the sole predictor of masculinity (R^2 = .33 and .23 for female and male photographs, respectively) and age (R^2 = .21 and .33 for female and male photographs, respectively). BMI was the sole predictor for intelligence (R^2 = .66 and .32 for female and male photographs, respectively), female photographs' interest in having children (R^2 = .16), and male photographs' ratings of good-looking (R^2 = .35), sexy (R^2 = .36), attractive for marriage (R^2 = .22), attractive for brief casual sex (R^2 = .40), and global ranking (R^2 = .50). The variance of many ratings was best explained by BMI, with a lesser contribution from WHR. In these cases, percent of variance explained was typically fairly substantial for BMI (.44 - .91), with a statistically significant but negligible contribution from WHR (.03 - .13). Specifically, these included ratings of female photographs on femininity ($R^2\Delta$ = .44 and .13 for BMI and WHR, respectively), good-looking ($R^2\Delta$ = .64 and .07), sexy ($R^2\Delta$ = .63 and .07), weight ($R^2\Delta$ = .91 and .03), attractiveness for marriage ($R^2\Delta$ = .68 and .07), attractiveness for brief casual sex ($R^2\Delta$ = .67 and .08), and global ranking ($R^2\Delta$ = .79 and .05) and male photographs' weight estimates ($R^2\Delta$ = .84 and .05).

Multiple regressions were conducted separately for each sex of rater to determine whether male and female observers use different information (WHR vs. BMI) to come to conclusions about people based on their body shape. Results are summarized in Table 10. A number of differences emerge when compared to the analysis of overall ratings (male and female raters analyzed together), as discussed below.

As mentioned above, when ratings are considered irrespective of rater sex, WHR seems to be a main influence in raters' judgements of masculinity. However, when sex of rater is taken into account, it appears that female raters use WHR to determine masculinity of both female and male photographs ($\underline{R}^2$ = .28 and .28, respectively). Male raters, however, apply this variation only to female photographs ($\underline{R}^2$ = .34). WHR and masculinity ratings are positively correlated ($\underline{r}$ = .44, $p < .05$ and $\underline{r}$ = .56, $p < .05$ for female and male photographs, respectively). Thus, it would seem that female raters find male and female photographs more masculine as the WHR increases and male raters find female photographs more masculine as the WHR increases.

Irrespective of sex, WHR was also the sole predictor of age estimates. When male and female raters were examined in separate multiple regressions, this pattern held for female raters ($\underline{R}^2$ = .20 and .30 for female and male photographs, respectively) and for male raters when viewing male figures ($\underline{R}^2$ = .38). However, for male raters viewing female figures, BMI was the sole influence of their estimates of female photographs' age ($\underline{R}^2$ = .24). In other words, men may use a different benchmark for guessing the ages of other men (WHR) and women (BMI), where women use the same benchmark (WHR) for both.

As mentioned above, irrespective of rater sex, BMI was the sole predictor of rated intelligence of male and female photographs. When male and female raters are examined separately, male raters apply this to female and male figures ($\underline{R}^2$ = .67 and .60, respectively), but female raters apply it only to other females ($\underline{R}^2$ = .55).

As for female interest in having children, the overall regression and separate by-rater-sex regressions paint a disparate picture of the influence of WHR and BMI.

Irrespective of rater sex, BMI was the sole predictor of female photographs' interest in having children. When rater sex was examined, this pattern held for male and female ratings of male photographs; both female and male ratings of male photographs' interest in having children were solely predicted by BMI ($\underline{R}^2$ = .25 and .36, respectively). However, WHR was the sole predictor of male ratings of female photographs' interest in having children ($\underline{R}^2$ = .18). Neither WHR nor BMI significantly predicted female ratings of female photographs' interest in having children.

Irrespective of rater sex, BMI was the sole predictor of male photographs' attractiveness for marriage. When sex of rater was taken into account, it remained a significant predictor of male raters' judgements ($\underline{R}^2$ = .37), but did not predict females' ratings of this dimension.

It could be argued that a more appropriate analysis would be to compare the simple correlations of each variable with the dependent variable (i.e., each rating). In stepwise regression, the independent variable with the highest correlation is selected for entry into the equation first. Very minor differences in the magnitude of the correlations can affect the equation. To explore this alternative, a series of Tests for Difference between Dependent Correlations was conducted as described by Bruning and Kintz (1987). The correlations for male and female photographs were examined separately, with WHR and BMI as independent variables and each rating and global ranking as separate dependent variables. None of the $\underline{t}$ tests were significant for male pictures, thus it is impossible to tell from this analysis which variable (WHR or BMI) contributes most to explaining the variance in attractiveness judgements of male photographs. For female photographs, judgements of "intelligent" ($\underline{t}$(25) = 2.45), estimated weight ($\underline{t}$(25) = -6.51), and global rank (t(25) = -2.80) were statistically significant, indicating that the two correlations for these dependent variables are very likely really different. An examination of the bivariate correlations suggests that BMI is more closely associated with these rater judgements (-.81, .96, and .89, respectively), compared to WHR (-.55, .67, and .68, respectively).

To summarize, using multiple regression analyses, BMI is a better predictor of attractiveness judgments than WHR, as shown by a greater number of ratings being solely predicted by BMI, as well as a greater proportion of variance explained being attributed to BMI. However, WHR was a sole predictor of age and masculinity. Some differences emerged when sex of rater was taken into account, when compared to analyses conducted irrespective of rater sex. At the level of simple correlations, however, BMI and WHR were often equivalent predictors.

Hypothesis 3. Will the preferred WHRs approximate those determined by previous research (.7 for women and .9 for men)? Will normal-weight figures be preferred to under- and overweight figures?

Where regression results from the Hypothesis 2 analysis indicated a sole predictor, two-way mixed ANOVAs were conducted with 3 levels of the independent variables (low, moderate and high levels of WHR or BMI) as the within-subjects factor and rater sex as the between-subjects factor. Significant main effects were followed up with examination of pairwise comparisons and significant interactions were followed up with F-tests for simple effects as recommended by Bruning and Kintz (1987, p.132-145). This will yield a description of the preferred body shape trials. In general, results of the two-way mixed ANOVAs (summarized in Table 11) indicate that the overall tendency of the raters was to adjust their ratings as a function of pictured body shape. Secondly, male and female raters often provided different ratings for the same pictured body shape.

WHR, as indicated by the above regression results, was a sole predictor of masculinity judgements. For male photographs, the two-way mixed ANOVA revealed a significant rater sex by WHR category interaction (F (2,254) = 95.84, p < .001). Post hoc F-tests for simple effects showed that female raters find moderate and high WHR men significantly more masculine than low WHR men (F (1,381) = 4.58, p < .05). For female photographs, the ANOVA showed significant main effects of WHR category (F (2,254) = 248.26, p < .001) and rater sex (F (1,127) = 4.67, p < .05). Post hoc tests for WHR category showed high WHRs were seen as significantly more masculine than moderate WHRs, which were significantly more masculine than low WHRs. For rater sex, group means indicate that male raters (M = 3.94) found the female photographs significantly more masculine than female raters (M = 3.42).

WHR was also a sole predictor of age ratings. For female photographs, the two-way mixed ANOVA showed a significant main effect of WHR category (F (2,242) = 96.76, p < .001), with post hoc pairwise comparisons showing that high WHR women were seen as significantly older than moderate and low WHR women. For male photographs, ANOVA results showed significantly main effects of WHR category (F (2,246) = 170.03, p < .001) and rater sex (F (1,123) = 4.96, p < .05. Pairwise comparisons for WHR category showed significant differences among all three groups, such that progressively higher age estimates were assigned as WHR increased. Group means indicate that female raters (M = 23.60) assigned significantly higher age estimates to male photographs compared to male raters (M = 22.71).

The multiple regressions described above with intelligence as the dependent variable indicated that BMI was the sole predictor. Follow up two-way mixed ANOVAs showed a main effect of BMI category for both female (F (2,238) = 60.64, $p < .001$) and male (F (2,226) =20.45, $p < .001$) photographs. Pairwise comparisons showed that obese males were seen as less intelligent than their lean and moderate counterparts. Obese females were seen as significantly less intelligent than normal-weight females, who were seen as significantly less intelligent than underweight females. As discussed below, there is no truth to the assumption that heavier people in this sample are less intelligent.

For female photographs, BMI was the sole predictor of ratings of "interest in having children." A two-way mixed ANOVA yielded significant main effects of BMI category (F (2,250) = 25.28, $p < .001$) and rater sex (F (1,125) = 7.17, $p < .05$). Pairwise comparisons on BMI showed that obese women were seen as significantly less interested in having children compared to normal- and underweight women. Group means for rater sex showed that female raters (M = 6.76) assigned significantly higher ratings compared to male raters (M = 6.14)

For male photographs, BMI was also the sole predictor of "good-looking," "sexy," "attractive for marriage," and "attractive for brief casual sex" ratings as well as global rankings. Separate two-way mixed ANOVAs showed significant main effects of BMI for "good-looking" (F (2,256) = 79.06, $p < .001$), "sexy" (F (2,250) = 89.44, $p < .001$), and "attractive for marriage" (F (2,246) = 44.01, $p < .001$). Pairwise comparisons on "good-looking" and "sexy" both revealed a similar pattern: obese men were seen as significantly less good-looking and sexy compared to normal- and underweight men. For "attractive for marriage," obese men were seen as significantly less attractive compared to under-weight men, who were significantly less attractive than normal weight men.

Separate two-way mixed ANOVAs on "attractive for brief casual sex" (F (2,244) = 3.46, p < .05) and global ranking (F (2,260) = 7.57, p < .001) revealed significant interactions between BMI category and rater sex. Simple F-tests were used as post hoc analysis. For attractiveness for brief casual sex, obese men were seen as significantly less attractive compared to normal- (F (1,366) = 4.74, p < .05) and underweight (F (1,366) = 7.42, p < .05) men. In addition, female raters saw normal- and underweight men as significantly less attractive than male raters. In other words, male and female raters provided similar ratings of obese men, but male raters were more generous in their ratings of normal- and underweight men compared to female raters. For global ranking, obese men (F (1,390) = 25.28, p < .05) received significantly lower rankings compared to normal- and underweight (F (1,390) = 14.86, p < .05) men, with male raters finding underweight men as more attractive than normal weight men and female raters finding normal weight men more attractive than underweight men.

In many cases, the above multiple regressions indicated that both BMI and WHR were significant predictors of rater judgements. Where this was the case, separate two-way mixed ANOVAs were conducted to determine body shape trial differences (also summarized in Table 11). Separate trials consisted of 8 body shapes for both male and female stimuli photographs, as described above in the materials section.

BMI and WHR were both predictors of raters' weight estimates. For male photographs, the two-way mixed ANOVA revealed a significant main effect of body shape trial, F (7,875) = 368.04, p < .001. Pairwise comparisons showed that the body shape trials were seen as progressively heavier as follows: lightest was low WHR-low BMI < moderate WHR-low BMI < all moderate BMI trials (low, moderate, and high BMI) and low WHR-high BMI < moderate WHR-high BMI < high WHR-high BMI. Thus, it seems that high BMI men with low WHRs appeared to be the same weight as men with moderate BMIs. The eight female body shape trials interacted with rater sex (F (7,868) = 5.41, p < .001), such that males gave lower weight estimates for high BMI and high WHR-moderate BMI trials compared to female raters. Otherwise, the eight trials were all significantly different from each other and assorted roughly according to low-moderate-high by WHR and BMI. However, the low WHR-moderate BMI and low WHR-high BMI trials were seen as heavier than their moderate WHR counterparts. This could have occurred because both of these trials consisted of only one photograph. The latter had a considerably higher BMI (41.57) than the rest of the stimuli (the next lowest were 38.17 and 35.17), which is also very unusual when coupled with such a low WHR (.70).

For female photographs, the above regressions also indicated that BMI and WHR were both predictors of several ratings. . Separate two-way mixed ANOVAs using "feminine" (F (7,868) = 8.26, p < .001), "goodlooking" (F (7,896) = 7.91, p < .001), "sexy" (F (7,896) = 9.02, p < .001), "attractive for marriage" (F (7,861) = 8.24, p < .001), "attractive for brief casual sex" (F (7,868) = 5.34, p < .001) and global ranking (F (7,889) =4.20, p < .001) as dependent variables showed significant interactions between body shape trial and rater sex. Follow-up F-tests for simple effects showed that, for femininity ratings, female raters found four groups significantly more attractive than male raters: low WHR-moderate BMI (F (1,992) = 9.22, p < .05), low WHR-high BMI (F (1,992) =

36.15, p < .05), moderate WHR-high BMI (F (1,992) = 4.14, p < .05), and high WHR-high BMI (F (1,992) = 4.37, p < .05). More generally, the body shape trials assorted as follows, from least to most attractive: high WHR-high BMI < high WHR-moderate BMI, moderate WHR-high BMI < low WHR-moderate BMI, low WHR-high BMI < moderate WHR-low BMI < moderate WHR-moderate BMI < low WHR-low BMI.

For "good-looking," "sexy," "attractive for marriage," "attractive for brief casual sex," and global ranking, post hoc F-tests for simple effects revealed a similar pattern of results: the low WHR-low BMI trial was seen as most attractive, followed by moderate WHR-low BMI and moderate WHR-moderate BMI trials. Low WHR-moderate BMI, high WHR-moderate BMI, and moderate WHR-high BMI trials were seen as similarly less attractive. High WHR-high BMI was next lowest, with low BMI-high BMI seen as least attractive, again, perhaps because her BMI was quite a bit higher than the other stimuli. This interacted with rater sex such that males generally assigned lower ratings than females. Females, however, assigned significantly lower global rankings.

Although WHR and BMI cannot, in nature, be carved at their joints, we can use the statistical technique of analysis of covariance to partial out the effects of WHR and BMI on each other for the sake of theoretical interest. Thus, we can determine, all else being equal, what proportions are, in the abstract sense, favoured. For each sex pictured, two-way mixed ANCOVAs were conducted with rater sex as the within-subjects variable, either WHR or BMI (3 groups each) as the between-subjects variables, and either WHR or BMI as the covariate. Alpha was set at .005 to protect against inflated familywise Type I error. Table 12 shows significant results. Variables for which the covariate was significant are included, indicating that its "noise" was significantly reduced. Analyses for which there was a covariate interaction are not included, as these indicate that the interacting variable is unevenly adjusted.

When WHR is used as the covariate, it only provided significant adjustment to female femininity ($\underline{F}$ (2,24) =4.81 , $\underline{p} < .05$) and attractiveness for marriage ($\underline{F}$ (2,24) = 4.32, $\underline{p} < .05$), and male weight estimates ($\underline{F}$ (2,16) = 7.37, $\underline{p} < .001$). In all cases, post hoc pairwise comparisons showed ratings are more favourable for low and moderate BMIs, with high BMIs being seen as significantly less feminine and attractive for marriage for female photographs and significantly heavier for male BMIs. When BMI was used as a covariate, it provided a significant adjustment for three dependent variables: female femininity ($\underline{F}$ (2,24) = 5.50, $\underline{p} < .05$), attractiveness for brief casual sex ($\underline{F}$ (2,24) = 3.90, $\underline{p} < .05$), and global ranking ($\underline{F}$ (2,24) = 3.87, $\underline{p} < .05$). In all three cases, pairwise comparisons indicated that the high WHR was seen as less feminine and less attractive than the low and moderate WHRs.

In brief, the preferred body proportions tend to be slimmer, and within weight categories, tend to favour lower WHRs in both men and women. Obese figures and those with higher WHRs received lower ratings of attractiveness and lower rankings.

<u>Hypothesis 4.</u> Are raters accurate in assessing photographs' age and weight? Pearson product-moment correlations were conducted comparing actual ages and weights of the people appearing in photographs, separately by sex pictured. Results indicate firstly that male and female raters' ratings converge nearly to the point of singularity, because both correlations are above .96. Secondly, it appears that estimates of weight ($\underline{r}$ = .82 and .90 for male and female photographs, respectively) and age ($\underline{r}$ = .69 and .82 for

male and female photographs, respectively) are significantly accurate ($p < .001$ for all), although of somewhat less so for age estimates of male photographs.

In addition to asking raters to estimate figures' weight in pounds, they were also asked to choose a descriptor of the figures' weight: under-, normal, or overweight. Male and female raters' categorizations are correlated .98, which converges to near singularity, so all raters were analyzed together. Multiple regressions entering WHR and BMI stepwise indicate that BMI is the sole predictor of weight category for male photographs ($R^2 = .78$), but that BMI ($R^2 = .78$), with a lesser contribution from WHR predict weight category for female photographs ($R^2\Delta = .06$).

Do assigned descriptors match objective criteria for being too thin or obese? The 15th and 85th percentiles are generally taken as cutoffs, which in this sample translate in to 66.43 and 97.52 kg for males and 53.64 and 83.64 kg for females, respectively. For male photographs, assigned weight category corresponds to objective classification, $r = .73$, $p < .001$. However, for female photographs, the correlation is of considerably lower magnitude, $r = .48$, although still statistically significant, $p < .05$. Photographs were grouped using previously described actual BMI cutoffs of 15th and 85th percentiles. These three groups were entered into a one-way ANOVAs with raters' mean subjective weight categorization of photographs as the dependent variable. For male photographs, ($F(2,19) = 10.14$, $p = .001$), post hoc pairwise comparisons indicate that all men below the 84th percentile (under- and normal weight) are viewed as "normal weight" by raters, compared to obese men (above the 85th percentile), who are classified by raters as "overweight". For female photographs, ($F(2,27) = 18.14$, $p < .001$), post hoc tests indicate that raters assign under-, normal, and overweight women to significantly different categories. In other words, people seem to make a distinction between all three types of women (under-, normal, and overweight), but treat under- and normal weight men similarly. The actual mean weights (and ranges) of these groups of men are 57.38 kg (50.85 – 61.65), 81.42 kg (70.65 – 96.75), and 113.40 kg (98.55 – 135.45), respectively, and for women, 49.65 kg (42.75 – 53.55), 70.23 kg (59.85 – 82.80), and 97.05 kg (91.35 – 103.50).

In short, raters tend to be accurate in assessing the age and weight of people pictured. Their subjective classification of a figure as "underweight," "normal," or "overweight" also corresponds to a reasonable degree with objective classification by percentiles.

Hypothesis 5. Do raters agree in their judgements? Intraclass correlations were computed for each rating and are summarized in Table 13. Results show an extraordinarily high level of agreement overall, as well as between male and female raters, as nearly all intraclass correlations are above .95. The only exceptions are "interest in having children" and "capable of having children." The former saw female raters agreeing at the .71 level and males at .85. The latter had an inter-rater agreement of .80, which is still quite high. In summary, rater judgements show an extraordinarily high level of agreement.

Hypothesis 6. Do personal characteristics of raters influence their judgements of attractiveness? A series of t-tests were conducted on the eleven ratings and global ranking with a corrected alpha level (.005) to prevent inflation of Type I error. Raters were grouped using median splits for age, age at maturation, body self-esteem, WHR, and BMI, and sex of rater was run as a dichotomous variable. Results show that personal characteristics often had a significant effect on ratings in many cases as given below, as summarized in Table 14. With the exception of female age at sexual maturity, each variable tested appears to have influenced at least one facet of attractiveness judgements. Males gave higher ratings of female masculinity ($\underline{t}(131) = 2.22$, $\underline{p} < .05$) and male attractiveness for brief casual sex ($\underline{t}(127) = 1.98$, $\underline{p} < .05$) and lower ratings of female interest in having children ($\underline{t}(130) = -2.84$, $\underline{p} < .05$) and attractiveness for marriage ($\underline{t}(128) = -4.08$, $\underline{p} < .001$) compared to female raters. People with a relatively unrestricted sociosexual orientation found female photographs more masculine ($\underline{t}(130) = -2.63$, $\underline{p} < .05$), less feminine ($\underline{t}(128) = 3.97$, $\underline{p} < .001$), less good-looking ($\underline{t}(132) = 2.22$, $\underline{p} < .05$), and less attractive for marriage ($\underline{t}(127) = 2.66$, $\underline{p} < .05$) compared to people with a more restricted sociosexual orientation. Older participants gave lower intelligence (for female ($\underline{t}(124) = 2.66$, $\underline{p} < .05$ and male ($\underline{t}(118) = 2.20$, $\underline{p} < .05$) photographs) and higher age estimates (for female ($\underline{t}(131) = 2.22$, $\underline{p} < .05$) and male ($\underline{t}(131) = 2.22$, $\underline{p} < .05$) photographs) and found female photographs less capable of having children ($\underline{t}(132) = 2.39$, $\underline{p} < .05$) and male photographs less masculine ($\underline{t}(132) = 2.06$, $\underline{p} < .05$) and lower in weight ($\underline{t}(130) = 2.36$, $\underline{p} < .05$) compared to younger participants. People with higher body self-esteem gave male photographs higher weight estimates compared to people with lower body self-esteem, $\underline{t}(129) = -2.01$, $\underline{p} < .05$. Men with lower WHRs gave lower age estimates than men with higher WHRs, (for female ($\underline{t}(55) = -2.22$, $\underline{p} < .05$) and male ($\underline{t}(55) = -2.43$, $\underline{p} < .05$) photographs). Women with lower WHRs gave male photographs lower weight estimates than women with higher WHRs, $\underline{t}(71) = 2.63$, $\underline{p} < .05$. Men with lower BMIs felt that female photographs were more capable of having children than men with higher BMIs, $t(58) = 2.93$, $p < .05$. Women with lower BMIs felt that male photographs were heavier than women with higher BMIs, $t(71) = 2.40$, $p < .05$.

Although rater accuracy at estimating weight is quite high, as discussed in reference to Hypothesis 4, there was a significant sex difference in estimates for female photographs, with male raters giving a mean estimate of 66.54 kg and female raters giving a mean of 69.19 kg. Which sex gives more accurate weight estimates? Pearson product-moment correlations indicate that, while men and women provide nearly identical estimates ($r = .893$ and .899, respectively, both significant $p < .001$), women's are about 2 kg (5 lb) higher, which is closer to the actual weight of the women appearing in the photographs ($M = 69.36$ kg). This suggests that men tend to slightly underestimate women's weight.

In brief, it seems that personal characteristics do have some influence on rater judgements of attractiveness. However, with the exception of sociosexuality, these differences can be interpreted as slight and following no discernable pattern.

Exploratory Analyses

Some of our research questions are exploratory in nature because there is scant previous research upon which to base predictions.

Hypothesis 7. What is the relationship between body shape and body self-esteem? Stepwise multiple regressions were conducted with body self-esteem as the dependent variable and WHR and BMI as independent variables. When male and female raters were considered together, BMI was the sole predictor, $F\ (1,185) = 32.57$, $p < .001$, $R^2 = .15$. However, when the sexes were considered separately, it was discovered that there was no significant correlation between male raters' body self-esteem and either dependent variable. BMI was, on the other hand, the sole predictor of body self-esteem for women raters, F (1, 105) = 45.06, $p < .001$, $R^2 = .30$. The correlation between body self-esteem and women's BMI was -.36, $p < .001$, which suggests that, as female raters' BMIs increase, their body self-esteems decrease.

In short, for males, body shape seems to have little bearing on their BSE. However, women seem to exhibit a lower BSE as their BMIs increase.

Hypothesis 8. Do judgements of attractiveness differ based on raters' sexual orientation or sociosexuality (see Table 14 for a summary)? Scores from heterosexual raters were compared to scores from non-heterosexual (homosexual and bisexual) raters using a series of t-tests for the various ratings and global ranking, with alpha levels adjusted for multiple comparisons to .005. Results indicate that sexual orientation affected ratings of sexiness (for female ($t(133) = -2.50$, $p < .05$) and male ($t(130) = -2.19$, $p < .05$) photographs), good-looking for female photographs ($t(133) = -1.98$, $p < .05$), and global ranking of male photographs ($t(135) = 2.03$, $p < .05$). Group means indicate that homosexual participants found the photographs sexier and female photographs more good-looking, but assigned male photographs lower global rankings. However, given that only 5 participants reported a gay/bisexual/lesbian orientation, drawing conclusions based on this information is premature.

A median split was conducted on sociosexuality and the two groups were compared as they were for sexual orientation. Results show that ratings of male photographs were unaffected. However, ratings of female photographs' were rated differently on masculinity ($t(130) = -2.63$, $p < .05$), femininity ($t(128) = 3.97$, $p < .001$), good-lookingness ($t(132) = 2.22$, $p < .05$), and attractiveness for marriage. Group means (reported in Table 14) show that people with relatively unrestricted sociosexuality (more liberal sexual attitudes and behaviour) found female photographs more masculine, less feminine, less good-looking, and less attractive for marriage.

To sum up, conclusions about the effect of sexual orientation on attractiveness judgements are premature given that only 5 homo- or bisexual participants volunteered. However, their ratings of female figures tended to be more generous. On the other hand, people with relatively unrestricted sociosexuality seemed to judge female figures less favourably than people with a relatively restricted sociosexual orientation.

Hypothesis 9. Regarding ratings of intelligence, is body shape an honest advertisement of intellectual functioning? In other words, can raters accurately estimate someone's cognitive functioning from their photograph? The t-test results indicate that males and females provide similar intelligence ratings. Pearson product-moment correlations between IQ as estimated by the Shipley and raters' estimates are statistically insignificant ($r = .31$, $p = .18$), suggesting that body shape is not an honest advertisement of intellectual functioning.

Do raters' intellectual functioning affect their judgements of others' attractiveness? A median split was conducted on rater estimated IQ and these two groups were compared using an independent samples t-test, with an alpha level adjusted for multiple comparisons (.005) and separate analyses for male and female photographs. Results indicated that judgements of intelligence are affected (for female ($t(124) = -2.86$, $p < .05$) and male ($t(118) = -2.00$, $p < .05$) photographs), as well as ratings of "good-looking" for male photographs ($t(133) = -2.31$, $p < .05$). Group means (as reported in

Table 14) indicate that people with higher intelligence attributed greater intelligence to people in the photographs and found male photographs more good-looking.

What body types are seen as most and least intelligent? A two-way mixed ANOVA was conducted with BMI trial as the within-subjects variable, rater sex as the between-subjects variable and intelligence ratings as the dependent variable. BMI was used to group photographs because previous stepwise regression analysis (reported above in the "Hypothesis 2" section) indicated that BMI was the sole determinant of intelligence ratings. Results of the two-way ANOVA show that BMI was significant, $\underline{F}$ (2,248) = 68.86, $\underline{p} < .001$ for female photographs and $\underline{F}$ (2,236) = 21.25, $\underline{p} < .001$ for male photographs. Post hoc pairwise comparisons indicate that, for male photographs, high BMI is seen as significantly less intelligent than moderate and low BMI. For female photographs, high BMI was rated significantly less intelligent than moderate BMI, which was seen as significantly less intelligent than low BMI.

In brief, raters were unable to discern the intelligence of a figure from their physical proportions. Compared to raters with lower intelligence, raters with higher intelligence assigned higher ratings of intelligence and found males more "good-looking." Under- and normal weight male figures are seen as more intelligent than obese males. Underweight females are seen as most intelligent, followed by normal weight females, who are in turn seen as more intelligent than obese females.

Hypothesis 10. Are ratings of particular characteristics from photographs presented consecutively comparable to global rankings obtained when people can compare all the stimuli at once? Raters were also asked to place photographs in order "from what they liked the best to what they liked the least." This yielded a rank of relative global attractiveness, because all photographs were presented simultaneously. Did ratings and ranking yield similar attractiveness judgements? Spearman correlations were used to compare these global rankings to the eleven ratings (as summarized in Table 15). Overall, they were highly correlated, suggesting that the two methods of obtaining rater judgements are fairly comparable. However, there were some differences across sex pictured and sex of rater. Overall, it would seem that male photograph age was not related to global ranked attractiveness, although it was for female photograph age. It would seem, also, that male and female raters use somewhat different criteria when judging the attractiveness of male and female photographs. Ratings of masculinity, femininity, and age are not related to global ranking for male photographs, but are quite highly correlated for female photographs. Female ratings of interest in children was unrelated to global rankings, whereas male ratings were quite highly correlated with global rankings.

Sometimes the relationship of ratings and rankings depended on sex of rater interacting with sex pictured. Females rankings of male photographs are unrelated to intelligence and age, where their rankings of female photographs are related. Males' rankings are not related to ability to have children of female photographs but are quite highly for male photographs, which may suggest that men do not consider this when evaluating a woman's attractiveness.

To summarize, it seems that the two methods of collecting attractiveness judgments, rating photographs presented consecutively versus ranking photographs presented simultaneously produced quite similar results, with a few exceptions, some of which may be related to rater sex.

Hypothesis 11. Does sex pictured or sex of rater affect how quickly participants rate and rank the photographic trials? Two-way mixed ANOVAs were conducted with rater sex as the between-subjects variable and sex pictured as the within-subjects variable. Time per photograph to either rate or rank was the dependent variable. The time to rate ANOVA showed a rater sex by sex pictured interaction, F (1, 124) = 270.26, $p < .001$, such that males take significantly longer to rate female photographs and females take significantly longer to rate male photographs. A plot of group means suggests that neither sex is choosier, but that each is as choosy when evaluating people of the opposite sex. Male raters spent an average of .99 seconds on each female photograph and .75 on each male photograph. Female raters spent an average of .75 seconds on each female photograph and 1.00 seconds on each male photograph.

The time to rank ANOVA also showed a rater sex by sex pictured interaction, F (1, 117) = 50.18, $p < .001$. Male and female raters took the same time to rank per female photograph (M = .16 and .13 seconds, respectively), and both took longer to place male photographs in rank order, with female raters (M = 1.0) taking significantly longer than male raters (M = .77).

To recap, people seem to take longer to rate photographs of the opposite sex. However, when ranking, males and females seem to rank female photographs more quickly. Females also seem to take longer than males to rank photographs of males.

Hypothesis 12. Are self-reported measurements reliable? Participants reported their waist girth, hip girth, height, and weight at prescreening and their waist and hip girths in the lab. Participants were allowed to report in imperial or metric, but the vast majority chose imperial. These were compared against measurements obtained by the experimenter. Pearson product-moment correlations were conducted to determine whether self-reported measurements are reliable. These were done separately by sex, partly because previous research only addresses female self-report and partly because some feel that males are less aware of their hip measurements.

Results are summarized in Table 16, including mean differences in absolute terms, indicate that both men and women, given simple instructions with a diagram and a standard tape measure, report fairly accurate body measurements. Correlations across self-reported prescreening or laboratory conditions differ statistically significantly for waist and hip, t (387) = -3.06, p < .05 and t (379) = -3.05, p < .05, respectively, such that prescreening measurements are slightly lower, with an actual difference of 3.5 cm for waist girth and 4 cm for hip girth.

Hypothesis 13. What is the psychometric quality of the rating scales? Intraclass correlations for the body shape trials are discussed above and shown in Table 6. To help determine what influenced ratings, the photograph with the highest intraclass correlations across the 11 dependent variables was chosen from the most (low WHR-low BMI) and least (high WHR-high BMI) attractive trials for male and female figures. These ratings were subjected to separate factor analyses for male and female raters to determine how the ratings relate to one another. Horn's Parallel Analysis was used to determine eigenvalue cutoffs from a Monte Carlo data set of the same sizes.

For the "attractive" male photograph (low WHR, low BMI), two factor emerged for male and female raters: "attractive" and "masculine." For the "unattractive" male photograph (high WHR, high BMI), again two factors resulted for female raters: "attractive" and "reproductive interest," and for male raters, "smart and attractive" and "masculine and reproductively interested." For the "attractive" female photograph (low WHR, low BMI), two factors emerged for male raters: "attractive and feminine" and "smart and reproductively interested." For female raters, only a "smart, attractive, reproductively interested" factor resulted. For the "unattractive" female photograph (high WHR, high BMI), two factors emerged for male and female raters: "attractive" and "smart and reproductively interested," but for female raters, the "attractive" factor also included "femininity" and "lack of masculinity."

Results Summary

The main findings of the present study suggest that WHR, despite a more parsimonious and seemingly compelling rationale than BMI, may not be as influential as previously reported in literature. Several findings seem to contradict previous work. Normatively, the present sample exhibits similar proportions compared to other university samples, but not compared to the "preferred" proportions determined by previous studies of WHR. Using regression analysis, BMI was a better predictor of observer judgements than WHR, although WHR was not entirely inconsequential. Generally, observers found male and female figures with lower BMIs and WHRs as more attractive. However, the simple correlations between BMI and WHR and each of the criterion measures were generally not significantly different. Observer judgements showed a high degree of consistency and their estimates of age and weight were quite accurate. Their estimates of intelligence, however, were not. Generally, observers' own characteristics did not systematically influence their judgements. Ratings for which photographs were presented one at a time were comparable to rankings for which photographs were presented simultaneously. Finally, the reliability of self-reported measurements for male and female participants was fairly high.

Discussion

Normative Considerations

The present sample shows similar proportions to previous investigations. Male WHRs were significantly higher than female WHRs, confirming that higher WHRs can, indeed, be considered more masculine. The distribution of female WHRs was positively skewed, which may be an artifact of a relatively young and healthy sample. Evidence to support stabilizing selection is lacking. The present sample is similar to other university samples from previous research (e.g., Davis & Cerullo, 1996; Milligan et al., 1997).

What is interesting, however, is the divergence between the present sample and the so-called "preferred" proportions determined by previous experimental work using line drawings and retouched photographs. Generally speaking, .7 for women and .95 for men have been deemed the most attractive WHRs. However, our sample showed significant differences, specifically the females had an average WHR of .75 and the males averaged .86. Would not evolutionary principles suggest that, if any group had a chance of meeting the young ideal, university students would be the most likely to exhibit the preferred proportions? Yet, they do not. One might argue that this group of successful, intelligent, prime-mating-age young adults may not be among the most desirable compared to the general population. This is an unlikely alternate explanation. More likely, the "preferred" WHRs distilled from previous investigations are not an accurate reflection of objective optimal WHRs.

BMI versus WHR

On paper, WHR seems a more persuasive candidate for an honest advertisement of reproductive health. It varies by hormonal regulation for men and women (a direct mechanism not only for variation but also a link to evolutionary concerns), predicts fertility at the high and low end (BMI can only predict afertility in women when they are underweight), and WHR ideals have been, as far as has been investigated, consistent across time and cultures. The dependent variables tested presently have all shown significant relationships with WHR in past research. However, Furnham, Lavancy, and McClelland (2001) claim that "weight of a figure [is] a more powerful predictor of attractiveness than WHR, a finding which has been consistently obtained by all WHR researchers" (p.493).

A main aim of the present work was to determine whether WHR or BMI is a better predictor of attractiveness and related variables. Although WHR was not entirely inconsequential, based on the present results, BMI must be declared superior. The present results, in large part, seem to replicate those of Tovée et al. (1999) and Maisey et al. (1999). A concern with their stimuli was the lack of control for female breast size, which was accounted for in the present study. Concern for the apparent restriction of range of WHRs was also raised in reference to Tovée et al. (1999). While their female stimuli ranged from .7 to .83, the present study's ranged from .66 to .91 for female figures, which represented that available from a large screening of university-aged potential participants. Tovée et al. used 19 female images; the present study included 28 female image and 20 male images.

On the whole, stepwise multiple regression results pitting WHR against BMI showed that most ratings of attractiveness were best predicted by either BMI or a BMI/WHR combination. The percent explained variance by BMI (~.70) and WHR (~.05) is consistent with Tovée's (1999) results. BMI was the sole predictor of ratings of intelligence, female figures' interest in having children, and male figures being rated "good-looking," attractive for marriage and brief casual sex, and global ranking. BMI, with a lesser contribution from WHR, were predictors for weight estimates and female figures being rated feminine, good-looking, sexy, attractive for marriage and brief casual sex, and global ranking. ANCOVA results are a further testament to BMI's dominance: WHR only provided significant adjustment to female femininity and male weight, where BMI was a significant covariate for twelve variables.

What was not replicated were Tovée and colleagues' results for male and female preferences for figures of the opposite sex (Maisey et al., 1999; Tovée, Reinhardt, Emery, & Cornelissen, 1998). In those two investigations, the BMIs of target photographs were plotted against attractiveness ratings, which yielded inverted-U curves, such that both male and female figures of moderate BMI were seen as most attractive, particularly for female figures. WHR showed a linear relationship with attractiveness ratings for female figures, such that women with lower WHRs were seen as more attractive than women with higher WHRs. There was no significant relationship between WHR in Maisey et al.'s study of male figures, in which waist-to-chest ratio explained more variance (56%) than did BMI (12.7%). In the present study, bivariate plots of BMI and WHR versus attractiveness ratings showed linear patterns such that lower BMIs and WHRs were seen as more attractive (bivariate plots were inspected prior to running multiple regressions, as reported in the "Pre-analysis Issues" section).

Evolutionary hypotheses about the underlying message of BMI states that underweight (female) figures are less attractive because it may signal amenorrhea or lower fertility. Similarly, one would anticipate that low BMI males would be seen as less attractive, possibly because a smaller male might be at a physical or social disadvantage to male rivals or environmental threats such as predators, disease, or famine.

In Canadian society, being overweight is a mark of ill health, as the threat of starvation is much less salient than in foraging or horticultural groups. Wetsman and Marlowe (1999) suggest that, among cultures still isolated from Western influence, plumpness is a sign of higher social status and heavier women are more attractive. They found that foraging males did not consider WHR when trying to determine a woman's marriageability; they rank-ordered photographs such that heavier figures were preferred to normal and underweight figures. Stimuli were Singh's line drawings, however, for which the actual apparent weight has yet to be determined.

In a later study, Marlowe and Wetsman (2001) held weight constant and varied only WHR. They found that these same group of foraging men preferred high WHRs compared to American men. However, again, the stimuli consist of a series of line drawings in which the waists are increasingly narrow, thus making the apparent weight of the figure increasingly small. However, since this group of foragers seems to prefer heavier and less curvaceous women, the weight confound would have compounded the effect of WHR. This would run in direct contradiction to most investigations of weight and WHR. Marlowe and Wetsman's comments on cultural differences in pregnancy may help to explain the apparent schism between samples. Among the Hadza, the seeming preference for obesity may simply be a preference for the increase in WHR and BMI that occurs when a women is pregnant. Total fertility among the Hadza (6.2) is considerably higher than the United States (2.0). According to the authors, the Hadza also have greater opportunity for short-term pairings (a somewhat questionable assumption), ability to bear children is more salient than long-term health when one is looking for a short-term mate.

Presently, WHR, when pitted against BMI in stepwise multiple regression, was the sole predictor for masculinity ratings and age estimates. Insofar as age is thought to be a prime indicator of fertility for women, the usual evolutionary "honest advertisement" explanation can be retained. Masculinity could be thought of in two ways. Firstly, masculinity in women could signal hormonal dysregulation and, thus, compromised fertility. Masculinity in men would signal reproductive health.

Conversely, if one considers WHR to be a signal, not of reproductive health, but a quick indicator of sex, one could detect whether a person is male or female from a distance or from various angles. This was confirmed by pilot data (collected separately from the current investigation) that showed that men were mistaken for women when their WHRs were low and that women were mistaken for men when their WHRs were high. Masculinity, then, would signal "lack of femaleness," such that males looking to mate would disregard women in poor reproductive health and females looking to size up rivals would not take much further notice of women in poor reproductive health. The problem with this view is that differentiating a male from a masculine woman would seem to be an important consideration. Men would want to keep an eye out for potential rivals and men and women would want to detect a male who might pose a physical threat to themselves or offspring. Men and women would also want to be aware of socially dominant men so they could display the proper reverence and perhaps form alliances. This interpretation is also supported by the factor analysis reported above: the presence of masculinity for men and lack of it, as well as the presence of femininity, for women seemed important predictors of attractiveness ratings.

Perhaps, as Singh (1993b) states, physical qualities, specifically WHR, may be a first-pass filter when people judge another's attractiveness. However, to date, it seems that only the current investigation has ascertained stimulus figures' actual BMI, outside of Puhl and Boland's (2001) two normal weight figures. Other available studies focus exclusively on WHR and alter WHR without regard to the effects on apparent BMI. One line of research cannot hope to include every possible confound. However, it would seem that routine comparison of BMI and WHR is in order, as BMI may be unwittingly responsible for certain attractiveness judgements that are being attributed to WHR. This rules out the use of line drawings. Retouched photographs also lack an objective measure of the figures' BMI, but the present results suggest that observers, particularly women, are excellent estimators of weight of people in photographs. Thus, participants could estimate the photographed figures' weights and BMI could be determined if the figures' heights were known.

Preferred Proportions in People Rated as Attractive

Conflict about BMI and WHR aside, what bodily proportions are favoured? Many of these results seem to contradict previous findings, as well. Generally, people with high BMI are seen as less attractive than people with moderate and low BMIs. This seems to be the case for female interest in having children and male good-lookingness, sexiness, intelligence, attractiveness for brief casual sex, and global ranking.

In situations where low and moderate BMI trials were significantly different from each other, it happened that low BMI females were seen as more intelligent, but moderate BMI men were seen as more attractive for marriage than low BMI men. This pattern was also the case when comparing numerical weight estimates to categorical judgements of weight. People seem to view low and moderate BMI men as "normal" and high BMI as "overweight." However, people seem to make a distinction between all three categories of women, "under-," "normal," and "overweight."

Where WHR was a significant predictor, females were seen as progressively more masculine as their WHRs increased, but moderate and high WHR men were seen as more masculine than low WHR men. Low and moderate WHR women were seen as younger than high WHR women, but each trial of male WHRs yielded progressively higher age estimates.

The photographs that were found most attractive also differ from previous findings in terms of WHR. The one study that tested women's perceptions of male figures determined that .95 or 1.0 was the preferred male proportion. However, the present study suggests that the preferred male WHR is closer to .8.

When BMI and WHR seemed to independently contribute to ratings, the low BMI-low WHR trial was consistently preferred among female photographs, followed by the moderate BMI-moderate WHR trial and the moderate BMI-low WHR trial. The less attractive end was similarly uncontroversial: the high BMI trials (low, moderate, and high WHRs) were consistently seen as the least attractive. The low WHR-high BMI trial generally placed last, which is plausibly due to this trial being composed of only one photograph whose BMI is considerably higher than the other photographs (BMI = 41.57).

Rater Accuracy

Raters appeared to be quite good at estimating photographs' ages and weights based on body shape, although they were not quite as accurate when guessing males' ages. As mentioned above, this could provide a rescue for the use of retouched photographs as stimuli in attractiveness research. Tovée et al. (2000) also report that their non-eating disordered female observers were quite accurate in estimating pictured BMI. While BMI could not be computed unless the height of the figure were known, at least weight could, in some manner, be taken into account. It should be noted that, in the current sample, men slightly underestimated female figures' weight by about 2 kg (5 lbs), which has implications for trying to estimate the weight of stimulus photographs.

Do Raters Agree?

Intraclass correlations show extraordinarily high inter-rater agreement on all ratings, although "interest in having children," particularly among female raters, and "capable of having children" were somewhat more modest, but still high. Firstly, this shows that male and female ratings are generally indistinguishable, meaning that the two sexes do not seem to hold different standards for male and female photographs. They agree on which photographs were attractive and which were not. This supports an "honest advertisement" view of attractiveness. Secondly, males and females largely agree. This argues against a view in which everyone has their own "type" or preferred body shape. All else being equal, physical beauty, it seems, is not in the eye of the beholder.

Do these results support a view in which our preferences for body shape developed in ancient times and are invariant over time? That everyone agrees could be interpreted as a shared cognitive process for assigning attractiveness judgements. However, our ratings were collected over the span of about a year, so we can only conclude that ratings were stable over that length of time. Any changes in what body shape is fashionable that occurred outside of that timeframe cannot be addressed by this study. Given other evidence of the stability of preferences over generations (ages 18-65) and over time (from the 1960's to the present), such changes are doubtful to have occurred, notwithstanding certain cultures' switch from agrarian foraging to Western lifestyle.

Do Our Own Characteristics Influence Our Attractiveness Judgements?

Information about raters was collected to determine whether various personal characteristics influence their perceptions of others. In past investigations, only male raters' BMI was examined in this way, with the conclusion that it did not affect attractiveness judgements. The current data suggests that BMI, among other variables, had a statistically significant but sporadic effects on attractiveness judgements. Men with lower BMIs saw female photographs as more capable of having children than men with higher BMIs. Compared to women with higher BMIs, women with lower BMIs thought that male photographs were heavier. Group means, however, suggest that these differences are very small. Thus, it is safe to conclude that raters' own sex, BMI, WHR, IQ, BSE, and age had little, if any, important effect on their judgements.

Sociosexual orientation stands as an exception to this. People with a relatively unrestricted sociosexual orientation seem to be tougher judges of female attractiveness.

Perhaps they, themselves, are more attractive and so prefer mates who are more attractive. Alternatively, they may be more discerning. It may also be a means of improving the genetic quality of one's offspring; short-term relationships do not require equity of mate value to sustain, therefore, one might as well aim to couple with the best-looking available alternative. However, these suggestions are highly speculative and require empirical confirmation.

How does body shape relate to body self-esteem?

Results suggest that male body self-esteem is predicted by neither BMI nor WHR. However, BMI is a significant predictor of female body self-esteem. Given copious public and academic attention to the connection between body shape and attitudes in women, one might not be surprised by this finding. Generally, such a finding might be interpreted as evidence that women are bombarded by media messages that they must conform to an unattainable ideal. However, from an evolutionary standpoint, it is not necessary to invoke an intervening factor: cross-cultural research (e.g., Buss, 1989) suggests that people around the globe place more emphasis on physical attractiveness when evaluating women as potential mates. The present results suggest that women who are slimmer are evaluated more favourably. Thus, would not women who are not slim recognize that they do not exhibit preferred proportions? Men who are not slim were also not favoured in the present results, but it seems that this would not affect how men feel about their attractiveness. If we may again appeal to Buss's (1989) results, people tend to desire less physical qualities in male mates – ambition and social dominance, so perhaps physical attractiveness is a less salient organizing feature of men's self-images.

The present results contrast with those of Davis and Cerullo (1996), who found that women with higher BMIs were less preoccupied with weight. However, they used a composite score that was partly composed of a body dissatisfaction subscale along with "drive-for-thinness" and "bulimia" subscales. Thus, it is difficult to make direct comparisons because they did not use a pure measure of body self-esteem.

How is body shape related to intelligence and perceptions of intelligence?

Raters were unable to correctly guess the intelligence of the people appearing in the stimulus photographs. However, that did not stop raters from making certain assumptions based on body shape. Men with high BMIs are seen as less intelligent than men with moderate or low BMIs. Women with high BMIs are seen as less intelligent than women with moderate BMIs, who are seen as less intelligent than women with low BMIs.

This pair of findings has obvious practical implications for daily social discourse. While the present investigation did not measure or attempt to objectively assess *behaviour* towards different body types, it is a safe bet that such judgements unfairly affect people's opportunities and interpersonal exchanges. Heavy men and women are seen as less intelligent than others and thin women are seen as more so. Some have recently speculated that humour and cleverness in the service of attracting mates are prime reasons why humans have developed such grossly oversized brains compared to our primate cousins (e.g., Miller, 2000; Ridley, 1994). It may be that this perceived lack of intelligence underlies much of the perceived unattractiveness of heavier people and the perceived attractiveness of thin women.

In addition to concerns raised above, this raises an interesting question: are people more discriminating of women's intelligence? If anything, evolutionary principles might predict that people would be more discriminating of men's intelligence, as their mate value seems more immediately affected by ambition and chances for social dominance. To test this interpretation, the correlations between rated intelligence and actual intelligence for male (.31) and female (-.02) photographs were computed. Neither was statistically significant, but their relative magnitude confirm that raters' judgements of female photographs is even less accurate than their judgements of male photographs.

Participants with higher intelligence attributed higher intelligence to the people pictured. Perhaps this is a case of seeing others as similar to oneself. Alternatively, they may have given relatively generous ratings because they felt they could not accurately discern photographs' intelligence.

Does methodology affect judgements of attractiveness?

The current study presented stimuli in two ways: consecutive single photographs that were rated on several dimensions and simultaneous presentations of a group of photographs that were rank-ordered according to global preference. Generally, the two methods yielded similar attractiveness ratings. However, it seems that people use different dimensions in reaching that decision depending on the sex pictured. Global rank was highly correlated with masculinity, femininity, and age for female, but not male photographs. This may reflect the general emphasis on physical characteristics and age in female beauty, such that these are thought to reflect reproductive health.

Men and women also differ slightly such that male raters' judgements of interest in children was highly correlated with global rankings, but female raters' judgements were not. Perhaps partner willingness to have children is more influential in men's decisions to invest in a relationship than in women's. Women's rankings of male photographs are unrelated to ratings of intelligence and age, but their rankings of female photographs were. One would think that women would be concerned about a potential male partner's intelligence, although age is generally thought of as a secondary consideration, outside of the tendency to "marry up." However, perhaps women use age and intelligence to assess threat posed by a female rival.

Men's rankings of female photographs were unrelated to ratings of capable of having children, but their rankings of male photographs were. Does this imply that men's general preferences are unrelated to reproductive ability? Such a tendency would surely, in the long run, harm one's reproductive fitness. However, the men in this university sample may be more interested in the recreational aspects of short-term relationships and may be adopting a "K" strategy of putting off childbearing.

Does sex of rater or sex pictured affect how quickly people rate and rank photographs?

It seems that people take longer to rate photographs of the opposite sex compared to photographs of the same sex. This may suggest that they are more careful or choosier when evaluating potential mates than potential rivals. Men and especially women took longer to rank-order male photographs compared to female photographs. This may suggest that the latter are easier to rank. This could confirm that the female form is more informative. People tend to judge female attractiveness on physical parameters, where male attractiveness is based more on qualities that take investigation, such as ambition and social dominance (Buss, 1989).

Are self-reported measurement reliable?

Although self-reported measurements were very highly correlated with experimenter measurements, it is still recommended that these measurements be confirmed, as hip measurements for both sexes were noticeably trimmed by up to 10 cm. Reliability of males' hip measurements was nearly as high as females' suggesting that a perceived lack of awareness of their measurements or differential social pressure are unfounded concerns.

One might also notice that all of the mean differences are in the negative direction, suggesting that people reporting their own measurements are somewhat conservative, particularly when reporting their hip girth. (It is unfortunate that chest girth was not collected – perhaps we might observe the opposite tendency?). This, coupled with the expense of providing hundreds of tape measures and the logistics of recruiting participants with an intermediate step, leads us to recommend relying on lab measurements unless one is interested in selected particular body types, which should yield reasonably accurate results, but should, nonetheless, be confirmed by an experimenter.

What dimensions of attractiveness are the various ratings tapping?

Unfortunately, our various dependent variables are, at this point in the development of the area, too specific to be combined using a technique using factor analysis. However, prototypical attractive and unattractive male and female photographs were examined using this technique to attempt to determine what underlying dimensions might be involved in attractiveness judgments. The procedure yielded essentially three main considerations: "sexiness-attractiveness," "masculinity/femininity," and "reproductive interest." For female photographs, "smart" was associated with reproductive interest. For the attractive male, "smart" was associated with attractiveness. These factors corroborate findings of Buss (1989), who suggests that people around the world, when asked their preferences in a potential mate, tend to prefer women who are likely to be successful reproductively and men who are likely to be successful financially and socially.

Limitations of the Current Study

While the present stimuli represented an advance over that used previously chiefly because the actual proportions of the figures were known, need for improvement is still evident. The prescreening yielded neither males nor females with both very high WHRs and very low BMIs. Similarly, certain photographic trials were composed of only one (female low WHR-moderate BMI; male and female low WHR high BMI) or two (male moderate WHR-moderate BMI; female moderate WHR-low BMI) photographs. This is mainly due to the apparent rarity of such bodily proportions. Epel et al. (2000) had a low WHR-high BMI and high WHR-low BMI groups, but their actual proportions were not as extreme as those in this sample. Furthermore, photographs were nearly all of people of university age and in excellent health. Future studies might consider including a broad range of ages and reproductive statuses. In particular, comparing premenopausal women to postmenopausal women would be of interest.

Restriction of range compromises statistical methods based on correlation. The present range of WHR in stimuli was somewhat higher than that included by Tovée et al. However, BMI still had a much higher range than WHR, which may have deflated the apparent correlation between WHR and ratings of attractiveness. Furnham, Lavancy, and

McClelland (2001) note that, in order to directly compare two variables, one must demonstrate that differences in the levels of variables are equivalent. Arguably, this has been accomplished for BMI and WHR. However, because one cannot present a BMI without simultaneously presenting a WHR, this would have to be accomplished by having raters evaluate a set of unaltered pictures with oppositely equivalent BMIs and WHRs (i.e., high and low BMI pictures with the same WHR and high and low WHR pictures with the same BMI).

Designing analyses that combined rater and photograph characteristics necessitated an array of analyses with different dependent variables. Until statistical software can accommodate three dimensions or SPSS allows repeated measure MANOVA, we are limited to examining one sex at a time – raters or photographs on multiple dependent variables.

Directions for Future Research

More naturalistic stimuli is certainly welcome, but the current results strongly suggest that future research on WHR should not be conducted unless a measure of weight or BMI is included. Altering the apparent WHRs of drawings or photographs cannot be accomplished without altering the apparent BMI. However, it seems as though raters are quite good at estimating weight, even when the height, upper torso, and head of the person pictured is obscured. This may provide an avenue for using retouched photographs.

WHR may still be an honest advertisement of reproductive status. This study did not find differential judgements of whether someone is desirous or capable of having children according to WHR. However, it may still figure into judgements of whether a women is or has been pregnant, since, from an evolutionary point of view, people would be interested in such information and women themselves may find advantage in concealing such information. Furnham, Lavancy, and McClelland compared facial attractiveness and WHR, finding that WHR was not related to attractiveness or fertility judgements, but that it predicted whether raters thought the female figures were pregnant. These results suggest that WHR may be more influential in determining whether a woman is currently a viable reproductive partner, which might make her more attractive in a more general sense. Examining how pregnancy or artificial hormones (e.g., estrogen replacement at menopause, birth control) affect WHR over time would also help to elucidate its functional significance.

Alternately, WHR may help people quickly determine someone's sex from a distance. For instance, the sex of chimpanzees can be determined by their gait (Malto, personal communication). In the present study, participants were explicitly told which sex they were rating. However, pilot data mentioned above suggests that people mistook photographs for the opposite sex when the WHR was more similar to the opposite sex. The sorts of errors people make and the potential information to be gained from such judgements would be interesting avenues. Studies of voice recognition suggest that the sex of the speaker is the information that is first determined by a listener and the last to degrade when recordings are damaged, suggesting that determining the sex of conspecifics has important ramifications for life in a social species.

Along similar lines, the present study presented male and female photographs separately, with participants explicitly told which they were evaluating. Although providing somewhat of a tangle in terms of analysis, it would be interesting to present subjects with a mix of male and female photographs for evaluation not only on attractiveness, but also on other evolutionary considerations, such as social dominance, threat, or potentiality for alliance.

It would also be interesting to incorporate the mate value of the person providing the evaluations. In other words, how does the person in the photograph compare to them on social dominance or attractiveness? Would they ask the person out? Singh et al. (1999) measured WHR in lesbian couples and found little in the way of inter-group differences between "butch" and "femme" women. However, intra-couple differences in WHR were apparent, such that the more masculine of the pair behaviourally also exhibited a higher WHR than their more feminine-behaving partner. This has yet to be replicated among straight and gay male couples. This intra-couple methodology could be extended to other concerns about mating, stability, fidelity, and the like.

No one has yet directly compared the effect of viewing photographs simultaneously versus one at a time. Does it matter whether people are making relative judgements by being able to refer to more than one photograph in a session? Henss (1995) and Puhl and Boland (2001) used a between-subjects design such that each person saw only one photograph. Many studies exhibit all the figures simultaneously. The present study showed photographs in sequence, which somewhat limited people's ability to directly compare, followed by all the photographs presented simultaneously. Results using these two methods were very comparable, however, the former was used to collect ratings and the latter to collect rankings. Use of a consistent manner of collecting data would be preferable to more accurately assess the effects of "array" versus "sole" presentation.

Final Conclusions

People speak of using physical parameters to make assumptions about others as superficial, of little consequence, or morally wrong (cf. Etcoff, 1999). However, choosing the parent of your future children is a matter of considerable gravity. Nearly every creature continually assesses others by appearance to a variety of reproductive and survivalist ends.

People continually judge books by their covers. Booksellers display them in stores, catalogues, and websites to spur sales, as a mere description of the book's content is not as enticing to consumers. The flaw in the analogy is that snappy book jackets may not be an accurate reflection of the book's contents. Honest bodily advertisements or reliable indicators of fitness are, because they are difficult to fake. While many freely admit to buying a book because the cover made it look interesting, most are loathe saying the same about their mates. Likewise, rarely does one hear "this book looks good enough to match my reading standards" at the till. This is the second flaw in the analogy – the mating game is not a level playing field. We all bring slightly different costs and benefits to the table.

This study is unique in employing unretouched photographs and asking both men and women to evaluate the attractiveness of men and women. Compared to most studies where two-dimensional line drawing or photographs are used (a criticism levelled by Henss (2000), the actual exact WHRs of the figures were known. It also allowed a comparison of ratings to rankings. It also included a more thorough characterization of the people providing attractiveness judgements, such that the effect of many more personal characteristics could be examined. This study is different from some in finding that BMI is more influential than WHR in determining how attractive we find people based solely on their body shape. This study is similar to most examining bodily proportions and attractiveness in confirming that everyone seems to like and dislike similar body shapes.

So, what is the functional significance of WHR? According to the present results, it has little to do with attractiveness in the sense of whether someone is good-looking or sexy. However, given the relationship between WHR and apparent age and masculinity of people pictured, it may still be an indication of mate value (young women are more fertile and masculine women are not) or physical dominance (masculine men are higher on the social hierarchy).

The current work addresses only one aspect of whether a couple will begin dating and eventually get married or simply pass each other on the street. However, while love may be blind, lovers are not. As unpopular as it is to admit that physical parameters figure into our attractiveness judgements, clearly they do. Good-looking people are thought to possess mainly positive traits just by virtue of their outward appearance (Myers, 2001). People with other features, such as blonde hair or stoutness, are apparently also subject to many assumptions which may also have tangible effects on their quality of life or interpersonal interactions.

Why do people make assumptions about people based on appearance? Because they can. Does this imply that such assumptions are true? No, not even if everyone agrees. Does this imply that such assumptions guide our mate preferences? Probably. Apparently, it is the first step in weeding out unattractive choices. However, it is far from the last step in selecting the most viable from an array of enticing possibilities.

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Table 1

Summary of WHRs Obtained in Previous Research

Study	Sample	Female WHR Mean (SD)	Male WHR Mean (SD)
Lippa (1983)	University	.75	.86
Lanska et al. (1985)	52,953 reproductive age women	.67 - .80	
Jones et al. (1986)	British reproductive age men	–	.85 - .95
Radke-Sharpe et al. (1990)	Aged 21-50	.75 (.05)	–
Laws et al. (1993)	Healthy, postmenopausal, not on hormones, Swedish	.91 (.08)	–
Reported in Singh (1993b)	Healthy premenopausal	.67-.80	.85-.95
Räikkönen et al. (1994)	Healthy, aged 30-55, lean or moderately obese, Finnish	–	.92 (.07) R = .78 - 1.12
Simken-Silverman et al. (1995)	Healthy premenopausal, aged 44-50, not on hormones	.77 R = .76-.78	–
Reported by Singh & Luis (1995)	Black American	.75	.84
	Mexican American	.84	.94
	Caucasian	.73	.82
	Mongolian Moost group	.76	.85
Davis & Cerullo (1996)	Healthy university	.74 (.05) R = .64 - .89	–
Horsten et al. (1997)	Healthy, aged 31-65, Swedish	.80 (.09) R = .53-1.44	–
Milligan et al. (1997)	18-year-old Australian	.72 (.04)	.80 (.04)
Bell et al. (1998)	Type 2 diabetes	.96 (.06)	.90 (.08)
Marmot et al. (1998)	MIDUS American National	.83	.96
Sharpe & Hills (1998)	Chronic mental illness	.95 (.06)	.99 (.10)
Keller et al. (1999)	Mexican American referred for abdominal CT scans	.88 (.07) R = .75-1.10	–
Singh et al. (1999)	Heterosexual	.77 (.10)	–
	"Femme" lesbian	.78 (.10)	
	"Butch" lesbian	.81 (.10)	

Table 2

Physical Proportions of Females Appearing in Stimulus Photographs by Body Shape Group

Trial	Mean WHR	Mean BMI	Photo#	WHR	BMI
Low WHR Low BMI	.688	18.91	23	.698	17.98
			31	.668	19.70
			47	.725	20.06
			62	.662	19.03
			66	.699	16.80
			87	.694	18.31
			119	.667	20.48
Low WHR Mod BMI	.721	22.54	75	.721	22.54
Low WHR High BMI	.704	41.34	139	.704	41.34
Mod WHR Low BMI	.744	20.00	35	.745	20.55
			39	.742	19.45
Mod WHR Mod BMI	.742	24.18	63	.757	27.38
			78	.741	27.47
			91	.750	22.93
			94	.730	21.57
			138	.731	21.53
Mod WHR High BMI	.736	30.55	22	.729	28.23
			29	.750	34.48
			51	.729	28.95
High WHR Mod BMI	.805	24.45	48	.848	23.39
			84	.764	23.07
			123	.804	26.90
High WHR High BMI	.833	32.55	42	.911	35.17
			55	.825	33.49
			60	.860	27.62
			61	.793	33.34
			73	.769	27.49
			92	.838	38.17

Note. WHR cutoffs at the 33rd and 66th percentiles were .7274 and .7592. BMI cutoffs at the 15th and 85th percentiles were 20.26 and 28.37.

Table 3

Physical Proportions of Males Appearing in Stimulus Photographs by Body Shape Group

Trial	Mean WHR	Mean BMI	Photo#	WHR	BMI
Low WHR Low BMI	.764	19.69	11	.775	19.56
			104	.774	20.41
			121	.744	19.10
Low WHR Mod BMI	.811	24.61	18	.781	24.25
			109	.840	24.97
Low WHR High BMI	.802	26.16	2	.802	26.16
Mod WHR Low BMI	.869	20.70	6	.876	20.45
			8	.869	18.69
			105	.861	22.97
Mod WHR Mod BMI	.856	23.78	100	.854	23.51
			107	.857	24.05
Mod WHR High BMI	.861	31.24	10	.858	28.62
			115	.863	33.86
High WHR Mod BMI	.896	24.36	17	.918	25.46
			20	.880	23.17
			114	.889	24.44
High WHR High BMI	.905	29.91	3	.881	28.64
			9	.969	34.18
			15	.884	27.65
			129	.885	29.17

Note. WHR cutoffs at the 33rd and 66th percentiles were.8544 and .8798. BMI cutoffs at the 15th and 85th percentiles were 21.99 and 30.17.

Table 4

Mean Ratings for Photographs of Females by Body Shape Trial (with Trial Means)

Trial	Photo#	Masc	Fem	Gdlk	Sexy	Ingt	Int C	Cap C	Age	Wt (kg)	Marr	Cas Sex
Low WHR Low BMI	23	2.4(2.3)	7.5 (7.8)	6.5 (6.7)	6.3 (6.3)	6.4 (6.6)	6.3 (6.6)	7.0 (7.4)	20.3 (20.9)	54.9 (56.2)	6.4 (6.6)	6.6 (6.6)
	31	1.7	8.5	7.9	7.7	6.8	7.0	7.7	20.4	55.7	7.5	7.8
	47	1.7	8.7	7.8	7.9	6.8	7.0	7.7	21.9	57.6	7.4	7.9
	62	1.8	8.5	7.3	7.1	6.6	6.8	7.7	21.0	57.5	7.2	7.4
	66	2.3	7.4	5.9	5.5	6.6	6.2	6.6	20.1	51.8	5.5	5.8
	87	3.4	6.4	5.2	4.7	6.4	6.3	7.1	21.0	56.4	5.4	5.1
	119	2.8	7.3	6.0	5.2	6.5	7.0	8.0	21.6	60.0	6.6	5.8
Low WHR Mod BMI	75	4.1 (4.1)	5.8 (5.8)	4.2 (4.2)	3.5 (3.5)	6.7 (6.7)	6.5 (6.5)	7.4 (7.4)	28.2 (28.2)	66.3 (66.3)	5.0 (5.0)	3.4 (3.4)
Low WHR High BMI	139	3.1 (3.1)	5.9 (5.9)	2.8 (2.8)	2.0 (2.0)	5.8 (5.8)	6.4 (6.4)	7.4 (7.4)	24.6 (24.6)	89.5 (89.5)	3.3 (3.3)	1.8 (1.8)
Mod WHR Low BMI	35	4.3 (3.9)	6.0 (6.4)	5.6 (5.8)	5.1 (5.3)	6.4 (6.5)	6.4 (6.5)	7.3 (7.4)	22.4 (21.8)	61.7 (60.1)	5.7 (5.9)	5.1 (5.3)
	39	3.4	6.7	5.9	5.5	6.6	6.7	7.4	21.3	58.5	6.1	5.6
Mod WHR Mod BMI	63	3.5 (3.2)	6.3 (6.8)	4.5 (5.6)	3.7 (5.1)	6.4 (6.5)	6.8 (6.7)	7.7 (7.5)	22.9 (22.1)	72.0 (64.7)	5.0 (5.8)	3.5 (5.1)
	78	4.3	5.6	4.0	3.2	6.3	6.4	7.3	21.9	69.9	4.7	3.2
	91	4.1	6.2	5.4	4.9	6.6	6.6	7.5	22.8	64.4	5.7	4.9
	94	1.9	8.3	7.6	7.5	6.8	7.0	7.6	22.0	58.4	7.2	7.3
	138	2.5	7.5	6.6	6.3	6.7	6.6	7.4	20.6	58.8	6.7	6.4
Mod WHR High BMI	22	3.9 (4.1)	6.1 (5.5)	5.2 (3.9)	4.6 (3.3)	6.2 (6.1)	6.5 (6.4)	7.5 (7.4)	22.0 (22.5)	64.3 (73.6)	5.5 (4.4)	4.6 (3.1)
	29	4.4	5.1	3.2	2.4	5.9	6.4	7.3	21.6	81.2	3.7	2.2
	51	4.1	5.4	3.5	2.8	6.0	6.4	7.4	23.8	75.5	4.0	2.6
High WHR Mod BMI	48	4.9 (4.3)	4.9 (5.5)	3.4 (4.0)	2.6 (3.2)	6.3 (6.3)	6.5 (6.6)	7.3 (7.5)	27.4 (23.8)	73.2 (70.9)	4.2 (4.6)	2.5 (3.2)
	84	4.6	5.4	4.7	4.0	6.4	6.4	7.3	21.9	64.5	5.2	4.2
	123	3.4	6.2	3.9	3.1	6.2	7.0	7.7	22.2	74.9	4.4	2.8
High WHR High BMI	42	4.7 (4.9)	4.6 (4.6)	2.7 (3.1)	2.0 (2.4)	5.7 (5.9)	6.1 (6.1)	6.9 (7.0)	23.4 (23.7)	87.9 (79.9)	3.1 (3.6)	1.8 (2.2)
	55	2.8	6.4	3.7	2.9	6.4	6.8	7.6	26.0	80.4	4.1	2.4
	60	4.1	5.3	3.8	2.9	6.2	6.4	7.4	22.6	72.0	4.3	2.9
	61	7.4	2.9	2.7	2.0	5.6	5.2	6.5	23.7	76.5	3.2	1.9
	73	5.3	4.4	3.2	2.5	5.7	5.9	7.0	22.5	75.4	3.7	2.2
	92	5.2	4.1	2.7	2.0	5.7	6.0	6.8	24.1	87.2	3.3	1.8

Note. Dependent variables are ratings of masculine, feminine, good-looking, sexy, intelligent, interested in having children, capable of having children, age, weight, attractive for marriage, and attractive for brief casual sex.

Table 5

Mean Ratings for Photographs of Males by Body Shape Trial (with Trial Means)

Trial	Photo#	Masc	Fem	Gdlk	Sexy	Ingt	Int C	Cap C	Age	Wt (kg)	Marr	Cas Sex
Low WHR Low BMI	11	5.5 (5.7)	3.5 (3.6)	4.4 (5.0)	3.7 (4.4)	6.2 (6.1)	6.0 (5.9)	7.1 (7.1)	19.7 (20.2)	65.0 (65.8)	4.4 (4.9)	3.7 (4.4)
	104	5.5	3.9	5.0	4.4	5.6	5.5	6.9	20.7	64.5	4.9	4.4
	121	6.1	3.5	5.6	5.1	6.4	6.3	7.4	20.3	67.8	5.4	5.2
Low WHR Mod BMI	18	7.0 (7.3)	2.6 (2.4)	5.5 (6.0)	4.9 (5.5)	6.3 (6.2)	6.3 (6.4)	7.4(7.5)	22.9 (23.0)	75.8 (76.0)	5.6 (6.0)	5.0 (5.6)
	109	7.5	2.1	6.5	6.1	6.1	6.4	7.6	23.0	76.3	6.4	6.2
Low WHR High BMI	2	6.8 (6.8)	2.6 (2.6)	4.5 (4.5)	4.0 (4.0)	5.9 (5.9)	6.1 (6.1)	7.0 (7.0)	23.5 (23.5)	76.7 (76.7)	4.8 (4.8)	3.8 (3.8)
Mod WHR Low BMI	6	6.9 (7.2)	2.9 (2.4)	5.7 (5.7)	5.4 (5.2)	6.2 (6.1)	6.1(6.3)	7.2 (7.3)	21.4 (22.5)	70.4 (73.2)	5.4 (5.6)	5.4 (5.3)
	8	6.9	2.4	5.4	4.9	6.2	6.1	7.3	21.9	70.6	5.4	4.9
	105	7.8	1.9	6.0	5.5	5.9	6.5	7.5	24.3	78.5	6.1	5.6
Mod WHR Mod BMI	100	8.1 (7.1)	1.7 (2.6)	5.2 (5.4)	4.4 (4.7)	5.7 (6.0)	6.3 (6.2)	7.3 (7.3)	27.8 (25.2)	78.9 (77.3)	5.6 (5.6)	4.5 (4.7)
	107	6.1	3.6	5.5	4.9	6.3	6.1	7.2	22.5	75.7	5.5	4.9
Mod WHR High BMI	10	6.7 (7.0)	2.4 (2.2)	4.2 (4.1)	3.4 (3.3)	5.6 (5.6)	6.0 (6.1)	7.0 (7.1)	21.7 (23.0)	80.4 (84.8)	4.6 (4.4)	3.3 (3.1)
	115	7.2	2.0	3.9	3.2	5.7	6.1	7.1	24.3	89.2	4.3	2.8
High WHR Mod BMI	17	7.1 (7.1)	2.2 (2.4)	3.9 (5.0)	3.2 (4.4)	5.8 (6.0)	6.2 (6.2)	7.2 (7.2)	27.1 (24.3)	84.8 (77.3)	4.5 (5.2)	3.0 (4.4)
	20	7.7	2.0	5.9	5.3	6.3	6.4	7.4	23.9	75.2	6.1	5.5
	114	6.5	3.0	5.2	4.7	6.0	6.0	7.1	21.8	71.7	5.0	4.6
High WHR High BMI	3	7.9 (7.3)	1.8 (2.1)	6.0 (4.6)	5.5 (3.9)	6.2 (5.8)	6.5 (6.2)	7.5 (7.2)	23.9 (24.7)	80.8 (87.5)	6.2 (4.9)	5.6 (3.7)
	9	7.0	2.0	3.2	2.5	5.6	6.2	6.9	25.3	100.7	3.7	2.1
	15	6.8	2.5	4.8	4.1	5.9	5.9	7.2	23.2	79.6	5.0	4.1
	129	7.6	1.9	4.2	3.3	5.6	6.1	7.1	26.6	89.1	4.5	3.0

Note. Dependent variables are ratings of masculine, feminine, good-looking, sexy, intelligent, interested in having children, capable of having children, age, weight, attractive for marriage, and attractive for brief casual sex.

Table 6

Average Measure Intraclass Correlations for Photograph Trials by Dependent Variable

Trial	Masc	Fem	Gdlk	Sexy	Ingt	Int C	Cap C	Age	Wt	Marr	Cas Sex
Male Photographs											
Low WHR Low BMI	.79	.77	.76	.76	.78	.73	.85	.47	.80	.81	.79
Low WHR Mod BMI	.59	.68	.70	.61	.56	.73	.79	.64	.73	.73	.71
Mod WHR Low BMI	.76	.75	.68	.63	.67	.73	.87	.66	.69	.75	.73
Mod WHR Mod BMI	.13*	.25**	.44	.42	.39	.55	.75	.45	.66	.56	.47
Mod WHR High BMI	.81	.85	.81	.86	.74	.77	.90	.65	.84	.86	.84
High WHR Mod BMI	.81	.69	.80	.81	.80	.81	.91	.74	.78	.87	.79
High WHR High BMI	.84	.82	.84	.82	.85	.84	.92	.80	.87	.85	.76
Female Photographs											
Low WHR Low BMI	.77	.80	.84	.82	.93	.91	.93	.83	.91	.87	.89
Mod WHR Low BMI	.77	.75	.75	.74	.87	.81	.83	.45	.78	.82	.78
Mod WHR Mod BMI	.78	.78	.83	.82	.90	.90	.91	.78	.85	.88	.81
Mod WHR High BMI	.80	.79	.80	.77	.82	.77	.88	.66	.79	.84	.76
High WHR Mod BMI	.70	.67	.77	.73	.78	.79	.81	.52	.75	.84	.75
High WHR High BMI	.90	.89	.93	.93	.92	.89	.93	.78	.91	.96	.93

Note: All correlations are significant, $p < .001$, except *, which was non significant and **, which was significant, $p < .05$. Dependent variables are ratings of masculine, feminine, good-looking, sexy, intelligent, interested in having children, capable of having children, age, weight, attractive for marriage, and attractive for brief casual sex. Male low WHR-high BMI, female low WHR-mod BMI, and female low WHR-high BMI trials are omitted because they were composed of only one photograph.

Table 7

Cell Means (and Standard Deviations) for Demographic Information of Participants

Characteristic	Overall	Males	Females
Overall			
Age (years)	22.89 (.40)	22.35 (.49)	23.30 (.60)
Body self-esteem	18.10 (2.90)	18.74 (2.75)	17.62 (2.93)
Estimated WAIS-IQ	105.54 (.64)	107.25 (.80)	104.25 (.94)
Number of medical conditions in family history	1.18 (1.33)	.62 (.11)	1.51 (1.39)
Number of medical conditions in personal history	.09 (.32)	.08 (.27)	.10 (.35)
Raters Only			
Age at sexual maturity (months)	-	168.62 (20.17)	155.60 (1.81)
Sociosexuality summary score	19.45 (.84)	25.13 (1.48)	15.19 (.74)
Waist girth (cm)	83.58 (11.78)	90.68 (9.78)	78.05 (10.17)
Hip girth (cm)	104.77 (8.36)	105.78 (8.65)	103.99 (8.10)
Weight (kg)	72.98 (15.82)	81.23 (16.62)	66.55 (11.75)
Height (cm)	171.55 (9.30)	178.82 (7.33)	165.89 (6.25)
WHR	.80 (.74)	.86 (.43)	.75 (.57)
BMI	24.68 (4.15)	25.30 (4.21)	24.19 (4.06)

Table 8a

Pooled Correlations Among Female Rater Characteristics Variables

Measure	1	2	3	4	5	6	7	8	9	10	11
1. Age	--	.06	-.11	-.24*	.08	.13	-.05	.05	-.14	.28*	.12
2. Age at sexual maturity		--	-.13	-.08	-.02	-.00	-.10	-.07	.02	.09	-.09
3. Body self-esteem			--	-.08	.07	-.35**	-.24*	-.28*	.14	-.34**	-.36**
4. Estimated WAIS-IQ				--	-.12	-.05	-.06	-.06	.06	-.02	-.09
5. Sociosexuality summary score					--	.06	-.05	.01	.06	.16	-.01
6. Waist girth						--	.83**	.90**	.12	.82**	.89**
7. Hip girth							--	.93**	.28*	.37**	.85**
8. Weight								--	.33**	.56**	.90**
9. Height									--	-.09	-.11
10. WHR										--	.62**
11. BMI											--

Note. n = 75, as only female raters are included. * is significant at p < .05, ** at p< .001.

Table 8b

<u>Pooled Correlations Among Male Rater Characteristics Variables</u>

Measure	1	2	3	4	5	6	7	8	9	10	11
1. Age	--	.29*	-.31*	.09	.09	.35**	.29*	.34*	.06	.26*	.37*
2. Age at sexual maturity		--	.03	.14	-.01	-.01	.00	-.04	.09	-.05	-.10
3. Body self-esteem			--	.08	.10	-.25	-.21	-.19	-.09	-.17	-.17
4. Estimated WAIS-IQ				--	.05	.05	.06	.05	-.01	.00	.07
5. Sociosexuality summary score					--	.05	.06	.05	-.01	.00	.07
6. Waist girth						--	.90**	.91**	.42**	.64**	.84**
7. Hip girth							--	.94**	.46**	.24	.86**
8. Weight								--	.53**	.37**	.90**
9. Height									--	.12	.11
10. WHR										--	.37**
11. BMI											--

Note. n = 57, as only male raters are included. * is significant at p < .05, ** at p< .001.

Table 9

Regression Results Comparing WHR and BMI by Sex Pictured and Dependent Variable

Dependent Variable	Sex Pictured	Results
Masculinity	Female	WHR, $R^2 = .33$, F (1,26) = 12.92, $p = .001$
	Male	WHR, $R^2 = .23$, F (1,18) = 5.29, $p = .034$
Femininity	Female	BMI, $R^2 = .44$, F (1,26) = 20.69, $p < .001$ WHR, $R^2\Delta = .13$, F (1,25) = 7.30, $p = .012$
	Male	--
Good-looking	Female	BMI, $R^2 = .64$, F (1,26) = 47.14, $p < .001$ WHR, $R^2\Delta = .07$, F (1,25) = 6.15, $p = .020$
	Male	BMI, $R^2 = .35$, F (1,18) = 9.87, $p = .006$
Sexy	Female	BMI, $R^2 = .63$, F (1,26) = 43.30, $p < .001$ WHR, $R^2\Delta = .07$, F (1,25) = 5.49, $p = .03$
	Male	BMI, $R^2 = .36$, F (1,18) = 10.01, $p = .005$
Intelligent	Female	BMI, $R^2 = .66$, F (1,26) = 49.50, $p < .001$
	Male	BMI, $R^2 = .32$, F (1,18) = 8.78, $p = .008$
Interested in Having Children	Female	BMI, $R^2 = .16$, F (1,26) = 5.06, $p = .033$
	Male	--
Capable of Having Children	Female	--
	Male	--
Age	Female	WHR, $R^2 = .21$, F (1,26) = 7.05, $p = .013$
	Male	WHR, $R^2 = .33$, F (1,18) = 9.04, $p = .008$
Weight	Female	BMI, $R^2 = .91$, F (1,26) = 261.57, $p < .001$ WHR, $R^2\Delta = .03$, F (1,25) = 13.41, $p = .001$
	Male	BMI, $R^2 = .84$, F (1,18) = 97.35, $p < .001$ WHR, $R^2\Delta = .05$, F (1,17) = 7.21, $p = .016$
Attractive for Marriage	Female	BMI, $R^2 = .68$, F (1,26) = 54.39, $p < .001$ WHR, $R^2\Delta = .07$, F (1,25) = 7.27, $p = .012$
	Male	BMI, $R^2 = .22$, F (1,18) = 5.17, $p = .035$
Attractive for Brief Casual Sex	Female	BMI, $R^2 = .67$, F (1,26) = 52.21, $p < .001$ WHR, $R^2\Delta = .08$, F (1,25) = 7.33, $p = .012$
	Male	BMI, $R^2 = .40$, F (1,18) = 11.74, $p = .003$
Global Ranking	Female	BMI, $R^2 = .79$, F (1,26) = 97.98, $p < .001$ WHR, $R^2\Delta = .05$, F (1,25) = 8.34, $p = .008$
	Male	BMI, $R^2 = .50$, F (1,18) = 18.20, $p < .001$

Note. -- denotes a lack of correlation between variables, thus no regression was possible.

Table 10

Regression Results Comparing WHR and BMI Separately by Rater Sex

Dependent Variable	Sex Pictured	Male Raters	Female Raters
Masculinity	Female	WHR, $R^2 = .34^{**}$	WHR, $R^2 = .28^{*}$
	Male	--	WHR, $R^2 = .28^{*}$
Femininity	Female	BMI, $R^2 = .46^{**}$, WHR, $R^2\Delta = .14^{*}$	BMI, $R^2 = .38^{**}$, WHR, $R^2\Delta = .10^{*}$
	Male	WHR, $R^2 = .24^{*}$	WHR, $R^2 = .37^{*}$
Good-looking	Female	BMI, $R^2 = .63^{**}$, WHR, $R^2\Delta = .08^{*}$	BMI, $R^2 = .64^{**}$, WHR, $R^2\Delta = .06^{*}$
	Male	BMI, $R^2 = .57^{*}$	BMI, $R^2 = .22^{*}$
Sexy	Female	BMI, $R^2 = .60^{**}$, WHR, $R^2\Delta = .08^{*}$	BMI, $R^2 = .63^{**}$, WHR, $R^2\Delta = .06^{*}$
	Male	BMI, $R^2 = .53^{*}$	--
Intelligent	Female	BMI, $R^2 = .67^{**}$	BMI, $R^2 = .55^{**}$
	Male	BMI, $R^2 = .60^{**}$	--
Interested in Having Children	Female	WHR, $R^2 = .18^{*}$	--
	Male	BMI, $R^2 = .36^{*}$	BMI, $R^2 = .25^{*}$
Capable of Having Children	Female	--	--
	Male	BMI, $R^2 = .56^{**}$	--
Age	Female	BMI, $R^2 = .24^{*}$	WHR, $R^2 = .20^{*}$
	Male	WHR, $R^2 = .38^{*}$	WHR, $R^2 = .30^{*}$
Weight	Female	BMI, $R^2 = .88^{**}$, WHR, $R^2\Delta = .04^{*}$	BMI, $R^2 = .92^{**}$, WHR, $R^2\Delta = .03^{*}$
	Male	BMI, $R^2 = .86^{**}$, WHR, $R^2\Delta = .05^{*}$	BMI, $R^2 = .82^{**}$, WHR, $R^2\Delta = .05^{*}$
Attractive for Marriage	Female	BMI, $R^2 = .67^{**}$, WHR, $R^2\Delta = .09^{*}$	BMI, $R^2 = .66^{**}$, WHR, $R^2\Delta = .06^{*}$
	Male	BMI, $R^2 = .37^{*}$	--
Attractive for Brief Casual Sex	Female	BMI, $R^2 = .63^{**}$, WHR, $R^2\Delta = .09^{*}$	BMI, $R^2 = .69^{**}$, WHR, $R^2\Delta = .06^{*}$
	Male	BMI, $R^2 = .53^{**}$	BMI, $R^2 = .27^{*}$
Global Ranking	Female	BMI, $R^2 = .77^{**}$, WHR, $R^2\Delta = .06^{*}$	BMI, $R^2 = .80^{**}$, WHR, $R^2\Delta = .05^{*}$
	Male	BMI, $R^2 = .59^{**}$	BMI, $R^2 = .40^{*}$

Note. * were significant $p < .05$, ** were significant $p < .001$. -- denotes a lack of correlation between variables, thus no regression was possible.

Table 11

Results for Two-Way Mixed ANOVAs by Dependent Variable (All Raters)

Independent Variable	Dependent Variable	Sex Pictured	Significant Effects
WHR	Masculinity	Female	WHR: Low < Moderate < High Rater Sex: Female < Male
		Male	(Female raters only) WHR x Rater Sex: Low < Moderate and High
	Age	Female	WHR: Low and Moderate < High
		Male	WHR: Low < Moderate < High Rater Sex: Male < Female
BMI	Good-looking	Male	BMI: High < Low and Moderate
	Sexy	Male	BMI: High < Low and Moderate
	Intelligent	Female	BMI: High < Moderate < Low
		Male	BMI: High < Low and Moderate
	Interest in Having Children	Female	BMI: High < Low and Moderate Rater Sex: Male < Female
	Attractive for Marriage	Male	BMI: High < Low < Moderate
	Attractive for Brief Casual Sex	Male	BMI x Rater Sex: High < Low and Moderate, with females rating Low and Moderate lower than male raters
	Global Ranking	Male	BMI x Rater Sex: Low and Moderate < High, with females ranking Low BMI higher and High BMI lower than male raters
BMI & WHR	Femininity	Female	Body Shape Trial x Rater Sex: 8 < 5 7 < 6 3 < 2 < 4 < 1, with males < females on trials 3, 5, 6, and 8
	Good-looking	Female	Body Shape Trial x Rater Sex: 6 < 8 < 3 5 7 < 2 4 < 1, with males < females on trials 3, 4, 5, and 8
	Sexy	Female	Body Shape Trial x Rater Sex: 6 < 8 < 3 5 7 < 2 4 < 1, with males < females approaching significance on trials 3 and 8
	Weight	Female	Body Shape Trial x Rater Sex: 1 < 2 < 4 < 3 < 5 < 7 < 8 < 6, with males < females on trials 5, 6, 7, and 8
		Male	Body Shape Trial: 1 < 2 < 3 4 5 6 < 7 < 8
	Attractive for Marriage	Female	Body Shape Trial x Rater Sex: 6 < 8 < 7 < 5 < 3 < 2 4 < 1, with males < females on trials 2, 3, 4, 5, 6, 7, and 8, especially trial 3
	Attractive for Brief Casual Sex	Female	Body Shape Trial x Rater Sex: 6 < 8 < 3 5 7 < 4 < 2 < 1, with males < females on trial 3
	Global Ranking	Female	Body Shape Trial x Rater Sex: 1 < 2 < 4 < 3 5 7 < 8 < 6, with females < males on trials 1 and 3

Note. Body shape trial numbers refer to these groups: 1) low WHR-low BMI, 2) mod WHR-low BMI, 3) low WHR-mod BMI, 4) mod WHR-mod BMI, 5) high WHR-mod BMI, 6) low WHR-high BMI, 7) mod WHR-high BMI, 8) high WHR-high BMI.

Table 12

Results of ANCOVAs Examining Independent Effects of WHR and BMI

Independent Variable	Covariate	Dependent Variable	Sex Pictured	Significant Effects	Trial Ratings[a]
BMI	WHR	Femininity	Female	BMI *	High < Low & Moderate
		Weight	Male	BMI **	Low & Moderate < High
		Attractive for Marriage	Female	Rater sex x BMI*	High < Low & Moderate, with female raters judging Low & Moderate more similarly than male raters
WHR	BMI	Femininity	Female	WHR *	High < Low & Moderate
		Good-looking	Male	--	
		Sexy	Female Male	-- --	
		Intelligent	Female Male	-- --	
		Weight	Male	--	
		Attractive for Marriage	Male	--	
		Attractive for Casual Sex	Female Male	WHR * Rater Sex *	High < Low & Moderate Females < Males
		Global Ranking[b]	Female Male	WHR * --	Low & Moderate < High

Note. * are significant p < .05, ** p < .001. – denotes a lack of significant effect. [a]High ratings denote a higher level of the quality. [b] Low rankings denote higher attractiveness.

Table 13

Intraclass Correlations for Ratings for All Raters and by Rater Sex

Rating	Raters		
	All	Male	Female
Masculine	.98	.99	.97
Feminine	.97	.99	.97
Good-looking	.98	.99	.97
Sexy	.98	.99	.97
Intelligent	.92	.89	.81
Interested in Having Children	.62	.85	.71
Capable of Having Children	.84	.81	.80
Age	.98	.97	.98
Estimated Weight	>.99	>.99	>.99
Attractive for Marriage	.98	.98	.97
Attractive for Brief Casual Sex	.99	.99	.98

Note. All are significant, p <.001.

Table 14

Summary of Whether Raters' Personal Characteristics Influenced Attractiveness Judgements

Variable Tested	Sex Pictured	Dependent Variable	Groups (Mean Rating)
Sex	Female	Masculine	Male (2.94) > female (3.41)
		Interest in Having Children	Female (6.77) > male (6.14)
		Weight	Female (153.77) > male (147.86)
		Attractive for Marriage*	Female (5.67) > male (4.62)
	Male	Attractive for Brief Casual Sex	Male (4.69) > female (4.14)
Sociosexuality	Female	Masculine	Unrestricted (3.98) > restricted (3.36)
		Feminine*	Restricted (6.59) > unrestricted (5.75)
		Good-looking	Restricted (5.14) > unrestricted (4.69)
		Attractive for Marriage	Restricted (5.55) > unrestricted (4.84)
Age	Female	Intelligent	Younger (6.56) > older (6.06)
		Capable of Having Children	Younger (7.62) > older (7.04)
		Age*	Older (23.34) > younger (22.03)
	Male	Masculine	Younger (6.77) > older (6.34)
		Intelligent	Younger (5.85) > older (5.46)
		Capable of Having Children	Younger (7.11) > older (6.55)
		Age*	Older (22.98) > younger (21.41)
		Weight	Younger (164.65) > older (159.73)
Body Self-esteem	Male	Weight	Higher BSE (165.18) > lower BSE (160.80)
Estimated IQ	Female	Intelligent	Higher IQ (6.59) > lower IQ (6.06)
	Male	Good-looking	Higher IQ (5.15) > lower IQ (4.63)
		Intelligent	Higher IQ (5.86) > lower IQ (5.50)
Sexual Orientation	Female	Good-looking	Homo- or bisexual (5.94)> heterosexual (4.86)
		Sexy	Homo- or bisexual (5.57)> heterosexual (4.28)
	Male	Sexy	Homo- or bisexual (5.62)> heterosexual (4.25)
WHR	Female	Age	Male raters: Higher WHR (22.88) > lower WHR (21.71)
	Male	Weight	Female raters: Lower WHR (166.23) > higher WHR (158.34)
		Age	Male raters: Higher WHR (22.28) > lower WHR (21.02)
BMI	Female	Capable of Having Children	Male raters: Lower BMI (7.68) > higher BMI (6.73)
	Male	Weight	Female raters: Higher BMI (165.82) > lower BMI (158.55)

Note. Comparisons were conducted with an alpha level of .005. All listed were significant p < .05, except for *, which were significant p < .001.

Table 15

Spearman Correlations between Global Relative Ratings[a] and Ranking[b] of Photographs

Dependent Variable	Male Photographs			Female Photographs		
	All Raters	Male Raters	Female Raters	All Raters	Male Raters	Female Raters
Masculinity	-.38	-.39	-.28	.73**	.74**	.63**
Femininity	.15	.14	.02	-.85**	-.88**	-.74**
Good-looking	-.92**	-.95**	-.90**	-.97**	-.96**	-.94**
Sexy	-.92**	-.94**	-.88**	-.98**	-.96**	-.94**
Intelligent	-.61**	-.76**	-.39	-.85**	-.86**	-.72**
Interested in Having Children	-.60**	-.70**	-.13	-.53**	-.65**	-.36
Capable of Having Children	-.81**	-.81**	-.48*	-.46*	-.30	-.46*
Age	.10	.29	.10	.75**	.72**	.69**
Weight	-.88**	.69**	.37	.94**	.93**	.89**
Attractive for Marriage	-.91**	-.86**	-.88**	-.96**	-.96**	-.92**
Attractive for Brief Casual Sex	-.92**	-.93**	-.86**	-.99**	-.97**	-.95**

Note. [a]High ratings denote a higher level of the quality. [b]Low rankings denote higher attractiveness. * are significant p < .05, ** are significant p < .001.

Table 16

Correlations between Self-reported and Experimenter-obtained Body Measurements

	Phase	Measurement	Correlation with Experimenter Measurement	Mean Difference
Female Participants	Prescreening	Waist Girth	.89	-1.0 cm
		Hip Girth	.88	-6.9 cm
		Height	.75	-1.5 cm
		Weight	.91	-.9 kg
	Lab	Waist Girth	.87	1.0 cm
		Hip Girth	.85	-3.0 cm
Male Participants	Prescreening	Waist Girth	.86	-4.7 cm
		Hip Girth	.79	-9.5 cm
		Height	.95	-2.6 cm
		Weight	.96	.1 kg
	Lab	Waist Girth	.83	-1.9 cm
		Hip Girth	.87	-6.3 cm

Note. All correlations are significant, $p < .001$. Mean difference was calculated by subtracting participant measurements from experimenter measurements for each participant, then averaging the result.

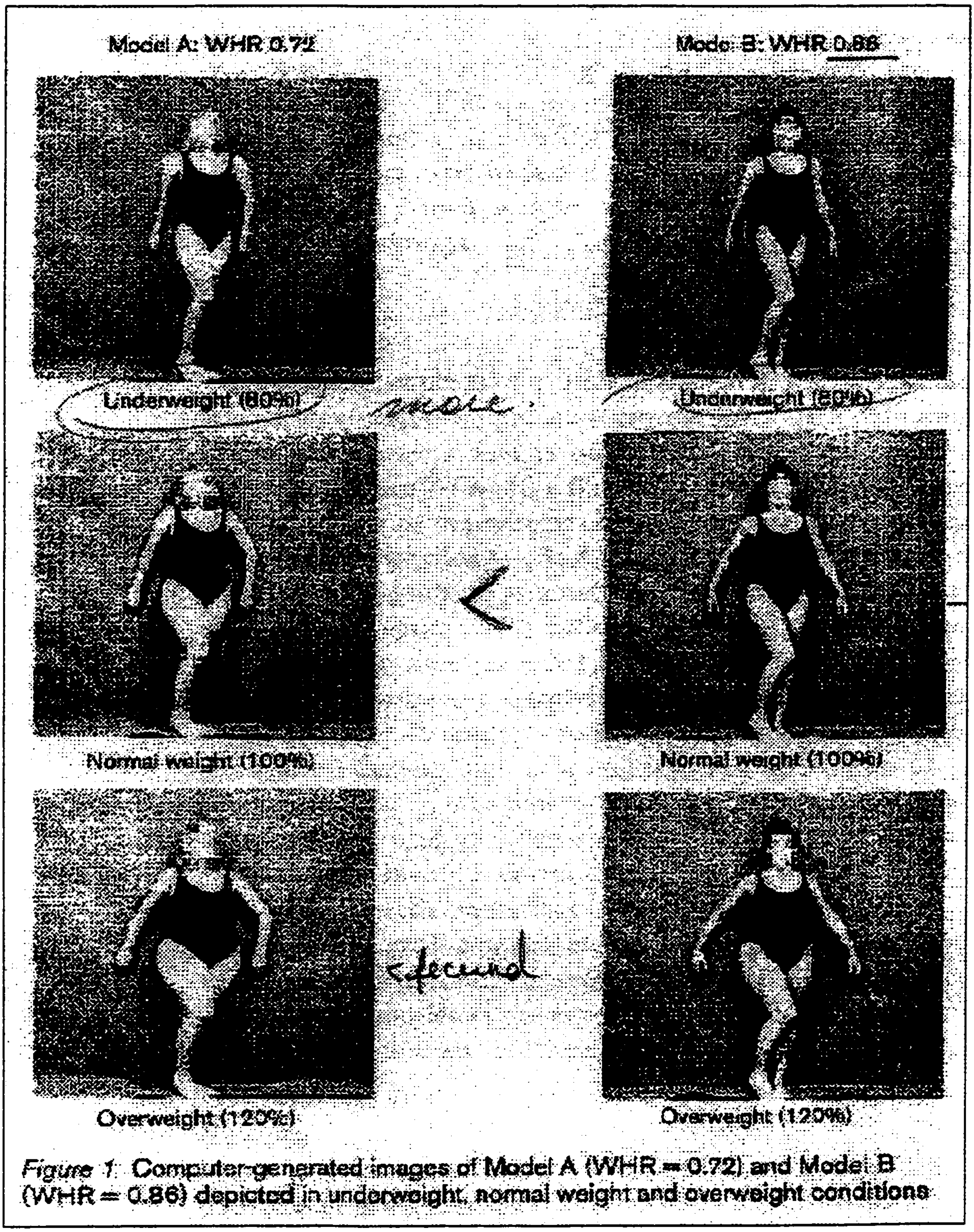


Figure 1: Computer-generated images of Model A (WHR = 0.72) and Model B (WHR = 0.86) depicted in underweight, normal weight and overweight conditions

Figure 1. Stimuli used by Puhl and Boland (2001).

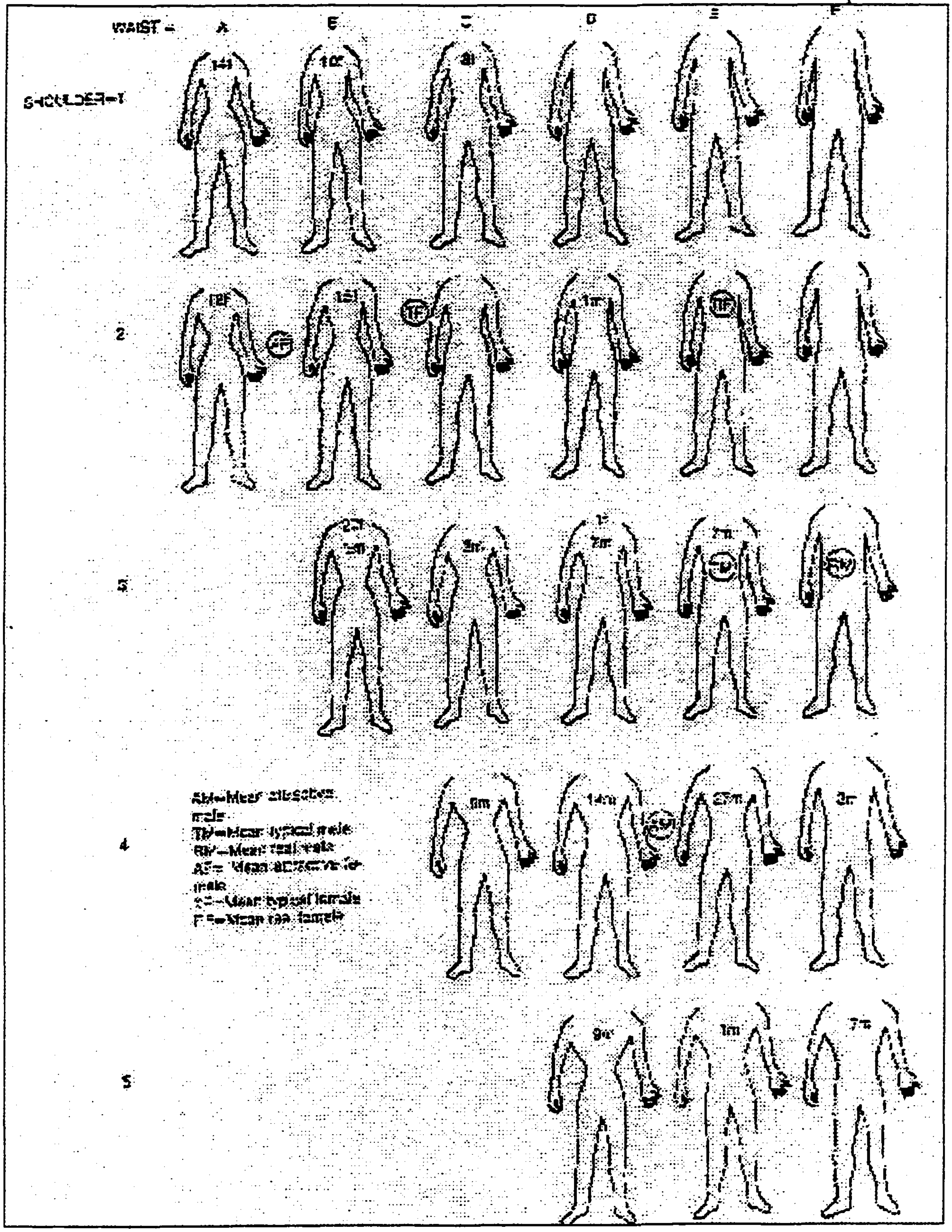


Figure 2. Stimuli used by Lippa (1983).

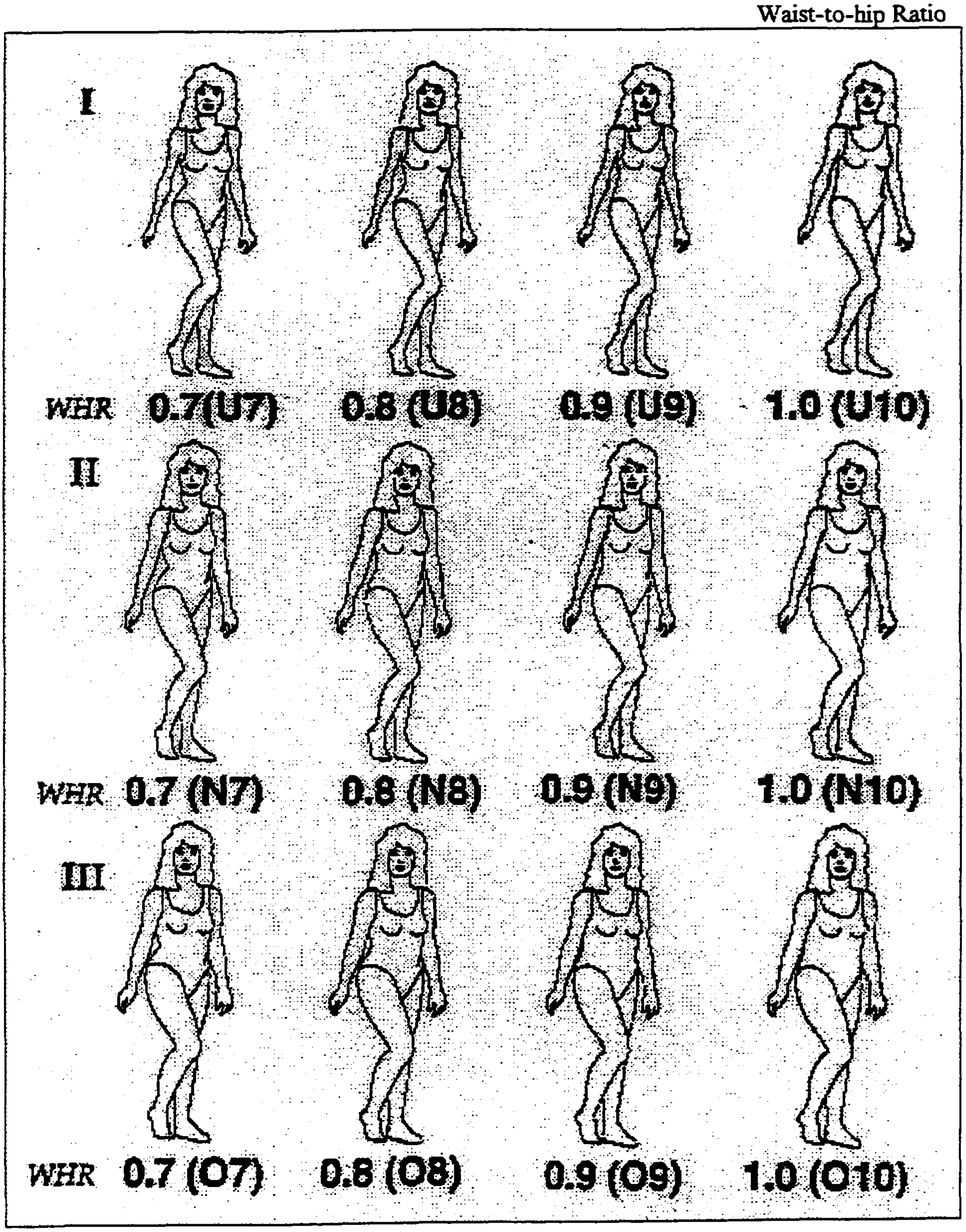


Figure 3. Stimuli used by Singh (e.g., 1993a, 1994a) and Tassinary and Hansen (1998).

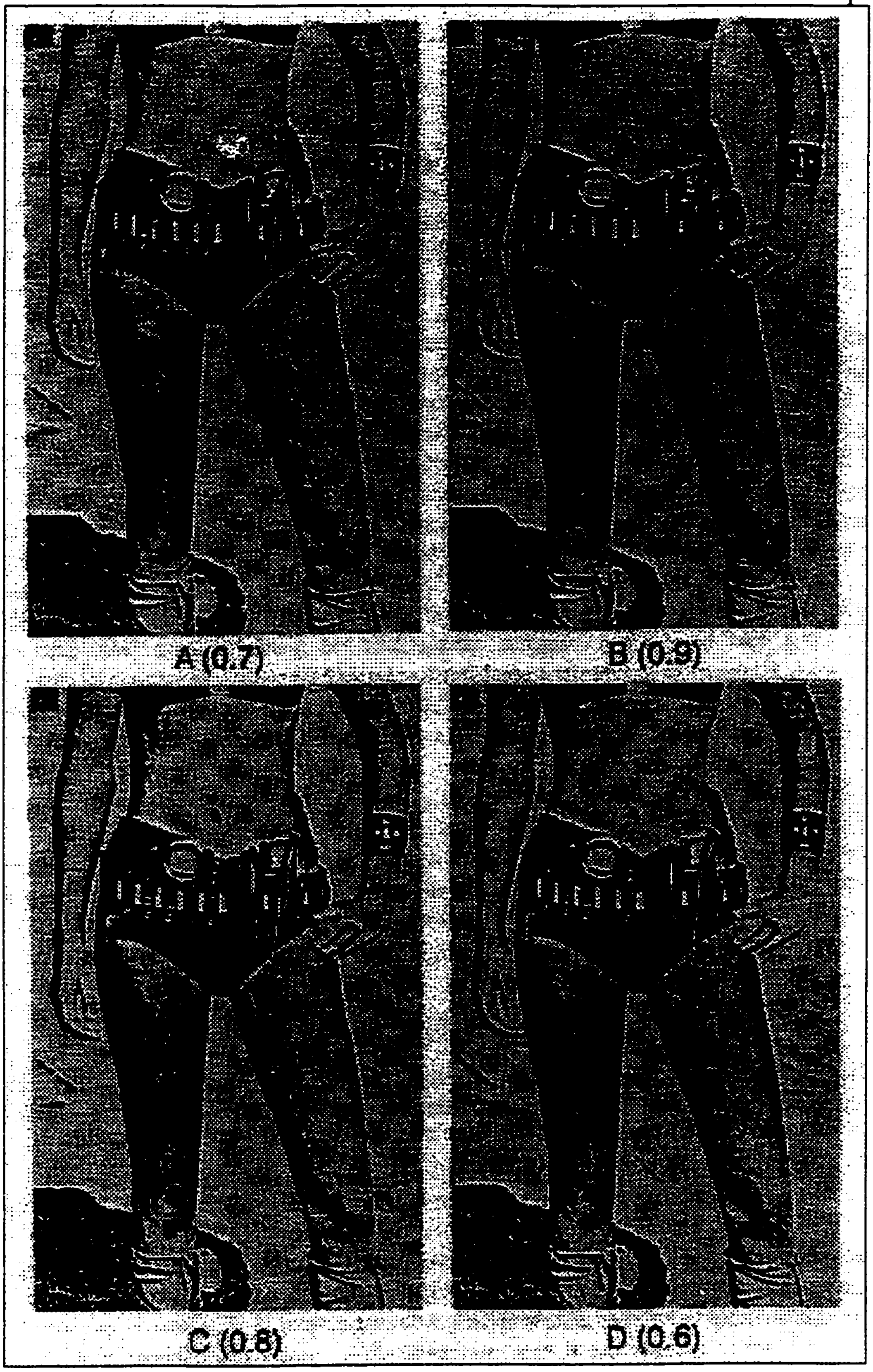


Figure 4. Stimuli used by Singh (1994a).

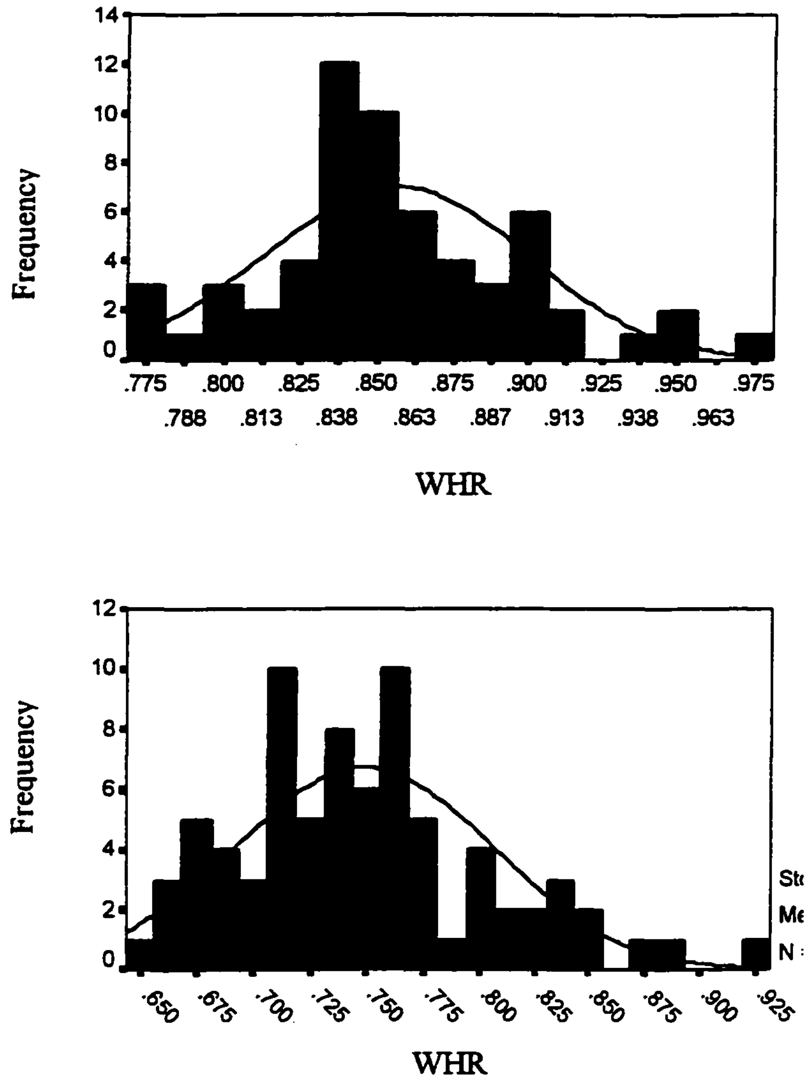


Figure 5. Waist-to-hip ratios of male (top) and female (bottom) raters.

Appendix A

Prescreening Questionnaire

Prescreening Questionnaire Confidential once completed

We are conducting an experiment on body shape and body perception. We are asking a large group of people to provide some basic information on body shape. It will only take a couple of minutes. We will ask people of **many different body types** to participate in the study's next phase, for which you may receive bonus points.

Health

Sex (Circle one.): **MALE** **FEMALE**

If you are female, have you ever been pregnant? **NO** **YES**

Are you pregnant now? **NO** **YES**

If yes, by how many weeks? ___________ weeks pregnant

Put a check next to the medical conditions of which your immediate **family** has a history (Check all that apply). Put an "X" next to the medical conditions of which **you** have a history ("X" all that apply).

___ Heart disease
___ High cholesterol
___ Breast cancer
___ Trouble conceiving
___ Diabetes (Type I, insulin-dependent)
___ Diabetes (Type II, non-insulin-dependent)
___ Thyroid dysfunction
___ Trouble carrying a baby to term

Body Shape

Please indicate the following body proportions, including whether you are sure or whether you are estimating. Remember, we are interested in recruiting people of **all body types**. If you are called to participate in the next phase, we may take these measurements again. Please refer to the attached diagrams.

What is your waist circumference (the narrowest part of your torso)?

________ inches OR ________ cm Circle one: **I KNOW** **I'M ESTIMATING**

What is your hip circumference (the widest part of your lower torso)?

________ inches OR ________ cm Circle one: **I KNOW** **I'M ESTIMATING**

What is your height?

________ inches OR ________ cm Circle one: **I KNOW** **I'M ESTIMATING**

What is your weight?

________ lbs. OR ________ kg Circle one: **I KNOW** **I'M ESTIMATING**

Contact Information

Name: ______________________________________ Phone number: ____________________

Thank you for your time.

If you are selected to participate in the next phase of the study, we will contact you.

Appendix B

Phase I Participant Information Sheet

Phase I Participant Information Sheet Confidential once comple ed

Please complete the following:

Age: ______ years

Sex (Circle one.): **MALE FEMALE**

If female, how old were you at menarche (first menstruation)? _____ years _____ months

Are you pregnant? **NO** **YES**

If male, how old were you: at first nocturnal emission (wet dream)? _____ years _____ months
when your voice changed? _____ years _____ months
when you started shaving? _____ years _____ months

Do you take any medication containing hormones or that might alter your natural hormones? This might include birth control (pills or implants, e.g., Triphasil), estrogen replacement (e.g., Premarin), thyroid medicine (e.g., Thyroxin), or testosterone.

NO **YES** Please list: ____
____
____

Do you have a medical condition that might alter endocrine function? (e.g., hypo- or hyperthyroidism, Cushing's, Turner's, Kleinfelter's)

NO **YES** Please list: ____
____
____

Current Thoughts

Please circle the number of your response for each of the following:

	NOT AT ALL	A LITTLE BIT	SOMEWHAT	VERY MUCH	EXTREMELY
I feel satisfied with the way my body looks right now.	1	2	3	4	5
I feel that others respect and admire me.	1	2	3	4	5
I am dissatisfied with my weight.	1	2	3	4	5
I am pleased with my appearance right now.	1	2	3	4	5
I feel unattractive.	1	2	3	4	5

Please go on to the next page.

Sexual Attitudes & Behaviour Survey

Please answer all of the following questions honestly.

For the questions dealing with behaviour, *write* your answers in the blank spaces provided. For questions dealing with thoughts and attitudes, *circle* the appropriate number on the scales provided.

Behaviour

1. With how many different partners have you had sex (sexual intercourse) with in the past year? _____

2. How many different partners do you foresee yourself having sex with during the next five years? (Please give a *specific, realistic* estimate.) _____

3. With how many different partners have you had sex on *one and only one* occasion? _____

4. How often do you fantasize about having sex with someone other than your current dating/marriage partner? (Circle one.)
    1. Never
    2. Once every two or three months
    3. Once a month
    4. Once every two weeks
    5. Once a week
    6. A few times each week
    7. Nearly every day
    8. At least once a day

Attitudes

	I strongly disagree								I strongly agree
Sex without love is OK.	1	2	3	4	5	6	7	8	9
I can imagine myself being comfortable and enjoying "casual" sex with different partners.	1	2	3	4	5	6	7	8	9
I would have to be closely attached to someone (both emotionally and psychologically) before I could feel comfortable and fully enjoy having sex with him or her.	1	2	3	4	5	6	7	8	9

Please go on to the next page.

Perceptual Processing Scale – Part I

The first word in each line appears in capital letters along with four other words. Circle the one word that means the same thing, or most nearly the same thing, as the first word. If you don't know, guess. Be sure to circle the one word in each line that means the same thing as the first word.

EXAMPLE: LARGE red [✓ big] silent wet

(1)	TALK	draw	eat	speak	sleep
(2)	PERMIT	allow	sew	cut	drive
(3)	PARDON	forgive	pound	divide	tell
(4)	COUCH	pin	eraser	sofa	glass
(5)	REMEMBER	swim	recall	number	defy
(6)	TUMBLE	drink	dress	fall	think
(7)	HIDEOUS	silvery	tilted	young	dreadful
(8)	CORDIAL	swift	muddy	leafy	hearty
(9)	EVIDENT	green	obvious	skeptical	afraid
(10)	IMPOSTOR	conductor	officer	book	pretender
(11)	MERIT	deserve	distrust	fight	separate
(12)	FASCINATE	welcome	fix	stir	enchant
(13)	INDICATE	defy	excite	signify	bicker
(14)	IGNORANT	red	sharp	uninformed	precise
(15)	FORTIFY	submerge	strengthen	vent	deaden
(16)	RENOWN	length	head	fame	loyalty
(17)	NARRATE	yield	buy	associate	tell
(18)	MASSIVE	bright	large	speedy	low
(19)	HILARITY	laughter	speed	grace	malice
(20)	SMIRCHED	stolen	pointed	remade	soiled
(21)	SQUANDER	tease	belittle	cut	waste
(22)	CAPTION	drum	ballast	heading	ape
(23)	FACILITATE	help	turn	strip	bewilder
(24)	JOCOSE	humourous	paltry	fervid	plain
(25)	APPRISE	reduce	strew	inform	delight
(26)	RUE	eat	lament	dominate	cure
(27)	DENIZEN	senator	inhabitant	fish	atom
(28)	DIVEST	dispossess	intrude	rally	pledge
(29)	AMULET	charm	orphan	dingo	pond
(30)	INEXORABLE	untidy	involatile	rigid	sparse
(31)	SERRATED	dried	notched	armed	blunt
(32)	LISSOM	moldy	loose	supple	convex
(33)	MOLLIFY	mitigate	direct	pertain	abuse
(34)	PLAGIARIZE	appropriate	intend	revoke	maintain
(35)	ORIFICE	brush	hole	building	lute
(36)	QUERULOUS	maniacal	curious	devout	complaining
(37)	PARIAH	outcast	priest	lentil	locker
(38)	ABET	waken	ensue	incite	placate
(39)	TEMERITY	rashness	timidity	desire	kindness
(40)	PRISTINE	vain	sound	first	level

Please go on to the next page.

Vocabulary raw score ______

Perceptual Processing Scale – Part II

Complete the following by filling in either a number or a letter for each dash (_____). Do the items in order, but don't spend too much time on any one item.

EXAMPLE: A B C D _E_

(1) 1 2 3 4 5 ___

(2) white black short long down ___ ___

(3) AB BC CD D___

(4) Z Y X W V U ___

(5) 1 2 3 2 1 2 3 4 3 2 3 4 5 4 3 4 5 6 ___ ___

(6) NE / SW SE / NW E / W N / ___

(7) escape scape cape ___ ___ ___

(8) oh ho rat tar mood ___ ___ ___ ___

(9) A Z B Y C X D ___

(10) tot tot bard drab 537 ___ ___ ___

(11) mist is wasp as pint in tone ___ ___

(12) 57326 73265 32657 26573 ___ ___ ___ ___ ___

(13) knit in spud up both to stay ___ ___

(14) Scotland landscape scapegoat ___ ___ ___ ___ ee

(15) surgeon 1234567 snore 17635 rogue ___ ___ ___ ___ ___

(16) tam tan rib rid rat raw hip ___ ___ ___

(17) tar pitch throw saloon bar rod fee tip end plank ___ ___ ___ ___ ___ meals

(18) 3124 82 73 154 46 13___

(19) lag leg pen pin big bog rob ___ ___ ___

(20) two w four r one o three ___

Please go on to the next page.

___

Abstraction raw score ___

Summary Scores

V: Raw ___ *T* ___ A: Raw ___ *T* ___ Total: Raw ___ *T* ___

CQ: ___ AQ: ___ Est.: ___

Anthropometrics

Please take the following measurements according to the posted instructions:

Please measure your waist and write the result here: _______ cm

Please measure your hips and write the result here: _______ cm

Please tell your experimenter that you are finished the questionnaire.

Your experimenter will now collect the following information:

Waist: _______ cm

Hip: _______ cm

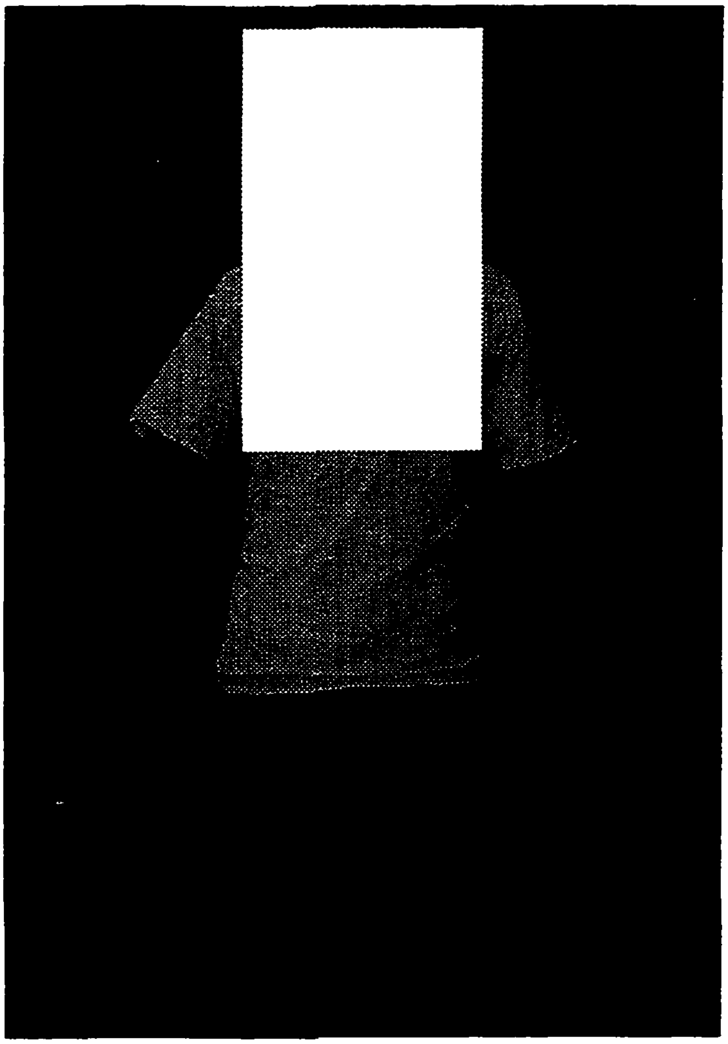
Weight: _______ kg

Height: _______ cm

Lastly, we will be taking three photographs. These will never appear without your face and upper torso being deleted. Please refer to the posted sample photograph.

Appendix C

Sample Stimuli



Appendix D

Phase II Participant Information Sheet

Phase II Participant Information Sheet — Confidential once completed

Demographics

Sex (Circle one.): **MALE** **FEMALE**

Age: ______ years

Circle the number that corresponds to your sexual preference:

Exclusively heterosexual **1 2 3 4 5 6 7** **Exclusively homosexual**

If **female**, how old were you at menarche (first menstruation)? __________ years old

If **male**, how old were you: at first nocturnal emission (wet dream)? _____ years _____ months

when your voice changed? _____ years _____ months

when you started shaving? _____ years _____ months

Current Thoughts

This is a questionnaire designed to measure what you are thinking right now. There is, of course, no right answer for any statement. The best answer is what you feel is true of yourself at the moment. Be sure to answer all of the items, even if you are not certain of the best answer. Again, answer these questions as they are true for you RIGHT NOW.

	NOT AT ALL	A LITTLE BIT	SOMEWHAT	VERY MUCH	EXTREMELY
I feel satisfied with the way my body looks right now.	1	2	3	4	5
I feel that others respect and admire me.	1	2	3	4	5
I am dissatisfied with my weight.	1	2	3	4	5
I am pleased with my appearance right now.	1	2	3	4	5
I feel unattractive.	1	2	3	4	5

Please complete the questionnaires that follow.

After that, you will be asked to look at some photographs & answer some questions.

Sexual Attitudes & Behaviour Survey

Please answer all of the following questions honestly.

For the questions dealing with behaviour, *write* your answers in the blank spaces provided. For questions dealing with thoughts and attitudes, *circle* the appropriate number on the scales provided.

Behaviour

1. With how many different partners have you had sex (sexual intercourse) with in the past year? _____

2. How many different partners do you foresee yourself having sex with during the next five years? (Please give a *specific, realistic* estimate.) _____

3. With how many different partners have you had sex on *one and only one* occasion? _____

4. How often do you fantasize about having sex with someone other than your current dating/marriage partner? (Circle one.)
    1. Never
    2. Once every two or three months
    3. Once a month
    4. Once every two weeks
    5. Once a week
    6. A few times each week
    7. Nearly every day
    8. At least once a day

Attitudes

	I strongly disagree								I strongly agree
Sex without love is OK.	1	2	3	4	5	6	7	8	9
I can imagine myself being comfortable and enjoying "casual" sex with different partners.	1	2	3	4	5	6	7	8	9
I would have to be closely attached to someone (both emotionally and psychologically) before I could feel comfortable and fully enjoy having sex with him or her.	1	2	3	4	5	6	7	8	9

Please go on to the next page.

Perceptual Processing Scale – Part I

The first word in each line appears in capital letters along with four other words. Circle the one word that means the same thing, or most nearly the same thing, as the first word. If you don't know, guess. Be sure to circle the one word in each line that means the same thing as the first word.

EXAMPLE: LARGE red [✓ big] silent wet

(1)	TALK	draw	eat	speak	sleep	☐
(2)	PERMIT	allow	sew	cut	drive	☐
(3)	PARDON	forgive	pound	divide	tell	☐
(4)	COUCH	pin	eraser	sofa	glass	☐
(5)	REMEMBER	swim	recall	number	defy	☐
(6)	TUMBLE	drink	dress	fall	think	☐
(7)	HIDEOUS	silvery	tilted	young	dreadful	☐
(8)	CORDIAL	swift	muddy	leafy	hearty	☐
(9)	EVIDENT	green	obvious	skeptical	afraid	☐
(10)	IMPOSTOR	conductor	officer	book	pretender	☐
(11)	MERIT	deserve	distrust	fight	separate	☐
(12)	FASCINATE	welcome	fix	stir	enchant	☐
(13)	INDICATE	defy	excite	signify	bicker	☐
(14)	IGNORANT	red	sharp	uninformed	precise	☐
(15)	FORTIFY	submerge	strengthen	vent	deaden	☐
(16)	RENOWN	length	head	fame	loyalty	☐
(17)	NARRATE	yield	buy	associate	tell	☐
(18)	MASSIVE	bright	large	speedy	low	☐
(19)	HILARITY	laughter	speed	grace	malice	☐
(20)	SMIRCHED	stolen	pointed	remade	soiled	☐
(21)	SQUANDER	tease	belittle	cut	waste	☐
(22)	CAPTION	drum	ballast	heading	ape	☐
(23)	FACILITATE	help	turn	strip	bewilder	☐
(24)	JOCOSE	humourous	paltry	fervid	plain	☐
(25)	APPRISE	reduce	strew	inform	delight	☐
(26)	RUE	eat	lament	dominate	cure	☐
(27)	DENIZEN	senator	inhabitant	fish	atom	☐
(28)	DIVEST	dispossess	intrude	rally	pledge	☐
(29)	AMULET	charm	orphan	dingo	pond	☐
(30)	INEXORABLE	untidy	involatile	rigid	sparse	☐
(31)	SERRATED	dried	notched	armed	blunt	☐
(32)	LISSOM	moldy	loose	supple	convex	☐
(33)	MOLLIFY	mitigate	direct	pertain	abuse	☐
(34)	PLAGIARIZE	appropriate	intend	revoke	maintain	☐
(35)	ORIFICE	brush	hole	building	lute	☐
(36)	QUERULOUS	maniacal	curious	devout	complaining	☐
(37)	PARIAH	outcast	priest	lentil	locker	☐
(38)	ABET	waken	ensue	incite	placate	☐
(39)	TEMERITY	rashness	timidity	desire	kindness	☐
(40)	PRISTINE	vain	sound	first	level	☐

Please go on to the next page.

Vocabulary raw score ______

Perceptual Processing Scale – Part II

Complete the following by filling in either a number or a letter for each dash (_____). Do the items in order, but don't spend too much time on any one item.

EXAMPLE: A B C D E

(1) 1 2 3 4 5 ___

(2) white black short long down ___ ___

(3) AB BC CD D___

(4) Z Y X W V U ___

(5) 1 2 3 2 1 2 3 4 3 2 3 4 5 4 3 4 5 6 ___ ___

(6) NE / SW SE / NW E / W N / ___

(7) escape scape cape ___ ___ ___

(8) oh ho rat tar mood ___ ___ ___ ___

(9) A Z B Y C X D ___

(10) tot tot bard drab 537 ___ ___ ___

(11) mist is wasp as pint in tone ___ ___

(12) 57326 73265 32657 26573 ___ ___ ___ ___ ___

(13) knit in spud up both to stay ___ ___

(14) Scotland landscape scapegoat ___ ___ ___ ___ ee

(15) surgeon 1234567 snore 17635 rogue ___ ___ ___ ___ ___

(16) tam tan rib rid rat raw hip ___ ___ ___

(17) tar pitch throw saloon bar rod fee tip end plank ___ ___ ___ ___ ___ meals

(18) 3124 82 73 154 46 13___

(19) lag leg pen pin big bog rob ___ ___ ___

(20) two w four r one o three ___

Please go on to the next page.

Summary Scores

V: Raw ______ T ______ A: Raw ______ T ______ Total: Raw ______ T ______

CQ: ______ AQ: ______ Est.: ______

______

Abstraction raw score ______

Anthropometrics

Please take the following measurements according to the posted instructions:

Please measure your waist and write the result here: ________ cm

Please measure your hips and write the result here: ________ cm

Please tell your experimenter that you are finished the questionnaire.

Your experimenter will now collect the following information:

Waist: _______ cm

Hip: _______ cm

Weight: _______ kg

Height: _______ cm

Appendix E

Photograph Rating Sheet

Phase II Rating Sheet	Confidential once completed

Photo #: _____

The person in the photograph is:

Not at all masculine	1	2	3	4	5	6	7	8	9	10	Very masculine
Not at all feminine	1	2	3	4	5	6	7	8	9	10	Very feminine
Not at all good-looking	1	2	3	4	5	6	7	8	9	10	Very good-looking
Not at all sexy	1	2	3	4	5	6	7	8	9	10	Very sexy
Not at all intelligent	1	2	3	4	5	6	7	8	9	10	Very intelligent
Not at all interested in having children someday	1	2	3	4	5	6	7	8	9	10	Very interested in having children someday
Not at all capable of having children	1	2	3	4	5	6	7	8	9	10	Very capable of having children

The person in the photograph is: (Age) Approximately ______ years old

Circle One: **UNDERWEIGHT** **NORMAL** **OVERWEIGHT**

(Weight) Approximately ______ lbs or ______ kg

If I were interested in getting married and having children, I would consider this person:

Not at all attractive	10	9	8	7	6	5	4	3	2	1	Very attractive

If I were interested in having a very brief casual sexual encounter, I would consider this person:

Not at all attractive	10	9	8	7	6	5	4	3	2	1	Very attractive

Please rate the next photograph in the series.

Modeling and Vibration Control Of Turboprop Installations

by

Rabih Fawaz Alkhatib

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Mechanical Engineering

Waterloo, Ontario, Canada, 2002

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Acknowledgements

I would like to express my gratitude to my supervisor Professor Dr. Farid Golnaraghi for his guidance and invaluable advice over the duration of my graduate studies at the University of Waterloo. I would like to thank Professor F.M. Ismail, Professor G.M.T. D'Eleuterio, Professor G.R. Heppler, and Professor K. Morris for serving on my examination committee. I also wish to extend my thanks to my colleagues and friends Reza Nakhaie, Mohammad Hashemi and Arash Narimani for their useful and insightful discussions. Thanks are especially due for the financial support from Bombardier Aerospace, the Ontario Graduate Scholarships for Science and Technology, the University of Waterloo, and the Natural Sciences and Engineering Research Council (NSERC).

Many very special thanks and gratitudes are due to my parents, Fawaz Alkhatib and Marim Helou, for their love and care which has made me the person who I am today. I am in eternal debt to them as an inexhaustible source of inspiration. My words cannot express the love I have for them. I also would like to express my great appreciation to my uncle, Fares Helou, for believing in me and for his continuous encouragement and support throughout my life. I am grateful to my sisters Ohyla, Diana, and Hayat for their encouragement and support. I am also thankful to my fiancée, Ghada, and here family for their comforting words and prayers for my success.

Abstract

This thesis addresses specific modeling aspects of turboprop engines and ways to reduce and control vibration. Accordingly, three areas are examined: modeling, passive vibration optimization, and active vibration control. A mathematical formulation of a turboprop installation is developed. The proposed model takes into account the rigid body of the engine, the flexibility of the blade, the resilience of the mounting system, and the effects of the aerodynamic forces. By utilizing Lagrange's technique, equations of motion are established. The employment of the Multi-blade Coordinates Transformation eliminates periodic coefficients, which appear in the equations of motion due to blade flexibility. Also, a stability study is performed on the model, and two types of self-excited unstable motion are identified: mechanical instability and whirl flutter instability. Mechanical instability is caused by the coupling of the blades' motions with the transverse vibration of the engine, which transforms rotational energy into unstable vibration; whirl flutter instability emanates from aerodynamic energy being converted into engine lateral vibration.

The design of the engine mounting system is viewed as an optimization problem. A two degrees of freedom model representing the engine and wing dynamics is adopted to determine the best mount stiffness and damping coefficient. The optimization problem is solved analytically by using the frequency response functions of the system. The method seeks to minimize the root mean square of the engine absolute acceleration with respect to the root mean square of the relative displacement. The results, which are presented graphically, facilitate the selection of the optimal mount characteristics when the allowable relative displacement is given. A numerical example demonstrates the optimality of the obtained solution.

In order to expand on the optimization method, a Genetic Algorithm is developed to numerically optimize the mounting system. First, the method is developed for a single degree of freedom model of an engine mount system. Next, the algorithm is extended to the two degree of freedom model of the engine and wing. The results of the GA optimization match the analytical solution.

In addition, this thesis presents a preliminary investigation of the effect of a nonlinear mounting system on the imbalance response of the rotor. The Harmonic Balance and the Averaging method are used to derive a closed form solution of a simplified version of the equations of motion. The influence of the system parameters on the steady state motion is discussed, and the analytical solution is compared to the direct integration of the system equations. The numerical solution reveals the limitation of the presented analytical approach.

An experimental investigation of active vibration control is also carried on a laboratory model of an engine. First, natural frequencies and mode shapes of the apparatus are identified by using modal analysis. Second, the influence of the rotating imbalance on the system response is explored at various rotational speeds. Finally, a direct output feedback active vibration control is implanted. A significant reduction in vibration amplitude is achieved using the MIMO strategy.

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Chapter 1

Background and Literature Review

1.1 Introduction

The reduction of vibration and noise is a high priority for aircraft designers. In order to enhance passenger comfort and improve safety, engineers must meet increasingly stringent industry standard for quieter cabins and lower vibration levels. Although turboprop planes are preferred for short flights because of their low fuel consumption, they have a much higher level of noise and vibration than turbojets. Turboprop airplanes are notorious for their vibration and vibration-induced noise, despite the sterling achievements of vibration analysts and engineers in the industry. The increase demand for passenger and crew comfort requires a greater level of reduction in vibration and vibration-induced noise. The inherent flexibility of the propeller blades is a major cause of the propeller engine vibration. The rotating imbalance generated by the deflected blades gives rise to a whirling motion in the engine block. Then, the vibration travels through the wings to the airplane fuselage creating an uncomfortable ride for the passengers and crew. Experiments have revealed that the vibration transmitted through the mounting system often creates up to 90% of the cabin noise and vibration [1]. Hence, reducing the transmission of vibration through efficient and novel engine suspension system design would lead to the much needed improvements in aircraft cabin noise and vibration isolation.

The vibration energy from engine rotary imbalances causes vibration of the aircraft structure, which in turn, creates noise and vibration in the aircraft cabin. Expensive and time-consuming procedures are required for the precise balancing of propellers. Consequently, a good isolation system is the preferred method for reducing vibration produced by the propeller rotary imbalance [16]. Engine vibration isolation is achieved by using simple compliant mounts. Several elastomeric mounts make up the suspension system, which connects the engine to the nacelle structure. The design of the suspension system involves the selection of stiffness coefficients, and the orientation of the individual mount. On the one hand, vibration attenuation necessitates the use of mounts that are as soft as possible; on the other hand, the susceptibility of turboprops to aerodynamic instabilities places lower limits on the mount stiffness. Therefore, reducing vibration while maintain aeroelastic stability presents a challenge to designers. Engineers are obliged to maintain structural integrity, and at the same time, attain a high level of vibration and vibration-induced noise reduction. Design tradeoffs on mount stiffness are necessary to achieve a high static stiffness that limits engine motion under thrust, maneuver (i.e. "g" load), and weight; and to achieve a low dynamic stiffness for noise and vibration isolation at operating frequencies. Hence, the design problem can benefit from employing optimization techniques for mount selection.

Passive engine isolation systems have performance limitations, and by themselves they may not be adequate to suppress aircraft vibration to a satisfactory level. With the demand for ever increasing cabin comfort that includes decreased noise and vibration, inventive in the design of hydraulic mounts and active structure control will become increasingly important. Therefore, one of the next challenges for hydraulic mount design and active vibration control is aircraft engine suspension systems. Hydraulic mount technology is an improvement because it allows for relatively high static stiffness but will provide a low dynamic stiffness at the specific operating frequency(s). This is attained by using the vibration absorber effect of the oscillating fluid in the mount. An active system allows a further decrease in the dynamic stiffness as well as an increase in the frequency band of isolation.

This thesis focuses on the following objectives:

- Development of a mathematical model of a propeller engine and isolation system, and conducting stability analysis and a parametric study.

- Optimizing a passive suspension system to allow the selection of the best mount stiffness and damping coefficient, and implementing a Genetic Algorithm (GA) for numerical optimization.
- Analyzing the imbalance response of the system with nonlinear mounts, and conducting a parametric study to evaluate the effect of various parameters on the steady state response of the system.
- Implementing an output feedback active vibration control method as the primary active control technique to suppress engine vibration, and conducting an experimental investigation to evaluate the effectiveness of the control strategy.

1.2 Literature Review

The literature review is divided into three main categories. The first one deals with the modeling aspects of the propeller engine. The second part examines vibration control techniques both passive and active. Finally, Genetic Algorithms for optimization are reviewed

1.2.1 Propeller Engine Modeling

The turboprop engine is classified under the general category of rotordynamics. This complex topic includes gyroscopic forces, blade flexibility, propeller geometry, aerodynamic forces, and resilient suspension system, which give rise to various types of complicated phenomena. A great deal of research has been conducted to address these aspects of turboprop modeling.

Propellers are classified as rotationally periodic structures, consisting of identical flexible blades commonly interfaced at equidistance on the hub circumference. Thomas [2] investigated the dynamics of general cyclic symmetric structures. He observed that information about the vibration behavior of the complete assembly could be deduced from analyzing a single element of the repetitive substructures, thus simplifying the required analysis of such systems. Ren and Zheng [3] showed that each natural frequency of the blade appeared as a frequency of the whole structure with a multiplicity related to the number of blades. Samaranyake et al. [4,5] presented a model of a cyclic symmetric system with nonlinear coupling between the adjacent blades.

Blade flexibility causes the appearance of periodic coefficients in the equations of motion. Several methods exist for the analysis of equations with periodic terms including the use of the Floquet method, the use of multi-blade coordinates, and Harmonic Balance [6]. The periodic terms are due to describing individual blade deflections in terms of a rotating frame. The multi-blade coordinates technique, first introduced by Coleman [7] and later generalized by Hohenemser and Yin [8], is a powerful method to describe the motion of a multi-bladed system. Multi-blade coordinate describe the over all rotor motion in a non-rotating coordinate frame fix on the engine. The transformation to multi-blade coordinate eliminates the periodic terms in the equations of motion. The transformation between individual blade coordinates and multi-blade coordinates is orthogonal and therefore preserves the information about system stability [9]. Sela and Rosen [10] presented a modified version of the multi-blade coordinates method.

Rotating systems are rich in destabilizing mechanisms known as self-excited vibrations [11]. Turboprops manifest several kinds of unstable motion such as mechanical instability and whirl flutter instability. Mechanical instability originates from the rotational energy of the propeller being transferred to lateral engine vibration due to blade flexibility [7]. In contrast, the propeller extracting energy from airstreams causes propeller whirl flutter [12]. Several mechanical models have been employed to explain the diverse phenomena associated with the turboprop engine. Earlier studies on propeller-nacelle whirl flutter have a two degrees of freedom (DOF) model [13,14]. The idealized model represented the power plant as a rigid body restrained by a set of springs and dampers at a pivot located behind the propeller disk. The dynamic behavior of the system was described in terms of small angular deflections in pitch, and yaw of the propeller axis relative to static the equilibrium position. The model was suitable for theoretical analysis and parametric studies but more degrees of freedom were needed for a more realistic model [15,16]. Crandall and Dugundji [17] studied the resonant whirling of an aircraft three-bladed propeller engine system, which had six rigid body degrees of freedom plus six blade vibration degrees of freedom. They identified regions of unstable self-excited vibration that resulted from the coupling between the whirling of the mass center of the flexible propeller, and the vibration of the engine. Aerodynamic effects and mounts stiffness were not considered in their analysis. Boulahbal et al. [18] studied the mount stiffness effect on the stability of a four blade propeller engine by using a 14 DOF model that incorporated blade flexibility. Again aerodynamic forces were neglected. Alkhatib and Golnaraghi [19] presented a six rigid body DOF model of a turboprop installation that incorporated aerodynamic forces. A four-bladed propeller engine was simplified to have six rigid body degrees of freedom. With the use of the formulated dynamic model, an analysis of the stability of the engine mount system was conducted by deriving a second order eigenvalue problem. The system natural frequencies were found to be dependent on the rotational speed. At lower speeds, the aerodynamic forces had a stabilizing effect on the system; at higher rotational frequencies, the engine reached a speed after which the system became unstable.

Several authors have emphasized the importance of including the wing dynamics effects on the engine dynamics. Baker et al. [15] pointed out the importance of incorporating a flexible wing in propeller engine modeling to insure that the flexible wing would not destabilize the engine, and that the whirl mode would not adversely affect the flutter stability of the wing. Nietzsche [20,21] investigated the whirl flutter problem of an advanced turboprop configuration with two pusher propellers, supported by short pylons that were cantilevered with the aircraft aft fuselage cone. A complex dynamic coupling involving not only the propeller-nacelle whirl modes but also the natural modes of the supporting backup structure was observed. Ashrafiuon and Nataraj [22] showed that the dynamic model of the supporting structure was critical in the design of engine mounting systems, specially at the operating speed close to one of the foundation natural frequencies.

1.2.2 Vibration control

Fundamentally, there are two approaches to control the vibration in structures: vibration isolation and vibration absorption. A comprehensive and detailed treatment of the classical theory of vibration isolation and absorption is presented in [23].

Vibration isolation is based on the idea of minimizing the transmitted forces from the vibrating structure to the supporting foundation, or vice versa, by introducing resilient elements between them. The use of such elements modifies the natural frequencies, and shifts them away from the excitation frequency without any change in the degrees of freedom of the system. In recent years, there has been a noticeable shift toward a semi-active/active control of vibration. Such a move is driven by the advent of powerful and relatively inexpensive signal processors. Karnopp [24] presented an excellent historical account of the development of active/semi-active vibration isolation along with basic theoretical concepts. Some existing suspension systems in the automobile industry employ semi-active and active isolators [25]. Normally, the semi-active isolators contain a tunable or active component like a damper or a spring. When both the stiffness and the damping are varied by using a microprocessor/computer and an intelligent controller, the suspension becomes active. Variations of available active control systems embody the well-known skyhook damper [24].

Vibration absorption is based on attaching a tunable auxiliary spring-mass-damper to the principal structure in order to absorb the vibrations. Changing the degrees of freedom, facilitates tuning the auxiliary system natural frequencies in such a manner that the principle structure does not feel the transmitted force. In the literature, vibration absorbers are referred to as Tuned Vibration Absorbers (TVAs), Tuned Mass Dampers (TMDs), and Dynamic Vibration Absorbers (DVAs). An overview of passive, adaptive, and active tuned vibration absorbers along with some contemporary applications is surveyed in the paper by J. Q. Sun et al. [26]. Active TVAs consist of an active element parallel to a resilient element that supports a reaction mass. This active element produces a force acting on the reaction mass. The advantages of active TVAs over passive ones include broader bandwidth and higher control authority.

In general, vibration isolation analyses are concerned with reducing the magnitude of the forces transmitted from the engine to the nacelle and the wing at large. Connecting the engine to the nacelle structure through compliant mounts made from rubber and metal serves as a simple method to attenuate unwanted vibrations [22]. Usually, engine mounts are manufactured from viscoelastic material bonded to metals. Snowdon [27] described the various aspects of rubber-like material usage as vibration isolators. Other types of mounts include circular steel rings [28]. More sophisticated concepts are continuously being introduced and developed including hydraulic mounts [29-31], and the usage of magnetorheological (MR) or electrorheological (ER) fluids [32,33]. The mounts are to be considered linear springs in order to simplify the analysis but several studies have introduced nonlinear models [34-39].

All mounting systems are intended to represent a balance between static and dynamic stiffness. The static stiffness has to be sufficient to withstand the static loads created by thrust, "g" load, weight, and torque thus constraining the relative motion between the engine and the supporting structure. On the other hand dynamic stiffness has to be low enough that the vibration is attenuated before transmission to the mounting structure. To limit the relative motion, the mounting system needs to be stiff. In order to minimize the transmitted vibration, however, the mounting system needs to be dynamically soft. An added complication in the case of the turboprop is the aerodynamic effects that cause unstable motions and place limitations on the suspension system.

Typically, an engine mounting system consists of an engine, mounts, and a supporting structure. The mounts are strategically positioned to reduce vibration transmission. The overall performance of the mounting system depends on the characteristics of the individual mounts characteristics as well as on their number and arrangement in the whole system [41]. Therefore, the design of an engine mount system entails the selection of the number of mounts, their stiffness, damping coefficients, locations, and orientations [42]. Analysis of the placement of mounts and the suspension system configuration for propeller driven aircraft in the literature dates back to 1935 [43].

Traditionally, the engine is considered to behave as a rigid body; therefore, its motion is fully identified by three translations and three rotations [44,45,46]. This assumption is justified on the basis that the flexible natural frequencies of the engine are much higher than the natural frequencies of the mounting system. The mounts are modeled as three directional springs with stiffness and damping coefficients. The supporting structures are usually treated as rigid [47,48] but some studies have considered them to be flexible [42].

The location, stiffness, and orientation of the mounts are important factors in minimizing vibration. Several contradicting considerations govern the selection of each of these factors. For example, selecting a mounting system that cuts off the unpleasant forced vibrations generated by the propellers is likely to be characterized by soft spring rates that are prone to generate unstable motion. The designers of aircraft suspension systems must reconcile such conflicting requirements, which suggest approaching the issue from an optimization point of view. The design of an engine passive suspension system can be treated as an optimization problem. Spiekermann et al. [47] used an optimization procedure to move the natural frequencies away from the excitation frequency range, thus reducing the forces transmitted through the mounts. The engine was modeled as a rigid body with six degrees of freedom. The mount stiffness, attachment location, and orientation were used as the design variables. The approach minimizes an objective function, which places a large penalty on the natural frequencies in an undesirable frequency range, or large design changes. Swansow et al. [48] formed an objective function from the weighted sum of the magnitude of the transmitted dynamic forces. The function is constrained by a maximum allowable deflection of the engine to static forces. The aircraft engine was modeled as a rigid body with six degrees of freedom mounted on a rigid base representing the nacelle. The problem was solved using a recursive quadratic programming technique based on a constrained variable metric approach. Later, Ashrafiuon [42] followed the same procedures, but added the influence of base flexibility.

In the last few decades, there has been a tremendous increase in research in the area of active vibration control. A classical treatment of the subject is found in [49,50]. The ultimate goal of active vibration control is to attenuate the vibration of a mechanical system by automatically modifying the system's structural response. The typical components of an active vibration control system are a sensor (to detect vibration), an intelligent controller (to suitably manipulate the signal from the sensor) and an actuator (which influences the mechanical response of the system). An actuator is used to supply mechanical power to the system, and produce a secondary vibration response in the linear mechanical system. The secondary vibration reduces the overall response of the mechanical system through destructive interference with the original response caused by the primary source of vibration.

The active vibration control systems used for vibration isolation and cancellation purposes can be divided into two general categories: feedback and feedforward [51]. In feedback control, no assumption is made about the disturbance signal. The force applied to the structure by the actuator is dependent on the measurements obtained from the sensor. Hughes and Skelton [52] investigated the controllability and observability of linear matrix second order systems. Simple criteria provided insights into the modal behavior of the system, and furnished information on the number and positions of sensors and actuators. Ram and Inman [53] studied the optimal control problem for linear mechanical vibrating systems in the second order formulation that arises naturally from the application of Newton's laws. This method eliminated the need to transform the system into the state space as is done traditionally. Also the method did not involve solving the Riccati equation. Serrand and Elliott [54] implemented a multichannel feedback controller for the isolation of base-excited vibration. Experiments were carried out on a two degree of freedom system involving both translation and rotation motions. Two decentralized controllers were employed; their cross influence were neglected. Feedback control with a fixed controller may not always give the satisfactory performance that it was originally designed to do. The difficulty arises because of the possible changing properties of the controlled process and their signals, parameter uncertainty, and the existence of unknown disturbances. Gallet and Bellizzi [55] employed the H_∞ feedback controller to provide robustness against model uncertainty, and to guarantee close loop stability. A mechanical model consisting of a two degree of freedom rigid body (a vibrating machine), supported on a uniform flexible beam (the supporting structure), was used in the analysis. Two dual passive and active mounts linked the two systems. Both coupled and decoupled control strategies were investigated.

For a feedforward system, the control signal is generated by a reference signal derived from the primary source of the disturbance. The reference signal is used to maintain the synchronization of the secondary excitation. In this case, the response sensor is only used to monitor the performance of the controller. The frequency response or impulse response of the controller can be adjusted or tuned, in response to the output of this sensor in order to make the feedforward control system adaptive. Feedforward control has been used extensively in active machinery isolation procedures involving a time domain least mean square (LMS) adaptive filter [56,57]. The efficiency of this approach depends on the determination of an appropriate reference signal (excitation disturbance signal) [58]. Howard et al. [59] present a method to enable the use of vibratory power transmission as an error signal with filtered-x LMS feedforward adaptive controller. An experiment was performed to demonstrate the technique.

1.2.3 Genetic Algorithm

The Genetic Algorithm (GA) is a stochastic optimization technique based on the mechanics of natural evolution and survival of the fittest strategy found in biological organisms. The GA is well-known method for the global optimization of complex systems. The initiation of the GA can be traced back to the 1950's, but the work done in the 1970's by John Holland at the University of Michigan led to the GA as it is today [61,62] and later, it was documented by DeJong [65], and Goldberg [66]. In simple terms, the algorithm represents a search strategy based on the mechanics of natural selection and reproduction in biological systems. In the introduction of the GA, it is appropriate to cite the effect that the search procedure derives from the process of natural selection and evaluation, originally observed and documented by Charles Darwin. The advantage of being able to proceed with a large population of designs, facilitates the arrival at the globally optimal solution. The philosophy of "survival of the fittest" has been adopted, implemented numerically, and developed for the general problem of optimization in which natural evolution and adaptation to environment variation is simulated mathematically by using GA [63].

The GA starts with a set of randomly selected potential solutions to the problem at hand, and initiates their evolvement by iteratively applying a set of stochastic operators, known as selection, crossover, and mutation. The technique relies on the cost function (fitness) evaluation [64]. No gradient information is required; only evaluations of the objective function and the constraints are necessary to determine the fitness. Such a derivative freeness technique makes the GA versatile and gives it the ability to deal with problems with a complicated cost function where a derivative is difficult to obtain, or is unattainable (non-differentiable functions). The stochastic and randomness nature of the GA avoids the gradient-based optimization methods drawback of being trapped in local optima.

DeJong [65] studied the use of the GA in a general function optimization. He showed that the ability of the GA to learn from the history, and exploit the environment provided the basis of its effectiveness in optimization. Recently, the GA has been used in a vast variety of sciences exponentially. Forrest [70] collected a good summary of the GA applications in science and engineering up to 1993. In vibration isolation systems, the works reported by Esat and Bahai [67], Baumal et al. [68], and Baldanzini et al. [69] should be mentioned.

1.3 Thesis Organization

The organization of this thesis is as follows: Chapter 1 offers the motivation behind the thesis. The literature survey reviews the major issues involved and covered in this work, including turboprop engine modeling, passive and active vibration control, and Genetic Algorithms. Chapter 2 presents a mathematical model of a turboprop engine, and a stability analysis of the developed model. Chapter 3 addresses passive vibration isolation and optimization. An analytical method, based on the Root Mean Square of frequency response functions, is outlined. The Genetic Algorithm technique for optimization is introduced in Chapter 4. Chapter 5 analyzes a simplified version of the system developed in Chapter 2 to study the effects of nonlinear mounts on the imbalance response. Chapter 6 explains the active vibration control implementation on an experimental apparatus. The rig models imbalance vibration in a turboprop, and a brief description of the active control theory is given with the results. Finally, Chapter 7 is dedicated to a conclusion and further research objectives.

Chapter 2

Mathematical Modeling and Stability Analysis

2.1 Introduction

This chapter is concerned with the mathematical modeling and stability analysis of turboprop installations for the ultimate purpose of vibration control. Consequently, the details of how a turboprop engine work are not important. The Task is to present a simple formulation of a dynamic model of a turboprop installations, incorporating aerodynamic forces. A four-bladed propeller engine is simplified to have six rigid body degrees of freedom plus four additional degrees of freedom to account for blade flexibility. The engine is connected to the nacelle by resilient elements in order to reduce vibration transmission from the engine to the airplane structure. The aerodynamic forces acting on the propeller are modeled, utilizing the quasi-steady airfoil theory, by considering their effects as a lifting force on a cross section. By the employment of the formulated dynamic model, an analysis of the stability of the system is conducted by deriving a second order eigenvalue problem. The system natural frequencies are found to be dependent on the rotational speed. Two types of self-exciting instabilities are discovered to be characteristic of the system; mechanical instability and whirl flutter instability. Mechanical instability is due to blade flexibility, whereas whirl flutter instability originates from the aerodynamic forces.

2.2 Coordinate System

The typical installation of a turboprop is shown in Figure 2.1. The system is composed of nonrotating parts (stator), a rotating shaft (rotor), and a propeller. In this analysis, the propeller is assumed to be comprised of four identical blades. The engine is attached to the nacelle system of the aircraft by an arbitrary number of elastic mounts; each mount acts as a three directional spring. These mounts, typically made of rubber bonded to metal, are used to reduce vibration transmissibility from the engine to the structure. A common practice is to distribute the mounts in one or more planes. A sway-bar mechanism, idealized as a torsional spring, is installed to prevent excessive rotational deformation of the engine during startup. The effect of gravity is neglected.

The engine block, consisting of the stator and the rotor, can be treated as a rigid body with six degrees of freedom. An additional degree of freedom per blade is needed to account for its flexibility. The overall system has ten degrees of freedom; ten generalized coordinates must be defined for the study of its dynamic behavior. The generalized coordinates are defined with reference to the frames shown in Figure 2.1 through Figure 2.5. The motion of the engine is described with respect to an inertial coordinate system, $(O_0X_0Y_0X_0)$, fixed on the nacelle, and another coordinate system, $(O_IX_IY_IX_I)$, fixed on the engine. The two sets of coordinates coincide when the engine is in equilibrium state, i.e., solely under the action of gravity. The motion of the engine is described by the displacements of the engine fixed axes relative to the inertial axes. The translational displacements of the origin of the engine fixed axes are x, y, and z in the X_0-, Y_0-, Z_0-direction, respectively. The rotational displacements of the engine are defined by roll, pitch and yaw angles, which are denoted ϕ, ψ, and θ, respectively and they are characterized by the rotational angles of the engine fixed axes $(O_IX_IY_IX_I)$ around the inertial axes $(O_0X_0Y_0X_0)$, i.e., Euler's angles.

A propeller blade may be considered to be a highly twisted wing. The cross sections of the blade are essentially of the same shape as those of a wing, with a well-rounded leading edge and a sharp trailing edge. For simplicity, the blades are assumed to vibrate in their first mode. Neglecting the effects of higher order modes has a minor effect on the accuracy, because the blades are quite rigid. If only the first mode is considered, each blade can be modeled as a rigid pendulum restrained at its root with a torsional spring. The restraining stiffness of each blade is calculated by the use of its first bending mode assuming clamped-free boundary conditions. The deflection of each blade is measured relative to a rotating coordinate axes, $(O_{2i}X_{2i}Y_{2i}X_{2i})$. Due to the cross-section shape and twist, the blade has both in-plane and out-of-plane of components. This is reflected in the modeling by imposing the angle χ which is related to the first bending modes of the continuous model of the blade. Such a configuration permits the examination of the influence of blade flexibility blade, i.e., in-plane and out-of-plane deflections on the vibration of the system. Two additional coordinate axes, $(O_{3i}X_{3i}Y_{3i}X_{3i})$ and $(O_{4i}X_{4i}Y_{4i}X_{4i})$, are used to decompose the blade deflection into in-plane and out-of-plane terms. Table 2-1 provides a summary of the coordinates axes utilized in the development of the equations of motion. The transformation matrices are given in Appendix A.

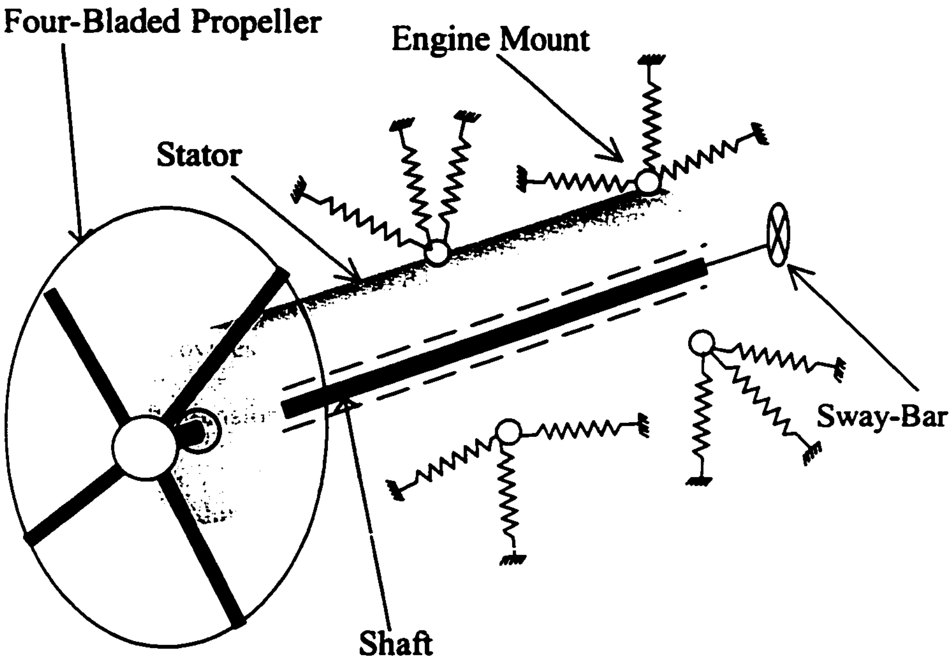


Figure 2.1 Typical turboprop installation components

Table 2-1 Coordinate systems

Co-ordinate System	Base Vector	Description
$O_0X_0Y_0X_0$	$\mathbf{i}_0, \mathbf{j}_0, \mathbf{k}_0$	Inertial frame fixed to the nacelle
$O_IX_IY_IX_I$	$\mathbf{i}_1, \mathbf{j}_1, \mathbf{k}_1$	Engine fixed frame
$O_{2i}X_{2i}Y_{2i}X_{2i}$	$\mathbf{i}_{2i}, \mathbf{j}_{2i}, \mathbf{k}_{2i}$	Rotating frame, $\mathbf{k}_{2i}$ point toward the i^{th} blade
$O_{3i}X_{3i}Y_{3i}X_{3i}$	$\mathbf{i}_{3i}, \mathbf{j}_{3i}, \mathbf{k}_{3i}$	Defines in-plane deformation of the i^{th} blade
$O_{4i}X_{4i}Y_{4i}X_{4i}$	$\mathbf{i}_{4i}, \mathbf{j}_{4i}, \mathbf{k}_{4i}$	Defines out-of-plane deformation of the i^{th} blade

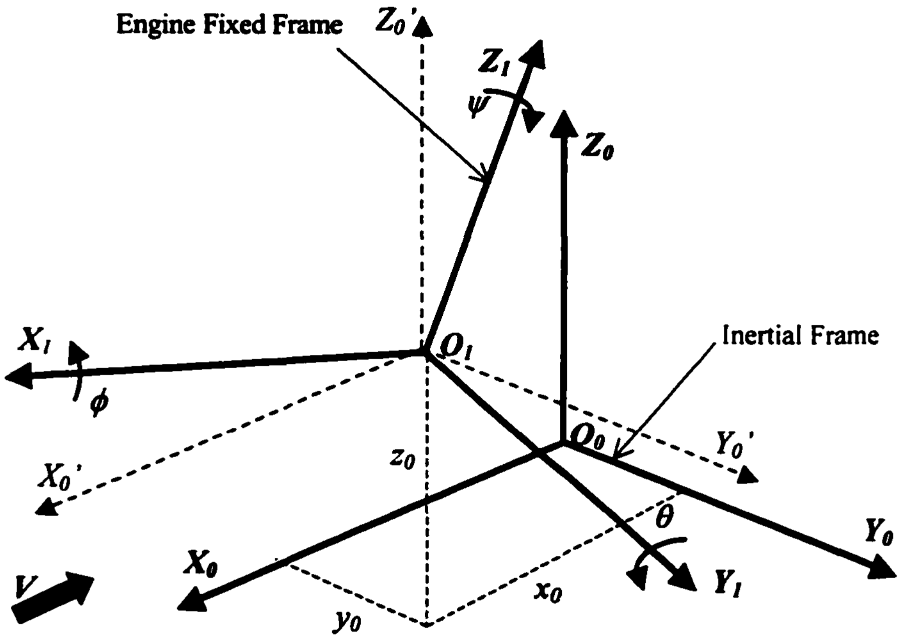


Figure 2.2 Inertial and engine fixed frames

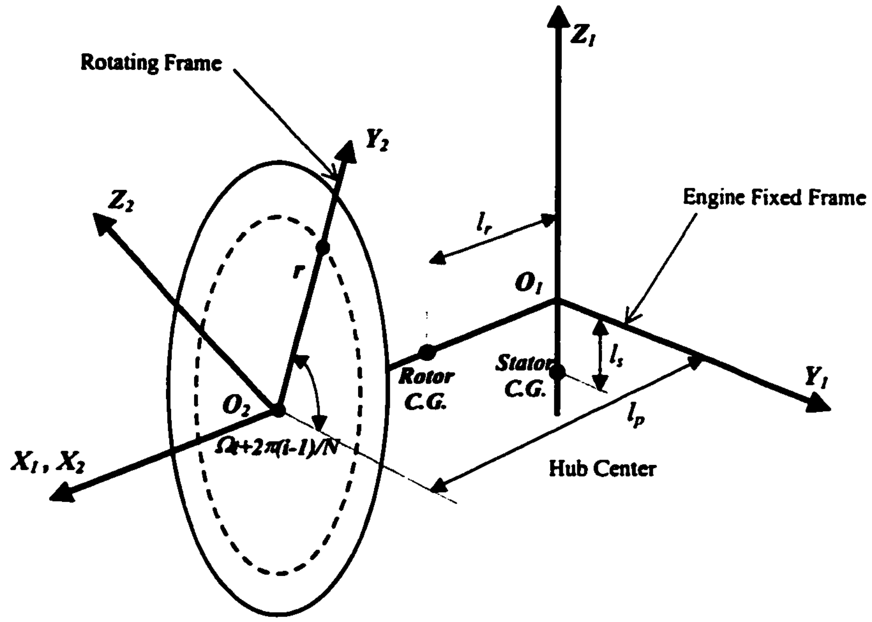


Figure 2.3 Propeller rotating frame

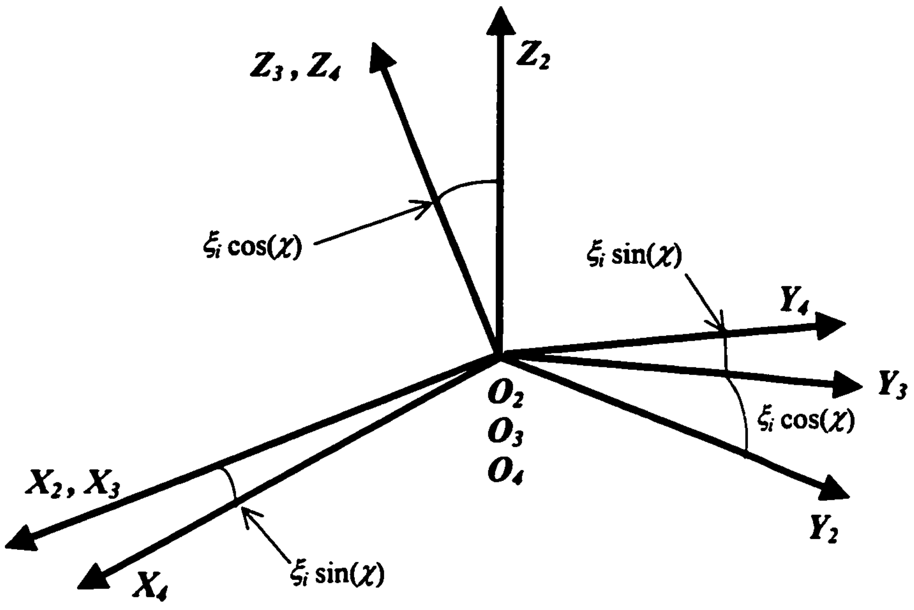


Figure 2.4 Blade deflections frames

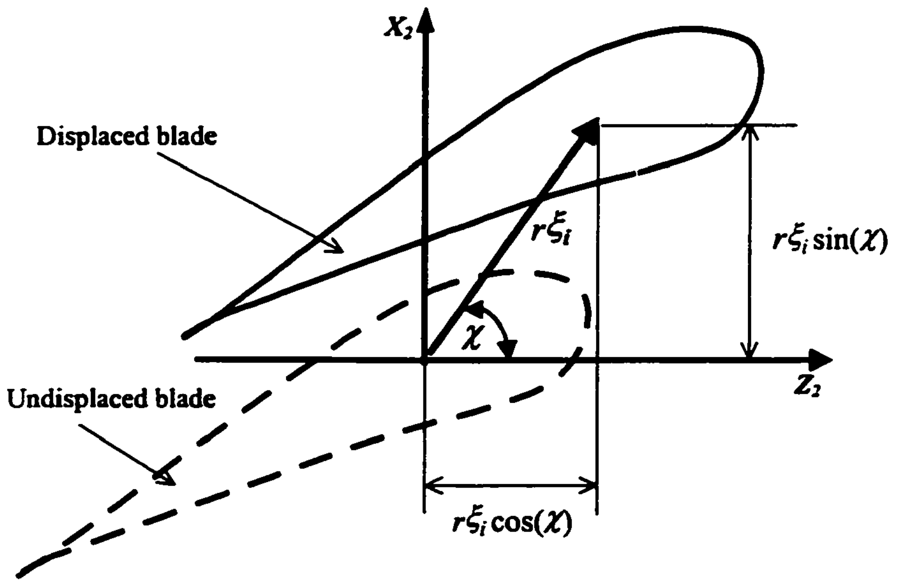


Figure 2.5 Blade deflection coordinates

2.3 Structural Dynamics

The equations of motion are derived by employing the Lagrange technique, which requires defining the potential and kinetic energies of the system. For the simplicity of analysis, the equations of motion are linearized from the beginning of the derivation. Under the assumption of small motion and neglecting the higher order term, the absolute position of an arbitrary point P(l_{XI},l_{YI},l_{ZI}) on the engine can be found from

$$\mathbf{r}_0 = \begin{Bmatrix} x_0 \\ y_0 \\ z_0 \end{Bmatrix} = \begin{Bmatrix} x \\ y \\ z \end{Bmatrix} + \begin{bmatrix} 0 & l_{ZI} & -l_{YI} \\ -l_{ZI} & 0 & l_{XI} \\ l_{YI} & -l_{XI} & 0 \end{bmatrix} \begin{Bmatrix} \phi \\ \theta \\ \psi \end{Bmatrix}. \tag{2.1}$$

The linearized velocity is found by direct time differentiation,

$$\mathbf{v}_0 = \frac{d\mathbf{r}_0}{dt}. \tag{2.2}$$

The linearized and angular velocities of the stator are then found to be

$$\mathbf{v}_s = \left\{ \dot{x} + l_s\dot{\theta} \quad \dot{y} - l_s\dot{\phi} \quad \dot{z} \right\}^T \tag{2.3}$$

and

$$\boldsymbol{\omega}_s = \left\{ \dot{\phi} \quad \dot{\theta} \quad \dot{\psi} \right\}^T . \tag{2.4}$$

Similarly, the linear and angular velocities of the rotor are

$$\mathbf{v}_r = \left\{ \dot{x} \quad \dot{y} + l_r\dot{\psi} \quad \dot{z} - l_r\dot{\theta} \right\}^T \tag{2.5}$$

and

$$\boldsymbol{\omega}_r = \left\{ \dot{\phi} + \Omega \quad \dot{\theta} \quad \dot{\psi} \right\}^T . \tag{2.6}$$

The location of the stator and rotor centers of gravity are depicted in Figure 2.3

$$\mathbf{r}_{pi} = \begin{Bmatrix} x_{pi} \\ y_{pi} \\ z_{pi} \end{Bmatrix} = \begin{Bmatrix} x + l_p + r\sin(\varphi_i)\theta - r\cos(\varphi_i)\psi - r\sin(\chi)\xi_i \\ y + l_p\psi - r\sin(\varphi_i)\phi + r\cos(\varphi_i) - r\sin(\varphi_i)\cos(\chi)\xi_i \\ z - l_p\theta + r\cos(\varphi_i)\phi + r\sin(\varphi_i) + r\cos(\varphi_i)\cos(\chi)\xi_i \end{Bmatrix} \tag{2.7}$$

where $\varphi_i = \Omega t + 2\pi(i\text{-}1)/N$ and N is the number of blade.

The velocity component of a point at radius r of i^{th} blade is

$$\mathbf{v}_{pi} = \frac{d\mathbf{r}_{pi}}{dt} . \tag{2.8}$$

The total kinetic energy of the system is:

$$T = T_s + T_r + T_p \tag{2.9}$$

where T_s, T_r, and T_p are the kinetic energies of the stator, rotor, and propeller, respectively.

The kinetic energy of the stator is

$$T_s = \frac{1}{2} m_s \mathbf{v}_s^T \mathbf{v}_s + \frac{1}{2} \boldsymbol{\omega}_s^T \mathbf{I}_s \boldsymbol{\omega}_s \tag{2.10}$$

where m_s and $\mathbf{I}_s$ are the stator mass and moment of inertia matrix respectively.

The kinetic energy of the rotor is

$$T_r = \frac{1}{2} m_r \mathbf{v}_r^T \mathbf{v}_r + \frac{1}{2} \boldsymbol{\omega}_r^T \mathbf{I}_r \boldsymbol{\omega}_r \tag{2.11}$$

where m_r and $\mathbf{I}_r$ are the stator mass and moment of inertia matrix, respectively.

The kinetic energy of the propeller is

$$T_p = \sum_i^{N_b} \frac{1}{2} \int_o^R \mathbf{v}_{pi}^T(r) \mathbf{v}_{pi}(r) dm. \tag{2.12}$$

The potential energy of the system arises from the elastic deflection of the mounts connecting the engine to the nacelle system, the sway bar, and each of the springs modeling the elastic deformation of the propeller blades:

$$V = V_m + V_{sb} + V_p. \tag{2.13}$$

where V_m, V_{sb}, and V_p are the potential energies of the mounts, sway bar, and propeller, respectively.

Assuming that, in the static equilibrium position, all the mounts are have zero stored energy, then the potential energy stored within them can be determined as

$$V_m = \frac{1}{2} \sum_i^N \Delta \mathbf{x}_i^T \mathbf{k}_i \Delta \mathbf{x}_i . \tag{2.14}$$

The potential energy stored in the sway-bar mechanism is

$$V_{sb}=\frac{1}{2}k_{sb}\phi^{2}. \tag{2.15}$$

The potential energy contributed by the propeller blades is calculated as

$$V_{p}=\frac{1}{2}\sum_{i}^{N}k_{b}\xi_{i}^{2}. \tag{2.16}$$

The Lagrangian is found from equation (2.9) and (2.13),

$$\mathcal{L}=T-V. \tag{2.17}$$

2.4 Aerodynamic Loads

The aerodynamic force distributed along the blade is found by using a quasi-steady blade element strip theory analysis. The cross sections of the blade are essentially the same shape as those of a wing, with a well-rounded leading edge and a sharp trailing edge. Each blade element behaves like an airfoil and undergoes lift. Therefore, the aerodynamic-induced forces and moments are calculated by first considering the forces on a segment of an individual blade. In this approach, the force on any blade segment depends on the relative velocity "seen" by the segment. This relative velocity vector at the blade is assumed to be the vector sum of the inflow velocity, the velocity due to blade deflection and engine motion, and the axial flow velocity decrement associated with the thrust on the blade. The forces and moments applied to the system result from integrating over the entire blade length, adding the contribution of all the blades, and then transferring the resultant to the inertial frame of reference.

In order to calculate the aerodynamic loads on the propeller, the quasi-steady airfoil theory begins by only considering the vector diagram of the air velocities at a typical section as depicted in Figure 2.6.

The air velocity, U_{ei}, and the direction, γ_i, relative to the i^{th} blade are defined as

$$U_{ei} = \sqrt{U_{pi}^2 + U_{ti}^2} \tag{2.18}$$

and

$$\gamma_i = \tan^{-1}\left(\frac{U_{pi}}{U_{ti}}\right) \tag{2.19}$$

where U_{pi} and U_{ti} are the velocity component perpendicular to and parallel to the plane of rotation.

The lifting airload distribution can be expressed in terms of the effective dynamic pressure and the angle of attack of the section,

$$\frac{dL_i}{dr} = \frac{1}{2}\rho U_{ei}^2 \cdot a_l \alpha_i \cdot c \tag{2.20}$$

where ρ is the air density, a_l is the local lift-curve slope, and c is the blade element chord.

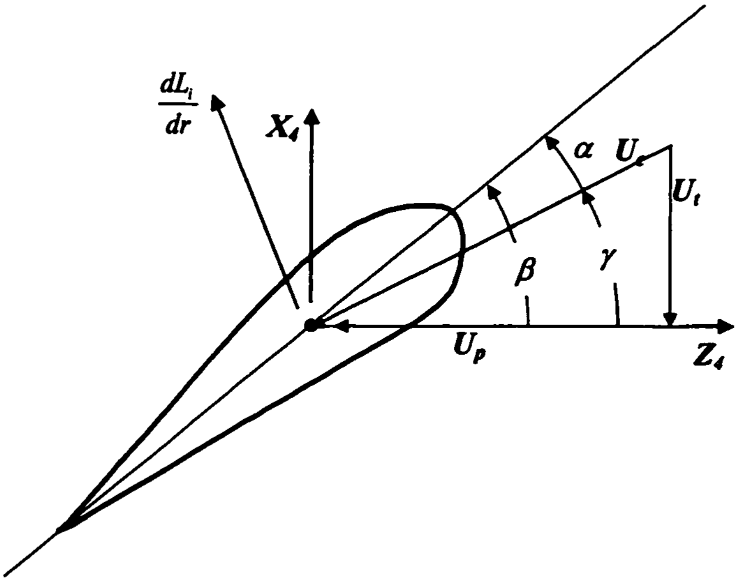


Figure 2.6 Lifting force on a blade section

The angle of attack is defined in terms of the geometric pitch, (β), and the inflow angles,

$$\alpha_i = \beta_i - \gamma_i . \tag{2.21}$$

Substituting (2.18), (2.19) and (2.21) in to (2.20), yields

$$\frac{dL_i}{dr} = \frac{1}{2}\rho\left(U_p^2 + U_t^2\right)\cdot a_i\left(\beta - \tan^{-1}\left(\frac{U_p}{U_t}\right)\right)\cdot c . \tag{2.22}$$

The next step is to find the ***resultant*** tangent and perpendicular components of velocity at the blade section, which depend on the free stream air speed (V), the rotational speed of the propeller, (Ω), and the degrees of freedom used in the model of the propeller engine.

The velocity components of the i^{th} blade at radius, r,

$$U_{ti} = r\left(\Omega + \dot{\phi} + \sin\left(\chi\right)\dot{\xi}_i\right) + \left(\dot{z} + V\theta - l_p\dot{\theta}\right)\cos\left(\varphi_i\right) + \left(-\dot{y} + V\psi - l_p\dot{\psi}\right)\sin\left(\varphi_i\right) \tag{2.23}$$

and

$$U_{pi} = (V + \dot{x} - \cos\left(\chi\right)r\dot{\xi}_i) - r\dot{\psi}\cos\left(\varphi_i\right) + r\dot{\theta}\sin\left(\varphi_i\right) \tag{2.24}$$

where l_p is the location of propeller hub along the X_l-axis.

Substituting (2.23) and (2.24) into (2.21) yields

$$\begin{aligned}\alpha_i = \alpha_0 + \frac{1}{\left(r\Omega\right)^2 + V^2}\Big[& r\Omega\dot{x} + rV\dot{\phi} + \cos(\chi)r\dot{\xi}_i \\ & + (V^2\theta + V\dot{z} - l_pV\dot{\theta} + r^2\Omega\dot{\psi})\cos\left(\varphi_i\right) \\ & + (V^2\psi - V\dot{y} - l_pV\dot{\psi} - r^2\Omega\dot{\theta})\sin\left(\varphi_i\right)\Big]\end{aligned} \tag{2.25}$$

where

$$\alpha_0 = \beta - \tan^{-1}\left(\frac{V}{r\Omega}\right). \qquad (2.26)$$

Substituting (2.23), (2.24) and (2.25) into (2.22) yields

$$\begin{aligned}\frac{dL_i}{dr} = \frac{1}{2}\rho a_l c U^2 \Bigg[& \alpha_0 - \frac{r\Omega}{U^2}\left(1 - \frac{2V}{r\Omega}\alpha_0\right)\left(\dot{x} - r\cos(\chi)\dot{\xi}_i\right) \\ & + \frac{rV}{U^2}\left(1 + \frac{2r\Omega}{V}\alpha_0\right)\left(\dot{\phi} + r\sin(\chi)\dot{\xi}_i\right) \\ & + \left\{\left(1 + \frac{2r\Omega}{V}\alpha_0\right)\left(\frac{V^2\theta + V\dot{z} - L_p V\dot{\theta}}{U^2}\right) + \frac{r^2\Omega}{U^2}\left(1 - \frac{2V}{r\Omega}\alpha_0\right)\dot{\psi}\right\}\cos(\varphi_i) \\ & + \left\{\left(1 + \frac{2r\Omega}{V}\alpha_0\right)\left(\frac{V^2\psi - V\dot{y} - L_p V\dot{\psi}}{U^2}\right) - \frac{r^2\Omega}{U^2}\left(1 - \frac{2V}{r\Omega}\alpha_0\right)\dot{\theta}\right\}\sin(\varphi_i)\Bigg] \end{aligned} \qquad (2.27)$$

The force is in terms of inertial frame:

$$\begin{Bmatrix} F_{x_{pi}} \\ F_{y_{pi}} \\ F_{z_{pi}} \end{Bmatrix} = \mathbf{R}_0^{4i} \cdot \left\{\frac{dL_i}{dr}\cos\gamma_i, \frac{dL_i}{dr}\cos\gamma_i, -\frac{dL_i}{dr}\sin\gamma_i\right\}^T \qquad (2.28)$$

where

$$\sin\gamma_i = \frac{V}{\sqrt{V^2 + (r\Omega)^2}} \qquad (2.29)$$

and

$$\cos\gamma_i = \frac{r\Omega}{\sqrt{V^2 + (r\Omega)^2}}. \qquad (2.30)$$

In order to simplify the analysis α_0 is assumed to be equal to zero[14].

2.5 System Equations of Motion

As the total kinetic and potential energies, and the generalized forces are expressed in terms of the generalized coordinates, the equations of motion of the system can be derived by the use of the Lagrange equations which take the form,

$$\frac{d}{dt}\left(\frac{\partial \mathscr{L}}{\partial \dot{q}_j}\right)-\left(\frac{\partial \mathscr{L}}{\partial q_j}\right)=F_j \tag{2.31}$$

where

$$F_j=\sum_{i=l}^{N}\int_{\ell}^{R}\left(F_{x_{pi}}\frac{dx_{pi}}{dq_j}+F_{y_{pi}}\frac{dy_{pi}}{dq_j}+F_{z_{pi}}\frac{dz_{pi}}{dq_j}\right)dr\,. \tag{2.32}$$

The equations of motion can be cast in the matrix form,

$$\mathbf{M}(t)\ddot{\mathbf{q}}+\Omega\mathbf{G}(t)\dot{\mathbf{q}}+\left(\mathbf{K}+\Omega^2\mathbf{E}(t)\right)\mathbf{q}=\Omega\mathbf{D}(t)\dot{\mathbf{q}}+\Omega^2\mathbf{H}(t)\mathbf{q} \tag{2.33}$$

where $\mathbf{q}=\{x,y,z,\phi,\theta,\psi,\xi_1,\xi_2,\xi_3,\xi_4\}$ is the vector of the generalized coordinates, and **M**(*t*), **G**(*t*), **K**, **E**(*t*), **D**(*t*), and **H**(*t*) are the mass, gyroscopic, stiffness, centripetal, aerodynamic damping, and aerodynamic stiffness matrices, respectively.

Blade deflection is measured with respect to the rotating frames which give rise to time varying coefficients in the entries coupling the blades' coordinates with the rest of the system.

2.6 Multi-blade Coordinate Transformation

Equations of motion with periodic coefficients are commonly found in the dynamic analysis of rotating wings (helicopter) or propeller engine systems. The Multi-blade Coordinates Transformation (MCT) is frequently employed to overcome difficulties that arise in the analysis of such systems by eliminating time dependent coefficients. The equations of the blades are written in the rotating undeformed blade coordinate directions. The transformation to nonrotating hub fixed (multi-blade) coordinate removes the time dependency of the system coefficients. For a four-bladed rotor experiencing azimuth-dependent aerodynamic and inertia loads, the multi-blade coordinates are

$$\begin{Bmatrix} \Gamma_0 \\ \Gamma_1 \\ \Gamma_2 \\ \Gamma_d \end{Bmatrix} = \frac{1}{4} \begin{bmatrix} 1 & 1 & 1 & 1 \\ \sin(\varphi_1) & \sin(\varphi_2) & \sin(\varphi_3) & \sin(\varphi_4) \\ \cos(\varphi_1) & \cos(\varphi_2) & \cos(\varphi_3) & \cos(\varphi_4) \\ -1 & 1 & -1 & 1 \end{bmatrix} \begin{Bmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \\ \xi_4 \end{Bmatrix} = \mathbf{T}(t) \begin{Bmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \\ \xi_4 \end{Bmatrix} \tag{2.34}$$

where $\varphi_i = \Omega t + 2\pi\,(i-1)/4$ and $i=1,2,3,4$.

The multi-blade coordinate, Γ_0, describes the uniform deflection of the propeller, i.e., all the blades deflect in the same direction with the same amplitude. Γ_1 and Γ_2 describe the cyclic deflection of the blades, i.e., the blades deflect in such a manner that the propeller mass center deviates from the geometric center and traces a wave. Γ_d describes the propeller when the deflection of each blade is equal in magnitude, but opposite in direction to its neighbor. The transformation is carried out as follows:

$$\mathbf{q} = \mathbf{R}(t)\mathbf{p} \tag{2.35}$$

and

$$\mathbf{R}(t) = \begin{bmatrix} \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{T}^{-1}(t) \end{bmatrix} \tag{2.36}$$

where $\mathbf{I}$ is a 6×6 identity matrix and $\mathbf{p} = \{x, y, z, \phi, \theta, \psi, \Gamma_1, \Gamma_2, \Gamma_3, \Gamma_d\}$.

The transformed and rearranged equations of motion are

$$\hat{\mathbf{M}}\ddot{\mathbf{p}} + \Omega\left(\hat{\mathbf{G}} - \hat{\mathbf{D}}\right)\dot{\mathbf{p}} + \left[\hat{\mathbf{K}} + \Omega^2\left(\hat{\mathbf{E}} - \hat{\mathbf{H}}\right)\right]\mathbf{p} = \mathbf{0} \tag{2.37}$$

where

$$\hat{\mathbf{M}} = \mathbf{R}^T\mathbf{M}(t)\mathbf{R}, \tag{2.38}$$

$$\hat{\mathbf{G}} = \mathbf{R}^T\left(2\Omega^{-1}\mathbf{M}(t)\dot{\mathbf{R}}+\mathbf{G}(t)\mathbf{R}\right), \tag{2.39}$$

$$\hat{\mathbf{D}} = \mathbf{R}^T\mathbf{D}(t)\mathbf{R}, \tag{2.40}$$

$$\hat{\mathbf{K}} = \mathbf{R}^T\mathbf{K}\mathbf{R}, \tag{2.41}$$

$$\hat{\mathbf{E}} = \mathbf{R}^T\left(\Omega^{-2}\mathbf{M}(t)\ddot{\mathbf{R}}+\Omega^{-1}\mathbf{G}(t)\dot{\mathbf{R}}+\mathbf{E}(t)\mathbf{R}\right), \tag{2.42}$$

and

$$\hat{\mathbf{H}} = \mathbf{R}^T\left(\Omega^{-1}\mathbf{D}(t)\dot{\mathbf{R}}+\mathbf{H}(t)\mathbf{R}\right). \tag{2.43}$$

The complete system matrices are given in Appendix B.

2.7 Stability Analysis and Critical Speed

With time-invariant coefficient matrices in the equations of motion, stability can be investigated by making use of the solution of an expanded characteristic polynomial or a matrix eigenvalue solution. The form $\mathbf{p} = \mathbf{u}e^{\lambda t}$ is assumed for the solution of the equations of motion.

Substituting into (2.37) yields

$$\Delta(\lambda) = \left|\hat{\mathbf{M}}\lambda^2 + \Omega\left(\hat{\mathbf{G}}-\hat{\mathbf{D}}\right)\lambda + \left[\hat{\mathbf{K}}+\Omega^2\left(\hat{\mathbf{E}}-\hat{\mathbf{H}}\right)\right]\right| = \mathbf{0} \tag{2.44}$$

which can be transformed into the eigenvalue problem

$$\left(\mathbf{A}-\lambda\mathbf{I}\right)\mathbf{z} = \mathbf{0} \tag{2.45}$$

where

$$\mathbf{A} = \begin{bmatrix} \mathbf{0} & \mathbf{I} \\ -\hat{\mathbf{M}}^{-1}\left[\hat{\mathbf{K}}+\Omega^2\left(\hat{\mathbf{E}}-\hat{\mathbf{H}}\right)\right] & -\hat{\mathbf{M}}^{-1}\left(\hat{\mathbf{G}}-\hat{\mathbf{D}}\right)\Omega \end{bmatrix} \tag{2.46}$$

and

$$\mathbf{z} = \begin{Bmatrix} \mathbf{u} \\ \lambda\mathbf{u} \end{Bmatrix}. \tag{2.47}$$

The eigenvalue problem depends on the rotational speed, Ω, of the propeller. The system is stable if the real parts of all the eigenvalues are negative. In the case of the pure imaginary eigenvalues the system is considered stable as long as the repeated roots have linearly independent eigenvectors.

In order to compute the critical speed, λ is replaced with Ω in equation (2.44), which yields a new eigenvalue problem in terms of Ω^2,

$$\Delta\left(\Omega^2\right) = \left|\Omega^2\left(\hat{\mathbf{M}}+\hat{\mathbf{G}}-\hat{\mathbf{D}}+\hat{\mathbf{E}}-\hat{\mathbf{H}}\right)+\hat{\mathbf{K}}\ \right| = \mathbf{0}. \tag{2.48}$$

2.8 Results and Discussion

The key concern in the design of turboprop installations is to assure structural integrity, while maintaining adequate vibration isolation. These two criteria place opposing requirements on the suspension system stiffness. On the one hand, the stiffness should be soft to reduce vibration transmissibility from the engine to the nacelle structures. On the other hand, the dynamic stability of the engine requires hard mounting to prevent unstable whirling of the propeller.

In this section, numerical simulations are presented for several cases to demonstrate the stability calculation for such a system. As noted before, the eigenvalue problem depends on the rotational speed of the rotor. Campbell diagrams are utilized to show the influence of rotating speed on the real and imaginary parts of the eigenvalues. Two distinct types of instabilities are identified: mechanical instability and propeller whirl flutter instability. Campbell diagrams are very common in the analysis of rotating machinery. They indicate the variation of natural frequencies as a function of rotational speed. The natural frequencies change with speed because of gyroscopic effects and aerodynamic effects.

2.8.1 Mechanical Instability

The first type of instability, that the system is susceptible to, is mechanical instability. The main cause behind this kind of self-excited vibration is the coupling that occurs between engine pitch and yaw degrees of freedom and the in-plane deflection of the propeller blades. The system is considered in vacuum where the airstream velocity is assumed to be zero. The aerodynamic damping and stiffness are eliminated from the equations of motion; i.e., equation (2.37).

The in-plane and out-of-plane deflections of the propeller blade is controlled through the angle, χ. In practice, the engine is maintained at a constant rotational speed and the angle χ is changed so as to control the forward speed of the airplane. Figure 2.7 through Figure 2.9 depict Campbell diagrams for three cases of χ ; a pure in-plane deflection, a combination of in-plane/out-of-plane deflection, and a pure out-of-plane deflection. These figures demonstrate that the in-plane motion permitted by blade flexibility facilitates the occurrence of self-excited vibration. As the propeller rotational speed Ω increases, a point is reached where two of the frequencies coalesce, resulting in two modes at the same frequency, one of which is damped and the other is unstable. This point marks the beginning of a region of mechanical instability in the forward whirl mode. In this form of instability, the whirling mode of the mass center of the propeller couples with the transverse vibration of the engine block. The rotational energy of the propeller is transformed into a whirl motion with an exponential growth in the motion orbit. The influence of blade rigidity on stability can be seen by comparing Figure 2.7

and Figure 2.10. Reducing the blade stiffness enhances the coupling between the in-plane blade deflection and transverse engine motion, thus reducing the stability margin.

Figure 2.11 and Figure 2.12 illustrate the effects of blade stiffness and mounting system stiffness on the onset speed of instability. It is clear from the figures that an increase in both blade stiffness and mounting system stiffness pushes the onset speed to a higher value and enhances the stability margin. From a practical point of view, there are limitations on increasing blade stiffness. Increasing mounting system stiffness is undesirable because it reduces vibration isolation effectiveness.

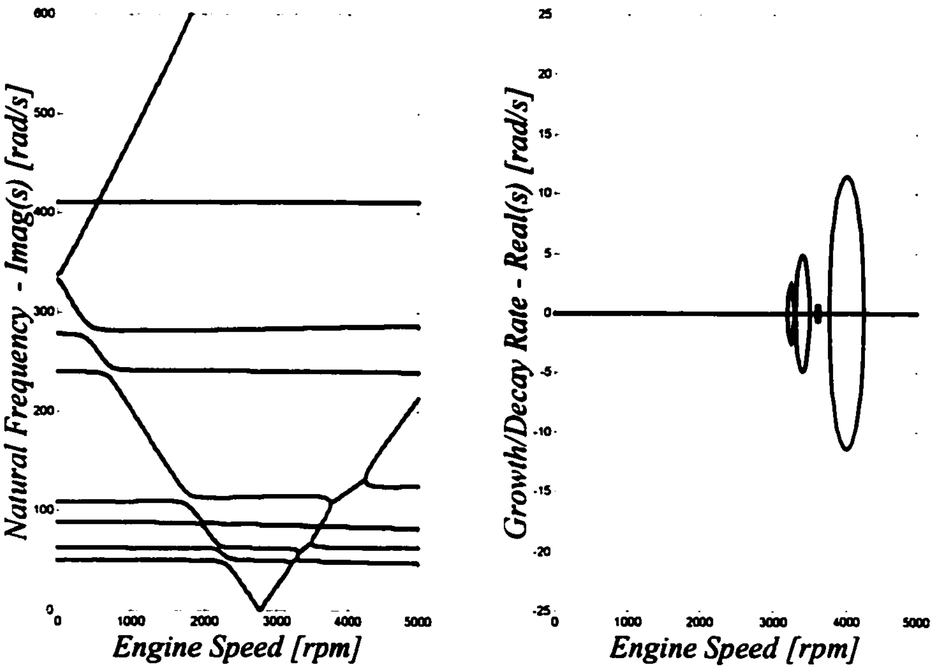


Figure 2.7 Campbell diagrams for blade stiffness k_b=10×10^6 N/m^2, and χ=0° (pure in-plane blade deflection)

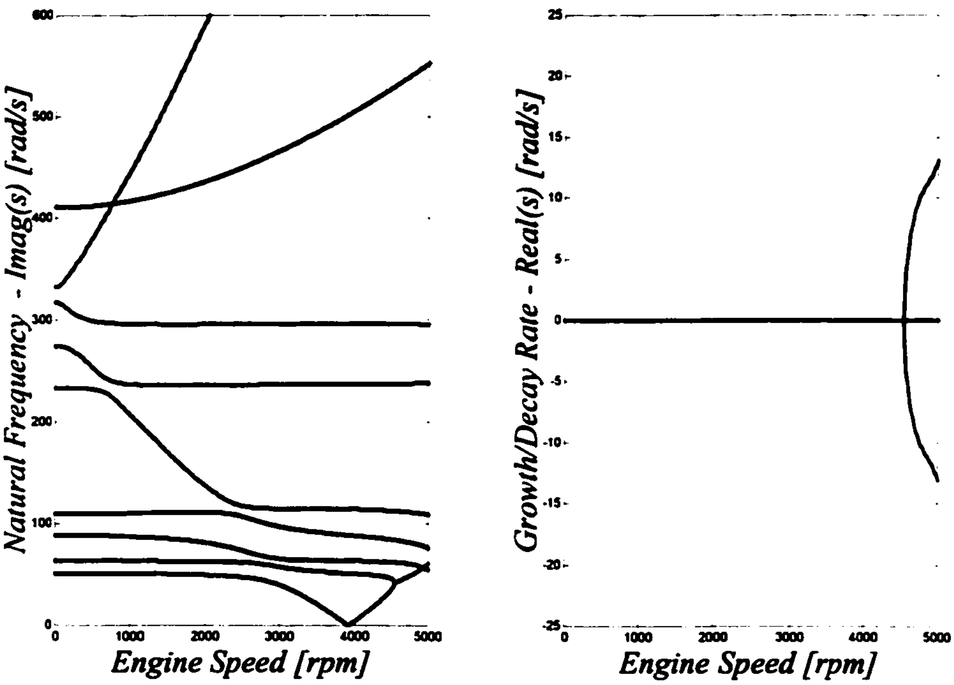


Figure 2.8 Campbell diagrams for blade stiffness k_b=10×10^6 N/m^2, and χ=45°

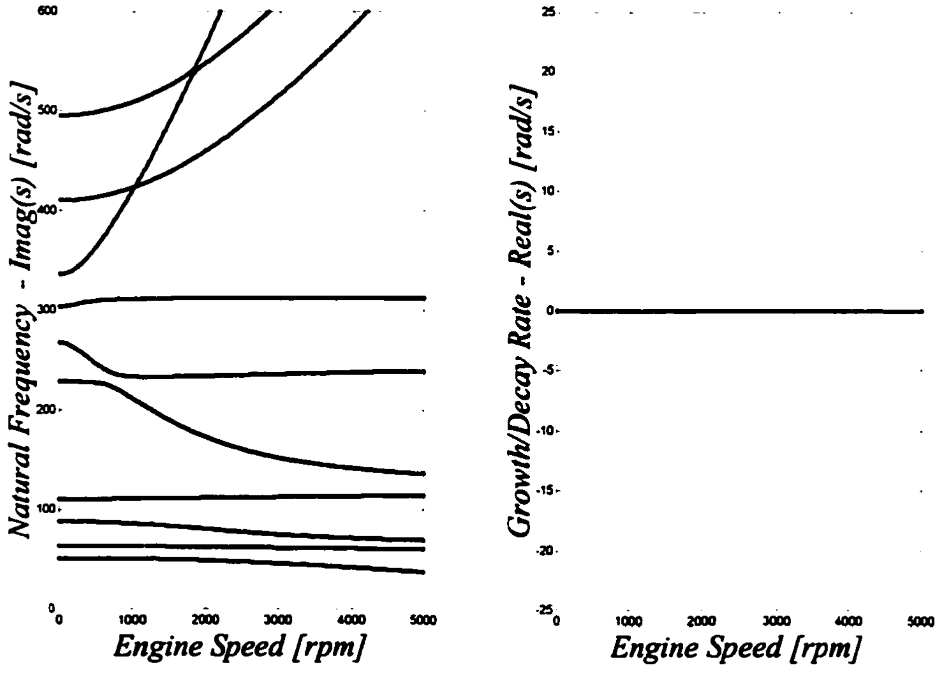


Figure 2.9 Campbell diagrams for blade stiffness k_b=10×10^6 N/m^2, and χ=90° (pure out-of-plane blade deflection)

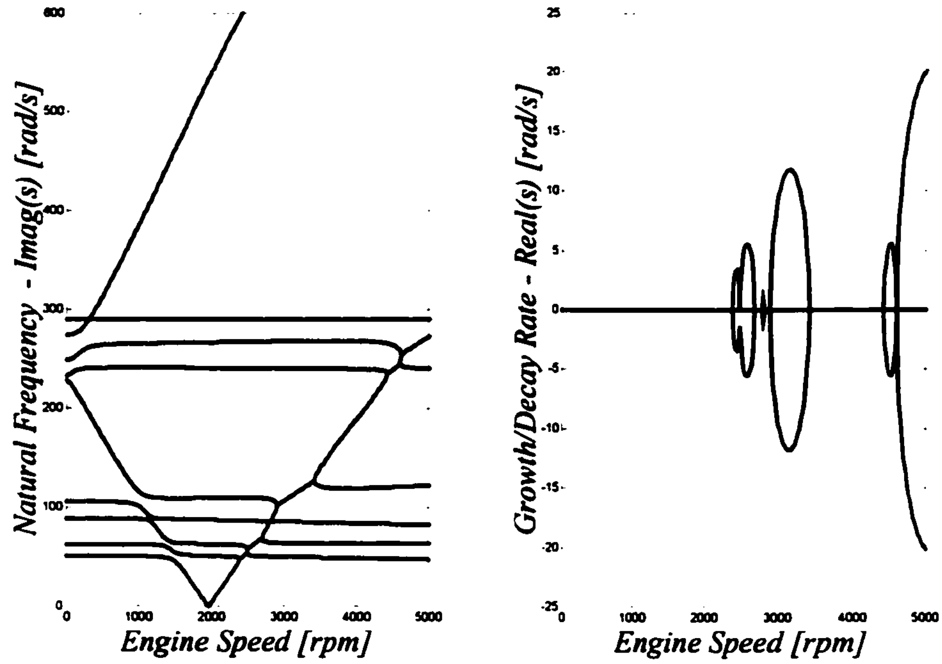


Figure 2.10 Campbell diagrams for blade stiffness k_b=5×10^6 N/m^2, and χ=0° (pure in-plane blade deflection)

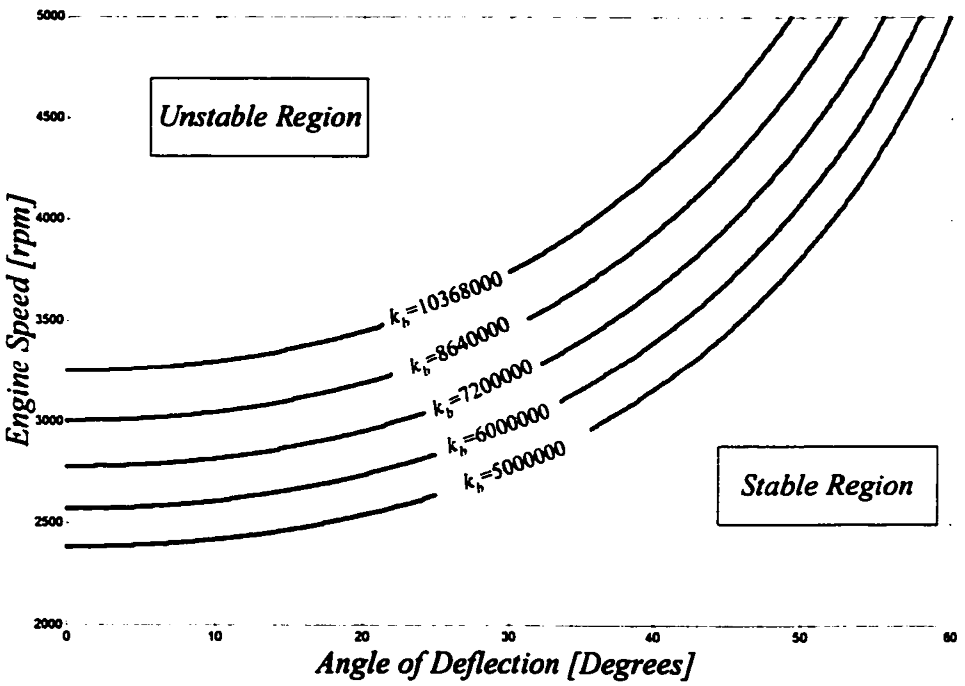


Figure 2.11 Stability Chart for different blade stiffness

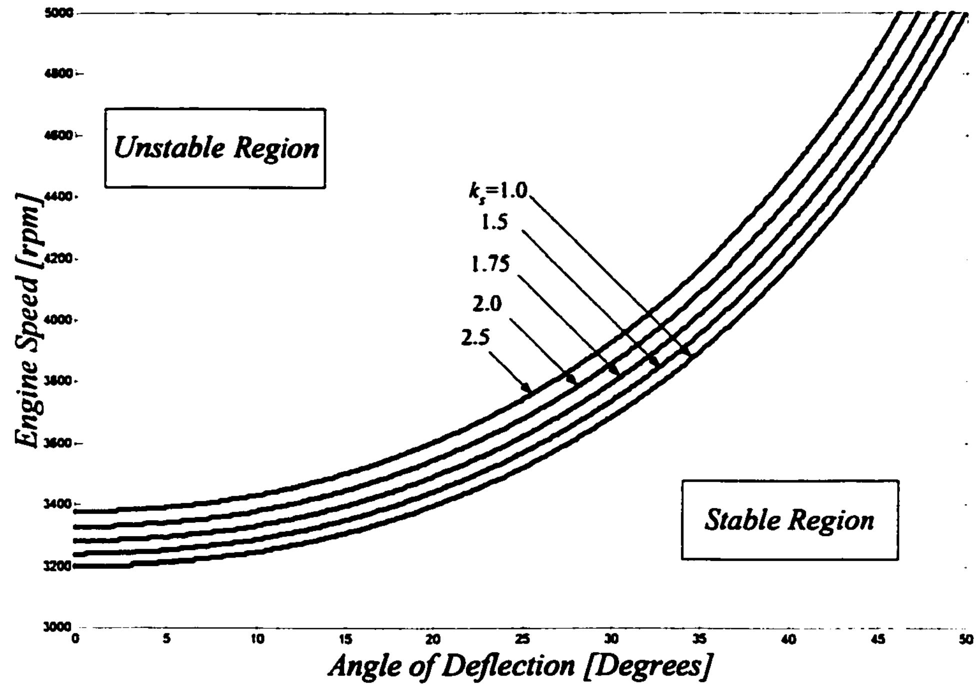


Figure 2.12 Stability Chart for different mounting system stiffness multiplier

2.8.2 Propeller Whirl Flutter Instability

Another class of self-excited vibration is recognized if the aerodynamic effects on the system are considered. This type of instability is termed propeller whirl flutter. The cases shown in Figure 2.13 to Figure 2.17 illustrate the effect of various parameters. At lower speeds, the aerodynamic forces stabilize the system. As the propeller speed increases, a point is reached where the rotor is vulnerable to unstable motion. When the propeller rotational speed is less than the whirl flutter speed, the path traced by the propeller hub is a spiral that converges to the original static equilibrium position. When the flutter speed is exceeded, however, a small disturbance results in a diverging spiral motion of the hub which continues to build up until the structure fails, or its motion becomes limited due to nonlinearities. In this form of instability, the propeller extracts energy from the airstream and transfers it to a transverse vibration of the engine. A comparison of Figure 2.13 through Figure 2.15

demonstrates the influence of in-plane blade deflection on stability. Contrary to the previous section where only in-plane blade deflection leads to mechanical instability, it is evident that the unstable motion is possible even when the blade is in pure out-of-plane deflection. The propeller advance ratio (*J*) measures the relation between the rotational speed of the propeller and the forward motion of the airplane; it can be taken as an efficiency indicator. The higher advance ratio, (*J*), leads to a larger lifting force on the propeller section lowering the instability onset speed, as seen in Figure 2.16 and Figure 2.17. The influence of in-plane blade deflection and blade rigidity on stability diminishes at higher values of advance ratio (*J*), as illustrated in Figure 2.18 and Figure 2.19.

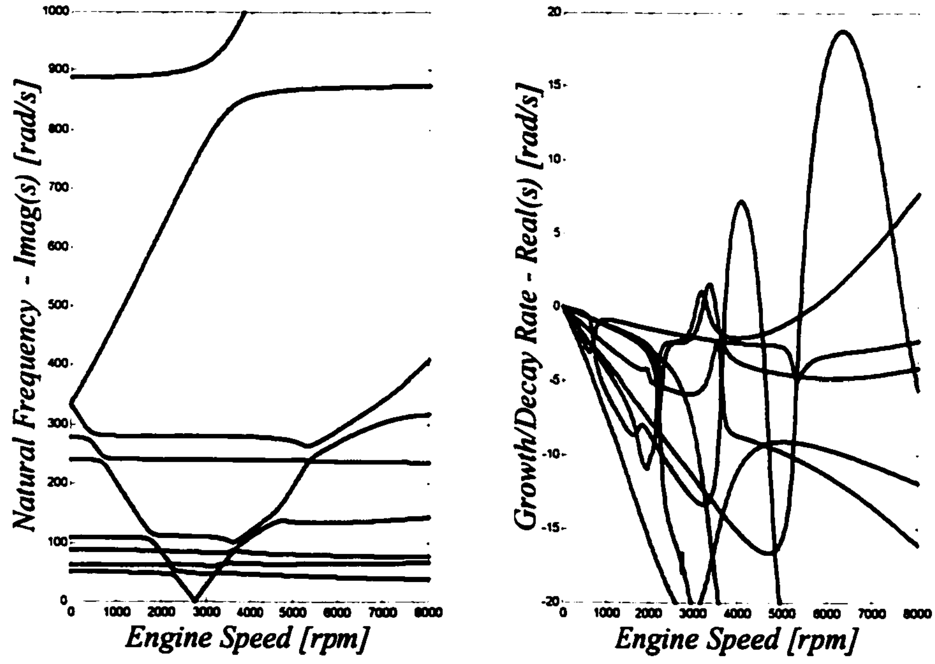


Figure 2.13 Campbell diagrams k_b=10×10^6 N/m^2, and χ=0°, J= 0.8

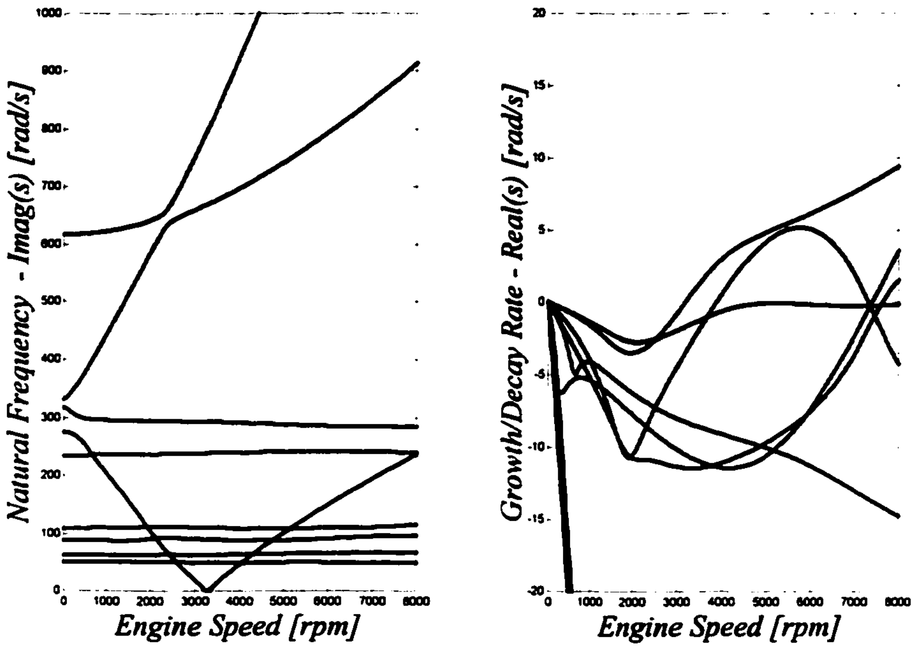


Figure 2.14 Campbell diagrams k_b=10×10^6 N/m^2, and χ=45°, J= 0.8

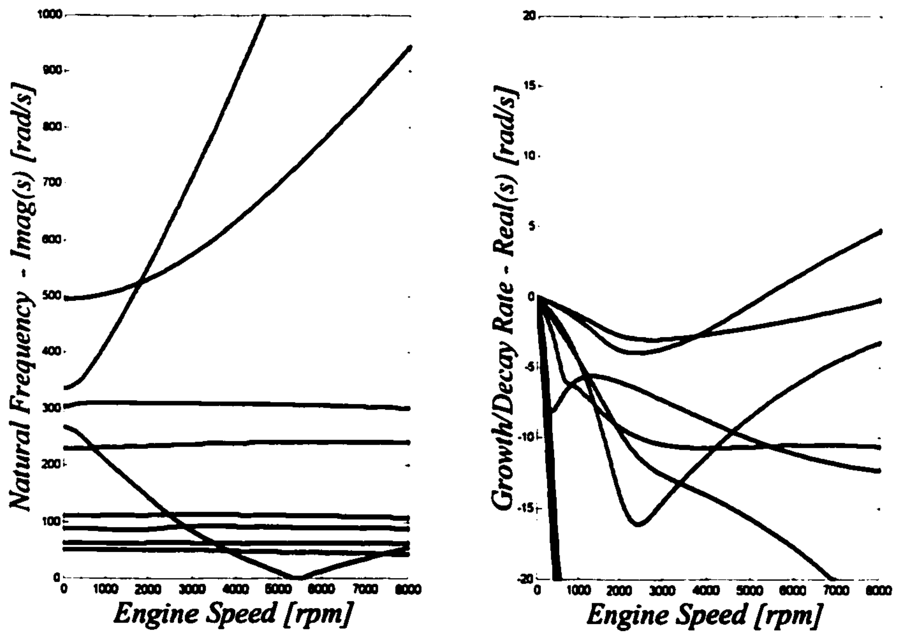


Figure 2.15 Campbell diagrams k_b=10×10^6 N/m^2, and χ=90°, J= 0.8

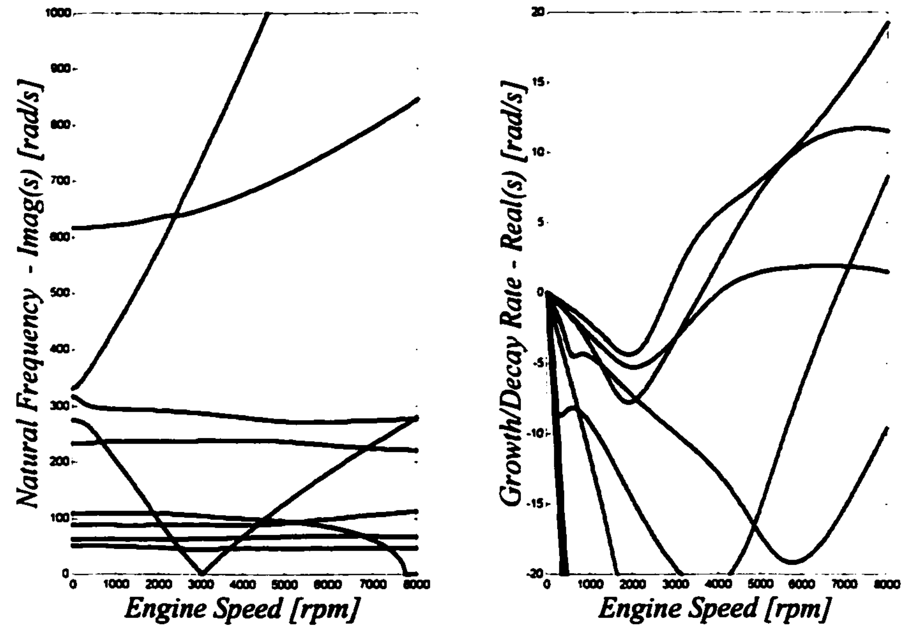


Figure 2.16 Campbell diagrams k_b=10×10^6 N/m^2, and χ=45°, J= 1.5

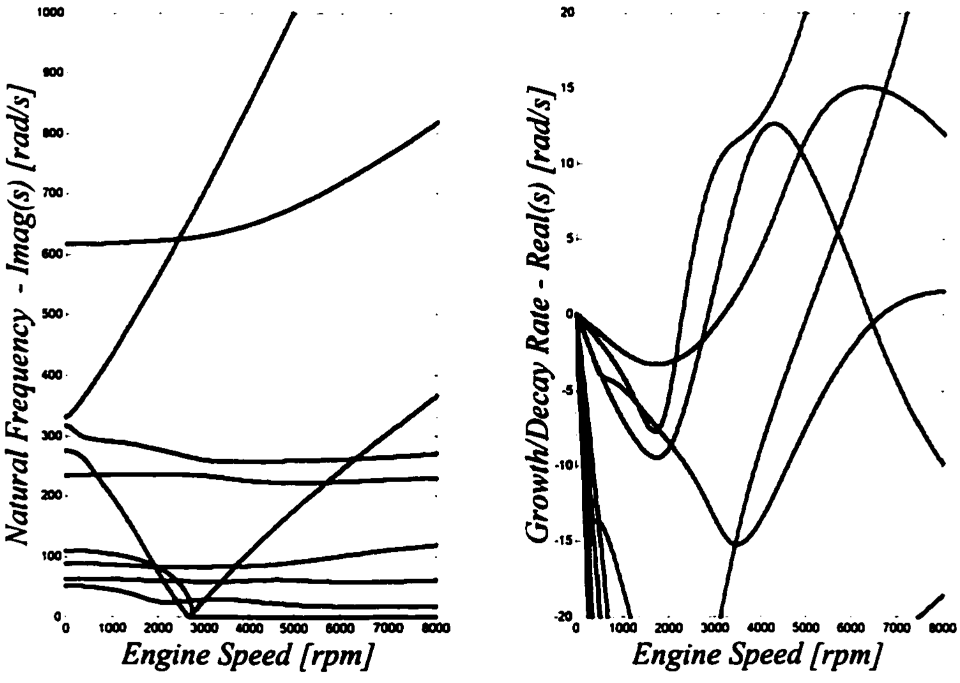


Figure 2.17 Campbell diagrams k_b=10×10^6 N/m^2, and χ=45°, J= 3.0

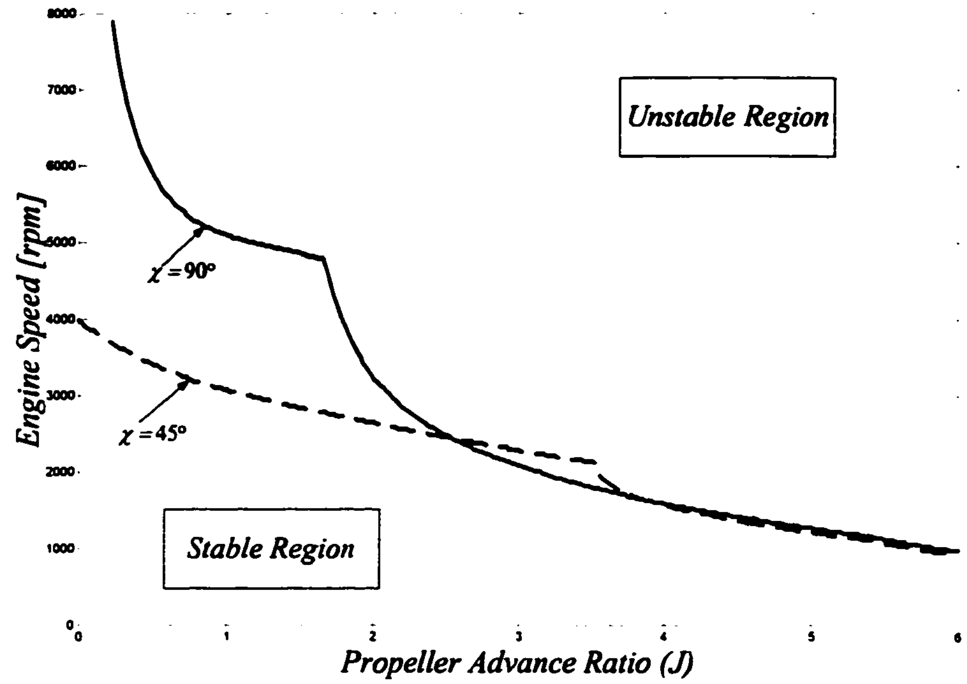


Figure 2.18 Stability chart for blade stiffness k_b=10×10^6 N/m^2, and two blade set angle χ=45°,

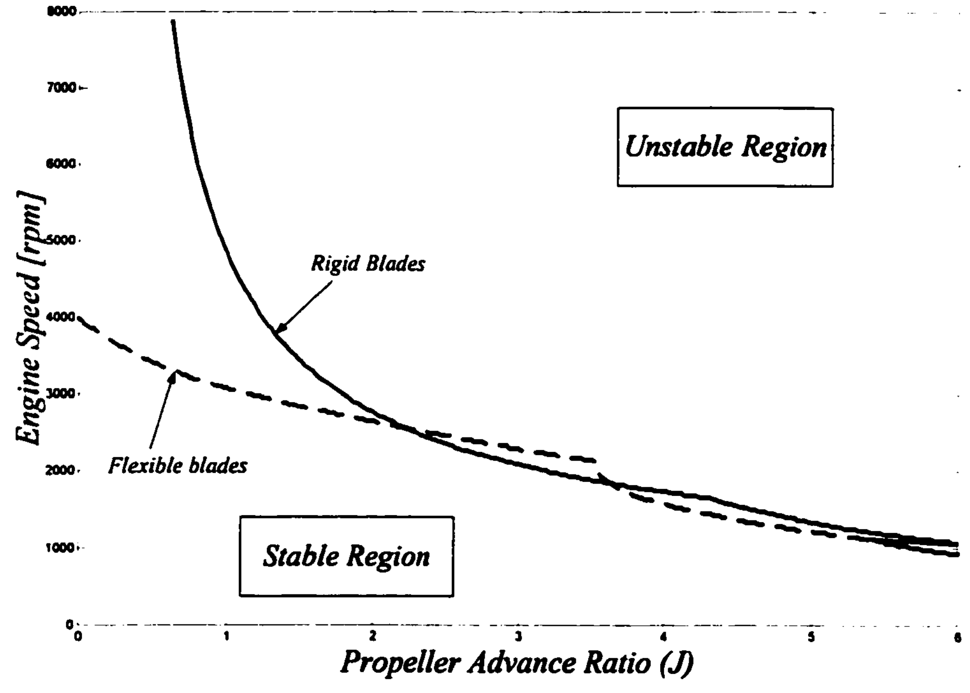


Figure 2.19 Stability chart for blade stiffness k_b=10×10^6 N/m^2, and rigid blade with blade set angle

χ=45° χ=90°

Chapter 3

Passive Vibration Isolation of The Engine: Analytical Approach

3.1 Introduction

Due to the complexity of the model developed in the chapter 2, a simpler model is proposed in chapter 3 in order to study passive vibration isolation. This new model results in a two degrees of freedom linear system, which takes into account both the engine motion and the wing motion. The new model allows an analytical treatment of the optimization problem thus lending better insights into the performance of the system. The objective of the optimization procedure is to obtain the best stiffness and damping coefficient for the mounting system. The optimization method is based on the Root Mean Square (RMS) of the steady state response. The optimization criterion is defined in terms of the relative displacement RMS, and the absolute acceleration RMS. It becomes evident that there is an optimal relationship between the RMS of the absolute acceleration and the RMS of the relative displacement. Designers can use the results to specify the optimal suspension, given the allowable relative displacement (working space).

3.2 Vibration Isolation Optimization

There are numerous practical applications where it is desirable to isolate a vibrating device from the surrounding structure by minimizing the vibration transmitted away from the vibrating device. For vibrating devices such as engines, vibration isolation mounts have typically been used to isolate the structure from the foundation on which they are mounted. Isolation system design presents a challenge to engineers due to the conflicting requirement criteria involved. For example, it is desirable to reduce engine vibration, and ultimately, the dynamic forces transmitted from the engine to the frame. Usually, this is achieved by using a soft suspension or soft vibration isolator (a mount, in this case) to connect the engine to the base structure. However, restrictions on engine deflection due to physical limitations confines mount stiffness to a lower boundary. Therefore, the selection of mount characteristics can benefit from optimization techniques.

The goal of optimization processes is to achieve the best possible vibration attenuation for various isolator and absorber systems. The procedure involves three major tasks: choosing which measure should be minimized to best depict the problem under study, deciding which parameters will be varied during the optimization, and decide which constraints must be satisfied in order to avoid trivial solutions to the problem.

The most important function of an isolator is to reduce the magnitude of motion transmitted from a vibrating supporting structure to the equipment, or to reduce the magnitude of force transmitted from the equipment to its supporting structure, both in the time and frequency domain [72]. Various methods exist to address time and frequency domain isolation system optimization [27]. Time domain optimization deals with the dynamic response and transient characteristics of the system. Frequency optimization is concerned with the steady state performance of the system. Lastly, optimization in the frequency domain is essential, especially when the excitation has various combinations of frequencies. The optimization of vibrating systems for a harmonic excitation may be used for any kind of periodic excitation. This is possible because any periodic excitation can be expanded to a Fourier series of harmonic excitations.

There are various approaches to optimization, but none is universally accepted yet. The appropriate choice of the cost function is paramount, because it determines which isolation system design is best, or optimum. Most of the criteria used in cost functions for the optimization of vibrating systems are based on the acceleration, jerk, and displacement. The reduction of the absolute acceleration is a main goal in the optimization of suspensions, because it measures the transmitted force. Hence, the absolute acceleration is an important parameter of every cost function in the vibration isolation optimization theory. Displacement transmissibility is another significant factor to be taken into consideration. It measures the deflection amplitude of the isolated engine. A vibration isolator produces a reduction in the absolute acceleration, and the absolute displacement vibrations by permitting the deflection of the isolator [60]. The relative deflection is a measure of the clearance (known as the working space) required in the isolator. The clearance should be bounded due to the physical consideration of the mechanical design. Also, considerable attention has been given to the minimization of the absolute displacement.

The frequency response analysis, based on the steady state system response to a sinusoidal input, is one of the most common and effective methods for optimization in the frequency domain. This method is based on obtaining the frequency response functions (FRF) that relates the input to the output of the steady state solution of the equations of motion. The derivation of the required frequency response functions is cumbersome, especially for the statistical characteristics, and is almost impossible for nonlinear systems.

3.3 Mathematical Modeling

Figure 3.1 illustrates a possible simple mechanical representation of a propeller engine mounted on an airplane wing. In order to simplify the analysis, the wing is assumed to be vibrating in the first mode; thus, it can be modeled as a mass spring system with its stiffness derived from the first bending natural frequency. Furthermore, the engine is assumed to be capable of vertical motion only. Hence, the system can be reduced to the linear representation shown in Figure 3.2. Such simplification allows analytical derivation of the steady state solution that permits a qualitative understanding of the method.

The equation of motion of the system is adapted to derive the transmissibility equations to be used for the RMS evaluation. The governing differential equations of motion for the system model shown in Figure 3.2 are

$$\begin{aligned} m_e\left(\frac{d^2}{dt^2}x_e\right)+c_e\left(\frac{d}{dt}\left(x_e-x_w\right)\right)+k_e\left(x_e-x_w\right)=f_e \\ m_w\left(\frac{d^2}{dt^2}x_w\right)+c_e\left(\frac{d}{dt}\left(x_w-x_e\right)\right)+\left(k_e+k_w\right)x_w-k_ex_e=f_w. \end{aligned} \tag{3.1}$$

The wing has a mass, m_w, stiffness, k_w, and external excitation, f_w, and the engine has a mass, m_e, and is supported on a resilient mount with stiffness, k_e, and damping coefficients, c_e, and excitation, f_e. The excitation force on the wing comes from the aerodynamic force, while the rotating imbalance is the main cause of the engine excitation. A simple approach is to examine the wing excitation, and demonstrate the optimization procedures, which can be extended to engine imbalance.

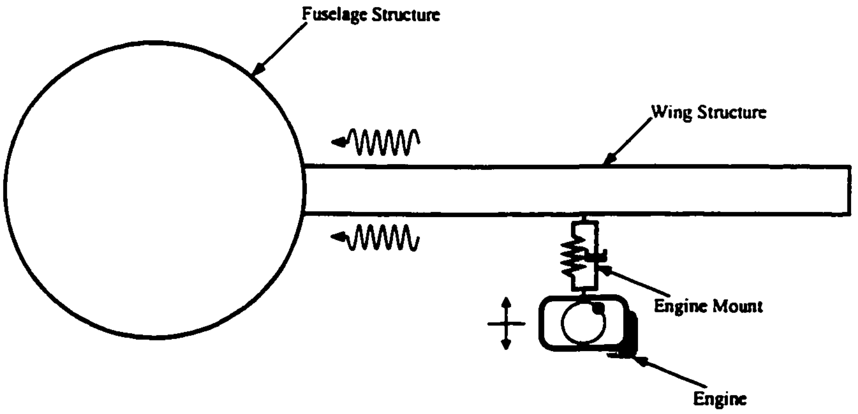


Figure 3.1 Sketch of representing mechanical model of an airplane wing and engine

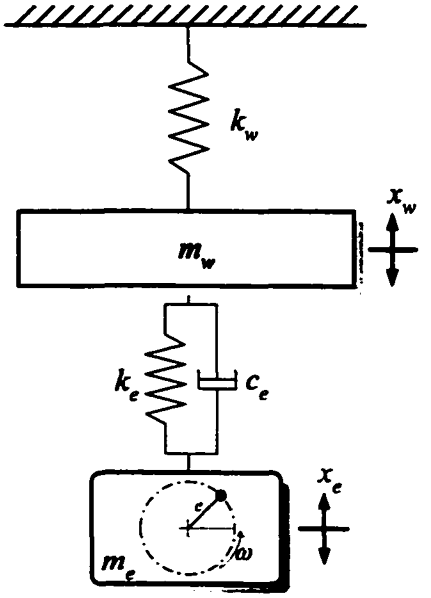


Figure 3.2 Linear 2 DOF model representation of turboprop mounted to a wing

In order to investigate the frequency response, and develop an optimization procedure based on the frequency response, a harmonic excitation, $f_w=F_w \exp(i\omega t)$ is assumed, and a periodic solution in the form, $x_e=X_e \exp(i\omega t)$, and, $x_w=X_w \exp(i\omega t)$, is sought where F_w, X_e, and X_w are complex amplitudes.

The following dimensionless characteristics are introduced:

$$\omega_w=\sqrt{\frac{k_w}{m_w}} \quad \omega_e=\sqrt{\frac{k_e}{m_e}} \quad r=\frac{\omega}{\omega_e} \quad \alpha=\frac{\omega_e}{\omega_w} \quad \varepsilon=\frac{m_e}{m_w} \quad \xi_e=\frac{c_e}{2\cdot\omega_e\cdot m_e} \tag{3.2}$$

and after some manipulations, the transmissibilities, $\mu=X_e/\left(F\omega_w^4 m_w^2\right)$, $\tau=X_w/\left(F\omega_w^4 m_w^2\right)$ and $\eta=\left(X_e\text{-}X_w\right)/\left(F\omega_w^4 m_w^2\right)$ are obtained, respectively,

$$\mu^2=\frac{4\xi_e^2 r^2+1}{\left[r^2\left(r^2\alpha^2-1\right)+\left(1-\left(1+\varepsilon\right)r^2\alpha^2\right)\right]^2+4\xi_e^2 r^2\left(1-\left(1+\varepsilon\right)r^2\alpha^2\right)^2} \tag{3.3}$$

$$\tau^2 = \frac{4\xi_e^2 r^2 + 1 + r^2\left(r^2 - 2\right)}{\left[r^2\left(r^2\alpha^2 - 1\right) + \left(1 - (1+\varepsilon) r^2\alpha^2\right)\right]^2 + 4\xi_e^2 r^2\left(1 - (1+\varepsilon) r^2\alpha^2\right)^2} \tag{3.4}$$

$$\eta^2 = \frac{r^4}{\left[r^2\left(r^2\alpha^2 - 1\right) + \left(1 - (1+\varepsilon) r^2\alpha^2\right)\right]^2 + 4\xi_e^2 r^2\left(1 - (1+\varepsilon) r^2\alpha^2\right)^2}. \tag{3.5}$$

Equations (3.3) to (3.5) show that the transmissibility μ, τ, and η are functions of four essential variables: mass ratio ε, damping ratio ξ, natural frequency ratio α, and excitation frequency ratio r. The frequency ratios, α, and, r, only appear in even powers only. Transforming the system parameters to a nondimensional form frees the analysis from the need to use actual physical values.

3.4 Optimization Procedure

In this section the optimization method is defined and the equations for the RMS of the absolute acceleration and relative displacement are calculated in order to use them in the optimization condition. The optimal vibration isolation in the frequency domain should be formulated as a minimization of a suitable cost function, J. There is no unique method for selecting the proper cost function for vibration isolation purposes. Choosing the proper cost function depends, however, on the design objectives. A variety of different cost functions are suggested and applied on a given frequency range, $\bar{\omega} = [\omega_1, \omega_2]$. Usually, as a first try, the cost function is chosen as the amplitude of frequency response,

$$J = \mu(\bar{\omega}) \qquad \bar{\omega} \in [\omega_1, \omega_2]. \tag{3.6}$$

The cost function may include any state variable (such as the absolute acceleration), which is related to the design parameters ξ and α. Similarly, the constraint on the relative displacement implies a relationship (an inequality) with the design parameters, by applying the equation of motion and kinematics conditions. Other constraints may involve the explicit design parameters as prescribed by the upper and lower bounds on ξ and α. The problem is even more complex if an overall consideration of the system such as weight, cost, maintainability, and reliability is included.

A second possibility of measuring the magnitude of amplitudes over a frequency range, $\bar{\omega} = \left[\omega_1, \omega_2\right]$, is rendered by the linear amplitude frequency response integrals,

$$J = \sum w_i \int_{\omega_1}^{\omega_2} A_i(\omega)d\omega \qquad i = 1,2,\cdots,n. \tag{3.7}$$

As a third cost functional, the squared amplitude frequency response integral

$$J = \sum w_i \int_{\omega_1}^{\omega_2} A_i^2(\omega)d\omega, \tag{3.8}$$

can be used.

For the system depicted in Figure 2.1, it is generally desirable to select ξ_e and α such that the absolute acceleration (or the relative displacement) of the engine is minimized on a specific frequency range, and the relative displacement (or the absolute acceleration) does not exceed a prescribed level. An obvious solution is to use a search method and set up a matrix of the admissible values of ξ_e and α, and solve the equations of motion of the system to determine the cost function value. The associated pair of (ξ_e, α) for the minimum value of the cost function are the optimal values.

The most important defined optimization methods applicable to our system are as follow [40]:

- Minimax Absolute Acceleration for Specified Relative Displacement,

$$\frac{\partial\mu}{\partial\omega_e} = 0 \quad \frac{\partial\mu}{\partial\xi_e} = 0 \quad \eta = \eta_0. \tag{3.9}$$

- Minimax Relative Displacement for Specified Absolute Acceleration,

$$\frac{\partial \eta}{\partial \omega_e}=0 \quad \frac{\partial \eta}{\partial \xi_e}=0 \quad \mu=\mu_0. \tag{3.10}$$

- **Minimum Sum of Maximum Absolute Acceleration,**

$$\frac{\partial f}{\partial \omega_e}=0 \quad \frac{\partial f}{\partial \xi_e}=0. \tag{3.11}$$

where

$$f=\int \mu_m d\omega_e+\int \mu_p d\xi_e, \tag{3.12}$$

and

$$\mu_m = \textit{Maximum of } \mu \textit{ with respect to } \omega_e$$
$$\mu_p = \textit{Maximum of } \mu \textit{ with respect to } \xi_e.$$

- **Minimum Sum of Maximum Absolute Acceleration and Maximum Relative Displacement.**

$$\frac{\partial f}{\partial \omega_e}=0 \quad \frac{\partial f}{\partial \xi_e}=0, \tag{3.13}$$

where

$$f=\int \mu_m d\omega_e+\int \mu_p d\xi_e+\int \eta_m d\omega_e+\int \eta_p d\xi_e, \tag{3.14}$$

and

$$\mu_m = \textit{Maximum of } \mu \textit{ with respect to } \omega_e$$
$$\mu_p = \textit{Maximum of } \mu \textit{ with respect to } \xi_e$$
$$\eta_m = \textit{Maximum of } \eta \textit{ with respect to } \omega_e$$
$$\eta_p = \textit{Maximum of } \eta \textit{ with respect to } \xi_e.$$

Sometimes, engineers claim that the following cost function is a suitable cost function to optimize suspension:

$$J = \eta^2 + wu^2 \tag{3.15}$$

where u is the absolute acceleration of the engine,

$$u = \frac{\ddot{X}_e}{\omega_w^2 F} = r^2 \alpha^2 \mu . \tag{3.16}$$

Similarly, the acceleration of the wing is defined as follows:

$$v = \frac{\ddot{X}_w}{\omega_w^2 F_w} = r^2 \alpha^2 \tau . \tag{3.17}$$

The weighting factor, w, is a design tuning parameter such that a larger w will result in a smaller relative displacement and larger absolute acceleration weight.

In this thesis, a Root Mean Square (RMS) based optimization criterion is defined, and use it to optimize the suspension system. The RMS is used as the frequency averaged value. The RMS of any function such as

$$g = g(\alpha, \xi, \varepsilon) \tag{3.18}$$

is

$$RMS(g) = \sqrt{\frac{1}{\omega_f - \omega_i} \int_{\omega_i}^{\omega_f} g^2(\alpha, \xi, \varepsilon) d\omega} . \tag{3.19}$$

Probably, the RMS acceleration and the RMS displacement are the simplest and most effective measures that are representative of the vibration transmission. They have traditionally been used to obtain the suspension optimum parameter values. They may both be used as cost or objective functions to optimize the suspension performance, with respect to the design variables, ξ_e, and α. The optimization criterion is

- Minimum RMS of Absolute Acceleration, *U*,

$$U = \sqrt{\frac{1}{r_2 - r_1} \int_{r_1}^{r_2} u^2 dr} \,, \tag{3.20}$$

with respect to RMS of Relative Displacement, Φ,

$$\Phi = \sqrt{\frac{1}{r_2 - r_1} \int_{r_1}^{r_2} \eta^2 dr} \,. \tag{3.21}$$

Mathematically, it is equivalent to the following constrained minimization:

$$\frac{\partial U}{\partial \Phi} = 0 \qquad \frac{\partial^2 U}{\partial \Phi^2} > 0 \,. \tag{3.22}$$

There is a tradeoff between the acceleration and the relative motion of the mounting system as illustrated in Figure 3.3. The ratio of *U* to Φ is a monotonically increasing function of α, and ξ_e. It shows that keeping *U* constant, Φ is a decreasing function of α and ξ_e, and keeping Φ constant, *U* is an increasing function of α and ξ_e. There is no minimum and maximum point. Therefore, if there is no constraint, the optimum design is the trivial solution of α=0 and ξ_e =0. Otherwise, the optimum design lies on the boundary of the constraint domains. The method, introduced in this thesis, avoids such a problem.

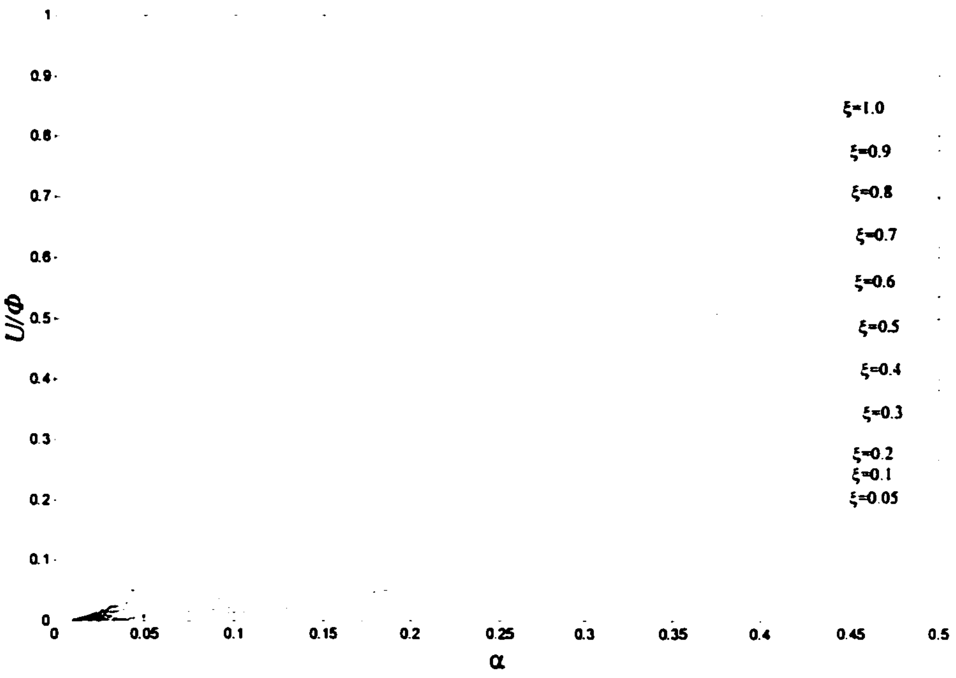


Figure 3.3 Tradeoff between the RMS of engine absolute acceleration and the RMS of the relative displacement

For a real problem, the values of mass ratio ε, and wing stiffness ω_w, are fixed, and the challenge is to find the optimum values of α and ξ_e. The parameters α, and ξ_e, include the unknown stiffness of the main mounting system and the unknown damping coefficient, respectively. The above optimization procedure is implemented numerically by calculating U and Φ. The frequency ratio is taken to be $r = [0, 10]$, and the mass ratio is $\varepsilon = 0.3$. Each of equation (3.20) and (3.21) is numerically integrated for various values of α and ξ_e. The RMS acceleration U is then defined as a function of the

RMS relative displacement Φ, by using α and ξ_e as parameters. A plot of the absolute acceleration against the relative displacement for the different design parameter pair (α,ξ_e), results in a four dimensional surface. Figure 3.4 plots the contour curve of α and ξ_e in the *U*-Φ plane. It appears that the function, $U=U(\Phi)$, has a minimum for constant α. The points of minima introduce an optimal curve on the *U*-Φ plane that may be used for the optimization of the linear mounting system. The line of minima satisfies the optimality condition (3.22). Each point of the line of minima introduces a specific suspension with as minimum as possible acceleration for a specific value of the relative displacement. On the line of minima, the sensitivity of the acceleration with respect to relative displacement is minimum at any point of the optimal curve.

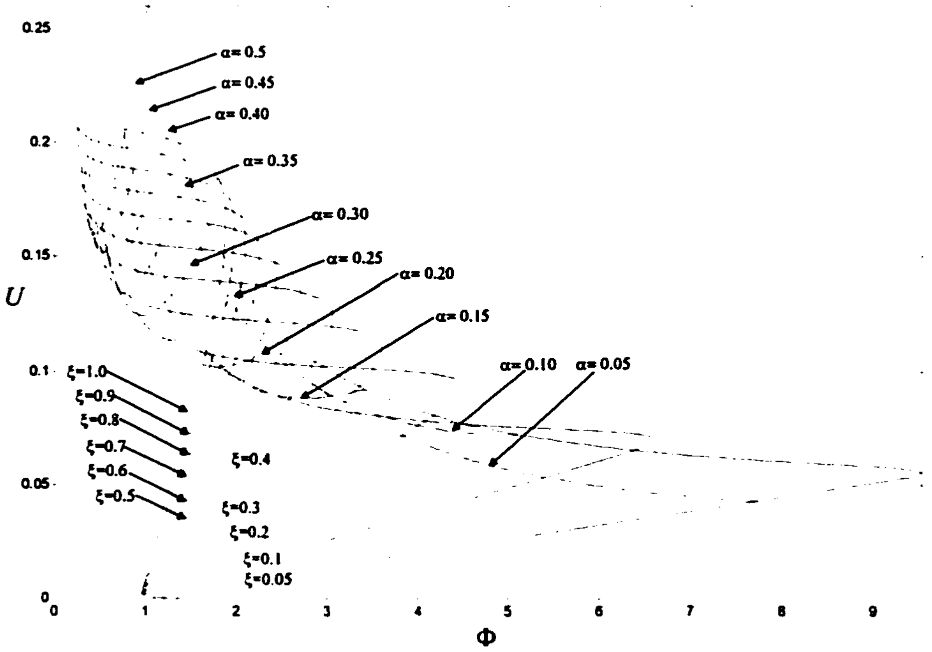


Figure 3.4 Contour curves for the function $U=U(\Phi)$

Figure 3.5 provides a better view of the optimal curve indicating the relationship between U and Φ. The line of minima indicates that at optimum conditions, increasing the damping ratio is followed by an increase in the natural frequency ratio.

Now, if the limit value of the relative displacement (or acceleration) is known, then the intersection of the corresponding vertical (horizontal) line with the line of optima indicates the optimum value of ξ_c, α, and the corresponding level of the acceleration (relative displacement). A desired value for the relative displacement RMS (or the absolute acceleration RMS) is selected, and the associated values for ξ_e and α are found from the intersection of the associated vertical (horizontal) line with the optimal curve.

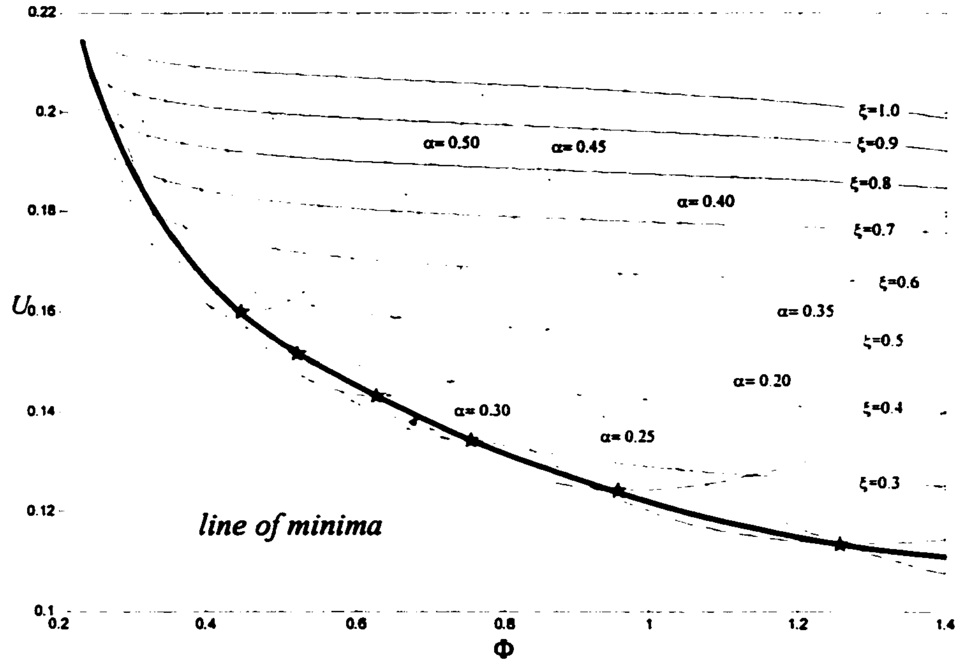


Figure 3.5 Contour curves and line of minima in the U-Φ plane

3.5 Numerical Simulation

The optimization results may be verified through a numerical simulation by examining the frequency response behavior of the system for the optimal parameters. The analysis of the frequency responses is a good measure for comparing the suspension parameters in order to find the effect of the RMS optimized parameters on the frequency responses. Then, a harmonic excitation is applied to the wing, and the frequency responses of the system are depicted. It is noteworthy that the results based on the RMS optimization analysis are equivalent, with the, the variance optimization, to a white noise random excitation with a zero mean value. Therefore, suspensions on the line of minima have an optimal behavior in the random domain also.

In the analysis of the behavior of the system for a three different cases indicated in Figure 3.6. Point 1 is a randomly picked point on the *U*-Φ Plane; points 2 and 3 are two alternative points on the line of minima. The relative displacement RMS of the points 1 and 3 are equal. Also the absolute acceleration RMS of points 1 and 2 are the same. Therefore, points 1 and 3 may show a soft suspension and point 2 may indicate a stiff suspension. According to the optimal prediction, the behavior of the suspension at point 1 is supposed to be worse than at points 2 and 3.

The dynamical parameters of the system for the three points are collected in Table 3-1. In Figure 3.7 and Figure 3.8, the absolute acceleration frequency response u, and the relative displacement frequency response η are compared. Also in Figure 3.9, the frequency responses of the absolute displacement μ are depicted.

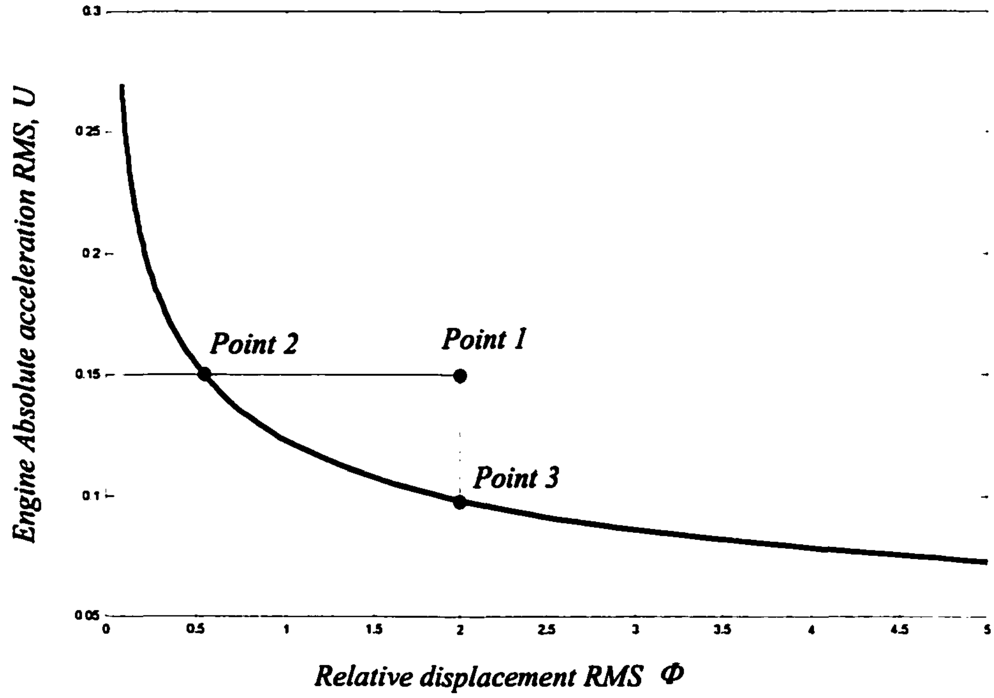


Figure 3.6 Three compared suspensions

Table 3-1 Numerical values of dynamical parameters for three different suspensions

	U	Φ	α	ξ
Point 1	0.15	2	0.265	0.0465
Point 2	0.15	0.543	0.45	0.23
Point 3	0.0982	2	0.1858	0.0949

Figure 3.7 shows that the acceleration of the engine for point 1 is the worst in the high frequencies. The relative displacement of the system for point 2, in Figure 3.8, is better than the others, as expected by the RMS prediction in Figure 3.6. Although the allowed relative displacement RMS for point 1 and 2 are equal, the relative displacement frequency response for point 1 is much higher than point 2 at high frequencies. The absolute displacement frequency response shown in Figure 3.9 has the same behavior as the relative displacement frequency response.

In order to compare the optimal design in the other domain, it is reasonable to study the transient and random wing excitations. Figure 3.10 shows the response to a unit step input at the wing. It is obvious that the response for points 2 and 3 are better than for point 1. Figure 3.11 depicts the power spectral density for the absolute displacement of the engine. The response is obtained for a unit white noise input. The results appear similar to the frequency response plot, as expected for the white noise inputs.

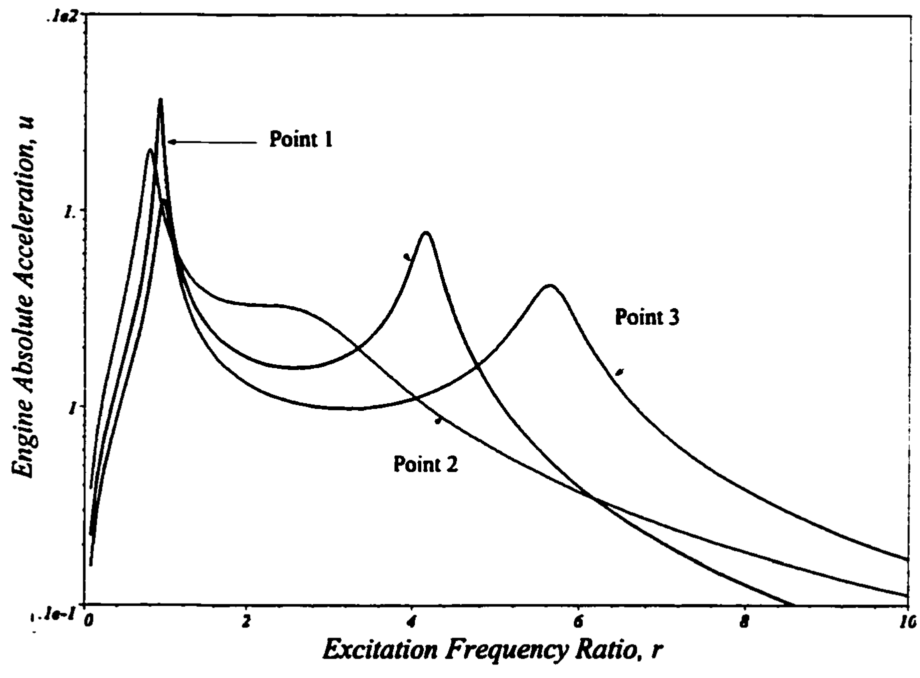


Figure 3.7 Absolute acceleration frequency response u; comparison of three suspensions

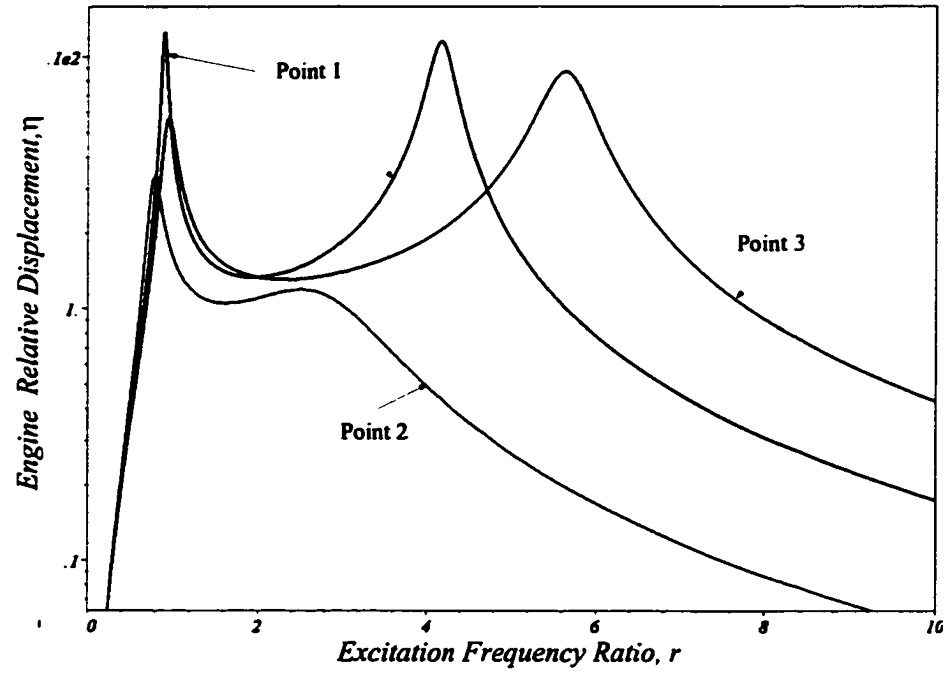


Figure 3.8 Relative displacement frequency response η; comparison of three suspensions

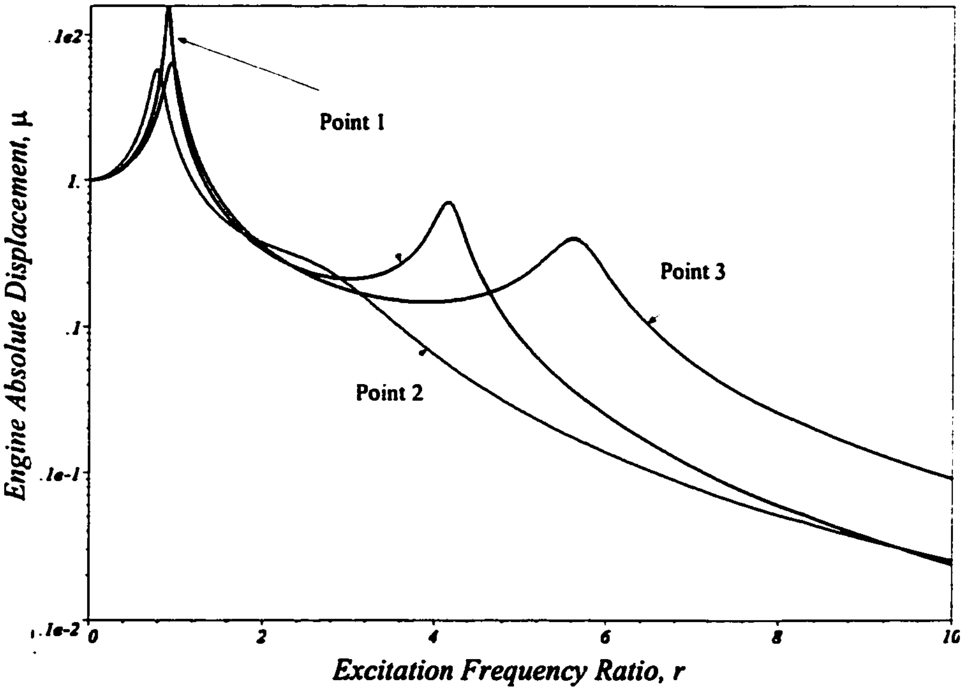


Figure 3.9 Absolute displacement frequency response μ; comparison of three suspensions

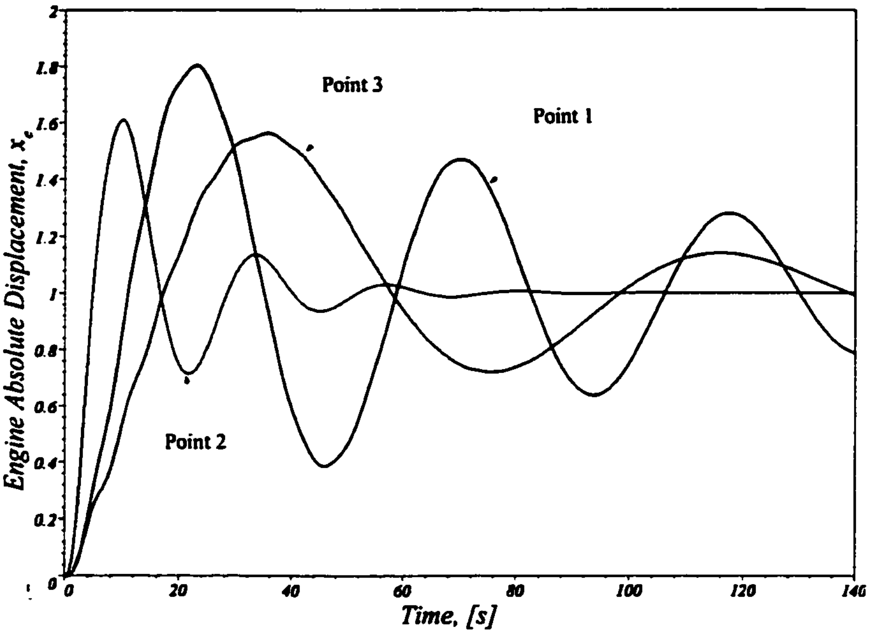


Figure 3.10 Time response to a unit step input; comparison of three suspensions

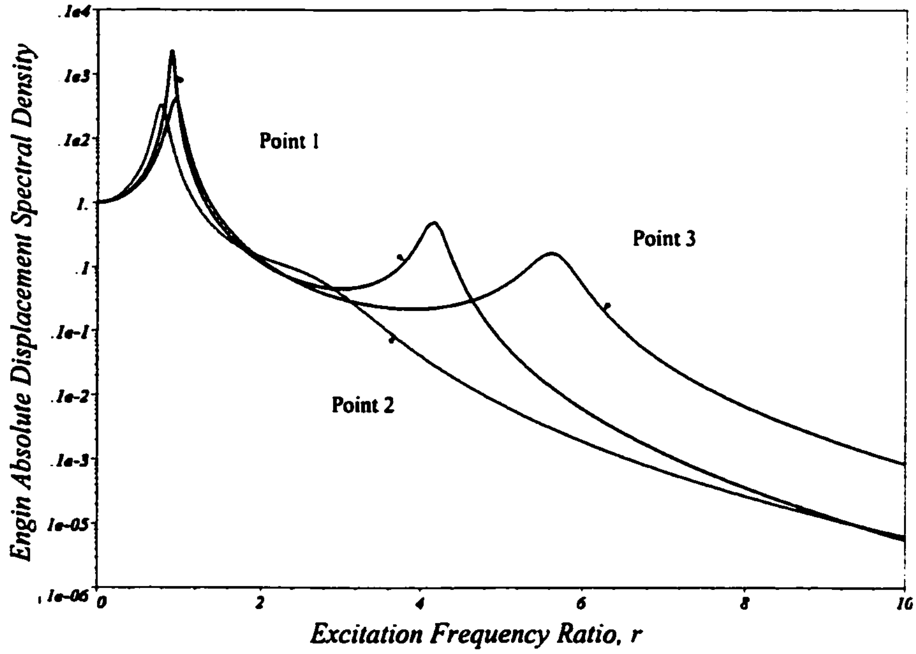


Figure 3.11 Absolute displacement spectral density for a unity white noise excitation; comparison of three suspensions

Chapter 4

Passive Vibration Isolation of The Engine Using a Genetic Algorithm

4.1 Introduction

In this chapter, the Genetic Algorithm (GA) is introduced and applied to optimize the problem described in the previous chapter. First, the GA is developed for a linear one degree of freedom vibration isolator mount, and then extended to the system presented in Chapter 3. The criterion for the optimal suspension is specified and used to develop a cost function that seeks to minimize the absolute acceleration RMS sensitivity to changes in the relative displacement RMS. The use of the GA assures high probability of locating the global optimum solution. The implementation of the optimization procedure on the model renders design charts, which allow designers to choose the mount stiffness and damping coefficient, given the RMS of the relative displacement.

4.2 Vibration Isolation

In the simplest approach to the problem of estimating the effectiveness of a vibration mount researchers assume that the engine or equipment to be isolated is a rigid mass *m*, and the mount is a massless, mechanically paralleled spring and damper of stiffness *k*, and resistance *c* (Figure 4.1).

The equations that govern the linear model of an isolator with a harmonic excitation, and the relevant transfer functions of the proposed linear model may be found in mechanical vibration texts, e.g. [23]. The nondimensionalized equation of motion for the system is

$$\ddot{x} + 2\xi\omega_n\dot{x} + \omega_n^2 x = e\omega^2\, sin(\omega t) \qquad (4.1)$$

where the parameters of equation (4.1) are related to the physical parameters of the system by

$$\xi = \frac{c}{c_c} \qquad \omega_n = \sqrt{\frac{k}{m}} = 2\pi f_n \qquad c_c = 2m\omega_n . \tag{4.2}$$

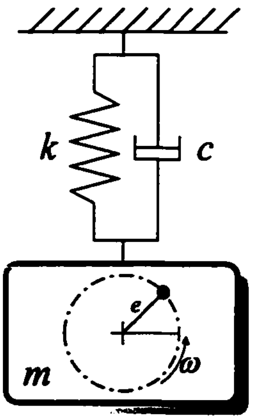


Figure 4.1 Simple linear model of an engine and mount

The most important transfer functions for the system are: displacement λ, and acceleration *a*, which are defined as follows:

$$\lambda = \left|\frac{X}{e}\right| = \frac{\left(\frac{\omega}{\omega_n}\right)^2}{\sqrt{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2 + \left(2\xi\frac{\omega}{\omega_n}\right)^2}} \tag{4.3}$$

and

$$a = \left|\frac{\ddot{X}}{e}\right| = \frac{\omega^2\sqrt{1+\left(2\xi\frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2 + \left(2\xi\frac{\omega}{\omega_n}\right)^2}} . \tag{4.4}$$

Figure 4.2 and Figure 4.3 depict the variation of the system displacement amplitude transmissibility, and the acceleration amplitude transmissibility versus the frequency ratio.

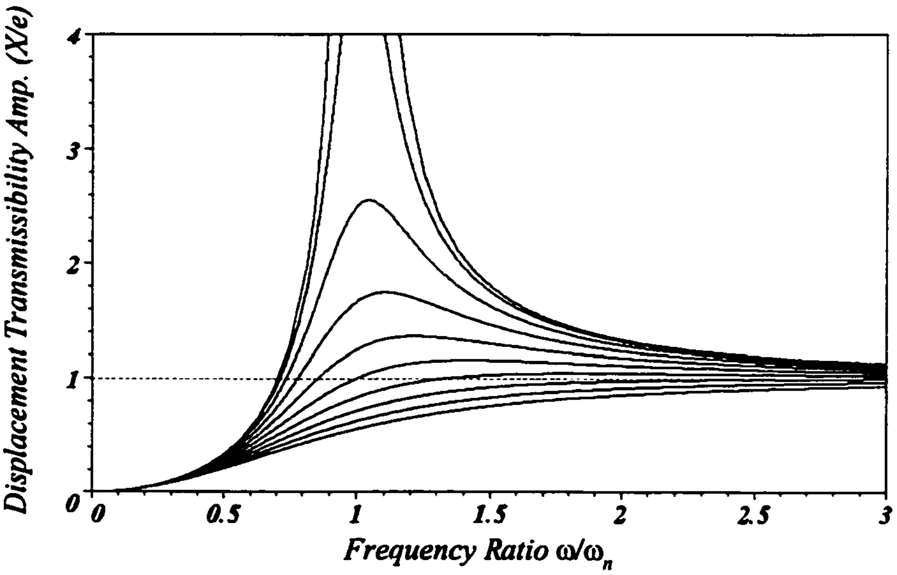


Figure 4.2 Displacement transmissibility versus frequency ratio

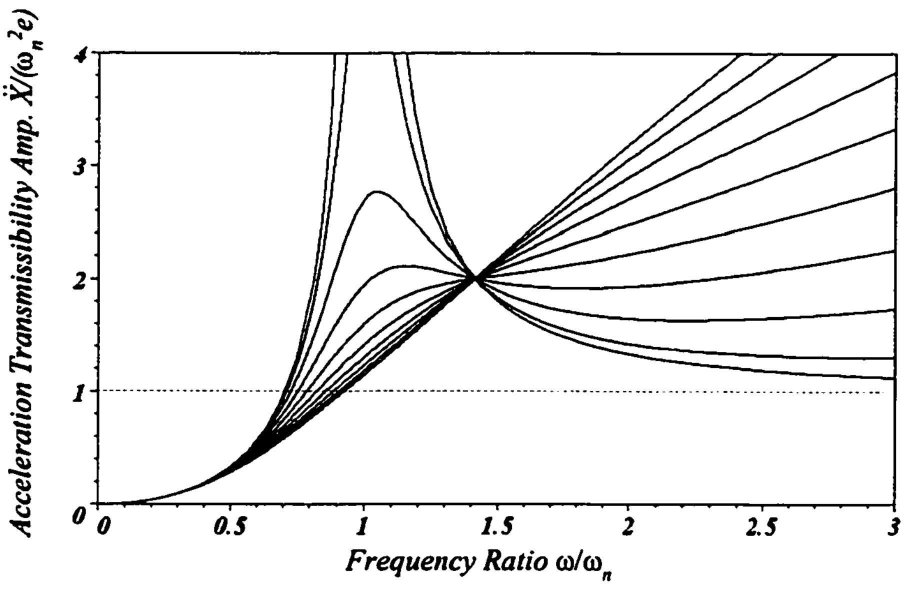


Figure 4.3 Acceleration transmissibility versus frequency ratio

4.3 Optimization Problem

For the system shown in Figure 4.1, it is generally desired to select ξ and ω_n such that the acceleration (or displacement) of the system is minimized, and the displacement (or the acceleration) does not exceed a prescribed level.

The Root Mean Square (RMS) is used as the average, and [0, 20] Hz as the frequency domain. The RMS of the acceleration and the RMS of the displacement are defined by the following functions:

$$R = \sqrt{\frac{1}{40\pi} \int_0^{40\pi} a^2 d\omega} \tag{4.5}$$

and

$$\eta = \sqrt{\frac{1}{40\pi} \int_0^{40\pi} \lambda^2 d\omega} \ . \tag{4.6}$$

There is a tradeoff between the acceleration and displacement. Figure 4.4 illustrates this tradeoff. The ratio of the RMS of the acceleration to the RMS of the displacement is a monotonically increasing function of ω_n and ξ. It shows that if the displacement RMS is constant, then the acceleration RMS increases with an increase in ω_n or ξ. Also if the acceleration RMS is kept constant, then the displacement RMS decreases with an increase in ω_n or ξ. Hence, both the acceleration and displacement cannot be minimized at the same time. In other words, decreasing the acceleration necessarily increases the displacement and vice versa. Therefore, if there is no constraint, the optimum design is the trivial solution of $\omega_n=0$ and $\xi=0$.

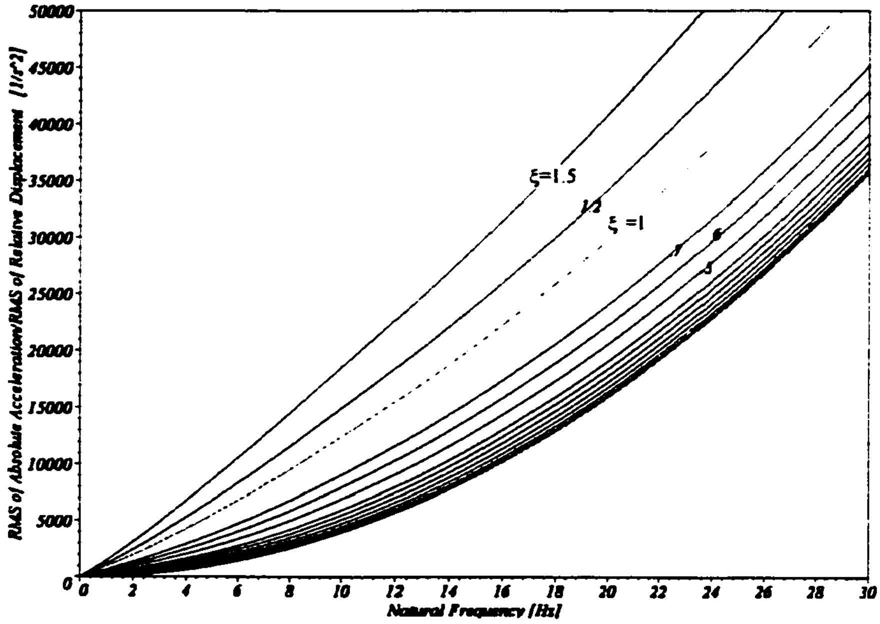


Figure 4.4 The tradeoff between the RMS of the acceleration and the RMS of the displacement

As a result of the design specifications introduced, a general design optimization statement for a mount system can now be given. It is noteworthy that the RMS of the acceleration R, and the RMS of the displacement η, are functions of the two variables ω_n and ξ, as indicated in Equations (4.3) through (4.6)

The appropriate optimization criterion, used in the optimization method can be defined as

> ***Optimization Criterion:*** *the Minimum RMS of Acceleration with respect to the RMS of Displacement for a given value of RMS of Displacement.*

The result of this optimization criterion is an optimal curve on the R-η plane. If a desired value for the allowable displacement is selected, the associated values for ξ and ω_n are found such that the above statement is true.

4.4 Genetic Algorithm Optimization Procedure

Section 4.4 gives a complete and concise description of the implementation of the GA to the optimization of a linear mount system. The GA is a subset of evolutionary algorithms that model and mimic biological processes to find the optimal solutions to highly complex problems. The GA draws an analogy to the natural process of reproduction, natural selection and evolution in the biological population, where genetic characteristics, stored in chromosomal strings, evolves over generations to give individuals better chance of survivability in a static or changing environment. This chromosomal configuration represents the generational memory, and is partially transferred and altered when members of the population reproduced [70].

The three basic processes that affect the chromosomal makeup in natural evolution are the crossover of genetic information between the reproduction parents, an occasional mutation of the genetic information, and the survival of the fittest to reproduce the upcoming generations. The crossover process exchanges genetic structures between the parents, and allows for the beneficial genes to be represented in the offspring. Mutation is a sudden and infrequent alternation in the chromosomal makeup, which causes new traits to surface in individuals. Individuals with favorable qualities have a better chance to adapt and survive, and therefore procreate.

The Genetic Algorithm which, in a fashion, is analogous to the natural counterpart, uses chromosome-type representations of the feasible solutions of the problem to explore the searching space for improved solutions. The Genetic Algorithm incorporates a bias reproduction strategy, where members of the population that are deemed the most fit are preferred for reproduction, and given greater opportunity to strengthen the chromosomal composition of the offspring generation. This approach is implemented by assigning a fitness value or scale that indicates the goodness of an individual of the population in a given generation during the evolution process. The objective function serves as an excellent candidate in measuring an individual's fitness.

The major components of GA include an encoding scheme, fitness evaluation, parents selection, crossover operators, and mutation operators; these are briefly explained next in the context of the mount optimization.

4.4.1 Principle of Encoding Scheme

The first step is to transform points in the parameter space into bit string representations. By converting each parameter into its binary equivalent, it is mapped into a fixed-length string of 0s and 1s (*gene*). Clearly, the string (*gene*) length determines the numerical precision with which this parameter is represented. For the problem in this thesis, it is decided to represent each variable, x_i, by 16-digit binary number with maximum and minimum values of the design variable mapped to the maximum and minimum of the binary number as follows:

$$x_{i\,\min} = 0000000000000000$$

$$x_{i\,\max} = 1111111111111111$$

Two such binary numbers are needed for the mount optimization problem to represent the damping ratio and the natural frequency $(x_1, x_2) = (\xi, \omega_n)$ with a domain of possible values limited to $0<\xi<1.5$ and $0<\omega_n<100$ *rad/sec*. The two genes are then placed end to end to create a 32-digit string concatenated binary string *chromosome* of 0s and 1s

$$chromosome = \left[\underbrace{1010111\cdots}_{gene_1=\xi}\underbrace{0011101\cdots}_{gene_2=\omega_n}\right] \tag{4.7}$$

This 32-digit string represents one design of the mount, and so there are 2^{16} possibilities for each variable and 2^{32} possible designs. A sequence of such strings can be introduced to construct a population of designs. An initial population of 100 designs is randomly generated.

4.4.2 Cost Function and Fitness Evaluation

The GA uses selection, crossover, and mutation operators to breed good solutions. The "goodness" of the solution is measured by the so-called "fitness function." The fitness function is based on the objective function of the problem and must be nonnegative [71]. The fitness must be evaluated for each design in every generation. In order to proceed with the GA, a cost function must be defined which embodies the optimization criterion defined in the section 4.3. For a given value of the RMS of the absolute displacement η_g, the optimization criterion is expressed mathematically as

$$\left.\frac{\partial R}{\partial \eta}\right|_{\eta_g} = 0 \quad , \quad \left.\frac{\partial^2 R}{\partial \eta^2}\right|_{\eta_g} > 0 \tag{4.8}$$

If R is assumed to be parabolic in terms η, the problem is reduced to finding a parabola which has minimum at η_g.

Assume that $\left(\xi_j,\ \omega_{n_j}\right)$ is the jth individual in any generation. Based on $\left(\xi_j,\ \omega_{n_j}\right)$, two more points $\left(\xi_i,\ \omega_{n_i}\right)$ and $\left(\xi_k,\ \omega_{n_k}\right)$, are defined where

$$\xi_i = \xi_j - e \qquad \omega_{n_i} = \omega_{n_j} \qquad \xi_k = \xi_j + e \qquad \omega_{n_k} = \omega_{n_j} \qquad e \ll 1. \tag{4.9}$$

The RMS of the displacement for the three points $\left(\xi_i,\ \omega_{n_i}\right)$, $\left(\xi_j,\ \omega_{n_j}\right)$, and $\left(\xi_k,\ \omega_{n_k}\right)$ are η_i, η_j, and η_k respectively, whereas the RMS of the acceleration are R_i, R_j, and R_k respectively. The equation of a parabola passing through the three points

$$R = A\eta^2 + B\eta + C \tag{4.10}$$

where

$$\begin{aligned} A &= -\frac{R_i(\eta_j - \eta_k) + R_j(\eta_k - \eta_i) + R_k(\eta_i - \eta_j)}{-\eta_i^2(\eta_j - \eta_k) - \eta_j^2(\eta_k - \eta_i) - \eta_j^2(\eta_k - \eta_i)} \\ B &= -\frac{R_i(\eta_j^2 - \eta_k^2) + R_j(\eta_k^2 - \eta_i^2) + R_k(\eta_i^2 - \eta_j^2)}{-\eta_i^2(\eta_j - \eta_k) - \eta_j^2(\eta_k - \eta_i) - \eta_j^2(\eta_k - \eta_i)} \\ C &= \frac{-R_i\eta_j\eta_k(\eta_j - \eta_k) + R_j\eta_k\eta_i(\eta_k - \eta_i) + R_k\eta_i\eta_j(\eta_i - \eta_j)}{-\eta_i^2(\eta_j - \eta_k) - \eta_j^2(\eta_k - \eta_i) - \eta_j^2(\eta_k - \eta_i)}. \end{aligned} \tag{4.11}$$

The minimum of the parabola occurs at

$$\eta_m = -\frac{1}{2}\frac{R_i(\eta_j^2 - \eta_k^2) + R_j(\eta_k^2 - \eta_i^2) + R_k(\eta_i^2 - \eta_j^2)}{R_i(\eta_j - \eta_k) + R_j(\eta_k - \eta_i) + R_k(\eta_i - \eta_j)}. \tag{4.12}$$

Now the cost function which forces η_j, and η_m to coincide with η_g, is defined as

$$J_j = (\eta_j - \eta_m)^2 + (\eta_m - \eta_g)^2 + (\eta_g - \eta_j)^2, \tag{4.13}$$

along with the following conditions:

$$R_j > R_i \quad , \quad R_j < R_k. \tag{4.14}$$

4.4.3 Selection

After the evaluation of the fineness of each member of the current population, a selection process for individuals to participate in the creation of next generation is in order. The selection should be biased toward individuals with a higher fitness value analogous to the survival of the fittest in the natural selection. The selection for reproduction among members of a higher fitness ensures moving the search toward producing more fit members in the population and eliminating the less fit ones. First, the population is ranked according to the fitness of the individuals. A mating pool, consisting of 50%

of the population with individuals with the highest fitness is created. Members are selected from the mating pool and paired (i.e., {parent1, parent2}) with selection probability proportional to their fitness value. If J_r is the fitness measure of the r^{th} member, it can be allotted a probability of $J_r \Big/ \sum_{j=1}^{n} J_j$ where n is the population size. Self-pairing is not permitted. The paired individuals are used to create new individuals through crossover operators to replace the discarded ones.

4.4.4 Crossover

The crossover is the exchange of design characteristics among randomly selected pairs from the parent pool. There are many types of crossovers; the most general one (i.e., uniform crossover) is briefly introduced here and implemented for the mount optimization. The uniform crossover looks at each bit in the parents and randomly assigns the bit from one parent to one offspring, and the bit from the other parent to the other offspring. First, a random mask is generated. This mask is a random vector of ones and zeros, and is the same length as the parents. When the bit in the mask is 0, then the corresponding bit in *parent₁* is passed to *offspring₁* and the corresponding bit in *parent₂* is passed to *offspring₂*. When the bit in the mask is 1, then the corresponding bit in *parent₁* is passed to *offspring₂* and the corresponding bit in *parent₂* is passed to *offspring₁*:

Parent_1	**01001101101011100001010101110111**
Parent_2	11000110110110111111010011001001
Mask	00011010001111001101101000101111
Offspring_1	01000111100110101101010101011001
Offspring_2	11001100111011110011010011100111

4.4.5 Mutation

This step diversifies the population so that different areas of the parameters space can be explored. Mutation also prevents the solution from premature convergence. A mutation operator is capable of spontaneously generating new chromosomes. The most common way of implementing mutation is by switching a 0 with a 1 or vice-versa, with a probability equal to a very low given mutation rate. The mutation rate is taken to be 10% of the total number of binary digits in the whole population in the case of this study. The population passed from one generation to the other remains the same size. A complete iteration or new generation of designs is formed after completion all of the above steps.

4.5 Application of Genetic Algorithms

The GA is applied, and the optimal design charts for the linear engine mount are obtained by running the GA for a hundred points of given allowable displacement RMS in the range $0.22 \leq \eta_g \leq 1.35$. For each point, the algorithm stops after a fixed number of iterations set to be 500 iterations. The result yields the optimal values of the damping ratio, and the natural frequency corresponding to each given allowable displacement RMS.

Figure 4.5 depicts the connected optimal points in plane $RMS(\ddot{x})-RMS(x)$ that satisfies the optimality condition (4.8). The optimal line starts from a point between *1.4* and *1.5* on the $RMS(x)$ axis showing a soft mount (low stiffness and damping), and ends at a point close to ($7000\ s^{-2}$) on $RMS(\ddot{x})$ axis showing a hard mount (rigid connection). Point (*1, 0*) indicates a no connection condition between the mass and the base. The optimal line shows that if an optimality condition (4.8), is used, a way around the point (*1, 0*), which the other optimal conditions converge to, can be found. Reducing the working space requires increasing the acceleration along with using a more stiff mount and more damped. The level of R changes very little for $0<\eta<1$, but it changes faster for $\eta>1$. In other words, at high natural frequencies, the optimum RMS acceleration becomes insensitive to the value of the damping ratio.

Figure 4.6 plots the natural frequency and damping ratio versus the *RMS(x)*. If the limit value of the RMS of the displacement is known, then the intersection of the corresponding vertical line in Figure 4.6 with the optimum parameter curve indicates the optimum value of ξ, ω_n. The graphical illustration of the relationship between the natural frequency and the damping ratio on the optimal line is shown in Figure 4.7. At optimum conditions, the increase in the damping ratio results in an increase in the natural frequency, and vise versa. The natural frequency shows a saturating level. Increasing the damping ratio more than 0.6 does not affect the value of optimal natural frequency. The level of acceleration for the optimum mount always lies below the level of acceleration for a hard mount, which is desirable.

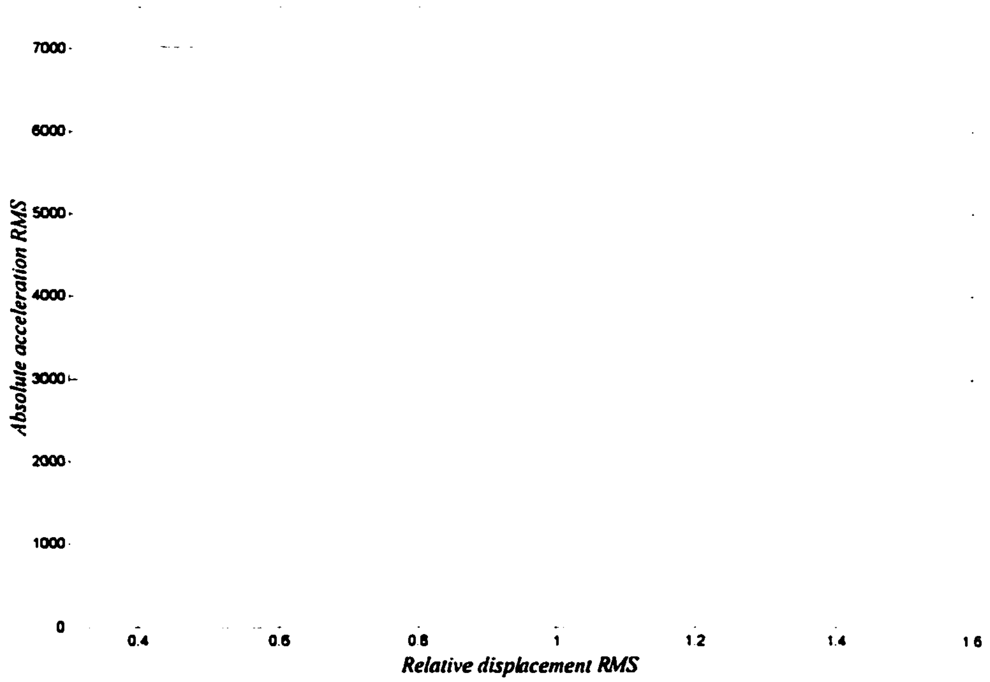


Figure 4.5 Optimal curve in $RMS(\ddot{x}) - RMS(x)$ plane

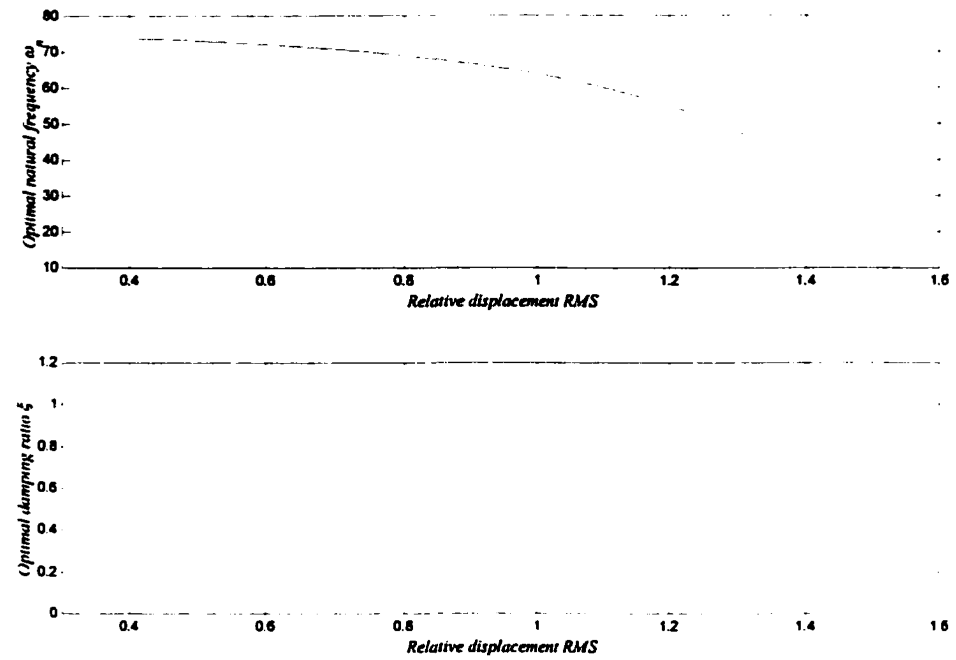


Figure 4.6 Optimal curve in $\omega_n - RMS(x_r)$ and $\xi - RMS(x_r)$ planes

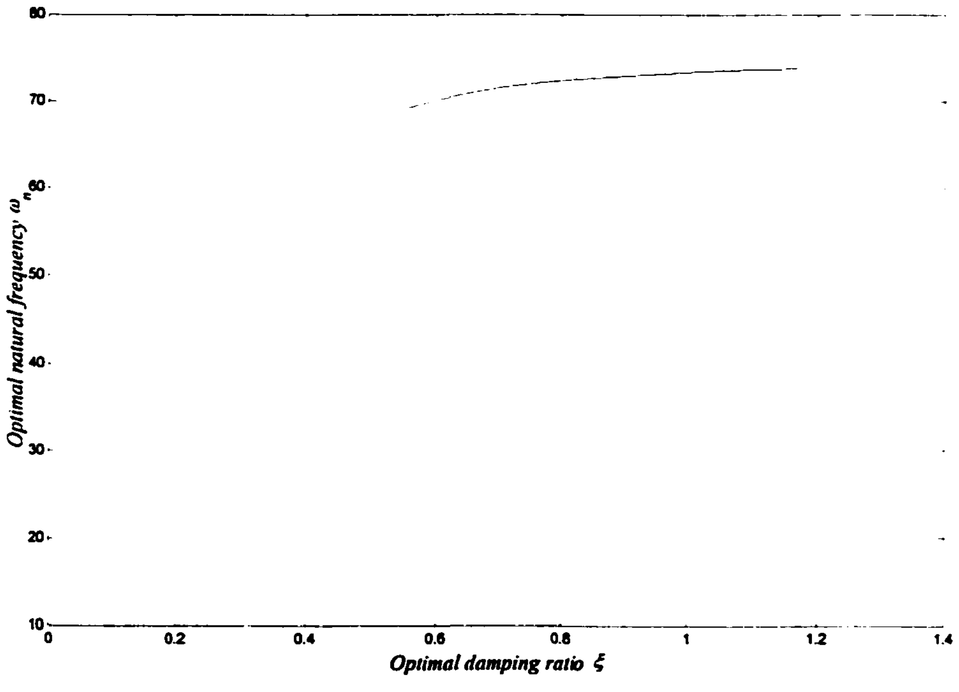


Figure 4.7 Optimal curve in plane $\xi - \omega_n$

Now the GA is applied to the model developed in Chapter 3. A similar optimization criterion is defined. The optimal damping ratio and stiffness values for the main suspension is obtained by minimizing the Root Mean Square (RMS) of the absolute acceleration of the engine, with respect to the relative displacement RMS. The RMS values are used to create the design curves for the suspension parameters, which are particularly useful in the presence of physical constraints such as a limit on the relative displacement.

The transmissibilities are given in equation (3.3), (3.4), and (3.5). The definition of the following optimization criterion is similar to the previous one used for the linear mount.

> ***Optimization Criterion:*** *Minimum RMS of Absolute Acceleration U with respect to RMS of Relative Displacement* Φ.

where U=RMS(u), Φ=RMS(η), and u is the absolute acceleration of the engine

With optimality condition, the absolute acceleration RMS is minimized with respect to the relative displacement RMS. The result is an optimal curve on the U-Φ plane. A desired value for relative displacement as the traveling space is selected, and the associated values for ξ and α are found at the intersection of the associated vertical line with the optimal curve.

Mathematically, the optimization criterion is equivalent to the following constrained minimization:

$$\frac{\partial U}{\partial \Phi}=0 \qquad \frac{\partial^2 U}{\partial \Phi^2}>0. \tag{4.15}$$

For a real problem, the values of mass ratio, ε, and wing frequency, ω_w, are fixed, and the goal is to find the optimum values of α and ξ. The parameters, α and ξ include the unknown stiffness of main spring and the unknown damping of mounting system, respectively.

The application of the GA to this problem produces the optimal relationship between α and ξ. Figure 4.8 through Figure 4.10 show the results graphically. In Figure 4.8, the optimal curve on the *U*-Φ plane is depicted. The associated value of α and ξ are depicted in Figure 4.9, and the relationship between α and ξ is indicated in Figure 4.10. The results are in total agreement with Chapter 3.

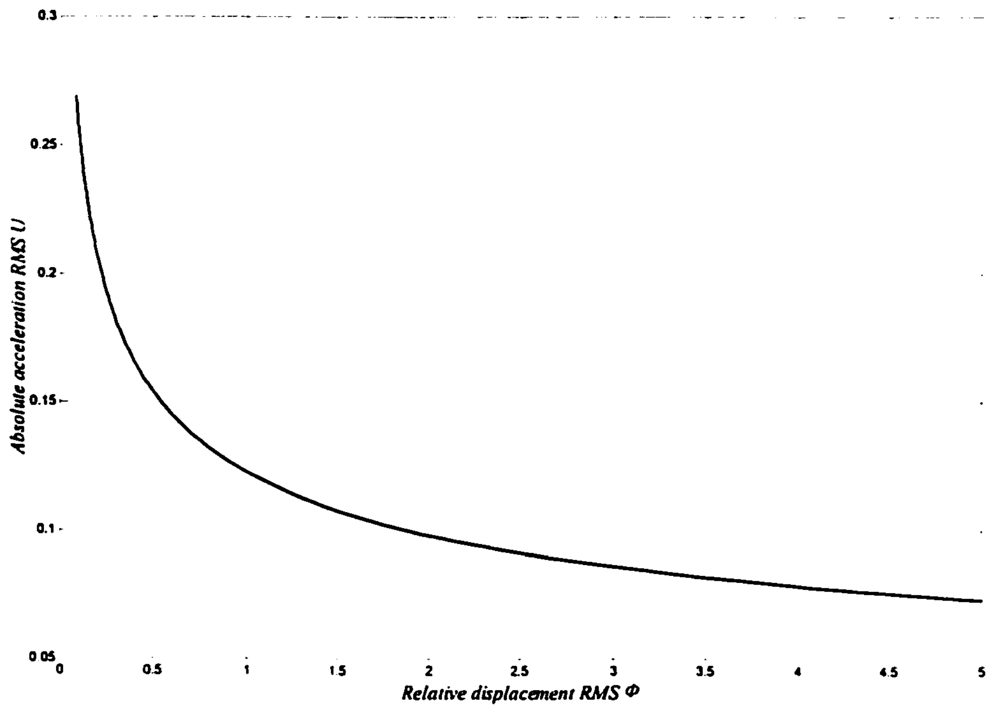


Figure 4.8 Optimal curve in plane *U*-Φ

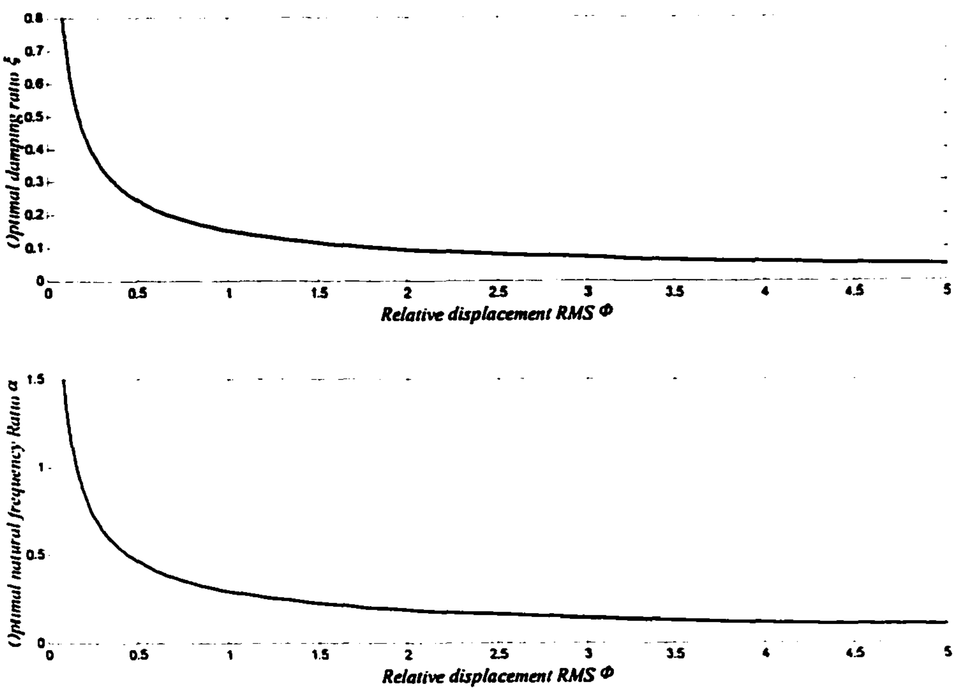


Figure 4.9 Optimal α and ξ versus Φ.

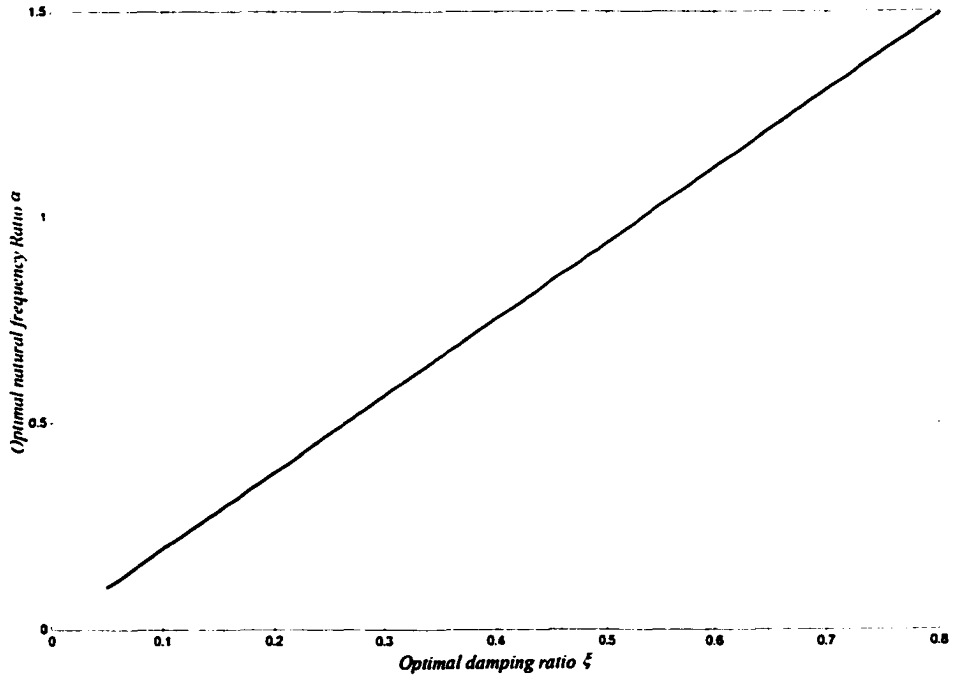


Figure 4.10 Relationship between α and ξ at optimal condition.

Chapter 5

Nonlinear Mount stiffness Effects on Imbalance Steady State Response

5.1 Introduction

Chapter 5 provides a preliminary investigation of the effects of nonlinearity on the imbalance response. Such a source of nonlinearity may be caused by the inherent characteristic of the material used in the mounts. Also the new employment of hydraulic mounts contributes to a deviation from the linear model because hydraulic mounts are fundamentally nonlinear. For this end, a two degrees of freedom idealized model is used. The equations of motion for the system are presented, non-dimensionalized, and solved in an approximate closed form solution by the use of Harmonic Balance and Averaging methods. The effects of certain system parameters on the steady state response are investigated, and then compared to the linear frequency response. Finally, the analytical findings are complemented by the numerical results through the direct integration of the system equations.

5.2 Equations of Motion

A common practice in analyzing engine mounting systems is to model the mounts as elastic springs with a linear stiffness, and linear damping coefficients. Linear models of the mounts are adequate representations of the rubber-like isolators, but fall short in accurately describing other types of mounts. For example, hydraulic mounts are best modeled as nonlinear. In order to investigate the nonlinearity either inherent in the mount material or introduced by the use of hydraulic mounts, a simplified version of the propeller model is utilized. The rigid power plant structure is assumed to be spring-restrained about the pitch and yaw axes located at distance (l) behind the propeller disk. The system is axially symmetric about the spinning axis of the propeller, and the two restoring mounts are identical with stiffness k, and viscous damping c. It is assumed that the vibration characteristics of the system can be described by two degrees of freedom - pitch θ motion in a vertical plane, and, yaw ψ motion in a horizontal plane. The binary system is fairly representative of engines with mounts in a single plane, and the center of gravity is close to that plane. The system is illustrated schematically in Figure 5.1. The engine has a mass, m, a moment of inertia, I_d, and a polar moment of inertia, I_r. The propeller rotates at a constant angular speed, Ω. In order to model the nonlinear effects, the springs are assumed to have Duffing type stiffness to account for the nonlinearity of the mount material. Furthermore, the damping is assumed to be displacement dependent (i.e., a characteristic of the hydraulic mounts). Here, attention is focused on the response of the system under the rotating imbalance excitation caused by the center of mass deviation from the geometric center by e. The aerodynamic forces are neglected for simplicity. Thus, the following basic equations of motion can be written for this dynamic system:

$$\begin{aligned} I_d\ddot{\theta}+c\dot{\theta}\left(1+\hat{\mu}_1\theta^2\right)-\Omega I_r\psi+k\theta\left(1+\hat{\mu}_2\theta^2\right)&=lem\Omega^2\cos\left(\Omega t\right) \\ I_d\ddot{\psi}+\Omega I_r\theta+c\dot{\psi}\left(1+\hat{\mu}_1\psi^2\right)+k\psi\left(1+\hat{\mu}_2\psi^2\right)&=-lem\Omega^2\sin\left(\Omega t\right). \end{aligned} \tag{5.1}$$

It should be noted that in addition to the usual dynamic forces associated with the inertia, damping, and elastic properties of the system, the rotating propeller introduces gyroscopic forces. Such forces couple the equations of motion. As a result of this coupling, natural modes, which for a non-rotating propeller occur independently in the vertical or horizontal planes, are now characterized by a precession motion about the axis of the undisturbed system.

By introducing the dimensionless time and angular displacement co-ordinates, and employing the following definitions of the parameters

$$\tau = \Omega t \ , x = \frac{lem\theta}{I_d},\ y = \frac{lem\psi}{I_d},\ \omega_n^2 = \frac{k}{I_d},\ 2\xi\omega_n = \frac{c}{I_d},\ r = \frac{\Omega}{\omega_n},\ \varepsilon = \frac{I_d}{I_r}$$
$$(\cdot)' = \frac{d(\cdot)}{d\tau} = \frac{1}{\Omega}\frac{d(\cdot)}{dt},\ (\cdot)'' = \frac{d^2(\cdot)}{d\tau^2} = \frac{1}{\Omega^2}\frac{d^2(\cdot)}{dt^2},\ \mu_1 = \hat{\mu}_1\left(\frac{I_d}{lem}\right)^2,\ \mu_2 = \hat{\mu}_2\left(\frac{I_d}{lem}\right)^2, \quad (5.2)$$

The equations of motion of the system can be expressed in the normalized forms,

$$x'' + \frac{2\xi x'\left(1+\mu_1 x^2\right)}{r} - \varepsilon y' + \frac{x\left(1+\mu_2 x^2\right)}{r^2} = \cos(\tau)$$
$$y'' + \varepsilon x' + \frac{2\xi y'\left(1+\mu_1 y^2\right)}{r} + \frac{y\left(1+\mu_2 y^2\right)}{r^2} = -\sin(\tau). \quad (5.3)$$

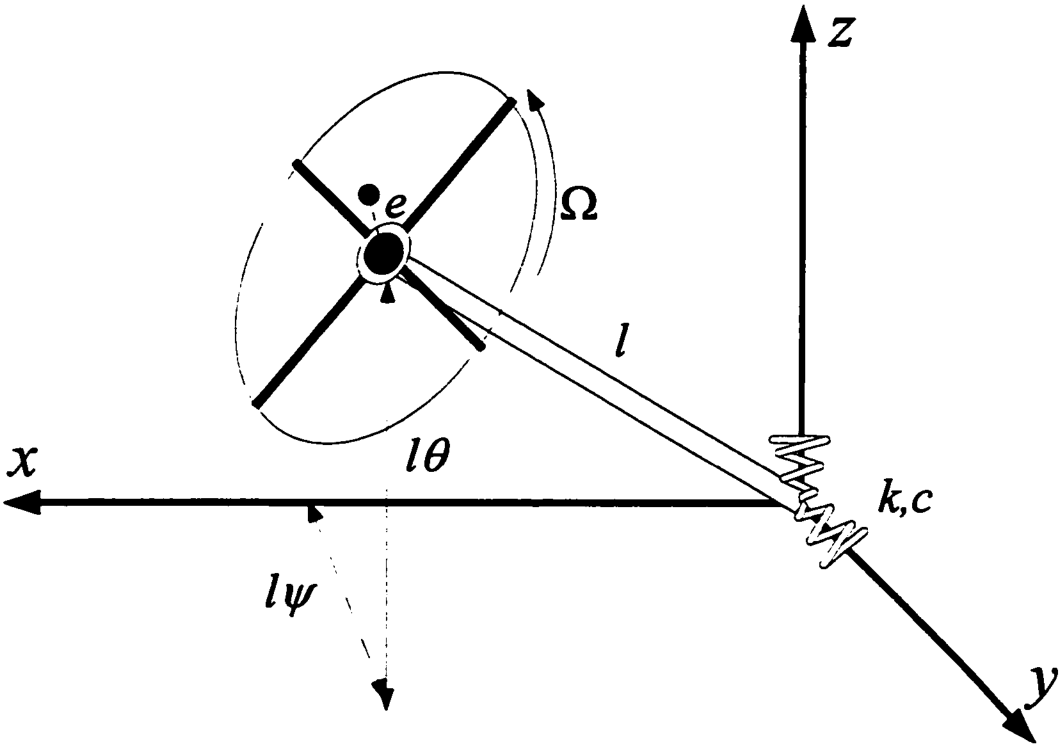


Figure 5.1 Dynamic system

5.3 Approximate Closed Form Solution

For a small amplitude of vibration, the solution of the system equations is assumed to be periodic. When the natural frequencies and forcing satisfy certain external resonance conditions, different types of external resonance such as fundamental, subharmonic and superharmonic can occur. Here, the fundamental resonance is analyzed. Two approximate methods are used to obtain the steady state solution of the frequency response, and the phase of the system: the Harmonic Balance Method and Averaging Method. Both solutions give identical results.

5.3.1 Harmonic Balance

For applying the Harmonic Balance Method, the solution to the system equations is assumed to be harmonic with a frequency equal to the excitation frequency:

$$\begin{aligned} x(\tau) &= a_1\cos(\tau)+b_1\sin(\tau)=h_1\cos(\tau-\beta_1) \\ y(\tau) &= a_2\cos(\tau)+b_2\sin(\tau)=h_2\cos(\tau-\beta_2). \end{aligned} \tag{5.4}$$

in which the following relations hold:

$$\begin{aligned} &a_1=h_1\cos(\beta_1), && b_1=h_1\sin(\beta_1), && h_1^2=a_1^2+b_1^2, \\ &a_2=h_2\cos(\beta_2), && b_2=h_2\sin(\beta_2), && h_2^2=a_2^2+b_2^2. \end{aligned} \tag{5.5}$$

Substituting (5.5) in (5.1) and comparing the coefficients of $\cos(\tau)$ and $\sin(\tau)$ gives four algebraic equations for determining h_1, β_1, h_2, and β_1,

$$
\begin{aligned}
&(\varepsilon h_1)\sin(\beta_1)+\left(\frac{4h_2-4h_2r^2+3\mu_2h_2^3}{4r^2}\right)\cos(\beta_2)+\left(\frac{2\mu_1r\xi h_2^3+8r\xi h_2}{4r^2}\right)\sin(\beta_2)=0\\
&(\varepsilon h_1)\cos(\beta_1)+\left(\frac{2\mu_1r\xi h_2^3+8r\xi h_2}{4r^2}\right)\cos(\beta_2)+\left(\frac{4h_2r^2-4h_2-3\mu_2h_2^3}{4r^2}\right)\sin(\beta_2)=-1\\
&\left(\frac{2\mu_1r\xi h_1^3+8r\xi h_1}{4r^2}\right)\cos(\beta_1)+\left(\frac{4h_1r^2-4h_1-3\mu_2h_1^3}{4r^2}\right)\sin(\beta_1)-(\varepsilon h_2)\cos(\beta_2)=0\\
&\left(\frac{4h_1r^2-4h_1+3\mu_2h_1^3}{4r^2}\right)\cos(\beta_1)+\left(\frac{2\mu_1r\xi h_1^3+8r\xi h_1}{4r^2}\right)\sin(\beta_1)-(\varepsilon h_2)\sin(\beta_2)=-1.
\end{aligned}
\tag{5.6}
$$

Solving the above equation for $\sin(\beta_1)$, $\cos(\beta_1)$, $\sin(\beta_2)$, and $\cos(\beta_2)$ and then using the trigonometric identity ,

$$
\begin{aligned}
&\cos(\beta_1)^2+\sin(\beta_1)^2=1\\
&\cos(\beta_2)^2+\sin(\beta_2)^2=1.
\end{aligned}
\tag{5.7}
$$

The solution is found to be

$$h_1=h_2=h \tag{5.8}$$

and

$$a_1r^4+a_2r^2+a_3=0 \tag{5.9}$$

where

$$
\begin{aligned}
&a_1=16\left[1-(\varepsilon-1)^2h^2\right]\\
&a_2=-4\left[\xi^2\left(4+\mu_1h^2\right)^2+6\mu_2h^2(\varepsilon-1)+8(\varepsilon-1)\right]h^2\\
&a_3=-\left(4+3\mu_2h^2\right)^2h^2.
\end{aligned}
\tag{5.10}
$$

Solving for r^2 using quadratic equation yields

$$r_{1,2}^2 = \frac{-a_2 \pm \sqrt{a_2^2 - 4a_1 a_3}}{2a_1} \tag{5.11}$$

or

$$r_{1,2}^2 = \frac{-\Delta_1 h^6 + 2\Delta_2 h^4 + 8\Delta_3 h^2 \pm \sqrt{\Delta_1^2 h^{12} - 4\Delta_4 h^{10} + 16\Delta_5 h^8 + 4\Delta_6 h^6 + 32\Delta_7 h^4 + 64h^2}}{8\left[h^2(\varepsilon-1)^2 - 1\right]} \tag{5.12}$$

where

$$\begin{aligned}
\Delta_1 &= \xi^2 \mu_1^2 \\
\Delta_2 &= 3\mu_2(1-\varepsilon) - 4\xi^2 \mu_1 \\
\Delta_3 &= (1-\varepsilon) - 2\xi^2 \\
\Delta_4 &= \mu_1^2 \xi^2 \Delta_2 \\
\Delta_5 &= \mu_1 \xi^2 \left[6\mu_2(\varepsilon-1) + \mu_1(\varepsilon-1) + 6\mu_1 \xi^2\right] \\
\Delta_6 &= 32\mu_1 \xi^2 \left[(\varepsilon-1) + 2\xi^2\right] + 3\mu_2\left[16\xi^2(\varepsilon-1) + 3\mu_2\right] \\
\Delta_7 &= 3\mu_2 + 8\xi^2\left(\varepsilon - 1 + \xi^2\right).
\end{aligned} \tag{5.13}$$

The phase is found to be

$$\begin{aligned}
\beta_1 &= -\arctan\left[\frac{3\mu_2 h^2 + 4(\varepsilon-1)r^2 + 4}{2\xi r\left(\mu_1 h^2 + 4\right)}\right] \\
\beta_2 &= \beta_1 + \frac{\pi}{2}.
\end{aligned} \tag{5.14}$$

It should be noted that the above solution is valid for only small nonlinear coefficients.

5.3.2 Averaging Method

A solution by the Averaging Method is sought for in the form,

$$\begin{aligned} x(\tau) &= h_1(\tau)\cos(\tau-\beta_1(\tau)) \\ y(\tau) &= h_2(\tau)\cos(\tau-\beta_2(\tau)) \end{aligned} \tag{5.15}$$

with slowly varying functions $h_1 = h_1(\tau)$, $\beta_1 = \beta_1(\tau)$, $h_2 = h_2(\tau)$, and $\beta_2 = \beta_2(\tau)$ for which the following conditions can be fixed:

$$\begin{aligned} &h_1'\cos(\tau-\beta_1)+h_1\beta_1'\sin(\tau-\beta_1)=0 \\ &h_2'\cos(\tau-\beta_2)+h_2\beta_2'\sin(\tau-\beta_2)=0. \end{aligned} \tag{5.16}$$

Differentiation of (5.15) yields

$$\begin{aligned} x'(\tau) &= h_1'\cos(\tau-\beta_1)-h_1(1-\beta_1')\sin(\tau-\beta_1) \\ y'(\tau) &= h_2'\cos(\tau-\beta_2)-h_2(1-\beta_2')\sin(\tau-\beta_2) \end{aligned} \tag{5.17}$$

from (5.16); hence.

$$\begin{aligned} x'(\tau) &= -h_1\sin(\tau-\beta_1) \\ y'(\tau) &= -h_2\sin(\tau-\beta_2) \end{aligned} \tag{5.18}$$

Differentiating (5.18), with respect to τ, gives

$$\begin{aligned} x''(\tau) &= -h_1'\sin(\tau-\beta_1)-h_1(1-\beta_1')\cos(\tau-\beta_1) \\ y''(\tau) &= -h_2'\sin(\tau-\beta_2)-h_2(1-\beta_2')\cos(\tau-\beta_2). \end{aligned} \tag{5.19}$$

Substituting (5.15), (5.18), and (5.19) into (5.3) and averaging over one period gives the equations in standard form,

$$
\begin{aligned}
h_1' &= \frac{-4\xi h_1 - \xi h_1^3 \mu_1 + 2\varepsilon h_2 r\cos(\beta_2 - \beta_1) - 2r\cos(\beta_1)}{4r} \\
h_1\beta_1' &= \frac{-4\xi h_1 r^2 + 4\varepsilon h_2 r^2 \sin(\beta_2 - \beta_1) + 4h_1 + 3h_1^3\mu_2 - 4r^2\sin(\beta_1)}{8r^2} \\
h_2' &= \frac{-4\xi h_2 - \xi h_2^3 \mu_1 - 2\varepsilon h_1 r\cos(\beta_2 - \beta_1) + 2r\sin(\beta_2)}{4r} \\
h_2\beta_2' &= \frac{-4h_2 r^2 + 4\varepsilon h_1 r^2 \sin(\beta_2 - \beta_1) + 4h_2 + 3h_2^3\mu_2 - 4r^2\cos(\beta_2)}{8r^2}.
\end{aligned}
\qquad (5.20)
$$

For the steady state response setting, $h_1' = \beta_1' = h_2' = \beta_2' = 0$, and by solving the above equations simultaneously, the same solution as (5.12) and (5.14) is obtained.

5.4 Results and Discussion

The results are presented here to demonstrate the analytical solution and compare it with the numerical integration. First, the linear model is offered as a base line for comparison. Next, the analytical approximate solution is illustrated graphically. Finally, a direct integration of the equations of motion reveals the limitation of the analytical approximate.

5.4.1 Linear Model

In this section, the linear system and the influence of various system parameters on steady state response are examined. Setting the nonlinear coefficients to zero gives the linear exact solution as follows:

$$
h = h_1 = h_2 = \frac{r^2}{\sqrt{\left[r^2(\varepsilon - 1) + 1\right]^2 + \left[2\xi r\right]^2}} \qquad (5.21)
$$

and the phase is

$$\beta_1 = -\arctan\left(\frac{r^2(\varepsilon-1)+1}{2r\xi}\right)$$
$$\beta_2 = \beta_1 + \frac{\pi}{2} \tag{5.22}$$

It is clear from the above equations that the vibration amplitudes are equal but there is a 90° phase shift between the yaw and pitch angular deflections, which indicates a circular orbit. Figure 5.2 through Figure 5.5 illustrate the various system parameter influences on the steady state imbalance response amplitude and phase. Increasing the damping coefficient reduces the vibration amplitude at the resonance as shown in Figure 5.2. The ratio between the moment of inertia and the polar moment of inertia ($\varepsilon = I_d/I_r$) has a major consequence on the imbalance response of the system. The increase in ε values enhances the gyroscopic coupling between the two coordinates which leads to a shift in the resonance frequency to a higher magnitude and an increase in the imbalance response amplitude, at and after, resonance as seen in Figure 5.4.

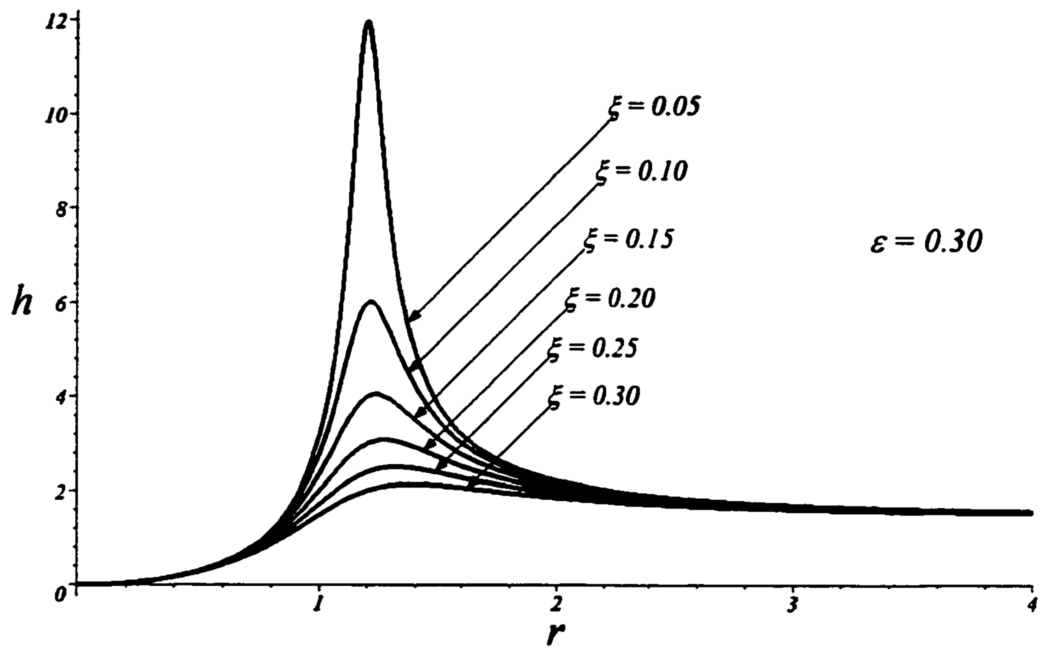


Figure 5.2 Imbalance response amplitude versus frequency ratio for different damping ratios ξ

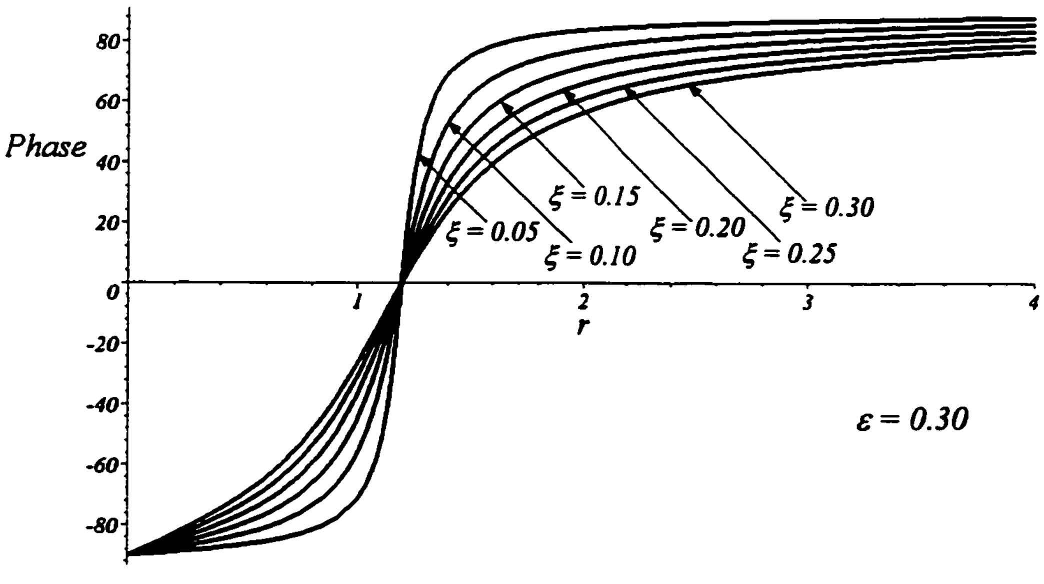


Figure 5.3 Imbalance response phase versus frequency ratio for different damping ratios ξ

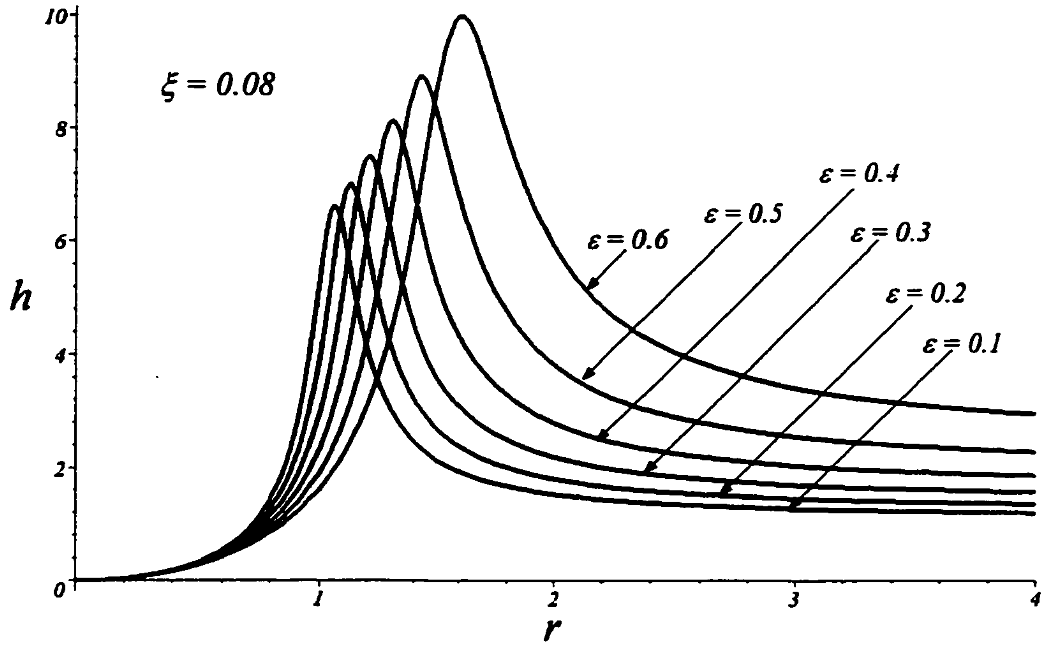


Figure 5.4 Imbalance response amplitude versus frequency ratio for different ε values

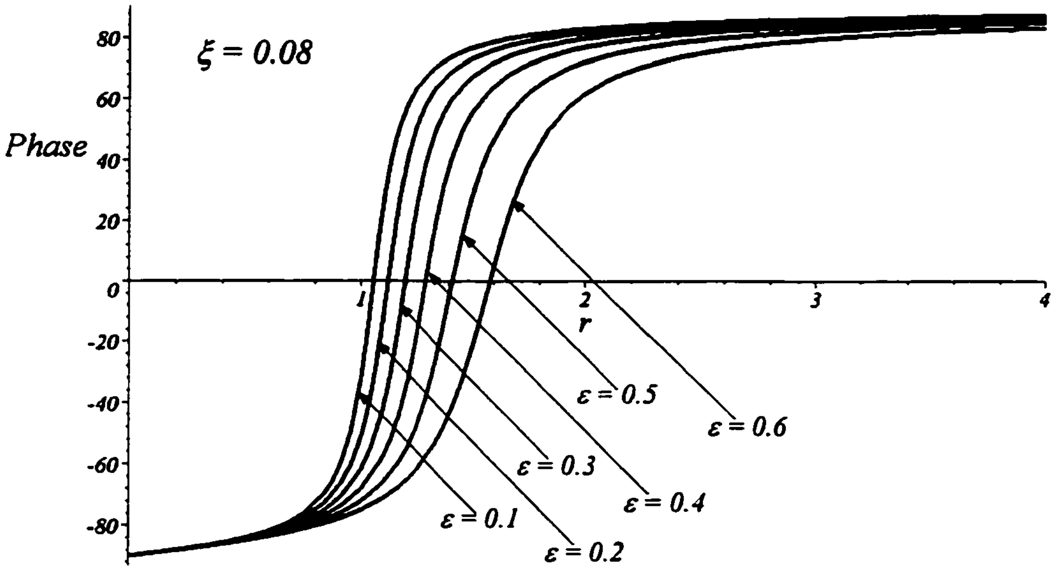


Figure 5.5 Imbalance response phase versus frequency ratio for different ε values

5.4.2 Nonlinear Model

This section focuses on the influence that the nonlinearity causes to the steady state response of the system. Figure 5.6 plots the frequency response curve for the different damping ratios. The system response is a well-known backbone curve due to the cubic nonlinearity in the system. At a low propeller speed, there is only one solution, whereas for higher speeds there are three different solutions. The three solutions are depicted by branch *a*, *b*, and *c*. Only branch *a* and *c* are stable while branch *b* is unstable. As damping increases in the system, the path to nonlinear characteristics is reduced. Figure 5.7 illustrates the phase curve that accompanies Figure 5.6.

Figure 5.8 through Figure 5.11 demonstrate the effect of the non-linearity, represented by the coefficients μ_1 and μ_2, on the system. Increasing the nonlinear damping reduces the response amplitude at resonance while increasing the nonlinear stiffness leads to the enlargement of the resonance region.

The increase in the ratio of the polar movement of inertia to the moment of inertia ε tends to shift the resonance to the right, as illustrated in Figure 5.12 and Figure 5.13. Also the higher ratio, ε, leads to an expansion in the resonance section.

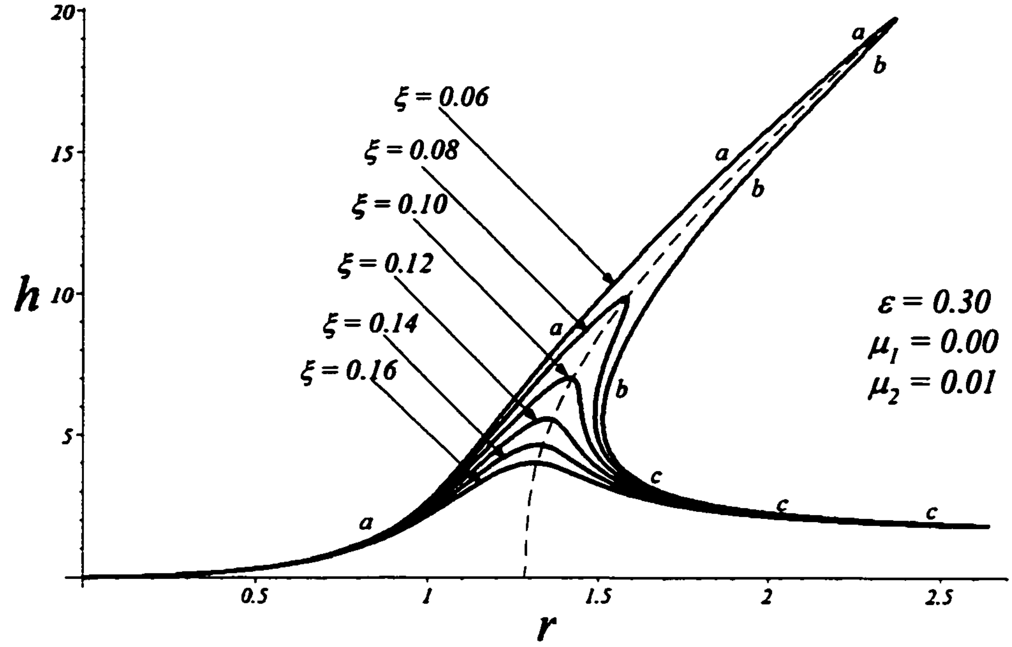


Figure 5.6 Nonlinear imbalance response amplitude versus frequency ratio for different damping ratios ξ

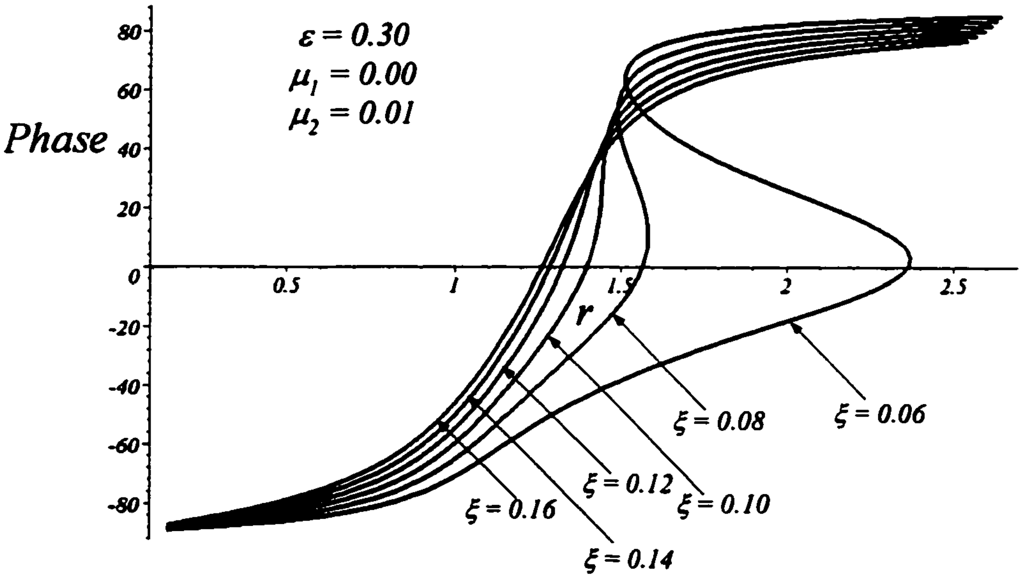


Figure 5.7 Nonlinear imbalance response phase versus frequency ratio for different damping ratios ξ

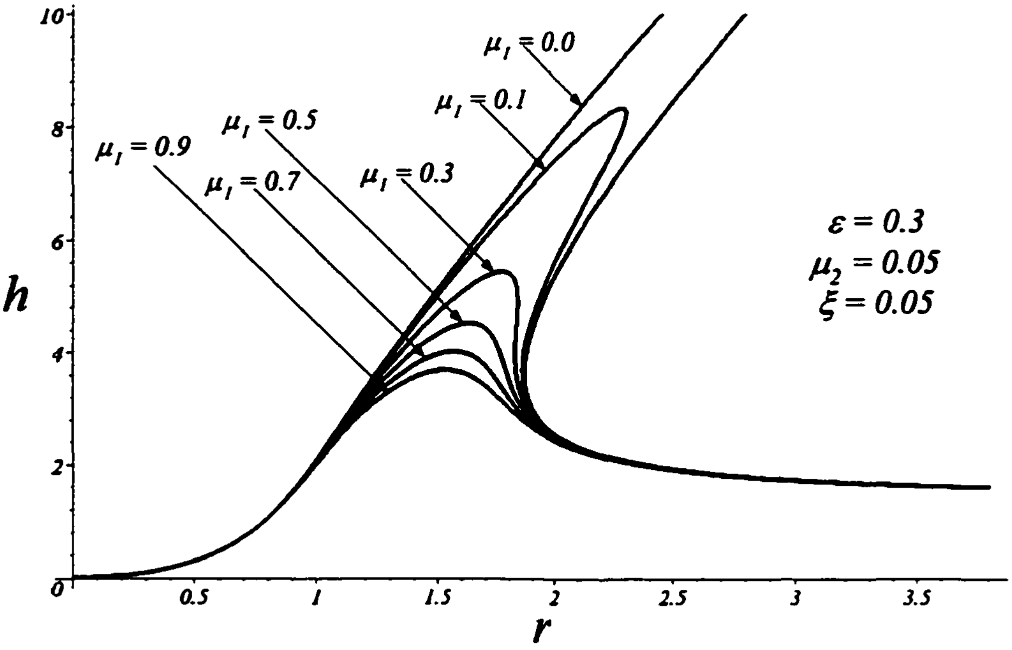


Figure 5.8 Nonlinear imbalance response amplitude versus frequency ratio for different μ_l values

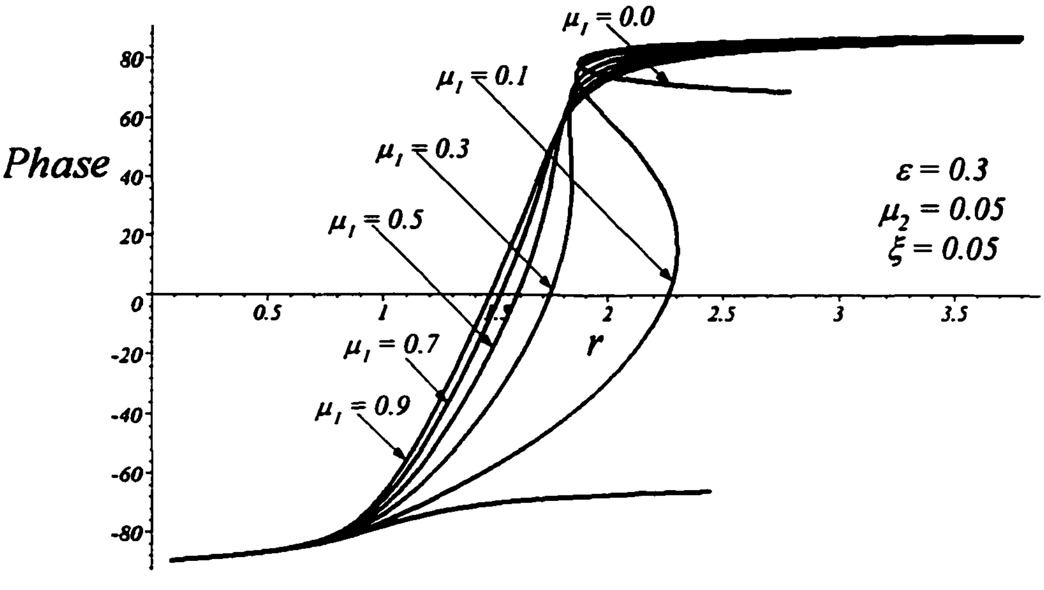


Figure 5.9 Nonlinear imbalance response phase versus frequency ratio for different μ_l values

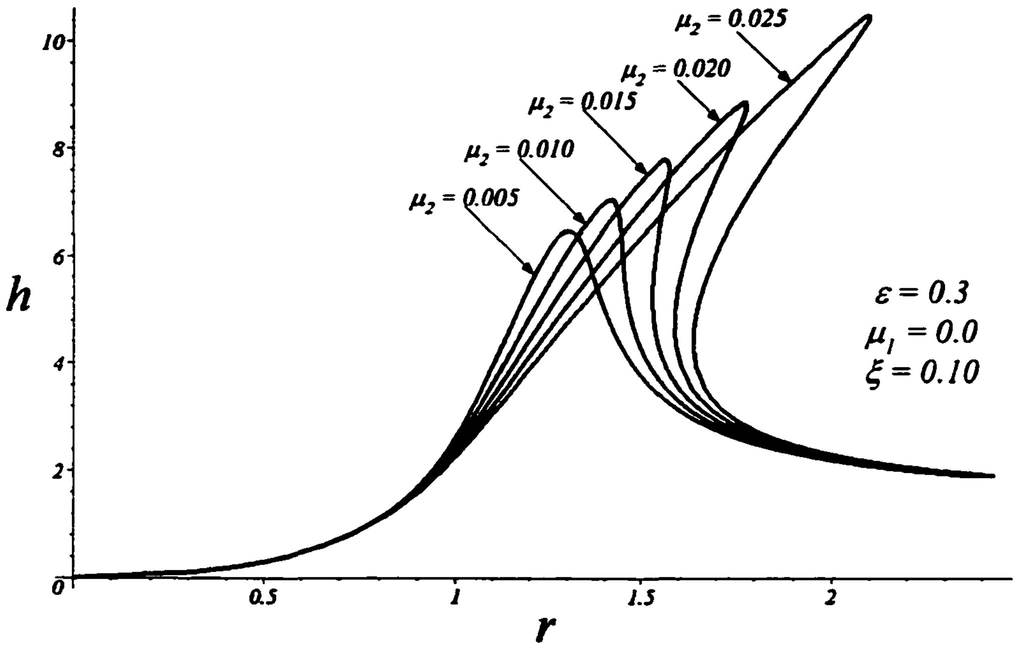


Figure 5.10 Nonlinear imbalance response amplitude versus frequency ratio for different μ_2 values

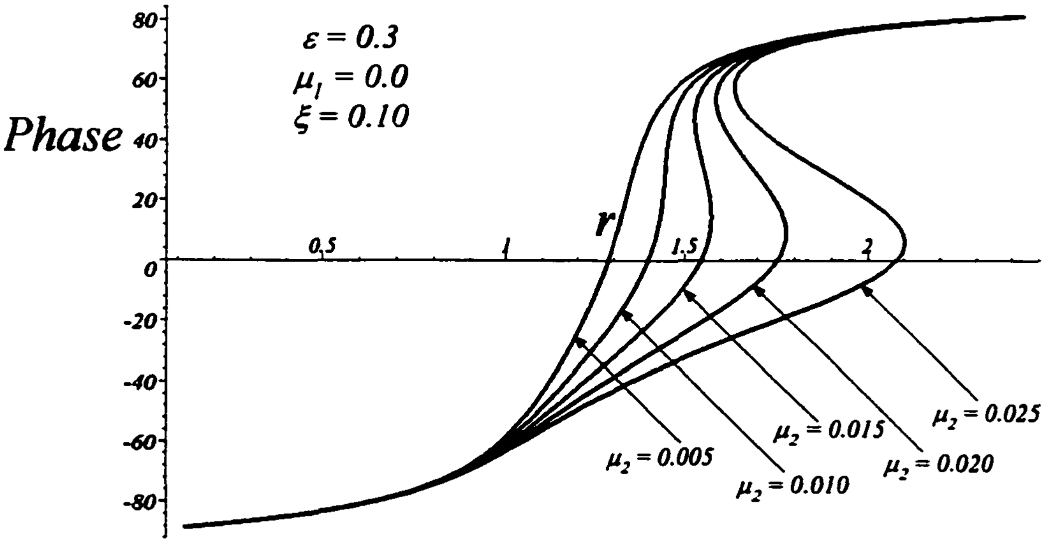


Figure 5.11 Nonlinear imbalance response phase versus frequency ratio for different μ_2 values

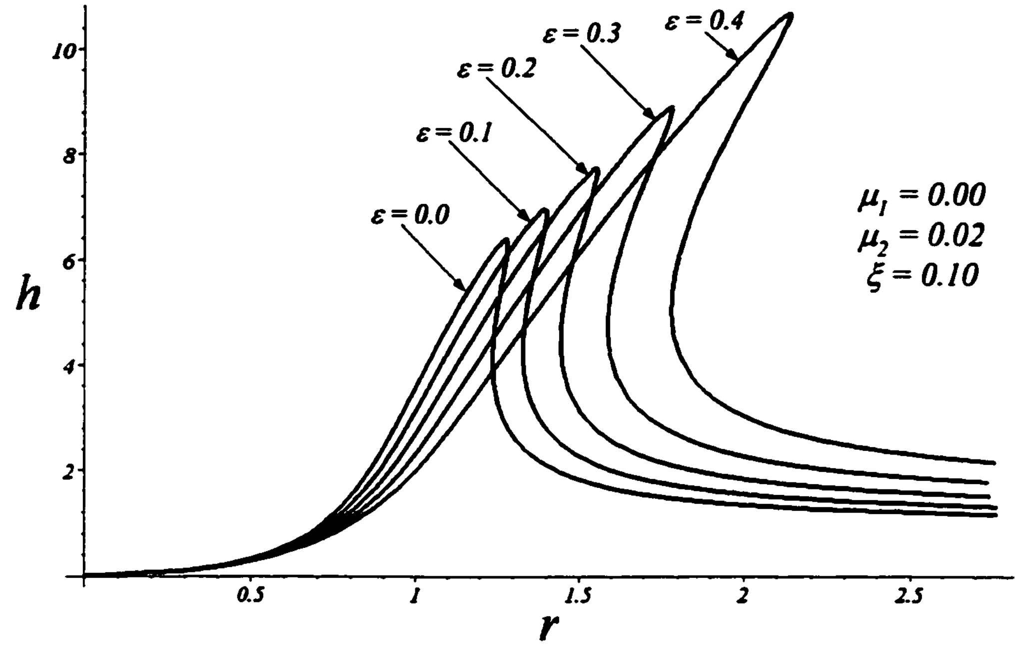


Figure 5.12 Nonlinear imbalance response amplitude versus frequency ratio for different ε values

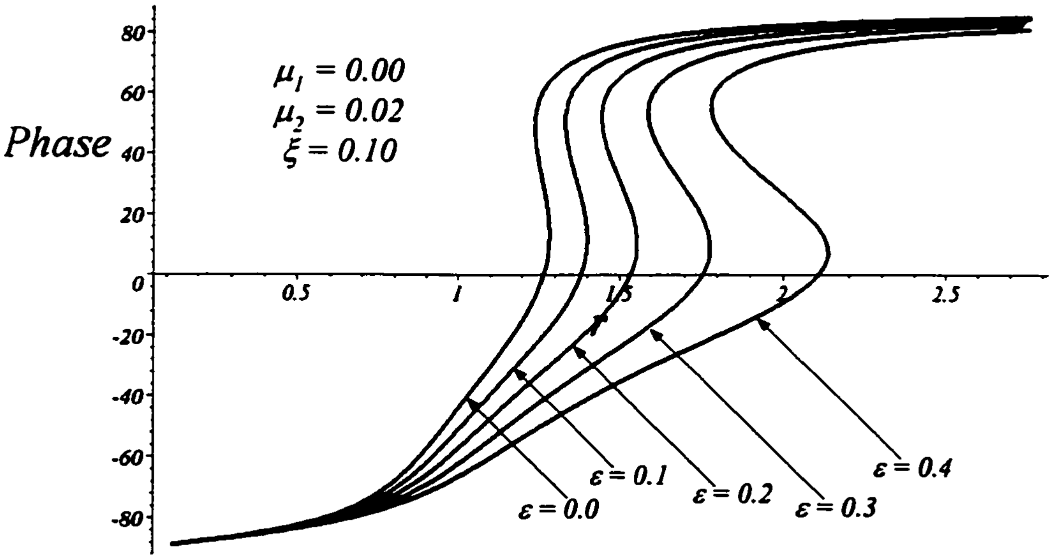


Figure 5.13 Nonlinear imbalance response phase versus frequency ratio for different ε values

5.4.3 Numerical integration

In this section, a numerical investigation of the system equations (5.3) in support of the analytical approximate results is conducted. Figure 5.14 illustrates how the introduction of nonlinear stiffness leads to an increase in the steady state amplitude response of the system, compared to the linear one. Also the numerical solution matches well with the analytically predicted one. The numerical results illustrate the jump phenomenon which causes a sudden drop in the steady state amplitude of vibration after r =1.42. Figure 5.15 demonstrates the time response of the system. After the transient dies out, the amplitude of both coordinates are equal, i.e., h_1=h_2, which confirms with the analytical solution.

Increasing the nonlinearity in the system produces a complex dynamic that is not predicted by the analytical results. An example of such phenomenon is presented in Figure 5.16, where three different regions are identified in the frequency domain of the amplitude response. For $r \leq 1.25$ and $r \geq 1.79$ (region 1 and 3 on the plots) the system has a single stable response, h_1=h_2, and the difference between analytical and numerical solutions is unnoticeable. The orbit generated by the vibration is circular (depicted in Figure 5.17) for the frequency ratio $r = 1.0$ and $r = 1.9$, with, a zero initial condition. A notable deviation from the analytical approximation occurs in regions 2. In a typical linear dynamic system, the steady state amplitude is independent of the initial conditions; i.e., the response is unique. This is not necessarily the case for non-linear systems. For a forced non-linear system, when two or more stable steady state solutions exist, the initial conditions determine which steady state solution is picked up. Region 2 depicts two steady state solutions for h_1 and h_2 and $h_1 \neq h_2$. Figure 5.18 depicts two potential orbital motions of the system in those frequency ratio regions depending on the initial conditions. The orbital motion represented by a is reached through zero initial conditions, i.e., $x_0 = \dot{x}_0 = y_0 = \dot{y}_0 = 0$, while orbit b corresponds to the non zero initial conditions, i.e., $x_0 = \dot{x}_0 = \dot{y}_0 = 0, y_0 = 1$. Region 4 differs from the pervious case in that only unique solutions exist for h_1 and h_2 and they are not equal. The analytical solution is not able to predict the solutions because the nonlinearity coefficient is large and the analytical solution assumes small nonlinearity. Further research is required but the results are promising.

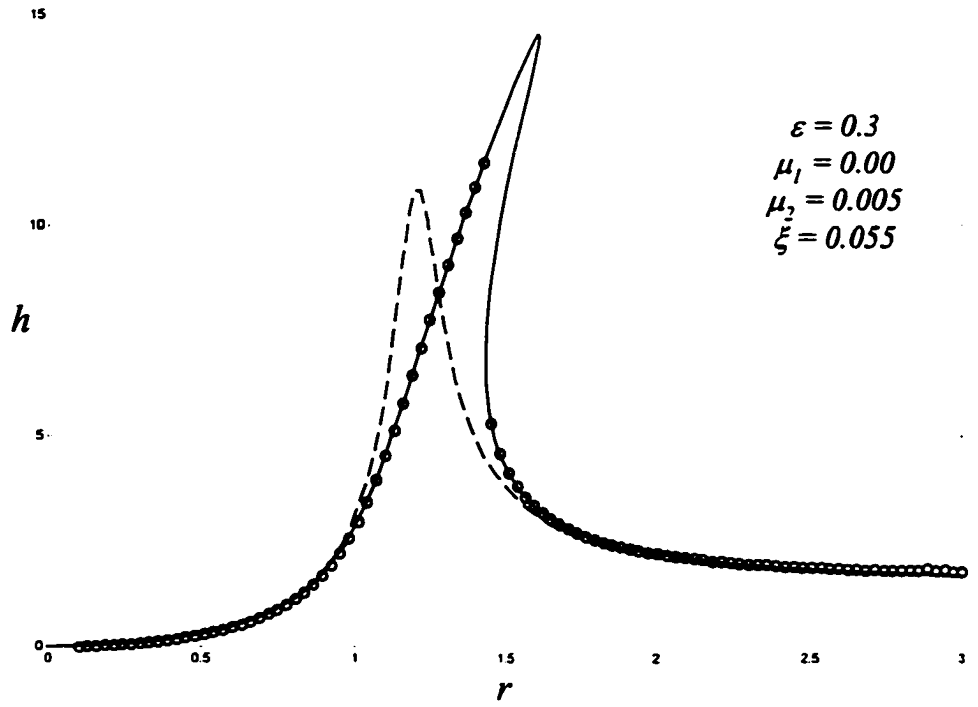


Figure 5.14 Frequency response curve; (solid) analytical nonlinear, (dashed) linear, (circle) numerical

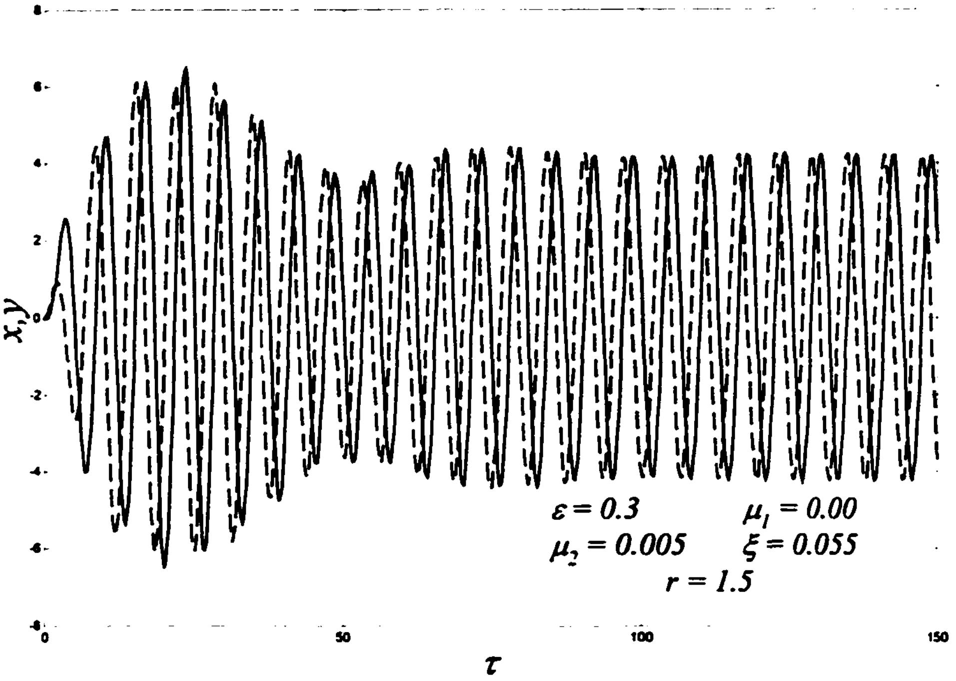


Figure 5.15 Time response of the system

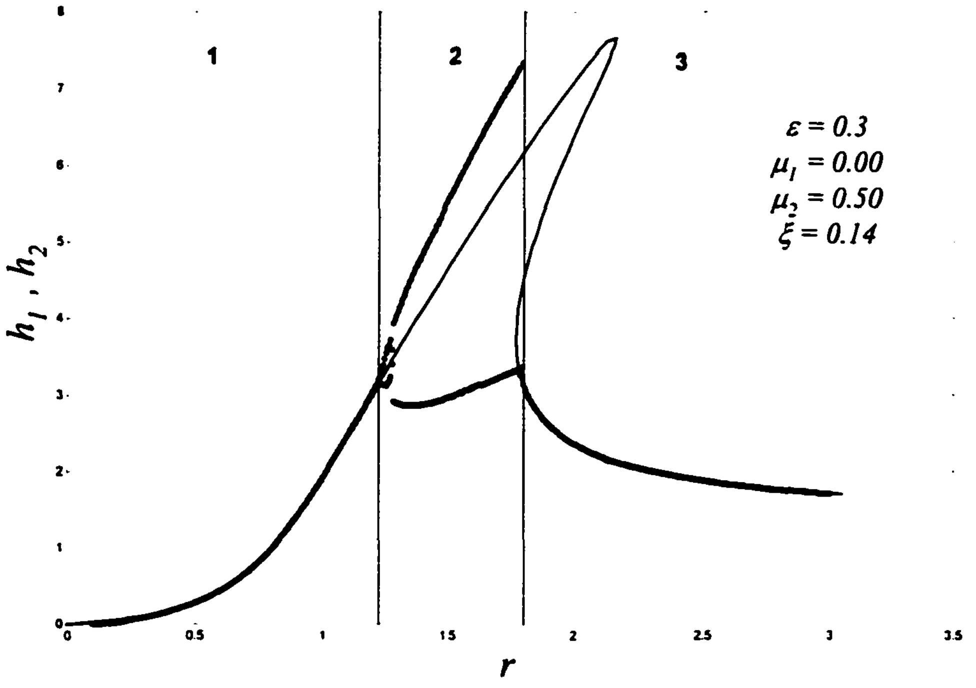
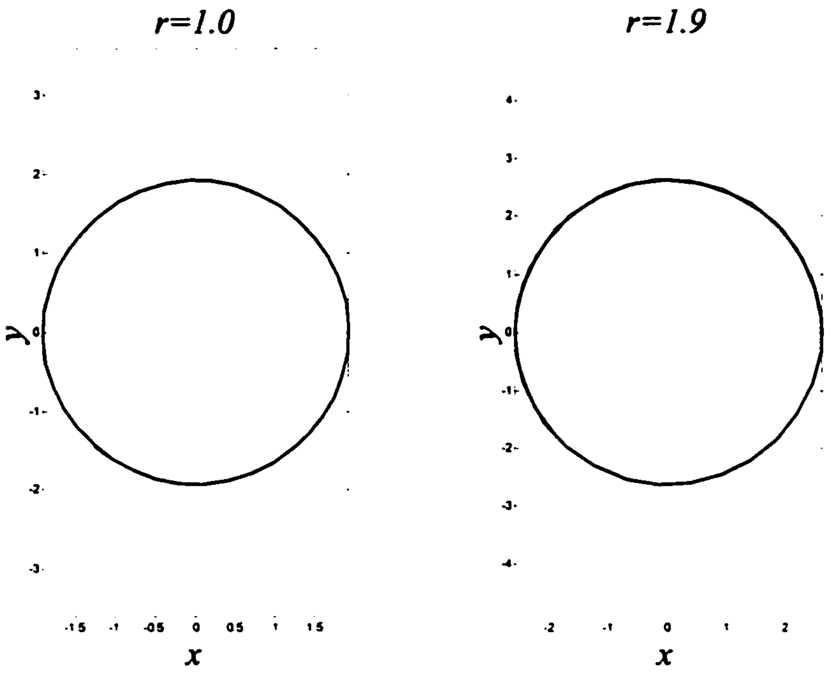


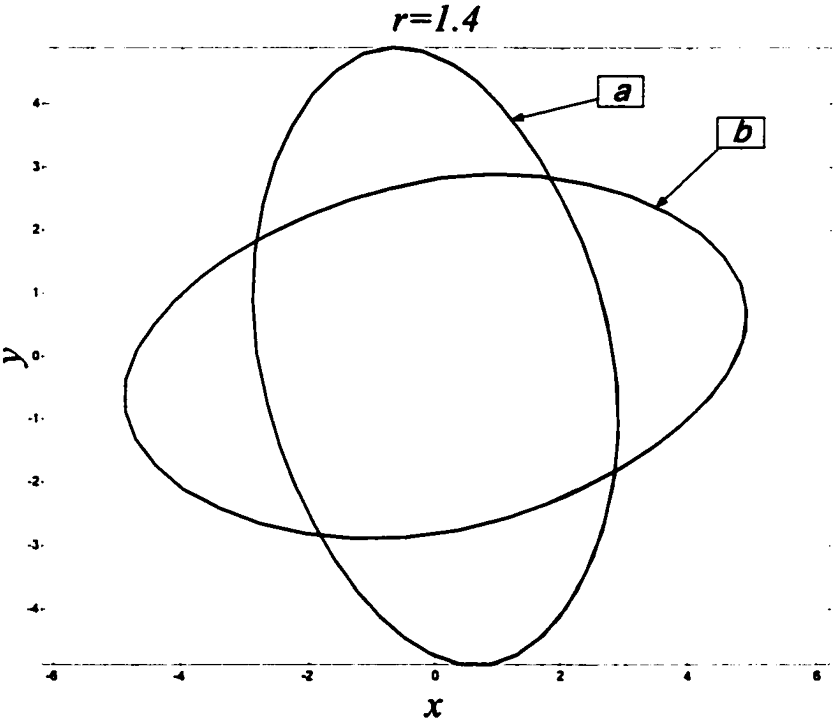
Figure 5.16 Amplitude response h_l; (solid) analytical (doted) numerical



r=1.0

r=1.9

Figure 5.17 Orbital motion for region 1 and 5



r=1.4

Figure 5.18 Orbital motion for region 2 for two different initial conditions

Chapter 6

Active Vibration Cancellation

6.1 Introduction

Chapters 3 and 4 address passive vibration isolation. However, passive systems have their limitation and to further reduce the vibration an active system must be employed. This chapter explores active vibration cancellation. The goal is to implement a simple and low cost active vibration cancellation strategy. Therefore, a comprehensive understanding of the dynamic behavior of the system is crucial for a successful implementation of the active control strategy. To this end, an experimental rig was designed and fabricated [74]. The equations of motion for the experiential model are given which describe the relevant degrees of freedom, disturbance, and control forces. Modal parameters and the forced response of the system are analyzed by using modal testing, time domain analysis, and FFT analysis. The output feedback active vibration control is utilized for active vibration attenuation. A brief description of the output feedback theory is given. The active strategy is implemented and the results are presented. Another active vibration cancellation strategy has been implemented on the experiment apparatus based on filtered x-LMS and for further details the reader is referred to Aucoin [73] and Aucoin, Alkhatib, and Golnaraghi [75].

6.2 Equations of Motion

A simplified version of the equations of motion is given in this section. Aerodynamic forces are neglected, and roll and aft-forward motions are eliminated, because their effects are minimal on transverse vibration of the engine. The proposed model is intended to copy an experimental rig for the implementation of active vibration cancellation. A rigid rotor on flexible supports (mounts), as show in Figure 6.1, is considered.

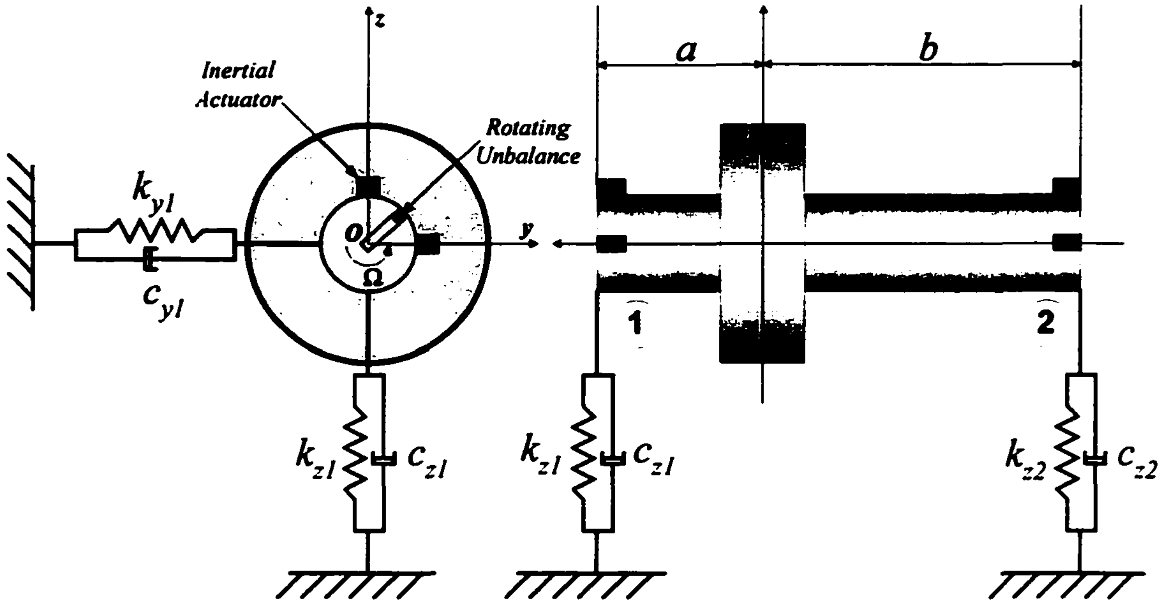


Figure 6.1 Rigid rotor on resilient mounts

The coordinate system origin is placed at the rotor center of gravity. The O_y and O_z axes are orthogonal to each other, and orthogonal to the rotor axis, O_x. Flexible mounts that are distributed in two planes support the rotor. The effective stiffness and damping, in each plane, is modeled as a spring and a dashpot pair along the O_y and O_z axes. A rotating imbalance with a constant speed Ω causes transverse vibration and rigid body whirling in the system. The equations of motion can be written as

$$\begin{aligned}
&m\ddot{y}+c_{yT}\dot{y}-c_{yC}\dot{\theta}+k_{yT}y-k_{yC}\theta=me\Omega^2\cos(\Omega t)\\
&m\ddot{z}+c_{zT}\dot{z}+c_{zC}\dot{\psi}+k_{zT}y+k_{zC}\psi=me\Omega^2\sin(\Omega t)\\
&I_d\ddot{\theta}+I_p\Omega\dot{\psi}-c_{yC}\dot{y}+c_{yR}\dot{\theta}-k_{yC}y+k_{yR}\theta=-mea\Omega^2\cos(\Omega t)\\
&I_d\ddot{\psi}-I_p\Omega\dot{\theta}+c_{zC}\dot{z}+c_{zR}\dot{\psi}+k_{zC}z+k_{yR}\psi=mea\Omega^2\sin(\Omega t)
\end{aligned} \tag{6.1}$$

where

$$\begin{aligned} c_{yT} &= c_{y1} + c_{y2}, \quad c_{zT} = c_{z1} + c_{z2}, \\ c_{yC} &= -ac_{y1} + bc_{y2}, \quad c_{zC} = -ac_{z1} + bc_{z2}, \\ c_{yR} &= a^2 c_{y1} + b^2 c_{y2}, \quad c_{zR} = a^2 c_{z1} + b^2 c_{z2}, \end{aligned} \tag{6.2}$$

which can be written in matrix form

$$\mathbf{M}\ddot{\mathbf{q}} + (\mathbf{C} + \Omega\mathbf{G})\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{f}, \tag{6.3}$$

where

$$\mathbf{q}^T = \{y \quad \theta \quad z \quad \psi\}, \tag{6.4}$$

$$\mathbf{M} = \begin{bmatrix} m & 0 & 0 & 0 \\ 0 & m & 0 & 0 \\ 0 & 0 & I_d & 0 \\ 0 & 0 & 0 & I_d \end{bmatrix}, \tag{6.5}$$

$$\mathbf{C} = \begin{bmatrix} c_{yT} & 0 & -c_{yC} & 0 \\ 0 & c_{zT} & 0 & c_{zC} \\ -c_{yC} & 0 & c_{yR} & 0 \\ 0 & c_{zC} & 0 & c_{zR} \end{bmatrix}, \tag{6.6}$$

$$\mathbf{G} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & I_p \\ 0 & 0 & -I_p & 0 \end{bmatrix} \tag{6.7}$$

$$\mathbf{K} = \begin{bmatrix} k_{yT} & 0 & -k_{yC} & 0 \\ 0 & k_{zT} & 0 & k_{zC} \\ -k_{yC} & 0 & k_{yR} & 0 \\ 0 & k_{zC} & 0 & k_{zR} \end{bmatrix}, \tag{6.8}$$

$$\mathbf{f} = me\Omega^2 \begin{Bmatrix} \cos(\Omega t) \\ \sin(\Omega t) \\ -a\cos(\Omega t) \\ a\sin(\Omega t) \end{Bmatrix}. \tag{6.9}$$

The stiffness coefficients are defined in a similar way. y and z are the displacements in the O_y and O_z directions, and θ and ψ are the rotations about the O_y and O_z axes. a and b are the distances between the rotor center of gravity and the two mounting planes. The subscripts, T and R, represent the effective translational and rotational stiffness of the mounts referred to the coordinate origin. The subscripts, C, represent the coupling between the translational and rotational degrees of freedom.

6.3 Experimental Setup

By utilizing the Buckingham Pi theorem, a scale model of the engine was designed and manufactured for the experimental investigation [74]. The apparatus consists of an aluminum assembly mounted on a rigid supporting structured through five mounts, as illustrated in Figure 6.2 The assembly, representing the mass and inertia of the scaled down model, has a DC motor located at the front. It is used to rotate the propeller and the imbalance. A tachometer attached to the motor provides a signal that describes the speed of the motor. The mounts, as described in the theoretical model, consist of independent linear springs acting in two principal directions. A rigid frame constructed with steel I-beams is attached to a concrete slab, and serves as a mounting point to suspend the engine model. The frame is constructed such that its modes have little interaction with the rigid body modes of the engine model. The concrete base is an ideal platform for the system, because it isolates any vibrations coming from the ground. Mounting arms are attached to the frame to support the suspended engine model. For safety reasons, the system is enclosed in a lexan enclosure.

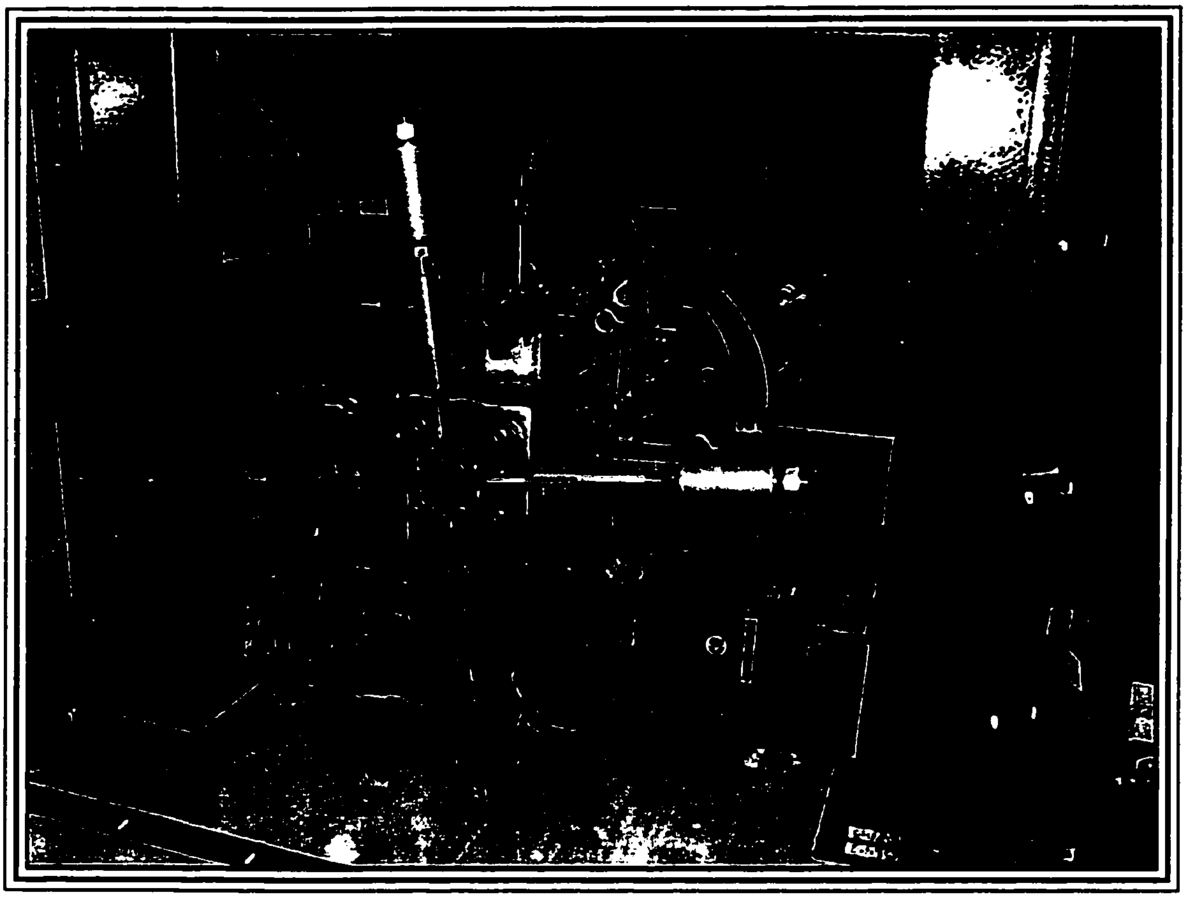


Figure 6.2 Experimental setup

Space Age Control Inc. linear potentiometers (Model # 173-0161) are used as position transducers. The potentiometers have a range of 2 in. and a resolution of 0.25 in peak-to-peak vibrations at 100 Hz. Their output is linearly dependent on the displacement of the cable. The system is expected to be perturbed at levels well below the maximum resolution of the transducers. A maximum power supply of pm 15V DC is used to provide a maximum output resolution of the signals.

The rigid body motion of the system has four degrees of freedom, which are identified as significant. To fully assess the transverse vibration of such a system, four points of measurements are needed. Two location are identified for measurements; each is at one of the two ends of the model, as marked in Figure 6.1. At each point, the linear deflection along the O_y and O_z axes is recorded; i.e., y_l,

z_1, y_2, and z_2. . The relationship relating the measured motion to the rigid body motion of the whole body is given as

$$y = \frac{by_1 + ay_2}{a+b}, \quad \theta = \frac{z_2 - z_1}{a+b} \tag{6.10}$$

and

$$z = \frac{bz_1 + az_2}{a+b}, \quad \psi = \frac{y_2 - y_1}{a+b}. \tag{6.11}$$

The new coordinate are found using the following transformation:

$$\begin{Bmatrix} y \\ \theta \\ z \\ \psi \end{Bmatrix} = \frac{1}{a+b} \begin{bmatrix} b & 0 & a & 0 \\ 0 & -1 & 0 & 1 \\ 0 & b & 0 & a \\ -1 & 0 & 1 & 0 \end{bmatrix} \begin{Bmatrix} y_1 \\ z_1 \\ y_2 \\ z_2 \end{Bmatrix} \tag{6.12}$$

or

$$\mathbf{q} = \mathbf{R}\mathbf{p} \tag{6.13}$$

where

$$\mathbf{p}^T = \{y_1 \quad z_1 \quad y_2 \quad z_2\} \tag{6.14}$$

and

$$\mathbf{R} = \frac{1}{a+b} \begin{bmatrix} b & 0 & a & 0 \\ 0 & -1 & 0 & 1 \\ 0 & b & 0 & a \\ -1 & 0 & 1 & 0 \end{bmatrix}. \tag{6.15}$$

Now, the equations of motion can be written in terms of the $\mathbf{p}$

$$\widehat{\mathbf{M}}\ddot{\mathbf{p}}+\widehat{\mathbf{D}}\dot{\mathbf{p}}+\widehat{\mathbf{K}}\mathbf{p}=\widehat{\mathbf{f}} \tag{6.16}$$

where

$$\widehat{\mathbf{M}}=\mathbf{R}^{T}\mathbf{M}\mathbf{R}, \tag{6.17}$$

$$\widehat{\mathbf{D}}=\mathbf{R}^{T}\left(\mathbf{C}+\Omega\mathbf{G}\right)\mathbf{R}, \tag{6.18}$$

$$\widehat{\mathbf{K}}=\mathbf{R}^{T}\mathbf{K}\mathbf{R}, \tag{6.19}$$

$$\widehat{\mathbf{f}}=\mathbf{R}^{T}\mathbf{f}. \tag{6.20}$$

In order to control the engine vibration, four *Motran* inertial actuators (Model # IFX 21-100), provided by Lord Corporation, are utilized. The actuator is constructed of a housing, a moveable mass which consists of a permanent magnet and core, flexible springs, and a coil (see Figure 6.3). The mass is supported on the spring, which is fixed to the housing. When a sinusoidal voltage is applied to the coil that is fixed to the housing, the polarity and strength of the coil magnetic field changes in phase with the applied voltage. This produces a force of attraction between the permanent magnet and the coil, resulting in axial force on the housing of the unit, which is transmitted through the mounting surface to the structure.

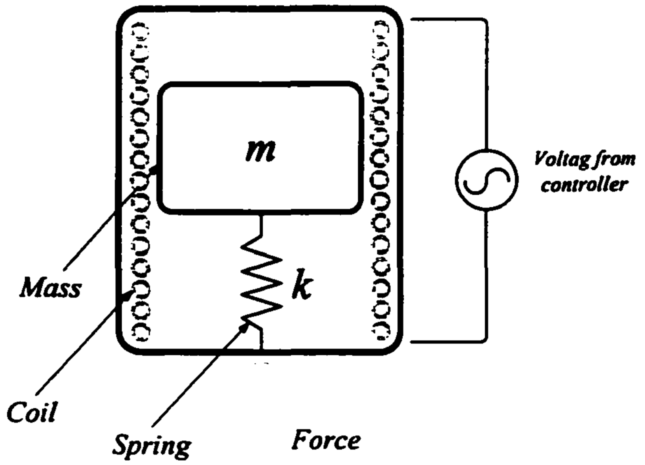


Figure 6.3 Inertial actuator

The maximum output force from the actuator is produced at the internal resonance frequency which is 43 Hz for the actuators at hand. The rotors nominal speed is between 700-900 RPM. Because the disturbance frequency (rotating imbalance) is equal to the rotational frequency, i.e. 11.67-15 Hz, the actuators must be tuned to provide a useful force output into the system at those frequencies. In general, the resonance frequency of a unit can be tuned by the modification of either the spring stiffness or the mass of the moveable element. To reduce the resonance frequency for the actuator considered here, the modification of the spring stiffness is easier than the modification of the moveable mass; so, the former modification is taken. Modifying the configuration of the spring can reduce the effective spring stiffness for the system, i.e., adding a spring in series with the original spring, as depicted in Figure 6.4. This is done by attaching the inertial actuators to a small aluminum beam as illustrated in Figure 6.5. By changing the beam length, the actuator can be tuned to frequencies between 11.67 and 15 Hz. The actuators, attachment points on the engine model are as close as possible to the measurement points to minimize control spillover.

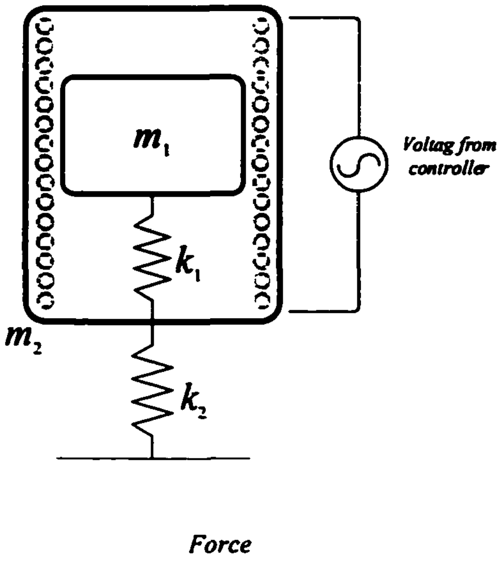


Figure 6.4 Modified inertial actuator

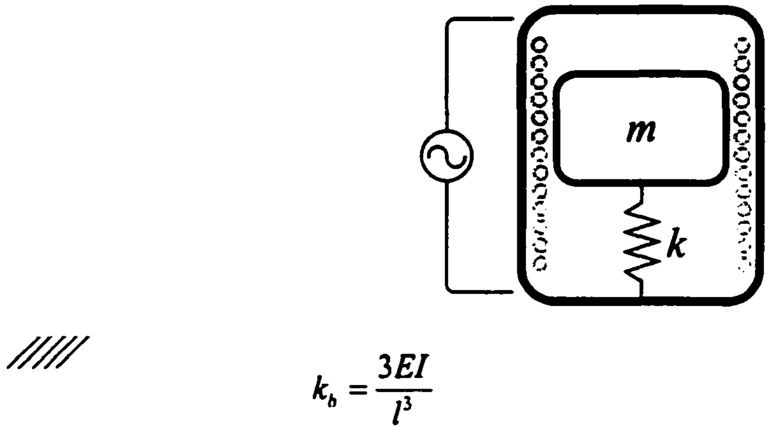


Figure 6.5 Cantilever Mechanism employed to reduce actuator resonance frequency

A Dell Dimension XPS D300 Pentium II personal computer, with 196 MB of RAM memory, is used to implement the control strategy, and to communicate with the controller card through the serial port. The operating system used is Microsoft Windows 95. Matlab's Simulink software is used for implementing the controller utilizing Realtime workshop. A Quansar Multi-Q board is installed on the computer to provide data acquisition capabilities. The card provides eight analog inputs, eight analog outputs, eight digital inputs, eight digital outputs, and three real-time clocks for use with control oriented interrupt service routines. Also installed is WinCon software, which consists of a graphical interface, which allows realtime communication between Matlab's Simulink software and Multi-Q board. The position transducer signals are inputted into the Multi-Q board so that they can be monitored, conditioned, and manipulated in Simulink. To assure that an accurate representation of the signal is achieved through the data acquisition card, a sampling rate of 1000 Hz is used. From the Ziegler Nichols's criteria, the sampling rate should be at least two times greater than the resolution that is desired. Since the desired resolution to achieve control on this system is between 11.67-15 Hz, a minimum sampling rate of 30Hz is required. With a sampling rate of 1000Hz, one is assured that the signal read is indeed an accurate representation of the system's response. The controller is implemented in Simulink, and output to the actuators through the Multi-Q card. Becuase the output signals from the card do not have enough power to drive the actuators, a Rane power amplifier amplifies the signals coming from the controller, and, thus, provides enough power to drive the actuators. Six isolated channels on the amplifier provide up to 150 times the power amplification.

6.4 System Identification of Vibration Modes

This section investigates the dynamic behavior of the experimental model. The understanding of the system performance is a prerequisite step for the effective implementation of active vibration cancellation. Experimental modal analysis is carried out on the system to identify its natural frequencies and vibration modes. Also of interest is the imbalanced response of the system, which takes the form of a whirling orbital motion. The steady state time response of the system is measured at various rotational speeds, and a frequency spectrum analysis is presented.

6.4.1 Model Testing

To developing a model that is valuable for analyzing the experimental rig vibration characteristic, frequency response functions (FRFs), characterized by output to input ratios in the frequency domain, can be used to represent the dynamic behavior of the engine and mounts model. FRFs are based on the observation that if a system is linear, a sinusoidal input excitation produces a steady state sinusoidal output at exactly the same frequency, but with a different magnitude and phase. The magnitude change and phase shift of the output to input characterize the dynamic (modal) nature of the system in the frequency domain. Analytical models, finite element analysis, or experimental measurements can be used to obtain the FRFs.

For this thesis, the experimental modal analysis is used as a tool to examine the dynamics behavior of experiment setup. Modal testing on the rig constructs the Modal Model by determining the modal parameters: natural frequencies, damping ratios, and mode shapes. This information can be used to generate both static and dynamic displays of the mode shapes. This lends a visual insight into the manner in which the structure vibrates.

Depending on the choice of input and output variables, different frequency response functions can be defined. In vibration analysis, the input and output quantities are forces and motions, where the motion variables are displacement, velocity, or acceleration. For example, receptance relates a displacement response to a force excitation. On the other hand mechanical impedance relates force output to a velocity input. The nomenclature of the various frequency response functions used in vibration analysis is given by [76]. Receptance is chosen for this thesis' study.

Four basic assumptions are made in order to perform modal testing on the experimental apparatus:

1) The structure is assumed to be linear, which permits invoking the superposition principle. In such a case, the response of the structure to any combination of forces,

simultaneously applied, is the sum of the individual responses to each of the forces acting alone. In spite of the fact that the linear assumption is simplistic, the obtained results can be considered a reasonable approximation of the structure's behavior.

2) The structure is time invariant, which means that the structural components, i.e., mass, damping, gyroscopic, and stiffness matrices, are constant with respect to time.

3) The structure follows Maxwell's Rule of Reciprocity: the measured frequency response function for a force applied at location, *j*, and a response at location, *i*, should correspond directly with the measured FRF for a force at location, *i*, and response at location, *j*.

4) The structure is observable such that enough number and locations of points can be identified for measurements to adequately describe the structure dynamic behavior.

From the homogeneous equations of motion, i.e., $\mathbf{f} = 0$, the natural vibrations can be calculated. A solution of the form

$$\mathbf{q} = \mathbf{v}e^{\lambda t} \tag{6.21}$$

is assumed and a quadratic eigenvalue problem

$$\left[\lambda^2\mathbf{M} + \lambda(\mathbf{C} + \Omega\mathbf{G}) + \mathbf{K}\right]\mathbf{v} = 0 \tag{6.22}$$

is obtained. For each rotational speed, the eigenvalue problem can be solved to give 2N eigenvalues λ_i and corresponding eigenvectors, $\mathbf{v}_i$. The eigenvalues as well as eigenvectors in most cases, occur in conjugate complex pairs,

$$\begin{array}{ll} \text{Eigenvalues:} & \lambda_j = \alpha_j + i\beta_j, \quad \bar{\lambda}_j = \alpha_j - i\beta_j \\ \text{Eigenvectors:} & \mathbf{v}_j = \mathbf{s}_j + i\mathbf{t}_j, \quad \bar{\mathbf{v}}_j = \mathbf{s}_j - i\mathbf{t}_j \end{array} \tag{6.23}$$

Thus, the eigenvalues and eigenvectors vary with the rotational speed. The dynamic behavior of the system by can be described by

$$\mathbf{v}=\left[\lambda^2\mathbf{M}+\lambda\left(\mathbf{C}+\Omega\mathbf{G}\right)+\mathbf{K}\right]^{-1}\mathbf{f}=\boldsymbol{\Lambda}\mathbf{f} \tag{6.24}$$

where

$$\boldsymbol{\Lambda}=\begin{bmatrix}\Lambda_{11} & \Lambda_{12} & \Lambda_{13} & \Lambda_{14}\\ \Lambda_{21} & \Lambda_{22} & \Lambda_{23} & \Lambda_{24}\\ \Lambda_{31} & \Lambda_{32} & \Lambda_{33} & \Lambda_{34}\\ \Lambda_{41} & \Lambda_{42} & \Lambda_{43} & \Lambda_{44}\end{bmatrix}. \tag{6.25}$$

The system receptance matrix Λ consists of different individual receptance elements, Λ_{ij}, relating the response at point i to the excitation at point j. It should be noted here that both eigenvalues and eigenvectors are needed for an expansion of the frequency response functions (FRFs) in terms of the modal parameters [76]. Due to the symmetric nature of the system receptance matrix Λ it is enough is to find a column of the matrix to identify the whole matrix [76].

The experimental procedure seeks to construct either an entire row or a column of the receptance matrix Λ. For each element Λ_{ij} the employed measurement method consists of applying an impact forcing function to a point j, of the structure while simultaneously picking up the displacement at point i. The time signals are transformed to the frequency domain by means of the Fast Fourier Transformation (FFT) and the ratio is calculated. The frequency content and the amplitude of the forcing signal can be influenced by the selection of the hammer mass, the flexibility of the impact cap, and the impact velocity. With a short impulse the energy is distributed in a wide frequency range; with long impulse, the energy is distributed in a narrower frequency range.

Typically, the transverse vibrations of a rigid rotor involve four degrees of freedom, two translations, and two rotations. For the experimental rig, considering small motion, the rotational degrees of freedom are fairly approximated with two translations as established in equation (6.10) and (6.11). Hence, two points and two directions, i.e., y_1, z_1, y_2, and z_2, are identified for the impact force application and response measurements to completely establish a modal model, corresponding to equations (6.1). The experiment setup utilized the following equipment:

- An *hp 35660A* spectrum analyzer.
- PC computer with the SMS STAR system (a specialized software for modal testing).
- Two PCB 480A 18volt power supplies (amplifiers).
- A PCB 308A Accelerometer.
- A PCB 208A03 Transducer on a medium hammer with a soft plastic tip.

The analyzer has two channels: channel 1 is connected to the force transducer on the impact hammer to measure the excitation, and channel 2 is connected to the accelerometer to measure the response. Both excitation and response signals are amplified using two power supplies. Then the data is transferred from the analyzer to the PC with the SMS STAR software for further processing.

The FRF method is used for the testing in this study. It is based upon the use of digital signal processing and the FFT (Fast Fourier Transform) algorithm to measure transfer functions between various points on the structure. A single FRF measurement is obtained by exciting the structure with a hammer at one point, while simultaneously measuring the input force and corresponding response motion signals, and then dividing the Fourier transform of the response by the transform of the input. In this case a set of transfer functions is measured between each of the two points marked with a number as shown Figure 6.2 and the single response at point #2 in the *z*-direction. The structure is excited in the two principal Cartesian directions, i.e., y-axis and z-axis, at each point, which gives a total of four transfer functions, or complete row of the transfer function matrix. The analyzer performs the following:

- Simultaneously samples the input force and response motion signals,
- Fourier transforms the sampled time waveforms,
- Computes the transfer function by dividing the input transform into the response transform.

Then, the data is transferred to the PC with SMS STAR software to perform further computations (i.e., "curve fitting"). The curve fitting is applied to the set of transfer function measurements in order to identify the modal parameters. The modal frequencies correspond to the peaks in the transfer functions. A peak should exist at the same frequency in all the measurements, except those measured at the node points where the modal amplitude is zero. The width of the modal peak is related to the damping of that mode, i.e., the wider the peak, the higher the modal damping. The mode shape is obtained by assembling the peak values at the same frequency from all the measurements. The mode shapes are displayed in animation by using the animation feature of the STAR software

Figure 6.6 shows a frequency response over the range of 0 to 50 Hertz, which is typical of the measurement set. The three peaks correspond to the natural frequency of the system, i.e. 12.8Hz, 13.8Hz, and 25Hz, at zero rotational speed. Polynomial curves are fit to each of the frequencies of interest on all of the FRFs. Then, Star is used to produce animations of the three specified mode shapes. Figure 6.7 through Figure 6.9 illustrate the mode shapes of the system. The magnitudes of oscillation are completely arbitrary, and are exaggerated to better illustrate the nature of the mode shape. The animation frames are superimposed on one image to depict several instances in time, within one period of oscillation. The structure vibrates at a combination of those modes except when it is excited with a frequency equal to its natural one, a single mode is observed to be dominating the motion.

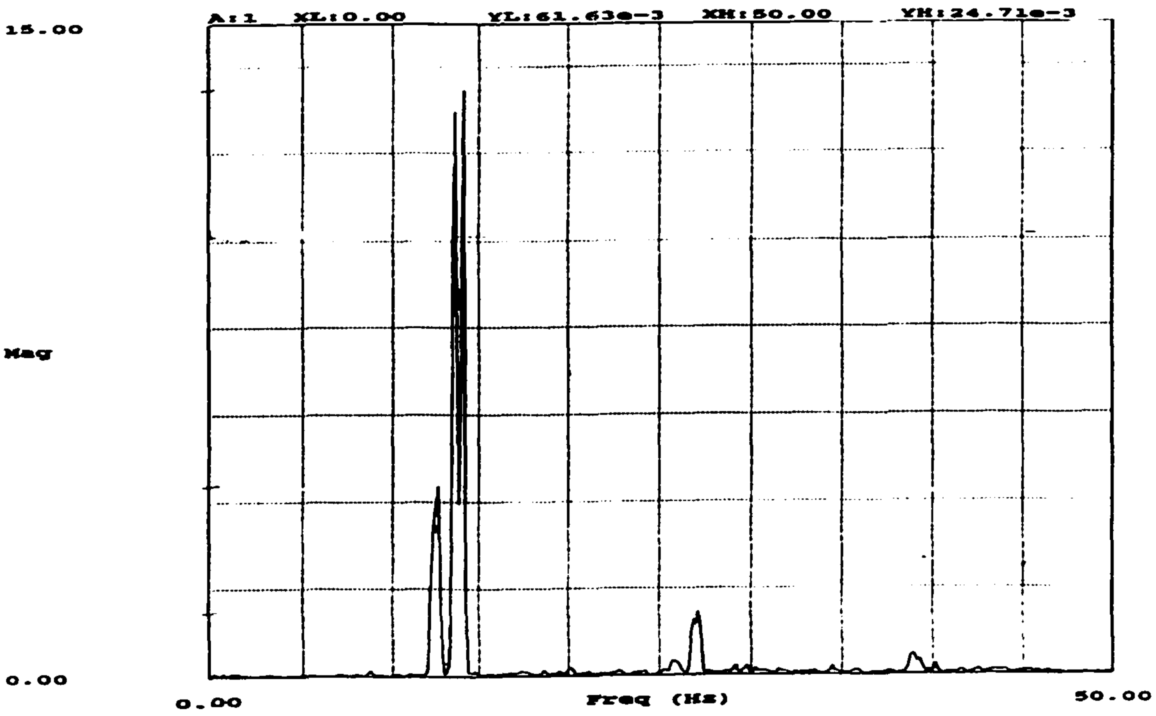


Figure 6.6 Frequency response function

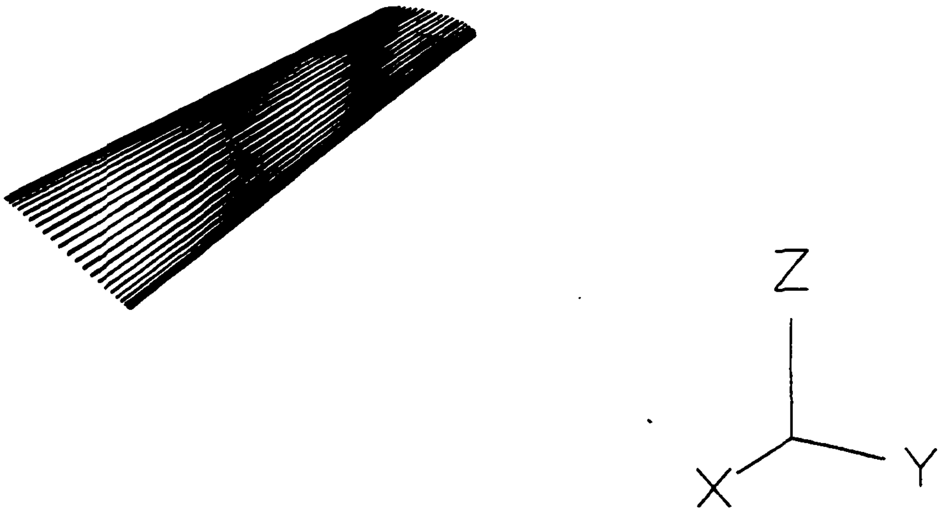


Figure 6.7 Engine model first mode shape (12.8Hz)

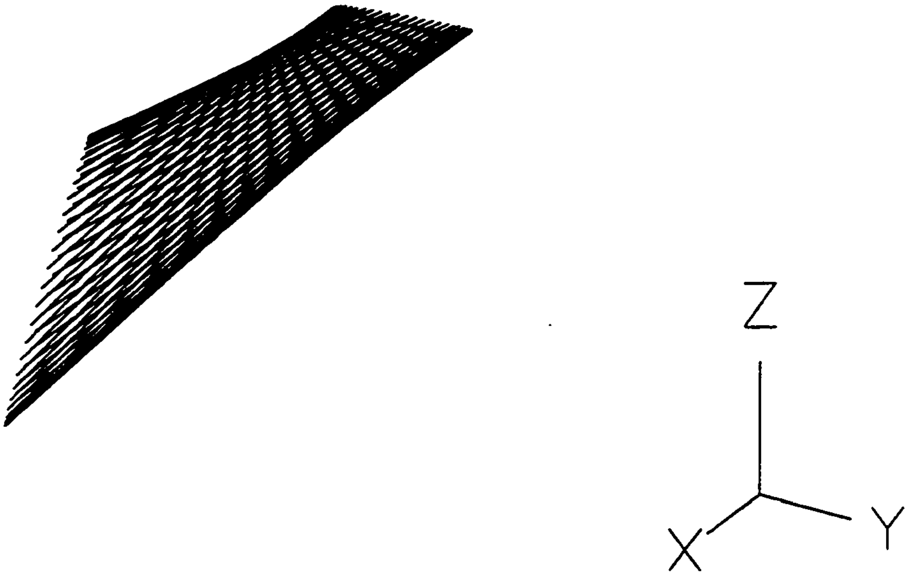


Figure 6.8 Engine model second mode shape (13.8Hz)

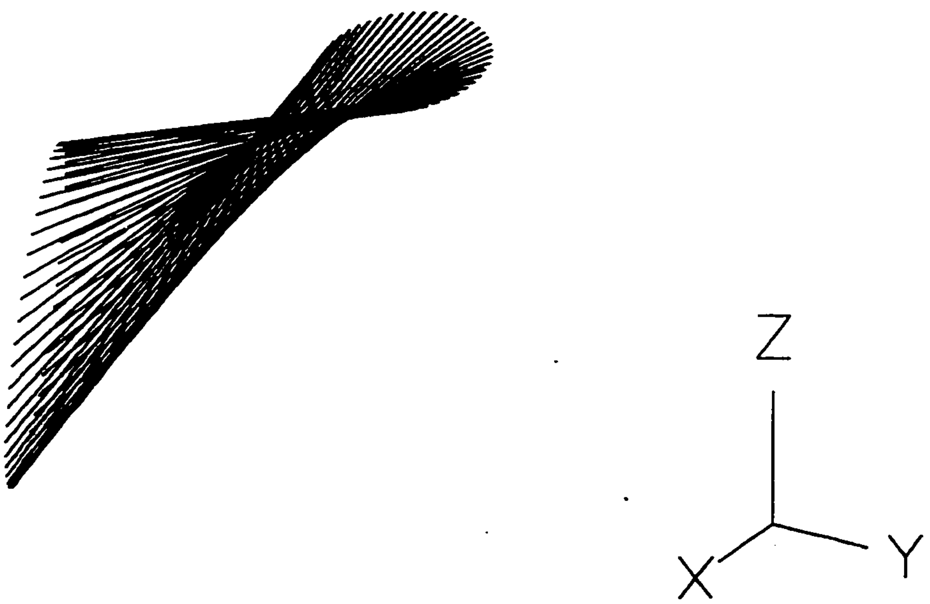


Figure 6.9 Engine model third mode shape (25Hz)

At low excitation frequencies, the apparatus vibrates in a plane parallel to *xy*-plane with little motion in *z*-direction. The rear end of the rig form an elliptical orbit, i.e., a translatory whirl. When the excitation frequencies are high, the apparatus performs conical whirl.

Knowledge of the natural frequencies and mode shapes of apparatus helps in the selection of sensors/actuators locations for active vibration control.

6.4.2 Synchronous Out-Of-Balance Excitation

Another excitation of considerable interest is that which can be generated internally in the rotating structure by virtue of its own out-of-balance, whether inherent or added deliberately. The effect of this type of excitation force can be seen by introducing the relevant forces to the equations of motion.

In order to examine the effects of the imbalance on the experimental model, a 65 g imbalance mass was attached to the DC motor. Figure 6.10 through Figure 6.17 show the orbital motion of the system as the rotational speed is varied from 790 RPM to 940 RPM. At low rotational speeds the orbital motion resembles a horizontal ellipse where the vibration amplitude in the *y*-axis is larger then in the *z*-axis for both the front and the rear ends of the engine model. As the speed is increased, there is substantial increase in the vibration in the *z*-axis direction. At higher rotational frequencies, the front vibration is oblique while the rear end motion takes the form of a vertical ellipse.

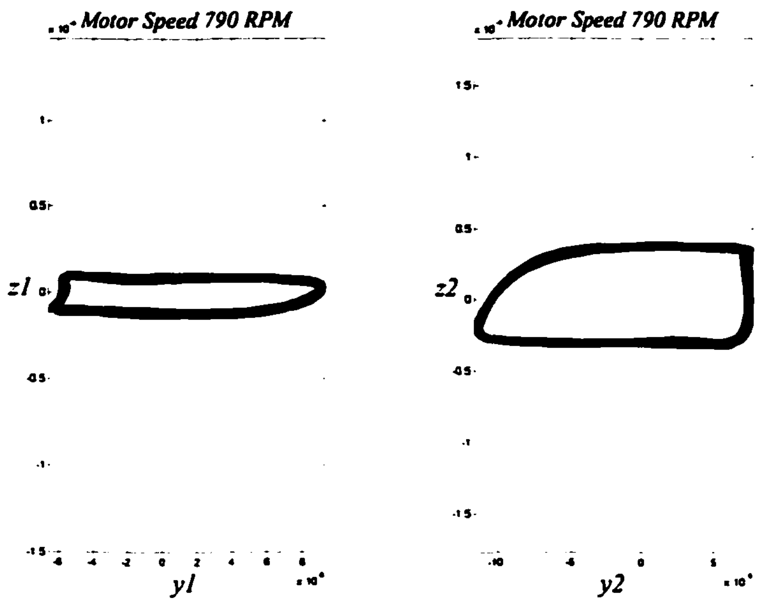


Figure 6.10 Front and rear orbital motion of the engine model at 790 RPM

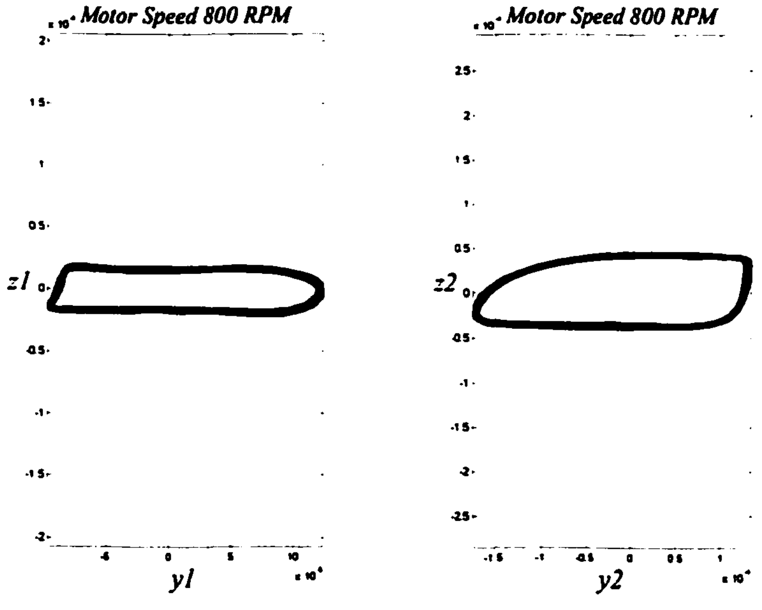


Figure 6.11 Front and rear orbital motion of the engine model at 800 RPM

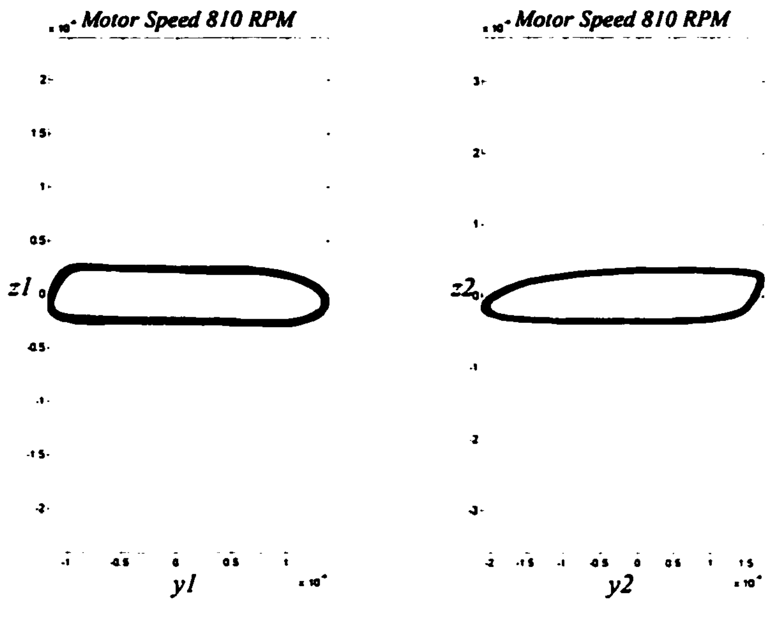


Figure 6.12 Front and rear orbital motion of the engine model at 800 RPM

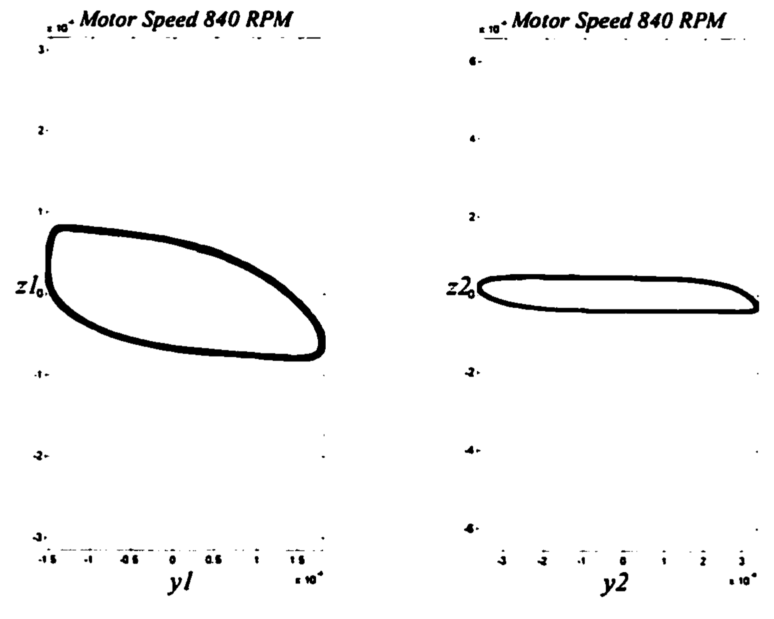


Figure 6.13 Front and rear orbital motion of the engine model at 840 RPM

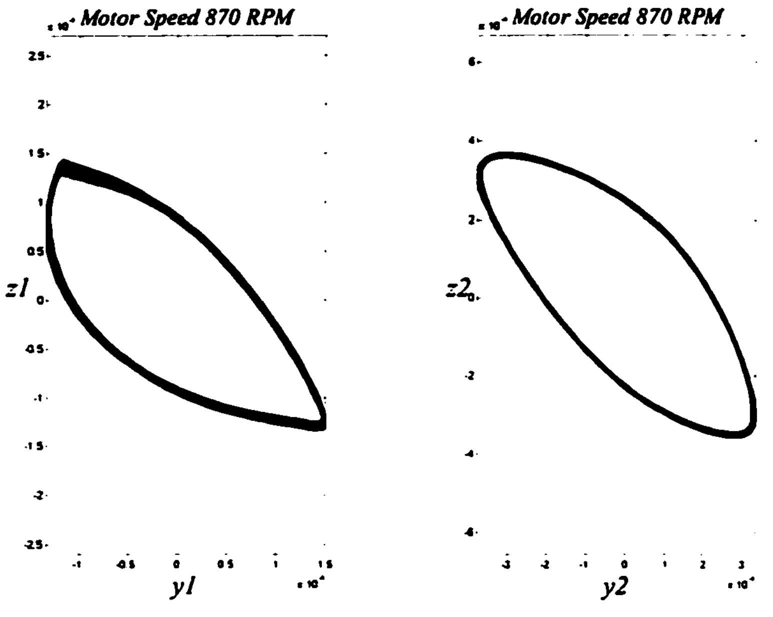


Figure 6.14 Front and rear orbital motion of the engine model at 870 RPM

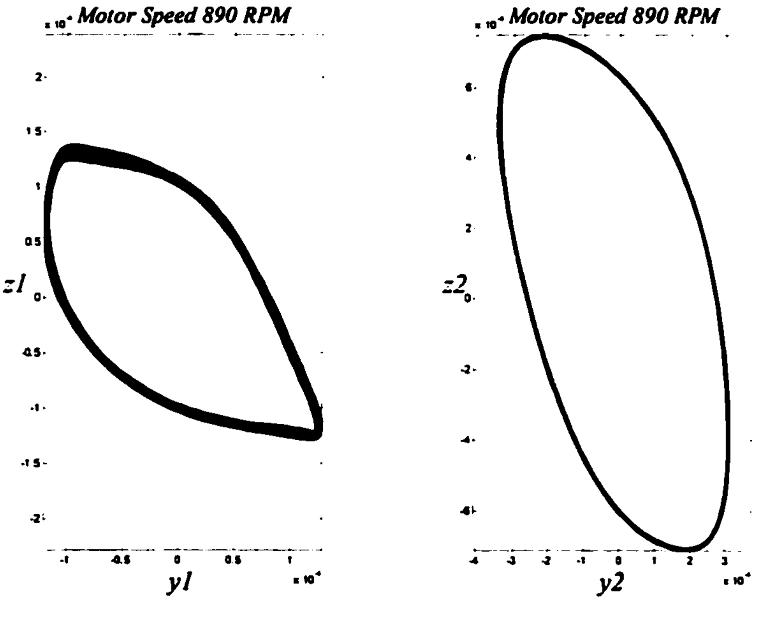


Figure 6.15 Front and rear orbital motion of the engine model at 890 RPM

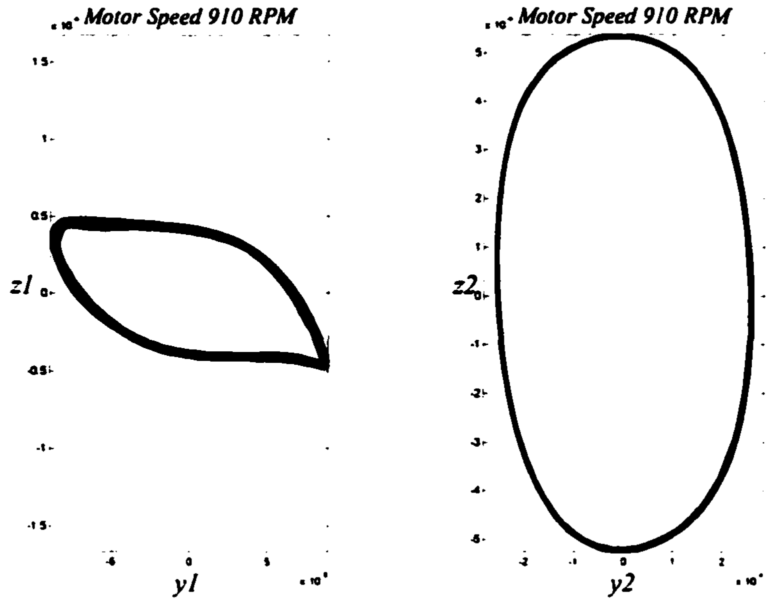


Figure 6.16 Front and rear orbital motion of the engine model at 910 RPM

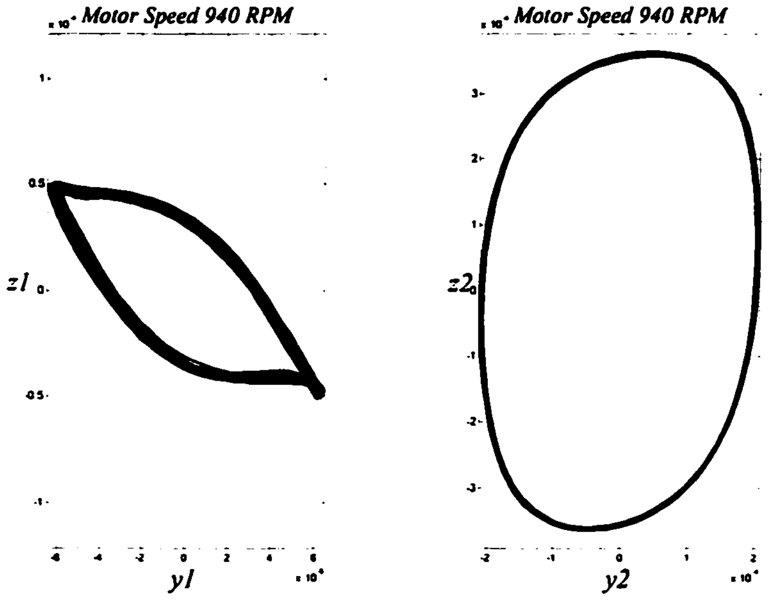


Figure 6.17 Front and rear orbital motion of the engine model at 940 RPM

6.4.3 FFT Analysis

The frequency spectrum analysis is done to identify the frequency content of the force response of the system. Figure 6.18 to Figure 6.21 depict the frequency spectrum of the response at various rotational speeds. The diagrams demonstrate that the response frequency spectrum contains an integer multiple of the fundamental frequency.

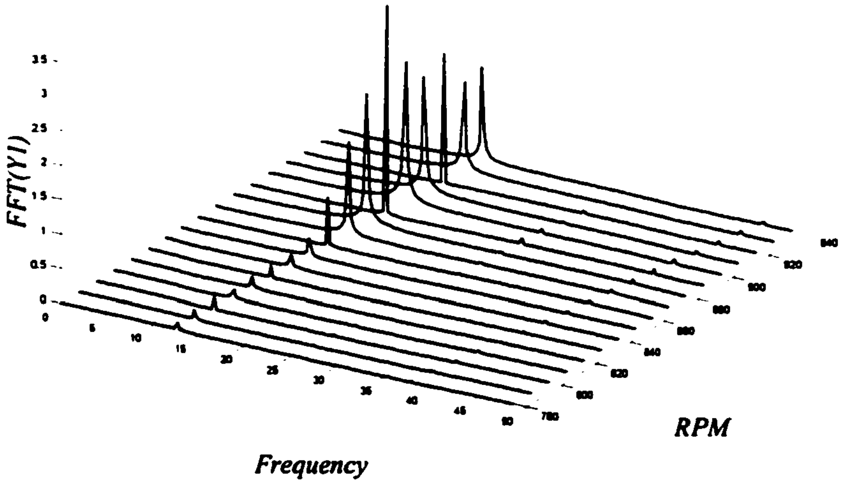


Figure 6.18 Frequency Spectrum of y_l at various rotational speeds

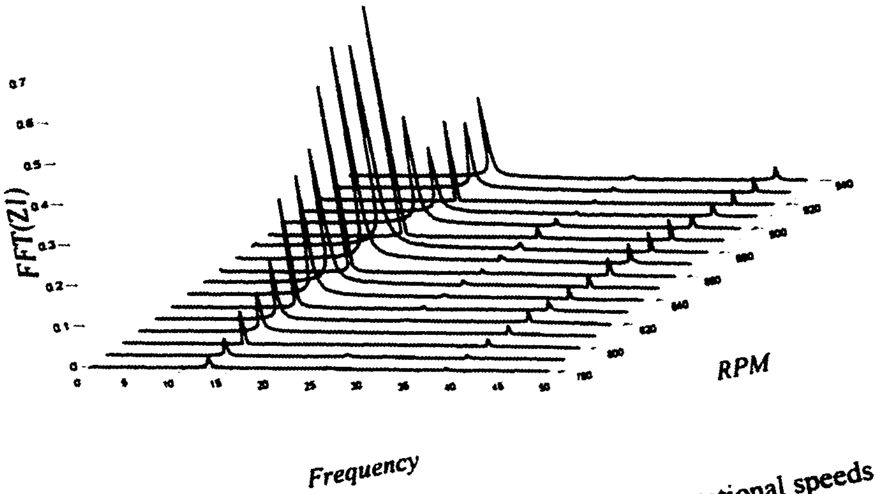


Figure 6.19 Frequency Spectrum of z_1 at various rotational speeds

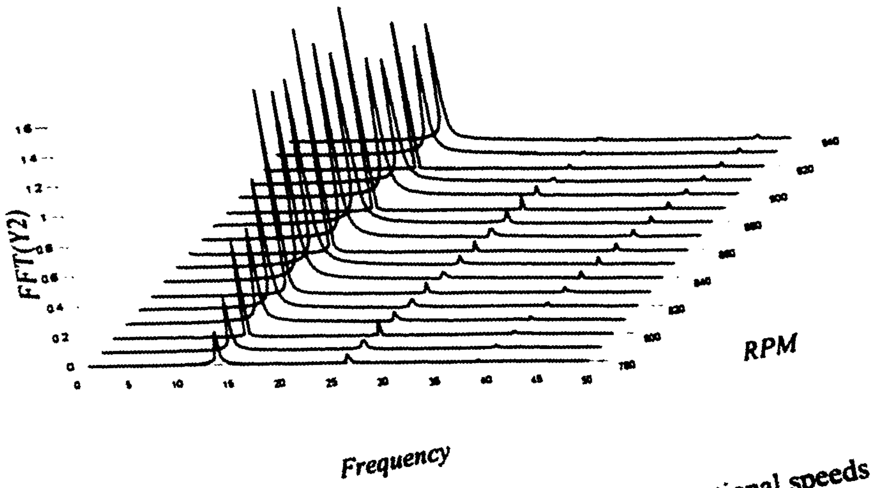


Figure 6.20 Frequency Spectrum of y_2 at various rotational speeds

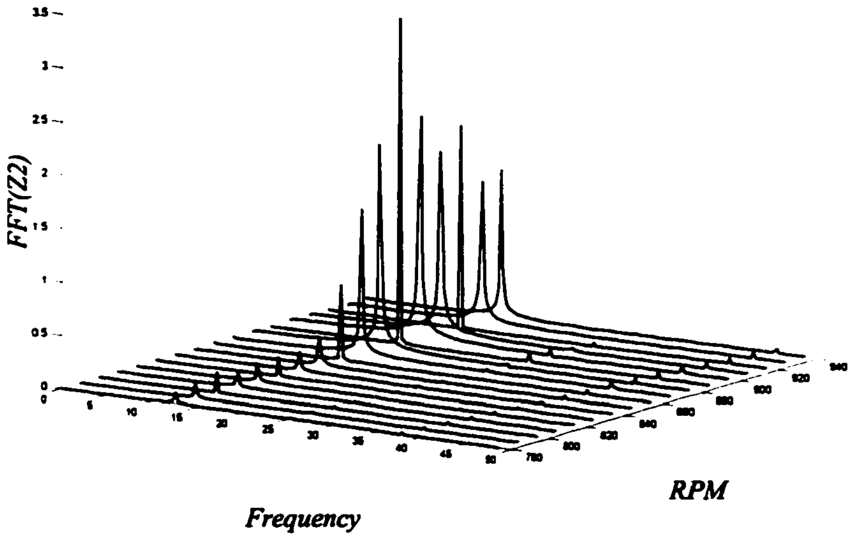


Figure 6.21 Frequency Spectrum of z_2 at various rotational speeds

6.5 Active Vibration Control Theory

The objective of active vibration control is to reduce the vibration of the mechanical system by an automatic modification of the system's structural response. In this thesis a four-channel feedback controller is implemented to minimize the effects of the imbalance on the system. Under consideration is the block diagram of a multi-channel feedback control system in Figure 6.22. The system equations of motion are rewritten to account for the control force,

$$\hat{\mathbf{M}}\ddot{\mathbf{p}} + \hat{\mathbf{D}}\dot{\mathbf{p}} + \hat{\mathbf{K}}\mathbf{p} = \hat{\mathbf{f}} + \mathbf{f}_f \tag{6.26}$$

where the vector $\mathbf{f}_f$ represents the control force derived from the action of four force actuators represented by

$$\mathbf{f}_f = \mathbf{G}_f \mathbf{u}(t) \tag{6.27}$$

where the 4×1 vector $\mathbf{u}(t)$ denotes the four inputs, one for each actuators, and $\mathbf{B}_f$ denotes the 4×4 matrix of the weighting factor, influence coefficients or actuator gains. In order to introduce the output feedback control law, $\mathbf{w}$ a 4×1 vector of the sensors outputs, is defined as

$$\mathbf{w} = \mathbf{C}_v\dot{\mathbf{p}} + \mathbf{C}_p\mathbf{p} \tag{6.28}$$

where $\mathbf{C}_v$ and $\mathbf{C}_p$ are 4×4 matrices of the velocity and displacement influence coefficients, respectively. Equation (6.28) represents those coordinates that are measured as part of the control system and is a mathematical model of the transducer and the signal processing used to measure the system's response. The input vector is selected to be of the special form,

$$\mathbf{u}(t) = -\mathbf{G}_f\mathbf{w} = -\mathbf{G}_f\mathbf{C}_v\dot{\mathbf{p}} - \mathbf{G}_f\mathbf{C}_p\mathbf{p} \tag{6.29}$$

where the 4×4 matrix $\mathbf{G}_f$ consists of constant feedback gains. This form of control law is called output feedback. The matrix $\mathbf{G}_f$ is chosen so that the response $\mathbf{p}$ has the desired property.

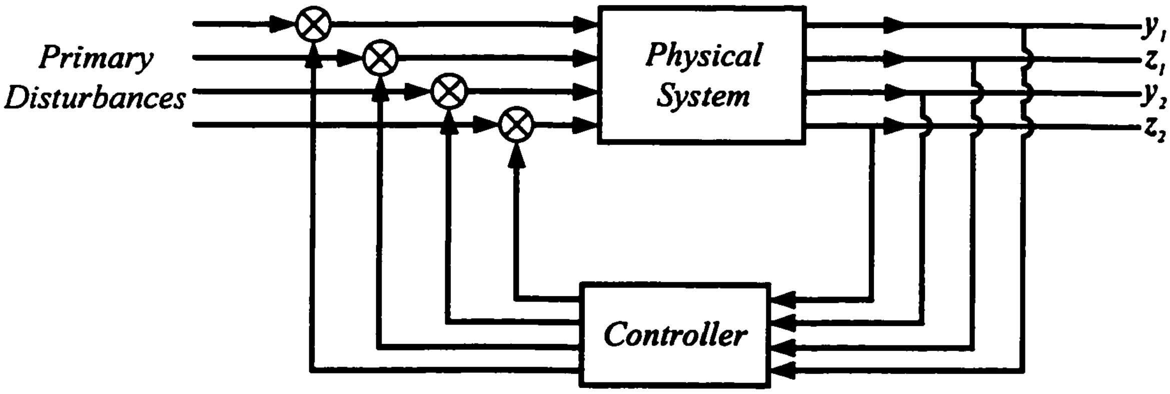


Figure 6.22 Block diagram of a feedback control of four-degree-of-freedom system

The feedback modifies the equations of motion which become

$$\hat{\mathbf{M}}\ddot{\mathbf{p}}+\left(\hat{\mathbf{D}}+\mathbf{G}_f\mathbf{C}_v\right)\dot{\mathbf{p}}+\left(\hat{\mathbf{K}}+\mathbf{G}_f\mathbf{C}_p\right)\mathbf{p}=\hat{\mathbf{f}} \tag{6.30}$$

In order to guarantee system stability in the feedback loop, an eigenvalue problem is derived from the homogenous system equations by setting $\hat{\mathbf{f}}=\mathbf{0}$,

$$\left|\hat{\mathbf{M}}\lambda^2+\left(\hat{\mathbf{D}}+\mathbf{G}_f\mathbf{C}_v\right)\lambda+\left(\hat{\mathbf{K}}+\mathbf{G}_f\mathbf{C}_p\right)\right|=0. \tag{6.31}$$

The feedback gain matrix, $\mathbf{G}_f$, must be chosen such that all the eigenvalues of the system have negative real part. The choice of the feedback gain matrix, $\mathbf{G}_f$, is a topic of on going research. For gyroscopic systems, the feedback gain matrix, $\mathbf{G}_f$, depends on the rotational speed. Also the velocity influence coefficients matrix, ($\mathbf{C}_v$), and displacement influence coefficients matrix, ($\mathbf{C}_p$), are dependent on the rotational speed.

6.6 Results and Discussion

This section describes an example of the implementation of the four channel controller. There are several approaches to such an implementation. The simplest way is to use a decentralized controller for each of the four actuators. In this case, the gain for each actuator is calculated based on the output of the sensor measuring motion in the same direction. For example, only the sensor measuring the deflection in y_l is employed to generate the force applied in y_l-direction. The number gain coefficients in this case grow linearly with the number of actuators and sensors used (assuming collocated sensors and actuators). This strategy treats each collocated sensor and actuator as a Single Input Single Output system (SISO). Since the engine-mount system is highly coupled through elastic and gyroscopic forces, this SISO method causes a control spillover. An alternative method is to treat the controller design as a Multi-Input Multi-output (MIMO) system. The signal fed to each actuator is the weighted sum of the signals collected from all the sensors. In this case, the number of gain coefficients is equal to the number of actuators/sensors square (assuming collocated sensors and actuators).

An MIMO output feedback strategy is implemented on the experimental apparatus. This is done to demonstrate the applicability of the control strategy, and its ability to significantly reduce the imbalance response. The 65 g mass is attached to the DC motor shaft to create the imbalance. The rotor speed is kept constant at 810 RPMs. This speed is close to the natural frequency of the system , and leads to magnification of the vibration. The velocity influence coefficients, C_v, are set to zero and only the position feedback is used. The composite G_fC_p matrix is of the following form:

$$\mathbf{G}_f\mathbf{C}_p = \begin{bmatrix} g_{11} & g_{12} & g_{13} & g_{14} \\ g_{21} & g_{22} & g_{23} & g_{24} \\ g_{31} & g_{32} & g_{33} & g_{34} \\ g_{41} & g_{42} & g_{43} & g_{44} \end{bmatrix}, \qquad (6.32)$$

At first, an approximate value for the gain matrix elements is found. This is done by supplying each of the four actuators, one at a time, with the maximum voltage, and then recording the deflection amplitude measured by the four sensors. The four deflection amplitudes, due to each sensor, make up a column in the gain matrix. Then each element in the matrix is divided by the largest element to find the gain matrix, the gain matrix is multiplied by a gain factor. By trial and error, the gain matrix elements are tuned such that the imbalance response is as small as possible. Another important factor in tuning the G_fC_p elements is to obtain the maximum effectiveness without saturating the actuators. Figure 6.23 through Figure 6.30 depict the effect of the feedback control on the steady state imbalance response for each point. It is evident that there is considerable reduction in the displacement amplitude of y_1, z_1, and z_2, but an increase in the amplitude of y_2. From the Frequency Spectrum, it can be seen that also the amplitude reduction occurs at the harmonics.

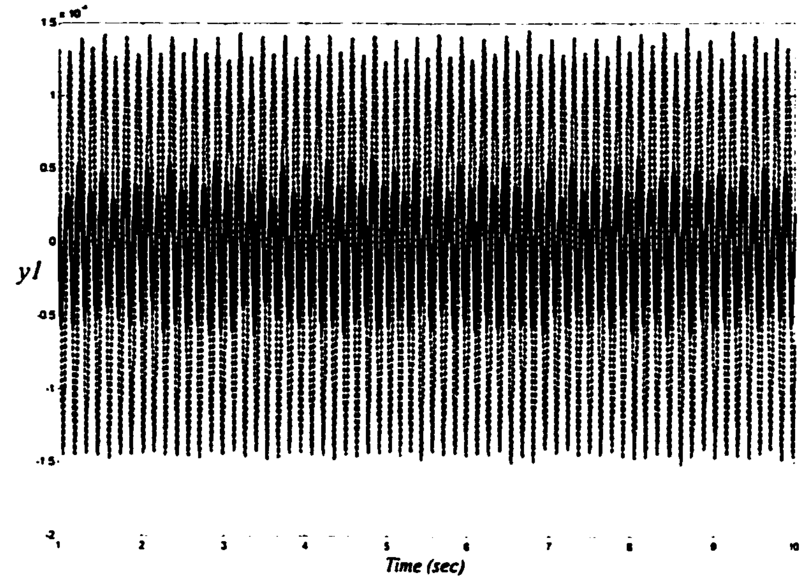


Figure 6.23 Steady state time response of y_l, (- - - -) controller off, (____) controller on

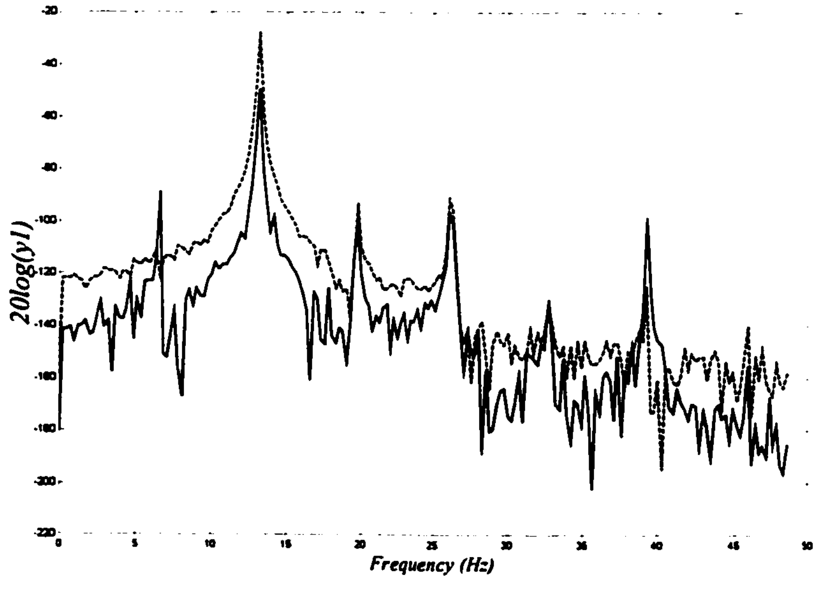


Figure 6.24 Frequency Spectrum of y_l, (- - - -) controller off, (____) controller on

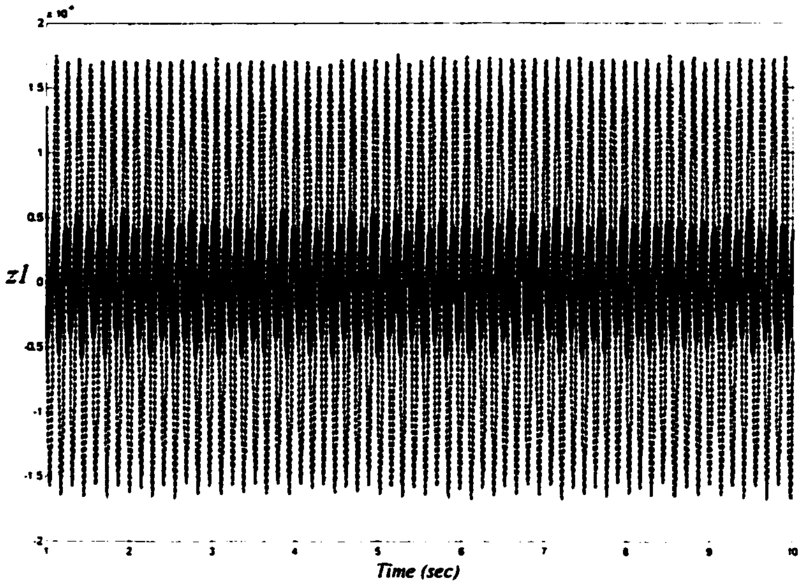


Figure 6.25 Steady state time response of z_l, (- - - -) controller off, (____) controller on

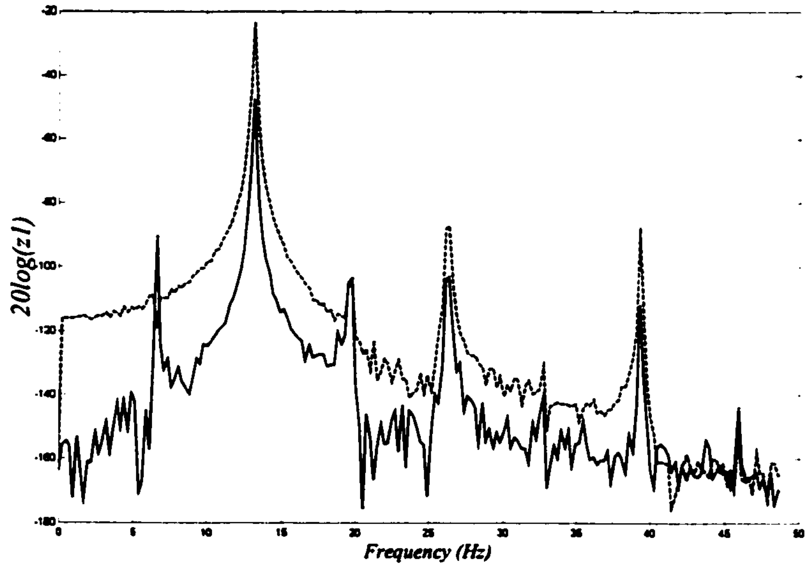


Figure 6.26 Frequency Spectrum of z_l, (- - - -) controller off, (____) controller on

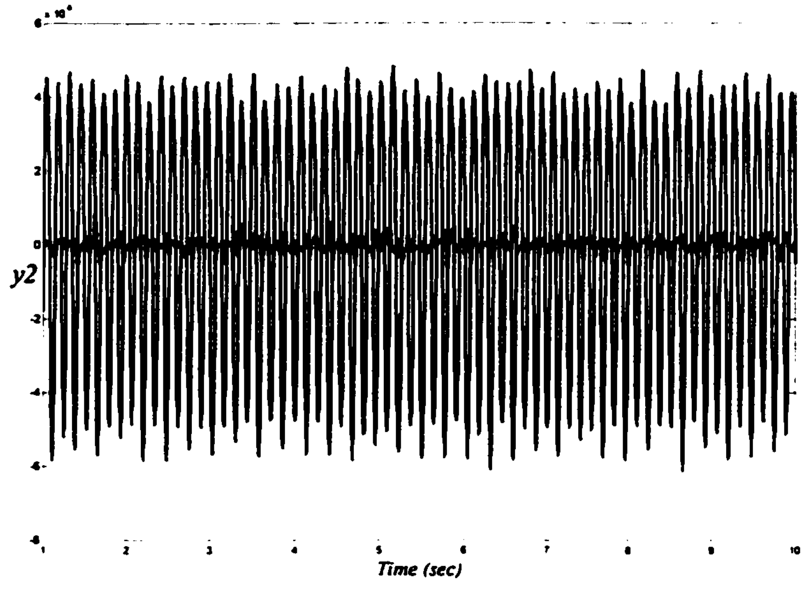


Figure 6.27 Steady state time response of y_2, (- - - -) controller off, (____) controller on

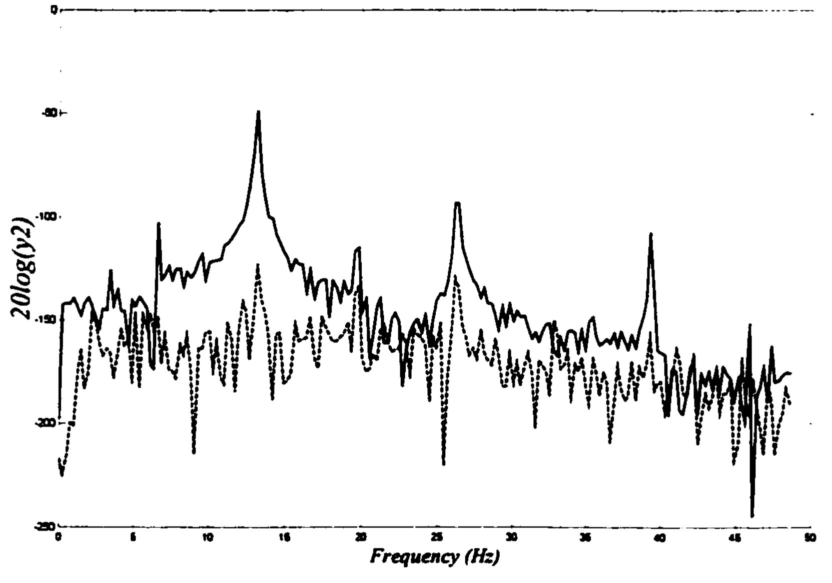


Figure 6.28 Frequency Spectrum of y_2, (- - - -) controller off, (____) controller on

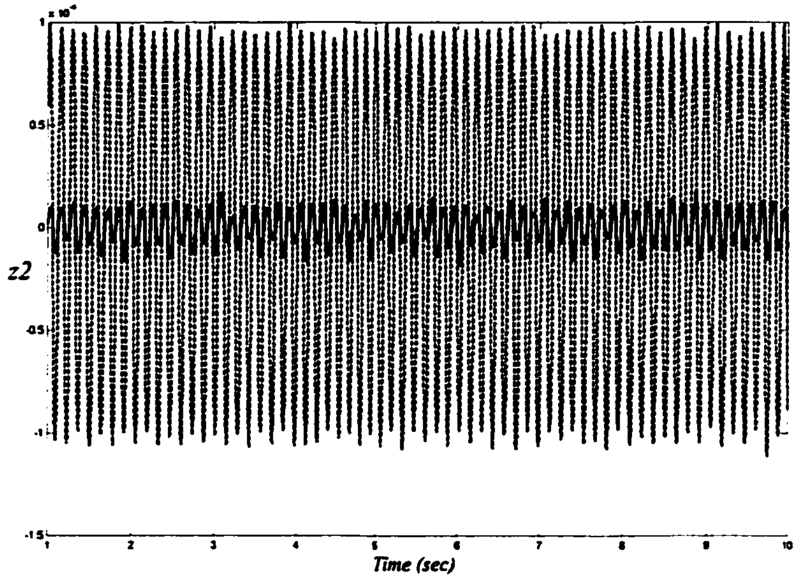


Figure 6.29 Steady state time response of z_2, (- - - -) controller off, (____) controller on

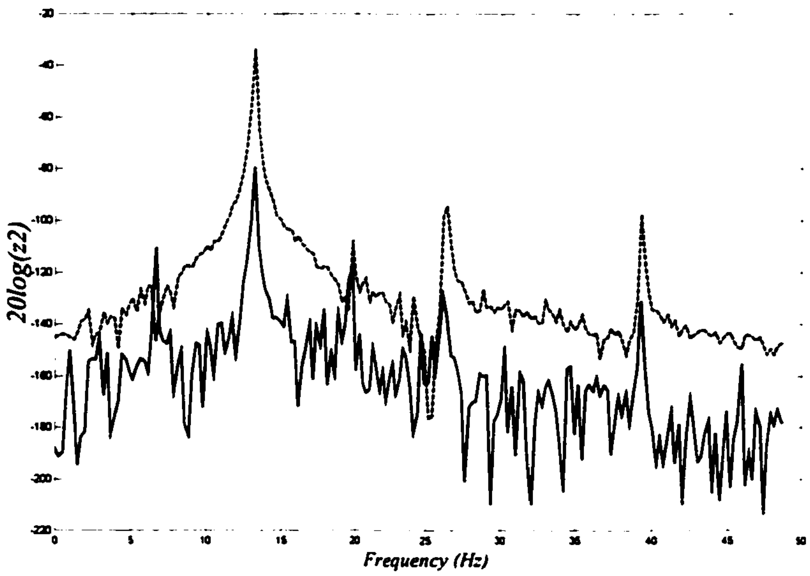


Figure 6.30 Frequency Spectrum of z_2, (- - - -) controller off, (____) controller on

Chapter 7

Conclusion and Recommendations

The objective of this thesis has been to explore various means for reducing the vibration of turboprop engines. Rotational imbalance causes engine vibration which is transmitted to the nacelle structure, which in turn, is transmitted to the fuselage. All of this introduces an uncomfortable ride for the passengers and crew in the aircraft. Unfavorable vibration and vibration-induced noise counter the benefit gained by using turboprops that are fuel-efficient in short flights.

A four bladed propeller engine is considered. The model accounts for the engines' rigid body, gyroscopic forces, blade flexibility, resilient mounting system, and aerodynamic forces. The entire system has a 10 DOF. The engine is considered to be a rigid body, fully identified by three translations and three rotations. The four additional degrees of freedom describe blade deflection. The engine is connected to the nacelle through resilient elements in order to reduce vibration transmission from the engine to the airplane structure. Then, each mount is modeled as a three directional spring. The aerodynamic forces acting on the propeller are modeled by utilizing a quasi-steady airfoil theory by considering the forces effect to be a lifting force on a cross section. The equations of motion are used to perform stability study on the system. Two types of self-excited unstable motion are identified. Mechanical instability is due to blade flexibility, whereas whirl flutter instability is due to aerodynamic forces.

The optimization of the passive vibration isolation system is addressed both analytically, and numerically. A simple two degree of freedom model is proposed. The model takes into consideration the dynamics of both the engine and the wing. The optimization method is based on the Root Mean Square (RMS) of the steady state response. The frequency response functions are derived and employed in the optimization process. The criterion for optimality is specified to be minimizing the

Root Mean Square (RMS) of the absolute acceleration with respect the Root Mean Square of the relative displacement. The results are displayed graphically, and a numerical example is given to illustrate the optimality of the obtained solutions.

Next, the Genetic Algorithm (GA) is applied to the optimization problem. First, the procedure is developed to a single degree of freedom mount, then, extended to the two degree of freedom model. The numerical results match the analytical one. The obtained set of curves allows the specification of optimal mount stiffness and damping coefficient for a given allowable deflection.

Generally, the mounts are modeled as linear springs, which are an adequate approximation for rubber-like materials. The introduction of new mounts such as hydraulic mounts, which are inherently nonlinear, requires the examination the effects of nonlinearity on the system response. Simplified equations of motion for the system are presented with nonlinear mounting. Then, an approximate periodic motion of the system is obtained by applying the method of Harmonic Balance and Averaging. Some aspects of the effects of the system parameters on the steady state response are investigated. The numerical results, which are presented, verify the analytical solution, and illustrate the effect of several important parameters on the dynamic behavior of the system examined. In addition, the direct integration of the equations of motion reveals the existence of some other, more complex responses of the mechanical oscillator studied which requires further research.

An apparatus for the experiment is built for the implementation of active vibration control. The intention is to use, a simple and cost effective, active vibration control strategy to attenuate the imbalance response. Full knowledge of the system vibration characteristic is essential for the successful implementation of the active vibration control strategy. The model's natural frequencies and mode shapes are identified using modal analysis. The time response of the system to imbalance is investigated. As the rotational speed of the model varies so does its rigid body vibration. An output feedback controller is designed and implemented on the experimental apparatus, and a noticeable reduction in vibration is realized.

The implemented controller has a limited effectiveness to a specific rotational speed. When the rotational speed of the system changes, the gain matrix coefficient must be varied. A look-up gain matrix strategy, where, the gain matrix is automatically matched with the rotational speed, may potentially provide improvement to the controller.

Future research should explore the concurrent development of passive and active vibration control system. A design process, which includes simultaneous development of both passive and active vibration control systems, may lead to a better treatment of the problem. The simultaneous design process can exploit the interaction between the two systems and use such an interaction to the advantage of the designer. Also parallel design process permits exploring novel optimal solutions that are not recognized otherwise. Currently passive and active vibration control systems are dealt with separately. Each of the two systems is designed in isolation of the other one. A better system can be produced if both design variables are calculated in a single design process. This allows using both passive system and active system variables in the optimization process.

The undertaken study shows the limitation of the use of passive suspension system to totally eliminate the unwanted vibration in turboprop engine. The Implementation of optimization techniques in the design process improves the isolation characteristics of the passive suspension system currently in use. For further enhancement to the isolation capabilities, an active vibration control system is identified as a valuable option. A hydride system, which consists of passive and active elements, increases the vibration attenuation of the suspension system. The passive elements provide the required static support and the adequate stability margin to the engine meanwhile active elements cancel the unwanted vibration.

Appendix A

Transformation Equations

This is a sample Appendix. Insert additional appendices with the "Start New Appendix" command.

$$\left\{\mathbf{i}_0,\mathbf{j}_0,\mathbf{k}_0\right\}^T=\mathbf{R}_0^1\cdot\left\{\mathbf{i}_1,\mathbf{j}_1,\mathbf{k}_1\right\}^T \tag{A.1}$$

$$\left\{\mathbf{i}_1,\mathbf{j}_1,\mathbf{k}_1\right\}^T=\mathbf{R}_1^{2i}\cdot\left\{\mathbf{i}_{2i},\mathbf{j}_{2i},\mathbf{k}_{2i}\right\}^T \tag{A.2}$$

$$\left\{\mathbf{i}_{2i},\mathbf{j}_{2i},\mathbf{k}_{2i}\right\}^T=\mathbf{R}_{2i}^{3i}\cdot\left\{\mathbf{i}_{3i},\mathbf{j}_{3i},\mathbf{k}_{3i}\right\}^T \tag{A.3}$$

$$\left\{\mathbf{i}_{3i},\mathbf{j}_{3i},\mathbf{k}_{3i}\right\}^T=\mathbf{R}_{3i}^{4i}\cdot\left\{\mathbf{i}_{4i},\mathbf{j}_{4i},\mathbf{k}_{4i}\right\}^T \tag{A.4}$$

$$\mathbf{R}_0^1=\begin{bmatrix} c_\psi c_\theta & -s_\psi c_\phi+c_\psi s_\theta s_\phi & s_\psi s_\phi+c_\psi s_\theta c_\phi \\ s_\psi c_\theta & -c_\psi c_\phi+s_\psi s_\theta s_\phi & -c_\psi s_\phi+s_\psi s_\theta c_\phi \\ -s_\theta & c_\theta s_\phi & c_\theta c_\phi \end{bmatrix} \tag{A.5}$$

$$\mathbf{R}_1^{2i}=\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{\Omega t+2\pi(i-1)/N} & s_{\Omega t+2\pi(i-1)/Nt} \\ 0 & -s_{\Omega t+2\pi(i-1)/Nt} & c_{\Omega t+2\pi(i-1)/Nt} \end{bmatrix} \tag{A.6}$$

$$\mathbf{R}_{2i}^{3i}=\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{\cos(\chi)\xi_t} & s_{\cos(\chi)\xi_t} \\ 0 & -s_{\cos(\chi)\xi_t} & c_{\cos(\chi)\xi_t} \end{bmatrix} \tag{A.7}$$

$$\mathbf{R}_{3i}^{4i}=\begin{bmatrix} c_{\sin(\chi)\xi_t} & s_{\sin(\chi)\xi_t} & 0 \\ -s_{\sin(\chi)\xi_t} & c_{\sin(\chi)\xi_t} & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{A.8}$$

Appendix B

System Matrices

The mass matrix:

$$\hat{\mathbf{M}} = \begin{bmatrix} \hat{\mathbf{M}}_{11} & \hat{\mathbf{M}}_{12} \\ \hat{\mathbf{M}}_{12}^T & \hat{\mathbf{M}}_{22} \end{bmatrix} \tag{B.1}$$

$$\hat{\mathbf{M}}_{11} = \begin{bmatrix} M & 0 & 0 & 0 & l_s m_s & 0 \\ 0 & M & 0 & -l_s m_s & 0 & l_p m_p + l_r m_r \\ 0 & 0 & M & 0 & -l_p m_p - l_r m_r & 0 \\ 0 & -l_s m_s & 0 & I_{xx} & 0 & 0 \\ l_s m_s & 0 & -l_p m_p - l_r m_r & 0 & I_{yy} & 0 \\ 0 & l_p m_p + l_r m_r & 0 & 0 & 0 & I_{zz} \end{bmatrix} \tag{B.2}$$

$$\hat{\mathbf{M}}_{12}^T = \begin{bmatrix} -S_p s(\chi) & 0 & 0 & I_{xxp} c(\chi) & 0 & 0 \\ 0 & S_p c(\chi) & 0 & 0 & I_{xxp} s(\chi) & S_p l_p c(\chi) \\ 0 & 0 & S_p c(\chi) & 0 & -S_p l_p c(\chi) & I_{xxp} s(\chi) \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{B.3}$$

$$\hat{\mathbf{M}}_{22} = I_{xxp} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{B.4}$$

$$\begin{aligned} M &= m_s + m_r + m_p \\ I_{xx} &= \left(I_{xxs} + m_s l_s^2\right) + I_{xxr} + I_{xxp} \\ I_{yy} &= \left(I_{yys} + m_s l_s^2\right) + \left(I_{yyr} + m_r l_r^2\right) + \left(I_{yyp} + m_p l_p^2\right) \\ I_{zz} &= I_{zzs} + \left(I_{zzr} + m_r l_r^2\right) + \left(I_{zzp} + m_p l_p^2\right) \\ I_b &= \int r^2 dm, \quad I_{xxp} = 4 I_b, \quad S_p = 4\int r dm, \quad m_p = 4\int dm \end{aligned} \tag{B.5}$$

Gyroscopic Matrix:

$$\hat{\mathbf{G}} = \begin{bmatrix} \hat{\mathbf{G}}_{11} & \hat{\mathbf{G}}_{12} \\ -\hat{\mathbf{G}}_{12}^{T} & \hat{\mathbf{G}}_{22} \end{bmatrix} \tag{B.6}$$

$$\hat{\mathbf{G}}_{11} = (I_{xxr} + I_{xxp}) \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & -1 & 0 \end{bmatrix} \tag{B.7}$$

$$\hat{\mathbf{G}}_{12}^{T} = 2I_{xxp} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -s(\chi) \\ 0 & 0 & 0 & 0 & s(\chi) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{B.8}$$

$$\hat{\mathbf{G}}_{22} = 4I_{xxp} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{B.9}$$

where

$$c(\chi) = \cos(\chi) \tag{B.10}$$

$$s(\chi) = \sin(\chi) \tag{B.11}$$

Centripetal Matrix

$$\hat{\mathbf{E}} = \begin{bmatrix} \mathbf{0}_{6\times 6} & \mathbf{0}_{6\times 4} \\ \mathbf{0}_{4\times 6} & \hat{\mathbf{E}}_{22} \end{bmatrix} \tag{B.12}$$

$$\hat{\mathbf{E}}_{22} = \frac{I_{xxp}}{4}\begin{bmatrix} -s^2(\chi) & 0 & 0 & 0 \\ 0 & c^2(\chi) & 0 & 0 \\ 0 & 0 & c^2(\chi) & 0 \\ 0 & 0 & 0 & -s^2(\chi) \end{bmatrix} \tag{B.13}$$

Stiffness Matrix

$$\hat{\mathbf{K}} = \left[\begin{array}{cc|c} \hat{\mathbf{K}}_{11} & \hat{\mathbf{K}}_{12} & \multirow{2}{*}{$\mathbf{0}_{6\times4}$} \\ \hat{\mathbf{K}}_{12}^{\mathbf{T}} & \hat{\mathbf{K}}_{22} & \\ \hline \multicolumn{2}{c|}{\mathbf{0}_{4\times6}} & \hat{\mathbf{K}}_b \end{array}\right] \tag{B.14}$$

where

$$\begin{aligned} \hat{\mathbf{K}}_b &= \operatorname{diag}\left(k_b, k_b, k_b, k_b\right) \\ k_b &= \omega_0^2 I_b \end{aligned} \tag{B.15}$$

and

$$\mathbf{k}_i = \operatorname{diag}\left(k_{xi}, k_{yi}, k_{zi}\right) \tag{B.16}$$

$$\hat{\mathbf{K}}_{11} = \sum_i^N \mathbf{k}_i \tag{B.17}$$

$$\hat{\mathbf{K}}_{12} = -\sum_i^N \mathbf{k}_i \tilde{\mathbf{l}}_i \tag{B.18}$$

$$\hat{\mathbf{K}}_{22} = -\sum_i^N \tilde{\mathbf{l}}_i \mathbf{k}_i \tilde{\mathbf{l}}_i + \begin{bmatrix} k_{sb} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \tag{B.19}$$

$$\tilde{\mathbf{l}}_i = \begin{bmatrix} 0 & -l_{zi} & l_{yi} \\ l_{zi} & 0 & -l_{xi} \\ -l_{yi} & l_{xi} & 0 \end{bmatrix} \tag{B.20}$$

Aerodynamic Stiffness

$$\hat{\mathbf{H}} = R^3 c_0 \rho \begin{bmatrix} \hat{\mathbf{H}}_{11} & \hat{\mathbf{H}}_{12} \\ \hat{\mathbf{H}}_{21} & \hat{\mathbf{H}}_{22} \end{bmatrix} \tag{B.21}$$

$$\hat{\mathbf{H}}_{11} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & A_1' \\ 0 & 0 & 0 & 0 & -A_1' & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & l_p A_1' & RA_2'' \\ 0 & 0 & 0 & 0 & -RA_2'' & l_p A_1' \end{bmatrix} \tag{B.22}$$

$$\hat{\mathbf{H}}_{12}^T = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2A_4 & 0 & -2l_p A_4 & 2RA_6 \\ 0 & -2A_4 & 0 & 0 & -2RA_6 & -2l_p A_4 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{B.23}$$

$$\hat{\mathbf{H}}_{21} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2RA_4' \\ 0 & 0 & 0 & 0 & -2RA_4' & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{B.24}$$

$$\hat{\mathbf{H}}_{22} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & -4RA_7 & 0 \\ 0 & 4RA_7 & 0 & 0 \\ 0 & & 0 & 0 \end{bmatrix} \tag{B.25}$$

Aerodynamic Damping

$$\hat{\mathbf{D}} = \Omega R^2 c_0 \rho \begin{bmatrix} \hat{\mathbf{D}}_{11} & \hat{\mathbf{D}}_{12} \\ \hat{\mathbf{D}}_{12}^T & \hat{\mathbf{D}}_{22} \end{bmatrix} \tag{B.26}$$

$$\hat{\mathbf{D}}_{11}=\begin{bmatrix} -2A_2 & 0 & 0 & 2RA_2' & 0 & 0 \\ 0 & -A_1 & 0 & 0 & -RA_2' & -l_pA_1 \\ 0 & 0 & -A_1 & 0 & l_pA_1 & -RA_2' \\ 2RA_2' & 0 & 0 & -2R^2A_2'' & 0 & 0 \\ 0 & -RA_2' & l_pA_1 & 0 & -l_p{}^2A_1-R^2A_3 & 0 \\ 0 & -l_pA_1 & -RA_2' & 0 & 0 & -l_p{}^2A_1-R^2A_3 \end{bmatrix} \tag{B.27}$$

$$\hat{\mathbf{D}}_{12}^T=\begin{bmatrix} 2RA_5 & 0 & 0 & -2R^2A_5' & 0 & 0 \\ 0 & -2RA_4 & 0 & 0 & -2R^2A_6 & -2l_pRA_4 \\ 0 & 0 & -2RA_4 & 0 & 2l_pRA_4 & -2R^2A_6 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{B.28}$$

$$\hat{\mathbf{D}}_{22}=\begin{bmatrix} -2R^2A_7 & 0 & 0 & 0 \\ 0 & -4R^2A_7 & 0 & 0 \\ 0 & 0 & -4R^2A_7 & 0 \\ 0 & 0 & 0 & -2R^2A_7 \end{bmatrix} \tag{B.29}$$

$$A_1=\int_\varepsilon^1 \frac{a_l(c/c_0)(J^2/\pi^2)}{\sqrt{J^2/\pi^2+\eta^2}}d\eta \tag{B.30}$$

$$A_1'=(J/\pi)A_1 \tag{B.31}$$

$$A_2=\int_\varepsilon^1 \frac{a_l(c/c_0)\eta^2}{\sqrt{J^2/\pi^2+\eta^2}}d\eta \tag{B.32}$$

$$A_2'=(J/\pi)A_2 \tag{B.33}$$

$$A_2''=(J/\pi)A_2' \tag{B.34}$$

$$A_3=\int_\varepsilon^1 \frac{a_l(c/c_0)\eta^4}{\sqrt{J^2/\pi^2+\eta^2}}d\eta \quad . \tag{B.35}$$

$$A_4 = \int_{\varepsilon}^{1} \frac{a_l\left(c/c_0\right)\left[\eta\cdot\sin(\chi) + J/\pi\cdot\cos(\chi)\right]\left(J/\pi\right)\eta}{\sqrt{J^2/\pi^2 + \eta^2}} d\eta \tag{B.36}$$

$$A_4' = \left(J/\pi\right)A_4 \tag{B.37}$$

$$A_5 = \int_{\varepsilon}^{1} \frac{a_l\left(c/c_0\right)\left[\eta\cdot\sin(\chi) + J/\pi\cdot\cos(\chi)\right]\eta^2}{\sqrt{J^2/\pi^2 + \eta^2}} d\eta \tag{B.38}$$

$$A_5' = \left(J/\pi\right)A_5 \tag{B.39}$$

$$A_6 = \int_{\varepsilon}^{1} \frac{a_l\left(c/c_0\right)\left[\eta\cdot\sin(\chi) + J/\pi\cdot\cos(\chi)\right]\eta^3}{\sqrt{J^2/\pi^2 + \eta^2}} d\eta \tag{B.40}$$

$$A_7 = \int_{\varepsilon}^{1} \frac{a_l\left(c/c_0\right)\left[\eta\cdot\sin(\chi) + J/\pi\cdot\cos(\chi)\right]^2 \eta^2}{\sqrt{J^2/\pi^2 + \eta^2}} d\eta \tag{B.41}$$

$$J/\pi = \frac{V}{R\Omega} \tag{B.42}$$

$$\eta = \frac{r}{R} \tag{B.43}$$

$$\varepsilon = \frac{e}{R} \tag{B.44}$$

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(Re)Constructing Conservation Practice: Ecological Dynamics, Socio-Institutional Change and Adaptive Management in Central Sulawesi, Indonesia

by

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A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Geography

Waterloo, Ontario, Canada, 2002

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ABSTRACT

Conservation science and practice are being transformed. A growing understanding of the complexity of interconnected social and ecological systems, the frequency with which conservation and ecosystem management initiatives have failed or led to unexpected and unpleasant surprise, and the inequitable costs of conservation action borne, in particular, by indigenous and/or local people, require that new avenues of thought and action be explored. Integrative strategies for informed action must be developed in the context of specific, problematic and complex situations. In addressing this challenge, two basic questions are asked: (i) how can we better understand the coupled nature of complex, ecological and social systems at multiple scales, and their implications for biodiversity, ecological integrity and sustainability; and, (ii) how can this knowledge and understanding be most effectively utilized by a full range of stakeholders concerned with ecosystem-based management.

Drawing on a complementary suite of theoretical and conceptual frameworks, this hybrid research has developed and applied an integrative analytical framework for conservation science and practice in upland and coastal systems in a region of Central Sulawesi, Indonesia. A nuanced and critical analysis of nature-society dynamics has been developed by linking theory, concepts and methods from complex systems, as well as political and cultural ecology, landscape ecology, and narrative analysis. Data collection has been based primarily on social science methods. Specifically, participatory appraisal activities such as community mapping, preparation of seasonal calendars, semi-formal interviews with key community informants, facilitated workshops, and transects were undertaken in eight villages in the Banawa-Marawola region. A semi-formal questionnaire was also administered to senior provincial, regional and district government officials. In addition, a 1998 SPOT image was processed using

EASI/PACE imaging software and analyzed using Fragstats™ software to generate basic landscape level metrics about vegetation and land use cover.

The resulting critique illustrates the dynamic and recursive feedback relationships among people, the environment and ecosystem transformation in both the coastal and upland systems, and suggests that conservation science and practice must move beyond deterministic planning and management approaches allied to static, equilibrium models of ecological and social change. Moreover, the analysis illustrates that interpretations of complex nature-society interactions are differentially constructed by different social actors, the implications of which fundamentally influence ecosystem understanding and opportunities for conservation policies that are equitable and sustainable. Yet, how can critical analyses of underlying narratives and the temporal and spatial dynamics of nature-society interaction support efforts to transform conservation science and practice?

Adaptive management is increasingly presented as one approach that can frame this philosophical, methodological and practical challenge. With few exceptions, however, most experience and lessons from adaptive management have been derived from temperate, North American, and/or European case studies, suggesting that the applicability of an adaptive management approach in a developing country context be viewed with skepticism. Indeed, political uncertainty, institutional capacity limitations, financial constraints and limiting worldviews are identified as impediments to the adoption of an adaptive management approach within Central Sulawesi's formal planning and resource management bureaucracy. In contrast, a locally-evolved resource management system and knowledge framework has been identified in the region which illustrates adaptive management principles: a focus on learning, innovation and flexibility, recognition of inherent uncertainty in social-ecological systems, and a non-deterministic worldview. Moreover, there is an emerging opportunity to situate the local knowledge system and management practices within a nascent socio-political movement. The territorially explicit "Kamalise" movement identified in the Banawa-Marawola region provides not only a new geographical basis for conservation practice, but also a renewed political framework within which to develop an integrated and localized vision of nature and society, as well as negotiate the partnerships and power arrangements fundamental to conservation practice.

The transformation of conservation science and practice necessitates the development and application of integrative and innovative philosophical, conceptual and methodological frameworks. As this research illustrates, therefore, central to this process of transformation is a need to: (i) contextualize and democratize the definitions and analyses of environmental transformation; (ii) reconceptualize territory, scale and nature-society interactions; and (iii) reframe adaptive management theory and practice within the new socio-politics of conservation.

Acknowledgements

There are many individuals and organizations that have contributed to my research. I would like to acknowledge the financial and logistical support provided by the International Development Research Centre and the Canadian International Development Agency through the University Consortium on the Environment, a subcontractor for the Collaborative Environmental Project in Indonesia (CEPI). I would also like to thank the many individuals in Indonesia - in communities, government agencies and non-governmental offices - who offered their time, insight and support. This includes the assistance of faculty and staff at the Environmental Study Centre at the University of Tadulako, including Pak. Mujirin, Pak. Ramli, Pak. Rauf, Pak. Moelyono, Pak. Ramadhanil, Pak. Abdul Basir and Pak. Mujib. In particular, I owe a great deal to my research assistants Abdul Hakim Languha, Evi Yuniarti and Iksan whose knowledge, experience and patience were invaluable. I am likewise indebted to my colleagues at UW and in Palu, Achmed Rizal, his wife Ibu. Sri Mallombasang, and Agus Mohamad Rahmat and his family, for offering their support and friendship. Special thanks to Dr. Tim Babcock and Ibu. Daisy Susanto in the CEPI/UCE office in Jakarta for their help, and to Pak. Muchtar (Tadulako University) for helping me while in Palu.

I have had the fortune of working with a dissertation committee that has both supported and challenged me. My advisors Dr. Bruce Mitchell and Dr. Scott Slocombe, along with my committee, Dr. James Kay, Dr. Paul Eagles and Dr. Peter Deadman, each raised challenging questions and provided valuable contributions to my work. I would also like to thank Bruce Mitchell for providing the opportunity to undertake research in Indonesia, and for his support and effort on my behalf during the tenure of my doctoral program. Special thanks as well to James Kay for his efforts in helping me "understand" complexity - a work in progress still. As well, I would like to express appreciation to my external examiner, Dr. Fikret Berkes of the University of Manitoba, for his time, effort and valuable input into the final product.

I would also like to recognize the support offered to me by my family and friends. I owe much to my good friends, Alex Mackenzie and Lorraine McCallum, for opening their home to my wife Suman and I, and our son, Aidan, whenever we were in Jakarta. Thanks to friends and family closer to home, as well, for offering their encouragement and support, especially my in-laws Virinder, Rajinder and Kamal Garcha for helping out on many occasions.

To my parents, Howard and Phyllis, I am immeasurably grateful. Their faith in someone who, well into high school, still brought schoolwork home in a crumpled ball, is testament to their encouragement, support and love. Lucky are those as fortunate as I to have such wonderful parents.

And lastly, to my wonderful wife Suman, thank you for sharing in the many changes, experiences, ups and downs of the last several years. Your friendship, support, humour, determination and love made the journey.

To Suman and Aidan...thank you.

Out of the crooked timber of humanity,
No straight thing was ever made.

Immanuel Kant
1724-1804

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1.0 TRANSFORMING CONSERVATION SCIENCE AND PRACTICE

> *Some transformations are overt and heroic; others are quiet and uneventful in their folding but no less significant in their outcome...But intellectual transformations often remain under the surface. They ooze and diffuse into scientific consciousness, and people may slowly move from one pole to another, having never heard the call to arms (Gould, 1989:79)*

1.1 Overview

Conservation science and practice are being transformed. A growing understanding of the complexity of interconnected social and ecological systems, the frequency with which conservation and environmental management initiatives have failed or led to unexpected and unpleasant surprise, and the inequitable costs of conservation action borne, in particular, by indigenous and/or local people, require that new avenues of thought and action be explored. Yet current conservation science and practice too often continue to be guided by assumptions, theoretical constructs and epistemological frameworks only recently challenged. A set of preferred strategies and policy prescriptions is applied to widely divergent conservation challenges often with limited regard to contextual realities - standardization and replicability are a primary criterion of success[1]. As one critique of the Global Environmental Facility suggested:

> *WWF is deeply concerned that the Global Environmental Facility will produce a seemingly handsome portfolio of projects that actually are only of peripheral relevance to the central development issues that threaten the viability of the biosphere. Only through a fundamental shift toward promoting sustainability, and a change in the way policies are translated into operational criteria of project design and selection by the implementing agencies, can the GEF become a dynamic vehicle for addressing development challenges of the twenty-first century (Reed in Wood et al., 2000:6).*

In deference to this concern with standardization and replication, conservation initiatives often continue to be developed and implemented in a top-down, hierarchical manner, with inadequate attention to the livelihood implications for local communities and groups (Anderson and Grove, 1987; Poffenberger, 1990; Bailey, 1996). Statements espousing the need for participation and collaboration are contained within virtually all conservation policies, programs and proposals. However, the ideas for conservation programs generally come from independent researchers or conservation advocates before winding their way through conservation organizations and international lending agencies. Plans and management strategies are usually well formulated by the time local people are aware and/or involved (Bailey, 1996). The ensuing strategies for management, whether engineered by mainline state agencies (e.g., forestry departments), international lending agencies, or international conservation organizations, too often superimpose an artificial institutional framework that alters local access to and control over resources. There is often a bias towards the creation and support of government-sponsored institutions that may not reflect local priorities - to do so would raise impediments to state consolidation of power and centralized control of natural resources (Peluso, 1993; Bailey, 1996). The technical reports on which such conservation and ecosystem management strategies are designed, although imbued with a sense of certainty, are simply deterministic treatments targeted at situations of multiple-factor complexity (Dovers and Handmer, 1995). There is rarely explicit recognition of the inadequate social and ecological knowledge brought to bear when developing programs or policies and making management decisions (Ludwig et al., 1993; Bassett and Koli Bi, 2000). Thus, the resource management practices of traditional groups are perceived as uniform in time and space, and their resource practices as either compatible with nature or environmentally destructive (Zimmerer, 2000). As Brandon (in Wood et al., 2000:8) has noted:

> *In practical terms, conservationists would like to think they are knowledgeable about how to plan and execute conservation activities. But as increasing numbers of evaluations of these activities suggest, many of today's field-based initiatives are not living up to their proclaimed potential.*

Often, coercive measures and strategies are employed (e.g., exclusionary zoning, appropriation of social and environmental assets, resettlement) to protect remnant habitats, high profile species or threatened ecosystems (Peluso, 1993; Zimmerer, 2000). Not only does the exclusionary zoning of lands and resources create a corollary requirement for greater regulation and enforcement (Peluso, 1993), but the piecemeal patchwork of zones contravenes multiple equilibrium ecological dynamics at landscape scales (Sprugel, 1991; Scoones, 1999, Zimmerer, 2000). This orientation is grounded in the doctrine of "nature-tending-toward-equilibrium" and it proceeds to support a spatially, temporally and thematically decoupled conservation planning and management approach (Zimmerer, 2000). As a consequence of the primacy accorded to this "spatial discourse" in current conservation practice (see Dinerstein, 1995), biodiversity is portrayed as predominantly spatial, mappable, and timeless (Zimmerer, 2000). Such measures are justified in the context of an international conservation agenda driven by a set of ethics and conceptions of nature far from universal (Peluso, 1993; Guha, 1997). Diverse value sets and conflicting value judgements are rarely integrated into broader decision-making processes (Barry and Oelschlaeger, 1996; Cardinal and Day, 1998). Too often, this leads to what Fairhead and Leach (1995) have termed "complicit social analyses", social critiques based on a set of assumptions that give credence to popular, although incomplete, perceptions about traditional societies and their interaction with ecological systems.

Even when built on defensible scientific foundations and a recognition of local requirements, conservation policies and ecosystem management prescriptions regularly neglect the multiple political and institutional contexts in which they are enmeshed (Peluso, 1993; Yaffee, 1996; Cortner et al., 1998; Smith et al., 1999). For example, the generation of revenue, anticipation of capital accumulation, and valuation of resources associated with integrated conservation and development (ICD) schemes (e.g., ecotourism, biodiversity prospecting) heighten the interests of government and business and encourage conservation abuses (Zimmerer, 2000). Yet conservation programs and policies still assume that nation-states instrinsically value biodiversity and ecological integrity, and desire to manage their resources sustainably for future generations (Peluso, 1993). Brittle as this assumption may be, it supports a technocratic approach to conservation and ecosystem management (e.g., NEAPs, NCSs), and has led to the growth of command and control regulatory agencies and the formulation of numerous international environmental accords and agreements (e.g., United Nations Convention of Biological Diversity) (Honadle, 1999; Bassett and Koli Bi, 2000). According to this worldview, good science is tantamount to good policy and environmental sustainability will be achieved through the judicious and logical application of appropriate information (Guha, 1997; Honadle, 1999).

Lurking at the core of these maladies is a deeper epistemological and philosophical orientation and an excess of hubris - a belief that it is possible to shape the future, rather than simply prepare for it. Such "triumphalism", as the political scientist Thomas Homer-Dixon (2000) labels it, emerges from the past success of rationally-applied science and other Western institutions (e.g., liberal democracy). While there is obviously a valid reason to acknowledge the significant accomplishments of Western science, the hubris and underlying ethnocentrisim that accompany it have proven of limited value when addressing broader ecological and social issues central to biodiversity protection, the maintenance of ecological integrity and sustainability (Stanley, 1995; Eisenberg, 1998). Although knowledge of the functional and structural attributes of ecosystems is critical, scientific understanding alone does not provide a sufficient basis to maintain environmental systems (e.g., biodiversity, integrity), and meet human needs. Social and ecological systems are tightly coupled and efforts to link knowledge and understanding of ecosystems with effective planning, policy development and implementation processes are the cornerstone of effective conservation practice and sustainable development (Lee, 1993; Gunderson, et al., 1995; Dovers et al., 1996; Holling and Meffe, 1996; Smythe et al., 1996).

The shift in thinking required to engender this transdisciplinary orientation is at times dramatic. From the outset, scientists, policy makers and practitioners must explicitly acknowledge the limitations of expert-driven, technical or formal scientific analysis. As Funtowicz and Ravetz (1993:739) suggest, a "plurality of legitimate perspectives" is at play in any environmental planning context and is inadequately brought to bear when decision making depends on the results of technical analyses. Consequently, conservation science and practice must become more inclusive about the types and sources of knowledge and information considered relevant and valuable. Stories, oral histories, anecdotes and other forms of "extended fact" are an essential source of knowledge and information (Funtowicz and Ravetz, 1993; Roe, 1994; Agrawal, 1995). Furthermore, this broader range of data types and sources must be integrated in the assessment, decision making and monitoring stages of conservation planning and management (Cardinal and Day, 1998). Participatory appraisal and other ethnographic techniques provide a useful basis on which to carry out this integration process in a systematic manner (Chambers, 1992; Beebe, 1995; Sponsel et al., 1996). As a result, the science and practice of conservation should be viewed as involving "civic" activities; tools and resources for research and analysis need to be provided to a full range of stakeholders, not just those associated with formal institutions and regulatory mandates (O'Riordan, 1994; Nelson and Serafin, 1994; Walters, 1998). Finally, the underlying influence of political and institutional conditions on environment and conservation practice must be recognized. In this context, the potential of local (i.e., decentralized), collaborative institutional arrangements as sources of social learning and innovation must be explored.

The backdrop to the required epistemological and philosophical transformation of conservation science and practice is dispiriting. Cumulative impacts of exponential population growth and economic development are creating unparalleled ecological stress and biodiversity loss, particularly in developing countries. While tropical rainforests contain approximately 50% of the species on earth, they are disappearing at an average annual rate of 1.15% (FAO in Rudel and Roper, 1997; Olson and Dinerstein, 1998). Current species extinction rates are estimated at between 1000 and 10,000 times the normal background extinction rate expected in the absence of human influence (Wilson, 1989; Raup, 1991; Meffe and Carroll, 1994; Holdgate, 1996). Consequently, it is estimated that up to 25% of the Earth's biodiversity will likely disappear in the next 100 years (UNEP, 1995). As a "megadiversity" country (see Table 1.1), Indonesia provides habitat for 12% of the world's mammals, 15% of all known amphibians and reptiles, 17% of all birds, 37% of the world's species of fish, and 11% of the world's flowering plants (GOI, 1997). However, an estimated 900,000 ha to 1.3 million ha of forested land in Indonesia are cleared every year, while 126 birds, 63 mammals, and 21 reptiles are at risk of extinction, and 36 timber species are threatened (GOI, 1997). Such extinction risks are of particular concern in Sulawesi, given the island's high level of endemism. Of the 127 native mammals in Sulawesi, 79 (62%) are endemic. If the 45 bat species in Sulawesi are excluded from this count, the figure rises to an astonishing 98%. By comparison, only 18% of the mammalian fauna of the island of Borneo are endemic, although the total mammalian count is significantly higher. In addition, 88 species (or 34%) of all birds found on the island of Sulawesi are endemic - a level of endemism that is second in Asia only to Papua New Guinea.

The general causes of environmental decline in Indonesia, and elsewhere, that threaten such significant biodiversity values are understood. Direct stressors may include human population growth, deforestation from agricultural intensification, logging and forestry operations, land clearing for plantations and cattle ranching, urban and industrial development, as well as excessive harvesting of fuelwood and non-timber forest products (Harrison, 1987; McNeely et al., 1990; Sponsel et al., 1996; GOI, 1997). Approximately 40 million Indonesians depend directly on biological diversity, using more than 6000 species of plants and animals for subsistence purposes. As well, Indonesia's forests contain 100 timber species that provide average annual exports worth $US 4.5 billion (GOI, 1997). Such factors and circumstances are exacerbated by international commodity prices, debt, trade inequities, low literacy and education levels, local economic requirements, and poverty (Redclift, 1987; IUCN/UNEP/WWF, 1991; Rudel and Roper, 1997; GOI, 1997). Throughout much of the Indonesian archipelago, government-sponsored transmigration from the highly populated island of Java to the outer islands adds a further complicating factor (Fearnside, 1997), while Indonesia's ongoing economic and political crisis creates a situation of social and cultural tension.

Table 1.1: Comparison of biotic categories and known species in Indonesia and the World

Category	Indonesia (species)	World (species)
Bacteria, blue-green algae	300	4,700
Fungi	12,000	47,000
Sea grasses	1,800	21,000
Moss	1,500	16,000
Ferns	1,250	13,000
Flowering plants	25,000	250,000
Insects	250,000	750,000
Molluscs	20,000	50,000
Fish	8,500	19,000
Amphibians	1,000	4,200
Reptiles	2,000	6,300
Birds	1,500	9,200
Mammals	500	4,170

Source: GOI, 1997

Indonesia is now regarded as one of the poorest countries in the world, with economic growth declining to negative 14% in 1998, while the proportion of people living below the official government poverty line rose from 11.3% to 24.2% between 1994 and 1998 (UNICEF, 2000).

Less clear, of course, are the solutions to these complex problems and circumstances, given our limited understanding of the long-term ecological implications of environmental change, the dynamic socioeconomic, cultural and political context in which these variables coalesce, and the failure of past resource management practice. Developing and maintaining functioning ecological and social systems at multiple scales represents a fundamental challenge for sustainability. As Rollings and Brunckhorst (1999:65) argue:

> *The critical interplay between ecosystem function, institutional economics, culturally defined land tenure, land use, social and civic elements, and resource governance has generally been ignored in theoretical and applied research.*

1.2 Integration, Convergence and the End of Science

This thesis seeks to cover much territory, and my specific intention has been to develop and apply a conceptual and methodological framework that explores much of the *extant* literature. That is because this dissertation is, in many respects, about a critical need confronting conservation science and practice – the need for better integration and intellectual convergence (see Gober, 2000; National Research Council, 2000). This quest for integration and synthesis in resource management is not a recent phenomenon (see Geddes, 1915 and MacKaye, 1928 cited Slocombe, 2001; McHarg, 1969). Early regional scientists and planners sought to provide comprehensive frameworks to address ecological, economic and social system variables (Isard, 1972; Friedmann and Weaver, 1977; Hodge, 1994; Robinson and Hodge, 1998). However, as Hodge (1994:35) noted, there has been "...neither a sequential process of development of forms and practices, nor a definitive doctrine to which [regional planning and development] can be related". Consequently, early planning science and practice were dominated by economic perspectives and the use of administrative, rather than natural, boundaries (Slocombe, 1993a). Broader policy issues relating to ecological, social, political, and institutional development were given inadequate attention. A reliance on synoptic planning processes, economic methods (e.g., cost-benefit analysis, input-output analysis), and expert-driven, technical analyses further limited the impact of conventional environmental planning science and practice (Isard, 1972; Friedmann and Weaver, 1977; Briassoulis, 1989; Slocombe, 1993a). As a result, there remains a need for frameworks, conceptual tools and methodological approaches whose focus is, or ought to be, the integration of human, biological and physical dimensions of ecosystems across scales to support the goals of assessment, planning and management decision making (Slocombe, 2001).

More specifically, integrative approaches must seek to construct a quantitative and qualitative understanding of critical social-ecological system dynamics at multiple scales, incorporate indigenous knowledge and management practices, promote collaborative social learning among a broad range of stakeholders, and create flexible institutional and decision-making conditions. This is particularly true in many tropical regions in which improved conceptual tools, procedures and planning methodologies are urgently required to facilitate the co-evolutionary development of socioeconomic and ecological systems. As Woodhill and Röling (1998) have suggested, integrative strategies for informed action need to be developed in the context of specific, problematic and complex situations. Methodology, they argue, is likely the most appropriate meeting ground for the philosophical and pragmatic issues these strategies will engender.

Understanding and conceptual tools are available from many sources (formal and non-formal) and intellectual traditions to improve the science and practice of conservation. For example, the philosophical foundations for reconstructed conservation science and practice can be found in the writings and critiques of Enlightenment philosophers. Much of this writing stresses the dangers of drawing rigid distinctions about right and wrong, identifying objective "truths", and seeking uniformity or standardization. Humility, or an understanding of the limits to our knowledge and power, is a further theme in the writings of several Enlightenment philosophers such as (e.g., Vico, Kant, Pascal as discussed in Berlin, 1998). Consequently, this research has been undertaken with the belief that we must be humble in the way we perceive the natural world, how we interact with natural systems, and most importantly, how we make proposals and prescriptions to manage those systems. The conceptual and methodological framework I have sought to develop and apply is not intended to be an algorithm that will lead to ideal conservation science, practice and policy implementation. In no way should the conclusions drawn from the analysis of ecological-social systems in Central Sulawesi outlined in the following chapters be perceived as prescriptive.

Indeed, the transformation of the science and practice of conservation is not about developing new analytical methods, making pristine discoveries, or advancing by seeing the unseen (Gould, 1989). Nor, as Gould (1989:80) stated, is transformative science about "extending the boundaries of complex and expensive artifice". Rather, transformative science is about the integration and synthesis of complementary theories and concepts in an effort to create emergent understanding to address issues of surprise and uncertainty, and the mechanisms to encourage collaborative social learning. In fact, most of the ideas and constructs outlined in this dissertation are not new. To my knowledge, however, these ideas have not been brought together and synthesized in this manner in an effort to explore some potentially useful conceptual tools, and to capture additional insight into some of the inherent complexities of conservation science and practice. As a result, I believe the ideas outlined have heuristic value that can enhance the way conservation scientists and practitioners perceive and address the problems and challenges we face along the path towards a sustainable future generally, and more specifically in Central Sulawesi.

This research, then, is what Horgan (1996) might call "ironic science". Ironic science is a form of science more associated with literary criticism because it seeks to offer points of view, interesting insights, and informed opinions that can improve planning and management, but that do not necessarily converge on empirically verifiable truths, generate rigorously deduced conclusions, or follow strict rules of inference. I hope in the following pages, however, that the limitations of such rigid conceptions of conservation science when applied to complex, uncertain and heterogeneous environments are illuminated. In a more proactive sense, I hope to integrate and apply a suite of conceptual and analytical tools for planning and management that may offer a more suitable lens through which diverse conservation challenges can be viewed and reviewed - tools inherently more sensitive to uncertainty, complexity, and change. As Horgan (1996:158) stated:

> *Scientists.....are, of course, chasing after facts, but they can only capture facts, if at all, retrospectively; by the time they reach some understanding of what has taken place, the world has moved on, inscrutable as ever.*

1.3 Chasing Facts: Key Questions, Study Context and A Direction for Research

This exploration of the move towards reconstructed conservation science and practice addresses two basic questions: (i) how to better understand the coupled nature of complex, ecological and social systems at multiple scales, and their implications for biodiversity, ecological integrity and sustainability; and (ii) how this knowledge and understanding can be most effectively utilized by a full range of stakeholders concerned with ecosystem-based management. These questions have been explored in two sociobiophysical systems in the physiographically heterogeneous Banawa /

Marawola region of Donggala District, Central Sulawesi, Indonesia[2] (Figure 1.1; Figure 1.2): (i) an upland swidden agricultural and resource management system; and (ii) a mangrove forest / fish pond (*tambak*) system associated with extensive coastal areas throughout the region. Combined, the upland and coastal study area covers an area of approximately 76,600 hectares (Table 1.2; Annex I).

Table 1.2: Land Cover in the Study Area (1998)

Land Cover / Use	Area (ha)	Percent of Landscape
Mature Forest	34,466	45
Secondary Forest (disturbed, revegetating)	21,449	28
Mangrove Forest	172	0.2
Mixed Agriculture / Estate Crop (cocoa, clove, coconut)	18,357	24
Irrigated Rice	402	0.52
Swidden Plots (rainfed rice, corn and recently cleared lands)	1283	1.7
Fish Pond	391	0.5
Water (river, stream, lagoon)	87	0.1
Total	**76,607**	**100**

Source: Results of processed Spot image and subsequent analysis (see section 2.3.5)

Altitudes range from zero to over 2000 metres above sea level, and soils are typically composed of fragile, weakly developed fluvisols and regisols in coastal areas, along with podzols and lithosols in upland regions. Threatened endemic species in the region include the maleo (*Macrocephalon maleo*, a small forest bird whose eggs are harvested by local people), anoa (*Anoa* sp., a small forest buffalo), ebony (*Diospyros celebica*), and the black orchid (*Phalaneopsis celebiencies*) (Whitten et al., 1987; Centre for Environmental Studies, 1998). Not surprisingly, the forests of Sulawesi are noted for their regionally high degree of endemism in a range of taxa. This has led the WWF-US (Olson and Dinerstein, 1998) to identify tropical forest systems in Sulawesi as a Global 200 target (i.e., an outstanding example of the world's diverse ecosystems and one of 200+ priority targets for conservation action).

Figure 1.1: Banawa-Marawola Region, Central Sulawesi

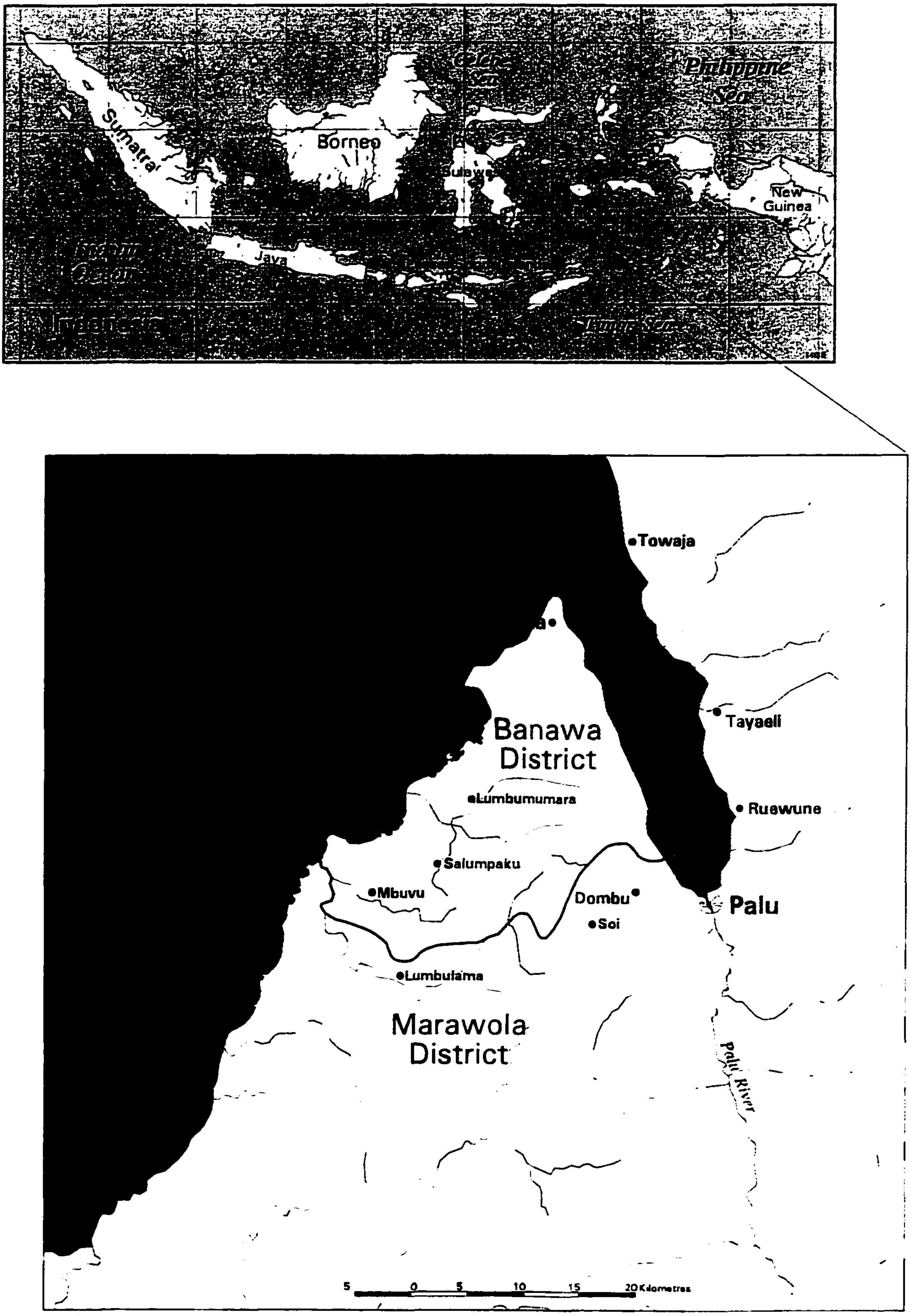


Figure 1.2: Processed Spot Image of Donggala Peninsula, Central Sulawesi

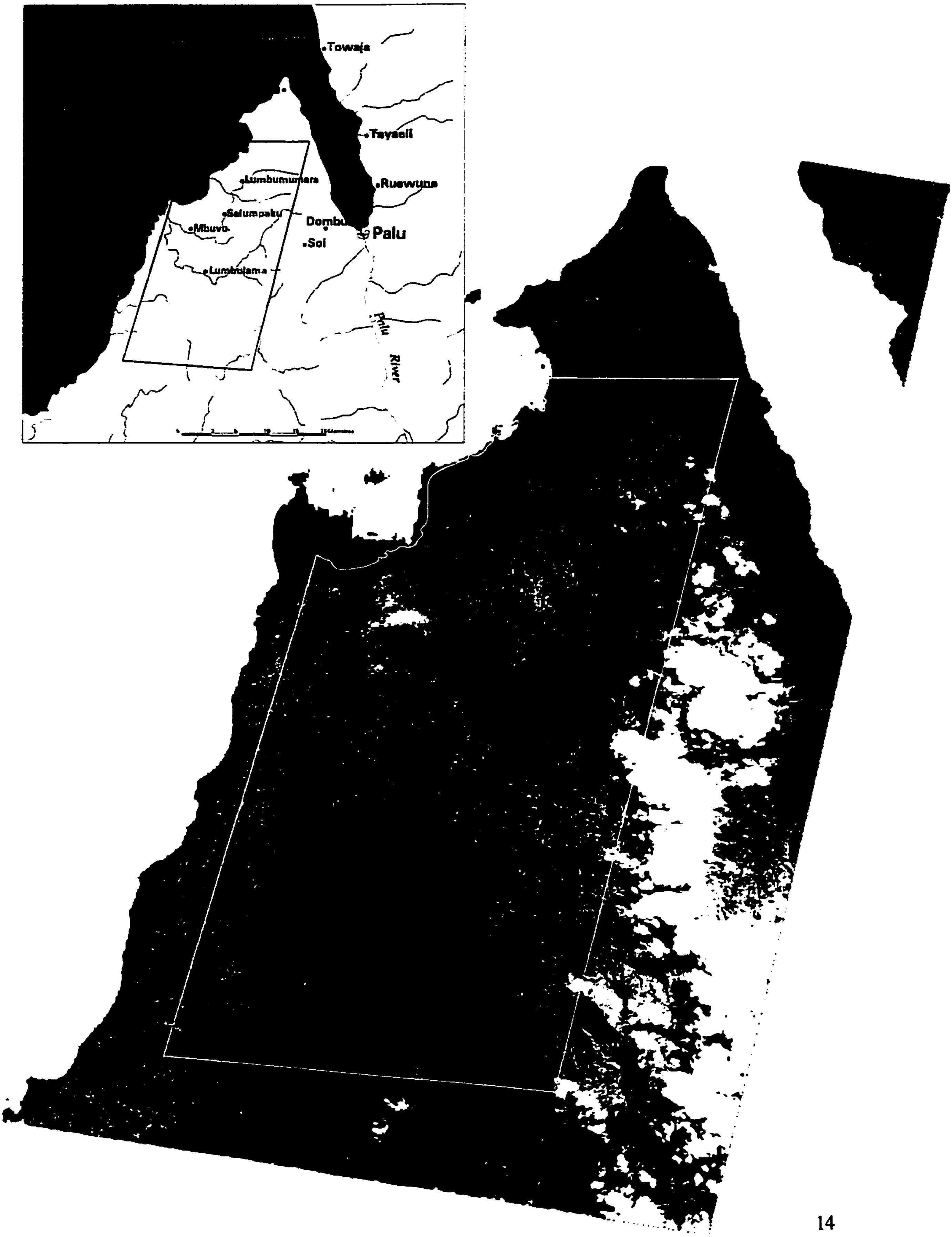
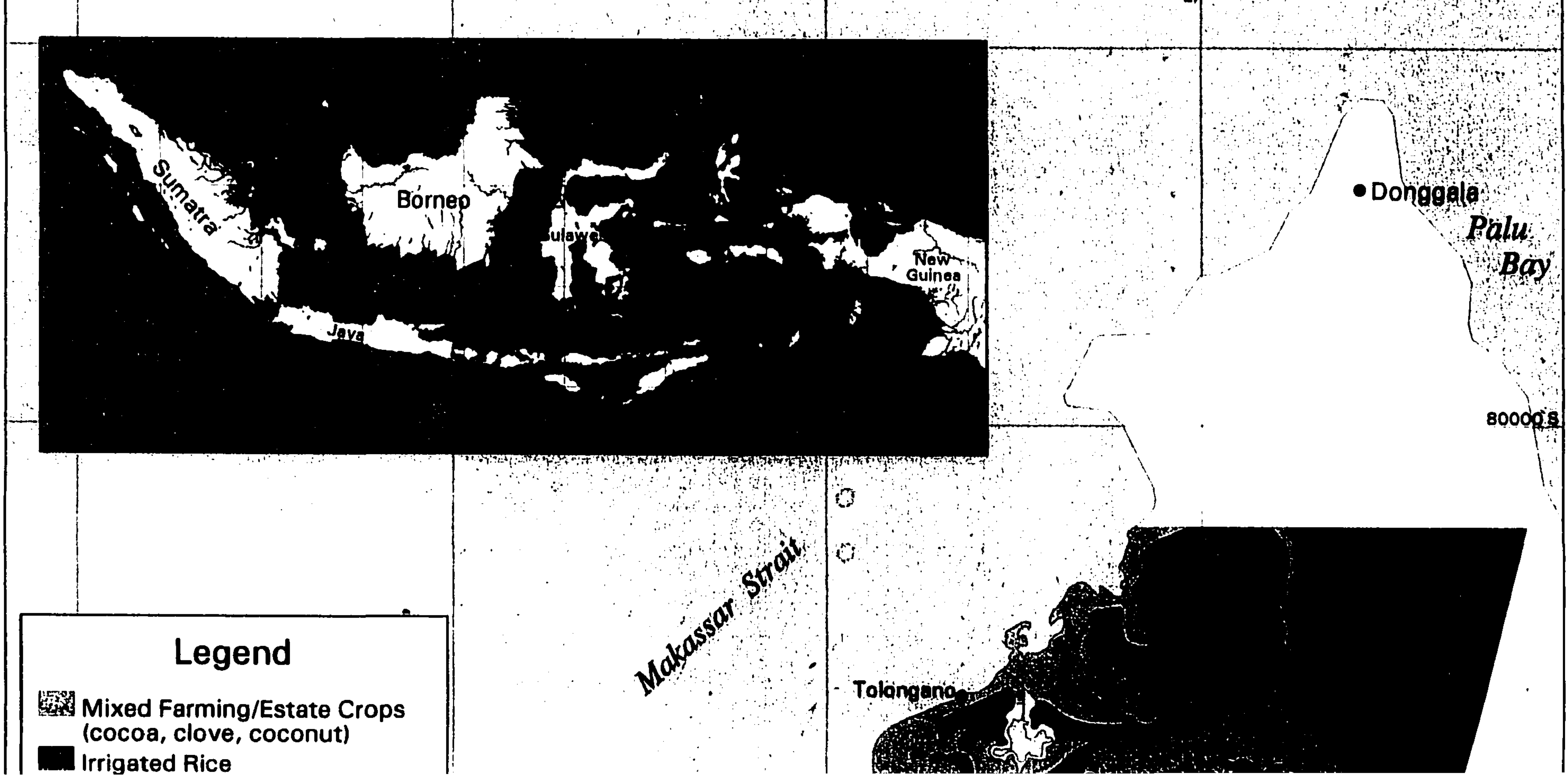
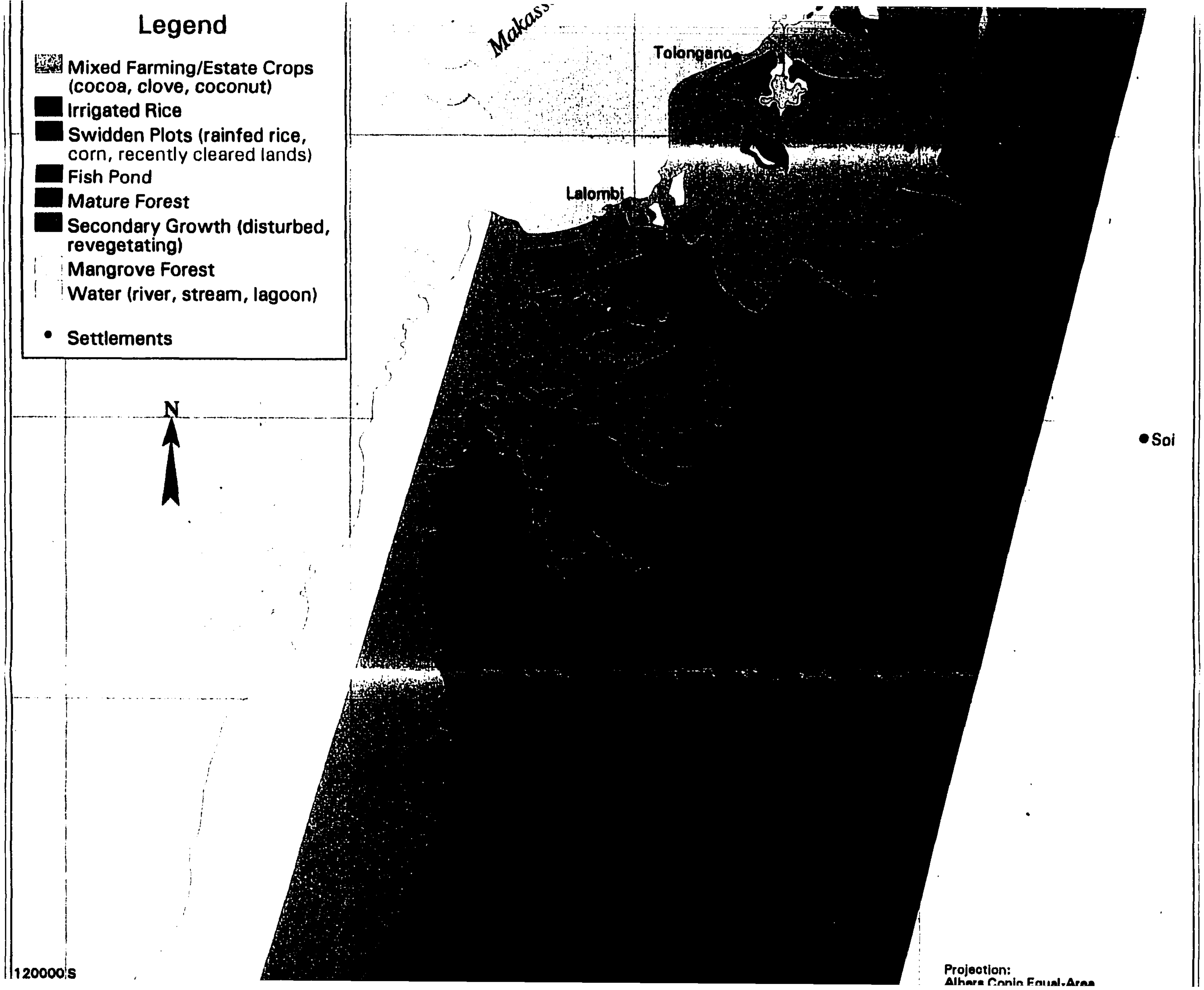


Figure 1.3: Land use and land cover in the study area.




Legend
▨ Mixed Farming/Estate Crops (cocoa, clove, coconut)
■ Irrigated Rice
■ Swidden Plots (rainfed rice, corn, recently cleared lands)
■ Fish Pond
■ Mature Forest
■ Secondary Growth (disturbed, revegetating)
☐ Mangrove Forest
☐ Water (river, stream, lagoon)
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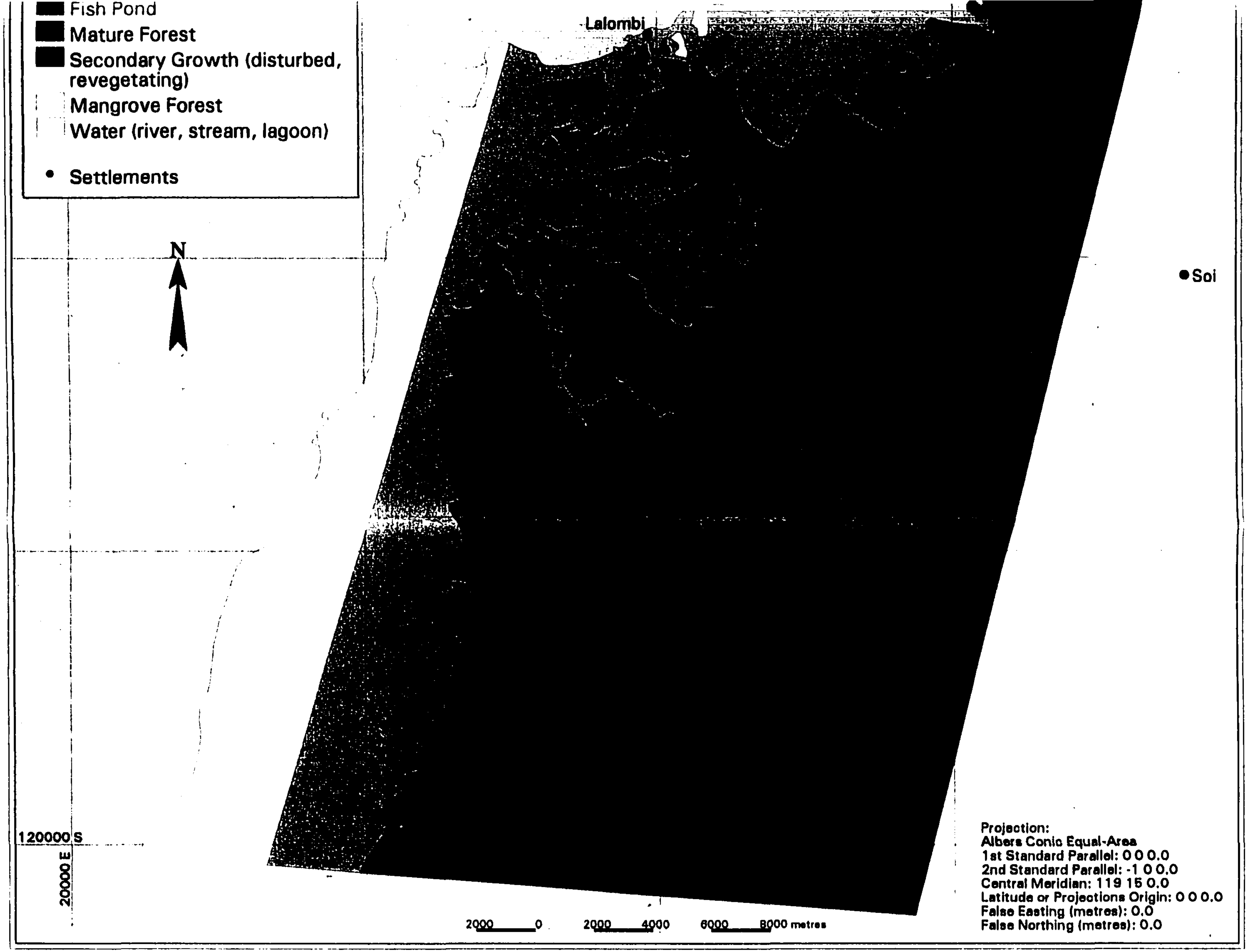
▇ Fish Pond
▇ Mature Forest
▇ Secondary Growth (disturbed, revegetating)
Mangrove Forest
Water (river, stream, lagoon)
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2000 0 2000 4000 6000 8000 metres
Projection:
Albers Conic Equal-Area
1st Standard Parallel: 0 0 0.0
2nd Standard Parallel: -1 0 0.0
Central Meridian: 119 15 0.0
Latitude or Projections Origin: 0 0 0.0
False Easting (metres): 0.0
False Northing (metres): 0.0

Coastal and upland forest ecosystems in this region of Central Sulawesi are in a state of transition as a result of competing and conflicting land uses (Centre for Environmental Studies, 1998). For example, between 1992 and 1997, the total area under forest cover in Central Sulawesi declined by 15% (Table 1.3). Cumulative results of land use modification are altering structural and functional ecological dynamics in the region. In turn, this influences opportunities for the sustainable use of resources necessary for local economic development and income generation. Socioeconomic and land use activities of particular concern in the region include intensive agricultural production (swidden, dry and wet rice farming, development of cocoa plantations, etc.), harvesting of timber and non-timber forest products (NTFPs), the conversion of mangrove forests to fish ponds, irrigation works, as well as transmigration and settlement schemes (Centre for Environmental Studies, 1998). For instance, the total area of land under cocoa production in Banawa increased from 2,154 ha in 1994 to 6,486 ha in 1998 (BPS, 1998). Likewise, regional fish pond production increased by 9% between 1995 and 1999, with a further 10% increase projected by 2005 (Perikanan, 2000).

Table 1.3: Change in forest area (hectare) by type in Central Sulawesi (1992-1999)

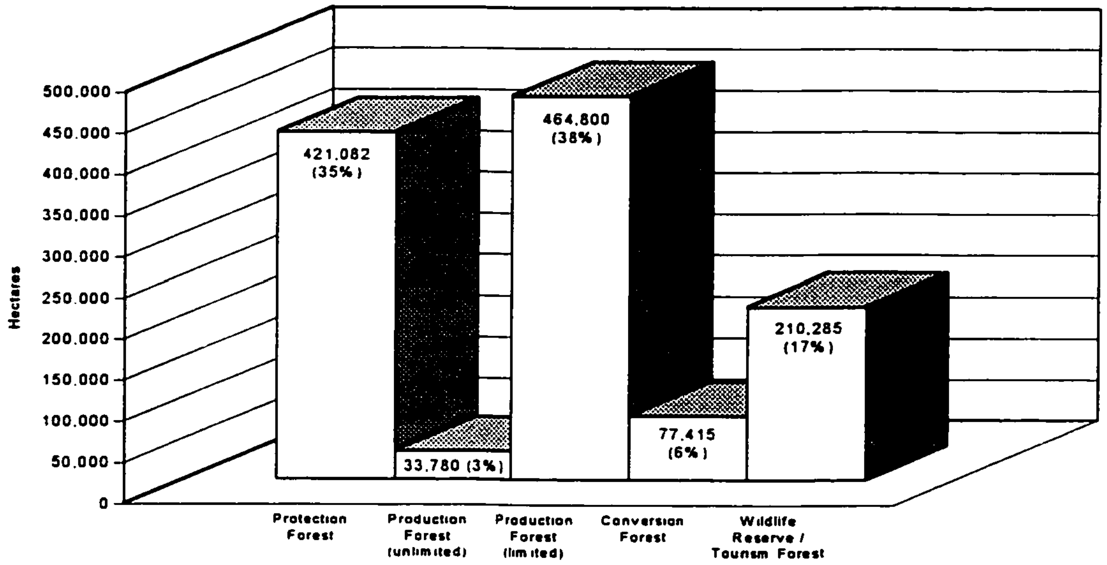
Year	Protection Forest	Unlimited Production Forest	Limited Production Forest	Conversion Forest	Wildlife Reserve and Tourism Forest	Total Forest Area
1992	1.764.720	422.089	2.142.606	241,757	604,780	5.196.872
1993	1.764.720	422.089	2.142.816	241,757	604,780	5.196.872
1994	1.764.720	422.089	2.142.606	241,759	604,780	5,176,674
1995	1.764.720	422.089	2.142.606	241,759	604,780	5,176,674
1996	1.489.923	483.034	1.476.316	269.411	676.248	4.394.932
1997	1.489.923	483.034	1.476.316	269.411	676.248	4.394.932
1998	1.489.923	483.034	1.476.316	269.411	676.248	4.394.932
1999	1.489.923	483.034	1.476.316	269.411	676.248	4.394.932

Source: Bappeda/BPS Propinsi, 1996; 2000

Adding to this challenging context is a heterogeneous socio-cultural environment involving several ethnic groups. This increases the complexity of planning and management since different groups are typically associated with specific land use and socioeconomic activities.

These groups include Mandar, Buginese, Javanese, Sundanese, and Torajanese, along with the indigenous Kaili. The Kaili further subdivide themselves into several distinct linguistic groups, of which the Da'a, Unde and Ledo are the most common in the area. Population densities vary dramatically between coastal and upland communities, although the average population density in Banawa and Marawola is 92 people / km^2 and 41 people / km^2, respectively (BPS Kabupaten, 1999a,b). In comparison, the average population density in Central Sulawesi is 32 people / km^2 (Bappeda/BPS, 2000). The population growth rate in one area (Banawa Selatan) is approximately 2.3 percent / year (Centre for Environmental Studies, 1998), while for Central Sulawesi, the population growth rate is 2.46 percent / year (Bappeda/BPS, 2000).

Figure 1.4: Forest Area by Function in Kabupaten Donggala, Central Sulawesi (1999)



Source: Bappeda/BPS Propinsi, 1996; 2000

In order to analyze these upland and coastal sociobiophysical systems, a "constructivist" methodological framework for conservation science was applied (see Chapter 2). The phenomena of complex ecological and social systems limit the efficacy of conventional science techniques and explanatory approaches as they tend to deconstruct rather than build emergent understanding. Therefore, this research sought to draw on the strengths provided by a broader epistemological framework. Indeed, policy-oriented conservation science should offer decision makers and other stakeholders an integrated understanding (in narrative form) of how the future of the systems may unfold, and the implications for regional conservation planning and policy. The development of these policy narratives has been accomplished by defining and examining critical systems and issues of interest (in the context of protecting biodiversity, promoting sustainability, etc.), describing system complexity, exploring change, trends and pathways, highlighting key variables and interactions that influence system resilience, and critiquing the underlying assumptions that guide current conservation policy.

With increased knowledge and understanding of key system attributes and a critique of the assumptions guiding system change, a full range of stakeholders must develop appropriate mechanisms for planning and management. Such mechanisms must adapt to environmental uncertainty, seek to mitigate the deleterious influences of socioeconomic development, and promote the social learning central to sustainable development. Choices are often required among conflicting and legitimate social interests and alternatives. While natural and social scientists have an important function in the evaluation of possible options, their role in a post-normal science context is bounded. Rather than providing expert predictions, scientists should seek to build scenarios, elucidate options, and promote discussion of choices in a transparent and collaborative process. Adaptive ecosystem management has emerged as a potentially viable framework in which to accomplish this difficult task. Yet numerous social, political and institutional variables may influence the feasibility of adaptive management in complex tropical landscapes such as those found in Central Sulawesi. To assess the feasibility of adaptive ecosystem management as a flexible framework for continuous learning and innovation in this tropical environment, a cross-scale assessment has been undertaken regarding: i) the capacity for adaptive management within formal governmental agencies charged with the responsibility for managing natural resources in the region; and ii) an analysis of local conditions that could facilitate a progression towards a more broadly-defined adaptive management - management that is contextually relevant and flexible.

The direction for this research emerges from two learning objectives. First, I have sought to develop an applied framework that contributes to improved conservation science and practice. This responds to a desire to understand how I might have better contributed to past projects in which I have been involved. The second learning objective has been to examine new areas of theory and practice relevant to conservation science and practice, and consolidate understanding in those knowledge areas in which I am already familiar. Inevitably, this has led to a dissertation that, in some respects, tends towards breadth as well as depth. The positive and negative aspects of this are self evident, and an anthropologist or sociologist might be critical of the focus on methodology over empiricism. However, I firmly believe the challenging issue presented in conservation and development contexts, and the potential solution to those challenges, is one of integration - integration of information from a range of sources across multiple scales. Methodology is the meeting ground for the pragmatic and philosophical issues that arise in seeking to achieve integration, and this dissertation offers a methodological example of relevance to those interested in linking the social and biophysical spheres in conservation science and practice.

In the following chapter, the epistemological and philosophical framework guiding reconstructed conservation science and practice is further elaborated. The intention in Chapter 2 is to highlight the broader principles that should guide conservation science and practice, as well as to develop the conceptual framework for this research. Chapters 3, 4 and 5 emerge from this critique and the development of the conceptual framework in order to assess critically the contemporary theoretical and conceptual approaches, methods and techniques, and empirical understanding relevant to reconstructed conservation science and practice. In Chapter 3, emphasis is placed on exploring recent insights provided by evolutionary concepts and ideas emerging from the ascent of the "new" ecology, or the study of complex adaptive systems. The focus of Chapter 4 turns to the problem of how this diverse knowledge and understanding can be linked to planning, policy and decision-making processes. Specifically, a critique of adaptive environmental planning and management is developed, with particular attention to its capacity for facilitating the type of learning and innovation required in complex systems. Also explored in this chapter are the insights provided by traditional resource management regimes and the potential role of locally developed adaptive strategies and mechanisms as a basis on which to design for sustainability. Chapter 5 links science and management with a critique of current policy approaches to conservation and development. The importance of underlying narratives and assumptions in decision making is highlighted. The dissertation then turns to the application of these concepts to the study area in Central Sulawesi, Indonesia.

In Chapters 6 and 7, the two key sociobiophysical systems are explored in detail using the theoretical and conceptual ideas and tools explored in the previous chapters. In Chapter 6, emphasis is placed on exploring socio-political and institutional dynamics, and the implications that emerge from a more complete understanding of their cross-scale interactions. In Chapter 7, the focus is on the social-ecological interactions in the upland, the manner in which the upland agroecological system is structured to account for ecological complexity, and the implications and insights for conservation science and practice that emerge from this analysis. The problem of effectively utilizing the knowledge and understanding of these two systems is then analyzed in Chapters 8 and 9, and consists of the cross-scale assessment of the capacity for adaptive management within the two complex sociobiophysical in the Banawa-Marawola region. Finally, empirical and methodological findings, conclusions and recommendations are outlined in Chapter 10.

2.0 THE PURSUIT OF THE IDEAL: AN INTEGRATIVE EPISTEMOLOGY FOR CONSERVATION SCIENCE AND PRACTICE

Reconstructed conservation science and practice will necessitate a complex social transformation of our use and perception of natural resources. Such a transformation, however, will not be accomplished solely on the basis of positivist science, expert-based knowledge, or the transfer of new, sophisticated technology (see Woodhill and Rōlings, 1998). Rather, relevant research will explore the opportunities provided by transdisciplinary approaches that overcome an exclusive focus on positivist and empiricist methods and enquiry (Schrader-Frechette and McCoy, 1993; Barry and Oelschlaeger, 1996; Schmutz 1996; Woodhill and Rōling, 1998). This move towards a broader epistemological orientation in conservation science and practice, as in other disciplines and fields of endeavour, is a reaction to central principles of the Enlightenment - universality, objectivity, rationality, and the mechanistic or cause and effect metaphor used to describe natural and social systems and processes. Such principles and metaphors have their origin in the intellectual transition from medieval times to modernity - a transition that began with Copernicus and Galileo and solidified with the French philosopher and mathematician Rene Descartes (Homer-Dixon, 2000). The monist model of thought this orientation has engendered encourages a belief in the capacity of human ingenuity to provide permanent solutions to fundamental problems of life, and the accessibility of rational methods to individuals possessing reasonable powers of observation and logical thinking (Berlin, 1998). The inevitable result for conservation practice is the primacy accorded to detailed technical analyses, the generation of certain knowledge, the elevation of experts as the primary sources of knowledge and innovation, and the standardization and bureaucratization of conservation programs and policies.

Yet early in the 18th century, Italian philosopher Giambattista Vico, in his treatise *Scienza Nuova*, wrote about how individual societies invariably possess a distinct vision of themselves - visions that are embodied in the words, language, images, metaphors and institutions they generate (Berlin, 1998). According to philosopher and historian Isaiah Berlin, Vico was the first to argue about the importance of understanding each society on its own terms, rather than judging it against a set of universal principles or ideals. Berlin (1998:391) himself has argued that the categorization and rigorous distinction of truth about the nature of reality needed to standardize and systematize will inevitably skew judgement in epistemology, politics, ethics, arts, and all other areas of experience. Such insights should have profound implications for the type of policies, practices, approaches and tools applied to traditional and/or agrarian societies in the name of conservation. Not only will conservation practices that emphasize standardization and uniformity inevitably falter, but more importantly, they may prevent societies and cultures from engaging in the creative processes necessary to find internally-derived or organic solutions. Yet these insights have not been adequately brought to bear in the era of preferred donor strategies and hierarchical, formalized policy setting in heterogeneous, complex environments (see Honadle, 1998).

2.1 Linking Post-Normal Science and Conservation Practice

Post-modernism has been described by geographer David Harvey (1989) as the rejection of efforts to find objective truths, universal and enduring patterns in natural systems and human endeavour, and ideal forms of social organization. At the core of post-modernism is a preference for fragmentation, indeterminance and a "distrust of universal and totalizing discourses" (Harvey, 1989). In a similar way, post-normal science is a reaction to the hubris of Enlightenment thinking - the efficiency of human reason and the ability to identify and eventually control underlying mechanisms of natural and social systems. In a post-normal science context, system uncertainties and the policy or decision-making process are the essential elements of analysis (Ravetz, 1999). A post-normal science approach to conservation science and practice thus helps illustrate new ways of identifying, exploring and addressing the complex and dynamic problems that we normally confront. 18th century philosopher Johann Herder captured the intent of post-normal science by arguing that the integration of theory and practice, intellectual judgement and emotional commitment, belongs not to several types, but a single type, of thinking (in Berlin, 1998). This secular doctrine of the unity of fact and value is the foundation of post-normal science.

These ideas suggest much for conservation science and practice. Importantly, we must preserve sensitivity to cultural and historical phenomenon in the context of projects, programs and policies that seek to classify, generalize and standardize - a propensity attributed to the natural sciences but one which weakens current conservation science and practice in complex contexts. For example, current practice is often based on the incorrect perception that traditional and/or rural people and their land tenure systems are similar from site to site and country to country; that they are uniform in time and space (see Honadle, 1999; Zimmerer, 2000). Li (1999) has argued that current research and practice too often dissagregate and classify communities according to such groups as "women", "farmers", and "the landless", hiding the inevitable variability within such groups. In most instances, local people are quite distinct from other groups within the larger society, notwithstanding the significant variations within localized communities (Bailey, 1996). In the highly heterogeneous Central Sulawesi region that is the focus of this research, significant cross-cultural differences occur between upland and coastal groups, as well as within the numerous and distinct upland and lowland groups themselves.

The very managerialism of conservation practice (see Li, 1999) associated with the structured, logical procedures of environmental impact assessment and scientific approaches to adaptive management may further confound how we interpret and understand complex, uncertain problems (McLain and Lee, 1996; Bassett and Koli Bi, 2000; Zimmerer, 2000). The point is not to reject the value of the ideas generated and the contribution such processes make. We need to reduce and classify simply to allow for cognitive exploration and deal with the inherent complexity. However, we should not, and in fact cannot, forget that in doing so we are obscuring much and perhaps missing even more. Consequently, post-normal science represents a method for understanding that is well-suited to situations in which there is little useable science, high uncertainty, and the likelihood of significant repercussions for ecological systems and the people who inhabit those systems as a result of decision-making processes (Ravetz, 1999; Kay et al., 1999) (Table 2.1). In contrast, "normal" science is best suited to contexts in which uncertainty is relatively limited and the impacts from decision-making processes likely to be moderate (Ravetz, 1999). This critique is not intended to be a rejection of normal science, but rather an effort to highlight its limitations and the ways in which scientific endeavor can be enhanced.

Table 2.1: A comparison of normal and post-normal science

Aspect	Normal Applied Science	Post-Normal Science
Intended goals	Certainty and objective truth	Understanding, resolution and acceptance of uncertainty
Desired results	Quantitative and predictable, hard fact	Quantitative and qualitative, understanding unpredictability
Mode of inquiry	Hypothesis testing, reductionism and analysis	Ecosystem approach, holarchic, synthesis
Explanatory frameworks and metaphors	Linear cause and effect, mechanistic, stability, laws and principles	Change, evolution, adaptation, negative and positive feedback, emergence
Core principles	Predictive management, objective, value free, and universality	Anticipatory and adaptive management, pluralism, subjectivity

Source: adapted from Kay et al., 1999

A "post-normal" perspective is valuable for several reasons. First, conservation practice must deal with multiple goals that are often incompatible. As noted, the assumption of unambiguous goals and the focus on technological or expert-driven solutions are increasingly irrelevant. Rather, the arbitration of contested goals is a key challenge (Woodhill and Rōling, 1998). Second, in a positivist paradigm, learning and innovation are perceived as originating in science and then being transferred to others in a linear fashion. However, learning and innovation are more likely to emerge from the interaction of stakeholders, with each contributing to the intended outcome. Therefore, local knowledge and experience share equal status with experts and expert knowledge (Cardinal and Day, 1999). Moreover, market changes (local, national and international), enhanced institutional arrangements, flexible policy conditions, and social organization are central to the stimulus of innovation and social learning (Woodhill and Rōling, 1998). Indeed, policy decisions regarding natural resources are increasingly less a matter of appropriate expertise or the domain of specialist institutions, and more determined by negotiation and agreement among stakeholders. Reconstructed conservation science and practice are as much a social as biophysical science, and the focus must be oriented towards relationships, collaboration, and process.

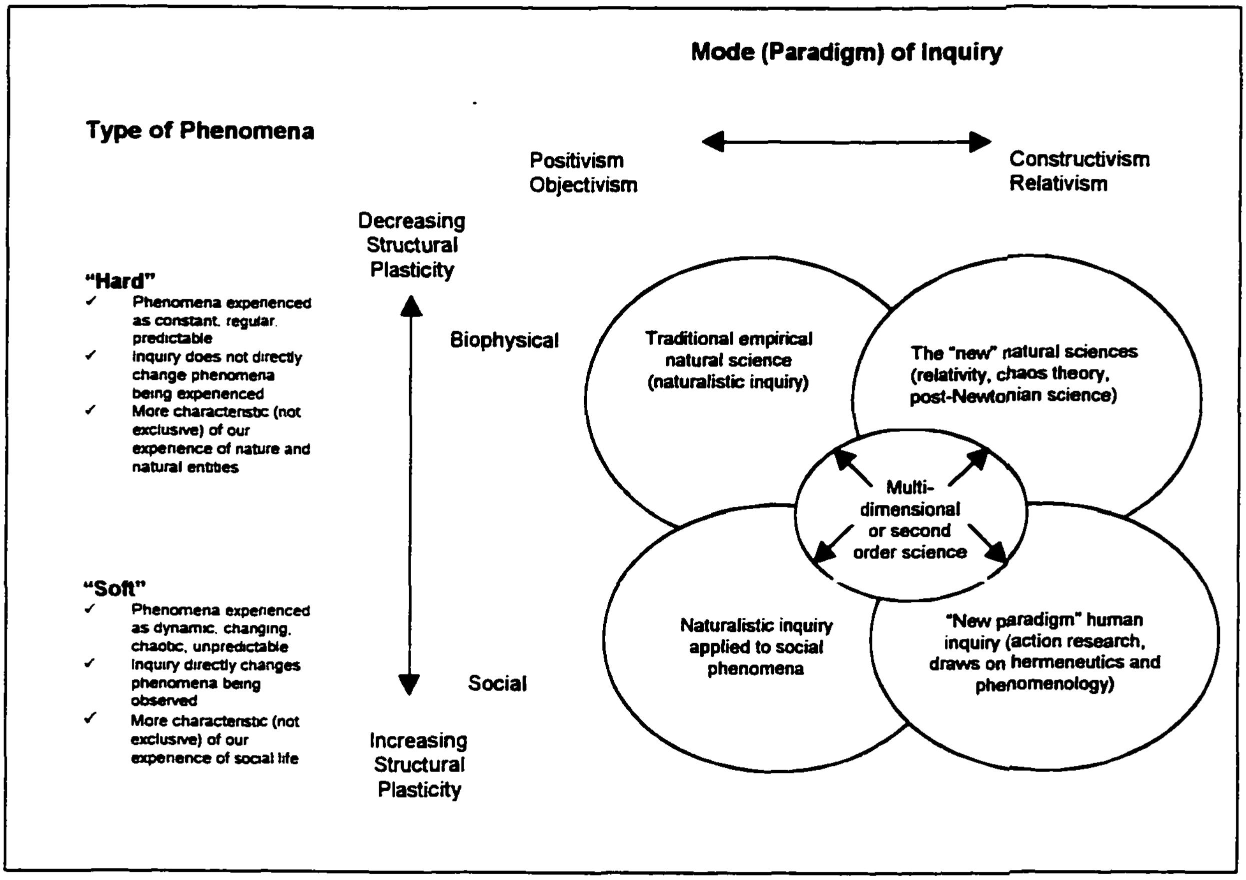
Figure 2.1 outlines an epistemological framework for post-normal conservation science and practice. The framework builds the basis for "second-order" or post-normal science by drawing on the strengths provided by the different modes of inquiry available to researchers and practitioners. These include traditional or empirical natural science, the "new" natural sciences associated with complexity, naturalistic inquiry applied to social phenomenon, and the types of human inquiry associated with action research and phenomenology (Woodhill and Rōling, 1998). This innovative epistemological framework can provide a useful starting point when identifying the multiple requirements of conservation science and practice. The spirit of this framework is the notion of pluralism, not because it is morally appropriate, but because it is methodologically necessary if conservation science and practice are to integrate the full range of values, perceptions and knowledge that must be addressed in complex circumstances (see Roe, 1994). Isaiah Berlin eloquently captured the importance of pluralism in his essay, *The Pursuit of the Ideal*. These are his words:

> *The notion of the perfect whole, the ultimate solution, in which all good things coexist, seems to me to be not merely unattainable - that is a truism - but conceptually incoherent.....We are doomed to choose and every choice may entail an irreparable loss. Happy are those who live under a discipline which they accept without question, who freely obey the orders of leaders, spiritual or temporal, whose word is fully accepted as unbreakable law; or those who have, by their own methods, arrived at clear and unshakeable convictions about what to do and what to be that brook no possible doubt. I can only say that those who rest on such comfortable beds of dogma are victims of forms of self-induced myopia, blinkers that may make for contentment, but not for understanding of what it is to be human (Berlin, 1998:11).*

2.2 A Conceptual Framework for Research

Although the epistemological and philosophical framework outlined above may offer an appropriate foundation for conservation science and practice, a more detailed conceptual framework is required. Specifically, an ecosystem approach provides a useful conceptual framework for this research and conservation science and practice generally. Such an approach exemplifies the integration of the "new science" paradigm in environment and conservation planning (see Hersperger, 1994; Hwang, 1996) with its emphasis on change, complexity and uncertainty (Dovers and Handmer, 1995; Mitchell, 1997), non-linear systems, heterogeneity, spatial diversity, dynamic equilibrium and non-equilibrium dynamics (Kay, 1991; Schneider and Kay, 1994; Gunderson et al., 1995). The ecosystem approach also highlights the importance of procedural concepts necessary to integrate regional ecological understanding into the planning and management process (Hersperger, 1994; Slocombe 1998a). As people are considered an integral element of the regional ecosystem, they must play an active role in understanding and planning its use and protection. Finally, this approach seeks to enhance the social learning identified as critical to ecosystem management and conservation practice (Lee, 1993; Berkes and Folke, 1998). An appropriate ecosystem approach, therefore, is one that integrates a "...necessary mixture of verifiable, reliable scientific knowledge, cultural values and civic responsibility" (Meine and Meffe, 1996:917).

Figure 2.1: An epistemological framework for post-normal conservation science



Source: Woodhill and Röling (1998:63)

This move towards "pragmatic realism" in ecosystem research (see Barry and Oelschlaeger, 1996) is similar to the development of "pragmatic pluralism" in geographical research as conceived by Taffe (1974) and Gregory (1976) (in Mitchell, 1979:18), and the civic science model promoted by Lee (1993), O'Riordan (1994), and Nelson and Serafin (1996). Specifically, a civic science approach to research engenders a concern for relevance and value (or "advocacy-oriented" research), along with attempts at theory building. The critical point is that a diversity of approaches is both feasible and desirable, and conservation research and practice should strive to maintain such diversity (Table 2.2).

Table 2.2: Principles to guide conservation research and practice

✓	a concern for pragmatism and plurality: utilizing tools and conceptual frameworks appropriate to the task, not to a particular discipline;
✓	the acceptance of uncertainty: questioning real world issues we are unable to answer;
✓	focusing on data quality rather than completeness;
✓	utilization of a systems approach characterized by comprehensiveness, holism, global, long-term and contextual concerns;
✓	incorporating an explicit concern for inter- and intra-generational equity and sustainability;
✓	a concern for dynamic processes, dynamic equilibrium, heterogeneity and discontinuity;
✓	a concern for societal as well as individualistic points of view; and
✓	a regard for the processes which govern individual and institutional behavioural change.

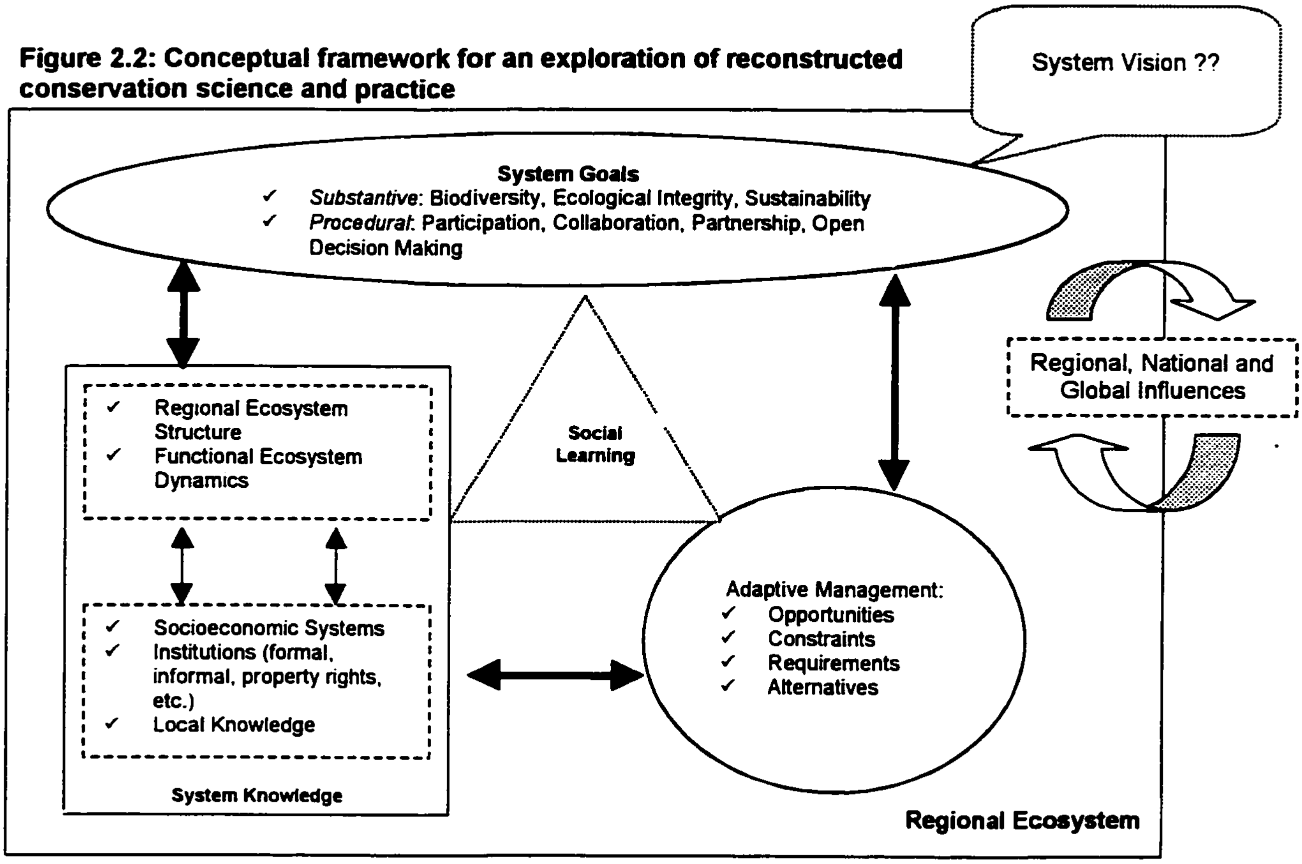
Source: adapted from Meffe and Carroll (1994)

Figure 2.2 outlines the conceptual framework for this research. Within this framework, several components are highlighted that correspond to key elements and concepts of conservation science and practice previously discussed; specifically, building an integrative understanding of complex sociobiophysical dynamics, the need for continuous learning and innovation, and the integration of post-normal science and policy.

At the core of this framework is the notion of social learning. As rates of change, risks of environmental decline, and complexities of globalization escalate in developing countries, the demand on societies to develop adaptive, flexible and sustainable responses will be significant (Woodhill and Röling, 1998). However, such adaptation will only be achieved if societies can generate the learning required to make the necessary changes. Homer-Dixon (2000) calls this the "ingenuity gap" and describes it as the having two key aspects. The first is the ability of a society to develop new technologies – such as computers, irrigation systems, and hybrid crops.

The second, and more important component, however, is the ability of a society to transform old institutions and social arrangements and develop new ones, such as competent governments, efficient markets, and methods for improving equity (social, economic and political). Such learning and ingenuity are critical for the effective arrangement of our social, political and economic affairs and are a prerequisite to a sustainable future. In the long term, they are also a prerequisite to the type of ingenuity needed to develop new technologies and products (Homer-Dixon, 2000).

Figure 2.2: Conceptual framework for an exploration of reconstructed conservation science and practice



Many factors influence the capacity for social learning or "ingenuity" required to address the complex problems we face, including the ability to generate innovative ideas, market incentives or rewards given to those who produce useful knowledge, and most importantly, political opposition by powerful interests and groups who are threatened by reform and change (Homer-

Dixon, 2000). These are beyond the scope of this dissertation. However, effective conservation science and practice should be focused on building the knowledge, procedural tools and methods that effectively engage different segments of society and that seek to promote social learning. As development specialist Frances Korten has clearly articulated:

> *The key to social learning is not analytical method, but organizational process; and the central methodological concern is not with isolation of variables or the control of bureaucratic deviations from centrally-designed blueprints, but with effectively engaging the necessary participation of system members in contributing to the collective knowledge of the system (in Rondinelli, 1993:167).*

Social learning requires adequate system knowledge. As a result, a central component of the conceptual framework guiding this research is how to better understand the coupled nature of complex ecological-social systems at multiple scales, and their implications for biodiversity, ecological integrity and sustainability. As has been argued above, the phenomenon of complex ecological and social systems limits the efficacy of conventional scientific techniques and explanatory approaches. Consequently, this research seeks to draw on several theoretical and conceptual frameworks (see Chapters 3 and 4), and to utilize multiple methods and techniques, in order to generate insight into system functioning. In short, this policy-oriented research seeks to provide decision makers and other stakeholders with a quantitative and qualitative understanding of how the future of the two systems may unfold, and the implications for conservation planning and policy. Such understanding provided in narrative form offers opportunities to illustrate the diversity and complexity of system functioning (Kay et al., 1999). The development of system narratives will be accomplished by defining and examining the system and issues of interest (in the context of protecting biodiversity, promoting sustainability, etc.), describing system complexity, exploring change, trends and pathways, and highlighting key variables and interactions that influence system resilience (Slocombe, 1989; Kay et al., 1999).

With increased knowledge and understanding of key system interactions, variables, trends and future possibilities, a full range of stakeholders must find appropriate decision-making procedures and tools to mitigate and/or adapt to environmental uncertainty and promote social learning. Adaptive ecosystem management provides one potential framework within which to address this difficult task and is a further component of the research framework. Indeed, adaptive management provides a unique framework in which social and environmental uncertainty and surprise are embraced, and systematic learning encouraged (e.g., limited data and limited theory). Consequently, an adaptive approach may provide an appropriate framework in which the complex requirements of co-evolutionary sustainable development can be addressed (e.g., regional-local tensions, development of complex compromises, lack of agreement regarding key questions, no agreement on essential facts, or framework for analysis, and improving information for public decisions, such as using local knowledge, etc.) (see Norgaard, 1988). Yet numerous social, institutional and political factors influence the feasibility of adaptive management, particularly in developing countries. As a result, a cross-scale assessment of the capacity for adaptive ecosystem management in the upland and coastal systems of the Banawa / Marawola region is undertaken to explore this issue. In particular, effort is given to identifying and learning from traditional adaptive socio-ecological strategies designed to function within the dynamics of complex and uncertain ecological systems

The development of system goals is a further component of this framework, and guides the search for appropriate system understanding and knowledge, as well as the effective use of this knowledge in an effort to promote social learning. Although not a specific focus of this research, the importance of goal development in effective ecosystem-based management has been highlighted (see Slocombe, 1998b). Synthetic goals such as biodiversity, ecological integrity and sustainability are often cited examples, although each has certain limitations and opportunities. Likewise, procedural goals such as participation, open decision making, collaboration and partnership have been identified as critical (Grumbine, 1994; Slocombe, 1998b; Johnson, 1999). A range of structural, organizational and procedural goals covering a range of temporal and spatial scales will likely be required (Slocombe, 1998b). The point is that a set of goals tied to a collaborative vision of how the system should evolve will play an important role in guiding the social learning process. For the purposes of this research, the conceptual framework presupposes a generic set of system goals and objectives and assumes a general desire for sustainable livelihoods among the people of the region. Finally, the research framework recognizes the cross-scale influence of other regional, national and international systems. Although by necessity bounded, conservation science and practice should seek to recognize and address cross-scale influences.

2.3 Research Methods and Techniques

The epistemological and methodological framework for this research has been outlined above. A "constructivist" framework has been developed that seeks to assemble a more complete picture of the complex social-ecological dynamics at play in the Banawa-Marawola landscape. Thus, this research has sought to address the challenge of interdisciplinary or "hybrid" research (see Batterbury et al., 1997) which emphasizes contemporary understanding of dynamic social and ecological processes within an historical context. This is done to evaluate processes of environmental transformation, the socio-political and economic factors that influence (and are influenced by) environmental transformation, as well as the impact of cultural processes, practices and interpretations of nature-society interactions (Scoones, 1999).

Integration is a formidable challenge and the development of an appropriate epistemological and conceptual framework is but the first step - research frameworks must invariably be supported with data collection and analytical techniques that generate qualitative and quantitative information across both temporal and spatial scales. The methods and techniques utilized to gather the types of information required in synthesis or hybrid research studies such as this can be numerous and varied, and benefit from an eclectic combination of relevant social and natural science methods. As Slocombe (1997) suggests, the focus of these data collection and analysis activities is, or ought to be, the integration of human, biological and physical dimensions of ecosystems at all scales to support the goals of assessment, planning and management decision making.

Employing methods and techniques that meaningfully link information about different dimensions and relationships at multiple scales is a conceptual and practical challenge (Allen and Hoekstra, 1992; Lee, 1993, Lee et al., 1993; Hobbs, 1997). For example, two major challenges to large system studies include: (i) the time and cost of assembling spatial databases over large areas (Yeh, 1991; Davis, 1995, Delorme, 1998); and (ii) the logistical challenge of undertaking landscape or regional-scale experimentation (Walters and Holling, 1990; Lee, 1993; Turner et al., 1995; Hobbs, 1997). Lack of experimentation is viewed by some as a weakness since it precludes adequate hypothesis testing and hard inference (e.g., establishing control groups, controlling for dependent and independent variables) (Hobbs, 1997). Yet laboratory-level studies (and even population level studies) in which experimental research design is more feasible, may offer little that can be reasonably extrapolated to broader scales (Pimm 1991; Stanley 1995).

Flexible, integrative approaches are necessary that foster the development of understanding and learning (Lee, 1993; Gunderson et al., 1995; Batterbury et al., 1997), and therefore, involve all avenues of information acquisition including classical experimentation where possible, quasi-experimental approaches (e.g., using management practices), observations, inference, modelling and participatory or multi-stakeholder methods. Novel approaches to the study of complex systems are needed as complexity and uncertainty are inherent characteristics of the subject matter (Hobbs, 1997). There is no one right set of methods, techniques or scales of analysis in the study of complex sociobiophysical systems. For example, choices about which methods are most suitable are influenced by the specific questions being asked and the information desired. The methods and techniques utilized are thus dependent on context - both the form and nature of the system being explored, as well as the researcher's experience and comfort with the methods to be utilized. In the exploration of social-ecological system dynamics and opportunities for adaptive management in the Banawa-Marawola region of Central Sulawesi, several methods and techniques were employed. Methods from the social sciences were primarily used for information gathering, but were supplemented with an assessment of landscape structure using remotely sensed imagery and geographic information systems analysis (i.e., Fragstats analysis). The goal in using a variety of methods was to combine the ability of qualitative methods to capture complexity and nuance, with more precise quantitative information (see McCracken, 1988).

In-field research activities took place over a period of approximately 5.5 months in two stages during the year 2000. The data collection methods outlined below were complemented with a review of relevant documentation from local, national and international sources. Following a clarification regarding study area definition, an overview of the research methods employed is provided.

2.3.1 Definition of the Study Area

Definition of the research study area requires elaboration. Two "systems" are the primary focus of this study: (i) an upland agroecological system; and (ii) a coastal mangrove / aquaculture system. Both systems are defined by the approximate spatial extent of the land and resource use activities they involve. However, a spatially explicit study area was also defined by the coverage of a remotely sensed image obtained for the area (see below). The coverage obtained does not completely correspond to the systems as defined by the spatial extent of their respective land and resource uses. While the analysis and critique of the upland swidden system is applicable across the Banawa-Marawola uplands, the corresponding Fragstats analysis, based on the remotely sensed imagery, is relevant for only a portion of the uplands (see Figure 1.2 and 1.3). Therefore, the image analysis offers insights applicable for only a defined land area. If the scene included the uplands further to the east, results would likely be different as there is a greater degree of permanent agriculture and intensity of use in the eastern uplands. The decision not to obtain coverage for the entire uplands was based on cost and the lack of cloud-free coverage. The analysis of the coastal system is unaffected by this differential delineation of study areas. The focus of the coastal zone research was the southern portion of the district of Banawa (Banawa Selatan), all of which is captured in the image.

2.3.2 Rapid / Participatory Appraisal Process

Participatory appraisal is a creative, flexible approach to data collection, analysis and sharing that challenges existing assumptions and biases about local or indigenous natural resource management. Of critical importance is that participatory appraisal views knowledge and the generation of potential solutions to natural resource management (and other) problems as the right and responsibility of those most affected. Much has been written about participatory appraisal and the various versions, meanings and applications the approach may entail (Khon Kaen, University 1987; Chambers, 1994; Beebe, 1995; Armitage and Garcha, 1995; Mitchell, 1997). Typically, the methods and techniques utilized in participatory appraisal include a range of field-based visualization exercises, semi-structured interviewing and group work that promotes learning, shared knowledge and a flexible, yet structured analysis. Emphasis in participatory appraisal activities is placed on triangulating the information obtained. While participatory appraisal has traditionally been oriented towards local or small-scale problems (e.g., village level initiatives), the conceptual framework and methods it embodies may provide a significant contribution to landscape and regional scale planning and management. In particular, participatory appraisal provides:

- methods and techniques suitable for adaptive planing and management, such as participatory modelling, workshops and group processes;
- a focus on social learning central to the development of local and regional sustainability (see Lee, 1993);
- a framework to bring together multiple disciplines and perspectives in an effort to develop an integrated understanding of local perceptions, the value of resources, and processes associated with social and institutional relations;
- a flexible, evolutionary perspective to understand and account for highly contextual, dynamic, and complex systems; and
- a potential bridge between indigenous and scientific knowledge (see Agrawal, 1995).

Participatory appraisal activities involving mapping, preparation of seasonal calendars, semi-formal interviews with key community informants and transects were undertaken in eight villages in the Banawa-Marawola region: Tolangano, Lalombi, Salumpaku, Mbuwu, and

Lumbumumara in Kecamatan Banawa, as well as Lumbulama, Soi, and Dombu in Kecamatan Marawola. Participatory mapping of village lands was used to identify key spatial and resource use issues and to focus discussion on land transformation processes in the region. The preparation of seasonal calendars with groups of local individuals was undertaken to explore cycles of resource use and assess social-ecological interaction in the agroecological practices of both upland and coastal communities. Information derived from these two participatory appraisal techniques was supplemented with the semi-formal interviews which provided an opportunity to obtain further detail or information as required about social and ecological aspects. Transects were undertaken to make observational notes and cross-check the information obtained from other data collection activities.

Five maps and four seasonal calendars were prepared by community focus groups of between 5 and 15 people typically composed of a cross-section of men, women, and youth. Effort was made to preclude the participation of village leaders in the mapping and seasonal calendar sessions as their insights were later captured using semi-formal interview techniques. In addition, three formal transects in coastal, middle hill and upland areas were undertaken in seven of the eight villages (Table 2.3). Research findings were also drawn from, and triangulated with, the results of participatory research activities undertaken in the southern portion of Banawa in 1999 and 2000 by the Environmental Study Centre, University of Tadulako. Finally, my insight and understanding regarding nature-society issues in the region have been enhanced through a mutual exchange of information with a fellow researcher, Achmed Rizal, working in the coastal zone of Banawa.

Table 2.3: Summary of Participatory Appraisal Activities in Villages

Village Method	Tolangano	Lalombi	Salumpaku	Mbuwu	Lumbumumara	Lumbulama	Sol	Dombu[1]
Participatory Mapping	✓	✓	✓	✓	✓			
Seasonal Calendars	✓	✓		✓		✓		
Semi-formal interviews	✓	✓	✓	✓	✓	✓	✓	✓
Transects	✓		✓	✓	✓	✓	✓	✓
Workshops	✓	✓		✓				✓

[1] *The Congress in Dombu was organized and facilitated by YPR, a local NGO.*

2.3.3 Facilitated Workshops

Workshops implemented as part of a participatory appraisal process or as an independent activity provide a valuable research and data analysis technique for regional environmental planning (Holling, 1978; Walters, 1986). For example, they provide an effective venue in which a range of perspectives and disciplinary orientations can be brought together to define, explore, analyze, discuss, and model (informally or formally) complex problems at regional and landscape scales. Workshops may also provide a suitable arena in which to generate ideas regarding potential interventions or solutions to those problems. In particular, workshops can help to circumvent the tendency of individuals to reduce problems into increasingly smaller components. This is essential given the need to address management requirements associated with broad scales and significant complexity (Holling, 1978). However, if workshop participants consist of stakeholders sharing similar perspectives and worldviews (i.e., oriented towards exclusive consideration of scientific knowledge), then efforts to build an understanding of ecological, social, institutional and decision-making interactions will be undermined (see McLain and Lee, 1996). Moreover, Beebe (1995) suggests that group processes may influence people's interpretation of what they believe is desirable, rather than what actually exists. Workshops also have the potential to limit contributions of certain individuals if they feel threatened. Follow-up discussion with individuals to further explore issues and findings is critical.

Nevertheless, workshops oriented towards integrating data and understanding about system interactions can provide several benefits (see Holling, 1978): (i) workshops are an effective way to initiate problem analysis since they can bring a range of stakeholders together to define a problem, examine existing data, and chart a course for future steps in problem analysis; (ii) workshops provide a structure for long-term, in-depth analysis to explore ongoing management, development, and/or policy initiatives; and (iii) workshops provide a useful mechanism to transfer new knowledge and understanding to agencies or groups that do not participate in all steps in a process.

Workshops were conducted in Tolangano, Salulari (Mbuwu), and Lalombi in order to explore key aspects of this research (Table 2.3). The workshops lasted approximately two hours and were conducted in several of the villages in which the participatory appraisal process was carried out. The objective of these workshops was to explore specific issues associated with the management of land and forest resources. In particular, the workshops focused on identifying institutional designs and practices that could foster social learning and management adaptation. The number of participants ranged from 12 to 22 and included those involved in the previous participatory appraisal process (men and women), as well as key informants (formal and informal village leaders).

The workshops were facilitated by a local research assistant with extensive experience in the area. Results of the workshop were collated, typed-up, photocopied and returned to the respective villages - both to the formal and informal village leaders. As well, a copy of the results of all three workshops was presented to the Camat, Kecamatan Banawa. A workshop was also held with 10 individuals from five local non-governmental organizations in Palu. The intent of this workshop process was to present the findings of the research and explore the institutional and natural resource management implications associated with the regional autonomy process and the reemergence of customary rights (see Annex 2).

2.3.4 Agency Questionnaire

A short questionnaire was administered to 15 senior provincial, regional and district government officials in order to gather additional empirical data and insight on the management perspectives of these various governmental agencies (Table 2.4). The questionnaire was administered in person with the help of a research assistant. Results of the questionnaire were entered into an Excel spreadsheet to facilitate basic analysis.

The focus of the questionnaire was to identify and explore key administrative and institutional issues influencing the potential for adaptive management in Central Sulawesi. One way to assess the feasibility of adaptive management is to explore the worldviews, perceptions and understanding of senior decision makers in relevant agencies which would be charged with dealing with the institutional complexities of the approach. It should be noted that the sample of officials interviewed is fairly small. However, while not representative of the broader universe of bureaucratic worldviews, perceptions and understanding in Sulawesi, or Indonesia generally, the individuals interviewed were all senior directors and decision makers in key planning and resource management agencies at provincial and district levels. Thus, they provide a strong indication of the officially sanctioned perceptions and understanding of an important segment of the State administrative apparatus.

Table 2.4: Government Official Participants in Questionnaire Survey

Name	Agency	Title
Mr. Said Awad	Bapedalda Propinsi	Director
Mr. Lanto Baso	Bapedalda Propinsi	Director - Policy
Mr. Zainal Arafin	Bapedalda Propinsi	Director - Monitoring and Restoration
Mr. Rais Laman Gmona	Bappeda Propinsi	Director - Division of Research
Mr. A.A.N. Buana	Kehutanan - Kanwil	Director - Rehabilitation and Land Conservation
Mr. Hudiyono	BKSDA (Balai Konservasi Sumber Daya Alam - SULTENG)	Director
Mr. H. Taufik R. Triangso	Bappeda Propinsi	Director
Mr. Akhmad Solihin	Kehutanan - Dinas Propinsi	Sub-Director - Reforestation and Rehabilitation
Mr. M. Nawir	BRLKT (Balai Rehabilitasi Lingkungan dan Konservasi Tanah)	Director - Programs
Mr. Gosal Syah Ramli	Perikanan Kabupaten (Tingkat II)	Section Head - Production
Mr. Chaerullah Lamoro	Perikanan Kabupaten (Tingkat II)	Director
Mr. Gustam Kamase	Bappeda Kabupaten	Section Head - Natural Resources and Environment
Mr. Ansui Kiliyo	Perkebunan Kabupaten (Tingkat II)	Section Head - Management
Mr. Rustam Puluko	Perkebunan Kabupaten (Tingkat II)	Director
Mr. Yasir	Perikanan Kabupaten (Tingkat II)	Section Head - Conservation

2.3.5 Remote Sensing and Geographic Information Systems Analysis

A landscape assessment of forest and land cover using remotely sensed imagery and Fragstats analysis was undertaken in order to generate landscape level metrics about ecological structure and inferences about ecological function (Figure 1.3). As well, the quantitative output of the landscape assessment provides a balance to the qualitative data collection activities.

A 1998 SPOT image was processed using EASI/PACE imaging software (Table 2.5). Using the processed image output, land type classes were defined based on two criteria: (i) applicability to information requirements of the study; and (ii) ability to accurately identify land cover types in the absence of supporting aerial photographs or updated base maps. Land cover types identified were mature forest, secondary forest, mangrove forest, mixed agricultural lands, irrigated rice fields, fish pond, swidden fields, and open water. A manual, mylar overlay process was employed to delineate polygons for each land cover type. Identification of land cover types on the processed image plots was supported by knowledge of the landscape obtained from transects, as well as with comparisons to known land cover types geo-referenced in the field using a handheld Garmin 12 Channel Geographic Positioning System (GPS). Manually derived polygons were digitized into an ARC/INFO database and analyzed using Fragstats™ software.

Table 2.5: Scene Parameters (SPOT image)

Variable	Parameter
Date	April 26, 1998
Time	02 hours 22 minutes 35 seconds GMT
Instrument	HRV 1
Number of spectral bands	3
Orientation angle	008.9 degrees
Incidence angle	R 14.4 degrees
Sun angles	Azimuth: 058.8 degrees / Elevation: 062.1 degrees
Scene centre location	S 000° 52' 16" E 119° 32' 41"

Several limitations associated with the RS/GIS analysis must be pointed out. First, during the process of manual identification and delineation of the land cover type polygons, some classification error is inevitable. Moreover, differentiating tropical vegetation is difficult and limited the distinction of forest cover in this analysis to three primary types (mature forest, secondary forest and mangrove forest) - all of which are broad categories incorporating significant inter-category variation. Likewise, areas classified as "swidden" will include lands recently cleared, recently planted, harvested, and/or characterized by early successional re-growth. Thus, the coarse scale analysis does not provide a suitable basis on which to generate accurate landscape metrics at patch scales. Moreover, no baseline reference values or norms are available for the region that can be used in a comparative manner with the metrics calculated for the Banawa-Marawola landscape. A more complete analysis requires that the metrics be compared in different land use contexts across the landscape using controlled studies. Finally, the results of the image analysis offer insight into the coarse-scale structure of the landscape at one point in time. The lack of a longitudinal land cover series hinders opportunities to undertake trend analysis. The RS/GIS landscape analysis undertaken as part of this research is best recognized for what it offers - an overall, coarse-scale assessment of landscape structure useful for suggesting potential impacts associated with different agroecological schemes and raising questions that require further research.

2.4 Towards a theoretical locus for conservation science and practice

The epistemological and conceptual framework for reconstructed conservation science and practice outlined above synthesizes various concepts and ideas. However, each of these concepts and ideas can be grounded in emerging theoretical and conceptual approaches, empirical understanding, and methods and techniques. First, evolutionary concepts emerging from the ascent of the "new ecology" illustrate that specific resources cannot be treated in isolation from broader ecological and social systems; complex, self-organizing linkages and system feedback across different scales and types of influence must be considered (Holling, 1978; Botkin, 1990; Gunderson et al., 1995). Insights provided from the study of complex adaptive systems challenge notions of stability, equilibrium, prediction, and linear causality in both natural and social domains, and suggest instead a need to account for change, surprise, thresholds, system integrity and resilience. Second, adaptive ecosystem management has emerged as a potentially valuable tool for planning and management as it embraces social and environmental uncertainty and encourages structured learning (Holling, 1978; Lee, 1993). An adaptive approach may provide an appropriate framework in which the complex requirements of co-evolutionary sustainable development can be addressed (Gunderson et al., 1995; Lee, 1999). Third, it is generally recognized that social and institutional systems, decision-making processes, property rights and local knowledge are the critical foundation of conservation and sustainable ecosystem management (Redclift, 1987; Lee, 1993; Berkes and Folke, 1998). In particular, a cultural ecological perspective highlights the contextual understanding that emerges from an analysis of local sociocultural and institutional adaptations to environmental uncertainty, and the influence local adaptive strategies have on the management of ecological systems (Netting, 1986; Butzer, 1989; Moran, 1991; Berkes and Folke, 1998). Fourth, the analysis and development of policy narratives are increasingly recognized as a valuable method in which the qualitative and quantitative understanding of complex systems can be integrated for decision making (Roe, 1994). Understanding policy narratives, and the stabilizing assumptions behind them, helps to portray the nuances of complex systems in order to capture the diversity of policy options, choices and possibilities (Fairhead and Leach, 1995; Fortmann, 1995; Bassett and Koli Bi, 2000). In particular, political ecology offers a useful conceptual framework in which to explore narratives of environmental transformation by focusing on, for example, power relationships and control over natural resources, and the differentiated role of stakeholder groups in the construction and legitimization of knowledge (Peet and Watts, 1996; Berkes, 1999; Scoones, 1999; Vandergeest et al., 1999).

When combined, these approaches and methods of understanding can offer innovative avenues for analysis, action and the development of effective conservation and ecosystem management strategies. The locus of the following chapters, therefore, is to explore and critique the complementary theoretical frameworks and conceptual approaches identified above. Given the scope of frameworks and approaches to be surveyed, however, brevity is paramount. This critique of relevant frameworks seeks to focus only on the central concepts and principles that further the goals of reconstructed conservation science and practice. Broader critiques and detailed historical examination of the frameworks are by necessity left to others.

3.0 SCIENCE AND MANAGEMENT IN COMPLEX SOCIAL-ECOLOGICAL SYSTEMS

The intent of this chapter is to provide an overview of complex adaptive systems and associated concepts, explore the theoretical and empirical insights that complexity science ascribes to sociobiophysical systems, and highlight the corresponding planning and management implications for reconstructed conservation science and practice; in other words, offer specific conclusions about the applicability and utility of complex systems thinking in fostering a more nuanced understanding of nature-society dynamics across multiple scales.

3.1 Complexity and Evolutionary Dynamics in Social-Ecological Systems

An *ecosystem* can be defined as "... a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries" (Likens in Christensen et al., 1996:670). While Arthur Tansley (1935) popularized the ecosystem as a spatially explicit unit of scientific study, underlying concepts of ecosystem science (e.g., functional connections between biota and their abiotic environment, hierarchical organization of individuals, populations and communities, etc.) are implicit in the work of several nineteenth and early twentieth century scholars[3]. The interdisciplinary focus on natural resource and ecological systems emerging in the 1960s provided further valuable, spatially explicit understanding of "...multivariate and highly interdependent systems involving a number of different organisms operating in a multitude of environments which vary in time and space" (Spurr, 1969:7). This concentration on producers, consumers, microorganisms, abiotic issues and their linkages enhanced scientific understanding of material cycles and energy flows in ecosystems and provided an emerging empirical basis for ecosystem-based natural resource management (see Van Dyne, 1969)[4].

Further efforts to understand whole ecosystems in terms of interacting physical and biological components (including the role of humans) have led to expanded knowledge of ecosystem structure, function, evolution, change and response to perturbation (Slocombe, 1993a). Although understanding of ecosystem structure and function is improving, ecosystem science is still characterized by uncertainty, surprise and limited knowledge. Specifically, (i) ecosystems are characterized by multiple, complex interactions and processes; (ii) we know very little about the functional aspects of landscapes and ecosystems (e.g., biogeochemical cycling); (iii) our understanding is further complicated by such processes as cascading trophic effects and non-linear causality[5]; (iv) ecosystems are characterized by multiple steady state conditions; and (v) we must understand relationships at spatial and temporal scales that extend beyond finite boundaries, projects and careers (Stanley 1995; Christensen et al. 1996; Reichman and Pulliam 1996). Thus, ecosystem science is both a fragmented and a growing field of inquiry in which complementary theories, concepts and methods are described and implemented separately (see Slocombe, 1993a,b). Despite these limitations, Christensen *et al.* (1996) highlight several principles of ecosystem science that provide an appropriate basis on which to orient conservation science and practice.

Spatial and temporal scales are critical: Ecosystem inputs, outputs, material cycling and interactions occur over an incredible array of spatial and temporal scales and hierarchies (see O'Neill et al., 1986; Urban et al., 1987; Fresco and Kroonenberg, 1992). Boundaries appropriate for one management problem (e.g., water quality) may be inadequate for another (e.g., wildlife management). Consequently, hierarchy theory provides a conceptually useful tool as it helps to define how components at different scales are related to one another, and helps suggest how external factors will alter an ecosystem.

Ecosystems are dynamic in space and time: Ecosystems are continuously changing over scales of centuries or more. Most observable or detectable ecosystem phenomena (i.e., the change we can more easily measure) occur in the context of continuous, long-term change associated with biological generations and geological time-scales. Empirical studies demonstrate that ecosystems either lack equilibrium, or that equilibrium conditions are observed only at a particular temporal and spatial scale. Thus, ecosystem organization and function may be characterized by homeorhetic stability (i.e., the return to normal dynamics), rather than homeostasis (i.e., the return to some pre-disturbance state) (Christensen et al., 1996).

Ecosystem function depends on diversity, structure, and integrity: Biodiversity plays an important role in ecosystem functioning, including the provision of ecological processes, resistance to and recovery from disturbance (e.g., through redundancies), and adaptability to long-term changes in environmental conditions (Holdgate, 1996; Orians et al., 1996; Silver et al., 1996). Therefore, it is important to acknowledge and account for complex species interactions that influence and are influenced by ecosystem function, as well as the role that diversity plays in maintaining processes across complex environmental gradients through space and time (Christensen *et al.*, 1996). However, biodiversity is largely about structure (areas, amounts, diversity and patterns) rather than about the integrity of the system or its ability to maintain self organization or evolutionary potential (Slocombe, 1998b). In complex systems, therefore, integrity ought to the primary issue of concern because it refers to the ability of a system to maintain normal functioning under diverse conditions, be resilient to stress and have the capacity to continue processes of self organization (Kay, 1991; Schneider and Kay, 1994; Slocombe, 1998b)[6].

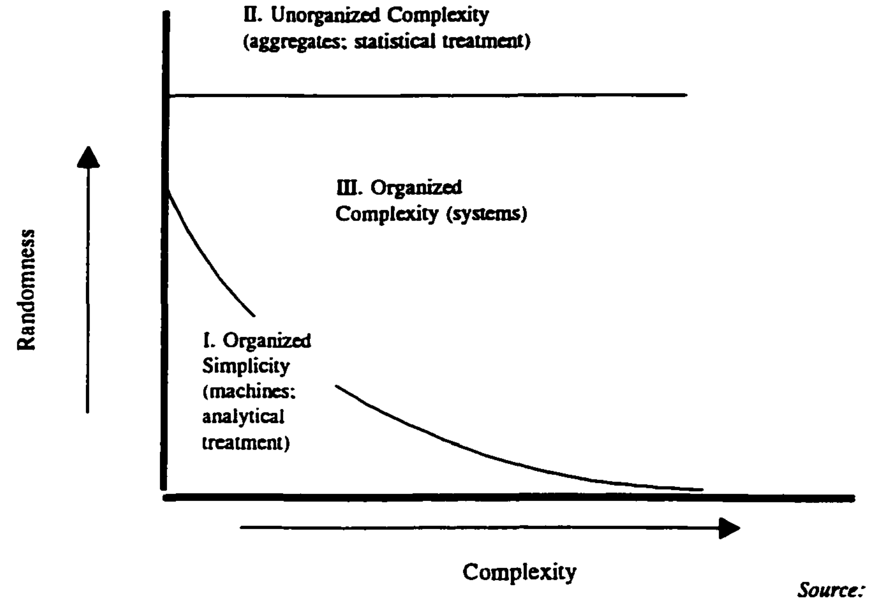
Such empirical understanding in ecosystem science has led to the development of a theoretical and conceptual perspective of ecosystems as evolutionary and adaptive (Holling, 1994, 1995). The "new ecology" concepts emerging from this perspective include notions of complex systems behaviour, self organization, chaos and order, discontinuous change, dynamic equilibrium dynamics, and non-linear causality (Cartwright, 1991; Kay, 1991; Schneider and Kay, 1994; Holling, 1995; Zimmerer in Hwang, 1996; Slocombe, 1998b). Although distinct in meaning, each of these new ecology concepts can be grouped under the broad idea of complex adaptive systems or complexity science, and provides the theoretical, conceptual and empirical basis for the application of complex systems thinking.

3.2 Properties of Complex Adaptive Systems

> *Complexity in ecology is not so much a matter of what occurs in nature as it is a consequence of how we choose to describe ecological situations....Complexity is a function of the terms in which we wish to understand nature (Allen and Roberts, 1992:xiii).*

Complexity science offers one way in which to look at, describe, interpret and cognitively structure not only ecological systems, but increasingly, linked social-ecological or nature-society systems as well. Complex systems, therefore, function as a valuable heuristic framework whose aim is to improve thinking. Central to this improvement in thinking is a recognition of where, how and why complex systems are applicable and relevant. Weinberg's (1975) "Law of Medium Numbers" is helpful in this regard[7]. As Weinberg (1975) illustrated, three system domains or regions can be identified (Figure 3.1).

Figure 3.1: Types of systems and associated techniques



Source: Weinberg (1975:18)

Region I is the domain of *organized simplicity* (small numbers), or the region of mechanisms suitable for analytical treatment. Region II is the domain of *unorganized complexity* or inherent randomness (large numbers) suitable for statistical treatment. Region III, however, is the domain of *organized complexity* or complex systems (middle numbers) too organized for statistics and too complex for analysis. Cartesian science (see Chapter 2) is philosophically coupled to techniques appropriate for small number systems (analytical) and large number systems (statistics) (Weinberg, 1975)[8]. Yet the domain of organized complexity is the domain of complex social-ecological systems - systems which require synthetic theoretical, conceptual and methodological approaches for understanding. Such systems are characterized by an emerging set of properties which provide valuable metaphorical, if not always empirical, insight[9]. An overview of the properties and characteristics of complex systems particularly relevant to the science and practice of conservation is outlined below (see Table 3.1).

Table 3.1: Properties of complex adaptive systems

Open to material and energy flows.

Nonequilibrium: Exist in quasi-steady states some distance from equilibrium.

Thermodynamics: Maintained by energy *gradients* (exergy) across their boundaries. The gradients are *irreversibly* degraded (the exergy is used) in order to build and maintain organization. These systems maintain their organized state by exporting entropy to other hierarchical levels.

Propensities: As *dissipative* systems are moved away from equilibrium they become organized:

- ✓ They use more exergy
- ✓ They build more structure
- ✓ This happens in spurts as new attractors become accessible
- ✓ It becomes harder to move them away from equilibrium

Feedback loops: Exhibit material or energy *cycling*. Cycling and especially autocatalytic cycling is intrinsic to the nature of dissipative systems. The very process of cycling leads to organization. *Autocatalysis* (positive feedback) is a powerful organizational and selective process.

Hierarchical: Are *holarchically nested*. The system is nested within a system and is made up of systems. Such nestings cannot be understood by focusing on one hierarchical level (holon) alone. Understanding comes from the multiple perspectives of different *types* and *scales*.

Multiple Steady States: There is *not* necessarily a unique preferred system state in a given situation. *Multiple attractors* can be possible in a given situation and the current system state may be as much a function of historical accidents as anything else.

Exhibit **chaotic** and **catastrophic** behavior. Will undergo dramatic and sudden changes in **discontinuous** and **unpredictable** ways.

- ✓ **Catastrophic behavior**: The norm
  - *Bifurcations*: moments of unpredictable behavior
  - *Flips*: sudden discontinuities, rapid change
  - *Holling four box cycle*: shifting steady state mosaic

- ✓ **Chaotic behavior**: our ability to forecast and predict is always limited, for example to between five and ten days for weather forecasts, regardless of how sophisticated our computers are and how much information we have.

Dynamically Stable?: There may not exist equilibrium points for the system.

Non-linear: Behave as a whole, a *system*. Cannot be understood by simply decomposing into pieces which are added or multiplied together.

Internal Causality: Non-Newtonian, not a mechanism, but rather *self-organizing*. Characterized by goals, positive and negative feedback, autocatalysis, emergent properties and surprise.

Window of Vitality: Must have enough complexity but not too much. There is a range within which self-organization can occur. Complex systems strive for *optimum*, not minimum or maximum.

Source: Kay (2001:10)

In providing this overview, however, effort will be made to be explicit about the intent and meaning of the terms utilized in the context of the subsequent analysis. As Kay (pers. comm., 2001) points out, complexity terminology is often defined and used in different ways (i.e., as a technical definition, a codeword implying certain conditions, or in colloquial terms) and it is important to be clear about the meanings ascribed to the different concepts.

The locus of complexity, according to Beyerchen (2000), is the distinction between linearity and non-linearity. In a system characterized by linear causality, changes in output would be proportional to changes in input; in other words system inputs (energy, materials) would always equal system outputs (energy dissipation, waste)[10], and the whole system would be equal to the sum of its parts. However, complex adaptive systems are characterized by non-linear causality. There is no linear relationship among cause and effect in complex systems, and small perturbations and changes at one point typically lead to large changes in overall system effects. Non-linear causality is exhibited in systems with feedback loops.

Complex adaptive systems are also characterized by the multiplicity of component parts and entities that contribute to overall complexity - the more entities and parts, the greater the complexity of the system. As Capra (1996) points out, however, ultimately there are no parts at all because what we term a part or entity is actually a pattern in an inseparable web of relationships. While the traditional approach to analysis is to focus on parts or objects in order to establish the relationships between them, complex systems thinking is oriented towards understanding relationships or networks; and, the most obvious property of a network is its non-linearity (Capra, 1996). However described, component parts or entities typically display tightly coupled linkages and feedback mechanisms, including positive feedback (i.e., those that reinforce a particular system trajectory or initial system change) and negative feedback (i.e., those that react to initial conditions and tend to counter trends or pathways). Positive feedback generates self-reinforcing spirals of behaviour which may trigger dramatic change in a system, while negative feedback results in a system that resists change.

A further characteristic of complex systems is the extent to which they exhibit stable and/or unstable conditions. Central to this debate are the tricky concepts of equilibrium, non-equilibrium and the variations between them that are used in different, sometimes contradictory ways. As Wu and Loucks (1995) point out, the lack of clarity and disagreement associated with equilibrium and non-equilibrium concepts stems in part from definitional ambiguities in the literature. Indeed, "non-equilibrium" is a code word used at present in the ecological literature to characterize those systems that are presently not, or typically not, "at equilibrium" (Illius and O'Conner, 1999). In other words, "non-equilibrium" is used to describe any system which is not temporally static or which exhibits some degree of unpredictability, uncertainty or lack of order. However, this is technically incorrect because as Kay (1991:491) noted, equilibrium in a dynamic mechanical (stability) context is different from equilibrium in a thermodynamic context. In a stability context, understanding system equilibrium requires an understanding of the influences of the range of forces acting on a system, and the manner in which a system state may experience dynamic change through time. In a thermodynamic context, equilibrium conditions imply a uniform system state that is indistinguishable from its surroundings. In contrast, non-equilibrium thermodynamics refers to the organization of systems in order that they are not in a thermodynamic equilibrium state (Kay, 1991). Both concepts, however, are important in an effort to better understand coupled socio-ecological systems.

For example, with respect to equilibrial concepts and their relevance for analyzing complex social-ecological systems, the key issue is the ability of a system to maintain stability (Kay, 1991). Of importance, however, is the recognition that complex socio-ecological systems may oscillate in potentially unpredictable ways around multiple equilibrium points in response to various disturbances and perturbations (external and internal), but within a bounded domain around an attractor[11] - a distinct contrast to past "balance-of-nature" and/or static, single point equilibrium perspectives (see Wu and Loucks, 1995). Therefore, complex socio-ecological systems in which behaviours are bounded around an attractor or cyclical in nature are exhibiting stable equilibrium dynamics (e.g., the Holling four-phase concept described below, or the swidden cycle analyzed in Chapter 7) (Kay, pers. comm., 2001). Moreover, although such systems are described as "stable", they may exhibit multiple steady states or equilibrium points that can involve "flips", periods of re-organization, and unpredictability. Issues of "resilience" thus become a central concern in analyzing system dynamics (see below). As Kay (pers comm., 2001) notes, therefore, it is not correct to describe steady states, attractors or resiliency in a "non-equilibrium" sense as they do not exist (e.g., multiple steady states and attractors are equilibrium points). Therefore, the term non-equilibrium is not appropriate as a general description of the dynamics associated with social-ecological interactions analyzed in subsequent chapters. Rather, effort has been made to utilize terms in their technical sense as outlined above.

Despite the lack of clarity surrounding equilibrium and non-equilibrium concepts, non-equilibrium thermodynamic theory offers a valuable framework to further describe stability and instability in ecological systems. Specifically, non-equilibrium thermodynamic theory has led to descriptions of ecosystems as dissipative, self-organizing systems.

> *According to the theory of dissipative structures, non-linear interactions of components and stochasticities can make ecological systems sensitive to small local perturbations, producing consequent fluctuations in behaviour. A small random fluctuation can self-amplify, with an increase in entropy production until a new stable state is reached. In other words, fluctuations that imply instability are now triggers or levers for the formation of a new dissipative structure, a phenomenon of order out of disorder (Wu and Loucks, 1995:444).*

Kay et al. (1999:724) define such self-organizing systems[12] as a "nested constellation of self-organizing, dissipative processes/structures, organized about a particular set of sources of exergy [an enduring flow of high quality energy], materials and information, embedded in a physical environment that give rise to coherent self-perpetuating behaviours". Thus, self-organizing systems can be conceived as complex living systems that reorganize or adapt in the face of environmental change. At a certain point, however, a threshold may be reached, often unexpectedly, and the system may flip into a new stable domain[13]. As Wu and Loucks (1995:444) conclude, such self-organizing processes may result in the "hierarchical structure of open systems" and conditions of "stratified stability" - conditions similar to notions of multiple equilibrium states and/or domains of attraction.

Holling's (1994, 1995) four-phase ecosystem development concept, consisting of renewal, conservation, release and reorganization, provides a useful framework to understand this dynamism. The first two phases, renewal (e.g., establishment of pioneering species) and conservation (e.g., consolidation of nutrients and biomass into a climax state) lead to the development of stable, but brittle, systems. Such brittleness encourages environmental surprise (e.g., fire, disease) and the sudden release of accumulated capital, allowing new opportunities and directions for exploitation. This rapid phase is followed by reorganization of system components (e.g., nutrients discharged during the release phase are captured or fixed in other parts of the system) and a process of renewal (Holling, 1994, 1995). The concept of resilience is of central importance to this four-phase ecosystem development model. Resilience, the capacity of the system to absorb disturbance, reflects the system's ability to maintain a specific pathway as it passes through the four-phase cycle. A loss of resilience will move the system closer to threshold limits and eventually cause the system to "flip" into a new equilibrium state

(Holling et al., 1998). Under conditions of loss of resilience, it is not possible to predict the type or probability of change.

However, according to Kay et al., (1999), there is an upper limit to a systems' ability to flip into a new stable system domain, since the capacity of the system to maintain structure and function may be overwhelmed. In such circumstances the behaviour of the system may become chaotic. Empirically determining at what points a system may reach this threshold is a significant challenge (Table 3.2).

Table 3.2: Potential responses of an ecosystem to perturbation

1. The ecosystem does not move from its original optimum operating point

2. The ecosystem moves from its original optimum operating point but returns to it

   Issues concerning integrity to be considered for this case:
   - ✓ How far does the system move from its optimum operating point before returning?
   - ✓ How long will it take to return to its optimum operating point?
   - ✓ What is the stability of the system upon its return?

3. The ecosystem moves permanently from its optimum operating point

   Case 0: The ecosystem collapses
   Case 1: The ecosystem remains on the original thermodynamic branch
   Case 2: System bifurcation to a new thermodynamic branch
   Case 3: The system moves to a new thermodynamic branch

   Issues concerning integrity to be considered for this case:
   - ✓ How far is the new optimum operating point from the old?
   - ✓ How long does it take it to reach the new optimum operating point?
   - ✓ What is the stability of the system about the new optimum operating point?
   - ✓ If the environmental conditions return to their original state, will the system return to the optimum operating point?

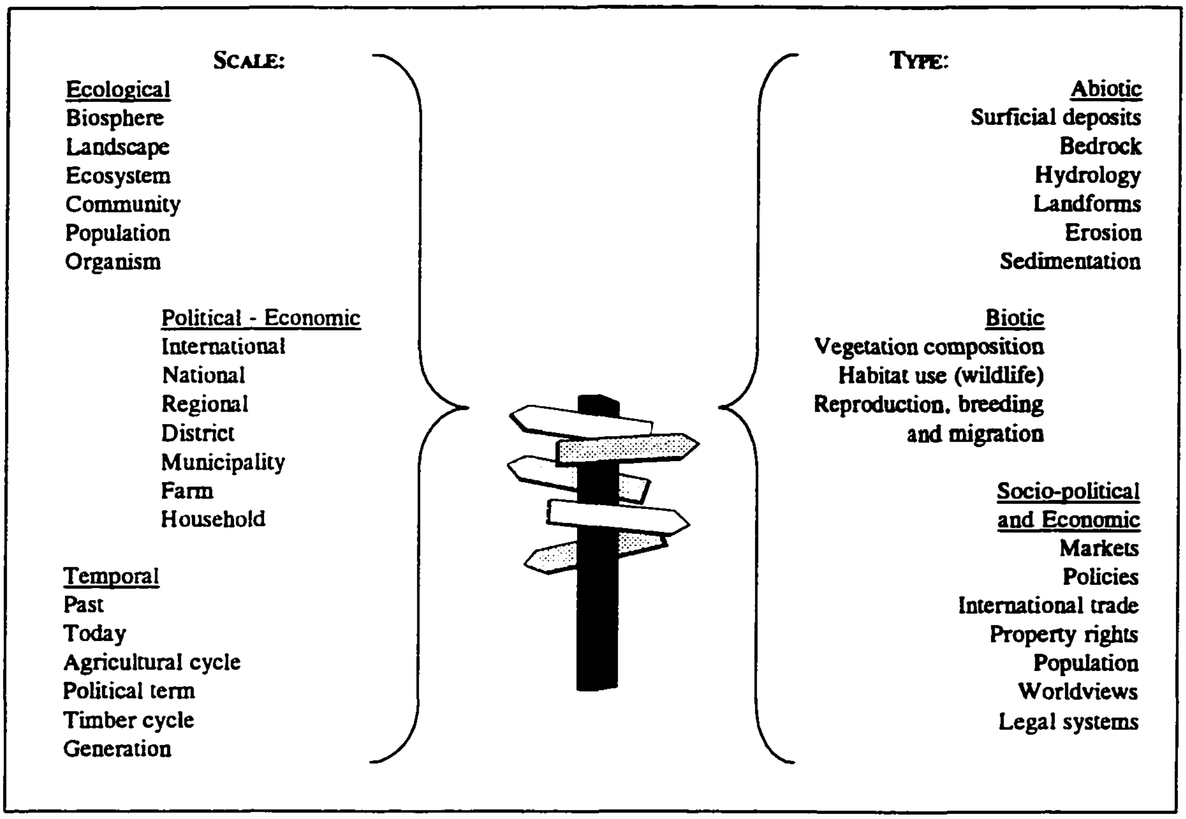
Source: Kay (1991:487)

However, the process as described makes intuitive sense, and the metaphor it provides is useful. Also, it is important to recognize that self-organizing systems can have more than one developmental or organizational state or pathway, and that such pathways may be discontinuous (Kay, 1991). Consequently, complex systems may be characterized by multiple steady states (see above) of which there is not necessarily a uniquely preferred system state in a specific situation (Kay et al., 1999; Kay, 2001). Rather, a range of system organizational conditions may be possible because current conditions are a function of historical accident, past trajectories and current circumstance (Wu and Loucks, 1995; Scheffer et al., 2001; see also Chapter 5).

Complex systems also possess "holarchic" or nested hierarchical properties. Each system is situated contextually within a nested network of systems with reciprocal power relationships between the different levels, rather than an influence of power exerted from the top downwards (Kay et al., 1999). Understanding the complex interactions between different nested systems is not possible by focusing on only one hierarchical level. Rather, insight and understanding emerge from the integration of multiple perspectives of different type and scale (Allen and Hoekstra, 1992; Kay, 2001) (Figure 3.2). Thus, complex adaptive systems are also characterized by the interdependence of component parts and entities, or their synergy. In complex systems, the combined effects of a change in two or more system components is not equal to the sum of those parts; rather, they reveal emergent properties. A basic element in any living systems approach, therefore, is the recognition that open systems are integrated wholes whose properties cannot be reduced to their smaller parts (Capra, 1996). At each level within a particular system, some properties or phenomenon do not occur at lower levels.

In addition, emergent phenomenon are characterized by three functional "rules". First, interaction between individual parts or entities and the emergent phenomena influences overall system properties. Second, system properties in turn influence component parts and entities. Third, properties of the system can only be understood within the broader context in which they are enmeshed. Thus, systems thinking is contextual thinking - explanations must account for contextual or environmental conditions (Capra, 1996). As such, emergent properties and phenomenon can be neither foreseeable nor expected based on an examination of individuals entities. Sociobiophysical systems such as those that are the focus of conservation practice generate significant complexity which cannot be predicted from *a priori* knowledge of separate system parts.

Figure 3.2: Examples of scale and type perspectives in social-ecological system understanding



Chaos and catastrophe are closely related concepts applicable in complex adaptive systems. Chaos is defined as invisible order, or order without predictability (Cartwright, 1991; Eisenberg, 1998), and often arises from the conditions and properties associated with tightly coupled feedback mechanisms, equilibrial dynamics, non-linearity and synergy (Homer-Dixon, 2000). In chaotic systems, effects of small perturbations are magnified, causing the system to become sensitive to small, sometimes minute, changes in initial conditions. While the basic process of cause and effect is relevant in chaotic systems, the manner in which those interactions will proceed though time and their implications for system behaviour are to a large extent unknowable. Efforts to extrapolate and/or predict system behaviour, or the behaviour of component parts, are at a minimum difficult, and according to some, nothing short of impossible (Cartwright, 1991; Kay 1991; Schneider and Kay, 1994). Of course, not everything exhibits or is governed by chaotic behaviour. However, the phenomena associated with sociobiophysical systems are to some extent influenced by chaotic processes. This implies that the challenges of understanding the rules and interactions governing social-ecological interactions and the behaviours of individuals and communities (human and non-human) are inherent rather than situational challenges (Cartwright, 1991). Finally, it should be stressed that most insights regarding the implications of chaos emerge from the study of natural entities or systems. Attempts to link the phenomenon of chaotic properties characterized in physical systems to social and economic systems need to be viewed with caution. International financial systems, markets and institutions do exhibit chaotic behaviour at times. However, as Homer-Dixon (2000) points out, humans have a capacity for learning and adaptation which means we should be able to better plan for inherent social-ecological system chaos. Finally, catastrophe refers to those points of unpredictable behaviour, sudden discontinuities and rapid change that result in radical system flips or state changes (e.g., from disturbance) (Kay, 2001; Scheffer et al., 2001). Such sudden flips in system states can be considered normal depending on the spatial and temporal scale at which the change is viewed (see Table 3.2 and the discussion of Holling's (1994, 1995) four phase cycle), and result in the shifting steady state mosaics described above.

3.3 Theory to Practice: Complexity and its Implications for Planning and Management

Complex adaptive systems are self-organizing, open systems characterized by positive and negative feedback, loose hierarchical structures, emergent properties and phenomena, relatively sudden (or unexpected) reconfigurations from one system state to another, and inherent unpredictability (Kay et al., 1999). The application of complex systems theory, systems thinking, and the implications for planning and management in sociobiophysical systems is often cited as representing a dramatic shift in how we interpret and interact with broader ecological and social domains. However, despite the recent rhetoric surrounding the influence of complex adaptive systems understanding, application of these ideas in planning and management is not an entirely new phenomenon. As Rosenhead (1998) points out, individuals such as Vickers (1965), Etzioni (1971), and Schon (1973) linked early self-organizing system concepts to social, economic and institutional contexts. The point is not whether these ideas and insights are "original", and therefore worthy of intellectual standing, but whether the insights can have real impact on the way we plan and manage sociobiophysical systems. According to proponents of complex adaptive systems (Senge, 1990; Wheatly, 1992; Stacey, 1993, 1996), most current planning and management is characterized by rationalist thinking (see Chapter 2) focused on the identification of a mission, the determination of strategy, and the elimination of the threat of deviation through the careful identification of factors, targets, and appropriate organizational structures (Rosenhead, 1998). Strategic planning and management activities such as goal formation, environmental analysis, strategy formulation, evaluation and implementation, and strategic control are inherently flawed since the natural world does not operate in this sequential, linear way. Inherent unknowability, unpredictability, and uncertainty limit the utility of conventional planning and management. As a result, analysis loses its primacy, cause and effect loses its meaning, long-term planning becomes impossible, visions become illusions, consensus and strong cultures become dangerous, and statistical relationships become suspect (Stacey in Rosenhead, 1998).

For Rosenhead (1998), however, the evidence supporting application of the planning and management principles that emerge from complex adaptive system understanding is tenuous. First, many of the ideas and corresponding management principles are derived from mathematics, physics and meteorology. Empirical evidence illustrating self organization, for example, in social and economic systems is limited, and in most management-related literature anecdotal (Mittleton-Kelly in Rosenhead, 1998; Homer-Dixon, 2000). At a minimum, this emphasizes a need for caution when transferring such concepts from the natural to human domain. For example, while natural systems may be governed by laws, the very awareness of laws in the social domain may actually influence behaviour (Homer-Dixon, 2000).

Yet the presumption that social, economic and institutional entities should operate "at the edge of chaos" (i.e., the point where creativity is greatest), although seemingly risky, is a popular tenet in management circles (Rosenhead, 1998). It is certainly counterintuitive in conservation planning and management situations in which the livelihoods of individuals and communities are contested and the institutions that formally govern critical natural resources are ill-equipped, under-staffed, and ill-prepared for even reactive management. As Rosenhead (1998) concludes, the application of complex adaptive system concepts in planning and management has several limitations. For example, the field of complexity is a rapidly developing but still young and imperfectly integrated field. The extent to which the emerging concepts serve as a reliable source of principles or analogies for planning and management is still a matter of debate. As well, proponents of the application of complex adaptive system principles in planning and management are somewhat unclear about what organizational aspects are linked with what concepts drawn from the theory; for example, is the organization or its environment the focus of interest where chaotic behaviour is concerned? (Rosenhead, 1998).

All this is not to suggest that complex adaptive system concepts do not have utility in planning and management. Although complexity science, generally, suffers an empirical credibility gap, the emerging concepts and ideas provide valuable metaphors that can enhance how we analyze natural and social systems and our role in those systems. Such metaphors enhance our analytical creativity and provide new ways of thinking about the issues and problems which conservation science and practice must address. In particular, Stacey (1993) makes an important distinction between *ordinary* management and *extraordinary* management - a distinction relevant for planning in conservation contexts.

According to Stacey (1993), ordinary planning and management involves a logical, analytical process consisting of data analysis, goal setting, evaluation of options, rational decision making among choices and hierarchical implementation (i.e., rational/comprehensive planning). Ordinary planning has a role to play in facilitating decision making and promoting cost effectiveness. In contrast, extraordinary management is required when people must transform their environments in fluid, open-ended situations. Rational planning and decision making are not suitable in this circumstance since informal structures, collaborative groups, and epistemic communities are required for planning and management that can form spontaneously and adapt as conditions change (Stacey, 1993; see also Lee, 1993; Gunderson et al., 1995). The challenge is to find the appropriate boundary between ordinary and extraordinary management, and adapt accordingly as those boundaries shift.

According to Rosenhead (1998), the challenge of finding that appropriate boundary suggests a need for "double-loop" learning. For example, planners, managers and other stakeholders must adjust and adapt their behaviour in response to on going feedback and changing conditions. However, they must also reflect on the appropriateness of the assumptions and mental models they use to establish ensuing strategies and interventions (Rosenhead, 1998). This conclusion highlights a need to rethink the institutional and organizational arrangements used for conservation planning and management, given that increasing complexity is causing our social, economic and institutional arrangements to become unworkable (Homer-Dixon, 2000). Formal, hierarchical institutional arrangements are a form of social bureaucratization used to compartmentalize tasks and centralize authority - a process that supports the goal of bureaucracy to make the world linear, and thus, more predictable and controllable (Beyerchen, 2000). The challenge, therefore, is to encourage a shift to cooperative networks and web-like institutional and organizational arrangements that better "handle" uncertainty and change.

As Fukayama (2000) explains, there are two basic ways to organize. Organization can take the form of centralized bureaucracies (e.g., as in Indonesia in which the central state authority has historically decided on virtually all aspects of society - roads, bridges, schools). In contrast, organization can also rely on people to come together to form self-organizing, decision-making entities (see also Lee, 1993; Gunderson et al., 1995). According to Fukayama (2000), this approach means moving from hierarchical arrangements to network arrangements guided by both formal and informal rules. Still, some fundamental challenges are associated with self-organizing, decentralized network arrangements, including the challenges of scale (the higher the scale the more relationships break down) and boundaries (i.e., lack of clarity about responsibilities, jurisdictions, etc.). Indeed, hierarchy is in many respects inevitable, despite the general move towards decentralized frameworks, because it is a natural trait of human relationships (Fukayama, 2000).

Despite the limitations identified above, the dynamic, evolutionary perspective offered by complex systems theory represents a countervailing approach for conservation science and practice guided by the classical stability ecosystem paradigm (e.g., assumptions that problems are bounded, defined, possess linear cause and effect, etc.) (Knight and Bates, 1995; Holling and Meffe, 1996; Zimmerer, 2000). Such perspectives and emerging criteria should help to overcome the inadequacies of the "command and control" or "scientific" resource management paradigm that inevitably leads to increased brittleness and a loss of system resilience, more inflexible management institutions, and greater societal dependence on the system (Holling, 1995; Holling and Meffe, 1996). Schneider and Kay (1994) have summarized several lessons and insights gained from complex systems and evolutionary concepts that are applicable to reconstructed conservation science and practice. For example, a hierarchical perspective is critical in order to understand systems, subsystems and elements within those systems. Neither reductionist nor holistic methodological approaches and methods are sufficient in isolation. Moreover, as everything is connected to everything else, it is necessary to be explicit about the units and scale of the phenomenon under investigation. This is subjective but none-the-less requires consistency and rigour. Likewise, given the nature of complex systems, our ability to predict is limited, regardless of the amount of information we collect or the sophistication of models utilized (Schneider and Kay, 1994). Building more elaborate models and obtaining more information as a basis for planning and action may be futile (see Cartwright, 1991). Instead, we must rethink beliefs regarding the virtues of order and predictability, accepting as well, the role of chaos; we will need to work with multiple narratives about the trends and pathways of the system(s) under study or management; and, we must accept an incremental (rather than comprehensive) approach as they mesh well with the need to build capacity for adaptation and flexibility (Cartwright, 1991) (see Table 3.3).

Table 3.3: Complex systems attributes and potential management implications

Principle	Planning and Management Implications
System as open and self-organizing	If a system is closed, any unit of nature would be manageable as a separate entity (e.g., a national park, hazardous waste site, endangered species). However, this ignores critical interactions across spatial and temporal scales and hierarchies that must be accounted for in management.
System as chaotic	Chaos is order without predictability. As a result, prediction of management outcomes or impacts may be virtually impossible, regardless of how much data are collected, or how much we refine and test system models. Instead, management should be incremental, accept unpredictability, focus on identifying patterns of behaviour, and be oriented towards feasible scales.
System characterized by dynamic equilibrium or multiple steady state conditions	If a single stable point equilibrium is the primary type of stability in nature, then managers can simply observe how nature is at a particular point in time and do what is necessary to maintain that state. This assumption also suffers from the bias that systems in equilibrium are the most desirable. However, dynamic equilibrium or multiple steady state conditions – none of which are necessarily preferable over others - may exist which require management to be flexible and adaptable to changing conditions.
System as non-linear	After disturbance, systems are unlikely to recover their previous state through a process of obligatory succession (*à la* Clementsian successional concepts). Managers can attempt to facilitate this process, but the outcome is inevitably non-linear (see disturbance below) and inexorably leads to an unexpected endpoint.
Disturbance is desirable	If disturbance is considered exceptional, then management can be undertaken without taking it into account. As a result, managers are unprepared for disturbance when it does arise, or attempt to mitigate against it. Yet disturbance is a critical component in maintaining structural heterogeneity, biodiversity, and a driver of functional ecological processes.
Humans are part of system	If humans are not considered a system component and the critical historical or contemporary influences of humans are neglected, then management prescriptions and/or strategies will be flawed.
Multiple methods of inquiry are necessary	Both inductive and deductive methods of inquiry should be utilized, although the focus of deductive inquiry on reduction and abstraction in order to predict is limiting. Consequently, inductive modes of inquiry are also required that seek to address the multiple or cross-scale reality of systems, to promote learning and innovation, and that utilize multiple techniques and sources of evidence.

The insights provided by complex adaptive system understanding raise important issues for reconstructed conservation science and practice. If everything is interconnected, how can we understand anything? Efforts to explain or understand one aspect of a system require the need to understand and explain all others. However, as Capra (1996) points out, what makes it possible to borrow and utilize the insights from complex systems is the discovery of approximate knowledge. While we do not possess complete understanding, we do have approximate knowledge of the infinite web of interconnected patterns and systems. Finally, it is important to differentiate between what Eisenberg (1998) calls "complexity jocks", and the more modest proponents of complex adaptive systems. The former are those theorists who believe complexity sciences will derive universal laws that predict and explain all phenomenon or behaviour. In this regard, complexity theorists are extending the classical program of Western science (i.e., reductionism and determinism) to the non-linear realm (Eisenberg, 1998). As Rosenhead (1998:15) has pointed out:

> *It is indeed curious that a message based on the importance of accepting instability, uncertainty and the limits to our knowledge should be presented with such an excess of certainty. The explanation for this paradox may lie in the twin heritage of management complexity. The 'systems' community world-wide has been particularly prone to sectarianism and evangelism, while the audience for management texts is conditioned to expect large generalisations supported anecdotally. It can be a heady mixture.*

In contrast, there are those who see the insights provided by the application of complex adaptive system understanding as more modest. Indeed, the insights emerging from complex systems do seem useful as a basis for describing the world around us (Horgan, 1996; Kay et al., 1999), and they do offer valuable metaphors for characterizing inherent system change, uncertainty and complexity.

4.0 ADAPTIVE ECOSYSTEM MANAGEMENT AND INDIGENOUS ADAPTIVE STRATEGIES

4.1 Adaptive Ecosystem Management: Structured Experimentation and Institutional Flexibility

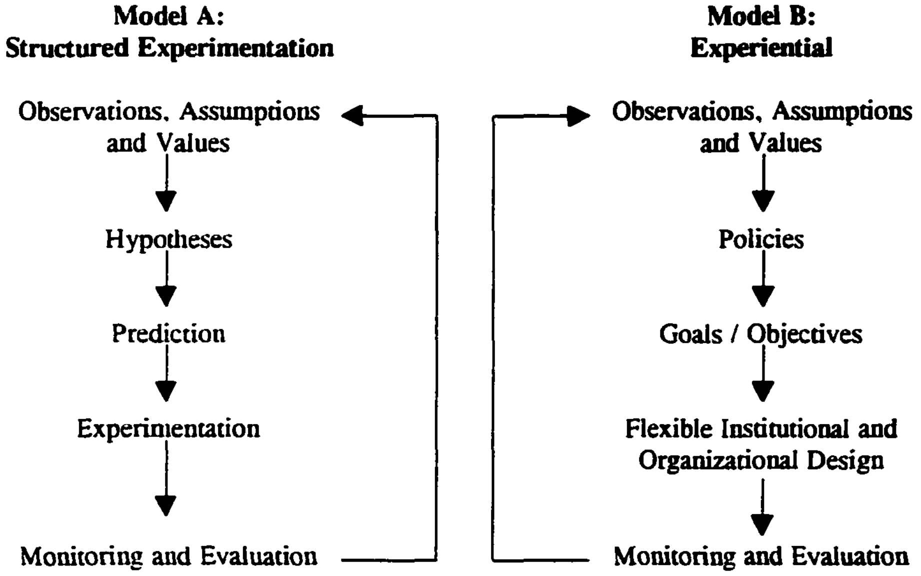
Adaptive ecosystem management[14] has been promoted as an integrated approach to address uncertainty in the use and management of natural resources. The premise is simple: policies are experiments - learn from them (Lee, 1993). As Grumbine (1994) noted, adaptive management assumes scientific uncertainty and offers an approach that encourages continuous learning through structured experimentation <u>and</u> management flexibility. The institutional requirements of adaptive ecosystem management have, therefore, taken on an increasingly central role (Lee, 1993; Johnson, 1999a,b; Gunderson, 1999). Adaptive planning and management has emerged as a potential decision-making framework to integrate ecological, social and economic variables at multiple scales. A comprehensive overview of adaptive ecosystem management has been developed by numerous authors (Lee, 1993, 1999; Gunderson et al., 1995; Mitchell, 1997; Gunderson, 1999) and is, therefore, not required here. Rather, a brief overview of the salient features and characteristics of adaptive ecosystem management are provided in order to establish a basis for a broader critique of its applicability in diverse contexts (e.g., developing country contexts).

The adaptive management approach is not a new concept, but it does seek to build on past planning approaches (e.g., synoptic, incremental and mixed-scanning) by overcoming certain assumptions and formalizing the assessment and choice of alternatives. At large scales, the dominant planning model has been a rational comprehensive, or synoptic, approach; specifically, the application of scientific and technical information in a set of predetermined steps in order to reach a decision regarding a range of public and private choices (see Mitchell, 1997). Concern with the basic assumptions (e.g., primacy of expert knowledge, rational decision making, universal truths) underlying the synoptic planning model led to the emergence of more flexible planning approaches. Transactive or participatory planning, for example, stresses the experience of people most affected by a planning process. Such collaborative approaches are fundamental if the planning process seeks to alter human behaviour and attitudes. Likewise, incremental planning and mixed-scanning seek to capture the reality of the system in which planners operate (Lindblom, 1974; Friedmann, 1987). Therefore, incremental planning concentrates on familiar human experiences, reduces the number of alternatives to be explored, and reduces the number and complexity of variables to be considered. While mixed scanning is similar in this regard, it also stresses the importance of continuously scanning a limited range of other alternatives, each of which represents a significant departure point from present practice (Mitchell, 1997). The opportunities and constraints of these approaches have informed the development of the adaptive planning and management approach.

An adaptive approach is guided by several important principles (Lee, 1993): (i) adaptive management is ecosystemic rather than jurisdictional - decision making crosses many boundaries and links a range of functions; (ii) the focus of management is the ecosystem or population, not an individual organism or specific project (as a result, individual-level failures need to be tolerated if certain hypotheses are to be tested); (iii) time scales must be measured in biological generations, rather than in political, budgetary or business cycles; and, (iv) adaptive management recognizes that surprise is inevitable and that all natural resource policies are, in effect, experiments. Despite the overriding themes embedded in these principles, adaptive ecosystem management is defined and practiced in diverse ways and in varying degrees of intensity (Figure 4.1), a difference which is often overlooked but which has important implications for adaptive management practice in developing country contexts in particular. For example, McLain and Lee (1996) suggest that many managers view adaptive management as developing predictive tools that can be used for site-specific management. Policy makers view adaptive planning and management as a process that allows them to see the broad impact of policies and emphasize the need to develop large-scale models. Scientists adhere to the meaning provided by Holling (1978) and Walters (1986): the application of experimentation to the design and implementation of environmental policy (see McLain and Lee, 1996). Consequently, in practice, an adaptive management approach can be focused on a specific resource (e.g., fish or waterfowl population), and therefore, not be explicitly ecosystem-based (although the habitats and environment, e.g., relatively natural, human-modified, in which such populations reside must clearly be considered). However, an adaptive approach is defined in this dissertation as an approach that seeks to explicitly address ecosystem interrelationships - applying the concepts and methods of adaptive management to the challenges and issues of complex ecological, socio-political and economic interactions in order to promote new knowledge and learning.

In addition, Walters and Holling (1990) differentiate between passive adaptive management and active adaptive management. Passive adaptive management is similar to the learning process approach promulgated in the development administration literature in which the focus is on building the institutional and organizational capacity for learning. In contrast, active adaptive planning and management applies the concept of experimentation to the design and implementation of natural resource policy. The latter process is explicitly crafted to test clearly formulated hypotheses about the behaviour of an ecosystem in order to improve management effectiveness (Holling, 1978; Walters, 1986). As Lee (1993) points out, the focus should be on developing true experiments with random control groups. Where randomized treatments are not feasible, self-critical quasi-experimental research design can be employed. Regardless, an adaptive planning and management approach advocates that problems be addressed systematically so that reliable knowledge is obtained and its validity assessed. Without some form of experimentation (which facilitates rapid knowledge acquisition through falsification of hypotheses), reliable knowledge accumulates slowly, and without reliable knowledge and learning, progress towards sustainability may be slow (Lee, 1993). Yet as Lee (1993, 1999) suggests, social learning is critical in large ecosystems in which compelling problems of environmental science and policy merge (e.g., ecological complexity, interdependence, significant environmental damage, multiple governing jurisdictions, social heterogeneity, etc.).

Figure 4.1: Two idealized models of an adaptive approach to planning and management



Process and Methods: Learning through structured experimentation (assisted by simulation models, workshops, etc.)	Process and Methods: Learning-by-doing (assisted by participatory analysis and workshops; application of local and/or traditional knowledge and management practice)
Characterization: Active	Characterization: Passive
Primary Intended Outcome: Management of populations or harvestable resources using a complex ecosystem approach	Primary Intended Outcome: Institutions and organizations focused on testing and exploring integrated policy prescriptions and strategies in complex social-ecological systems
Implementation Context: Typically the formal bureaucratic and administrative agencies and organizations concerned with natural resource management	Implementation Context: Formal and non-formal institutional and organizational structures including traditional or customary practices and institutions

Adaptive management provides a unique framework in which social and environmental uncertainty and surprise are embraced (e.g., limited data and limited theory), and systematic learning is encouraged. Consequently, an adaptive approach may provide an appropriate framework in which the complex requirements of co-evolutionary sustainable development can be addressed (e.g., regional-local tensions, development of complex compromises, lack of agreement of key questions, no agreement on essential facts, or framework for analysis, and improving information for public decisions, such as using local knowledge, etc.) (see Norgaard, 1988).

4.2 Operationalizing Adaptive Environmental Management in a Developing Country Context

> *If we were asked to design a mechanism for decisions to maximize every known disability and minimize any possible advantage of poor countries, we could hardly do better than comprehensive, multi-sectoral planning (Caiden and Wildavsky, 1974:293).*

Four decades of development planning in the South have illustrated the inadequacies of a synoptic or "blueprint" approach to project, program and policy implementation (Conyers and Hills, 1984; Brinkerhoff and Ingle, 1989). Instead, the importance of designing projects, programs and policies that are adaptive and responsive to evolving socio-economic circumstances, political complexity, and surprise has been highlighted (e.g., the "structured flexibility" approach) (see Johnstone and Clark, 1982; Uphoff, 1986; Brinkerhoff and Ingle, 1989; Rondinelli, 1993). As Rondinelli concluded (1993:4):

> *The complexity, uncertainty, lack of control, inability to predict behavior, inability to predetermine outcomes, and inadequate knowledge about the most appropriate ways of promoting economic and social development, in reality, [make] all development projects and programs "experiments".*

New tools, procedures and planning methodology are required in developing countries to effectively link socioeconomic and natural systems (see Hannah et al., 1998 for an interesting case study). Adaptive management provides one potential approach. For example, Holling (1978) has argued that an adaptive approach may have inherent benefits in a developing country context as it is oriented towards the search for locally appropriate policies, accepts the change and uncertainty characteristic in many developing countries, and focuses management decision making in the absence of complete data. Yet, with few exceptions, most experience and lessons from adaptive environmental management have been derived from temperate, North American, and/or European case studies[15]. As a result, the applicability of an adaptive management approach to regional ecosystem planning in a developing country context must be viewed with skepticism. The all too common transfer of solutions from the North to South often ignores the impact of colonialism, vulnerability to external stress, economic dependence, internal administrative weakness, population growth, and political instability common to many developing countries (see Sanderson, 1995). At times, this transfer of solutions results simply in inadequate programs or policy; at other times, it can be outright dangerous (see Anderson and Grove (1987) for a review of this problem as it relates to conservation in developing countries).

Sanderson (1995) provides a preliminary critique of the potential application of adaptive management in developing countries. In particular, he highlights: (i) the importance of reflecting the natural and social history of the region in policies for ecosystem management; (ii) a limited understanding in many developing countries of the role of regional ecosystem structure and function in biodiversity protection and ecological integrity; (iii) a limited understanding of what a renewed ecosystem would entail; (iv) the significant limitations of the public sector in many developing country contexts that will be charged with coordinating regional environmental planning activities; and, (v) the tendency for systems that are more vulnerable to external influences to import answers from outside - the result of which will likely be decreased resilience, more rigid management institutions, and more dependent societies. Other constraints to the application of an adaptive approach in developing countries can also be identified. For example, McLain and Lee (1996) contend that "scientific" adaptive management contains several flawed assumptions about how environmental decisions are made. In particular, McLain and Lee (1996) point to the emphasis on scientific knowledge, and the capacity of those with financial resources and existing power to generate the "best" science. In a developing country context, where inequities in power relations are often dramatic, and countervailing forces weak (see Sanderson, 1995), decision making may be negatively influenced and social learning impaired. McLain and Lee (1996) have concluded that the scientific approach to adaptive planning and management has resulted in several negative attributes: (i) an over-reliance on the synoptic planning approach (this is worrisome given Caiden and Wildavsky's (1974) conclusions that synoptic planning fails in virtually all poor countries because it requires too much data, too many skills, and too much money); (ii) a tendency to discount non-scientific forms of knowledge; and, (iii) inattention to policy processes that promote the development of shared understanding among a diverse range of shareholders. As well, there is an inherent assumption that those involved in the adaptive experimentation process will make objective, rational decisions and will be supported by a responsive set of institutions.

Lee (1993) suggests that adaptive management should instead seek to: (i) suggest institutional designs and practices that can develop a learning strategy in the face of irrational decision making, uncertainty and surprise; and (ii) temper and frame expectations as to what is attainable in an imperfect world (Lee, 1993). Yet numerous institutional issues may influence the success of adaptive management in developing countries (see Table 4.1).

Table 4.1: Institutional conditions affecting adaptive management

There is a mandate to take action in the face of uncertainty: But experimentation and learning are at most secondary objectives in large ecosystems. Experimentation that conflicts with primary objectives will often be pushed aside or not proposed.
Decision makers are aware that they are experimenting anyway. But experimentation is an open admission that there may be no positive return. More generally, specifying hypotheses to be tested raises the risk of perceived failure.
Decision makers care about improving outcomes over biological time scales. But the costs of monitoring, controls, and replication are substantial, and they will appear especially high at the outset when compared with the costs of unmonitored trial and error. Individual decision makers rarely stay in office over times of biological significance.
Preservation of pristine environments is no longer an option, and human intervention cannot produce desired outcomes predictably. And remedial action crosses jurisdictional boundaries and requires coordinated implementation over long periods.
Resources are sufficient to measure ecosystem-scale behaviour. But data collection is vulnerable to external disruptions, such as budget cutbacks, changes in policy, and controversy. After changes in the leadership, decision makers may not be familiar with the purposes and value of an experimental approach.
Theory, models, and field methods are available to estimate and infer ecosystem-scale behaviour. But interim results may create panic or a realization that the experimental design was faulty. More generally, experimental findings will suggest changes in policy; controversial changes have the potential to disrupt the experimental program.
Hypotheses can be formulated. And accumulating knowledge may shift perceptions of what is worth examining via large-scale experimentation. For this reason, both policy actors and experimenters must adjust the tradeoffs among experimental and other policy objectives during the implementation process.
Organizational culture encourages learning from experience. But the advocates of adaptive management are likely to be staff who have professional incentives to appreciate a complex process and a career situation in which long-term learning can be beneficial. Where there is tension between staff and policy leadership, experimentation can become the focus of an internal struggle for control.
There is sufficient stability to measure long-term outcomes; institutional patience is essential. But stability is usually dependent on factors outside the control of experimenters and managers.

Source: Lee, (1993:85)

Given these demanding conditions, several important questions about the institutional feasibility of formal adaptive management (i.e., scientific) in developing countries must be posed (adapted from McLain and Lee, 1996). For example, do existing institutional bureaucracies in developing countries provide the flexibility needed for adaptive management? Can the contradiction between short-term political terms and the biological generation focus of an adaptive approach be adequately addressed? Can alternative institutional structures (i.e., neutral councils) be established that have the required authority (and the financial capacity) to implement adaptive planning and management? Moreover, are such institutional structures culturally appropriate and socially acceptable?

The centrality of sophisticated, analytical modelling in "scientific" adaptive management may also constrain its application in developing countries. While analytical models can be useful tools for enhancing information flow and stimulating discussion among stakeholders about goals, objectives, management options and values, they are based on the assumption that scientific knowledge is more valuable in resource management decision making than other forms of knowledge (McLain and Lee, 1996). However, the importance of indigenous knowledge as a source of valuable information and basis for interpretation of environmental and social conditions is well documented (Agrawal, 1995; Berkes and Folke, 1998), and for some, a central element in sustainable development (see Redclift, 1987). More importantly, perhaps, there is growing evidence of valuable adaptive strategies employed in traditional and/or agrarian societies that have evolved in response to ecological uncertainty and complexity. Planners and managers should, therefore, focus on identifying and strengthening the existing institutions and processes needed to support adaptive management, rather than on a creating better models. This has particular relevance in many developing countries.

Finally, the involvement and education of people within landscapes and regions are considered critical to the development of resilient solutions and the removal of institutional inertia (Gunderson et al., 1995; Smith et al., 1998; Shindler and Cheek, 1999; Johnson, 1999a; Lee, 1999). Yet individual citizens in the Columbia River basin, the site of the most widely applied example of adaptive planning and management, report a feeling of alienation from decision-making processes (Smith et al., 1998). Moreover, the process of "bounded conflict" (i.e., open, democratic discourse necessary for adaptive management) may not function in societies in which tradition, hierarchy, and respect for authority prevail (e.g., Southeast Asia) (see Boyle, 1998), although the flexibility and learning orientation of participatory appraisal may help address this constraint to adaptive management[16]. To conclude, a critical review of a broad range of adaptive management literature (Rondinelli, 1993; Micheal, 1995; Gunderson et al., 1995; McLain and Lee, 1996; Smith et al., 1998; Shindler and Cheek, 1999; Johnson, 1999; Lee, 1993, 1999; Gunderson, 1999) highlights numerous procedural and substantive constraints to an adaptive approach which are directly relevant to the effective implementation of adaptive ecosystem management in Central Sulawesi, and developing countries generally (Table 4.2).

Table 4.2: Procedural and substantive constraints to effective adaptive management[17]

Procedural constraints	Substantive constraints
✓ Conflict between ecological values and management goals	✓ Inability to develop predictive models
✓ Inflexible institutions (risks too high, costs too high)	✓ Over-emphasis on analytical models
✓ Inflexible stakeholders, entrenched interests	✓ Financial capacity and the high cost of information
✓ Lack of participation and collaboration with broad spectrum of stakeholders	✓ Technical capacity to conduct experimentation (i.e., strict protocols)
✓ Public distrust of agencies	✓ Long-term timeline for analysis and decision making
✓ Inadequate data sharing among stakeholders	✓ Situation of partially open resource access system (significantly raises complexity)
✓ Poor integration between regional institutions and local management efforts	✓ Inadequate enforcement of regulations
✓ Fear of error among stakeholders and inability to acknowledge vulnerability and uncertainty (e.g., taboo topics)	✓ Institutions and staff maintain perspective as source of solutions, not as facilitators
✓ Social, political and/or ecological risks outweigh potential benefits of adaptive management approach	✓ Inadequate attention to traditional knowledge
✓ Lack of agreement on vision, system objectives and collaborative arrangements prior to start of process	✓ Few institutional champions or charismatic leaders (e.g., lack of shadow networks or epistemic community)
✓ Inadequate focus on open and continuous social learning process (i.e., learning of all system stakeholders, not only institutions and staff)	✓ Lack of incentives, recognition and reinforcement
✓ Excessive and complex management and/or administrative protocols	✓ New worldview often required (e.g., systems, interdisciplinary, cross-scale, etc.)
✓ Focus on optimal system state, not optimal management capacity, flexible institutions and system resilience	✓ Lack of regular program staff in responsible institutions
✓ Overemphasis on synoptic process (i.e., top-down, formalized and institution driven)	✓ Lack of staff with multiple skills (scientific and diplomatic)
✓ Inadequate attention to political complexity of policy and decision making	
✓ Too few facilitators and group process skills	
✓ Poor communication among stakeholders (need for shared metaphor and symbols)	

Not surprisingly, the constraints are largely social and political, rather than scientific, and fundamentally influenced by[18]: (i) existing political and legal structures; (ii) the worldviews and attitudes of the range of stakeholders; (iii) the ability of a particular society to make coordinated and implementable decisions; (iv) the short-term economics of the decision; and, (v) the extent to which particular stakeholders "win" or gain from the decision-making process. In other words, no specific suite of techniques or normative process will overcome the challenges of achieving sustainability in complex social-ecological systems. A more detailed and empirical critique of the challenging socio-political, institutional and organizational context that influences the application of adaptive ecosystem.management in Central Sulawesi, Indonesia, is provided in Chapter 8.

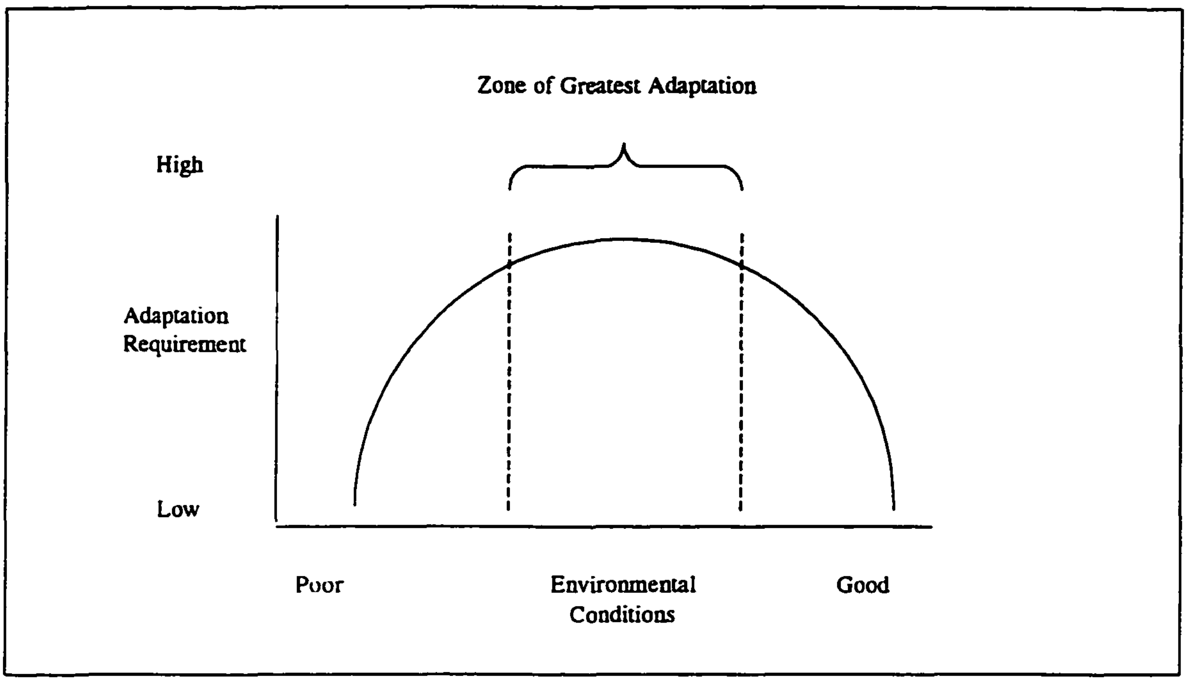
4.3 Cultural Ecology, Indigenous Adaptation and the Human Dimensions of Conservation Science and Practice

Lee (1993) has argued that adaptive management provides the compass we can use to search for a more sustainable future - a valuable link between science and human endeavor. As outlined above, however, the operational, institutional and intellectual challenges to adaptive ecosystem management are numerous. One of the most pressing challenges is a lack of experience and understanding of how to design and implement conservation and ecosystem management approaches and policies that ebb and flow with the intrinsic cycles of nature. The conventional command and control approach to the manipulation, modification and internment of natural systems and valuable resource stocks has greatly limited our capacity to interpret the dynamics of complex ecosystems. Fortunately, we have an opportunity to analyze and learn from traditional adaptive socio-ecological strategies designed to monitor, interpret and function within the dynamics of complex ecological systems. At a minimum, it is necessary to understand how traditional resource management systems are effected by change and the adaptive strategies indigenous societies utilize to buffer those changes (Lane, 1993; Scoones, 1994; Berkes et al., 2000). More importantly, however, we should seek to identify how those adaptive strategies, techniques and institutional mechanisms may address the complex requirements of coevolutionary sustainable development.

The importance of understanding sociocultural and institutional dynamics of environmental change, integrating indigenous knowledge in conservation and development plans, and promoting gender-sensitive resource management strategies is well ensconced in the formal policy and rhetoric of virtually all responsible governmental agencies, conservation organizations and international lending agencies. Corresponding principles are also elaborated upon in major international agreements and covenants (e.g., Agenda 21, Convention on Biological Diversity). Individual behaviours and knowledge, societal perceptions and values concerning natural resources, cultural norms and practices associated with valued resources (including gender differentiated understanding of resource access and control), the efficacy of formal and informal institutions (including property rights), and the extent to which people depend directly on natural resources for their livelihood, are without question, the foundation of conservation practice (Stanley, 1995; Roe, 1996; Sponsel et al., 1996). Thus, the integration of an ecological outlook in social and anthropological analysis has contributed to improved understanding of the human dimensions of natural resource management.

The adoption of an ecological perspective in socio-anthropological analysis originally emerged as a result of persistent dissatisfaction with structuralist social interpretations unable to cope with observed dynamism and individual variation, as well as generalizations about cultural values and types (the outgrowth of which was environmental determinism) (Netting, 1986). In response, Steward (1955) established a new mandate for the study of societies and their environments when he defined cultural ecology as the study of "...the adaptive processes by which the nature of society and an unpredictable number of features of culture are affected by the basic adjustment through which man utilizes nature" (in Netting, 1986:6). Corresponding principles of adaptation and associated ethnographic evidence were first assembled in *Man the Hunter* (Lee and DeVore, 1968), and socio-anthropological interest in adaptive human-ecological interactions is now well established (Rappaport, 1967; Netting, 1968; Vayda and McCay, 1975; Ellen, 1982). However, more recent empirical studies have sought to make a direct link between the socio-anthropological understanding of adaptation and subsistence management with the broader conservation and sustainability discourse (see Oldfield and Alcorn, 1991; Sponsel et al., 1996; Berkes and Folke, 1998; Berkes et al., 2000). Although the concept of adaptation is typically thought of as an ecological process comprising the interplay between human groups and specific resources (or environmental constraints), adaptation is first and foremost an evolutionary process (Hardesty, 1986) (Figure 4.2). In other words, cultural adaptation is an opportunistic process oriented towards the path of least resistance, either by generating mechanisms to cope with environmental limitations or by taking advantage of new resources and environmental circumstances (Hardesty, 1986). Indeed, Steward's (1955) theory of multi-linear evolution suggested that separate evolutionary pathways are created by the adaptive interplay between a culture's unique history and its environment. In order to explain this process, Hardesty (1986) has outlined a coevolutionary model of cultural adaptation consisting of small, gradual and accumulative adaptations, as well as sudden, dramatic events that create radically new sociocultural "structures", processes, or conditions. The former is related to how societal goals (e.g., food, security, leisure) are achieved within a given environment. The latter concerns fundamental evolutionary transformation after long periods of relatively little change[19].

Figure 4.2: Adaptation requirement and environmental conditions



Thus, cultural ecology (and more recently ecological anthropology) provides a particularly useful perspective on numerous human dimensions of biodiversity protection, ecological integrity and sustainability (Netting, 1986; Butzer, 1989; Bassett and Zimmerer, 1999). For example, a cultural ecological approach focuses on the complex web of social, cultural and subsistence aspects of conservation from the perspectives of local resource users (e.g., farmers, foragers) (Rappaport, 1967; Moran, 1982; Sponsel et al., 1996). A cultural ecological approach also provides a cross-cultural perspective on natural resource issues. In many geographical settings, and certainly in Central Sulawesi, a broad spectrum of societies, communities and groups coexists. Thus, cultural ecology provides a means of understanding differences among groups, their implications for planning and management, as well as the potential similarities across cultures that may unite groups toward a common cause (Sponsel *et al.*, 1996). Additionally, cultural ecology seeks to build in a temporal understanding of sociocultural change, institutional dynamics through time, and the changing landscape of natural resources and ecosystems (Boomgaard et al., 1997; EDEN, 2000; Ellen, *et al.*, 2000). An historical perspective helps to better interpret and inform understanding of current conditions and patterns of use. As such, cultural ecology seeks to consider multiple viewpoints and utilize multiple research methods in order to explore complex social-ecological linkages (Blaikie, 1995; Bassett and Zimmerer, 1999; Bassett and Koli Bi, 2000).

In particular, cultural ecology provides an analytical framework to explore the diverse indigenous social, cultural and institutional adaptations to environmental uncertainty, and the influence that locally-developed adaptive strategies have on the management of ecological systems (Bassett, 1988; Butzer, 1989; Lane, 1990; Moran, 1991). For example, traditional and/or agrarian societies often utilize management practices better suited to the monitoring and interpretation of complex ecosystems in an effort to secure benefits from natural resources (Woodburn, 1968; Dove, 1993; Folke, et al., 1998; Berkes et al., 2000) (Table 4.3). Many of these adaptive strategies and mechanisms prevent the emergence of large-scale ecological or social crisis by permitting disturbance to enter into the agroecological system at lower levels (Rappaport, 1967; Berkes and Folke, 1998; Folke, et al., 1998) (see Chapter 9). Thus, local management adaptations associated with small-scale movement of human populations, resource rotation, protection of species at vulnerable stages, and the institutionalized mechanisms associated with these adaptations are better positioned to avoid crossing ecological thresholds at scales that threaten whole sociobiophysical systems (Lane, 1990; Scoones, 1994; Berkes and Folke, 1998). Quite simply, understanding local adaptive strategies and mechanisms may significantly improve conventional conservation and ecosystem management practice by providing (see Folke et al., 1998):

- insights for the design of adaptive ecosystem management approaches that flow with natural systems;

- new approaches suitable for forestry, agriculture, fisheries, aquaculture and freshwater management;
- lessons for developing and implementing appropriate social sanctions and sustainable practices;
- approaches to avoid surprise created by conventional resource management; and,
- insight into how to manage system disturbance and fluctuation.

Table 4.3: Adaptive strategies for biodiversity, integrity and sustainability

1. Adaptive strategies for environmental uncertainty:

✓ monitoring change in ecosystems and in resource abundance
✓ total protection of certain species
✓ protection of vulnerable stages in the life-history of species
✓ protection of specific habitats
✓ temporal restrictions of harvest
✓ multiple species and integrated management
✓ resource rotation
✓ management of succession
✓ management of landscape patchiness
✓ watershed management
✓ managing ecological processes at multiple scales
✓ responding to and managing pulses and surprises
✓ nurturing sources of renewal

2. Mechanisms for adaptation:

a) Generation, accumulation and transmission of ecological knowledge:
✓ Reinterpreting signals for learning
✓ Revival of local knowledge
✓ Knowledge of carriers/folklore
✓ Integration of knowledge
✓ Intergenerational transmission of knowledge
✓ Geographical transfer of knowledge

b) Structure and dynamics of institutions:
✓ Role of stewards/wise people
✓ Community assessments
✓ Cross-scale institutions
✓ Taboos and regulations
✓ Social and cultural sanctions
✓ Coping mechanisms; short-term responses to surprises
✓ Ability to reorganize under changing circumstances
✓ Incipient institutions

c) Mechanisms for cultural internalization:
✓ Rituals, ceremonies and other traditions
✓ Coding or scripts as a cultural blueprint

d) Worldview and cultural values:
✓ Sharing, generosity, reciprocity, redistribution, respect, patience, humility

Source: adapted from Folke et al., (1998:418)

The indigenous adaptive strategies and mechanisms outlined in Table 4.3 offer critical insight when designing for sustainability (Folke et al., 1998). However, the integrity of these locally evolved social-ecological systems, and the adaptive strategies and mechanisms utilized by local people, are poorly buffered from broader social, economic and political forces, and the effects of globalization. Integrating locally-derived adaptive management strategies into broader policy and practice is an issue of paramount importance (see Chapter 9), yet one that is constrained by unarticulated perceptions and worldviews concerning indigenous resource management practices and their implications for ecological systems.

5.0 CONSERVATION POLICY, POLITICAL ECOLOGY AND COMPLICIT SOCIAL ANALYSIS

5.1 From Rationality to Incrementalism

Conservation practice is normally carried out within a given framework or set of rules. This collection of legislation, executive decrees, contracts and agreements is referred to as policy. Thus, policy is the "...stated objectives, operating rules, laws and legal codes, and binding agreements that are endorsed, pronounced and promulgated by governments and institutions" (Honadle, 1999:28). The intended outcome of this framework of rules is oriented towards changing behavior (either by encouraging people to cease certain activities or promoting new types of behavior), restoring a resource, or improving the efficiency and/or equity of resource use. Correspondingly, there is a range of mechanisms through which behavioral responses and other targeted consequences can be achieved (e.g., building awareness, using market mechanisms, or devolving management and/or ownership of a resource) (Table 5.1).

Table 5.1: Targeted consequences of policy and available mechanisms

Targeted consequences	Policy approaches	
✓ Less damaging activity ✓ Restoring resource ✓ New conserving behavior ✓ Sequestering resource ✓ More efficient consumption ✓ Substitute market creation ✓ New decision processes / adaptive capacity ✓ New accounting / measurement system	✓ Command and control ✓ Direct incentives ✓ Stakeholder self-management ✓ Indirect incentives (spillover effects)	
	Policy mechanisms	
	✓ Organizational champion ✓ Bureaucratic reorientation ✓ Environmental dispute resolution ✓ Markets ✓ Policy pronouncement ✓ Legislative decree and regulations ✓ Devolution of ownership / management	✓ Public trust (financial or physical) ✓ Debt-for-nature swap ✓ Political exhortation and mobilization ✓ Public awareness and publicity ✓ Subsidy ✓ Taxation ✓ Trade restrictions

Source: adapted from Honadle (1999)

Fiorino (1995) outlines several institutional challenges associated with environmental policy development and implementation that determine how problems are defined, compared and resolved; that is, determining what behavioral changes are desired and how best to achieve them. First, the process of setting a policy agenda is influenced by who decides, how and in what order new problems will become the focus of policy debate. Second, the maintenance of democratic values is an ongoing institutional challenge given the complexity of factors involved, the increasing role of technology and the associated focus on technical experts as providers and analyzers of the information used in decision making. Combined, these variables threaten to remove ordinary individuals from policy debate and analysis and place the process in the domain of technical experts and the administrative elite – a decidedly undemocratic process. Third, there is a need for clarity surrounding the economic benefits and costs associated with different policies. Understanding return on environmental investment is important if methods of using scarce resources wisely are to be designed. Fourth, Fiorino (1995) highlights the need to overcome institutional fragmentation or sectoralism, enhance the capacity to address cross-border, multi-jurisdictional issues, better integrate public and private sector interests, and build cooperation among them. Fifth, there is a need to develop better mechanisms to measure and evaluate progress. Policy makers need a continuous flow of reliable information in order to set priorities, design strategies, and make choices. At present, however, data sets are often unevenly distributed and inconsistent, and difficult to link to adequate performance measurements (Fiorino, 1995).

The manner in which these institutional issues are addressed is influenced to a large extent by the model of policy development and implementation employed[20]. Traditionally, a rational approach to the maximization of net benefits (social and environmental) has been applied that consists of defining policy options, quantifying (preferably) the likely effects of each option, comparing each option to a set of objectives, and selecting the option with the best return (Roe, 1994; Fiorino, 1995). However, inadequate outcomes associated with this linear, sequential approach to policy (Lindblom, 1974), planning (Isard, 1972; Friedmann and Weaver, 1977), and environmental practice (Holling and Meffe, 1996) encouraged the search for a broader policy model. Thus, the idea of "bounded rationality" or "satisficing" has been applied to better explain how decisions are made in practice. Rather than making optimal choices, decision makers often satisfice because they are bounded by inadequate resources, time, information and cognitive capacity. Lindblom's (1974) incremental approach offers a similar description of how policy is actually made and a prescription for how it should be made (Fiorino, 1995) (Table 5.2). In contrast to a rational approach to policy formation, an incremental approach more readily recognizes and corrects policy error, recognizes that agreement on goals will emerge and evolve as choices are made and issue understanding develops, utilizes past experience as a basis for action, and recognizes that piecemeal decision making is better suited to coping with limits of information and time than rational decision making (Fiorino, 1995; Mitchell, 1997). This process of "muddling through" is proffered as a more realistic way of describing policy and practice.

Table 5.2: Characteristics of an incremental approach

- ✓ Problems not clearly defined; key task is often to determine nature of the problem at hand
- ✓ Conflicting goals, objectives and values
- ✓ Consideration of a limited number of policy options which differ only incrementally from one another and other policy options
- ✓ Restricted set of impacts assessed and evaluated for each option
- ✓ Continuous redefinition of the problem; intended outputs typically adjusted with regard to available means
- ✓ No single, correct solution or strategy with a focus on avoiding undesirable outcome rather than on systematically achieving desired outcome
- ✓ Policy process never finished; sequential process involving ongoing series of incremental decisions

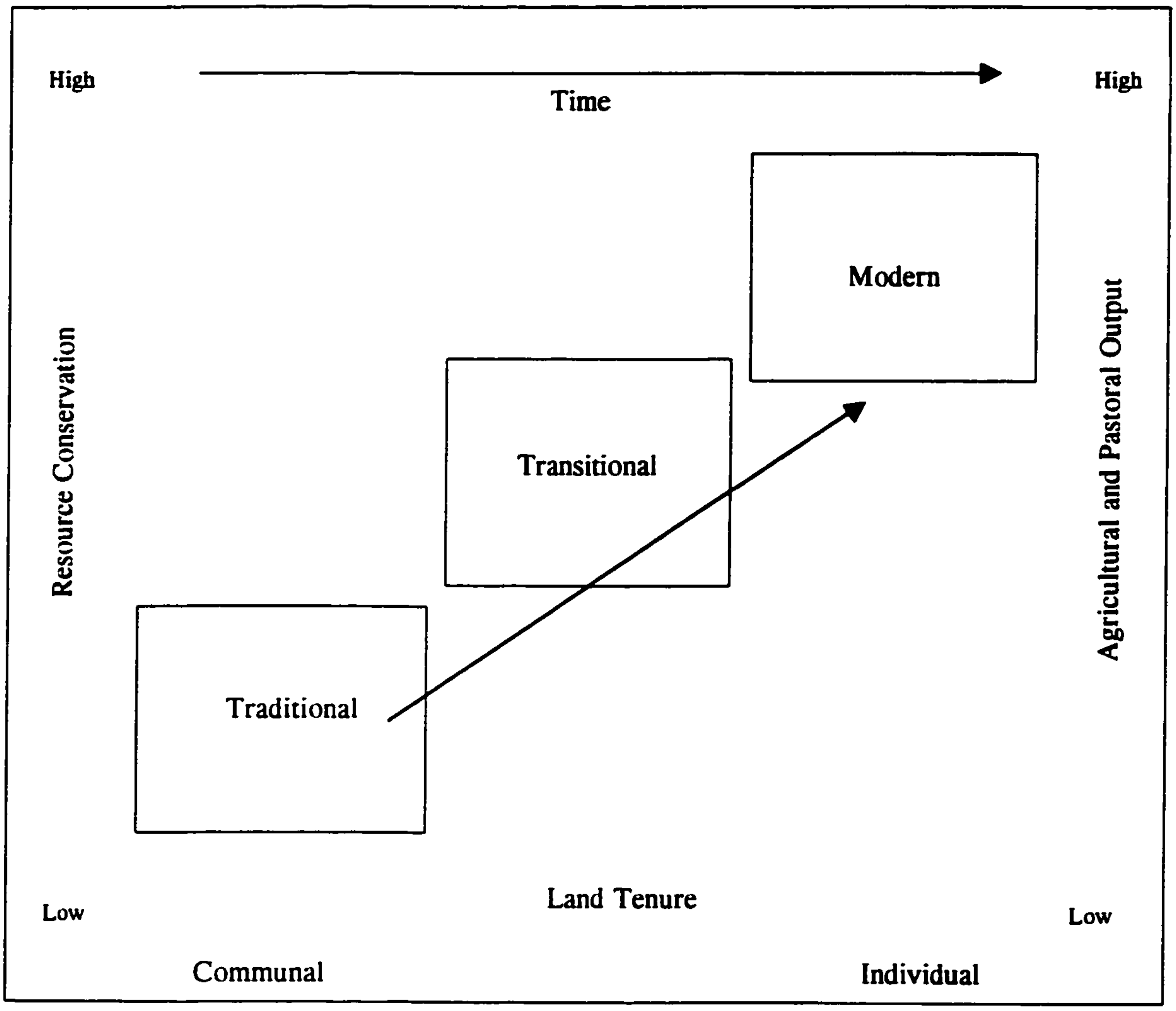
Source: adapted from Mitchell (1997:86-87)

5.2 Beyond Incrementalism: Conservation Narratives and Complicit Social Analysis

Despite the general acceptance of "bounded rationality", or incrementalism, as a conceptual framework for policy and practice, conservation and ecosystem management initiatives often inadequately capture the critical social, cultural and institutional factors that influence sustainability. Such inadequacies stem not only from the particular policy model employed, but from the tendency of program designers and policy makers to filter or interpret information and analysis, once collected, in accordance with broadly accepted assumptions or "narratives". Indeed, an aspect of the policy development process often missing from a technical overview of policy models is a critique of the fundamental drivers that shape and influence decision making.

Fairhead and Leach (1995) describe narratives as stories of incontrovertible logic that provide scripts and justifications for action based on a range of assumptions - assumptions that lend credence to possibly incomplete perceptions and understanding of the problems at hand, particularly about the manner in which traditional or agrarian individuals and communities interact with ecological systems (Anderson and Grove, 1987; Fortmann, 1995; Bassett and Koli Bi, 2000). Indeed, recent research has explored social-ecological linkages by focusing on environmental narratives and development discourse. The findings and insights of this work suggest that many environmental crises are improperly portrayed or exaggerated (Bassett and Koli Bi, 2000). For instance, Roe (1991, 1994) outlines several examples from the development literature to elaborate on this insight[21]. One example is the "tragedy of the commons" narrative that has provided a set of justifying, seemingly logical assumptions used to direct numerous development interventions in much of dryland Africa and elsewhere (see Anderson and Grove, 1987; Lane, 1993, Armitage, 1996). The common perception of African land users destroying resources because of open access to land has led to the conclusion that privatization will offer land users the security they require to invest in and sustainably manage their resources (Bassett and Koli Bi, 2000) (Figure 5.1).

Figure 5.1: Modernization model for tenure, environment and agricultural growth



Source: Bassett and Koli Bi (2000:76)

Despite the lack of supporting data and a wide-ranging critique of its tenets, the tragedy of the commons continues to possess considerable influence as a narrative by stabilizing the conditions necessary for decision making (Roe, 1991; 1994). The tragedy of the commons example illustrates that program planners and policy makers will inevitably turn to the interpretive models and heuristics they have, despite the extent to which they have been called into question. As Roe (1991) suggested, this is because more elaborate and demanding analyses will likely lead to greater uncertainty about complex ecological-social interactions, undermine the assumptions policy makers use, and leave the decision maker without a clear mechanism to shift from a discredited narrative to one that may offer better insight. The appeal of the tragedy of the commons narrative is its ready applicability to blueprint design processes associated with privatization of the commons (Roe, 1991). Uncertainty generation, therefore, will not help dispel narratives. Instead, an equally clear and correspondingly attractive counter-narrative must be developed. As Roe (1991:290) argued:

> *....if decision makers are to move beyond the prevailing model of an entirely unmanaged and open access commons, they will do so not merely by being told reality is more complex than they thought, but also by having a counternarrative which can predict when common property management will take place or not, and what are the implications of either event.*

Understanding the narratives that influence policy is a useful way of identifying appropriate decision options in postnormal science contexts – those circumstances with many unknowns, high interdependence, and little agreement (Roe, 1994; Cardinal and Day, 1999). As such, an analysis of policy narratives must begin with a recognition of inherent complexity and uncertainty and capture as many "voices" as possible to describe the system - not because of an *a priori* moral concern for pluralism, but because it is in multiple voices that the underlying assumptions (or metanarrative) can be identified (Roe, 1994). In this respect, identifying the voices and stories of marginalized groups is encouraged since the more stories are elaborated upon, the better our understanding of the metanarrative.

Methodologically, narrative policy analysis is described by Roe (1994) as involving four steps. The first step is to identify the stories or arguments that dominate the situation or problem –

those stories that underwrite and stabilize assumptions for decision making. Second, the narratives associated with the problem that do not conform to the prevailing story or argument - the counternarratives - are identified. Third, the two narratives are compared in order to identify a metanarrative - that is the "intertext" that accounts for how two countervailing policy narratives can both exist at the same time. The fourth and last step is to determine if or how this metanarrative remodels the problem so that it may become more amenable to conventional policy analysis (microeconomics, public administration approaches, statistics, etc.). The reliance of the metanarrative is defined by the degree to which it can help decision makers address the core issues of conventional policy analysis and development: i) defining the problem: ii) identifying the data and information necessary to analyze the problem; iii) selecting evaluation criteria to assess alternatives; iv) formulating those alternatives; v) projecting the consequences associated with each alternative: vi) analyzing and evaluating the trade-offs between the alternatives available; and, vii) deciding among alternatives (Roe, 1994).

The implications for reconstructed conservation science and practice are significant. Alternative sets of assumptions stabilized within narratives that better fit the facts are urgently required if incomplete social analyses are to be avoided (Fairhead and Leach, 1995; Fortmann, 1995; Bassett and Koli Bi, 2000). For example, the idea of "original climax vegetation" and "traditional functional society" provides two baseline assumptions nested within a policy narrative linking ecological destruction, population growth and the breakdown of traditional societies. This narrative inevitably leads to a claim of inherent problems in most traditional agroecological regimes, the need to assess the extent of associated ecological damage, and the requirement to identify corresponding external interventions (Fairhead and Leach, 1995; Fortmann, 1995). Typically, such interventions include the organization of resource management schemes to restore or protect remaining ecosystems and establish a lost or damaged social order, either by direct state intervention or the externally promoted community reorganization associated with the international decentralization agenda (see World Bank, 1995). As Fairhead and Leach (1995) outlined, however, dynamic perspectives in both ecological and social theory run counter to this narrative. The milieu in which this imperative is increasingly articulated (in developing countries at least), centres around World Bank requirements for National Environmental Action Plans (NEAPs) in those low-income countries that receive financial assistance from the International Development Association (IDA). NEAPs are portrayed in this context as valuable tools that will facilitate the ability of low-income countries to achieve sustainability in a rational, orderly manner. However, a key concern with the development of NEAPs is the haste with which the planning process identifies and prioritizes environmental problems and solutions using limited data and limited perspectives.

> *Indeed, the World Bank places the identification of environmental problems and their underlying causes as the first step in the NEAP process. Yet, from all indications, the Bank does not consider this to be a particularly challenging phase. Despite the glaring gaps in our knowledge, the Bank believes that most environmental issues are easy to identify and can be classified along a simple color scheme (Bassett and Koli Bi, 2000:90).*

Of course, NEAPs are not the only program and policy formation tool that suffers this weakness. Conservation strategies, assessments, and project design processes prepared by bilateral and multi-lateral development agencies, international conservation organizations, and state agencies are prone to the same form of hubris and predilection towards certainty in the context of limited data, including Indonesia's own National Conservation Strategy (GOI, 1997). In this policy context, the common portrayal of traditional land use practices as anarchic and ecologically destructive provides legitimization for new laws and land use regulations in order to control and/or manage ongoing environmental crises (Armitage, 1996; Bassett and Koli Bi, 2000). The restrictive territorial designations and bureaucratization of conservation and development practice that flow from this pernicious distortion of facts often cause a loss of access to valued resources for indigenous groups or local inhabitants of a particular space (Peluso, 1993; Grove, 1997; Goldman, 1998; Nuemann, 1998).

This is not to suggest that environmental degradation is not a serious challenge confronting many developing countries, including Indonesia. In fact, the evidence of environmental degradation in Indonesia is compelling. However, a critical analysis of narratives and assumptions guiding technocratic, managerial approaches to conservation policy emphasizes the importance of approaching natural resource planning and management from multiple and nested sociobiophysical scales (Bassett and Koli Bi, 2000; Zimmerer, 2000). Intrusive regulations and administrative arrangements for policy implementation must give way to contextually (i.e., culturally, institutionally, technologically and economically) appropriate strategies for conservation that are available to different groups of resource users across temporal and spatial scales (Zimmerer, 2000). Political ecology interpretations offer a useful conceptual framework in which to explore the issues associated with such strategies.

As Scoones (1999) has pointed out, the way in which ecosystems are classified, organized, labelled and interpreted has been closely linked to long-standing "stability" concepts of ecological systems and embedded in the management practices and approaches of State administrative apparatus, international and national non-governmental organizations, and development programs. According to Scoones (1999:489):

> *Notions of what is a forest, what is overgrazing, what soil loss is, and what wilderness is like, derived from a particular view of ecology, become wrapped up in the constructions of particular people - forest dwellers, pastoralists, small-scale farmers, or indigenous people - who are often seen as the causes of environmental problems.*

Political ecology[22] interpretations thus seek to address ecological concerns to account for those cultural and political influences in the analysis of nature-society relationships that are, in many respects, socially constructed (Berkes, 1999). As constructions of society and nature are fundamentally linked to the politics of power relations and control over natural resources, ecological transformation and change should be critiqued from the perspectives of multiple system actors or stakeholders (Berkes, 1999; Scoones, 1999). Application of a political ecology framework in conservation contexts, therefore, begins with an exploration and analysis of the political, economic and socio-cultural divisions among the multitude of stakeholders: international, national, local; officials and communities; class, ethnicity and gender; scientists and politicians; etc. (see Berkes, 1999). Such concerns mirror the earlier insights of philosopher Giambattista Vico regarding the individual visions that each group or society has of themselves and the implications this has for understanding and analysis (see Chapter 2). However, in addition to exploring the different ways in which different groups define, construct and/or politicize ecosystems and resources at different scales (Berkes, 1999; Vandergeest et al., 1999; Wood et al., 2000), political ecology interpretations also seek to: (i) understand the way in which ecosystems and the environment shape socio-political relationships (Vandergeest et al., 1999); and (ii) recognize the contingent manner in which natural and social systems interact to produce unexpected or unintended outcomes (Vandergeest et al., 1999). Increasingly, political ecology perspectives about knowledge, power, politics and environmental change are thus being linked to dynamic or complex ecological perspectives captured in the new ecology movement (Scoones, 1999; Vandergeest et al., 1999; Zimmerer, 2000).

Indeed, conceptions of social and ecological order and equilibrium in policy discourse are inherently attractive but they tend not to provide a complete picture (Blaikie, 1995; Fortmann, 1995; Zimmerer, 2000). As indicated above, the notion that societies possess an inherent structure and order maintained by rules, regulations and functional adaptations has been challenged by social theory which gives increasing value to the role of social action and societies' capacity to determine and influence rules and structure (Rappaport, 1967; Hardesty, 1986; Netting, 1986; Fairhead and Leach, 1995). Thus, the tenet of a traditional or "baseline" society, that at one time operated at equilibrium with its environment, does not have conceptual rigour given the reality of continuous societal restructuring through time (Bassett and Koli Bi, 2000; Zimmerer, 2000). Likewise, ideas of ecological stability inherent in terminology such as original climax vegetation, do not adequately describe the likely evolutionary transition between multiple stable states (Pimm, 1991: Sprugel, 1991). Vegetation cover is in continuous transition and the trajectory of vegetation cover is a function of past trajectories and current conditions, both of which are influenced by a multiplicity of factors including human disturbance (Sprugel, 1991; Blaikie, 1995). No single vegetation cover archetype can be identified for a given region and no one variant or trajectory is necessarily more natural than any other (Fairhead and Leach, 1995).

> *From this perspective, environmental policy can call on no moral high ground in recreating the natural (or the social that went with it). It becomes very clearly a question of social or political choice about what vegetation forms are desirable at any given time in social history, and about ensuring that conflicting perspectives on this - such as between local, global and intergenerational interests - are adequately addressed and articulated (Fairhead and Leach, 1995:1033).*

For reconstructed conservation science and practice, narrative policy analysis, aided in part by political ecology and complexity interpretations, provides a tool in which the potential for complicit social analysis can be reduced or avoided, and planning and management improved. In particular, linking a more detailed understanding of the policy discourse at play in a particular context, with formal and non-formal adaptive strategies for social learning and ecosystem management, offers new avenues for improving the science and practice of conservation.

5.3 Bridging Intellectual Solitudes: Coincidence and Complementarity

The theoretical and conceptual frameworks and approaches reviewed in the previous chapters come from diverse disciplines and traditions. Despite this, numerous themes connect these seemingly diverse intellectual frames of reference. The similarities, no doubt, stem in part from a broader shift in intellectual archetypes. What Kuhn (1962) defined as the "constellation of achievements - concepts, values, techniques, etc. - shared by a scientific community and used by that community to define legitimate problems and solutions", has over the last half century been challenged. This shift has not only influenced scientific endeavour but has influenced cultural and social relationships as well (Capra, 1996). Quite possibly, then, the linkages and similarities between the theoretical and conceptual frameworks previously outlined are in many respects an expected coincidence. Whether by coincidence or not, however, the inherent complementarity of these frameworks provides an opportunity for the integration of knowledge and epistemological traditions that would otherwise remain as solitudes on an ever changing and increasingly fragmented intellectual landscape (Table 5.3).

The intent of this and the previous two chapters has not been to provide an in-depth historical summary, nor comprehensive review of the frameworks described above, but rather to critique and explore their theoretical and empirical utility. Indeed, the incorporation of new ecology concepts with adaptive management and narrative policy critique has been done in an effort to highlight and synthesize useful insights and implications relevant to reconstructed conservation science and practice. Linked with the "environmental politics of progressive social movements" (see Zimmerer, 2000:358), equitable and responsible conservation approaches can be tested that are supportive of less powerful groups and oriented towards the maintenance of ecological systems. The challenge that logically follows is to explore and illustrate the use of these varied approaches in an effort to facilitate policy development and conservation practice in complex sociobiophysical systems. It is to this challenge that I now turn.

Table 5.3: Theoretical and conceptual complementarity

Analytical Frameworks Core Concepts and Operational Principles	Complex Adaptive Systems	Landscape Ecology	Adaptive Ecosystem Management	Cultural Ecology	Political Ecology	Narrative Policy Analysis
Dynamic equilibrium / Multiple stable states	•	•				
Non-linearity and networks	•	•				
Chaos	•					
Hierarchy and scale	•	•	•		•	
Evolutionary dynamics	•	•	•	•	•	
Uncertainty and change	•		•	•		•
Adaptation	•		•	•		
Pluralism			•	•	•	•
Qualitative and quantitative integration			•	•	•	•
Multiple system trajectories or pathways	•			•	•	•

6.0 CONSERVATION DISCOURSE IN THE COASTAL ZONE: SOCIO-INSTITUTIONAL DYNAMICS AND THE POLITICAL ECOLOGY OF MANGROVE FOREST CONVERSION

6.1 Environment and Culture in the Coastal Zone

Adjacent to the Makassar Strait on the western edge of the Donggala peninsula, the coastal zone of Banawa (Figure 1.1) is typified by picturesque rock-exposed capes and headlands, craggy inlets, beach-fringed bays and lagoons. Fringe, barrier and patch reefs protect much of the coastline and provide local fishers with opportunities to harvest subsistence and marketable marine resources. Beyond the reefs, schools of pelagic fish attract both local fishers and commercial fishing vessels. Inland from a shoreline dotted with stilted wood, thatch, and tin homes are remnant mangrove forest patches, coconut groves, vegetable gardens, occasional rice fields, and increasingly, aquaculture ponds. Five territorial villages comprise the coastal zone of the southern Banawa (Banawa Selatan) study area that is the focus of this chapter. Combined, they have an estimated population of 9,152 (see Table 6.1).

Table 6.1: Population, Area, and Density in Coastal Villages of Banawa Selatan, 1998

Village	Population	Area (km^2)	Population Density (people per km^2)
Surumana	1,280	14.0	91
Tolongano	2,912	37.4	77
Tosale	1,753	23.5	74
Lalombi	1,822	43.3	42
Tanameah	1,385	23.9	58

Source: BPS Kabupaten, 1998

Historically an area of Kaili people (e.g., Unde, Ledo and Da'a), the coastal zone of Banawa is now inhabited by many ethnic groups including Buginese, Mandarese, Sundanese and Javanese. According to one recent study (PSL-UNTAD, 2000), the population of Banawa Selatan has grown by approximately 10% in the last decade, largely as a result of in-migration, settlement schemes and the promotion of economically productive agricultural activities in the area. Individuals living in the multi-ethnic communities of Banawa Selatan are engaged in fishing and other small-scale resource harvesting activities, gardening, coconut farming (for copra), and small-scale trade. Family household incomes vary from $US 35 to $US 175 per month (PSL-UNTAD, 2000). Changing socio-economic and ecological dynamics, however, have led to a progressive transformation of the coastal zone. In particular, developments over the past 15 years have catalyzed the removal of mangrove forests that previously fringed the coastal zone and the subsequent expansion of aquaculture ponds or *tambak*. This dramatic flip in system states has broad-scale implications for environment and culture in Banawa, influencing the foundation of nature-society interactions in the coastal zone.

Of the estimated 181,000 km^2 of mangrove forests in the world, 75,173 km^2 (41.5%) are located in south and southeast Asia, and 42,550 km^2 (23%) are located in Indonesia alone (Spalding et al., 1997:24). Much of the remaining intact mangrove forest ecosystems in Indonesia are located along the coastlines of Kalimantan and Irian Jaya, although important areas of mangrove forest are present in Sulawesi as well. While 19 tree species are commonly encountered in intact mangrove forest ecosystems in the region, five major species dominate: *Rhizophora* spp., *Avicennia* spp., *Sonneratia* spp., *Bruguiera* spp., and *Nypa fruticans* (FAO, 1985; Whitten et al., 1987). In addition, 20 species of epiphytes and orchids may occasionally be present in mangrove forest systems in the region, along with a range of mosses and liverworts (Whitten et al., 1987). Typically, *Rhizophora* species dominate along river and channel edges, while *Avicennia* species and *Sonneratia* species occupy lands nearest to the sea. *Bruguiera* species, although interspersed with *Rhizophora*, form a distinct zone further inland. Mangrove forest furthest from the sea consists of pure stands of *B. gymnorrhiza*, while the boundary zone between mangrove and inland forest typically consists of *Xylocarpus* species and

Nypa fruticans (FAO, 1985; Whitten et al., 1987; Soendjoto and Arifin, 1999). Ecologically, the coastal estuarine environment plays a crucial role in maintaining the health of the Banawa coastal zone. Roots and stems of intact mangrove forests, sea grass beds and benthic algae provide shelter, habitat and sources of food for juvenile stages of numerous marine creatures (e.g., fish, prawn, crab and molluscs), many of which are economically important to coastal fisher communities (see Whitten et al., 1987; PSL-UNTAD, 2000). For example, an intertidal system including intact mangrove forest provides essential spawning habitat for a number of species, including milkfish (*Chanos chanos*) and prawn (*Penaeus monodon* and *P. merguiensis*). Moreover, like terrestrial forest ecosystems, mangrove forest assemblages are dynamic ecosystems subject to simultaneous accretion and erosion, variations in tidal regimes, soil chemistry and salinity. These dynamic processes interact to influence successional pathways and structural zonation within mangrove ecosystems (Whitten et al., 1987).

Local inhabitants categorize mangrove forest trees into three general classes which correspond to formal taxonomic species and habitats: *salasala* (*Bruguiera* spp.) found in sandy soils and better drained sites, *popu* (*Sonnetaria* and *Avicennia* spp.) and *bangko* (*Rhizophora* spp.) both typically found in muddy silts and poorly drained sites. However, a much more detailed knowledge of local mangrove species and their uses is possessed by people in coastal communities. Local use (direct and indirect) of mangrove forest resources is varied and significant, and includes timber for construction, fuelwood, charcoal, logs and wood chips, tannins and dyes, as well as the use of nipa (*Nypa fruticans*) for sugar, alcohol production, and thatching (FAO, 1985; Spalding et al., 1997). In the Banawa coastal zone, community members have identified a range of economically important products associated with intact mangrove ecosystems that can be harvested and utilized throughout the year by both men and women (Table 6.2).

Table 6.2: Seasonal Perspective on Socioeconomic Benefits of Intact Mangrove Ecosystems in Banawa Selatan, Central Sulawesi (2000)

Activity / Product	Resource trend	January	February	March	April	May	June	July	August	September	October	November	December	Gender*	Quantity	Economic Value (estimated by informants)**	Note
1) Fire Wood	↓	■	■	■	■	■	■	■	■	■	■	■	■	M	According to household	N.A.	
2) Building Materials	↓	■	■	■	■	■	■	■	■	■	■	■	■	M/W	Approx. 100 poles / month (variable)	5000 Rp / pole	
3) Charcoal	----	■	■	■	■	■	■	■	■	■	■	■	■	M	1 tree / person / month (	1500 Rp / basket (a basket equals 1 tree)	
4) Dye	↓	■	■	■	■	■	■	■	■	■	■	■	■	M	1 tree / person / month	1500 Rp / month	Note 1
5) Anchors for boats	↓	■	■	■	■	■	■	■	■	■	■	■	■	M	Every individual with a boat	As needed	Note 2
6) Joints for boat stabilizers	↓	■	■	■	■	■	■	■	■	■	■	■	■	M	As needed	Currently valued at 10,000Rp / four	Note 3
7) Fish																	
Bandeng (entry into mangrove) (Chanos chanos)	↓								■				■	M/w	Previously 10 tonnes / year	250 Rp / kg	
Bandeng (protection, spawning) (C. chanos)	↓	■	■							■	■			M/w			
Bandeng (harvest period) (C. chanos)	↓			■								■		M/w			
Sunu (Epiniphelus spp.)	↓	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	M/W		5000 Rp / Ekor (current price)	
Baronang (Signanus spp.)	↓	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	M/W		5000 Rp / Ekor (current price)	
Kakap (latin unkown)	↓	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	M/W		5000 Rp / Ekor (current price)	
Belanak (Mugil spp.)	↓	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	M/W		5000 Rp / Ekor (current price)	
Katamba (Lethrinus letjam)	↓	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	M/W		5000 Rp / Ekor (current price)	

Activity / Product	Resource trend	January	February	March	April	May	June	July	August	September	October	November	December	Gender*	Quantity	Economic Value (estimated by informants) **	Note
8) Shrimp	↓	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	M/W		5000 Rp / Ekor (current price)	
9) Eel	↓	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	M		1500 Rp / Eel (current price)	
10) Clam	*Almost Gone*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	W/m	Previously 3 baskets / person	5000 Rp / basket	
11) Crab	*Almost Gone*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	M	Previously 6 kg / person	5-10,000 Rp / kg (current)	Note 4
12) Sea Snail	*Almost Gone*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	*vr*	W	Previously 10 litres / day	1000 Rp / litre (current)	

Source: Derived from village focus groups in Baturoko (Lalombi) and Tolongano, August 28 and 29, 2000.

Notes:

"vr" refers to "varies".

** M = men; W = women; Upper case symbolizes a primary role in the activity while lower case symbolizes a secondary role in the activity*

*** Ekor refers to approximately one dozen "units" (e.g., fish)*

[1] *One tree generates approximately 30 branches which can be processed to make dye for fishing nets; the dye is red-brown so as not to startle the fish*

[2] *The roots of certain mangrove tree species are shaped like an anchor, and with additional weight added, utilized as such by local fishers*

[3] *The bent root of certain species (e.g., Rhizophora spp.) are used to join the pontoons to small fishing boats; previously these were not sold but used as needed. Now they are valued at approximately Rp 10,000 / four because they must be obtained from elsewhere.*

[4] *People previously harvested crab every three days or so.*

The mangrove forest products and species identified by local individuals all provide important sources of food and household income (see also FAO, 1985; Soendjoto and Arifin, 1999).

Despite the ecological, socio-economic and cultural values attributed to mangrove forest ecosystems, the rate of mangrove forest loss in Banawa Selatan over the last 15 years has been dramatic. Aggregate data on mangrove forest loss in Indonesia are not available, although global and regional trends are not promising. According to the United Nations Food and Agricultural Organization data from 2000 (FAO in Jakarta Post, 2001), aquaculture production increased by 115% from 13.13 million tons in 1990 to 28.27 million tons in 1997. In contrast, capture fisheries increased by only 9.3% from 86 million tons in 1990 to 94 million tons in 1997. In Malaysia, approximately 12% of all mangrove ecosystems disappeared between 1980 and 1990, with an estimated 1% annual decline in mangrove forest habitat. In the Philippines, an estimated 2,400 km^2 (60%) of all mangrove forest has been converted in the last few decades (Spalding et al., 1997:24). Based on data derived from a 1998 remotely sensed image of the Banawa region, an estimated 391 of the original 563 hectares of mangrove forest have been converted to aquaculture ponds over approximately the past 15 years. This represents a 69 percent decline in the total area of mangrove forest ecosystem coverage in the study area during the period 1985 to 2000. The approximately 172 hectares of mangrove forest that remain are fragmented and isolated, or in areas unsuitable for fishpond development. These data correspond well with more recent information derived from interviews and village focus groups in 2000 (see Chapter 2). For example, in Tolongano, an estimated 85 percent of the mangrove forest has been converted to fish pond, while 88 percent of the mangrove forest in Lalombi has been removed. Based on interview and observational data, Supriadi (1999) identified a similar loss of mangrove forest over the past 15 years in several of the coastal villages of Banawa as follows: Tolongano (180 ha). Tanahmea (32.75 ha), Lalombi (246.5 ha), and Surumana (48.75 ha).

Table 6.3: Mangrove Forest Properties in Banawa Selatan, Central Sulawesi (2000)

	Total Area (ha)	Percent of Study Area	Total Core Area (ha)	Mean Patch Size (ha)
Intact Mangrove Forest	172	0.22	3.4	57

The direct causes of this mangrove forest loss are clear. For example, the opening of the coastal road in Central Sulawesi in the early to mid 1980s exacerbated the depletion and use of mangrove forest ecosystems - trucks with available space would often stop to fill up with firewood (Li. 1991). Further depletion occurred during the height of rattan production in Central Sulawesi in the mid to late 1980s. as extensive amounts of fuelwood with suitable burning properties (i.e.. *Rhizophora* spp.) were required for the rattan stripping and sealing process (see Li. 1991). However, it is the more recent and dramatic expansion of aquaculture in the Banawa region that has become the primary factor in the conversion of mangrove forests and the transformation of the coastal ecosystem[23]. Since the mid 1980s, government, multilateral economic development agencies and private sector interests have promoted aquaculture development as a way to replace stagnant capture fisheries, increase local employment and income opportunities, pursue foreign exchange earnings and produce protein for human consumption (Bailey. 1988; Flaherty and Karnjanakesoran. 1995; Vandergeest et al., 1999). Between 1995 and 1999, regional fish pond production increased by nine percent (Perikanan, 2000) (Table 6.4). Such dramatic changes in the extent and quality of mangrove forest ecosystems in Banawa Selatan are likely to result in long-term biodiversity implications, changes in near-shore sediment loading (an issue for the coastal reef fishery), water quality and soil impacts.

Table 6.4: Fishery Production According to Type in Kabupaten Donggala (1995-1999) (ton)

Year	Total (ton)	Ocean Fish	Freshwater Fish	Fish Pond (Salt)	Fresh Water Pond	Irrigated Rice Field
1995	27.627	25.556	218	1.012	715	7.2
1996	28.702	26.447	218	1,243	787	4.4
1997	31.094	28.796	212	1.255	829	2.1
1998	34.204	31.676	233	1.380	912	2.3
1999	34.805	32.173	242	1.436	951	2.7
Average Change (%)	5.94	5.92	2.65	9.14	7.4	-21.75

Source: Perikanan, 2000:7

Already, local people have expressed a concern over the apparent links between mangrove forest conversion, the destruction of the coral reef system (either through the use of unsustainable fish harvesting practices or because of the harvesting of the reef itself for road construction) and other recent ecosystem changes. For example, the coastal zone of Banawa Selatan has been subject to significant erosional processes over the past two decades. The effects of high tide are currently experienced 20 metres further inland from the previous limits, threatening homes and coastal properties. In addition, coastal fishers have identified qualitative and quantitative changes in harvests. According to local fishers, they must increasingly extend their range since sites closer to home are yielding fewer and smaller fish. As well, residents of the area have identified an increased prevalence of mosquito in coastal villages since the conversion of large areas of mangrove forest. Locals attribute the loss of mangrove as forcing mosquitoes into settled human habitats. Whether or not these linkages are empirically valid requires further exploration. However, they highlight the development of contextual explanations of environmental change experienced by local communities.

6.2 Aquaculture Production Systems and Mangrove Ecosystem Productivity

Aquaculture ponds are generally constructed behind a narrow fringe of mangrove in order to limit tidal influence. Bunds or dykes are constructed between each pond and occasionally planted with mangrove trees in order to provide shade and some protection from bund erosion, as well as to provide limited organic matter through leaf and twig fall (Schuster in Whitten et al., 1987). The further inland aquaculture ponds are built, the more excavation is required. In Banawa, local wage labour has primarily been used to construct the existing ponds using machete, hand shovels and scoops. In contrast to the highly intensive aquaculture production systems in Taiwan, Latin America and parts of Thailand (Bailey, 1988; Sebastiani et al., 1994; Flaherty and Karnjanakesoran, 1995; DeWalt et al., 1996), the use of large earth-moving machinery in the study area is uncommon. Although excavation and bund construction work is difficult, local labourers are typically paid 10,000 Rupiah (approximately $1 US) for every one metre long by one metre high by two metre wide segment of bund that they construct. Typically, individuals from south Sulawesi are hired by the owners of aquaculture developments to care for the ponds, stock and harvest the crop. Compensation typically includes a portion of the harvest.

The aquaculture production system utilizes both extensive stocking methods (e.g., natural stocking of post-larval shrimp) and intensive stocking methods (e.g., the use of hatchery fry), along with the application of feeding and predator control measures (e.g., pesticide use). For example, ponds are drained after each harvest and often treated with a pesticide that eliminates organisms harmful to fish and shrimp but leads to significant agrochemical pollution and water quality impacts[24]. Control of water flow into and out of the fish ponds is a central component of successful production[25]. Regular water exchange is required and sluice gates are constructed to control water flow and maintain salinity levels. As a result, water containing significant amounts of fertilizer and pesticide is flushed into adjacent coastal waters several times a year. A significant number of coastal organisms are captured in the ponds when sluice gates are opened, some of which are harvested (e.g., balanak (*Mugil* spp.), bulan-bulan (*Megalops cyprinoides*), sunu (*Epinephelus* spp.), and kakap). However, these species are generally less profitable and more difficult to harvest than either milkfish or prawn (see below), and for several aquaculture farmers in Banawa, are considered to be somewhat of a nuisance.

The major product harvested from aquaculture ponds in the Banawa region is milkfish or bandeng (*Chanos chanos*) which is usually raised in the ponds from fry caught in coastal waters. About 2500 fry per hectare are required to harvest 500-800 fish which are marketable after approximately six months (Whitten et al., 1987). If properly managed, ponds typically produce two harvests of milkfish each year. With milkfish, small fry are raised in a small pond adjacent to the larger pond where they are transferred after one month. Once transferred, they are raised for four to five months and harvested in month six. Up to 3000 milkfish can be produced per hectare each harvest. In addition, two types of prawn are also cultivated - tiger prawn (*Penaeus monodon*) and banana prawn (*P. merguiensis*) - both of which can be harvested three times per year. Approximately 70 kilograms of each can be produced from one hectare every harvest (Table 6.5). The naturally occurring mangrove crab (*Scylla serrata*) is also harvested on an occasional basis.

Aquaculture production is generally perceived to be an economically inexpensive method of meeting increasing protein demands for human consumption, as well as a means of earning foreign exchange. Gross revenue generated by aquaculture production is potentially significant, and efficiently operated and well managed ponds can generate thousands of dollars annually (Table 6.6).

Table 6.5: Seasonal Perspective on Socioeconomic Benefits of Aquaculture Systems in Banawa Selatan, Central Sulawesi (2000)

Activity / Product	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Gender**	**Quantity (per harvest)**	**Economic Value (estimated by respondents)**
1) Fish															
Bandeng (stocked)	▓	░	░	░	░	░	▓	░	░	░	░	░	M	3000 fish / hectare	2000 Rp / fish
Belanak (occurs naturally, variable take)	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	M	5000 fish / hectare	2000 Rp / dozen
Bulan-bulan (occurs naturally, variable take)	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	M	5000 fish / hectare	2000 Rp / dozen
Kakap (occurs naturally, variable take)	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	M	50-100 fish / hectare	5000 Rp / fish
2) Shrimp															
White				▓	░	░	░	▓	░	░	░	▓	M	70 kg / hectare	72,000 Rp / kg
Black				▓	░	░	░	▓	░	░	░	▓	M	70 kg / hectare	72,000 Rp / kg
3) Crab ***(occurs naturally, variable take)***	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	M	N.A.	N.A.

░ *Stocking*

▓ *Harvesting*

Source: Derived from village focus group in Baturako (Lolombi) and key informant discussions (Tolongano), August 28 and October 11, 2000

For example, when shrimp prices are inflated, income generation opportunities are dramatic. Yet price fluctuations, pest and disease outbreaks, and variable prices for feed and stocking fry can quickly generate significant debt for aquaculture investors (Vandergeest et al., 1999). Based on comparisons of local aquaculture system productivity with those in Java and South Sulawesi (see FAO, 1985: Whitten et al., 1987), overall yields in the study area appear somewhat lower. This may be due to intentional underreporting, although a more likely reason is less effective or intensive management practices. Indeed, the overall efficiency of some fish ponds in Banawa Selatan is questionable. Certain areas have been converted to fish pond but do not provide the economic benefits or the harvests attributed to more efficiently or intensively managed aquaculture schemes. The reasons for this may vary (e.g., pest outbreaks, feed price increases) but may find their root cause in the lack of feasibility studies undertaken by many aquaculture owners - they often do not consider the significant financial requirements of maintaining productive ponds once the initially high expense of clearing and preparation has been paid (Hakim, A. pers. comm., 2000). Significant investment is required to purchase the food for stocks, the stocks (fry) themselves, as well as the chemical inputs to control pest outbreaks and disease.

Table 6.6: Optimal Revenue Generation in Aquaculture Systems, Banawa Selatan (per hectare), 2000

Species	Quantity	Price per unit	No. of Harvests	Gross Revenue (Rupiah / $US)[1]
Milkfish	3000 fish	2000 Rupiah per fish	2	R12,000,000 / $1,400
Shrimp	70 to 250 kg	72,000 Rupiah per kg	3	R15,120,000 to R60,000,000 / $1,680 to $6,660
Belanak	5000 fish	5000 Rupiah per dozen	2	R4,165,000 / $463
Bulan-bulan	5000 fish	5000 Rupiah per dozen	2	R4,165,000 / $463
Kakap	75 fish	5000 Rupiah per fish	2	R750,000 / $83

Source: derived from key informant interviews and village focus groups in Banawa Selatan, August and October, 2000

[1] 9000 Rupiah / one US dollar

Typically, milkfish are destined for local and/or domestic markets, while prawns are often bound for more lucrative export markets. Given the immediate foreign exchange and food production benefits of tambak, the Provincial Fishery Department has emphasized additional construction and projected a 10% production increase in coastal aquaculture development in its 2001-2005 strategic plan (Table 6.7) (Perikanan, 2000). Since production increases will undoubtedly result in the conversion of more mangrove forest, such plans run counter to the growing concern about mangrove forest decline and the recognition of a need for restoration efforts in coastal zones. Furthermore, the Department's strategic plan neglects the influence of biophysical conditions (e.g., soil suitability), or the longer term impacts on near-shore and pelagic coastal fisheries (e.g., intact mangrove provides habitat for juvenile milkfish and post-larval prawns) (Whitten et al., 1987). Finally, the strategy fails to address the issue of local property rights regimes that exist in mangrove areas and which likely provide a more sustainable basis for the protection and management of coastal resources.

Table 6.7: Projected Fishery Production According to Kabupaten Donggala (2001-2005) (ton)

Year	Total (tonne)	Ocean Fish	Freshwater Fish	Fish Pond (Salt)	Fresh Water Pond	Irrigated Rice Field
2001	38,071	34,999	253	1,737	1,078	2.9
2002	39,826	36,505	259	1,911	1,149	3.0
2003	41,667	38,074	264	2,102	1,223	3.2
2004	43,600	39,712	270	2,312	1,303	3.3
2005	45,230	41,419	276	2,543	1,288	3.4
Average Change (%)	4.57	4.30	2.20	10.00	6.50	4.00

Source: Perikanan, 2000:8

Although intact mangrove forest ecosystems are unable to generate the gross revenues associated with tambak production, they still provide a range of economically beneficial products and resources, ensure the availability of those products and resources throughout the year (i.e., there is no seasonal shortage or period of scarcity), and facilitate the equitable distribution of resources and benefits among a full compliment of community members. Despite the comprehensive suite of ecological, economic and socio-cultural values associated with intact mangrove forest ecosystems, many studies seeking to generate a policy case for mangrove protection are often market oriented and/or focused on show-casing the economic benefit of specific management options (Ruitenbeek, 1992; DeWalt et al., 1996; Gammage, 1997). For example, while numerous studies (Larsson et al., 1994; Sebastiani et al., 1994; Flaherty and Karnjanakesoran, 1995; DeWalt et al., 1996) highlight concerns about socio-economic and environmental impacts of aquaculture development, they tend not to explicitly address emergent cross-scale socio-political, institutional and ecological interactions and the challenging policy implications that arise from such analysis (however, see Vandergeest et al. (1999) and to some extent Bailey (1988)). Subtle factors influencing mangrove valuation such as political and institutional agendas, unclear legal frameworks and property rights regimes are often inadequately explored. For example, Ruitenbeek's (1992) detailed cost-benefit analysis of mangrove management options in Bintuni Bay, Irian Jaya seeks to link mangrove conversion, off-shore fishery productivity, traditional resource use, the benefits of erosion control and biodiversity protection. While Ruitenbeek (1992) found traditional mangrove contributed proportionally more to household incomes than participation in the formal wage economy, there was limited analysis regarding the manner in which local property rights, resource access regimes and opportunities for equitable resource use and management are undermined by administrative bureaucracies and inadequate legal frameworks.

6.3 Development Narratives and the Devaluation of Mangrove Forest Ecosystems

Nested within mainstream values and definitions of development in Indonesia, are several questionable assumptions regarding inefficiencies in local resource use and management regimes and the perceived socio-economic benefits of aquaculture production that guide a policy narrative that has supported mangrove forest conversion in Banawa Selatan. For example, aquaculture production systems are considered by the State to be economically efficient and congruent with broader economic development goals. Such assumptions and perceptions are captured in formal policy documents (Perikanan, 2000) and, as the previous discussion of the aquaculture production system illustrated, are also supported by evidence of significant income generating capacity. In contrast, traditional use of common property mangrove resources is not accorded the same economic value in mainstream discourse despite the numerous benefits provided to local communities (Bailey, 1988; Larsson et al., 1994; Vandergeest et al., 1999). Such conceptions of local inefficiencies and the economic productivity of aquaculture situate well within the value sets and definitions of "development" encouraged by Indonesia's bureaucratic machinery. Consequently, local values surrounding mangrove ecosystems have been usurped by an influx of different groups, their political agendas, and economic modes of production and policies focused on intensifying natural resource and agricultural sector output. However, even when the primary role of external agents in local environmental transformation is recognized, the onus and responsibility for protection and conservation of valued resources obligates additional local trade-offs and sacrifice (see Vandergeest et al., 1999; Lowe, 2000).

The underlying narrative influencing the coastal landscape in the Banawa regions of Central Sulawesi raises several fundamental issues that require a more nuanced assessment than current explanations provide. For example, why are local communities identified as primary catalysts in the transformation of coastal ecosystems? What forces (economic, institutional and legal) in the Central Sulawesi region, and Indonesia more generally, influence resource management at local scales and create conditions in which community resources are vulnerable to exploitation from outside interests? While local communities in the coastal zone of Banawa are associated with an oversimplified explanation of mangrove forest loss, there are in fact cross-scale market, institutional and legal interactions that affect who amasses wealth and accumulate property. While intact mangrove ecosystems have historically provided a range of benefits to multiple system stakeholders (Ruitenbeek, 1992; Soendjoto and Arifin, 1997), individual interviews and focus group discussions undertaken in the area in 2000 indicate the current aquaculture system is organized and controlled by relatively few well-connected officials and entrepreneurs. The high cost of acquiring land rights to the productive coastal zone, significant capital investment associated with pond construction, and high operational and maintenance costs exclude most local individuals and communities from engaging in aquaculture development (Flaherty and Karnjanakesoran, 1995). The negative impacts of this aquaculture development and mangrove conversion process, however, are unequivocal and well documented (Bailey, 1988; Larsson et al., 1994; Flaherty and Karnjanakesoran, 1995; DeWalt et al., 1996). Ecological damage associated with mangrove habitat and species loss, agrochemical pollution of local water supplies due to pond discharge and the associated human health impacts, near-shore coastal fishery declines and coastal erosion are exacerbated by the loss of local resource control and access to the benefits of common property resources, increased tension and conflict and a widening gap between the rich and poor. Such impacts have a disproportionate marginalizing effect on those individuals and communities closely connected to common property resources (Bailey, 1988; Flaherty and Karnjanakesoran, 1995; Vandergeest et al.,1999). As Larsson et al. (1994) have suggested, if proponents were required to internalize the environmental and social costs of production, aquaculture production would simply not be profitable. The significant inputs of water, feed, energy and the associated appropriation of ecosystem processes and services required in aquaculture production systems are artificially justified by the gross revenue and commodities they generate.

Condemnation of this situation is simple enough, but it is important to understand who participates, who benefits and what structures (political, market, legal) have facilitated those system actors who participate in the mangrove forest conversion process. Just as Lowe (2000) sought to accomplish in her analysis of the live-fish industry in Central Sulawesi's Togean Islands, any attempts to shift the impacts of a particular policy narrative away from local communities in Banawa Selatan must involve a critique of the institutional, market and legal forces that influence that region's coastal landscape. As Lowe (2000) notes, it is not desire but the lack of power that inhibits local communities from countering mainstream conservation and development narratives and analyses should, therefore, seek to facilitate more equitable and sustainable policies that protect valued resources and empower local communities.

Accomplishing this task requires differentiating among system actors and the role they play in environmental transformation, examining access to and control over resources, and illustrating how conflict over resource control has significant consequences for sustainable resource management (Scoones, 1999; Buckles, 2000). Such political ecology interpretations help to: (i) clarify the role of biophysical conditions in structuring socio-political relationships and processes; (ii) illustrate the manner in which landscapes are differentially interpreted and valued by different resource interests; and, (iii) contribute to a more nuanced critique of the politico-institutional processes that influence the relationship between human agency, ecosystem structure and ecosystem function (Scoones, 1999). In this regard, recent political ecology interpretations of human-environment transformation are facilitated by theory and methods of complex systems (e.g., cross-scale, nested interactions, the different types of influences and their self-organization) that suggest the contingent nature of nature-society relationships and illustrate how unexpected socio-political, institutional and ecological factors coalesce in unpredictable ways (see Vandergeest et al., 1999, as well as Chapter 3). Policy makers and scientists do tend to de-couple global, regional and local scales and the often overwhelming complexity of interactions that confound system interpretation. Moreover, the insights gained by more nuanced, cross-scale analyses may not sit comfortably with regional-national political, economic and/or environmental agendas (Zimmerer, 2000). In the Banawa region of Central Sulawesi, the influence of these interactions on system organization and coastal transformation can be expressed through critiques of administrative agendas and unclear legal frameworks, economic and ethnic hierarchies, and local property rights dynamics.

6.4 Administrative Agendas and Unclear Legal Frameworks

As dramatic declines in the mangrove forest ecosystems in the Banawa area indicate, mainline government agencies have not been effective in protecting mangrove forest ecosystems. Capacity constraints and the self-interested economic orientation of provincial and district agencies have culminated in few controls on the scale and intensity of mangrove forest conversion in the region. Moreover, until 2000 (see below), zoning and protection of mangrove forests were not adequately supported in law. For example, the basic legal framework for environmental protection in Indonesia is provided by the *Conservation of Natural Resources and Ecosystems Act* (1989). This law states that the natural environment should be preserved for the common welfare of Indonesian citizens specifically, and humankind more generally. Moreover, the law acknowledges the interdependence of ecosystems and ecological processes as central components of life support systems and stipulates that ecosystems and species should be utilized in a manner protective of ecosystem processes, flora and fauna (Lowe, 2000:250). The *Conservation of Natural Resources and Ecosystems Act* is further supported by other relevant laws, including the *Basic Fisheries Act* and the *Basic Forestry Law*, as well as the *Environmental Management Act* with its establishment of impact assessment guidelines and institutional/organizational arrangements to facilitate impact assessment (i.e., the Environmental Impact Management Agency). More recently, the GOI has drafted a bill on coastal zone management that outlines criteria to differentiate between areas for conservation, exploration, tourism, development and other uses. In addition to this spatial planning orientation, the proposed legislation will address resource management, waste management, engineering, biodiversity and community issues. As the Minister of Maritime Affairs and Fisheries has stated (in Jakarta Post, 2001), "...if investors come by and want to set up some business here, they will know the exact rules and regulations". Indonesia has thus created a fairly comprehensive legal framework to protect both ecosystems and the communities that depend on them, and which seek to prohibit the use of destructive technologies and/or the harvest and export of endangered species (Lowe, 2000).

However, while such laws may clarify the overt intentions of the State, according to Lowe (2000:249), they also support a "subtext of unstated agendas". As Lowe (2000) argues, in a country in which development is theology, the subtext of environmental legislation is the creation of enabling conditions for profitable business ventures, both for private sector interests and government bureaucracy (what Küchli (1997:130) refers to as "office capitalists"), while simultaneously shifting conservation responsibility, enforcement and punitive measures onto local communities. To support this argument, Lowe (2000) provides an interesting case study of fishery legislation that enables the exploitation of Napolean Wrasse (*Cheilinus undulatus*), a threatened fish, by exporters and government officials, while focusing enforcement and punitive action against the local fishers engaged in harvesting on behalf of the proponents of the live fish trade. While many of the specifics of this case are unique, the analysis resonates well with the process of coastal transformation in Banawa Selatan and the mangrove conversion – aquaculture development dichotomy. Policies that simultaneously promote mangrove forest protection and permit aquaculture development augment local and regional bureaucracies and benefit government officials through the reporting, evaluation and permit-granting process. Bureaucracies in Indonesia must secure much of their own funding, as only the most rudimentary operations are supported by mainline budget allocations. In this context, staff salaries are often connected to overall office income and permitting, licensing fees and trade facilitation become regular profit-making activities (formal and informal) for many government agencies (Lowe, 2000). As local communities are all too aware, "...laws, as they are written, interpreted, and enforced within an entrepreneurial bureaucracy, enrich bureaucrats and their organizations while failing to protect either species or citizens" (Lowe, 2000:253). It is in the self interest of government staff to grant permits, not restrict access to natural resources.

In the Central Sulawesi context, an obscure local investment coordination centre, the *Badan Koordinasi Penganaman Modal* (BKPN), grants licenses to individuals and/or companies wishing to develop an aquaculture project or associated investment. The mandate in which the BKPN executes this function is the promotion of regional development, investment and growth. This agency, however, is not required to coordinate with fishery or forestry officials, for example, when granting the license. Presumably, notification of Bapedal (the Environmental Management Impact Agency) or an impact assessment process (AMDAL) would be required for all aquaculture developments. Similarly, approved developments must also obtain an authorization license provided by the relevant fishery authority (*Surat Izin Usaha Perikanan*). Yet few individual tambak owners in Banawa Selatan are able to produce the necessary permits (Supriadi, 1999). Such inconsistency and lack of clarity plays out well within an "entrepreneurial bureaucracy". Informal fees encourage officials to look the other way, while ample room remains to generate formal licensing revenue should civil society demands for regulation become more pervasive[36]. There is little understanding or experience with this process at local scales in Banawa Selatan, and local groups, not surprisingly, perceive themselves as powerless in the context of Indonesia's system of patronage, graft and corruption - a system that pervades, as Lowe (2000:246) describes, local, regional and national government apparatus in often subtle ways:

> *From there we proceeded to a less affluent part of the village, far from where any officials live, and it was mentioned to the parents that their children had been caught using bius [cyanide for fishing]. In the same breath, the khakied bureaucrat made a casual inquiry as to whether there were any ripe mangoes. We were soon sitting on the porch, chins dripping with mango juice. He asked again for fried sago (don't forget the coconut!), which they procured with ingredients quickly borrowed from a neighbor. Coffee with tablespoons of expensive sugar was served after the mangoes; "gifts" of limes and chilies were taken before leaving. Our group had imposed on the hospitality of a family clearly struggling to meet its own food needs. Conversation between the high-status village officials and the subordinate fellow villagers had been smooth, never strained, polite. The threat was always implied, wound around, sweet and hot, in and out of discussions of mangoes and chilies.*

Local government officials, however, are not the original villains. The entrepreneurial culture of Indonesian bureaucracy begins at the top of the leadership hierarchy, and local leaders at district and village levels are inducted into this culture by regional and national bureaucrats (Lowe, 2000). While local leaders may participate in the process, they did not create the manner in which economic systems are organized and controlled in Indonesia (Lowe, 2000). Failure to participate in the administrative hierarchy of economic advantage and accumulation is likely to result in peer censure or job loss - a threat that serves to subvert political opposition (Lowe, 2000). In Banawa Selatan, the recent granting of 22 hectares of mangrove by a village head to an officer of the regional government is a case in point (PSL-UNTAD, 2000). The government officer has since sold four hectares, presumably to an individual with aspirations to develop an aquaculture scheme. Importantly, it also serves to highlight the limited complicity of local people in the conversion and destruction of mangrove forest ecosystems in the region.

6.5 Mangroves, Markets and Ethnic Identity

Mangrove forest conversion and the subsequent development of aquaculture are often portrayed as a primarily local process unfolding in the context of local demographic, resource use and property rights interactions. While such factors do play a role, the mangrove forest conversion process in Banawa Selatan is decidedly more complex. For example, the outputs of aquaculture production are both domestic and international in scope (Bailey, 1988; Flaherty and Karnjanakesoran, 1995; Vandergeest et al., 1999). Prawns are often exported for consumption by the residents and tourists of southeast Asia in such places as Hong Kong and Singapore. In this regard, aquaculture development is well suited to a transnational, neo-liberal economic agenda oriented towards commodity flows, minimal trade barriers and limited governmental regulation[27]. The market for prawns thus unites wealthy elites, government officials, entrepreneurs and some of southeast Asia's poorest individuals. Although the consumption of prawns in distant locales may seem innocuous, the complex social-ecological interactions of the production process cannot be easily avoided in the coastal zone of Banawa Selatan. While aquaculture commodities (particularly shrimp) are generally quite expensive and typically consumed by the region's middle class and wealthy elite (see DeWalt et al., 1996), entire local communities are directly affected by the loss of a low-intensity mangrove fishery that included among other resources, economically valuable shrimp, fish and crab. Moreover, while a limited number of local people were initially hired to provide low-skill construction labour, most labour was brought in from the regional capital given the technical skills and equipment needed to initially clear the land and construct the fish ponds. The occasional labour opportunities afforded local people (e.g., construction and maintenance of fish ponds) link a few people into their own localized economies of subsistence (food, school fees) and luxury (cigarettes, candies, trips to larger regional centres) (Lowe, 2000).

Localized effects of national and international economic systems, however, are only one type of influence. The economically scaled process of coastal zone transformation in Banawa Selatan crosses ethnic divisions as well. According to local people, large aquaculture developments are typically owned by wealthy regional or trans-regional entrepreneurs, often of Chinese descent, with the financial capacity and established connections to construct ponds and market the products[28]. In Banawa Selatan, the ponds themselves are often maintained and operated by individuals from southern Sulawesi (Buginese, Sundanese, etc.) who have migrated into the area or have been transferred specifically to tend to the ponds. Moreover, even those individual community members with small areas of fish pond are typically from southern Sulawesi. In contrast, the Kailinese (e.g., Unde and Ledo) and landless labourers typically provide labour for the construction and maintenance of fish ponds and bunds as they rarely have the resources to finance construction, pay permitting fees or invest in pond maintenance. Economic and ethnic hierarchies in the mangrove forest conversion process in Banawa are thus well established and place urban and government elites and Chinese entrepreneurs at the top, and Buginese caretakers at the centre of a profitable economic enterprise. Local people are marginalized from both the economic benefits of tambak production and the historically significant benefits of intact mangrove forest. Local and regional elites have the dual advantage of relatively greater wealth and education, offering them access to both the knowledge and capital required to participate in aquaculture development (Bailey, 1988). Moreover, these benefits translate into the increased political influence required to access resources (credit, loans, subsidies and permits) not readily available to most local individuals and communities.

6.6 The Political Ecology of Property Rights

The analysis in the previous sections has already revealed a complex set of interactions that influence processes of coastal zone transformation in Banawa Selatan. Any conservation policies and practices directed toward ecological integrity and sustainability must, therefore, account for and address the influence of inequitable power arrangements, suspect administrative agendas and legal frameworks that are supportive of more powerful resource interests. The manner in which these variables influence resilience within local systems must be considered. In particular, the issue of common property resource rights regimes and traditional resource management practices must be addressed in this context. Numerous examples of effective communal property rights regimes have been documented in a range of contexts, including pastoral (Anderson and Grove, 1987; Lane, 1990, 1993), forestry (Sponsel et al., 1996) and fishery systems (Berkes and Folke, 1998; Olsson and Folke, 2000). Such regimes have engendered conditions of sustainable resource management and use, if not purposive conservation (Smith and Wishnie, 2000) and typically include socially-regulated access to resources, sanctions to punish violators and management rules to govern resource use. However, as linkages to broader political and market forces emerge, and population density increases, the ability of traditional societies to maintain locally relevant management systems is challenged (Smith and Wishnie, 2000). Once undermined, it is difficult to re-establish effective systems of common-property resource management (Smith and Wishnie, 2000) (see Chapters 8 and 9).

Prior to the exacerbated process of mangrove forest conversion in Banawa Selatan, a community-based property rights regime existed. Despite opportunities for individualized, open access, a framework of traditional regulations was present which included rules and regulations governing mangrove forest use. For example, a local regulation referred to as "*ombo*" placed temporal restrictions on harvesting milkfish during spawning periods in core coastal mangrove habitats in Banawa Selatan (see Table 6.2 and Chapter 9). Such a regulation limited the impacts of harvesting on a particular species during vulnerable stages in its life cycle. While the extent to which traditional property rights and resource access mechanisms may be reinvigorated to perform similar functions is addressed in a subsequent chapter (Chapter 9), it is informative at this point to explore how different types of influences have interacted across international, national and local scales to precipitate a decline in local property rights regimes, and to understand the implications for system resilience. For example, in the context of informal property rights, the "open access" mangrove forest ecosystems of Banawa have been an easy target of external interests unaware or ignorant of traditional resource use rights and intent on capturing an economically valuable ecosystem. Legal ownership of mangrove forest falls under the jurisdiction of the BPN, an administrative agency of the Directorate General of Forestry. However, despite the framework of formal governing bodies and an established licensing system (see above), the allocation of mangrove forest to aquaculture producers is plagued by limited information (or certainly few who want to share it) regarding how current landowners obtained their property rights[29]. What is known is that most aquaculture owners in Banawa are government officials or entrepreneurs from outside the region who have increasingly enforced exclusionary property rights (e.g., forbidding local communities access to the land to collect firewood from remaining mangrove forest) (see also Bailey, 1988; Li, 1991).

The structure of aquaculture development in the Banawa region is very much influenced by different forms of access to land and capital (see Vandergeest et al., 1999), and ownership and control of the ponds are thus highly concentrated: the five individuals controlling ponds in one village (Tolongano) are district government officials or wealthy individuals supported by investors from the regional capital (Palu). In fact, one interviewed individual owned 90 ha of aquaculture pond (not all productive). In the village of Lalombi, two individuals own the majority of aquaculture ponds (approximately 50 hectares each - again not all productive). Several others own 5-10 hectares, while many more own 1-2 hectares. In all cases, local communities have borne the cost of mangrove forest conversion, losing both a local property rights regime and access to traditional resources. In turn, they have been offered limited labour opportunities in the construction and maintenance of the ponds, but even this activity is available for a limited few. According to many local community members, it is not clear how external interests "purchased" former mangrove areas. Some suggest that private deals arranged through the village head are the most likely mechanism, although few are able or willing to clarify this. In the village of Lalombi, for example, in which local people do own some aquaculture areas, they too are members of the village government. In theory, revenues generated from aquaculture production are subject to a 20% surcharge on profits to be allocated to the community. Communities feel that a local tax (*Anggaran Pendepatan dan Pengeluaran Keuangan Desa*) of Rupiah 150,000 per hectare per harvest should be levied on individual owners. However, such mechanisms for benefit redistribution are not always honoured. Thus, in circumstances in which local community interests are expecting funds for local development, the potential for increased conflict between aquaculture owners/operators and other community interests is high. Despite this situation, the ideological and legal strength of private property rights makes it very difficult for local individuals or concerned government agencies to constrain the process of aquaculture development even where common property resources are being degraded (see Bailey, 1988; Vandergeest et al., 1999).

6.7 Towards A Restoration Narrative

Mangrove forest conversion and aquaculture development are embedded in an evolving process of multiple interactions created by: (i) demands for foreign exchange; (ii) requirements for domestic protein; (iii) flawed bureaucracies; (iv) unclear legal frameworks; (v) ethnic division with economic externalities; and, (vi) State-sanctioned and sponsored worldviews and ideology supportive of intensive aquaculture production and privatization of resource use over traditional resource approaches. All of these variables coalesce to undermine local property rights and traditional resource management regimes. As Figure 6.1 illustrates, multiple scales and types of influences have interacted to produce dramatic environmental transformation. Facilitated by theory and approaches that link complex system insights and political ecology, the preceding analysis has sought to illustrate how a mix of intentional and unintentional actions of different system actors has generated a dramatic transformation in the coastal zone of Banawa Selatan, revealing both the contingent and dynamic nature of environmental change. The relationship between nature and society in the process of transformation is not easy to discern, as the coastal environment of Banawa Selatan has been created in a non-linear, non-deterministic manner.

A sensitivity to the multiple influences of human agency across a range of scales, and the combined influence on system organization, is required to build a dynamic understanding of nature-society interactions in the coastal zone of Banawa Selatan. Issues of scale are particularly important in this context because, as has been illustrated, interactions of different types occur across multiple scales, often at different intensities and speeds (Scoones, 1999). Understanding linkages among nested hierarchies of system interaction (at least qualitatively) is critical given the pervasive influence of globalization. In practical terms, a better understanding of system dynamics can play a central role in designing more relevant and practical conservation strategies. Indeed, the aquaculture-mangrove process interaction elaborated upon here encourages a more complete and nuanced understanding of natural resource use in the Banawa context and better facilitates a process of collaborative planning and management with local people oriented toward social learning, equity and justice. As Lowe (2000) notes, recognizing that substantive ecosystem abuses are rarely locally organized, but underwritten by subversive entrepreneurial and bureaucratic arrangements, can help identify and form new alliances with local communities.

Approaches to alleviating the socio-economic and ecological impacts of aquaculture development must be connected to the specifics (political, institutional, environmental) of particular regions (Vandergeest et al., 1999). In the Banawa region of Central Sulawesi, the issue is not simply a matter of formulating, enforcing and monitoring regulations that guard against mangrove forest conversion, although these are important for the protection of the remaining mangroves. Rather the issue in the Banawa context is the apparent need to formulate, propose, implement and monitor strategies that fundamentally challenge entrenched economic interests and power relationships: reclaiming land currently used for aquaculture, restoring mangrove ecosystems and returning those lands to a common property resource regime. This would suggest a limited role for mainstream conservation strategies such as regulations (either by government agencies or through self-regulation frameworks), local economic incentive or income generation schemes, or protection through zoning given the capacity limitations of formal government agencies. Although remnant mangrove forest ecosystems are increasingly capturing the attention of local, national and international NGOs and conservation-minded organizations (see Vandergeest et al., 1999), the extent to which the proposed coastal zone legislation will improve regulation and enforcement is yet to be determined.

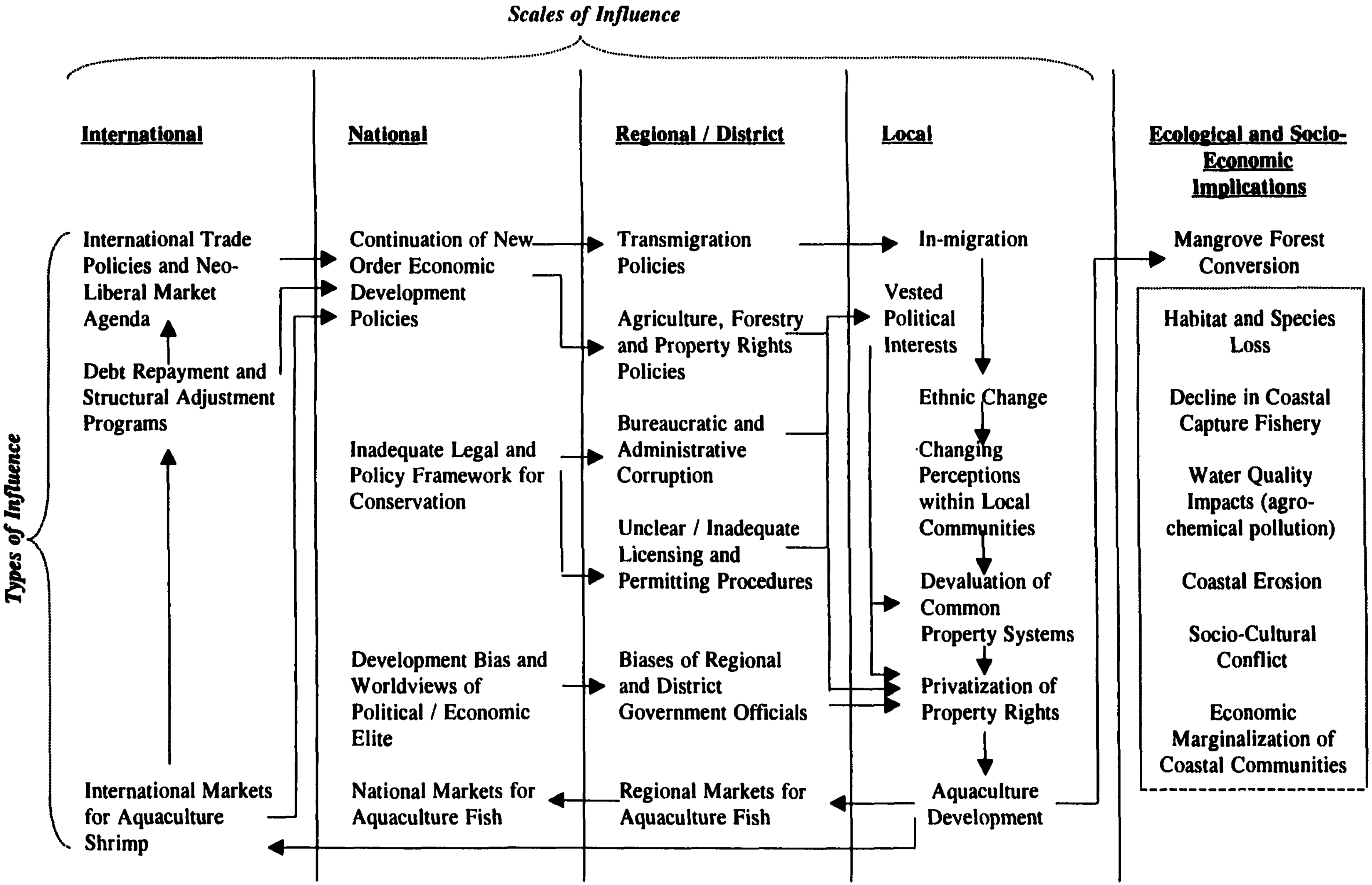


Figure 6.1: Conceptual Model of Mangrove Forest Conversion and Aquaculture Development Process, Banawa Selatan, Central Sulawesi

Indeed, any fundamental change in the region would appear to hinge on localized resistance, inevitable politicization and potential conflict surrounding the property rights situation; for example, demands to clarify legal titles of all aquaculture developments and the corresponding return to community ownership where there is a failure to do so. Yet in the Banawa region, opportunities for political resistance to the local loss of property rights have been undermined by the formal effects of politico-institutional and legal regimes, the pernicious influence of local and regional elites, and corruption within private sector-public agency relationships. In this challenging context, opportunities for an adaptive approach to conservation science and practice would seemingly be constrained. However, as analyses in Chapters 8 and 9 seek to illustrate, emergent politico-institutional conditions in the region may provide the conditions and mechanisms in which mangrove restoration can be promoted, and corresponding issues of justice, equity and accountability accorded a chance for renewal.

7.0 CONSERVATION DISCOURSE IN THE UPLANDS: SOCIAL-ECOLOGICAL CONNECTIONS IN A COMPLEX SYSTEM

7.1 Conservation Narratives and the Environmental Orthodoxy of Upland Transformation

Forest conversion, biodiversity loss, rivers of silt and mud flowing from the highlands, and the breakdown of subsistence communities are just a few of the prevailing conceptions about ecological and social change in the tropical uplands (Sponsel et al., 1996; Li, 1999; Tsing, 1999). Centre-stage in this story of decline is the swidden agricultural practice imprecisely characterized as slash and burn agriculture or shifting cultivation (Dove, 1993; Peluso, 1995; Li, 1999). Swidden cultivation[30], a form of rotational agriculture, involves the use and management of agricultural fields and forested fallows derived from a range of successional vegetation assemblages, including standing mature forest (Brady, 1996; Hayes, 1997; Montagnini and Mendelsohn, 1997; Lawrence et al., 1998). Such active use and management of the ecologically significant and biologically rich forests of the tropics have been the target of much scrutiny and debate by legions of development practitioners, conservationists and tropical ecosystem researchers over the past several decades (Ramakrishnan, 1992; Brady, 1996; Harwood, 1996; Vosti and Witcover, 1996; Hayes, 1997; Montagnini and Mendelsohn, 1997; Li, 1999). Estimates of the influence of swidden systems on tropical forest ecology have not only been the cornerstone of academic debate, but invariably, the basis for heavy-handed conservation policy that seeks to foster state control of forest resources and enclose large tracts of forested or primarily forested land. Marginalization of forest communities has been an inevitable result (Poffenberger, 1990; Peluso, 1993; Li, 1999; Zerner, 2000).

Identification of the causes of and/or solutions to deforestation is neither politically neutral nor value free. Governments and other vested interests, such as forest concession holders, those who support an unfettered neoliberal market agenda, and even proponents of large-scale conservation and protection projects, all have an interest in deflecting culpability towards politically and economically marginalized groups. Unclear deforestation estimates and discrepancies surrounding nature-society interactions in the uplands provide ample latitude for those interested in situating the conservation debate around specific agendas. For example, according to the United Nations Environment Program (UNEP) (1992), shifting cultivators were responsible for approximately 45% of the deforestation of tropical forests globally, while Myers (1992) suggested that "non-traditional" shifting cultivators accounted for 60% of the tropical deforestation total[31]. As Lambert (1996:420) depicted, in the diminishing forest environments of the world's tropical regions, shifting cultivators are being forced to find new means of subsistence in areas that have essentially become "post-deforestation" ecosystems. In the mid-1990s, however, the World Bank (see Angelsen, 1995) shifted its policy position with respect to traditional swidden cultivation, recognizing that the main challenge to sustainable forest management was not traditional agriculture, but logging and government policies that provide incentives to deforestation. Dick (in Angelsen, 1995) has thus argued that programs sponsored or promoted by the Government of Indonesia have accounted for 67% of all deforestation, while that attributable to traditional shifting or swidden cultivation is only 22%. Of that 22%, a significant portion would involve forest that has been in a long-term rotation cycle.

Despite the lack of compelling evidence to suggest traditional swidden agriculture is the primary cause of deforestation, the Government of Indonesia encourages a transition from swidden agricultural practices to intensive, permanent estate crop cultivation. For example, a formal political and ideological position regarding traditional swidden agriculture as "undeveloped" and ecologically destructive is found in Indonesia's Agenda 21 document (GOI, 1997:429):

> *In regions where the farming pattern is still underdeveloped, farms still use indigenous technology, e.g., slash and burn. This practice takes place in the regions outside Java island, such as Sumatra and Kalimantan. The low productivity of land forces farmers to become nomads, so that they simply leave their farms when the land is no longer productive.*

Likewise, a comprehensive survey of forest lands in Indonesia completed in 1988, the Regional Physical Planning Program for Transmigration (RePPProT) study, considered swidden agriculture a non-permanent activity:

> *...shifting cultivation is considered as a "non-permanent" use of the land, although it is recognized that this may not agree with the views expressed under customary rights. The villages associated solely with this extensive form of land use are not permanent in the long-term, although some may remain on the same site for 10-20 years or more before moving elsewhere (RePPProT West Kalimantan Executive Summary in Peluso, 1995:390).*

Under the RePPProT classification scheme, land utilized for swidden agriculture has been classified as "convertible" (i.e., suitable for timber extraction, industrial forest management and/or estate crop development). Yet the zones classified as "convertible" often consist of large areas of forested and mixed-forest landscapes in which local people have had historical access and traditional territorial rights (Peluso, 1995). As Peluso (1995) noted, landscapes utilized by swidden cultivators were grouped by the RePPProT planners along with areas of scrub, regrowth and grassland, all of which are classified as land types deemed available for conversion or development. Neither territorial rights nor the legitimization of resource rights was recognized. From where is this policy orientation derived, and what are the implications for conservation science and practice in uplands ecosystems?

In part the problem is definitional. The influential World Resources Institute (WRI) defines deforestation as "...a complete change in land use from forest to agriculture - including shifting cultivation and pasture - or urban use. It does not include forest that has been logged and left to regrow, even if it was clear cut" (in Angelsen, 1995:1714). However, as Angelsen (1995) points out, this definition is contradictory and illustrates an incomplete understanding of swidden systems practiced by upland communities. For example, the forest utilized by swidden cultivators is in most cases previously cleared, disturbed or secondary forest left to fallow and regenerate (see more detailed discussion below). According to the WRI, lands cleared by forest concessions, but left to regenerate, are not considered deforestation, while the process of swidden clearing and fallow regeneration practiced by swidden cultivators is deemed deforestation. This definition incorrectly assumes that areas of shifting cultivation are replaced by permanently cleared lands (Angelsen, 1995). Moreover, the further assumption that all deforestation is additive neglects the differences between temporary and permanent forest clearing (see Dick in Angelsen, 1995).

Imprecise definitions aside, evidence from the region suggests that forest concessions and illegal logging are a more significant factor in the deforestation process - a process exacerbated by the consequent in-migration of "outsiders" and intensification of estate crop plantations (e.g., cocoa). For example, evidence from Thailand, Malaysia and the Philippines illustrates that tropical forest conversion results primarily from the combined influence of timber extraction and the consequent expansion of non-shifting, small-scale and/or estate crop agriculture (Lawrence et al., 1998). Since the simultaneous ascent of the *Basic Forestry Law* (No. 5/1967) empowering the state to administer all forest lands in Indonesia, and the *Foreign Investment Act* (No.1/1967) granting timber concessions (*Hak Pengusahaan Hutan*) to international and joint venture logging interests, approximately 561 concessions had been granted throughout the outer islands by the end of 1989 (see Peluso, 1995). While many of these concessions have since ceased operations, they have resulted in the extraction of hundreds of thousands of cubic metres of tropical hardwood (Peluso, 1995:388). Moreover, most of these concessions were granted without due regard to ecological and socioeconomic impacts, nor detailed assessments of site-specific physical conditions or already existing local management activities (Peluso, 1995). A recent moratorium on new forest conversion licenses upheld by the Ministry of Forest and Estate Crops until "transparent, rules-based procedures" are developed to minimize forest loss and ecological impacts (GOI/IMF, 2000) may ease the situation, although it is unlikely to reduce the estimated $US 500 million loss associated with illegal logging (Witoelar, 2000). Nevertheless, as illustrated in key policy documents such as Indonesia's Agenda 21 document (GOI, 1997), much of the responsibility for the approximately 900,000 to 1.2 million hectares of tropical rainforest converted every year in Indonesia is still laid at the feet of Indonesia's traditional agrarian and forest-based communities (see Angelsen, 1995; Peluso, 1995; Li, 1999).

The influence and impacts of swidden cultivators and other subsistence-based communities on tropical forests are unquestionably issues. Forest cover loss due to swidden practices in the Banawa-Marawola uplands can be linked to demographic change, decreased fallow periods and soil nutrient depletion. However, the underlying causes are not necessarily the practices and resource management strategies utilized, but the socioeconomic and political context in which swidden cultivators increasingly operate. Inadequate recognition of the broader political and economic interrelationships, and the conclusions such conceptions generate about the impacts of swidden cultivation stem in part from ahistorical characterizations of swidden cultivation systems. However, without a corresponding historical analysis of the structure and composition of the landscape though time, or more detailed demographic information, conclusions about the true nature of swidden expansion and forest conversion are difficult to make (Fairhead and Leach, 1996; Scoones, 1999; Bassett and Koli Bi, 2000). There is a long history of nature-society interaction in the uplands of Sulawesi (Boomgaard et al., 1997; Henley, 2000; Li, 1999) and the extent to which older-growth forest cleared for swidden activities is in fact "pristine" is debatable (see Sprugel, 1991; Fairhead and Leach, 1996; Zimmerer, 2000). Causal generalizations linking traditional upland communities with deforestation, biodiversity loss and soil erosion should not be the basis of conservation policy and practice.

The current narrative guiding conservation and development discourse in the uplands of Central Sulawesi is straightforward. First, the narrative is premised on the canon that swidden or shifting cultivators are the primary cause of deforestation, biodiversity loss and soil erosion because of their practice of continuous land clearing and removal of undisturbed forest. Second, the narrative assumes that swidden cultivators would be more economically productive (i.e., productive members of society as defined by State development ideology) if they were settled and engaged in the intensive production of more valuable economic commodities (e.g., cocoa, clove, etc.) (Dove, 1999; Li, 1999). Narratives of similar genus have also provided the scripts and justification for poorly conceived conservation and development practice in dryland Africa (Anderson and Grove, 1987; Lane, 1993; Armitage, 1996; Fairhead and Leach, 1996; Scoones, 1999). To clarify the genesis of this narrative as it applies to the uplands of Banawa and Marawola, the remainder of this chapter will seek to: (i) describe the local agroecological system; (ii) explore alternative system perspectives from diverse scales that may provide useful information for conservation science and practice; and, (iii) illustrate the key system variables and interactions across scales that are the primary threats to upland system sustainability and resilience. Based on this critique, a conceptual framework for a more complete narrative to guide conservation science and practice in the Banawa-Marawola uplands will be developed.

7.2 Environment and Culture in the Banawa-Marawola Uplands

The Banawa-Marawola uplands consist of significant portions of two sub-districts (Kecamatan) of the same name in Donggala District (Kabupaten Donggala). The high relief (altitudes extend over 2000 metres above sea level) and rugged topography of the Banawa-Marawola uplands are the dominant features of the landscape, while highly dissected river valleys and slopes over 60% are common in interior zones. Notable heights of land in Kecamatan Banawa include Gunung Gawalise (2,032 m) and Gunung Ulayo (2,109 m), while Gunung Balanti (2,326m) and Gunung Pompalesuba (1,710 m) dominate the Marawola landscape. To the east, the upland system is bounded by a dramatic escarpment that descends into the Palu River valley and eventually Palu Bay. To the west, the descent into the coastal plains along the Makassar Strait is less pronounced but includes several north and south-oriented ridge structures. The region is characterized by two wet seasons, one extending from May through August, and the second shorter wet season extending from December through January. Average annual rainfall ranges from 2000-3000 mm (Whitten et al., 1987; PSL-UNTAD, 2000). Soils consist primarily of well-drained, iron-rich podzols and lithosols (BPPP, 1993).

Vegetation in the Banawa-Marawola uplands consists of lowland (less than 1000 metres) and lower montane (between 1000-2100 metres) forest. Although the forests of Sulawesi are not dominated by any single genus, typical species of the Banawa-Marawola uplands include *Ficus* species, *Heritiera* species (palapi), *Artocarpus teymanii* (tea), *Durio ziberthinus* (durian), numerous palms (e.g., *Livistona rotundifolia, Licuala celebensis*), and a diversity of epiphytes including ferns, lichens, mosses and liverworts. Although less numerous than in Kalimantan and Sumatra, several *Dipterocarp* species have been documented in the lowland and lower montane forests of the region (e.g., *Shorea assamica*, *Vatica rassak* and *V. flavovirens*), while *Diospyros celebica* (ebony), a heavily logged endemic species, is still present in forested zones (PSL-UNTAD, 2000). Grasslands are often dominated by *Imperta cylindrica* (alang-alang), although typically associated with other grasses, legumes and tree species such as *Albizzia procera* and *Morinda tinctoria* (Whitten et al., 1987). Mammalian species associated with the uplands may include the anoa (*Babulus depressicornis*), babirusa (*Babyroussa babyrussa*), the Sulawesi civet cat (*Macrogalidia musschenbroecki*), tarsier (*Tarsius* spp.), the endemic wild pig (*Sus celebensis*) and Macaques (*Macacus* spp.) (Whitten et al., 1987; PSL-UNTAD, 2000).

In contrast to the coastal zone (see Chapter 6), the people of the uplands are relatively homogeneous. While the dominant ethnic group throughout Donggala District is the Kaili, there are approximately 19 Kailinese sub-groups each with their own dialect. Although linguistically distinct, most groups share many common cultural characteristics (e.g., ceremonies) and describe their origins in a similar manner (see Li, 1991). In the uplands of Banawa and Marawola, the Da'a people are the primary inhabitants, along with the Unde and to a lesser extent the Ledo[32]. Demographic data on upland populations are scarce and because the study area defined for this analysis is partly related to the availability of cloud-free remotely sensed coverage, the aggregated population data available for Kecamatan Banawa and Marawola through the *Budan Pusat Statistik* (Statistics Office) are of limited value. For example, in Banawa, many of the villages that include upland communities also include coastal zones where the demographic change over the past several decades has been most pronounced. In Marawola, the situation is somewhat less obscure because of the greater homogeneity of the overall sub-district population. Population densities in 1999 ranged from 10-100 people / km^2 (BPS, 1999), while the total population may range from 10,000 to 15,000 people over an area of approximately 1000 km^2. Population growth rates among upland communities were not identified, although population growth rates for Central Sulawesi are estimated to be 2.46 percent per annum (Bappeda, 2000).

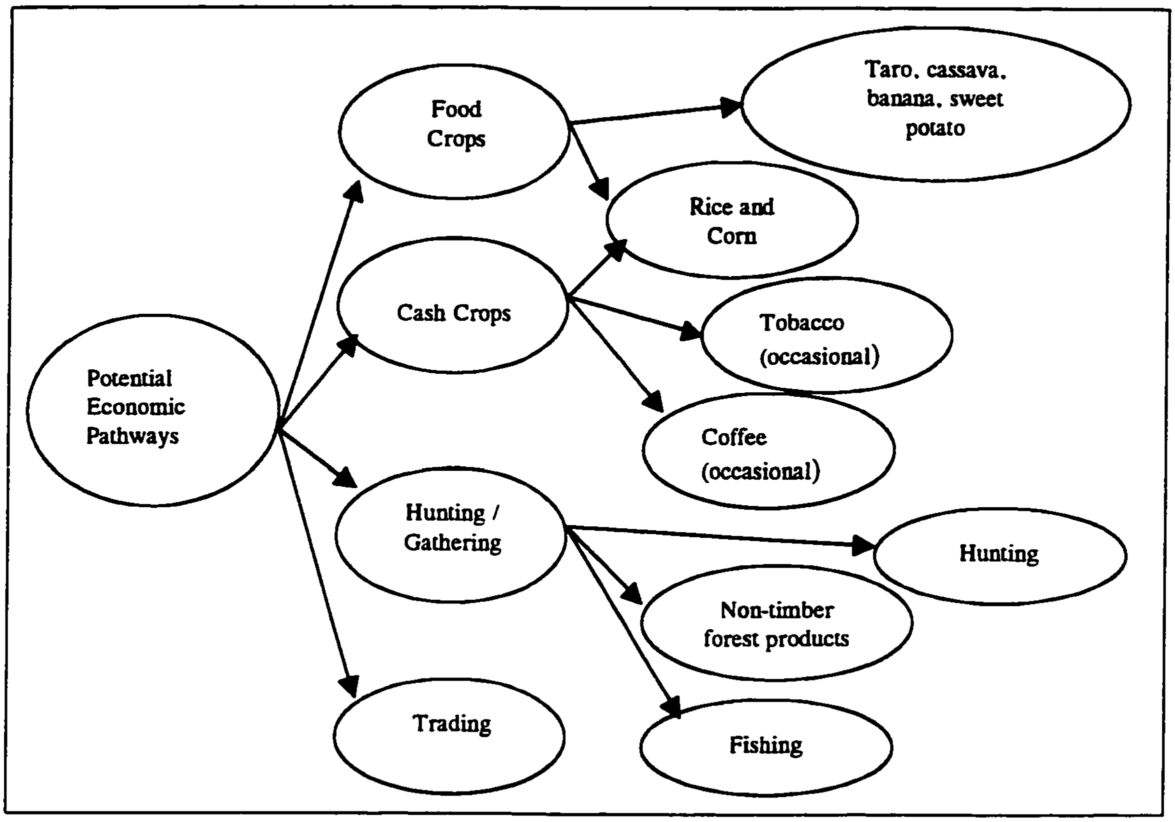
According to the state-sponsored RePPProT land classification scheme, the uplands of Banawa and Marawola are currently classified as mainly limited and unlimited production forest. As determined by the same classification scheme, the recommended land use in the uplands is protection forest (i.e., forest subject to restrictions on use and access) (GOI, 1988). However, low-intensity swidden agricultural practices have long been a factor in shaping the Banawa-Marawola upland landscape. Indeed, the Da'a and other upland groups have developed and utilized a diversified agroecological system for centuries that is oriented around both food and cash crops, as well as the occasional harvesting of timber and non-timber forest products. An overview of this agroecological system is provided below.

7.3 Agroecology of the Da'a

Generating a more complete analysis of the upland agroecological system is an issue of central interest in constructing better conservation policy and practice. While the description of the Da'a agroecological system outlined here is comprehensive, two concerns associated with this analysis require explanation. First, very limited agroecological or anthropological research of the Da'a has been undertaken. Beyond the outline provided here, which is based on individual interviews, focus group discussions and observational data, information about the Da'a and their practices has been collected primarily by a local advocacy NGO (*Yayasan Pendidikan Rakyat*) (R. Saleh, pers. comm., 2000). Supplementary information has also been obtained from reviews of similar upland communities in Central Sulawesi, most notably Li's (1991) work in the Tinombo region, as well as research on other swidden groups in Indonesia (e.g., Dove, 1993; Lawrence et al., 1998; Ellen, 1999). Second, it should be noted that small modifications to the extent, intent and timing of certain system activities are made by different Da'a groups and individuals depending on their location, current conditions and past practices. Differences between the Da'a and other associated upland communities (e.g., Unde) are also common.

The swidden system of the Banawa-Marawola uplands typically involves Da'a families each clearing and cultivating between 2-5 ha of land for a period of one year (or one harvest cycle), followed by a 5-20 year fallow period[33]. The primary crops cultivated by the Da'a include rain-fed rice (*Orzya sativa*) and corn (*Zea mays*), along with several staple food cultivars such as cassava (*Manihot uttilisima*), sweet potato or yam, taro (*Caladicum bicolor*) and banana (*Musa* spp.). Coffee (*Coffea robusta* or *C. arabica*) and tobacco are occasionally grown in the uplands of Banawa and Marawola, although these crops are more prominent in other areas of Central Sulawesi (see Boomgaard, 1999). Rice and corn are typically sold as cash crops in coastal markets in order to purchase clothing, coffee and other consumables, while cassava and taro function as the staple food crops. Several non-timber forest products are also collected from forested areas such as durian (*Durio ziberthinus*) and langsat (*Lansium caudatum*), both of which are harvested in December and January. Non-timber forest products typically provide supplements to the diet of local people, particularly in times of celebration or ceremony. Thus, the agroecological system of the Da'a provides a relatively diversified household and livelihood strategy (Figure 7.1). The strategy consists of both cash and food crop production, hunting and gathering of supplemental products either for consumption or for sale, as well as trade among and between different upland groups and with coastal communities.

Figure 7.1: Schematic representation of Da'a subsistence economy



Da'a groups of approximately 20 families typically form distinct upland communities (functional groups) - although the number of families in a functional group can vary from 10 to 50 - with each family consisting of between seven and 10 people. Approximately 20 to 100 hectares of land are cultivated at any one time, depending on the size of the functional group. Each functional group follows a seasonal or cyclical pattern of clearing, planting and harvesting based on established practices and decision-making systems outlined below (Table 7.1 and Figure 7.2). For example, clearing of lands in preparation for planting typically occurs between June and August, and coincides with the primary wet season. Small vegetation, shrubs and bushes are cleared in June, while larger trees and more established vegetation are cleared in July and August.

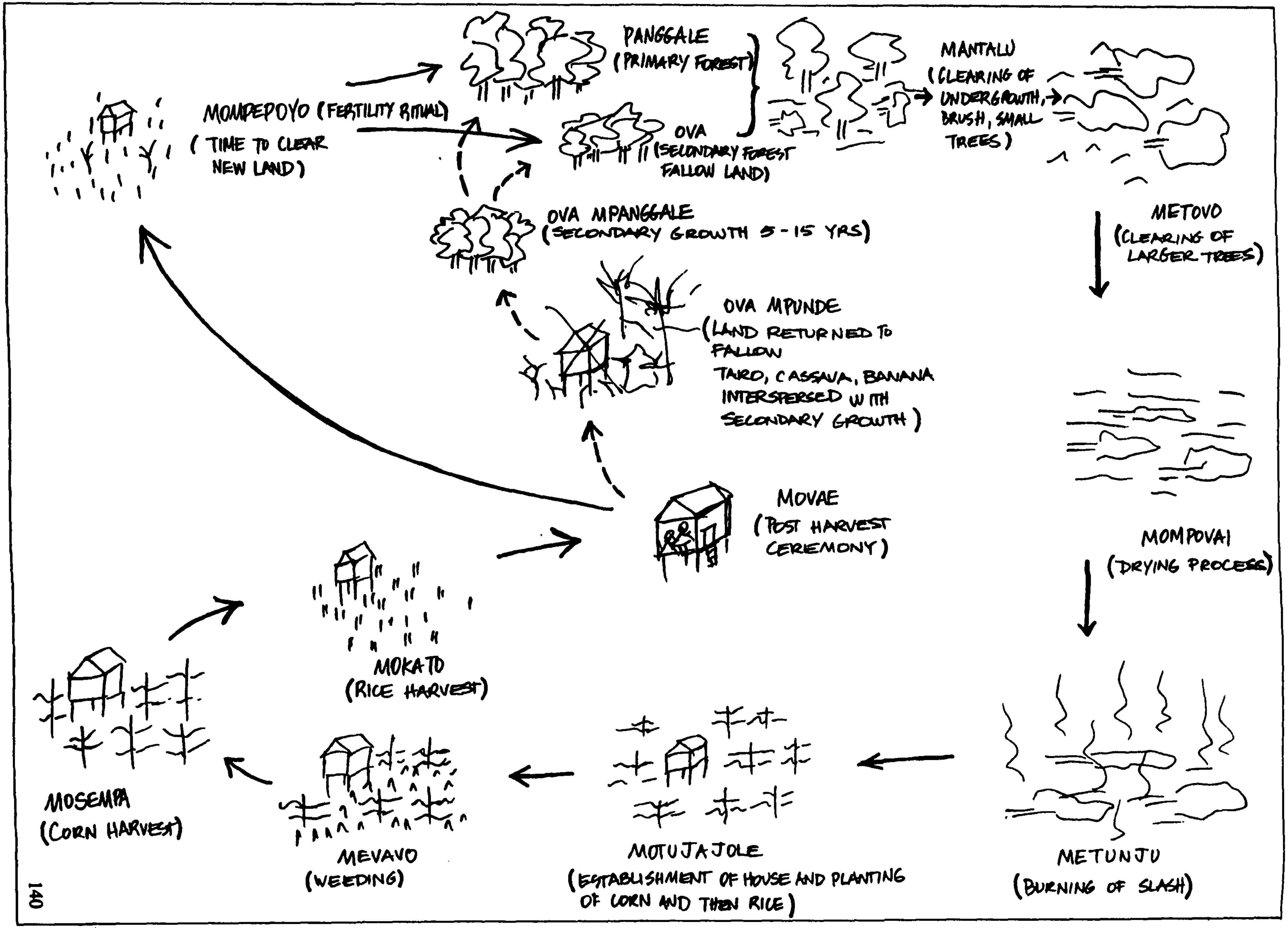
Table 7.1: Seasonal Overview of Upland Swidden Agroecological System in Banawa-Marawola, Central Sulawesi

Variable	June	July	August	September	October	November	December	January	February	March	April	May	Gender*
1) Wet Season	■	■	■				■	■				■	N.A.
2) Dry Season			■	■	■	■			■	■	■		N.A.
3) Clearing													
Malunu	■												M / w
Pantolo		■											M / w
Totoluongo			■										M / w
4) Drying of fields			■	■	■								N.A.
5) Burning of slash				■	■	■							M/W
6) Planting													
Rain-fed rice					■	■							W / m
Corn					■	■							-
Taro	■												-
Cassava	■												-
Banana	■												-
7) Weeding							■	■					-
8) Harvesting													
Rain-fed rice												■	-
Corn									■				-
Taro	■												-
Cassava								■					-
Banana	■												-
9) NTFP Harvesting													
Durian							■	■					M
Langsat							■	■					M
10) Selected Practices and Rituals													
Mompepoyo												■	M
Mosi pengava	■			■		■	■		■			■	M/w
Movae												■	M/w
Motamba		■	■										M/w

Source: Derived from seasonal calendars prepared by key informants and village focus groups at Sintulu and Lumbulama, September 3 and 26, 2000

**M = men; W = women; Upper case symbolizes a primary role in the activity while lower case symbolizes a secondary role in the activity*

Figure 7.2: Upland Swidden Agroecological System



Typically, one or two plots of land are actively worked on a yearly basis (i.e., in order to cultivate rice, corn and supplementary food crops), although a number of other fallow lands may be utilized which require limited maintenance, and where taro, banana and other secondary food crops are harvested from regenerating secondary forest. The Da'a refer to lands left after harvest (i.e., in fallow) as *ova*. Clearing for cultivation purposes usually occurs in ova (regenerating forest of multiple age classes), or occasionally in older-aged or mature forest (see below for a more complete discussion).

Cleared fields are left to dry during a period extending from August through to October. Clearing starts with the arrival of several star formations that emerge in the night sky and which signal the beginning of a new agroecological cycle for local people. Numerous star formations can be identified by local people (see YPR, 2000), and star formations of particular significance for the beginning of a new cycle include *malunu* (a cluster formation), *pantolo* (three stars in an east-west configuration), and *totoluongo* (two stars in the east and one in the centre of the sky). Once the land is sufficiently dry - a condition which depends on prevailing weather conditions, the time of clearing, and whether the cleared land was early secondary, late secondary, or mature forest - burning begins. Typically, burning may take place between September and November.

Ova comprising early regenerating forest is more amenable to efficient burns, and therefore, provides a greater likelihood of an abundant harvest. As Li (1991:40) has noted in the Tinombo region of Central Sulawesi, good burns produce good harvests but occur only two times out of five. The planting and harvesting process utilized by the Da'a is staggered. Banana, taro, cassava and other secondary crops (e.g., sweet potato) are typically planted in the early part of the season (i.e., June) because they provide the primary staple food crops utilized by the Da'a.

They also tend to be planted in existing secondary and/or older-aged fallows, and as a result, require minimal maintenance in order to generate yields.

In contrast, rice and corn are planted once a suitable ova has been identified and the clearing, drying and burning process has been completed, usually between October and November. Although the two crops are planted in the same ova, corn is planted first, with rice planted approximately one week later. No specific reason could be ascertained as to why corn and rice were planted in this manner, except that it is the process that has been used by the parents of the current generation, and their parents prior to that. Weeding of the primary ova in which corn and rice are planted occurs only once, approximately one month after planting (e.g., December and January).

Clearing and planting are done communally. Utilizing a practice of mutual assistance called *mosi pengava*, Da'a groups work together to clear and prepare ova for rice and corn, and then proceed to seed the lands of each individual family. *Mosi pengava* is practiced at various times throughout the year in order to coincide with the most labour intensive activities - clearing, planting and sometimes harvesting. Typically, the traditional leader of a Da'a group will organize a process in which everyone meets to discuss which plot of land will be cleared and prepared first. With the completion of preparations in one plot of land, work groups move to the next plot and so on. No hierarchy has been identified in terms of deciding which plot of land will be prepared first. Rather, the decision appears to be based upon consensus and/or request. From a management perspective, *mosi pengava* offers a potential vehicle for local community organization (see Chapter 9). Harvesting of taro and banana takes place approximately one year following planting (June), ensuring food sources for the upcoming season. Cassava is harvested in January and provides a supplementary interim food source.

Although the timing may vary somewhat, the essential process of staggered planting and harvesting of supplementary crops is maintained throughout the Da'a swidden system. Corn is usually harvested around February (approximately three to four months after it is planted), while rice is harvested in May. Harvesting of non-timber forest products (NTFPs) may occur at different times of the year, although two NTFPS identified as the most significant, durian and langsat, are harvested as they ripen in December and January. No seasonal period of food scarcity associated with the Da'a agroecological system has been identified. This is likely due to the farming techniques utilized by the Da'a, the reasonable variation in crops grown in the uplands, and the staggered times the crops are planted and harvested (Netting, 1968). Hunting in forested lands, around fallow lands (ova) and other cultivated sites is practiced by the Da'a, although it does not play a significant role in food provision strategies. More likely, non-timber forest products (e.g., rattan (*Calamus* spp.)) are collected in order to augment individual incomes, or to trade for knives and other durables.

Swidden cultivators typically manage the production of several crop varieties, non-timber forest products and occasionally timber (Montagnini and Mendelsohn, 1997). The management of these resources occurs in accordance with a set of variable access rights and household decision-making mechanisms that may differ significantly within and across groups (Dove, 1993; Peluso, 1995; Vosti and Witcover, 1996). However, contrary to the belief that swidden cultivators utilize an open access resource regime, individuals and groups have implicit territorial rights to lands, trees and other forest-based resources. For example, rights to specific products (e.g., NTFPs) can be held by the individual (see Siebert, 1997), while rights to fallowed swidden lands can be inherited - sometimes by either male or female off-spring (see Peluso, 1995:394). In the Banawa-Marawola uplands, rights to land are typically held by the individual who originally prepared the land. Thus, the person who cleared the original forest has the right of cultivation following subsequent fallow periods, can pass the rights of cultivation on to descendants, others who request the lands for cultivation, as well as the ability to completely transfer rights to an individual in return for compensation (see also Li, 1991). The latter, although increasingly common at the upland margins where in-migration from coastal dwellers is an issue, appears relatively uncommon in the interior uplands. Access to mature forest can conceivably be considered "open", although in practice a complex set of kinship and locational factors limits its use (e.g., is the forest land adjacent to land holdings of unrelated individuals?, has permission been obtained from those cultivating lands closest to the forest patch to be cleared?, etc.) (see Li, 1991). More importantly, access to certain lands may be constrained due to the presence of traditional and/or formal regulations restricting use.

7.4 Spatial and Temporal Dynamics in the Da'a Agroecological System

The previous critique of the policy discourse that underwrites explanations of environmental change in the Banawa-Marawola uplands illustrates how issues surrounding deforestation are often tied to particular political agendas. At present, the debate uses concepts and language suggesting that a deterministic, linear process is underway in the uplands involving the conversion of stable or pristine natural forest vegetation to permanently cleared lands, and subsequent biodiversity decline and soil erosion. Having provided an overview of the Banawa-Marawola upland context and the Da'a swidden agroecological system, however, it is informative to further critique the canons of this narrative using dynamic perspectives more appropriately linked to the theory, concepts and metaphors of complex systems, cultural and political ecology.

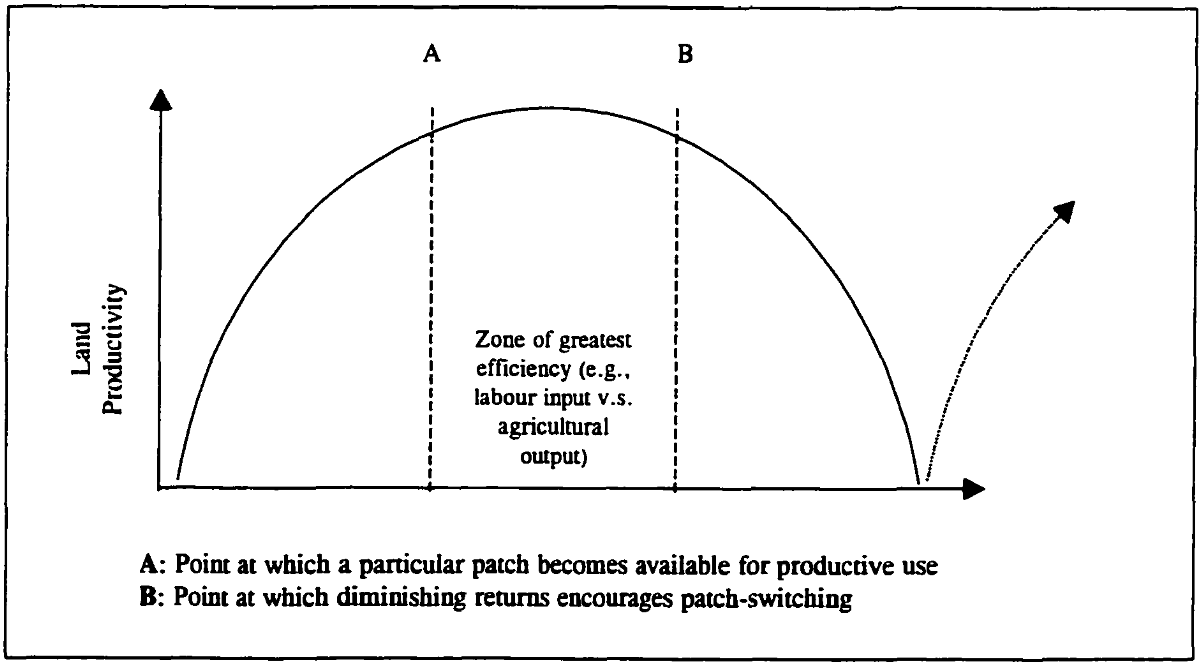
7.4.1 Resource Rotation, Conservation and Economic Optimization

The Da'a, along with other similar upland communities throughout Central Sulawesi (see Li, 1991), engage in a rotational resource cycle contingent upon several cultural, socioeconomic and ecological variables. Within the different functional groups of families, the Da'a practice both an internal (or micro-rotational) as well as an external (macro-rotational) process. With respect to the internal rotational process, every year families in a functional group rotate the cultivation of rice and corn among different ova, while maintaining a semi-permanent settlement at which supplementary food crops (e.g., banana, taro, sweet potato, cassava) are also grown. Typically, the land under cultivation is reasonably close to the settlement and to the other crop lands in order to ensure labour efficiency. As previously mentioned, the rotation among ova occurs on an annual basis, with a particular fallow cultivated for approximately one year and then left for five to 20 years[34]. Coincident to the process of internal resource rotation, a process of external rotation may also take place in which some or rarely all members of a functional group physically relocate themselves to a new area in order to "settle" on new lands and begin the process of internal resource rotation once again.

The factors that determine this micro- and macro-rotational movement are varied. Certainly, agroecological factors (e.g., declining soil fertility) relating to economic optimization and a desire to improve rates of return on labour input are important decision criteria. However, key decision criteria are as much socio-cultural as biophysical and may be related to, for example, the presence of interpersonal conflict, political differences among leadership in the functional group, invitations extended to specific individuals from another functional group as a result of marriage and new alliances. In general, few *formalized* rules or systems guide the rotational process (by necessity the process is fluid).

However, the dynamic internal and external resource rotation system outlined above has both important economic optimization and resource maintenance implications. The decision to rotate swidden areas is most likely based on the advantage created by leaving a specific patch before it becomes completely depleted and moving to an area of potentially higher yields (Clarke, 1976; Vosti and Witcover, 1996; Montagnini and Mendelsohn, 1997; Smith and Wishnie, 2000). Although the intent of the strategy may be economic optimization (i.e., maximizing productivity and returns on labour investment), the movement from one patch to another after a certain period of time facilitates the recovery of soil nutrients, permits forest regeneration and promotes biodiversity (Harwood, 1996; Schelhas and Greenberg, 1996; Ellen, 1999; Smith and Wishnie, 2000) (see Figure 7.3)[35].

Figure 7.3: Productivity and Efficiency in Swidden Decision-Making Systems



A: Point at which a particular patch becomes available for productive use
B: Point at which diminishing returns encourages patch-switching

7.4.2 Uncertainty, Randomization and the Selection of Swidden Sites

The most important stage in the Da'a swidden cycle is the selection of an appropriate swidden site (see Table 7.1 and Figure 7.2). In practice, numerous information sources could provide the basis on which to rationally determine lands suitable for cultivation in any given year: memory of previous yields in particular fallows, maturity of the vegetation cover, current soil characteristics and knowledge of soil fertility conditions, pests and pest outbreaks, and perceptions about water and drainage at different sites (Lambert, 1996). Utilization of such decision criteria would seemingly result in the annual identification of the preferred or most suitable swidden sites. However, due to inherent uncertainty produced by the interaction of a large number of environmental (see above) and socio-cultural variables (e.g., proximity of available lands, and group or family decision-making processes), site selection is intrinsically problematic. Consequently, the Da'a employ ritual and/or symbolic practices, along with the use of locally-derived knowledge, in an effort to randomize swidden behaviour and facilitate successful adaptation in a complex and uncertain environment.

Two types of decision criteria are utilized by the Da'a to select potential swidden sites and randomize resource management behaviour in the Banawa-Marawola uplands. Initially, a "coarse-filter" approach is applied across the range of potential swidden sites (i.e., fallow lands or ova) based on the presence or absence of indicator species. The presence of certain species and the stage of succession in a particular ova (e.g., a particular species achieving a certain diameter) provides a favourable indication that fallow lands have recovered sufficiently to permit cultivation again (i.e., soil fertility has returned). Key indicator species identified by the Da'a include *tea* (*Artocarpus teymanii*), *ngilo*, *voleara*, and *marambaka*. At a minimum, the process of indicator species regeneration requires five years. Once initial conditions have been established, a final decision to cultivate in a particular fallow is linked to a soil fertility ritual. *Mompepoyo* is a "fine-filter" ritual process utilized by the Da'a (and other local upland groups) to determine soil fertility in a fallow that has been established as suitable by the "coarse-filter" assessment of vegetation succession and the identification of indicator species regrowth. Specifically, *mompepoyo* involves the slaughter of a chicken and the divination of its liver and bile. If both the liver and bile are black, and the liver is solid, the fallow in question is considered fertile and suitable for cultivation. If the liver and bile are pale, the fallow under consideration is deemed infertile and a new area will be considered.

Principles of randomization inherent in the *mompepoyo* ritual thus inform decisions about the selection of swidden sites among differing age classes (e.g., early successional, late successional, or mature forest) and promote a non-deterministic resource management approach to nature-society interactions in the uplands. In the context of uncertain environmental and social conditions, the most profitable strategy (i.e., the strategy which provides the best trade-off between agricultural productivity and labour input) over time is to expect unpredictability. Rather than seek to control and manipulate system variables in an effort to maximize outputs, a probabilistic or randomization strategy is seen by upland communities as better suited to non-deterministic dynamic system conditions. Randomization is provided not only by the non-deterministic selection of swidden sites, however, but also by differences in swidden strategies of different households, differences among multiple swiddens in the same household, and among swidden strategies in the same household in different years (see Dove, 1993; Vosti and Witcover, 1996). The latter three as decision criteria for swidden site selection are not explored in the context of this research. However, empirical results obtained from the study of other swidden groups in Indonesia and elsewhere (Li, 1991; Dove, 1993; Lawrence et al., 1998) suggest their likely importance in the Da'a agroecological system.

Thus, like the augury of Dayak (Kantu) swidden cultivators in Kalimantan (Dove, 1985, 1993), the Da'a utilize both animistic (probabilistic), as well as locally-derived ecological knowledge (deterministic) as means of swidden site selection and the randomization of swidden behaviour. Although the analysis of the Da'a decision system is still preliminary, the Dayak from neighboring Kalimantan would appear to utilize a more complex decision-making system that relies on the presence of bird species to randomize swidden behaviour (i.e., the location of clearings) (Dove, 1993). Just as there is no ecological link between the bird species and enhanced siting of swidden plots by the Kantu, there appears to be no empirical link between the results of *mompepoyo* and effective swidden selection by the Da'a. Had the *mompepoyo* ritual some causal connection to swidden success, the supernatural aura it possesses would likely be undermined[36]. Nevertheless, in both cases, a diversified swidden strategy is promoted that facilitates adaptation in a complex and uncertain tropical environment. Indeed, the impossibility of empirical causality attributes supernatural power to the *mompepoyo* ritual (see Dove, 1993), and helps to foster a resource management strategy suitable to conditions of uncertainty, flux and unpredictability. This suggests intrinsic recognition by upland groups of the implications of seeking to control and systematize system variables: more rigid institutions, more dependent societies and decreased resilience (see Gunderson et al., 1995; Berkes and Folke, 1998).

7.4.3 Patch Dynamics, Successional Pathways and Landscape Mosaics: Biodiversity and Ecological Integrity in the Uplands

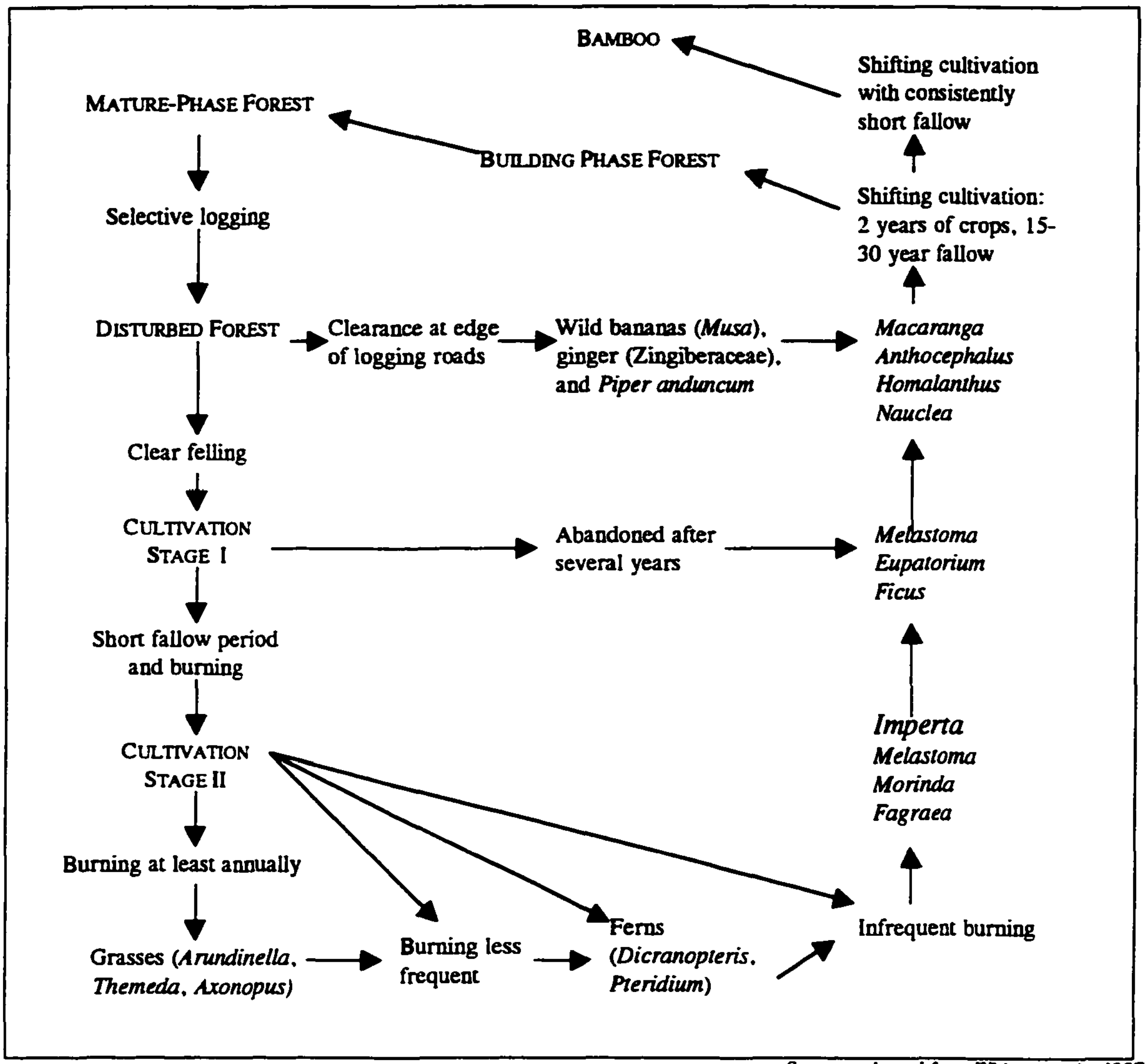
Nature-society interactions associated with the Da'a agroecological system must be contextualized within a more comprehensive understanding of ecological dynamics in the Banawa-Marawola uplands. Central to this analysis is a definition of the meaning of "natural" vegetation that is the focus of exclusionary protection efforts and policies to extirpate forest communities from their historical land base (Peluso, 1993; Guha, 1997). As Sprugel (1991) pointed out, defining natural vegetation is a challenge because vegetation in any given area is not stable over long periods of time, even when anthropogenic factors do not have a significant influence. Just as more recent social theory is countering notions of stable, timeless and functionalist traditional societies (Netting, 1967; Ellen, 1999; Kahn, 1999; Scoones, 1999), dynamic ecological concepts (see Chapter 3) suggest a need to broaden the definition of "natural" vegetation. Due to either biophysical or long-standing historical anthropogenic influences, several vegetation communities could be considered "natural" for a given site at a given time. For example, while tropical forests have often been conceived as being stable, more recent evidence suggests that they are, in fact, dynamic communities whose diversity is a result of significant disturbance patterns associated with climatic change, fires, floods, treefalls and human pressure (Whitmore, 1983; Primack and Hall, 1992; Baker, 1992; Orians et al., 1996). In the context of biophysical and anthropogenic change, the forest vegetation of the Banawa-Marawola uplands should be viewed not as having remnants of primary tropical forest serving as the last bastions of ecological integrity, but as a complex of multi-scaled (e.g., farm plot, forest stand, landscape) and multi-aged successional systems in a continuous state of flux and change (see Sprugel, 1991; Wu and Loucks, 1995; Guindon, 1996; Schelhas and Greenberg, 1996; Scoones, 1999; Zimmerer, 2000).

Wherever cumulative disturbance regimes are of such an extent that an additive disturbance event can affect a significant portion of the landscape, equilibrium conditions are unlikely (Sprugel, 1991). Therefore, since chance factors and events can cause substantial changes in vegetation conditions, successional trajectories and associated biotic processes, no specific vegetation variant is necessarily more natural than another (Sprugel, 1991; Fairhead and Leach, 1996). Secondary or disturbed forest is not inherently undesirable in the context of long-term flux, and in fact offers important opportunities for the maintenance of biological diversity and ecological integrity (Sprugel, 1991; Schelhas and Greenberg, 1996). Not all vegetation and/or biotic assemblages, however, are "sufficiently natural". For example, in the case of the Banawa-Marawola region, the conversion of secondary and other forest patches to permanent cocoa crop production is unlikely to constitute a vegetation community or ecosystem supportive of biodiversity values and maintenance of ecological integrity.

However, in the patchwork mosaic of the uplands where a variety of vegetation trajectories has been created by physical and anthropogenic processes, reasonable proxies of "natural" biotic assemblages may be maintained (see Schelhas and Greenberg, 1996). The upland vegetation mosaic would appear to provide a more resilient and sustainable alternative than the mono-cropping systems being promoted throughout the region. From the perspective of conservation policy and practice, the debate should move from the focus on halting or modifying swidden practices, to understanding how to incorporate the agroecological system knowledge that gives rise to multiple ecosystem trajectories with structural and functional resilience (Figure 7.4).

The Da'a, like other swidden cultivators, clear mature forest. What necessitates a more elaborate socio-ecological critique, however, is the actual extent to which the Da'a clear "natural" forest, and the ecological impacts (e.g., biodiversity loss, soil erosion) of forest clearing where and when it does occur. Central to this analysis are the messy problems associated with definitions of forest, wild and natural, that are difficult to situate in relation to landscape conditions and the meanings attached to them by local individuals and communities.

Figure 7.4: Successional Pathways in Lowland and Lower Montane Forest (Sulawesi)



Source: adapted from Whitten et al., 1987

When individuals discuss rotating swidden sites to utilize "forest" (*panggale*), instead of fallow, it does not necessarily signify the conversion of mature forest. As one Da'a elder in the Banawa-Marawola uplands commented, approximately three hectares of ova and three hectares of mature standing forest could be cleared each year by a typical family. With five individuals working to clear land, the same elder indicated that it was possible to clear up to eight hectares of late successional or mature forest every year. Nevertheless, this is not normally done because of the availability of ova (fallowed lands) which are much easier to clear and, therefore, offer a better return on labour invested. Indeed, Dayak swiddeners in Kalimantan prefer to establish swiddens in secondary forest rather than mature forest (Peluso, 1995). Individuals, therefore, manage a range of vegetation types in swidden plots with different origins, species, composition, uses and property relations that operate in a constant state of change and flux.

Thus, trade-offs between productive work and the time to travel to different swiddens influence Da'a decision making about the purpose, size and location of different swidden types and result in a changing patchwork of successional forest and vegetation types across the landscape (see Lawrence et al., 1998). Finally, in the Banawa-Marawola uplands, the incentive to clear mature forest lands depends primarily on the results of the *mompepoyo* ritual - if the results of the ritual are not positive for a particular fallow in question, immediately available fertile land (i.e., older growth forest) will be considered. Neither the different vegetation types utilized, nor the inherent dynamism in successional growth, however, are adequately recognized by government officials or conservation planners.

Utilizing data from a case study in Kalimantan, Lawrence et al. (1998) highlight a pattern of fallow land utilization among Dayak swidden cultivators, rather than continuous conversion of mature forest (Table 7.2). Where mature forest has been removed, the cause has been largely a result of a conversion to permanent rubber garden plantations. As Lawrence et al. (1998) conclude, the area disturbed by industrial logging in their study area (Gunung Palung National Park, Kalimantan) on an annual basis is approximately two to three times greater than the area disturbed by swidden cultivators. Moreover, the type and scope of the disturbance are significantly greater with industrial logging activity. Comparable detailed data from the Banawa-Marawola uplands are not available. However, information derived from research in another upland context in Central Sulawesi (see Li, 1991; Woodley, 1991) suggests a similar process. For example, although swidden farmers expressed a preference for establishing swiddens in mature forest because of enhanced soil fertility conditions, in practice close to three-quarters of all swiddens were established in early and late secondary growth[37].

Table 7.2: Conversion of primary and secondary forest for rice swiddens (Kalimantan)

Village	Number of fields sampled	From primary forest	From fallow	Primary forest converted (village total, hectares)	Primary forest converted (per household, hectares)	Mean fallow length
Dry-rice						
Banjur	21	3 (14%)	18 (86%)	9.6	0.15	12.9
Keranji-Baya	19	6 (32%)	13 (68%)	12.2	0.32	12.5
Jelutung	12	1 (8%)	11 (92%)	3.1	0.08	5.6
Kembera	26	4 (15%)	22 (85%)	15.0	0.16	20.5
Average	-	*17%*	*83%*	*10.0*	*0.18*	*12.9*
Wet-rice						
Banjur	3	0	3 (100%)	0.0	0.00	-
Keranji-Baya	7	1 (14%)	6 (86%)	2.0	0.05	3.7
Jelutung	6	1 (17%)	5 (83%)	2.3	0.06	1.0
Kembera	23	1 (4%)	22 (96%)	1.6	0.02	3.5
Average	-	*9%*	*91%*	*1.5*	*0.03*	*2.7*

Source: adapted from Lawrence et al. (1998:142)

As previously outlined, recognizing definitional imprecision surrounding deforestation is directly linked to assessments of the actual ecological and social costs associated with different land use strategies (Angelsen, 1995). For example, estimates of biodiversity loss associated with swidden resource management strategies may be inaccurate because comparative biodiversity estimates of mature forest and agricultural systems do not account for the importance of multiple-aged, successional forest patches (Angelsen, 1995; Schelhas and Greenberg, 1996). Moreover, such estimates do not account for the likelihood of generations of selective intervention between societies and forests, and the conclusive role of human agency on forest ecosystem conditions (Ellen, 1999). For example, data from Sumatra have illustrated that the faunal diversity of long fallow tropical forests (with or without the cultivation of economically valuable trees like rubber) is only slightly lower than for selectively logged or unlogged primary forest, and greater than that of plantations (NORINDRA in Angelsen, 1995:1715). Crop phase alone does not represent total diversity within swidden systems. When the fallow phase is included, total plant diversity may reach several hundred species (Swift et al., 1996). Moreover, many swidden cultivators practice varying degrees of fallow management that may promote biodiversity, such as harvesting additional food crops from younger fallow plots, managing old fallows to facilitate the growth of certain non-cultivated species, encouraging shade trees to limit weed growth, and encouraging forest regeneration and succession (Lambert, 1996). While active fallow management does not appear to be a major focus of the Da'a agroecological system, the management of fallows to generate additional food crops (e.g., taro, cassava, banana, and sweet potato) and the encouragement of forest succession is a component of system strategy. Likewise, benefits to soil resources (e.g., soil erosion protection, soil moisture retention) afforded by fallow-phase regenerative forest are often underestimated (soil moisture, erosion control, etc.) (Table 7.3).

Table 7.3: Soil erosion rates in swidden and natural forest systems

Land use system	Erosion (t ha –1 year –1)		
	Minimum	Median	Maximum
Natural rainforest	0.03	0.30	6.16
Shifting Cultivation			
Fallow period	0.05	0.15	7.40
Cropping period	0.40	2.78	70.05

Source: Brady (1996)

Tree crops (e.g., cocoa) or forest plantations where the ground cover has been removed register an average annual soil loss of approximately 50 tonnes per hectare. In contrast, the cropping phase of a swidden cycle may generate an average soil loss of between 0.40 and 70.05 tonnes per hectare on a one time basis before vegetation renewal begins (Brady, 1996). Thus, it is the ground cover and not the canopy structure that is the primary barrier to soil erosion, myths of raindrop impacts and particle splash effects notwithstanding (Hamilton in Angelsen, 1995:1715). Moreover, the release of heat-trapping emissions that contribute to climate change and global warming are relatively minor in swidden systems since most of the cleared land is secondary fallow forest that will regenerate to some level. While conversions of mature forest to swidden cultivation or tree plantation will result in a 30-60% loss of the initial carbon stock in vegetation, conversion to intensively cultivated land or pasture loses more than 90%, much of which is permanent loss (Houghton in Angelsen, 1995:1715).

Disturbance patterns associated with swidden systems share several important characteristics with natural tropical forest disturbance regimes (e.g., tree falls, wind, small-scale forest fires and landslides). For example, relatively small patches of disturbed forest are created at a low rate and dispersed randomly across the landscape. Based on data from Sumatra, the average gap size of between one and two hectares for swidden plots surveyed was calculated to be greater than gaps created by natural disturbance regimes in the primary and naturally regenerating secondary forest (typically 10-120 m^2). However, the overall percent of open landscape created by natural as opposed to swidden disturbance is similar (Lawrence et al., 1998). As Lawrence et al. (1998) illustrated, the percent of open (or gap phase) landscape in most tropical forest ecosystems ranges from one percent to 7.5%, while the area cleared for swiddens at any one time in their study area was approximately five percent. In the 76,607 hectare study area in the western portion of the Banawa-Marawola uplands, open or active swidden plots as a percentage of the total mature and naturally regenerating secondary forest have been calculated to be approximately two percent (based on remotely sensed data from 1998). Although this figure might be skewed towards the low end because of the presence of a large patch of mature forest in the southern end of the study area, the data do support the contention that the swidden system offers a proximate natural disturbance regime[38]. When the mixed agricultural category (i.e., permanent estate crops and /or food crops) is factored into the analysis, the percent of open area across the same 77,607 hectare landscape in comparison to mature and secondary forest cover increases to 35%. Based on several basic landscape metrics calculated using Fragstats (Table 7.4), several issues of landscape ecological structure and function in the Banawa-Marawola uplands emerge[39].

Table 7.4: Selected Landscape Metrics for the Banawa-Marawola Uplands, (1998)[40]

Metric / Class	Total Area (ha)	Percent of Landscape	Total Core Area (ha)	Total core as % of class	Mean Patch Size (ha)	Mean Nearest Neighbor (metres)	Number of Patches	Total Edge (metres)	Shannon's Evenness Index
Mature Forest	34,466	45	24,134	70	883.7	203.9	39	695,801	–
Secondary Forest	21,449	28	9,086	42.3	255.3	159.9	84	831,655	–
Swidden Fields	1,283	1.7	9	0.7	5.3	241.9	239	22,564	–
Secondary Forest and Swidden Combined	22,732	29.7	9,095	–	–	–	323	854,219	–
Study Area	76,607	100	46,082	100	201.1	–	381	2,137,310	0.68

While the insight generated by the Fragstats analysis in the absence of an adequate historical vegetation record is primarily hypothetical, the findings provide useful insight into the ecological implications of the Da'a swidden resource management system. Indeed, the behaviour of the metrics described below need to be compared, for example, in different land use contexts using controlled studies. Nevertheless, the metrics generate a useful baseline for further research and empirical examination regarding the dynamics of social and ecological interaction in the uplands. For example, landscape diversity typically comprises measures of evenness (the relative abundance of each vegetation class) and richness (the number of different classes) - both of which are scale dependent. The relatively high degree of forested or semi-forested lands in the Banawa-Marawola uplands (45% mature and 28% secondary growth) suggests suitable conditions for the maintenance of biodiversity and ecological integrity. Moreover, an indexed calculation (Shannon's Evenness Index of 0.68) for the entire study area suggests a moderately high level of uniform distribution of different class types across the landscape. Of the total area of secondary forest (21,449 ha), approximately 42.3% is more than 200 metres from the forest edge, while almost three quarters of the remaining mature forest (70%) provides core habitat (habitat that is more than 200 metres from the edge)[41]. Lower total core area calculations in comparison to the total study area would suggest a landscape with vegetation classes that are more fragmented – an issue for organisms that depend on largely intact habitat conditions.

Finally, fragmentation involves the process of altering the structure of the landscape by increasing the number of landscape patches, decreasing the interior area of key habitat types, increasing the extent of forest edge, or increasing the isolation or distance between similar patch types (MacGarigal,1999; Bridge et al., 2000). Consequently, forest fragmentation can be delineated in a number of ways, including calculations of mean patch size and mean nearest neighbor. However, with respect to mean patch size, the lack of adequate longitudinal data in the study area, or baseline reference values in similar tropical ecosystem habitats, limits its analytical applicability. For example, decreases in mean patch size may be indicative of potential habitat fragmentation. In the study area, mean patch size for mature forest habitat is 883.7 hectares, while the mean patch size for secondary forest is 255.3 hectares. With respect to mean nearest neighbor, mature forest patches are separated by a mean of 203.9 metres, while secondary forest patches are separated by a mean distance of 159.9 metres. Monitoring changes and trends in the landscape metrics calculated for the study area will provide valuable insight into important nature-society dynamics.

7.5 New Order, New Agenda: Disconnecting People and Place in the Uplands

The "New Order" era under Soeharto that began in the late 1960s supported a considerable ideological and philosophical commitment to the economic development of the Indonesian state. Implemented through a series of five-year development plans (*Repelita*), a key theme within the New Order development planning agenda has been the intensification of agricultural production in order to improve food security and generate foreign exchange. Corresponding worldviews of Indonesia's political, economic and bureaucratic elite regarding the goals of, and approaches to, modernization and economic development have filtered through the State machinery (Dove, 1999). A dogmatic adherence to rational development planning and policy making as well as the creation of rigid bureaucratic institutions and organizations have been the result (Ferrazi et al., 1993; GTZ, 1997). In this political and economic milieu, perspectives of upland, traditional agricultural and forest communities have been largely pejorative. For example, plans and policies have sought to address the seeming social and economic irrationality of swidden cultivation through a process of settlement and the adoption of permanent agricultural production, often without due regard to the temporal and spatial dynamics of indigenous systems, territoriality or tenure concerns, or an elaboration of historical conditions and circumstances (Peluso, 1993; Li, 1999; Tsing, 1999). The New Order era has since passed as a result of the economic and political crisis that began in the late 1990s. However, while new policies are being developed, the perceptions, worldviews and attitudes of policy makers and bureaucratic officials remain in many respects wedded to the past (see Chapter 8). Consequently, this section seeks to identify the exogenous and endogenous social, political, institutional and market variables, trends and factors that are negatively influencing the overall resilience and sustainability of the Banawa-Marawola upland system.

Angelsen's (1995) economic analysis of deforestation in a region of Sumatra provides a window on the implications of New Order policies and development narratives based on static views of upland people and places. The hypothesis of Angelsen's (1995) analysis is that change in any variable that increases profitability of frontier agriculture will augment deforestation. Thus, the pressure to permanently open cultivated lands in mature forest comes largely as a result of exogenous factors that make land use change profitable - new roads, new infrastructure or a pool of migrant workers – and which are exacerbated by efforts to secure property rights in the context of the breakdown of locally-evolved regulatory systems (see Chapter Nine). Central to this downward spiral of land transformation is the tripartite impact of forest concessions, settlement policies and permanent agriculture. For example, in Banawa and Marawola, forest concessions have typically been implemented in tandem with estate crop schemes, leading directly to a process of agricultural intensification and subsequent landscape transformation. A community forest concession (*Hak Pengelolaan Hutan Kamasyarakatkan*) initiated in 1999 in several villages along the Banawa – Marawola boundary provides a local example of this process.

The total area of the forest concession is approximately 450 hectares, although only 85 hectares have been opened to date. The project has received approval from the District (Kabupaten) government, as well as various governmental regulatory agencies, including the Departments of Agriculture, Forestry and Estate Crop Development (the regional Environmental Impact Management Agency was not one of those agencies involved in a review of the project). Although the project document lists a variety of local and provincial regulatory requirements, none are oriented towards environmental protection. The focus of this initiative is farmer working groups (*Klompok Usaha Tani*) which have been granted permission to exploit the production forest lands. Having forwarded the requisite fees, the KUT are free to enter into a joint venture or contractual agreement with a forest company - in this case one from south Sulawesi - that will remove timber, clear the land and prepare it for cocoa crop production. Each member of the KUT will receive two hectares of land once it has been cleared and prepared.

Once the timber has been logged, however, the company is unlikely to provide much in the way of benefits, other than making land available for cocoa production. Moreover, the extent to which local communities are aware of the project is unclear. Although the secretary in one village has a copy of the project plan, he apparently did not provide project approval - even though his name and signature are on the report. The implication is that many signatures in the project plan are forged. In addition, to facilitate the transportation of the logs, the forestry company is in the process of building a staging area where logs will be prepared for transport. Unfortunately, the staging area is being constructed in an area of intact mangrove forest in Banawa Selatan.

Local intrigue aside, the conversion process from swidden to permanent cropping systems has been facilitated by forest concessions granted in both Banawa and Marawola. For example, at least four individual forest concessions operated in the southern Banawa area from 1972 to 1979 and led to a significant increase in the area of estate crop plantation (e.g., cocoa, coconut) (PSL-UNTAD 2000). Moreover, a logging road constructed in 1972 provided increased mobility for individuals and enhanced an ongoing process of in-migration to the region, mostly of Buginese from southern Sulawesi into an historically Kaili (i.e., Da'a, Unde, and Ledo) area. The logging concessions have thus resulted in the permanent conversion of forest lands to intensive agricultural lands, as well as the clearance of "new" forest lands for cocoa, clove, coconut and coffee plantation (Table 7.5).

Table 7.5: Tree Crop Production (hectares) in Banawa and Marawola (1994 to 1998)

District	Crop	Cocoa	Clove	Coconut	Coffee
Banawa	1994	2154	2166	1645	25.5
	1995	2154	2166	1645	25.5
	1996	2358	7040	1645	25
	1997	2358	7040	1645	25
	1998	6486.5	7038	3409.9	67
	% increase	***201%***	***224%***	***107%***	***162%***
Marawola	1994	10,095	5,251	72,139	153,904
	1995	10,095	5,251	72,139	153,904
	1996	10,095	5,251	72,139	153,904
	1997	114,862	5,251	72,139	192,005
	1998	NA	NA	NA	NA
	% increase	***953%***	***no change***	***no change***	***25%***

BPS Kabupaten Donggala (1999a,b)

Efforts by both the state and the church to develop the region have had a significant influence on local land use strategies. In three locations in the middle hills of Banawa (Salolari, Uedepu, and Kativelu), settlement schemes have sought to permanently establish Da'a swidden cultivators and promote intensive cash and food crop production. For instance, a World Vision and local government initiative in the early 1980s offered building materials and assistance to clear lands in order to establish the village of Uedepu. By 2000, 37 families had settled at that site. At Salolari, the establishment of a Salvation Army church in the mid 1980s encouraged the settlement of approximately 10 families, while in Kativelu, a local transmigration program initiated by the District government sought to promote settlement of the Da'a by promising to clear lands for fields and homes. Consequently, in many areas in the middle hills and increasingly in the uplands, a movement towards settled or permanent agricultural production is in effect. Of significance, the establishment of permanent crops is taking place in previously fallowed lands. Since fallow lands normally retain a relatively high degree of biodiversity (see discussion above), overall agrobiodiversity across the landscape will decline as multiple-aged fallows are converted to structurally simplified, intensive cultivation systems. While concern over the loss of biodiversity has typically focused on the transformation of natural forest to agriculture, it must be recognized that biodiversity also decreases as a result of increasing management intensity within existing agroecosystems (Vandermeer, 1997). The transformation from low-intensity forms of agricultural land use to high-intensity forms has largely been ignored (Swift et al., 1996). Conversion to permanent cash crops (cocoa) in the region will eventually reduce the area of land available for swiddening, potentially forcing increased use of older-aged fallows or mature forest, as well as requiring modifications to existing tenure systems.

The short-term economic benefits of cocoa intensification offer comparative advantages over a more diversified crop mixture (in 2000, each hectare of cocoa could expect to gross one million rupiah per month, or $US 140). For example, increased revenues from cash crops will allow the Da'a and other upland groups to purchase food and other goods more readily. However, the overall effect is likely to result in a decline in food security and increased reliance on artificial or subsidized maintenance of soil fertility. As Clarke (1976) noted, swidden cultivation typically requires less labour to produce a specific unit of food than permanent, field-based agriculture and economically rational farmers are unlikely to switch to permanent cultivation systems in the absence of key drivers. Clarke (1976) suggested those drivers are population pressure and the degradation of forest fallows. However, as observations in the Banawa-Marawola upland system indicate, a range of socio-cultural, economic and political influences create incentives to landscape transformation, including the worldviews and inherent values of both the state and church, as well as the historical and present day influence of markets and other economic forces. Thus, the transition to estate crop agriculture does not necessarily constitute "rural development". Beyond the decline in economic efficiency (i.e., higher labour requirements per unit of food) is a subsequent shift away from food self-reliance and towards a food production system that requires substantial inputs (energy and materials) to maintain productivity (Clarke, 1976). However, there are endogenous reasons as well for settlement of the Da'a. As Da'a individuals explained, life in the uplands is difficult. Settlements are closer to markets, schools and essential services (e.g., health clinics) which is an issue for the children. And although not explicitly identified by individual community members, the role of their church and individual missionaries supporting settlement should not be underestimated. As one Da'a individual, and Deacon of the Salvation Army church stated, it is much easier to administer for the church when everyone is in one place than if they are all scattered about.

The official reason for encouraging settlement of swidden cultivators in the Banawa-Marawola uplands is the expressed desire to halt environmental degradation. As previously outlined, there is a general perception among policy makers and bureaucrats at local, regional and national levels that the swidden systems are responsible for deforestation, soil erosion and sedimentation in rivers. However, two less explicit reasons for this perspective also seem to contribute to the current perceptions: (i) the cultural bias that settled agriculture is an acceptable economic mode of production, whereas swidden cultivation is not; and (ii) the need for a *kambing hitam* (black goat) in the deforestation debate. As indicated above, it is likely more appropriate to point the finger of blame for deforestation at the poorly regulated forest concessions (*Hak Pengelolaan Hutan*) that have historically operated in Banawa and which presently operate in significant areas of Marawola.

7.6 Resilience and Adaptation in the Banawa-Marawola Uplands: A Dynamic Narrative for Conservation Science and Practice

Dynamic perspectives of the Da'a agroecological and resource management system outlined in the previous pages have sought to renew the debate about people, place and nature in Central Sulawesi. This has been accomplished by attempting to disengage the analysis from static or equilibrium viewpoints associated with conceptions of "natural" vegetation, timeless upland societies and their resource management practices (Ellen, 1999; Kahn, 1999; Scoones, 1999; Zimmerer, 2000). The implications for reconstructed conservation science and planning are significant. For example, a more detailed and situated analysis of the spatial and temporal dynamics of Da'a swidden practices in the Banawa-Marawola uplands offers a more discriminating explanation of upland environmental transformation. Efforts to understand contemporary Da'a resource management practices in a historical context (recent and past) have contributed to a narrative that challenges the uncritical acceptance of conventional Malthusian and/or balance-of-nature views (see Scoones, 1999). Specifically, historical and current conditions point to a multitude of social, political, religious and market factors influencing the Banawa-Marawola upland landscape, beyond simple population growth-environmental degradation causal or linear explanations. Although the demographic record is inadequate, anecdotal evidence points to an ongoing process of upland depopulation, or at least, the concentration of populations in a few upland settlements (e.g., Soi, Wugaga) where cropping systems are being sedentarized, rights to land increasingly privatized, and community services (e.g., school, small shops) more readily available. Under these conditions, the spectre of burgeoning swidden populations systematically clearing the uplands of mature forest cover seems implausible.

Historical evidence from the region further suggests an extended interaction between upland and coastal people, and the use and modification of natural resources by local groups (see Boomgaard et al., 1997; Henley, 2000; Li, 1999). As Cronon (in Scoones, 1999:12) has argued:

> *Ironically....efforts to understand ecosystems in more historical terms have made them [ecologists] suspicious of the very models of ecological 'community' - stable, self-equilibrated, organic, functionalist - on which our [social scientists] own balance-of-nature arguments rely....We can no longer assume the existence of a static and benign climax community in nature that contrasts with dynamic, but destructive, human change.*

The analysis encouraged by new ecological concepts (see Chapter 3) and more detailed critiques of conservation narratives (see Chapter 5) emphasizes multiple feedback relationships among people, their environments and ecosystem change. As Scoones (1999:13) notes, environments "....are dynamically and recursively created in a non-linear, non-deterministic, and contingent fashion.....Such perspectives require analysis to move beyond the simple functionalist, adaptationist, and deterministic models that have dominated.....social sciences in the past". Thus, complex sociobiophysical systems must be recognized as a result of continuous and discontinuous change influenced by path-dependent but non-linear dynamics (Scoones, 1999). In the Banawa-Marawola uplands, analysis of Da'a resource management practices illustrates the influence of intentional and unintentional actions in the creation of patch dynamics, multiple successional pathways and landscape mosaics (see Wu and Loucks, 1995). Moreover, this ecological analysis of Da'a resource management practice illustrates how the contingent and dynamic nature of upland environmental transformation is intimately linked to evolving social and cultural processes (e.g., *mompepoyo*).

Finally, the analysis of the Da'a system has outlined its inherent recognition of uncertainty, indeterminance and surprise. Whereas systematic attempts to control system variables in the upland agroecological system (e.g., soil fertility) would eventually lead to decreased resilience and societies more dependent on agrochemical inputs and international markets (see Gunderson et al., 1995; Holling and Meffe, 1996; Holling et al., 1998), the non-deterministic agroecological strategy of the Da'a assumes system complexity and incomplete knowledge, and represents a resilient and sustainable strategy appropriate to the context in which it operates. The issues that emerge from this analysis suggest the emergence of new conceptual challenges and opportunities for conservation science and practice. Of principal importance, policies oriented towards resilience, ecological integrity and sustainability must seek to build on the knowledge and understanding of system dynamics possessed by upland groups. Exclusionary and coercive conservation approaches supporting predominately spatial articulations of biodiversity, resettlement schemes and other mechanisms used to consolidate valued resources and landscapes, and conservation strategies based on an incomplete understanding of nature-society dynamics, must give way to innovative strategies.

This conclusion resonates well with a broader critique of the managerialist, deterministic discourse of tropical ecosystem conservation science and practice based on mechanistic metaphors and reductionist science (see Chapters 1 and 2). In contrast, proposed alternatives increasingly converge around the concept of adaptive management (see Chapter 4) in an effort to develop institutional and organizational structures more amenable to uncertainty, surprise and learning from past practice (Gunderson et al., 1995; Holling et al., 1998; Kay et al., 1999; Scoones, 1999; Berkes et al., 2000; Olsson and Folke, 2001). Moreover, concepts of adaptive planning and management are being linked to new concerns about the importance of non-formal interaction, relativistic cultural values, social relations and networked arrangements in order to promote learning-oriented institutional and organizational frameworks for ecosystem-based approaches. This generates many implications and innovative possibilities for sustainable management of natural resources that draw upon multiple sources of knowledge in a process of context specific social learning.

8.0 ADAPTIVE MANAGEMENT IN CENTRAL SULAWESI: ADMINISTRATIVE BARRIERS AND INSTITUTIONAL BRIDGES

Drawing primarily on theoretical and conceptual frameworks from complex systems theory, as well as cultural and political ecology, the social-ecological dynamics in an upland and a coastal system have been explored. A critique of incomplete conservation narratives intrinsic to the two systems has been developed with the intention of reframing policy discourse. A nuanced analysis of complex nature-society interactions has been the result, furthering understanding of: (i) the dynamic, recursive links between natural resources and local communities in the Banawa-Marawola region of Central Sulawesi; and (ii) the manner in which these interactions are nested within market, institutional and political influences across regional, national and international scales. Several questions emerge from this analysis: How do (and should) the insights provided by critiques of upland and coastal system narratives shape the philosophical and methodological foundations of conservation science and practice? How can understanding of spatial and temporal dynamics of nature and society in the Banawa-Marawola region form the basis for more effective conservation policies and programs, and facilitate the sustainable use of landscapes and ecosystems? How can a full range of system actors with disparate goals and visions chart a course for the future that is both pluralistic and focused on social learning? Since responses to these questions will not emerge without significant discussion, debate and conflict, the framework in which they are asked will need to be flexible, yet robust.

Adaptive management is increasingly cast as a tool that can frame the numerous philosophical, methodological and practical challenges which the previous questions raise (Holling, 1978; Walters, 1986; Walters and Holling, 1990; Lee, 1993; Gunderson et al., 1995; Berkes and Folke, 1998; Gunderson, 1999; Scoones, 1999). Yet there are many socio-political and institutional variables that influence the feasibility of adaptive management in complex tropical landscapes like those encountered in the Banawa-Marawola region. Caution in prescribing adaptive management as a requisite tool for conservation and ecosystem management in developing country contexts is therefore required, particularly given its limited history. As Honadle (1999:65) points out, environment and development practitioners "....have graduated from the micro-level obsession with imported physical artifacts to the macro-level obsession with imported physical prescriptions". Adaptive management need not be an example of this. Awareness of, and sensitivity to, contextual conditions that support or undermine adaptive ecosystem management is required. A realistic assessment of context can facilitate reinterpretations of prior resource management experience, as well as analyses of the specific circumstances that influence the identification of potential strategies and improved policy-making conditions (Honadle, 1999). Adaptive management is, ultimately, a political process and this must be recognized.

Required as well is greater sensitivity to issues of definition. Adaptive management means many things to many people (see Chapter 4). At a minimum, it is important to differentiate between active adaptive management and passive adaptive management (see Lee, 1993; Walters and Holling, 1990; McLain and Lee, 1996; Gunderson, 1999) (see Figure 4.1). Active adaptive management is an experimental or quasi-experimental approach used to test different resource management prescriptions, strategies or policies. Passive adaptive management implies a learning process approach associated with the design and implementation of projects, programs and policies supported by flexible institutional and organizational arrangements. Monitoring is a central component of both, although the applicability of the different models of adaptive management depends on a range of enabling conditions.

Evaluating the applicability of adaptive management in the Banawa-Marawola region, therefore, requires a two-stage, cross-scale analysis. The initial stage involves an assessment and comparison of the socio-economic, political and institutional conditions influencing the formal administrative bureaucracy in the region against a set of criteria and standards associated with effective active and/or passive adaptive management practice. This has included an assessment of existing technical capacity within responsible government agencies, the worldviews of decision makers, the implications of on-going political, economic, and legal uncertainty in the region, and the influence of the regional decentralization process and its associated legal ramifications. The second stage, which is the focus of Chapter 9, involves an analysis of locally-evolved resource management practices and strategies that may engender an adaptive management approach which is contextually relevant, supported by innovative institutional and organizational arrangements, and oriented towards social learning.

8.1 Adaptive Ecosystem Management in Central Sulawesi: A Propositional Evaluation

At the start of this new millennium, Indonesia is experiencing dramatic socio-political, economic and cultural change. Broad-scale effects of globalization have merged with localized political forces demanding change, thus destabilizing institutions and the very fabric of Indonesian society in the process. Catalyzed by the financial crisis that gripped southeast Asia in 1997, economic conditions throughout Indonesia have since deteriorated dramatically. As a direct result of the economic crisis, approximately 50 million Indonesians (one in four people) now live in absolute poverty, double the number prior to the economic crisis (UNICEF, 1999). Between 1996 and 1998, average household expenditures declined by 24 percent, while a 1998 inflation rate of 80 percent further eroded family incomes (UNICEF, 1999). The ensuing political and institutional turmoil led to the downfall of Soeharto's New Order regime. A development-oriented government emerged with a "*reformasi*" mandate to restructure Indonesia's political, economic and legal framework: free elections were held in 1999; international and domestic trade policies have been liberalized; financial sector restructuring has led to a reduction in inflation, stabilization of the rupiah, a recovery of foreign exchange reserves, and a return to pre-crisis level interest rates (GOI/IMF, 2001). Media outlets have benefited from greater openness, and supported by the growth of rights-oriented non-governmental organizations, an anti-corruption agenda has emerged. Finally, a process of decentralization and reorganization of the Java-based central government bureaucracy is underway (see GOI/IMF, 2001).

Despite improvements in Indonesia's economic and financial condition, deep structural economic and social problems remain. As the Government of Indonesia's own Memorandum of Understanding with the International Monetary Fund states, the country's natural resources have deteriorated throughout the crisis (GOI/IMF, 2001). In response, the GOI has committed to increased consultation and stakeholder participation in decisions affecting natural resources, including in the formulation of new policies. Moreover, the GOI has pledged to: (i) expand and improve environmental monitoring of Indonesia's air, water, forests, and marine resources; (ii) move towards a pricing structure for natural resources that better reflects their true value; and (iii) pay special attention to improving forest management and ensuring a sustainable production of goods and services from forest resources (GOI/IMF, 2001). How might these new management directions and socio-political, economic and institutional conditions influence the application of adaptive management in Central Sulawesi, and Indonesia generally?

As outlined in Chapter 4, Sanderson (1995) has highlighted several issues regarding the application of adaptive management in developing country contexts. Likewise, Lee (1993) has summarized the institutional characteristics that influence adaptive management (Table 4.1). Based on these analyses and the findings of several other reviews of adaptive management (Rondinelli, 1993; Micheal, 1995; Gunderson et al., 1995; McLain and Lee, 1996; Smith et al., 1998; Shindler and Cheek, 1999; Johnson, 1999; Lee, 1993, 1999; Gunderson, 1999), a range of procedural and substantive issues associated with administrative bureaucracies (institutional and organizational) that may constrain or facilitate adaptive management in developing country contexts has been identified (Table 4.2). The following analysis has further elaborated on this theme by distilling the previous reviews into nine propositional statements that form a contextual evaluation framework for adaptive management implementation potential (Table 8.1). Synthesis of qualitative research in this manner is an effective means of building theory through a process of induction and interpretation (Noblit and Hare 1988; Shindler and Cheek, 1999). Building on Shindler and Cheek's (1999)[42] approach assessing the role of citizen participation in adaptive management, this propositional analysis seeks to illuminate and investigate those contextual aspects of administration and management that create opportunities and constraints to the application of adaptive ecosystem management in Central Sulawesi. The intent, however, is not to determine causal linkages among different variables or predict when or if adaptive management is suitable. Indeed, the development of the propositions has been a subjective process involving the categorization of ideas and themes, and different researchers would likely develop somewhat different propositions. However, analyses of this type are well suited to generating insights about patterns and processes of social learning and decision making that are fundamental to adaptive ecosystem management (Lee, 1993; Shindler and Cheek, 1999). The propositions outlined below, therefore, are intended to evoke additional questions, analysis and debate (see Shindler and Cheek, 1999). Moreover, the propositions may be particularly valuable as reference points in further investigations of the applicability of adaptive management generally, and provide needed explanatory insight into the challenge of applying adaptive management in diverse developing country contexts.

Table 8.1: An Evaluative Framework for Adaptive Management Application

Proposition 1: Cultural factors influence all planning and decision-making processes

Proposition 2: Political and informational openness influences innovation and flexibility

Proposition 3: Worldviews of bureaucratic and political elite bias social learning

Proposition 4: Entrenched power inequities among system actors complicate resource decision making

Proposition 5: Inequitable balance of power among bureaucratic agencies limits integration

Proposition 6: Capacity constraints diminish adaptive management opportunities

Proposition 7: Bureaucratic planning processes constrain information gathering and analysis

Proposition 8: Lack of trust and legitimacy of government agencies hinders citizen participation

Proposition 9: Mainstream definitions of participation inhibit system understanding

Mainline Institutional and Organizational
Bureaucracy in Central Sulawesi
(Forestry, Fisheries, Environment, Planning, Etc.)

Opportunities for and Constraints to
Adaptive Ecosystem Management

8.1.1 Proposition 1: Cultural factors influence all planning and decision-making processes

Assessing the successful application of adaptive management in Central Sulawesi does not require a complete dissection and analysis of all aspects of the culture in which it is to be implemented (see Honadle, 1999). However, as Boyle (1998) has illustrated, cultural influences play a significant role when implementing policies, programs or strategies whose origins can be found in Western values and in contexts in which socio-cultural practices and political evolution are divergent. In Indonesia, key cultural processes that fundamentally influence how decisions are made include: (i) the emphasis on paternalistic authority, hierarchy and status; (ii) the importance of patron-client relationships in ensuring loyalty among the bureaucratic, political and private sector elite; and (iii) a desire to avoid conflict (see Boyle, 1998). Yet as a civic-oriented political process (Lee, 1993; McLain and Lee, 1996), adaptive management is based on the premise of open, democratic discourse and "bounded conflict". Thus, the civic science model proposed by Lee (1993) is grounded on a fundamentally different cultural worldview surrounding relationships within and across social, economic, political and administrative scales. Moreover, in the Banawa-Marawola region, limiting conditions to the open decision-making processes that are central to adaptive learning and management are further complicated by significant socio-cultural diversity (see PSL-UNTAD, 2000). In Banawa in particular, diverse cultural groups, each with its own set of norms and practices, must be accounted for in an adaptive management framework.

8.1.2 Proposition 2: Political and informational openness influences innovation and flexibility

The "*reformasi*" era in which the Indonesian State finds itself has catalyzed a growing demand for political transparency and openness. While media outlets have been emboldened, and greater rights to assembly and free speech are widely tested by civil society groups, access to information is limited and transparent decision-making processes are rare. As illustrated in Chapter 6, licensing and approval processes associated with aquaculture development in the coastal zone of Banawa Selatan are opaque at best. Likewise, the recent establishment of a community forestry concession along the Banawa-Marawola border (see Chapter 7) was done under suspicious circumstances and with little regard for local conservation or development aspirations. Constraints associated with closed decision-making systems among bureaucratic agencies and the lack of information exchange undermine the multiple stakeholder processes identified as central to adaptive planning and management (McLain and Lee, 1996; Shindler and Cheek, 1998; Smith et al., 1998). The ability of individuals, communities and civil society groups to participate in even the most rudimentary forms of planning and management (see Proposition 9) is severely constrained and serves as a barrier to the implementation of an adaptive approach. As Honadle (1999:82) argued:

> *The pervasive issue of human rights, informational openness, and political culture limit options for promoting participation, for setting incentives and for going beyond command and control approaches.*

8.1.3 Proposition 3: Worldviews of bureaucratic and political elite bias social learning

Social learning is premised on diverse system actors, guided by a shared vision, collaboratively developing adaptive, flexible and sustainable responses to the challenges wrought by globalization and environmental change. Learning and ingenuity (Homer-Dixon, 2000) are thus considered fundamental to the effective arrangement of social, political and economic affairs. Of the many factors that influence the capacity for social learning, political opposition of powerful groups threatened by reform and change is of particular significance. The biases and worldviews of decision makers are rooted in entrenched interests and are used to maintain positions of power and influence. For example, in Central Sulawesi, and Indonesia generally, pejorative terms used in colonial times to describe peasant, agrarian-based societies are still utilized today. In the Banawa-Marawola region, upland groups are often referred to as *Tolare* (literally people of the slopes), while in Indonesia, forest-based communities and groups not tied to mainstream formal political and economic system are referred to as *masyarakat terasing* (isolated or backward communities). Both are considered pejorative by the communities they seek to represent.

For a process that seeks to foster institutional designs and practices to facilitate a learning strategy in the face of irrational decision making, uncertainty and surprise (Lee, 1993; Gunderson et al., 1995; Gunderson, 1999), power imbalances created by characterizations of the "other" (see Dove, 1999; Tsing, 1999) are powerful obstacles. As Berry (in Li, 1999:24) suggests: "...struggles over meaning are as much a part of the process of resource allocation as are struggles over surplus or the labour process". Generalization and representations of the "other" as encapsulated in pejorative terminology, therefore, are not as Abu-Lughods (in Dove, 1999:205) points out "neutral description". Rather, generalizations and representations form a language of power that fundamentally undermines opportunities for adaptive decision making. Mainstream representations of traditional and/or rural agrarian communities as "irrational", "strange", or "uneducated" imply that innovation and social learning are a struggle between tradition (and traditional people) and change (positive development) (Dove, 1999). Such notions, however, must give way to an understanding that issues are about the type and rate of change and how such changes will be negotiated and managed (see Li, 2001). To perceive adaptive planning and management as an "apolitical" process will lead to inevitable inadequacy in outcomes. The ideology of development so entrenched in the worldviews of bureaucratic, political and economic elites in Indonesia remains a fundamental impediment to adaptive management and social learning.

> *The persistence of these views of the peasantry, in spite of changes in time, place and culture...suggests that they are not sociological but ideological in origin. It suggests that they are based less on social reality, the local variation in which they would otherwise reflect, than on an ideological reality, consisting of a... political and economic agenda (Dove, 1999:215).*

8.1.4 Proposition 4: Entrenched power inequities among system actors complicate resource decision making

Issues of power inequity (political, decision making, economic, etc.) among different system actors in Central Sulawesi must be considered a central barrier to effective adaptive management. Although such power inequities may exist in Western or developed country contexts, distributive mechanisms (e.g., taxes, subsidies, equal opportunity), levels of public awareness and political history help to ensure that inequities are managed. However, in situations in which cultural norms are more supportive of authoritarian and hierarchical decision making, access to information is limited, and dependency and loyalty to specific groups encouraged (see Boyle, 1998), power imbalances among different system actors become a significant issue for the adaptive management process. Even where such power imbalances are recognized, efforts to redress them in many developing country contexts, such as Central Sulawesi, are further complicated by cultural norms that seek to negate political opposition and limit frank and open criticism and direct communication. Conflict, disagreement and controversy are to be avoided (Boyle, 1998). Thus, many nested and sometimes subtle layers of power relations influence the open, decision-making processes advocated by civic-minded proponents of adaptive management. As illustrated in Chapter 6, monitoring, regulation and enforcement create avenues and opportunities for exploitation by officials ("office capitalists") with the powers of sanction over local communities and resource users (see Küchli, 1997; Lowe, 2000). As well, numerous other related factors influence power relations and resource decision systems. For example, internal community political dynamics and the degree of homogeneity or heterogeneity in a community are often pronounced in the Banawa-Marawola region and exacerbate existing inequities. In particular, cultural, ethnic and religious differences in these times of political turbulence in Indonesia take on an increasingly central role in resource decision making. Application of adaptive management in such challenging social contexts has not been widely tested.

8.1.5 Proposition 5: Inequitable balance of power among bureaucratic agencies limits integration

The seemingly intractable problems which an adaptive management approach seeks to frame and negotiate require the organizational knowledge, experience and resources of diverse agencies and administrative bodies (Lee, 1993; Gunderson, 1999; Johnson, 1999). Yet as is often the case, inter-agency jurisdictional conflict and poor integration limit opportunities to bring those resources to bear in problematic situations. In developing country contexts, where technical and resource constraints are common, the challenges of integration are particularly acute. In Central Sulawesi, the imbalance of power between mainline bureaucracies across and within administrative levels (Provincial and District) complicates opportunities for the adaptive management of natural resources. For example, two agencies at the provincial level - the planning agency (Bappeda) and the forestry department - embody significant power and authority. Supported with resources, staff and political persuasion, these agencies were identified by the government officials interviewed (see Chapter 2) as possessing an influence significantly greater than other natural resource management agencies. As the mandates of both agencies are driven by economic development priorities, however, this may complicate efforts to engender a balanced adaptive approach. Even the Natural Resource Conservation Unit (*Balai Konservasi Sumber Daya Alam*), for example, is situated in an agency with the mandate to produce timber, not protect forested ecosystems. In contrast, the primary agency responsible for environmental management and impact assessment (Bapedal), has little authority - real or perceived - to promote sustainable natural resource management. Bapedal has few technical or fiscal resources to review development plans, require modifications or ensure that they are enforced. Juxtaposed against Bappeda and the forestry department, agencies like Bapedal charged with managing natural resources have limited ability to influence management and decision making. The accountability mechanisms that depend on a balance of power between economic development oriented agencies and those with a protection mandate are fragile at best.

In addition, most administrative bodies at district and provincial levels are strongly influenced by the District Head (Bupati) and the Provincial Governor, respectively. Thus, independent civil service functions that provide yet another institutional and organizational precondition for adaptive management are not well established. Any attempts to apply adaptive management must account for the imbalance of resources and political agendas among government agencies and organizations, as well as between executive and legislative branches. As King (1988:254) noted:

> *...the structure of the personnel system reinforces the barriers to inter-agency communication that are created by different levels of government (e.g., province versus district) and different funding channels for projects (e.g., central government budget...versus regional government budget).*

Intra- and inter-agency cooperation is further inhibited by organizational structures, staff echelons and evaluative schemes that do not support innovation or experimentation. In the administrative culture of Indonesian bureaucracies, agencies or individuals of higher rank are unlikely to obtain or accept technical advice or input from those of a lower rank (King, 1988). As Buckman (in Honadle, 1999) has therefore argued, without first sorting through the administrative intricacies described above, any investments in testing and applying new decision-making frameworks are unlikely to prove effective.

8.1.6 Proposition 6: Capacity constraints diminish adaptive management opportunities

Active adaptive management applies the concept of experimentation to the design and implementation of natural resource policy. The process is explicitly crafted to test clearly formulated hypotheses about the behaviour of an ecosystem in order to improve management effectiveness (Holling, 1978; Walters, 1986). A passive adaptive management approach requires decision makers and managers with worldviews supportive of learning, innovation and change. As a result, there is a need to ensure: (1) adequate knowledge and understanding of the biophysical and socio-economic systems (e.g., how much is known about mangrove forest ecosystems and their use in the Banawa region); (2) capacity to undertake "experimental" or "quasi-experimental" approaches to management at regional scales; and (3) the capacity to build on existing knowledge and learn from experience in order to promote sustainable strategies.

Evidence and experience suggest, however, that the technical and financial capacity at local, district and provincial levels required to achieve such rigorous standards and practices in the Central Sulawesi context and implement an adaptive management approach is limited (King, 1988; Ferrazi et al., 1993; Ferrazi and Rohdewohld, 1999). Government organizations and agencies surveyed in Central Sulawesi suffer a serious lack of funds and facilities, supporting technical equipment (e.g., computers, analytical equipment), and are generally staffed with individuals who have neither the technical qualifications, or more importantly, the supportive conditions required in which to nurture their experience and promote innovation. Meager government salaries and incentives ensure that staff are unavailable and/or unmotivated. Moreover, agencies and organizations suffer from complex work procedures and protocols and often few opportunities for professional development or advancement (King, 1988). Key positions are almost always considered managerial rather than technical and are normally staffed on the basis of loyalty and seniority (Ferrazi and Rohdewohld, 1999).

The conditions described above are by no means uncommon in the administrative bureaucracies of developing countries. Nevertheless, the limitations they impose on any process that requires many enabling organizational and institutional conditions should not be discounted. Indeed, civil service policies in Indonesia generally have created a range of unique barriers to the application of an adaptive management approach. For example, as King (1988) has summarized: (i) individual technical qualifications are a secondary consideration when appointments to a particular position are made; (ii) a "brain-drain" into regional government agencies created by relatively greater opportunities for advancement affects the ability of district agencies to attract top people; (iii) there are excessive numbers of civil service staff; and, (iv) complex compensation and recognition systems within the civil service further act as a disincentive to the promotion of best practices and initiative.

8.1.7 Proposition 7: Bureaucratic planning processes constrain information gathering and analysis

Indonesia's planning system requires revision (Ferrazi et al., 1993; Ferrazi and Rohdewohld, 1999). Despite several multi-million dollar projects aimed at improving planning processes at local, district and provincial administrative levels, a rational or comprehensive planning approach remains the predominant model utilized by Indonesia's administrative bureaucracy. This is due in large part to underlying cultural requirements associated with paternalistic or authoritarian decision-making processes, the status accorded those in formal governmental positions, and the hierarchical nature of social relationships and interactions that permeate decision-making bodies (Boyle, 1998). Such cultural traits are reflected in the centralized and authoritarian administrative system and lend themselves to linear program implementation - they have also inspired the use of the five-year development plans (Repelita) that guide social and economic development in Indonesia. Indeed, the tendency toward synoptic planning in the Indonesian context is a result of the government's pervasive ideological and economic influence on all facets of society (Ferrazi and Rohdewohld, 1999). However, a more pluralistic society consisting of private sector interests, and an increasingly active civil society, are beginning to demand a more transactive or participatory approach (GTZ, 1997; Boyle, 1998). Therefore, it seems likely that a less rigid and linear planning process directed by central government agencies will evolve. While strategic functions, such as limited approval and supervisory roles will be retained at higher levels, central and provincial planners will increasingly be required to strengthen local planning processes and involve local actors in planning. The 1999 regional autonomy law or subsequent implementation of the decentralization process will play an important role in this regard (see discussion below).

8.1.8 Proposition 8: Lack of trust and legitimacy of government agencies hinders citizen participation

Decades of colonial and centralized, authoritarian post-colonial rule in Indonesia have disconnected people from decision-making processes. From national to village levels, individuals and communities perceive the formal State governing apparatus with a mixture of suspicion, resignation and occasional hostility. In part predetermined by socio-cultural characteristics (see Propositions 1 and 3), the administrative and political elite have succeeded in consolidating decision-making power and the benefits of economic development. While those economic benefits may filter through to subset networks of affiliates, allies and family (see Boyle, 1998), local individuals and communities too rarely experience such tangible relief. For example, at both regional and district levels, timber concessions are granted with limited regard to local resource management requirements or property rights regimes, while at local scales, individuals have repeatedly suggested that formal village officials too often view local development projects as profit-making mechanisms. As either arbitrators and facilitators of an adaptive management process, or as providers of the necessary technical information and knowledge, local, district and regional officials and agencies suffer a lack of legitimacy. Local perceptions determined from numerous workshops and participatory appraisal activities in the region regarding the commitment of officials or government bodies to equitable development and sustainable resource management, suggest they are not conducive to negotiation, learning or innovation - traits that serve as necessary preconditions to civic-oriented adaptive management.

8.1.9 Proposition 9: Mainstream definitions of participation inhibit system understanding

The centrality of stakeholder participation in the development and implementation of adaptive ecosystem management is increasingly articulated (Lee, 1993; McLain and Lee, 1996; Shindler and Cheek, 1999, Smith et al., 1999). Proponents of the importance of participation in adaptive management, however, are emphasizing not just access to information or occasional surveys of user perceptions, but long-term relationship building, educational strategies directed at diverse public interests and policy makers, and opportunities for direct input and experiential learning (Shindler and Cheek, 1999). In Central Sulawesi, such conceptions of participation are far from widespread, tending instead to focus on opportunities to comment on development plans and projects once they have been conceived and defined by external agents, or the contribution local communities can provide to projects initiated by the government agencies (e.g., labour, money, land, etc.).

While participation may be an often-quoted project planning and implementation objective, the mechanisms required to support local empowerment are rarely available. As Boyle (1999) found in a review of environmental impact assessment processes in southeast Asia, public consultation was usually limited to information gathering surveys - if it was undertaken at all. In Central Sulawesi, the most visible example of incomplete perceptions of participation among formal government agencies and bureaucrats is provided by *Gerakan Mandiri Membangun Desa Masugi* (GEMABANGDESA), or the Self-Reliance Movement to Develop Village Welfare. Unique to Indonesia and proposed by the Governor of Central Sulawesi in 1998 (Governors Decree No. 21), the objective of the GEMABANGDESA movement is to empower villages in Central Sulawesi by improving coordination among programs and improving participation within local government administrations.

Despite the presence of a "GEMABANGDESA MASUGI" slogan painted on virtually every entrance to every home in the region, few individuals have an understanding of the movement's intent. Developed in the regional capital, GEMABANGDESA is a bureaucratic, top-down and centralized attempt to fashion participation and empowerment from above. The result is a movement that is little more than sloganeering and which has little if any relevance to local communities. Moreover, the presence of officially uniformed civil servant GEMABANGDESA facilitators has provided little opportunity for connection with local communities. An alternative concept for GEMABANGDESA, first developed by a consortium of NGOs, proposed a more grassroots approach to local empowerment and participation involving the rebuilding and strengthening of traditional institutions. This concept, however, was never adopted by the regional government (Hakim, pers. comm., 2000). The lesson of the GEMABANGDESA initiative is unequivocal. Local communities need the freedom to fashion arrangements that best suit their own development needs and aspirations (Chapter 9). Freedom of this sort will facilitate the development of social organizations with emergent social power and the legitimacy to negotiate natural resource claims, property rights and socio-cultural agendas with higher government levels. Recognition of power relationships between local communities and the government bureaucracy is a prerequisite to designing more effective participation strategies, and therefore, to effective adaptive management as well.

8.2 Adaptive Management, Regional Autonomy and Fiscal Decentralization

Limited technical and financial capacity, entrenched worldviews of governmental elites surrounding traditional and/or agrarian societies, inadequate trust of bureaucratic agencies among civil society, a lack of political and informational openness, and incomplete definitions of participation suggest a challenging context in which to apply an active or passive adaptive management approach. These challenging constraints to adaptive management, however, are nested within a dynamic period of administrative flux in Indonesia created by recent attempts to decentralize bureaucratic responsibilities and devolve power to district and local levels. The implications for the adaptive management of natural resources in the Banawa-Marawola region of Central Sulawesi, and Indonesia generally, have yet to emerge (see Merrill and Effendi, 2000), although the opportunity to develop innovative and flexible institutional and organizational arrangements capable of integrating locally-evolved resource management strategies and practices may be one possibility (see Chapter 9). The following analysis, therefore, explores the theory and practice of decentralization and regional autonomy in the Central Sulawesi context, and its significance for the adaptive management and conservation of natural resources[43].

Decentralization has been a core administrative principle of the Government of Indonesia since independence (GTZ, 1997; Ferrazi and Rohdewohld, 1999). Originally elaborated upon in Article 18 of the 1945 constitution, the decentralization concept was further institutionalized in Law 5/1974 on Regional Autonomy and through a number of subsequent government regulations. In the context of Soeharto's centralized New Order rule, however, neither the principle nor the practice of regional autonomy was achieved (GTZ, 1997). With the promulgation of Law 22/1999 on Regional Autonomy and Law 25/1999 on Fiscal Decentralization, the GOI has undertaken a renewed effort to translate principles of regional autonomy as originally defined by Law 5/1974 into reality. On January 1, 2001, the responsibility for the delivery of all basic government services was officially devolved to the 361 district and city governments across Indonesia, thus returning much of the decision-making authority accumulated during the 32 years of Soeharto rule. This movement towards decentralized administration has historical roots in the animosity between Java and the resource-rich outer islands of the Indonesian archipelago; for many in the outer islands, the political and economic centralization of power in Java has been a source of frustration and resentment comparable to the Dutch colonial experience. Indeed, as recently as 1997, 60 percent of Indonesia's economic wealth was concentrated in five Javanese provinces, with Jakarta retaining 16 percent of that wealth (Jakarta Post, 2000b).

The implications of Law 22/1999 and Law 25/1999 appear at first glance to be straight forward. The central government will retain policy-setting authority on matters of foreign affairs, defense and national security, monetary and fiscal matters, as well as legal and religious affairs. The central government will also maintain the power to implement basic policies, set criteria and standards in key fields such as agriculture, education, transportation, industry and trade, environment and natural resources. Within the context of basic principles and a legal framework established at the national level, however, districts and mayoralties (city districts) will have the authority to develop and administer their own regions in an autonomous manner. District parliaments will take on an increasing legislative and decision-making role, have full administrative and fiscal autonomy, and be able to determine a suitable structure for local government departments and agencies (UNICEF, 1999). Provincial administrations will focus primarily on cross-district affairs and issues. At a meeting on April 22-23, 2001 of the Consultative Group on Indonesia (CGI)[44], the Minister of Home Affairs stated that most of the regulatory framework for regional autonomy had been established and that governmental reorganization (at the districts level) was well underway - including the transfer of some 1.6 million civil servants (Dodd, 2001). Indeed, over 100 associated regulations and decrees were to have been passed into law prior to January 1, 2001 in order to clarify the roles and responsibilities of provincial and district governments, and ensure common standards across the 361 autonomous jurisdictions (Dodd, 2001).

Despite movements to institutionalize the regional autonomy and fiscal decentralization process, administrative conditions in Central Sulawesi have experienced little change. Until the decentralization process has matured, significant political, economic and social uncertainty and turbulence are likely. For example, donors have urged the GOI to improve accountability mechanisms at district and provincial levels, address capacity problems, and resolve issues associated with the lack of equity between autonomous regions in the current revenue distribution mechanism (the General Allocation Fund). The serious lack of preparation for the transfer of powers by successive governments, however, continues to undermine the impact of the regional autonomy process, leading a previous Minister responsible for the process to abdicate responsibility for any potential failures (Dodd, 2001). Ironically, when initiating the current regional autonomy initiative, President Soeharto argued that the process would bring about stability (GTZ, 1997:1):

> *Granting wider autonomy to the regencies won't risk national disintegration... We don't have to worry about the consequences of greater autonomy because we have achieved a high level of national resiliency.*

Moreover, President Soeharto further stated during the inauguration speech of the District Autonomy Pilot Program (April, 25 1995) (in GTZ, 1997:4):

> *In implementing regional autonomy, the goal we wish to achieve is not uniformity. Uniformity regarding all aspects of our national character is already assured by the unitary nature of our nation. In regional autonomy, the focus of our attention is on the effectiveness, efficiency and harmony of governance in relation to the socio-economic and cultural conditions of the regions. This means that in its implementation opportunities must be given for variation and differences...This can be seen as a realization of our nation's motto 'Unity in Diversity'.*

Political and administrative turbulence and uncertainty, however, remain common traits of the decentralization process. For example, in the absence of adequate accountability structures, skeptical local observers expect that only the nepotism and corruption of Indonesia's bureaucracy will be decentralized. Placing large budgets in the hands of inexperienced district bureaucrats raises concerns about new opportunities for corruption. As well, there are concerns that public debt in Indonesia will grow since each district has the ability to borrow funds from national and international lending agencies (Dodd, 2001). Aside from commercial loans, two primary revenue generation mechanisms are available to the newly autonomous districts: taxation and increasing revenues from the harvesting and processing of natural resources. In the absence of a well-functioning taxation system, district governments are likely to turn to the increased exploitation and production of natural resources in areas of forestry, agriculture, fisheries and mining. For example, administrators in several provinces in Kalimantan have recently issued hundreds of timber concessions, raising suspicions of corruption in the multi-million dollar forestry sector (Murdoch, 2001). In response, the Inter-Department Committee on Forestry (ICDF) has called for strict penalties for forest law violations and the implementation of standards to guide government officials at the regional level in managing forests under decentralization (CGI, 2001; see also Merrill and Effendi, 2000). Yet in the context of Indonesia's entrepreneurial bureaucracy (see Chapter 6), the legal framework may be used to serve the agendas of powerful interests, while allowing local law enforcement to extort those over whom they have power - local people and forest communities. As previously indicated, the districts themselves are also poorly equipped and have few technical resources or the experience necessary to meet their numerous responsibilities. For example, mines are to be regulated at district levels, although few districts (including Kabupaten Donggala in Central Sulawesi) have a department or agency to regulate mining activities (Dodd, 2001).

The principles and practice of Laws 22 and 25 remain disjointed. Institutional and psychological reorientation associated with the regional autonomy process will require years of re-learning, negotiation and administrative uncertainty before the procedures, roles and responsibilities are reasonably well established. Confusion seems to remain even at the top of the administrative hierarchy: a key advisor (and expert on public administration) to the State Minister of Regional Autonomy stated (in Dodd, 2001) that the purpose of decentralizing authority to districts was not to share power but primarily to develop democracy, empower the people and ensure equitable distribution of wealth. Notwithstanding the inherent contradiction in this statement, the decentralization process is likely to offer significant power gains at regional and local levels - due in large part to the greater control over the management of natural resources. Districts and provinces are likely to improve their ability to negotiate with central government authorities because they will receive a larger portion of the revenues derived from their own natural resources. What was previously a jurisdictional debate has quickly become a financial debate. Since January 1, 2001, increased emphasis at local and regional levels has been oriented towards increased revenue generation opportunities rather than how local administrations might improve the delivery of services and programs.

Law 25/1999 on fiscal decentralization provides the revenue-sharing mechanism that will play a central role in the relative success of the regional autonomy process. Pre-decentralization conditions necessitated a dramatic transformation of the manner in which revenues were retained and shared. For example, in 1992/93, 79.4 percent of the total revenue of the Indonesian government was under the discretion of central administrative bodies, while 9.9 percent was available to provinces, nine percent to districts and 1.7 percent to villages (GTZ, 1997:34). Lower administrative hierarchies have been extremely dependent upon central government largesse - a key mechanism in maintaining political control. Indeed, tax revenues in Indonesia, particularly at provincial, district and local levels, have historically been the lowest in the southeast Asia region. Tax revenues account for only 11.87 percent of the gross domestic product because of non-tax compliance and perceptions of taxes in Indonesia as retributions and extra fees (GTZ, 1997:35). Therefore, provinces have typically received 55 percent of their budgets from central grants, while districts received 71% of their budgets from central grants. Villages are highly dependent on flow-through money from central agencies and rely primarily on "INPRES Desa" grants (Presidential grants to villages) and special poverty alleviation funds (GTZ, 1997:38).

The recent fiscal decentralization process (Law 25/1999), however, specifies new principles for revenue distribution and for sharing natural resource-based government revenue with autonomous provinces and districts. Autonomous regions are to retain 15 percent of onshore non-tax revenue from oil, 30 percent of the onshore non-tax revenue from natural gas and 80 percent of non-tax revenue from forestry, mining and fishery activities, while the regions will also keep 90 percent of all land and property taxes they collect (Islam, 1999; GOI/IMF, 2001). As well, the General Allocation Fund will consist of at least 25 percent of total domestic revenues of the central government and will be allocated to sub-national units in an effort to offset regional disparities (Islam, 1999; GOI/IMF, 2001). According to the GOI (GOI/IMF, 2001), implementation of the new fiscal decentralization principles will double transfers and the level of shared revenues directed at regional levels to six percent of GDP by 2002, thus matching new spending requirements associated with administrative autonomy. Fiscal transfers to the regions under the general allocation mechanism will further promote equity and be based on an assessment of each region's revenue-generating capacity and spending needs (GOI/IMF, 2001). Under the new fiscal decentralization framework, provincial and district administrations are expected to receive more than 61 percent of the government's total domestic revenue remaining after key expenditures (Jakarta Post, 2000a). For example, projected revenue for fiscal year 2001 was 230 trillion Rupiah ($US 25.5 billion). Of that amount, 79 trillion was marked for servicing domestic and foreign debt, while 39 trillion was directed at fuel and energy subsidies. Of the remaining 112 trillion, 69 trillion was to be allocated to provincial and district administrations, with the remaining 43 trillion to be retained by the central government (Jakarta Post, 2000a).

Emergent opportunities from and diverse challenges of the regional autonomy and fiscal decentralization process are many. As Islam (1999) points out, the extent to which the decentralization process is simply a response to fiscal difficulties at central levels and a cynical attempt to off-load responsibility remains to be determined. As well, the focus on districts rather than provinces may make it easier for the central government to maintain authority -

controlling a large number of relatively small and inexperienced districts is politically less challenging than controlling a few stronger and more organized provinces (Islam, 1999). More importantly, natural resource and property rights are still largely controlled by the central government, despite the core principles embedded within Law 22/1999. Moreover, the bureaucratic elite at local and district scales are still able to capture local development agendas and are often less sensitive to local poverty issues than higher level administrative personnel, in the absence of a strong over-sight authority. As Islam (1999:13) noted, district officials are neither more competent nor less corrupt than their counterparts in upper levels of government. Also, while the desire for autonomy and greater decision-making power at local to regional levels is significant, autonomy efforts in Indonesia have for the most part been a central government led initiative. Limited consultation has occurred with local, district or provincial stakeholders regarding their concerns and aspirations, and as a result, the decentralization initiative may not be adequately adjusted to local realities.

Finally, the decentralization discourse has revolved around formally sanctioned organizational and institutional bodies - particularly at local levels (see GTZ, 1997). As elsewhere, standardized policies, programs and procedures generated by central administrative bodies have an important role to play in promoting effective, efficient and flexible governance. However, in the Indonesian context, central dictates are often applied in a manner that limits the local initiative and innovation that is central to social learning and adaptive management. Nevertheless, despite the challenges, the autonomy process could be a crucial restructuring element that promotes equitable decision making. It may provide an opportunity for local communities to reinvigorate and reestablish control over local territories and their natural resources.

8.3 Strengthening Local Institutions: Emerging Opportunities for Adaptive Management at Local Scales

Decentralization theory posits that empowered local governments and communities are more likely to make better decisions about issues that affect local livelihoods (e.g., natural resource use) (Ingham and Kalam, 1992; World Bank, 1995; Crook and Manor, 1998; Manor, 1999). Such theory is premised on notions that the devolution of decision-making power and authority to autonomous local levels (e.g., districts or traditional village arrangements) will improve local government performance (World Bank, 1995; Crook and Manor, 1998; Islam, 1999; Manor, 1999). Key outputs of the regional autonomy process in Indonesia are thus expected to include: (i) the generation of adequate revenue to fulfil statutory obligations; (ii) more efficient use of public resources; and (iii) the promotion of democratic values (Islam, 1999). These outputs of decentralization play an important role in the pursuit of poverty alleviation, sustainable natural resource management and economic development (Crook and Manor, 1998). However, while most analyses seek to measure the success of decentralization (Olowu and Smoke, 1992; Ingham and Kalam, 1993; Crook and Manor, 1998), there is much less information on the actual structural arrangements that facilitate administrative performance (Ferrazi and Rohdewohld, 1999). This is due in large part to the highly contextual nature of local systems and their administrative requirements (i.e., what works in one area may not work in another) (see Ferrazi and Rohdewohld, 1999). However, as Ferrazi and Rohdewohld (1999) do indicate, the decentralization literature does acknowledge a clear need to introduce and test innovative institutional and organizational structures that promote efficiency and effectiveness in the delivery of basic services and which promote local development that is sustainable. As highlighted in previous chapters, adaptive management and effective conservation practice require flexible organizational and institutional frameworks that: (i) are receptive to inherent uncertainty and surprise associated with social-ecological system dynamics at multiple scales;

(ii) incorporate indigenous knowledge and management practices; and (iii) promote collaborative social learning among a broad range of stakeholders.

> *Successful decentralization must recognize the diversity and heterogeneity of the local government universe and allow for an equally diverse and heterogeneous set of responses to particular decentralization initiatives... (Bird in GTZ, 1997:4).*

Although village-level autonomy (*otonomi asli*) was recognized in Law 5/1979, rigid centralization of state administrative apparatus limited autonomous decision making at local levels. In response, traditional village societies have incrementally yielded control of virtually all decision-making functions (with the exception of traditional ceremonial activities) to formal government structures at local and district levels (GTZ, 1997). In the current political and legal climate, however, there is a clear opportunity to explore the extent to which local autonomous units (i.e., villages or collections of villages) can build and/or recapture their traditional legitimacy and social learning potential to promote sustainable community development. While there is significant concern with the extent to which traditional decision-making apparatus is still available for community development and natural resource management (see GTZ, 1997), according to participants of workshops held in Banawa and Marawola, there is a widespread interest and desire in reorienting community planning, management and development around traditional regulations and traditions. Local individuals and community members firmly believe that customary laws, regulations and sanctions must play a central role in village development. Although workshops held in the region suggest traditional regulations are at present weak, workshop participants in the Banawa-Marawola region believe they still offer a more suitable basis for decision making.

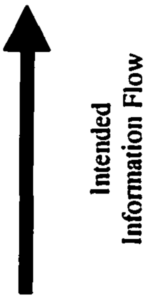
Traditional regulations and knowledge have faltered under the Indonesian system of governance. Presently, most decisions in the village or for the village are made with limited consultation, input or advice from customary community leaders. Even in their currently "degraded" form, however, customary practices have much to offer, including a locally-recognized, and therefore, potentially more legitimate basis for resource management, protection and sanction. Beyond issues of environmental protection, traditional leaders and institutions should be key participants in local decision-making processes, and at a minimum, be integrated with formal governmental structures (e.g., village head, LKMD, LMD). Yet the question remains: will the decision outcomes around village development initiatives be qualitatively better if traditional institutions and decision-making processes play a more significant role? No clear response to this challenge is yet forthcoming, but it seems the key is not that customary institutions and decision-making processes will necessarily provide "better" ideas, insights or decisions (although they certainly may), but that the level of accountability will be greater and local stakeholders much more confident that they can effect a positive outcome. In this regard, it is important to disavow any assumptions about altruistic traditional leaders, or that traditional institutions are inherently a source of ecologically sustainable knowledge and practice (see Chapter 9). However, there is an apparent opportunity for more effective decision making at local scales when customary leaders, institutions and practices are brought to bear.

Legitimization of an autonomy process oriented around customary concepts and principles still requires that government bodies at local levels provide certain functions and services in support of sustainable communities. While the manner in which this can be achieved is an issue better left to public administration specialists, many possible institutional and organizational arrangements can be forged among autonomous village units, higher government levels (sub-districts, districts), civil society organizations (e.g., NGO's) and conceivably the private sector, that are relevant to local communities (GTZ, 1997) (see Chapter 9). Building flexible institutional arrangements of this sort is particularly applicable with respect to issues of natural resource management given the high number of stakeholders involved, the importance of formal and informal institutions and their associated knowledge, and the links between natural resources and sustainable community development. Fundamental to this, however, is the need for local communities to possess a sense of ownership and connection to resources and their landscapes through appropriate property rights regimes (e.g., based on traditional regulations, customs and sanctions) that are more suited to fostering sustainable resource management and encouraging social learning (see Chapter 8).

The formal organizational and institutional framework at local levels in Indonesia has historically not adequately reflected this requirement. There have been three main administrative bodies at the village level: the village head (*kepala desa*), the *Lembaga Musyawarah Desa* (LMD), and the *Lembaga Kemasyarakatkan Musyawarah Desa* (LKMD)[45]. The LMD is only an advisory body under the village head, consisting of individuals from the community selected by the village head, and approved by the District Head (*Bupati*). Although the LMD must be consulted prior to the development of village regulations and final decisions, in practice the village head may often decide matters without their advice or approval. Likewise, the LKMD is expected to function as an elected and representative village body involved in all decision making and implementation activities that effect the village. However, the LKMD has no official capacity to pass regulations or sanction the village head, and it is not part of the official village government. In practice the LMD and LKMD are often not distinguishable, individuals on one may sit on the other, and both are incapable of providing the appropriate checks and balances necessary to maintain accountability at local levels (GTZ, 1997). Consequently, the institutional and organizational framework for development planning (Table 8.2) has proven largely ineffective as a basis for integrated development or adaptive decision making such as that required when critical natural resources are at stake (although it has occasionally worked for physical developments such as roads, schools, etc.; see Ferrazi et al., 1993). A complete set of potential interests at the community and village level is not brought together to set key development priorities.

Table 8.2: Development Planning Process

Provincial Development Priority Setting Meeting (*Rakorbang Propinsi*)
District Development Priority Setting Meeting (*Rakorbang Kabupaten)*
Sub-District Development Priority Setting Meeting (*Lokaharya Kecamatan*)
Village Development Priority Setting Meeting (*Musyawarah Pembangunan Desa*)
Community (*Masyarakat*)



However, in the context of Law 22/1999, positive institutional and organizational change may be possible and support emergent opportunities for the development of autonomous village organization. In particular, Article 93 of Law 22/1999 (GOI, 1999a) stipulates that:

> *Villages may be formed, eradicated and amalgamated by taking into account the initiatives of the people with the approval of the regency government and the DPRD* [provincial legislative council].

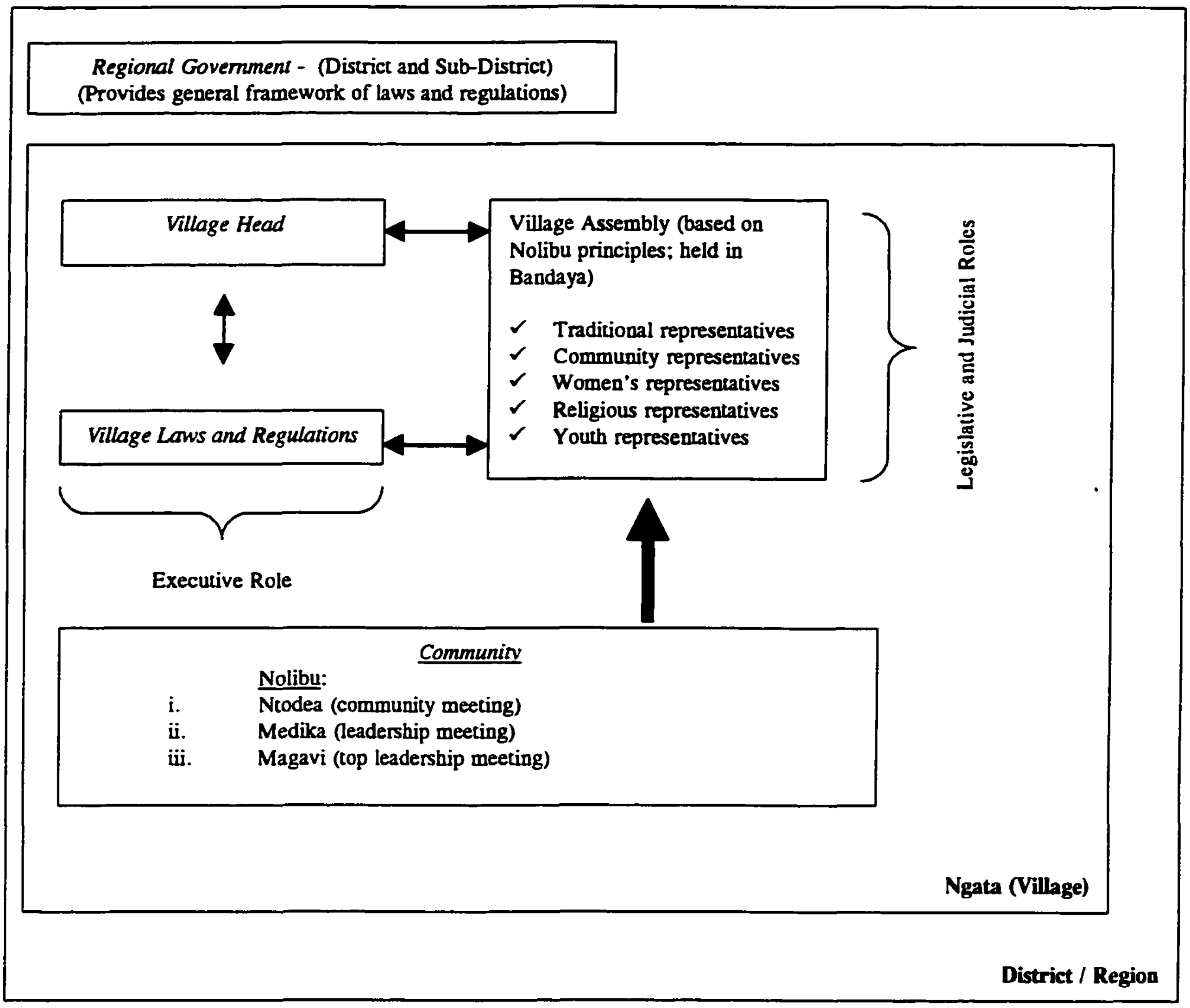
Elucidation of this point in law (GOI, 1999b) clarifies that the term used to describe the village or rural area shall be adapted to the socio-cultural conditions of local people (e.g., "*ngata*" in the Banawa-Marawola area). This point is further supported by Article 104 and Article 106 which strengthen the status given traditional or customary local control by replacing the LMD and LKMD with a "Rural Representatives Board" which can be organized according to traditional customs (e.g., "*nolibu*" in the Banawa-Marawola region; see Chapter 9):

> ***Article 104:** Rural Representative Boards have the function to protect customs and traditions, to make village regulations, to receive and channel community aspirations, as well as to conduct supervision over the organization of village governance.*
>
> ***Article 106:** Other institutions may be established in the village in accordance with village requirements and shall be stipulated with village regulations.*

These points in law provide ample latitude for the formation of new, innovative and legitimate organizational frameworks based on traditional customs and spatial entities built around traditional socio-cultural territories (see Chapter 9). Indeed, within the context of Law 22/1999, the village head is no longer responsible to the Sub-District Head (*Camat*), but to the people through the village assembly or Rural Representatives Board established by local communities according to their socio-cultural practices and desires. Under Article 100 of Law 22/1999, villages have the power to reject any duties or responsibilities assigned to them by the central, provincial or district governments that are unaccompanied by adequate financial support, facilities or the infrastructure necessary for the task (GOI, 1999a). Likewise, Article 105(3) and (4) clarify that village regulations need not be legalized by district authorities, but only submitted to the district within two weeks of their stipulation, with a carbon copy sent to the Camat (GOI, 1999a). Unfortunately, as Hassanudin University sociologist, Selo Soemardjan, has pointed out, most people, including key government officials at provincial and district levels, remain poorly informed about the implications of the regional autonomy law (Jakarta Post, 2000a). According to Soemardjan (Jakarta Post, 2000a), "...many people are unaware that the law acknowledges the traditional administration of villages".

An idealized institutional framework for local administration based on the results of discussions with individuals in the Banawa-Marawola region, and consistent with opportunities provided under Law 22/1999, is provided in Figure 8.1.

Figure 8.1: Institutional and Organizational Framework for Autonomous Traditional Villages



The schematic diagram illustrates the potential roles of different institutional and organizational units, situated within an traditional decision-making and process framework, yet connected to formalized administrative frameworks at district and provincial levels. Importance should be attributed not so much to the institutional and organizational structure as to the inherent process aspects of the framework. The delineation of the village as "*ngata*", the strengthened role of the village assembly, the use of the traditional decision-making process (*nolibu*) to determine representation of the village assembly, the role of *nolibu* in discussing and debating issues within the community prior to decisions being made at the village assembly, and the use of a traditional place (*bandaya*) when holding *nolibu*, provide a strong institutional and organizational basis for flexible, adaptive planning and management at local scales. The terminology is local, the choices made are local, the processes used to make those choices are local, the regulations, decisions and sanctions developed are local, and ultimately, control and accountability are local.

Several issues must be addressed in the context of this reconfigured institutional and organizational framework. For example, in more heterogeneous areas of the coast in Banawa, flexibility in the scope and nature of traditional regulations that could be adopted is necessary. The influx of different groups necessitates that the adoption of specific regulations, procedures and organizational frameworks would need to be negotiated. A return to traditions of any group that claim territorial rights to the land base is not likely to be politically tenable. As well, village or even quasi-territorial traditional organizations (see Chapter 9) are not prepared to perform the service delivery functions required of local and district government agencies. There is a significant imbalance between required functions and current capacities. It is important to keep a pragmatic eye towards the realities of village life in the rural areas of Banawa and Marawola where some villages have established organizational structures and have populations in the thousands, while other villages are primarily spatial entities with low populations, few organizational arrangements and little connection to higher governmental levels. The need for capacity building is paramount - not only at village levels, but at sub-district, district and provincial levels as well, in order to ensure that processes of negotiation, collaboration and conflict resolution are appropriately employed.

On-going confusion around the broader legal framework in Indonesia will further complicate local management attempts (see Chapter 9). There is a separate legal framework for agricultural lands and for forested lands. The agrarian framework administered through the National Land Management Agency has no legal basis for acknowledging traditional or customary rights - only those rights associated with private lands and state lands (Mink, S., pers. comm., 2000). Although use rights for traditional communities on agrarian land are suggested in the regulatory framework, it is at the discretion of local governments (districts and provinces) to determine if a particular community qualifies as traditional. As this is unlikely to be accomplished, the Land Management Agency is content to sit back and wait (Mink, S., pers. comm., 2000). In contrast, the Ministry of Forestry has been more involved in experimenting with traditional rights. However, as Li (2001) points out, the focus of the experimentation is on granting customary use rights on State lands, rather than recognizing traditional land rights. Given that much of the land classified as "forested" is actually under agricultural use (e.g., estate crops or communal farming land), merging these legal frameworks is an important issue. This process was partially initiated in 2000 with the merging of the forestry and land management agencies under one Ministry. However, while there may now be one Ministry, there are still two distinct bureaucracies protecting their own interests and jurisdictional mandates (Mink, S., pers. comm., 2000). Law 22/1999 could provide for a more unified approach to land management, although no government body is expressly responsible for integrated land policy and as a result, little is being done (Mink, S. pers. comm., 2000). Finally, despite efforts to promote bottom-up, participatory planning in Sulawesi[46], the move towards greater traditional autonomy at local levels will conflict with a long history of centralized and bureaucratic regional development planning (Ferrazi et al., 1993; Mitchell, 1994).

8.4 Contextualizing Adaptive Management: Traditional Knowledge, Dynamic Institutions and Social Learning

The conditions in which adaptive management can be applied in Central Sulawesi are difficult and constantly evolving. Core challenges such as financial and technical capacity constraints, worldviews of decision makers, and power imbalances among formal government agencies, for example, are further nested within a process of dramatic administrative change associated with the ongoing process of regional autonomy and fiscal decentralization. In isolation, formal administrative bodies appear inadequately prepared to promote and/or guide the science and politics of either active or passive adaptive planning and management. Consequently, it is a challenge for current administrations to use the regional autonomy and fiscal decentralization framework in a creative manner, and to build new opportunities to reconnect with traditional autonomous villages and knowledge frameworks to provide a contextually relevant basis for learning and innovation. There is significant potential for adaptive planning and management in traditional societies that have been neglected to date (Berkes, 1999; Berkes et al., 2000; Ford and Martinez, 2000). For example, the potential of traditional institutions in facilitating social learning appears significant and to limit the role of traditional knowledge and practice to one of ceremony will undermine opportunities to develop the practices and creative solutions fundamental to designing for sustainability. Although traditional rural institutions have proven sufficiently durable and dynamic to survive the decades of modernizing development, the extent to which they can continue to survive without adequate political and legal support is increasingly questioned (GTZ, 1997). As a key position paper on decentralization in Indonesia concluded:

> *As traditional organizations have often proven to be successful in handling [their] own affairs of the community, more efforts should be made to identify and recognize the present structures of these traditional institutions which can contribute to development while maintaining the core values of society in a dynamic setting. Stimulation of partnerships between local government and traditional society should be further considered (GTZ, 1997:46).*

9.0 TRADITIONAL RESOURCE USE STRATEGIES AND ADAPTIVE ECOSYSTEM MANAGEMENT

Political uncertainty, institutional capacity limitations, financial constraints, existing power relationships and limiting worldviews have been identified as impediments to the adoption of an adaptive management approach within Central Sulawesi's formal planning and resource management bureaucracy. However, recent changes in Indonesia's legal framework (i.e., the regional autonomy law) and the mainstreaming of local knowledge and resource management systems in conservation practice suggest opportunities to enhance adaptive management theory and application. As the analysis in Chapters 6 and 7 illustrated, for example, local resource users possess a detailed understanding of the indeterminant nature of ecosystem dynamics across scales (e.g., farm plot to landscape), and have correspondingly fashioned adaptive strategies and responses to address inherent system uncertainty (e.g., the practice of *ombo* as outlined in Chapter 6). Locally-evolved resource management systems often illustrate adaptive management principles (Berkes, 1999; Berkes et al., 2000; Fernandez-Gimenez, 2000; Olsson and Folke, 2001): a focus on learning, innovation and flexibility, recognition of inherent uncertainty in social-ecological systems, and a non-deterministic worldview. Adaptation and innovation at local scales, however, are typically facilitated by a learning-by-doing approach based on experiential knowledge, rather than knowledge gained through structured experimentation (Berkes and Folke, 1998; Berkes et al., 1999; Olsson and Folke, 2001). Despite compelling evidence of similarities to adaptive management, local knowledge systems and resource management practices have still not adequately contributed to the theory and application of passive or active forms of adaptive management (Olsson and Folke, 2001).

In this chapter, local knowledge systems and related management practices in the Banawa-Marawola region of Central Sulawesi that could support an adaptive approach to decision making are analyzed. This involves: (i) clarification of the meaning of "traditional" people and local knowledge with reference to the Indonesian context and the implications for conservation science and practice; (ii) an identification and assessment of the local knowledge framework and resource management practices still utilized by many individuals and communities in the Banawa-Marawola region; and (iii) an exploration of an emerging institutional and organizational framework in the study area that provides much needed context for an adaptive management approach. Conclusions are then drawn regarding opportunities for an adaptive approach to conservation science and practice in the Banawa-Marawola region of Central Sulawesi.

9.1 Conservation, Subsistence and Traditional Resource Use in Central Sulawesi

In Central Sulawesi, as in many parts of Indonesia, traditional or "indigenous" communities of people continue to practice locally-evolved resource management strategies, while maintaining a relatively distinct socio-cultural identity. These groups are often linked to historical socio-cultural and resource management practices, institutions and organizations, local rules and regulations collectively labeled as "*adat*", and pejoratively referred to in "mainstream" or urban Indonesian society as *masyarakat terasing* (see Chapter 8). A*dat*, therefore, is generally portrayed as customary law developed and utilized by members of Indonesia's sub-ethnic or indigenous groups who are thus more appropriately termed *masyarakat adat* (traditional communities) (Lowe, 2000; Li, 2001). In Indonesia, however, definitions surrounding traditional and/or indigenous communities are politically charged. For example, a prominent indigenous and human rights group, the *Aliansi Masyarakat Adat Nusuntara*, defines indigenous people as "communities which have ancestral lands in certain geographic locations and their own value systems, ideologies, economies, politics, culture and societies in their respective homelands" (see Li, 2001). This broad definition, however, applies to many groups in Indonesia, including the Da'a, Unde and other "original" people of the Banawa-Marawola region. In contrast, the Government of Indonesia has long maintained that Indonesia has no indigenous people, but simply communities that have been isolated or alienated from broader Indonesian society (Li, 2001).

The definition of *adat* likewise generates definitional and conceptual challenges in terms of the legal, institutional, social and ecological dimensions of Indonesian society. For example, as Peluso (1995) noted, *adat* rules and forms of regulation have been interpreted, written and rewritten by Dutch scholars, anthropologists, or government officials trying to standardize and homogenize the variations of *adat* practice among the country's diverse ethnic groups (Peluso, 1995:399). In the Banawa-Marawola region, a local effort to document traditional laws, customs and practices is underway and has been promoted by a local NGO (*Yayasan Pendidikan Rakyat*). The leaders of the Da'a community (both formal and informal) are seeking to collate and document all *adat* rules, regulations and practices in order to strengthen local attempts at socio-political development in the context of recent political events (see Chapter 8). Many challenges are associated with the documentation and description of local rules and regulations because of the local variations in practices within the Da'a community itself, as well as across other related sub-ethnic groups of the Kaili (e.g., Unde and Ledo). Moreover, there is a concern that documentation of traditional rules and regulations tends to "freeze" *adat* customs and knowledge; many writers, therefore, have outlined a concern about the effects of documenting and codifying customary law (Lev in Peluso, 1995; Holleman in Peluso, 1995).

The lack of clarity surrounding definitions of "*adat*" and "masyarakat *adat*" notwithstanding, Indonesian law requires that the extensive systems of customary law and practice (roughly *hukum adat*) be recognized by administrative bodies, although this is rarely the case in practice. As one legal analyst suggested, for example, the Basic Agrarian Law (No. 5/1960) provides the right for *adat* communities to utilize natural resources (B. Nongtji, pers. comm., 2000). However, Article 2.8.4 of the law stipulates that such use is acceptable provided it does not conflict with the national interest, offering a convenient loophole for governments to maintain resource control (B. Nongtji, pers. comm., 2000). In fact, this law was developed to address the ambiguity of legal entitlement under Dutch colonial law and sought to replace the dual system of *adat* and statutory law by providing full legal rights to all citizens of Indonesia. According to the Agrarian Law, all land was to be officially registered in order to clarify ownership status and confer clear legal rights under a single, country-wide property rights framework (Peluso, 1995). The law has had limited effect, however, given the scope such a registration process would entail in a country such as Indonesia. Likewise, the term "desa" (village) was originally defined in the Village Development Law (No. 5/1979) as an amalgamation of united *adat* communities, although the intent of this law was never fully implemented due to political interests, and the inflexibility and centralized nature of Indonesia's post-colonial bureaucratic system (B. Nongtji, pers. comm., 2000). Finally, *adat* territories are recognized by forest and development planners as overlapping forest territories and resources under state control, although there are rarely supporting documents lending official weight to these claims. For example, the original Basic Forestry Law (No. 5/1967) to a certain extent supported the rights of indigenous people to traditional lands and resources, except where in conflict with the "national interest" (in Peluso, 1995:392). Again, the ambiguity inherent in the law effectively means that any national development initiatives in the public interest (e.g., forest concessions, parks and protected areas, mining developments, etc.) can proceed despite *adat* claims to lands and resources.

In the context of the political vacuum created by the fall of Soeharto's government in 1998, and the more recent politicization of traditional rights (see Li, 2001), the intent of Indonesia's evolving legal framework provides ample scope for debate. For example, at two meetings of local traditional or indigenous people in Dombu (Marawola) in 2000, the existing legal framework was a primary focal point of contention and a central component of all discussions. The ultimately exclusionary criteria used to define *masyarakat adat* in the revised Basic Forestry Law have done little to facilitate clarity and foster consensus. According to the revised Forestry Law (1999), to qualify for traditional rights to lands and resources, communities must possess (Li, 2001): (i) clear social organization; (ii) formally recognized *adat* authority; (iii) a clearly defined *adat* territory; (iv) customary laws which are obeyed; and (v) a subsistence need to collect forest products in adjacent forests. Such ambiguity situates uncomfortably with the intent of the regional autonomy law (see Chapter 8) and the unification of Indonesia's legal framework (i.e., those that influence the management of natural resources and the rights of traditional communities) and is, therefore, an important challenge for Indonesia's policy makers.

Despite the inherent legal challenges and contradictions described above, compelling evidence suggests that locally evolved knowledge systems and resource management practices can help to advance conservation science and practice, and foster innovative management approaches (Berkes and Folke, 1998; Ford and Martinez, 2000; Olsson and Folke, 2001). For example, communities in Banawa and Marawola have generated a cumulative framework of ecological knowledge that has evolved, and continues to evolve, through a process of adaptation and learning. Knowledge of the intricate relationships between people and their ecological context has traversed generations and geographies through a process of cultural transmission. However, the application of local knowledge systems and resource management practices for adaptive conservation science and practice necessitates an evaluation of the rationale for their evolution and use. As Smith and Wishnie (2000) point out, it is important to determine if the local practices and strategies are purposive in their conservation intent or if they provide opportunities for sustainable resource management due to corollary, unintended reasons. Although the extent to which traditional, subsistence-based communities purposively conserve species and ecosystems (or even create biodiversity), and maintain an inherent conservation ethic is an ongoing debate (see Smith and Wishnie, 2000), there is a tendency to elevate *adat* in Indonesia as the framework of institutions, practices and rules used to sustainably manage natural resources at local scales prior to the emergence of a multi-national forest industry, market-oriented estate crop plantations, direct foreign investment, and the New Order economic era (Peluso, 1995:399; see also Li, 1999, 2001).

Such views of traditional communities, however, are derived from ahistorical generalizations of traditional societies in harmonious equilibrium with their ecological contexts (Li, 1999; Scoones, 1999; Smith and Wishnie, 2000). They are thus based on perceptions of *adat* institutions and traditional societies as previously stable through time (i.e., unconnected or influenced by processes of State formation and market forces) and representative of an idealized form of social organization and environmental practice (Fairhead and Leach, 1995; Li, 1999; Smith and Wishnie, 2000). Prescriptions for conservation policy and practice (i.e., a simple return to *adat* customs, decentralization, etc.) derived from such perceptions are hinged on idealized and/or outdated notions, and are likely to prove as ineffective as those policy prescriptions that fail to recognize local roles and practices. Traditional and/or rural agrarian societies are increasingly recognized as having played a historically significant role in shaping their environments (Fairhead and Leach, 1995; Scoones, 1999; Bassett and Koli Bi, 2000; Fernandez-Armesto, 2000). A renewed emphasis on critiques of nature-society interactions, local adaptation and the implications for conservation is thus required (Smith and Wishnie, 2000). In Central Sulawesi, the shaping of local environments can be linked to historical economic, political and institutional influences from regional and national scales. For example, the combined effects of centralized, autocratic governance at regional and national scales, as well as the historical connections with external market forces (e.g., upland-lowland, inter-regional trade) (Li, 1999; Henley, 2000), can significantly influence traditional resource management practices (Smith and Wishnie, 2000). While *adat* customs may provide locally relevant resource management traditions and forms of social organization, they are dynamic institutions that have evolved, and are continuing to evolve, in response to internal and external forces, including changes in internal demographics, the penetration of markets, and other political and economic influences (Peluso, 1995; Li, 1999; Li, 2001).

Under such conditions, the capacity of locally-evolved resource management systems to provide a basis for adaptive conservation science and practice is not linked to the historical coexistence of traditional societies and ecosystem function. As Smith and Wishnie (2000) argue, to suggest that purposive conservation is commensurate with sustainable use achieved through low population density, limited technology or restrained resource demands is a "causal misattribution". Similarly, the existence of holistic worldviews and beliefs regarding society and nature do not themselves suggest deliberate conservation practice. Rather, traditional practices and institutions that seek to intentionally conserve resources must: (i) prevent and/or mitigate the loss or degradation of species, habitats and valued ecological components; and (ii) be designed to do so (Smith and Wishnie, 2000:501). As Little (in Smith and Wishnie, 2000:516) concludes, "...cases in which local communities in low-income regions manage their resources with the prime objective of conservation - rather than improved social and economic welfare - are virtually non-existent".

Differentiating between purposive conservation and complementary sustainability, therefore, facilitates a more nuanced and realistic analysis of the applicability of locally-evolved resource management systems and socio-cultural institutions in the Banawa-Marawola region as a basis for adaptive conservation planning and management. Without recognition of the presence or absence of purposive conservation, descriptions and analyses of local resource management strategies and institutions in the Banawa-Marawola region are at risk of becoming ideologically biased, overly functionalist and/or adaptationist (i.e., traditional communities and their practices are simply a function or adaptation to their environments). At the same time, whether purposive in their conservation intent or not, local knowledge systems and resource management practices offer a potentially valuable framework for adaptive approaches as they are locally relevant, culturally internalized and respected by local communities. It simply needs to be pointed out that they are not likely to emerge from "harmonious" or "balanced" nature-society relationships unconnected to external political processes or market forces, nor are the practices simply functional responses to environmental conditions unconnected to human agency (Scoones, 1999; Smith and Wishnie, 2000).

9.2 Local Knowledge, Socio-Cultural Institutions and Adaptive Ecosystem Management

An integrated local knowledge framework and suite of resource management practices have been identified in the Banawa-Marawola region that provide the basis for innovative conservation science and practice anchored on principles of adaptive management (see below). However, a few caveats associated with the development of this framework require elaboration. First, the daily practices, customs and procedures outlined below are not a local expression;

rather they are simply a way of organizing local knowledge, practices, rules and institutions that govern patterns of life among local communities. Certainly, there is local recognition of "*adat*" as a set of norms and customs that should play a central role within communities. However, local expression of these *adat* customs and practices as an explicit framework is unlikely. Second, the framework should not be considered static. Practices, processes and cultural expressions have evolved and will continue to evolve in response to external and internal influences. A description of the framework (Figure 9.1) is provided below and organized according to: (i) resource management practices for dynamic systems; (ii) processes for social learning and innovation; (iii) social mechanisms for conservation and resource management; and (iv) mechanisms for cultural internalization.

9.2.1 Resource Management Practices for Dynamic Systems

Local knowledge systems and management strategies in Banawa-Marawola have historically contributed to the maintenance of ecological resilience. For example, *olo* and *ombo* are locally-evolved environmental protection regulations and strategies based on traditional system knowledge. Under an *olo* classification, specific areas, habitats, resources or species are protected from harvesting and extraction over the long term. Examples of areas or resources classified as *olo* by local people include large trees (typically *Ficus* spp.[47]) that may possess spirits, sites suitable for harvesting of honey, areas of steep slopes (e.g., Bambakeanu in Marawola), and important water catchment areas (e.g., *Gunung Payu* (Umbrella mountain) in Salumpaku, Banawa). The avoidance of use of certain resources or habitats suggests a form of conservation akin to the development of environmental regulations in conventional resource management practice (Berkes et al., 2000; Smith and Wishnie, 2000).

Table 9.1: Knowledge-Centred Adat Framework for Adaptive Management, Banawa-Marawola Region

SELECTED ADAT PRACTICES, PROCEDURES AND MECHANISMS	KEY IMPLICATIONS AND APPLICATION
RESOURCE MANAGEMENT PRACTICES AND REGULATIONS: *(a) Olo*: long-term restriction and/or protection of resource, habitat, species or place *(b) Ombo*: temporal or seasonal restriction on resource, habitat, species or place *(c) Ova / Panggale*: fallow lands and forested areas maintained in successional process through selective use and resource rotation system *(d) Mompepoyo*: multi-factor soil fertility assessment and land use decision system in uncertain environments *(e) Mantulu/metovo, mompovai, metunju*: key processes utilized in the agroecological system in upland areas that employ clearing, drying, and fire to create conditions for cultivation	**PRACTICES ASSOCIATED WITH THE DYNAMICS OF COMPLEX SOCIOBIOPHYSICAL SYSTEMS:** (i) protection of specific habitats / resources (e.g., water sources, large trees (e.g., Ficus spp.), etc.) and ensuring sources of ecosystem renewal (ii) temporal restrictions on harvesting (harvesting during vulnerable stages in the life cycle of certain species (e.g., *Chanos chanos*)). (iii) rotation of resource harvesting and land use impacts across landscape (e.g., swidden system with micro and macro-rotational patterns) (iv) multiple species management that facilitates the maintenance of ecosystem structure and function (v) responding to and managing pulses and surprises through resource rotation practice and use of fallow lands in non-determinate fashion (vi) managing ecological processes at multiple spatial and temporal scales (rice and corn at 1-2 year cycle at cultivated plot scale; taro and banana at 2-10 year cycle in fallow lands; trees and forests at cycles of 10 years and more across the landscape) (vii) management of succession and landscape patchiness (cultivated plots, regenerating fallow lands, secondary forest)
PROCEDURAL, PLANNING AND DECISION-MAKING PROCESSES: *(a) Nolibu*: traditional decision-making process utilized in the region *Ntodea*: community meeting *Medika*: leadership meeting *Magavi*: top leadership meeting *(b) Mosi pengawa*: community-based mutual assistance process and mechanism for information dissemination / learning	***PROCESSES THAT FOSTER SOCIAL LEARNING AND INNOVATION:*** (i) continuation and renewal of local knowledge systems (ii) transmission of folklore and knowledge (iii) vehicle for intergenerational transmission of knowledge (iv) geographical diffusion of knowledge (v) use of consensus-based, collaborative decision-making process (i) (vi) resolution of conflicts and disputes

SELECTED ADAT PRACTICES, PROCEDURES AND MECHANISMS	KEY IMPLICATIONS AND APPLICATION
SANCTIONS AND TABOOS : *(a) Sala kono*: clear guilt established *(b) Sala baba*: accidental harm *(c) Sala mbivi*: lies, misstatements intended to avoid guilt *(d) Pandoli, vatu* and *vatu di air pedidi*: mechanisms/rituals for determining guilt *(e) Viyata*: spirits contained in living (trees) and non-living (mountains) entities that can create sickness if disturbed *(f) Ramaiya*: custom requiring that cultivation takes place in the ova (fallow lands)	*CRITICAL SOCIAL MECHANISMS FOR RESOURCE CONSERVATION AND MANAGEMENT:* (i) provides historical and cultural continuity (ii) (ii) local recognition of a sanctioning system that is considered more just and humane by local populations
CEREMONIES AND SOCIAL INTERACTIONS: (a) *Movae*: post-harvest ceremony (b) *Motamba*: ceremony to request assistance from spirits before and after harvest (locally applied) (c) *Motamba ridombu*: similar to *motamba* but applied to whole community and held in Dombu, the cultural centre of the Da'a (undertaken only in times of great difficulty) (d) *Momperoya*: seeds not planted are covered and placed in a hole in the centre of the ova (form of offering) (e) *Montilu*: process where older men plant first, followed by others (rationale not determined, although may show sign of respect) (f) *Mosambalu*: ceremony directed at warding off or guarding against pests and disease (g) *Montuvu*: offering of food to spirits near cultivated fields	*MECHANISMS FOR CULTURAL INTERNALIZATION:* (i) rituals and ceremonies that internalize core practices, systems and beliefs (ii) provision of cultural framework for agroecological systems (iii) (iii) opportunity to operationalize worldview (e.g., *Tanaku Indoku, Umaku Langi* - The land is my mother, my father the sky)

Source: Key informant interviews, focus group discussions, and transects completed during field work in 2000; Framework for organization of table adapted from Berkes and Folke (1998)

Decisions regarding habitats or landscape elements protected under an *olo* regulation, however, may be as much related to cultural and religious factors (e.g., concern about disease, spirits, etc.) as a concern with the local protection and preservation of forest ecosystems, thus suggesting incidental conservation (see Olafson in Smith and Wishnie, 2000). The *ombo* classification likewise applies to specific areas, habitats, resources or species that are protected from harvesting and extraction but for a specific period of time. Historical and to some extent present examples of such temporal restrictions on harvesting in the region include areas of mangrove habitat in the coastal zone of Banawa, in which the harvest of milkfish or bandeng (*Chanos chanos*) has been restricted during spawning and post-spawning periods. Additionally, a temporal restriction (*ombo*) can be placed on key social functions. For example, during the post-harvest ceremony and celebration, the *adat* leader is placed under an *ombo* which limits any discussion of personal or community issues or problems for a period of up to three months. Community problems must resolve themselves during this time or wait for the *ombo* on this particular form of social interaction to end. *Ombo* and *olo* are, however, primarily examples of the prohibition on entry, harvest or exploitation in common property resource areas that are regulated through long-standing social institutions that restrict access, although it seems unlikely that the application of the *ombo* classification and harvesting restraint in this instance is explicitly crafted to conserve natural resources. Rather, the restraint on harvesting seems more likely an economic decision (e.g., maximizing economic control, maximizing returns on labour) with important conservation implications.

With *olo* and *ombo* classifications as core components, a generalized traditional zoning system can be identified in the Banawa-Marawola area (see Chapter 6), although it has not been given an explicit name. Nevertheless, the spatial demarcation of lands associated with traditional agroecological practices in the region includes areas of protection (i.e., *olo* and *ombo*), forested zones (*panggale*), areas of cultivation (*nivai*), specific sites for cultivation and fallow (*ova*), as well as settlement areas (*ngata*[48]). With the exception of the *olo* classification, this implicit spatial zoning system is dynamic and fluid. In accordance with seasons, the cyclical patterns of nature and in response to evolving ecological and social conditions, the spatial framework is modified to promote opportunities for ecosystem renewal (intended or not). Such traditional "spatial plans", however, have been undermined and/or ignored by government-led spatial planning exercises recently completed in the region (see Bappeda Kabupaten, 1999)[49]. Nevertheless, the spatial articulation of resource use zones is well suited to dynamic ecosystem conditions in Banawa-Marawola. For example, the upland farming system involves the management of individual crops (rice and corn) on a yearly basis, taro, banana and supplementary crops in early and mid-stage regenerating fallow lands, tree products in later-stage regenerating fallows, as well as standing forest. Furthermore, the swidden system of the Da'a results in the indirect creation and management of successional disturbance across the landscape (see Chapter 7). While crops are growing on one site, regenerating forest on fallow lands is creating conditions for future cyclical patterns of renewal, providing habitat for a range of species with ecosystem renewal and productive values and re-building soil conditions. Such anthropogenic creation and management of habitat mosaics through moderate or repeated disturbance of relatively low intensity (in the portion of the uplands under study) can facilitate propagation (see Chapter 7) of species at habitat and landscape scales. Indeed, citing an example of a swidden cultivation system in the Amazon, Smith and Wishnie (2000) outline the comparison of fallow lands and mature forest: floral composition is different in the two land uses although total levels of biodiversity are approximately similar[50].

The locus of these indirect ecological influences is the resource rotation practice. The Da'a swidden system is based on principles of uncertainty and surprise, and supports a non-deterministic decision-making framework appropriate to complex sociobiophysical systems. Indeed, the practices of the Da'a in the uplands of Banawa and Marawola provide insight into the adaptive management of complex systems rarely encountered in conventional conservation or resource management programs (see Berkes et al., 2000). For example, the practice of resource rotation and use of fallow lands is inherently more suited to local ecological variability and unpredictability than any attempts to directly manipulate a range of variables. Rather than intensive and systematic attempts to overcome or manage seasonal variability and its implications for resource management, the influence of natural pulses and surprises (e.g., climate fluctuations, pest outbreaks) is moderated over time. Moreover, the micro-rotational and macro-rotational resource rotation (see Chapter 7) contributes to the management of ecological processes at a range of temporal and spatial scales. For example, certain food crops (rice, corn) are managed over yearly scales in cultivated plots, while other food crops are managed over a period of several years in early regenerating lands (e.g., taro, banana). Tree crops and other forest products may be harvested on longer cycles of 10-20 years and more as forests regenerate across the landscape. As previously discussed, the *mompepoyo* soil fertility assessment provides the primary mechanism for non-deterministic resource rotation and land use decision making within the system. The very nature of the Da'a swidden system fosters disturbance patterns across the landscape that seem to allow for both the production of food resources and opportunities for ecosystem renewal (e.g., fallow succession). The resource practices (along with the social mechanisms described below) suggest a "strategy" that responds to and manages flux across temporal and spatial scales in order to build system resilience; more specifically, as Berkes et al. (2000) suggest, the capacity to recover after disturbance, absorb stresses, internalize the stress and rise above the stress. It is important to note, however, that such subsistence decision practices are likely directed at maximizing efficiency (agricultural yield versus labour input required), rather than purposive attempts to maintain ecological integrity and promote biodiversity. While the resource rotation practice has ecological benefits, patch-switching of this type is designed not for conservation but to maximize production returns (Figure 7.1).

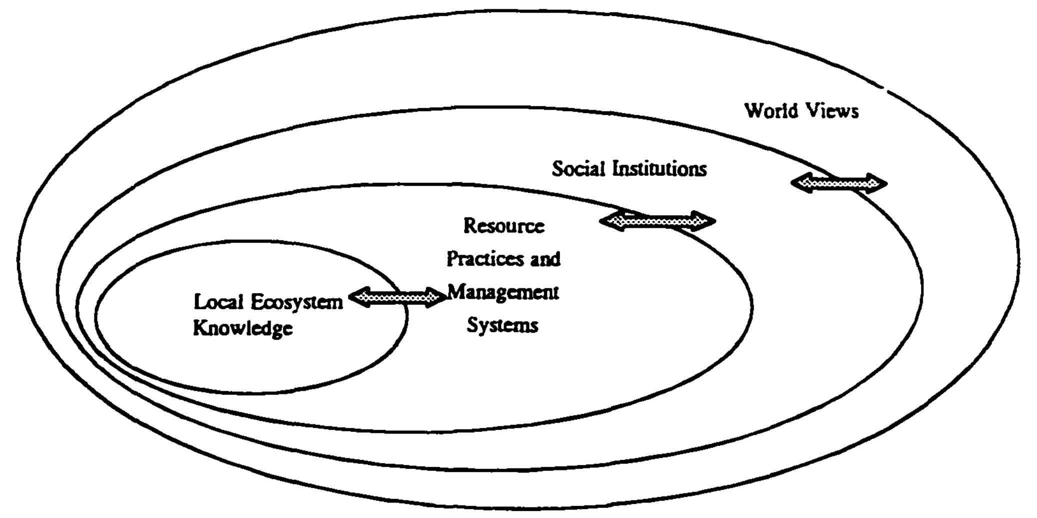
9.2.2 Processes for Social Learning and Innovation

Knowledge and system understanding must be supported by mechanisms and processes that foster learning, adaptation and innovation. In the Banawa-Marawola region, two local mechanisms or processes are of particular relevance: *Mosi pengawa* and *nolibu*. *Mosi pengawa* provides two important functions relevant to an adaptive management approach. First, *mosi pengawa* (or *Noisala pale* in the *Unde* dialect) literally means a process of mutual assistance in which the community or groups within the community work together in order to ensure the success of all members. However, this traditional process also functions as a learning system whereby knowledge and ideas are transferred among community members. For example, if any one farmer seems to be particularly successful, the variables that produce that success are more likely to be transferred to others through this mechanism. Likewise, *nolibu*, a traditional decision-making process, is perceived by individuals and communities in both coastal and upland areas as a central institution for community development. In particular, *nolibu* engenders a more open discussion of issues among community members. In the formal, structured meeting formats held in official village offices and presided over by the village head, marginalized local people are less inclined to discuss and debate issues (see also Rizal, 2001). The local elite typically set and structure agendas, and in the process, disengage the majority of local people from decision making. In contrast, *nolibu* supports procedural and decision-making processes that engender mutual learning based on local practices. Such mechanisms foster greater local accountability and thus offer local mechanisms for social learning, innovation and dispute resolution that are fundamental to effective adaptive management.

9.2.3 Social Mechanisms for Conservation and Resource Management

The resource management practices outlined above, and the knowledge of ecosystem processes upon which they are based, are embedded in often elaborate social institutions and worldviews (Figure 9.1). Such institutions consist of the formal constraints on certain activities (e.g., resource harvesting) such as rules, regulations and laws, informal constraints associated with moderation of certain behaviours, as well as their supporting enforcement mechanisms (Berkes and Folke, 1998; Berkes et al., 2000; Olsson and Folke, 2001). Successful ecosystem management necessitates that locally-evolved knowledge and understanding be linked to the institutions that govern human behaviour (Olsson and Folke, 2001). Indeed, *adat* sanctions and taboos form an important component of local knowledge-based frameworks for adaptive management in the Banawa-Marawola region (Table 9.1). In addition, certain taboos need to be respected. For example, there are community taboos against the cutting of large trees as they are perceived to house spirits (*viyata*) that will sicken people and damage crops. Animistic beliefs surrounding the different *viyata* in mountains, trees and certain areas of land provide assurance that valued resources are (or more precisely were) not removed. Species of particular significance identified by coastal and upland people include durian (*Durio zibenthinus*), beringin (*Ficus* spp.) and ebony (*Diospyros celebica*). For practical reasons as well, these same tree species are also protected by the very difficulty their removal would entail for local people equipped with machetes and other low-technololgy tools[51]. In addition, a further belief, *ramaiya*, holds that failure to plant in the ova will lead to sickness, either for individuals, families or groups. As a consequence, according to at least one informant, individuals will plant rice in ova even if they do not necessarily believe it will produce a good yield[52]. *Ramaiya* stems from the belief that rice padi is the source of life and is tied to a story of creation widely held throughout the Indonesian archipelago (see Li, 1991). However, *ramaiya* seems to have an added ecological benefit of encouraging and/or ensuring that people return to ova or fallow lands rather than opening new lands or returning to what are perceived to be the most fertile or advantageous sites.

Figure 9.1: Embedded nature of local knowledge, practices and beliefs



Source: adapted from Berkes et al, 2000:1257

Taboos are only one type of social mechanism of value to conservation and resource management. For example, in the Banawa-Marawola region, any contravention of *olo* or *ombo* regulations could result in the application of sanctions to the offending individual or group, although the diminished power of *adat* regulations in the region has undermined local sanctioning power[53]. However, the relative effectiveness of *adat* regulations vis-à-vis formal regulation is supported by their recognition and understanding within local communities and their intrinsic value in the socio-cultural framework of local communities. Three levels of sanctions or "charges" have been identified (*sala kono, sala baba* and *sala mbivi* (Table 9.1)), and the actual sentence or punishment imposed on an individual by *adat* leaders varies according to the specific contravention, as well as an individual's initial response when confronted. If individuals do not admit guilt but are later found to be guilty, the punishment is often doubled. Punishments and fines typically include repayment to the harmed party, or in the case of contraventions of *olo* and *ombo*, repayments in the form of livestock (chickens, pigs) or ceremonial plates (*dulang*). For those lacking the resources to pay fines, *adat* leaders may offer assistance - provided the individual originally admitted guilt. Local communities feel strongly that the *adat* system of regulations and sanctions is more recognizable, just and humane than the formal regulatory and sanctioning process currently in force. There is a clear preference for the strengthening and application of *hukum adat* in the Banawa-Marawola area because local individuals and communities find resonance in the historical and cultural continuity it provides.

9.2.4 Mechanisms for Cultural Internalization

Local knowledge and institutions inherent in the *adat* framework require mechanisms for cultural internalization. Such mechanisms engender the social learning central to adaptive management and the broader sustainability discourse. Several rituals, ceremonies and other traditions play a central role in this process of cultural internalization. For example, rituals such as *mompepoyo* help people to remember the intrinsic rules and how to interpret ecosystem change in accordance with broader worldviews (see Dove, 1993; Berkes et al., 2000). Ceremonial traditions (Table 9.1) such as *motamba*, *movae* and *montuvu* link nature and society, and provide avenues to internalize those core practices, systems and beliefs that guide local communities. Finally, the worldview of traditional local communities in the Banawa-Marawola region provides the broader religious and ethical context in which rituals, ceremonies and resource practices evolve. As Berkes et al., (2000:1259) note, the basic worldview of traditional societies may be characterized as the "community of beings" in which individuals and communities of people are part of an interacting milieu of living entities. In the Banawa-Marawola region, a similar worldview or cosmology has been captured in a socio-political movement (see below) to reestablish traditional values and knowledge as a basis for managing lands and resources and promoting sustainable community development. The slogan of the movement: *Tanaku Indoku, Umaku Langi* (The land is my mother, my father the sky).

It is important to point out, however, that *adat* rituals, ceremonies and practice are a phenomenon in and of history (Dove, 1993). For example, *mompepoyo* may have only developed along with the introduction of swidden-based rice cultivation, while the *ombo* protection utilized in the coastal zone has been undermined as the resource it was used to protect has been removed by external interests. Nevertheless, locally-evolved knowledge and practices in Banawa-Marawola provide both lessons of adaptation and humility in the use and management of tropical forests, as well as tools that can provide valuable insight when seeking to design pluralistic sustainability strategies. In the context of external pressure from market, political and religious agents occurring in the Banawa-Marawola region, however, the ability to retain key practices, rituals, ceremonies and worldviews has been challenged. As the loss of common property mangrove forest continues and the importance of rice swiddening in the uplands decreases (e.g., through the process of increased settlement and permanent agriculture), a consequent decline in the prominence and authority of *adat* customs and rituals should be expected[54].

9.3 Cross-Scale Conservation Politics in Banawa-Marawola: An Emerging Institutional and Organizational Framework for Adaptive Management

The knowledge-centred *adat* framework described above provides a valuable basis for adaptive management for several reasons. First, the *adat* framework described for the Banawa-Marawola region acknowledges that environmental conditions are dynamic and subject to change. A range of strategies and coping mechanisms has been developed to respond to that dynamism. Second, numerous elements within the framework emphasize resource use strategies and processes that account for and function within ecological cycles of renewal. Thus, the strategies assume that nature is unpredictable and that resource production can be controlled in only a rudimentary fashion. Third, adaptive management is fundamentally about learning, and central to the *adat* framework described above, is the transmission of knowledge and understanding at the level of individuals and larger societies. Finally, since the traditional resource practices and strategies associated with communities in the Banawa-Marawola region respond to and manage feedbacks instead of attempting to control or block them out, the management system seeks to avoid ecological thresholds at scales that threaten social and economic systems. Thus, traditional knowledge frameworks are analogous to adaptive management because they integrate uncertainty into management and emphasize practices that are oriented towards resilience (Berkes and Folke, 1998; Folke, 1999; Berkes et al., 2000).

Conservation and resource management strategies oriented towards resilience as an operational principle are often associated with (Berkes et al., 2000:1259): (i) rules and regulations that are locally crafted and enforced by local users themselves; (ii) flexible resource use, the use of rotations and other dynamic practices; (iii) a base of ecological knowledge that facilitates responses to environmental feedback; (iv) the use of diverse resources for livelihood security in order to minimize risk and maintain options; and (v) qualitative management in which feedback or ecosystem change indicates the direction in which management should move, rather than toward a quantitative target. As Lugo (in Berkes et al., 2000:1260) has argued, "...management does not require a precise capacity to predict the future, but only a qualitative capacity to devise systems that can absorb and accommodate future events". These conditions are readily identifiable in the Banawa-Marawola *adat* system. The implications for the design of conservation strategies and programs in the Banawa-Marawola region that seek to protect biodiversity, maintain ecological integrity and promote sustainability are profound. The use of the knowledge framework described above can facilitate monitoring, interpretation and responses to dynamic ecosystem processes, and provides understanding and knowledge that complements conventional resource management and conservation strategies (see Berkes et al., 2000). Having evolved through a self-organizing process of trial, error and feedback, the ecologically and socio-culturally sophisticated resource management practices and supporting social mechanisms identified in the Banawa-Marawola region, have a range of important applications relevant to reconstructed conservation science and practice

Recognizing the value of local knowledge systems and resource management practices for adaptive management is a key component of improved conservation science and practice. However, without a corresponding flexible institutional and organization framework in which to operate, local knowledge, understanding and its application are of limited utility. As Lee (1993) suggested, adaptive management is primarily about the institutional designs and practices that seek to develop a learning strategy in the face of irrational decision making, uncertainty and surprise. Likewise, Fukayama (2000) has noted that developing institutional and organizational arrangements more amenable to uncertainty and change is a significant challenge for management. In both cases, the importance of network or web-like arrangements is suggested, in which formal and non-formal (e.g., Lee's (1993) epistemic communities) interests are brought to bear on the problems at hand. Conceptualizations of organizational and institutional frameworks for adaptive ecosystem management, therefore, must include informal and culturally specific norms and practices, as well as networked social relationships (Lee, 1993; Scoones, 1999). In Central Sulawesi, the paucity of reliable formal organizations and administrative frameworks to foster social learning raises a serious impediment to adaptive ecosystem management. The propositional analysis outlined in Chapter 8 suggests a need to explore innovative institutional and organizational frameworks for conservation and sustainable resource management. In the Banawa-Marawola region, however, opportunities have emerged to link innovative organizational approaches around the nascent "*Kamalise*" movement (see below), potentially providing an entirely new geographical and socio-political basis for conservation practice. Certainly, it would appear that in the Indonesian context, evolving legal mechanisms (e.g., Law 22/1999) provide the latitude for this type of experimentation, even if the significant political will and ingenuity required for innovation have not yet coalesced.

The locus of this institutional and organizational opportunity in the Banawa-Marawola region is a socio-cultural and political movement loosely defined as the *Keluarga Besar Masyarakat Adat Da'a* (roughly translated: the large family of the traditional Da'a community) or the *Aliansi Masyarakat Adat Kamalise* (The Alliance of the Traditional Community of *Kamalise*)[55]. Briefly, *Kamalise* is a spatially-explicit traditional territory covering the upland and hill slopes of a large portion of the sub-districts of Banawa and Marawola, as well as extending into coastal regions in some areas. The vision of the traditional groups that have historically inhabited the *Kamalise* territory (Da'a, Unde and several other Kaili sub-groups) is to (R. Saleh, pers. comm., 2000):

- promote a return to *adat* laws and regulations;
- play an active role in any planning of programs to be implemented by government agencies in the region (a participatory focus is desired);
- develop improved facilities such as roads, schools, etc.; and
- rebuild capacity and strengthen *adat* institutions which are considered a critical need before the community decides future directions (i.e., facilitate a process of cultural revitalization).

According to a local advocacy NGO, *Yayasan Pendidikan Rakyat* (YPR), these aspirations provide a stark contrast to district and regional government plans for the region that include the promotion of estate crops, settlement of upland communities, and even the establishment of a tourism resort (R. Saleh, pers. comm., 2000). Efforts to operationalize the *Kamalise* movement have been catalyzed by two traditional people's conferences held in the village of Dombu (Marawola) in 2000. At one of the meetings, individuals from 57 villages and sub-villages in five sub-districts arrived in Dombu to address several specific tasks, including:

- encoding and writing down the traditional regulations, laws, practices and customs of the *Kamalise* people;
- meeting to discuss the key issues around strengthening of *adat* institutions;
- planning future activities and future developments in the community;
- seeking to change the terminology which people in urban areas use when referring to them (see Chapter 8); and
- finally, discussing the need to receive formal recognition from the Bupati (District Head) to enable a return to a more effective use of *adat* law in order to strengthen *adat* institutions

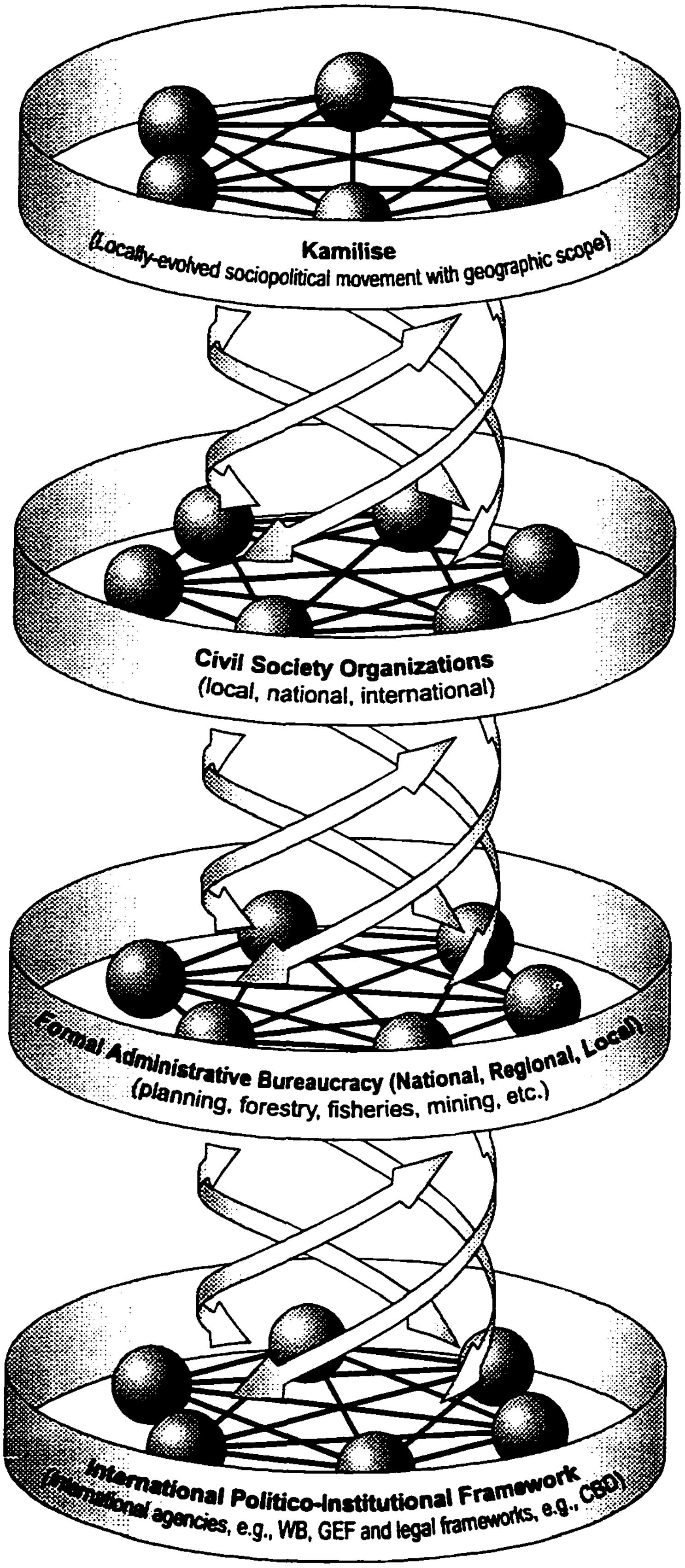
In the context of the reemergence of indigenous rights in Indonesia and the evolving legal framework, the socio-cultural, political and conservation implications of this movement deserve attention. There are a number of traditional and/or indigenous groups in Indonesia that are reasserting common property resource rights, advocating formal recognition of *adat* and demanding a greater role in the political and decision making process (Atok and Petebang, 2000; Li, 2001). Indeed, the *Kamalise* movement is an example of a networked, multi-community socio-political movement that has emerged in response to the demise of authoritarian rulers, service cutbacks and the inequitable development policies of a neoconservative economic agenda (see Peet and Watts, 1996; Zimmerer, 2000). The *Kamalise* movement provides an opportunity for innovative institutional design that can foster adaptive management and social learning. For example, participants of the two Congresses have identified the institutional challenge of upland property rights and state-control over forested ecosystems. The Forestry Department is identified as the owner of the trees, yet the local communities identify themselves closely with the forested landscapes. As representatives of the *Kamalise* movement articulated, partnerships are clearly required between formal government agencies and local communities, and there is a strong desire within the community to play a significant role in natural resource management. This desire, however, cannot simply be cast as an attempt by upland communities to protect traditional agroecosystems and subsistence modes of production. Rather, the desire is centred on renegotiating traditional power inequities created first by colonial intervention and then the subsequent decades of centralized, military-backed State control over resources experienced throughout the Indonesian archipelago (Li, 2001). As identified by several local representatives, if a forest concession or industrial plantation is desired (or any other extractive resource activity), interested external parties will need to negotiate with representatives of local communities, be prepared for significant discussion, and obtain approval from the traditional community. Such concerns are based on past experiences with government agencies that have moved groups of upland people from "protected forest", only to then grant forest concession rights to logging companies.

Changing socio-economic and institutional conditions must be accounted for in any conservation strategy - traditional groups are no longer isolated subsistence resource users (historically they rarely have been), but communities actively engaged in a process of development and change. Indeed, based on the results of discussions with individuals in the Banawa-Marawola area, there is a desire among many upland people and communities to engage more formally in settled agricultural production and ensure that their children have access to schools and medical care. However, as an increasingly politicized community, there is also a desire to manage processes of change on their own terms. Thus, the focus on rebuilding and returning to *adat* knowledge frameworks and resource management practices is not an attempt to recapture the past, but rather an attempt by upland communities to use their strong cultural heritage as a basis for renegotiating power relationships and improving livelihoods. In this regard, the *Kamalise* movement does not broker a rejection of formal government apparatus, but has an expectation that regional and district governments provide the broader institutional and organizational framework in which *adat* norms, practices and systems are sufficiently free to provide locally relevant solutions and insights into development challenges (Figure 8.1 and Figure 9.2). By necessity, a focus on organizational and institutional strengthening of the *Aliansi Masyarakat Adat Kamalise* has emerged among participants and supporting groups. Much discussion has revolved around formalizing roles (even developing job descriptions) and procedures in an attempt to create the perception of legitimacy. This has led to a discussion of leadership models supported by internal regulations including "foundation principles" (*anggaran dasar*) and "family principles" (*anggaran rumah tangga*), and presided over by a "presidium" (or board). This leadership and organizational model, however, has been introduced (in many respects by YPR) and does not differ greatly from the imposition of other external institutional models (e.g., the basic village government structure). The extent to which it "fits" with traditional decision-making processes and structures is yet to be determined.

Despite the many issues to be resolved, significantly new opportunities for the reconstruction of adaptive conservation science and practice in the Banawa-Marawola region of Central Sulawesi may emerge from the *Kamalise* movement. As illustrated in Figure 9.2, different spheres of organizational and institutional roles and responsibilities can be identified, but each is an element of an emergent framework that can foster ecological integrity and sustainable livelihoods. For example, the locally-evolved *Kamalise* movement itself provides not only a new geographical basis for conservation practice, but potentially the political basis to negotiate partnerships and power agreements, and provide the integrated vision of nature and society not likely possible through individual autonomous village units (see Chapter 8 and Figure 8.3). The focus of the *Kamalise* movement is "self-development" but achieved with coalitions of different system actors at different scales (local-local, local-regional, etc.) working towards a set of mutual goals. Public and private civil society organizations thus provide a range of roles including facilitation and direct investment, although their primary benefit is the intermediary role they can provide between formal administrative agencies and local socio-political arrangements (possibly expressed through the amalgamation of autonomous village units under the *Kamalise* movement). In the Banawa-Marawola region, civil society organizations (e.g., YPR or the Environmental Study Centre) and the *Kamalise* movement can combine to hold the State accountable for the impacts and decisions they create; they should not, however, be conceived as taking on the roles and responsibilities of the State. The formal administrative bureaucracy is still required to establish conditions (socio-political, legal, etc.) that enable self-determination and support sustainable development. Nevertheless, boundaries placed on the role of the formal administrative bureaucracy highlighted in Figure 9.2 (see also Chapter 8) are in stark contrast to the reality of governance currently experienced in the Indonesian context.

Figure 9.2

Potential Institutional and Organizational Arrangements for Conservation Practice in Banawa-Marawola, Central Sulawesi



Functional Roles and Responsibilities

- Strategic vision of nature and society
- Key decision-making capacities and strategic control of financial mechanisms to support decisions
- Knowledge-centred framework of practices and institutions
- Intra-territorial negotiation

- Intermediary role providing facilitation and assistance
- Mechanism for negotiation of outcomes between local-regional interests
- Mediator of local/traditional knowledge and formal scientific knowledge integration

- Provision of enabling conditions (e.g., clear, flexible legislation and policy)
- Maintenance of regional equity (economic and social)
- Adjudicator of cross-boundary conflicts (inter-territorial negotiation)

- Financing and leveraging of economic and human capital in support of conservation
- International norms, standards and best practices

10.0 RECONSTRUCTING CONSERVATION SCIENCE AND PRACTICE IN THE BANAWA-MARAWOLA REGION, CENTRAL SULAWESI

At the beginning of this dissertation, I argued that a growing understanding of social-ecological complexity and interconnectedness, and the frequency with which conservation practice too often leads to unexpected and unpleasant surprise for local people, require that new avenues of conservation thought and action be explored. In reassessing the science and practice of conservation, therefore, two simple questions were raised to guide this analysis: (i) how to better understand the coupled nature of complex ecological and social systems at multiple scales, and the implications for biodiversity, ecological integrity and sustainability; and (ii) how this knowledge and understanding can be most effectively utilized by a full range of stakeholders concerned with ecosystem-based management.

Several philosophical, theoretical and conceptual frameworks that may facilitate this transformation of thought and action were examined; specifically, insights, concepts and methods from complex systems, political and cultural ecology, narrative policy analysis, post-normal science and adaptive management. Subsequently, this integrative theoretical and conceptual framework was applied in a critical analysis of different nature-society interactions in two systems in the Banawa-Marawola region of Central Sulawesi, Indonesia: (i) a coastal mangrove forest / aquaculture system; and, (ii) an upland agroecological zone. Several key findings, summarized below, emerged from this analysis.

10.1 Summary of Key Findings

To better understand processes of environmental transformation and system dynamics in the coastal zone, the analysis drew on complex systems concepts such as self-organization and feedback across multiple socio-political, institutional and economic types and scales of influence, linked to political ecology interpretations of resource access and control. The dramatic loss of mangrove forest in the coastal zone of Banawa over the past 15 years was found to be embedded in a multi-factor autocatalytic process consisting of: (i) demands for foreign exchange; (ii) requirements for domestic protein; (iii) flawed bureaucracies; (iv) unclear legal frameworks; (v) ethnic division with economic externalities; and, (vi) State-sanctioned and sponsored ideology supportive of a development narrative predicated on the privatization of property rights, economic development and resource use intensification, and the devaluation of traditional mangrove common property resource systems. All of these factors coalesce to undermine local property rights and traditional resource management regimes, and facilitate mangrove forest conversion. As a result, the issue is not simply one of formulating, enforcing and monitoring regulations that guard against mangrove forest conversion. Rather, there is a need to formulate, propose, implement and monitor strategies that fundamentally challenge entrenched economic interests and power relationships: reclaiming land currently used for aquaculture, restoring mangrove ecosystems, and returning those lands to a common property resource regime.

Given the capacity limitations of formal government agencies in the region, these initiatives suggest a limited role for mainstream conservation strategies such as regulation (either by government agencies or through self-regulation frameworks), local economic incentive or income generation schemes, or protection through zoning. Rather, fundamental changes in nature-society interactions within the coastal zone will depend on a reassertion of common property resource values, localized resistance, inevitable politicization, and potential conflict surrounding the property rights situation. Attempts at such change will confront many challenges: opportunities for political resistance to the local loss of property rights have been undermined by the effects of formal politico-institutional and legal regimes, the pernicious influence of local and regional elites, and corruption within private sector-public agency relationships.

In the upland agroecological system in the Banawa-Marawola region, effort was placed on renewing the debate about people, place and nature. This was accomplished by disengaging the analysis of the upland agroecological system from static or equilibrium viewpoints associated with perceptions of inherently destructive local resource management practice, upland societies considered unchanging through time, and increasingly disputed concepts of "natural" vegetation. As with the coastal system, conventional policy discourse and supporting narratives associated with the upland system have been challenged. At a minimum, the uncritical acceptance of Malthusian or balance-of-nature views associated with upland social-ecological dynamics must be questioned. Simple population growth-environmental degradation causal analyses and explanations of change must be enhanced with explanations that offer insight into the way environments are created in a dynamic, non-linear and contingent fashion. Processes of change are both continuous and discontinuous, and associated with long-term (i.e., historical) interactions among ecological, social, political and market factors. Supported by theory and methods from complex systems, cultural and political ecology, as well as critiques of orthodox conservation and development narratives, a more nuanced understanding of the multiple feedback relationships among people, their environments and ecosystem change in the uplands was offered. The detailed critique of the upland dynamics further revealed a complex agroecological system utilized by upland people – an agroecological system premised on notions of uncertainty, non-determinance and surprise. The agroecological system represents a resilient and sustainable strategy appropriate to the context in which it operates, and offers important insight for the design of conservation policies and management strategies focused on biodiversity protection, ecological integrity and sustainability.

Following detailed critiques of the coastal and upland systems, analysis turned to issues of policy, decision making and management; more specifically, how an improved understanding of upland and coastal system dynamics could be most effectively utilized by a full range of stakeholders concerned with ecosystem-based management. Adaptive management is increasingly presented as a tool that can: (i) frame the numerous philosophical, methodological and practical challenges associated with understanding the spatial and temporal dynamics of complex nature-society interactions; and, (ii) foster more effective conservation policies and programs in which a full range of system actors with disparate goals and visions can chart a course for the future that is both pluralistic and focused on social learning (see Chapter 4). Thus, the formal bureaucratic and administrative context for the application of an adaptive management approach in the Banawa-Marawola region was critiqued.

Based on this analysis and evaluation, and given the institutionally and organizationally demanding nature of the approach, opportunities for the effective application of adaptive management within Central Sulawesi's formal administrative bureaucracy appear limited[56]. It should be noted that opportunities for the effective application of adaptive management within the administrative bureaucracies of most jurisdictions whether in Indonesia, Europe or Canada face a number of obstacles and challenges (e.g., capacity, funding). However, in the Central Sulawesi context, technical and financial capacity limitations, entrenched worldviews of governmental elites surrounding traditional and/or agrarian societies, inadequate trust of bureaucratic agencies among civil society, a lack of political and informational openness, and incomplete definitions of participation, do suggest a particularly challenging context in which to apply an active or passive adaptive management approach. However, emerging institutional conditions - particularly the regional autonomy process - suggest new opportunities to explore innovative ways in which an adaptive management approach can be fostered.

Specifically, an integrated traditional knowledge framework, suite of resource management practices, and supporting institutions were identified in the Banawa-Marawola region that provide the basis for innovative conservation science and practice anchored on principles of adaptive management: a focus on learning, innovation and flexibility, recognition of inherent uncertainty in social-ecological systems, and a non-deterministic worldview. The specific resource management practices identified as suitable for application in dynamic systems (e.g., resource use rotation, management of multiple species, etc.) are supported by processes for social learning and innovation (e.g., *mosi pengawa*, *nolibu*), social mechanisms for conservation and resource management (sanctions, regulations, etc.), and mechanisms for the cultural internalization of knowledge and practices. However, without a corresponding flexible institutional and organization design in which local practices, knowledge and understanding are legitimized, their application is of limited utility. In the Banawa-Marawola region, fortunately, opportunities have emerged to link traditional resource practices and knowledge with innovative organizational approaches around the nascent "*Kamalise*" movement, potentially providing an entirely new geographical and socio-political basis for adaptive conservation practice. Although the significant political will and ingenuity required for innovation have not yet coalesced, evolving legal mechanisms in Indonesia (e.g., Law 22/1999) may provide the latitude required for this type of experimentation.

10.2 Reconstructing Conservation: Conclusions and Recommendations for Policy and Practice

This dissertation provides an example of hybrid research based on critical analysis and debate over the nature of environmental change, policy and research agendas, and methodological approaches (see Batterbury et al., 1997; Berkes, 1999). The primary issues for a reconstruction of conservation science and practice, therefore, are not analytical. Rather, the locus of conservation science and practice is the long-standing challenge of synthesis and integration (see Chapter 1). Integrative conservation science and practice - that which is focused on problem solving - must seek to construct a quantitative and qualitative understanding of critical social-ecological system dynamics at multiple scales, incorporate indigenous knowledge and management practices, promote collaborative social learning among stakeholders, and create flexible institutional and decision-making conditions. Several conclusions, and the subsequent recommendations for policy and practice, based on the findings of the previous analysis are identified and summarized below. In reconsidering conservation science and practice, these conclusions offer strategic insight into how conservation planners and managers may be able to: (i) better understand the coupled nature of complex social-ecological systems, and the implications for biodiversity, ecological integrity and sustainability; and, (ii) how system stakeholders can effectively utilize this system knowledge and understanding in a pluralistic, ecosystem-based framework. Inevitably, the conclusions and subsequent recommendations for policy and practice challenge, in some respects, core tenets of conventional or mainstream conservation science. As such, the three conclusions and their policy and practice implications, although particularly salient in the Banawa-Marawola context, likely have broader applications as well. In order of strategic importance, the conclusions (and subsequent recommendations) are as follows (Table 10.1): (i) contextualize definitions for conservation; (ii) reconceptualize territory, scale and nature-society interactions; and, (iii) reframe adaptive management theory and practice within the "new" localized socio-politics of conservation.

Table 10.1: Summary of main conclusions and recommendations

Conclusion	Recommendations for Policy and Practice
1. Contextualize and democratize definitions of conservation	✓ Sensitize public sector officials and others to issues of knowledge construction and representation through training and awareness initiatives ✓ Use a civic science model to ensure that different stakeholder groups have access to the tools and resources of analysis ✓ Utilize participatory analysis approaches in which a broad range of stakeholders participate in problem definition, analysis and construction of the "picture" of the system ✓ Accord "bounded primacy" to the knowledge, insights and recommendations of local resource users even where such recommendations conflict with broader economic goals ✓ Support (legislatively and financially) nascent socio-political movements, institutional and organizational frameworks which more closely represent the voices of marginalized groups (e.g., Kamalise). ✓ Encourage civil society groups (e.g., the Environmental Study Centre, Tadulako University) to play a mediating role among different interests in support of pluralistic definitions and analyses of nature-society interaction.
2. Reconceptualize territory, scale and nature-society interactions	✓ Utilize the dynamic practices and spatial articulation of the traditional agroecological or resource management system identified in Banawa-Marawola as the basis for locally-relevant and realistic scaling and spatial planing processes (i.e., using the notion of overlapping patchworks) ✓ Develop and implement an ecological and social monitoring program based on the integrated land use management practices and complex systems knowledge of local resource users ✓ Review and modify as required, policy and legislation premised on spatial articulations of biodiversity, resource use restrictions and exclusionary approaches, and support instead local management practices that support system integrity, resilience and self-organization
3. Reframe adaptive management within the "new" socio-politics of conservation	✓ Build an understanding of and capacity for an adaptive approach to conservation science and practice among government agencies, NGOs and other civil society organizations, including a rebuilding of traditional (*adat*) knowledge frameworks and resource management practices ✓ Focus adaptive management practice on the institutional and organizational designs and frameworks which support local institutions (e.g., *nolibu*, *mosi pengawa*) and dynamic resource management practices, and which foster social learning, ✓ Support reflexive institutional and organizational arrangements in which local socio-political movements (i.e., Kamalise), civil society groups and the State engage in negotiation, dialogue and sustainable practice in order to address core issues of power, justice and accountability

10.2.1 Contextualizing conservation: by whom and for whom?

Ideas are generated and serve different purposes. That simple statement hides the powerful insight that processes of knowledge construction fundamentally inform the development of system understanding. Critics of conservation science and development practice from diverse fields are increasingly emphasizing this point (Peet and Watts, 1996; Batterbury et al., 1997; Li, 1999, 2001; Scoones, 1999; Tsing, 1999; Bassett and Koli Bi, 2000; Zimmerer, 2000).

Much of this criticism and analysis has emerged from attempts to rework the environment and development orthodoxy which has provided justifying scripts and narratives for questionable policy. Considering the uplands through a lens of degradation, for example, helps to hide those socio-cultural and institutional practices and resource management strategies used by local people to create their environments (see Li, 1999). As Li (1999:29) writes of uplands in general, "..the history of upland agriculture cannot be reduced to a story of ecological ruin. Nor is ecological change necessarily a story of impoverishment".

Social construction of knowledge involves a process in which people, their practices, spaces and social-ecological interactions become the focus of description, classification, categorization, and then almost inevitably, of simplification, distortion and stereotyping (see Li, 1999). Ultimately, such conceptions are judged against criteria defined by outside interests (e.g., government agencies, international conservation organizations, indigenous rights and environmental groups), and whether positive or negative, captured in biases of those who design strategies, set policy, make decisions and interpret outcomes (Shields in Li, 1999). Narratives are developed and persist because they support varied groups (e.g., NGOs, the State, researchers) and their varied agendas (Bassett and Koli Bi, 2000). The subtle and not-so-subtle influence of narratives on the way complex social-ecological systems are understood by different groups should be recognized. For example, as Li (1999) suggests, and the upland system analysis supports (Chapter 7), "uplands" have historically been equated with "forests", and forests equated with remnant "pristine wilderness". Upland people have been equated with that which is indigenous, traditional and isolated; in turn, such concepts of "traditional" have been equated with "stability" and the harmonious interaction with nature, neglecting the long-standing engagement between upland and coastal communities, or the dynamic and recursive relationships among people, their environments and ecosystem change (see Scoones, 1999).

> *For state agencies, environmentalists and social activists alike, assumptions about the marginality of upland ecologies, livelihoods and people form the basis of "development narratives" or "cultural scripts for action".....that is, they define problems, filter out contradictory data, and structure options in ways which enable and legitimise specific forms of intervention (Li, 1999:11).*

As Zimmerer (2000) notes, such processes tend to disconnect society and nature, encouraging an articulation of nature as wild or as untouched by humans. Such conceptions of nature, natural and wild (see Chapter 7) become the focus of protectionist conservation policy and mainstream conservation strategies that require ever greater enforcement, regulation and restriction (Peluso, 1993). Even those approaches less inclined towards strict regulation (e.g., buffer zone areas, integrated conservation and development strategies), however, succumb to exclusionary zoning practices and efforts to separate people and their traditional places.

> *These supposed intermediate zones have become spaces of strict regulation over the use of land and other resources, while 'core areas' are protected like conventional national parks (most or all use by local people is prohibited). In such cases, boundary making between the core areas, the recent intermediate zones, and surrounding areas are creating anew the schisms of nature and society in terms that are legal, discursive, environmental, and political-economic (Zimmerer, 2000:363).*

Recognition of the social construction of knowledge, and the manner in which knowledge "represents" traditional and/or local resource users in particular, is not simply an esoteric debate. As Fairhead and Leach (1996) illustrated in West Africa, for example, policy prescriptions and conservation strategies that emerged from the mainstream policy discourse surrounding population increase and environmental decline resulted in the significant marginalization of those least able to protect their rights and interests. In coastal and upland contexts in the Banawa-Marawola region, mainstream narratives and policy discourse (see Chapters 6 and 7) have likewise resulted in similar impacts. For instance, as portrayed in the Indonesian language, customs and practices of traditional communities in the region have been characterized as backward, ill-informed, isolated and in need of modernizing influence. Not only has the value of local knowledge been devalued or ignored, but the value of cultural forms of expression has been denied (Li, 2001). Moreover, mainstream perceptions regarding the role of local communities in environmental degradation have led to policies aimed at their resettlement, and the increased threat of regulation, fines and criminalization of traditional resource use activities (Peluso, 1993, 1995; Fairhead and Leach, 1995, 1996; Li, 1999, 2001), while fundamental changes to long-standing resource use practices have been brought about by the increasing privatization of property rights. Local communities, both in the coastal and upland zones, have been marginalized in the process and have experienced a reduced ability to benefit (socio-culturally and economically) from their resources.

Yet, how often in the environment and development practitioner realm are issues of knowledge construction and the representation of "others" considered? The answer is rarely, and to some extent understandably so, in the context of everyday, tangible challenges of conservation practice. However, the obstacles to critical analysis and system understanding which unchallenged discourse engenders, and the forms of intervention such discourse produces, are barriers to just, equitable, accountable, and therefore, effective conservation science and practice. Increased recognition of, and greater sensitivity to, issues of knowledge construction, representation and discourse among conservation and development proponents (e.g., bi- and multi-lateral development agencies, international conservation organizations and government agencies) is an identifiable need in Indonesia, as elsewhere.

This suggests a need to engage more explicitly in the debate about how conservation and development is defined - by whom and for whom - and how representations of and by different stakeholders inform policy and management interventions. In particular, it suggests a need to democratize the definitions and analyses of environmental change, since different knowledge sources offer different insights that can help to inform critiques of specific problems (Batterbury et al., 1997). The implication is that those most intimately tied to a particular place need the opportunity to construct interpretations of ecological and social change, to define the conservation and development challenges, and to determine the subsequent strategies for action. Perhaps only then should the debate be broadened to address the regional-global implications of environmental transformation attributable to local place. As Fairhead and Leach (1996) caution, however, any revisions to the present constructions of social and ecological knowledge, and the "new" policy implications that emerge from them, must also emerge from within the existing institutional and organizational structures (science, policy, development and State-village administrative relationships) that have produced the very narratives that need to be challenged. Despite such limitations, the inevitability of the degradation discourse and its implications for complex systems understanding must be challenged.

> *...the degradation discourse has constructed alien ideas of tradition and community, reinforced ethnic stereotypes and differentiation, and denied people their own history with all its significance for their social and political relations and capacity to live on their own terms (Fairhead and Leach, 1996:295).*

Challenging the degradation discourse and democratizing the definitions and analysis of environmental transformation will not be easily accomplished. Of central importance, however, is the need to make the tools and resources of analysis available to all stakeholder groups in order to generate a pluralistic "picture" of the system. In the coastal zone, for example, engaging local people and government officials in a joint analysis of the full costs and benefits of the aquaculture system would help illustrate the socioeconomic and ecological value of the common property mangrove forest system. Sensitizing those government officials (and other groups) to issues of knowledge construction and representation through training and awareness initiatives would also be helpful. More generally, support (legislative and perhaps even financial) for local socio-political, institutional and organizational frameworks (e.g., Kamalise in the Banawa-Marawola region) which better represent marginalized groups will significantly advance opportunities to democratize the definitions and analysis of environmental change and nature-society interactions. As well, third-party, intermediary or civil society groups can play a mediating role among different interests and foster pluralistic understanding of social-ecological system dynamics. In the coastal zone in particular, the Environmental Study Centre at the University of Tadulako has undertaken participatory research in the region and offers a potential example of one intermediary group that could conceivably play this role. Intermediary groups can serve to educate formal government institutions about local groups and help to overcome biases that may influence decision-making.

10.2.2 Reconceptualizing territory, scale and nature-society interactions

The sustainability dialogue necessitates that locally and culturally appropriate technical and socioeconomic opportunities be available to different land users; policy and practice must move away from intrusive and prescriptive blueprint or regulatory approaches. Greater sensitivity to the social construction of knowledge and its implications for social-ecological system understanding encourages this outlook, as do insights from complex systems analysis (e.g., unpredictability, non-determinance), historical, cultural and political ecology. This conclusion is not based on *a priori* moral grounds, but on the conceptual and methodological benefits provided by pluralist approaches (see Roe, 1994). In mainstream conservation discourse, however, nature-society debates are often linked to an elaboration of space and time that is static, equilibrium-oriented and/or ahistorical. As Zimmerer (2000) notes, there is a striking orientation towards the depiction of biodiversity, for example, as predominantly spatial (see Dinnerstein, 1998). Yet advances in spatial understanding, while impressive and important, do little to contribute to a better understanding of the historical ecological, political-economic and socio-cultural contingencies that have shaped, and continue to shape, those very same spatial configurations across landscapes and regions (Sprugel, 1991; Fairhead and Leach, 1995, 1996; Scoones, 1999; Zimmerer, 2000). Moreover, the focus on biodiversity itself raises questions about the validity of much conservation science and practice (Goodman, 1975; Nudds, 1999). The issue is not simply the maintenance of biodiversity despite human influence, but promoting and maintaining ecological integrity and system resilience in the context of the long-term influence of humans on ecosystem dynamics.

Advocates of conservation science, therefore, should reevaluate the standard territorial concepts that have played a significant role in many conservation and sustainable development initiatives (Zimmerer, 2000). As Zimmerer (2000) notes, the territorial orientation of many conservation activities (e.g., in biosphere reserves, integrated conservation and development areas, etc.) is based largely on biodiversity-centred spatial articulations such as valued ecoregions, protected landscapes, buffer zones, or strict protection zones. Too often, such spatial and territorial configurations generate negative impacts on local communities and groups, rather than providing the benefits they are expected to offer. Rigid territorial designations can lead to a loss of access to social and environmental entitlements among resource users (e.g., such as that experienced by nomadic pastoral groups who historically utilized grazing areas demarcated for conservation and protection in savanna Africa), and inadequately account for the inequitable power relations within communities which influence access to and benefits from resources (Peluso, 1993; Peet and Watts, 1996; Goldman, 1998; Zerner, 2000). The RePPProT planning process (see Chapter 7) is the most obvious example in Indonesia of externally created, rigid formulations of territory and scale that possess little relationship to the complexities of nature-society interaction actually evolving in Indonesia's landscapes. A local spatial master planning process implemented by district and provincial planning authorities in the Banawa-Marawola region provides another, more localized example of the nature-society disconnect (see below).

Yet, as those encouraging a focus on system self-organization, integrity and resilience (Kay, 1991; Hwang, 1996; Kay et al., 1999; Zimmerer, 2000) propose, insights provided by dynamic equilibrium (or multiple steady state conditions) and complex systems theory suggest, the absence of an a priori basis for the delineation of predetermined territories for conservation science or practice. Ecologically, a temporally and spatially static patchwork of zones contravenes ecological dynamics at multiple scales, such as fire, hurricanes, landslides and pest outbreaks (Sprugel, 1991; Baker, 1992; Scoones, 1999). Socially, spatial fixing of land and resource use in rigidly defined management units is, as well, often a source of serious socio-cultural and economic dissatisfaction among local communities because of the exclusionary orientation (Peluso, 1993). Contingent and coevolved natural processes and human activities that are the basis of system self-organization and dynamism are unlikely to conform to a rigid zonation of lands and resources. Consequently, concepts of dynamism, self-organization and flexibility are a more appropriate basis for temporally sensitive spatial configurations in conservation practice (see Wu and Loucks, 1995; Zimmerer, 2000). In the Banawa-Marawola region, concepts of territory, scale, dynamism and change utilized by local people to organize their resource systems do not match well with conventional classification schemes. Since traditional agroecological practices (whether in the uplands or in the coastal zone) are not inevitably degrading (see Li, 1999), conservation policy should seek to support those practices which improve soil, fallow vegetation and forest management (e.g., *ombo*), and the locally-evolved temporal and spatial scales upon which they are based. Rather than concentrating on policy that supports fundamental change in agricultural practices and livelihoods, dramatic restrictions on resource use, and/or the exclusionary protection of expanses of the landscape, policy and practice should seek to build on the knowledge-centred framework and resource management strategies in the Banawa-Marawola region that are oriented towards system resilience, the maintenance of integrity, self-organization and dynamic change. Dynamic equilibrium insights and social critiques of current conservation practice indicate that perceptions and practices of land and resource users should be central to conservation scaling and classification (Scoones, 1999; Zerner, 2000; Zimmerer, 2000).

Alternative territories should be considered that are relevant at local-regional scales. At such scales in the Banawa-Marawola region, the spatially-oriented Kamalise people's movement provides one alternative conservation territory based on the multi-community network of Da'a, Unde and other local groups. The natural focus of the Kamalise movement in a conservation context would be on people, their communities and their agroecological system, rather than on preconceived notions of stable patterns of vegetation and wildlife, thus providing a more relevant geographical basis for conservation policy and management. Standard territorial blueprints of mainstream conservation science and practice (e.g., parks, ICDPs, buffer zones, etc.) have been a key feature in the inadequacies of many conservation programs and initiatives because they fail to deliver the necessary socio-political development and sustainable environments which they often promise (Zimmerer, 2000). In contrast, dynamic temporal and spatial scales and territories created through local resource management practices, worldviews, supporting institutions and the nascent Kamalise movement support potentially innovative opportunities for policy formation, institutional and organizational design, and the implementation of conservation strategies that engender an adaptive management approach, a focus on social leaning, and a concern for pluralism.

> *We are situated, inexorably, in a landscape of shifting configurations of nature/culture, a landscape travelling within and across genomic, individual, communitarian, national, and international boundaries, confounding the social and environmental world watchers, monitors, and surveillance/information specialists attempting to keep people, things and nature in their places. We need to create more radically pluralist, democratic visions of nature and societal interconnections: visions in which the Creole and the hybrid, the mobile as well as the sedentary community, the provisional design as well as the ancient species are valued citizens of the changing state(s) of nature (Zerner, 2000:17).*

In the context of the Kamalise area, local resource management practices foster multiple, overlapping spatial patterns of use at diverse scales that integrate natural and social features (Table 9.1). Such nature-society interactions are similar to the notion of overlapping "patchworks" identified by Norgaard (1994), Zimmerer (2000), and referred to by Zerner (2000), and may provide an alternative to strategies and approaches that seek to remove human influence, establish rigid land use zones, and decouple nature and society. The locally-evolved spatial framework consisting of permanent and temporary restrictions on specific resources, habitats, species or places in the coastal and upland zones (e.g., *ombo*), as well as the maintenance of fallow lands and forested areas in different successional pathways in the uplands in particular, provides a local articulation of this patchwork analogy. Such locally-evolved "scaling" of the landscape thus provides a potentially valuable basis for conservation science as it is linked to processes of system integrity, resilience and self-organization - areas of permanent cropping, settlements, and mature forests are interwoven with working landscapes that mix swidden plots and fallow lands in multiply-aged successional stages. With the progression of time, areas of mature forest and configurations of the working landscape may change (i.e., areas of swidden, fallows and secondary forest of different ages)[57]. However, the resilience necessary to maintain biodiversity, system integrity and capacity for self-organization is sustained. Moreover, modifications, as required, of local practices and the scaling of social-ecological systems can be achieved through negotiation and input from other sources (civil society, the State, experts, etc.). The more rigid and formalized spatial plans (*Rencana Tata Ruang Wilayah, Kabupaten Donggala*) proposed by government agencies (Bappeda Kabupaten, 1999) provide a stark contrast to dynamic local perceptions of nature-society interaction. Recognition of the existence of an alternative spatial interpretation of the landscape provided by traditional resource users, however, has only just emerged among government officials, and the incorporation of local insights in the evolution of conservation and development planning is still a long way off[58]. In the Banawa-Marawola region of Central Sulawesi, key planning and resource management agencies should seek to better understand the social-ecological basis of local land use patterns prior to enacting and enforcing conservation and development policy. As the incorporation of local land use patterns in official land use planning processes is a long-term issue, initial steps to move forward could include more public consultation activities involving local groups and government planners to share ideas and concerns.

Finally, the ecological knowledge of traditional resource users in both the coastal and upland areas of the Banawa-Marawola region should be further elaborated and analyzed in an effort to generate indicators for monitoring ecological (and social) change that are easily measured, scientifically defensible and culturally appropriate (see Fernandez-Gimenez, 2000). The integrated land use management practices outlined in Chapter 9, along with the supporting institutions and worldviews (Table 9.1), provide a conceptual and operational framework for monitoring social-ecological interactions and their influence on ecosystem resilience. Innovative opportunities thus exist to encourage local individuals to undertake monitoring activities that can be linked to formal programs supported by mainline government agencies in an effort to address concerns about environmental change – programs ideally structured upon principles of adaptive management. Working with local resource users, as well as representatives of the Kamalise movement and civil society groups, mainline government agencies responsible for conservation and development should develop and implement a monitoring program to track issues of ecological resilience and sustainability in the region, and which can explore through time the evolution of multiple steady state land use configurations.

10.2.3 Reframing adaptive management within the "new" socio-politics of conservation

Adaptive management is increasingly presented as a framework in which a full range of system stakeholders can explore and utilize complex system understanding to protect biodiversity, maintain ecological integrity and promote sustainability. As such, opportunities for and constraints on the application of an adaptive approach to conservation science and practice in the Banawa-Marawola region have been assessed. In particular, the prospects for effective application within the formal administrative bureaucracy in the region appear limited – limitations that are likely similar in other developing country contexts. As a result, there is a need to reframe how we interpret and conceptualize adaptive management theory and practice, focusing not so much on the data, methods and technical facets, as on building the context in which the core principles can be promoted and utilized in the design of conservation and sustainability strategies: a focus on resilience, acceptance of surprise, encouraging a non-deterministic worldview, learning from experience (whether experiential or through structured experimentation), elevating the importance of monitoring, and focusing on innovation. Yet as the previous discussion indicated, since the knowledge and understanding that guides the process of integration, synthesis and problem solving are often socially constructed (Berkes, 1999), issues of politics, democracy, community, representation and governance provide the arena in which adaptive management must be operationalized.

Recognition and support of the diverse range of organizations and institutions actively engaged in resource management are required, along with strategies to ensure they have a responsive role in providing decision-making services (see Fairhead and Leach, 1996). As suggested in Chapter Nine, adaptive management must facilitate greater interaction between locally-evolved resource management systems knowledge and formal scientific ecological knowledge to foster the cooperative management of natural resources (Berkes et al., 2000; Olsson and Folke, 2001). For such a process to work, however, knowledge and understanding of complex nature-society dynamics must be embedded in an institutional and organizational framework suited to the interpretation of and response to ecological and socio-economic feedback. This is most likely to be achieved through flexible community-based systems and institutions of resource management that work in a collaborative, supportive fashion with relevant non-governmental and civil society organizations, educational institutions, and formal governmental agencies (Gadgil et al., 2000; Olsson and Folke, 2001). This nested, cross-scale institutional and organizational framework is important because ecological processes and the socio-cultural, political and economic factors that influence those processes, function at small, medium and large scales (Ostrom in Olsson and Folke, 2001) (see also Chapters 6 and 7). Innovative institutional and organizational frameworks are required that can cope with such system complexity, are sensitive to ecosystem changes and dynamics, and facilitate resilience in sociobiophysical systems (Olsson and Folke, 2001). An adaptive approach to conservation science and practice, therefore, requires strategies that offer local communities the opportunity to transform traditionally disadvantageous power relations and engage in politics that are more responsible, accountable and equitable (Peet and Watts, 1996; Zerner, 2000).

Just as "new" ecology perspectives (i.e., complex adaptive systems) have helped to challenge convention, a "new" politics of environment and development is challenging the organizational, political and institutional orthodoxy of conservation science and practice. Such processes are occuring in a broader rethinking of "development" (see Norgaard, 1994)[59], given the inadequacies of past experience and the new challenges created by the influences of globalization (Peet and Watts, 1996; Zerner, 2000).

> *This sizeable challenge for conservation is redoubled by the effect of globalization processes, neoliberal policies, and the general "hollowing out" of national governments. Perhaps in developing countries especially, the design of state agencies and power has been "scaled up" toward the increased authority of central governments, while, at the same time, there has been a "scaling down" in initiatives for decentralization and local decision-making...The "hollowing out" of the state at intermediate scales exemplifies those features of the transition to late capitalist modernity that seem both an integral part of today's conservation boom....and a formidable obstacle in the path of successful resource management and protection (Zimmerer, 2000:363).*

The new socio-politics of environment and development are very much centred on autonomy, self-determination and a reaction against those influences that threaten to further undermine or homogenize local traditions. Thus, the politics of conservation and development increasingly gravitate towards perspectives that are post-modernist, post-structuralist and anti-foundationalist, and consist of socio-political movements with an integrated perspective on environmental issues that incorporate concerns about justice, livelihood, human rights and the influence of neoliberal policies (Watts, 2000). According to Escobar (in Watts, 2000:30), the multi-dimensional nature of the new socio-politics is "self-organizing" or "self-producing" in that the movements seek to exercise power outside State jurisdiction in an effort to create "decentred autonomous spaces".

The Kamalise movement appears to offer an explicit and locally relevant example of this process in the Banawa-Marawola region, and needs to be recognized explicitly in any adaptive conservation policy and management framework. Indeed, the Kamalise movement is a form of social resistance concerned with issues of historical domination, exploitation, lack of participation in decision making, and the marginalization of local identity (see Bebbington, 1996; Li, 2001). At the same time, it is imperative that the populist appeal of movements like Kamalise is not accepted in an uncritical manner; that is, the uncritical acceptance of local people, place, and culture, or what Watts (2000) refers to as "agroecological populism". It would be all to easy to overlook or ignore the complex power relations that exist within local and/or traditional communities, which influence how traditional groups interact with external institutions and processes, and which influence how the benefits and costs of conservation and development are distributed among local people (see Zimmerer, 2000). As Bebbington (1996) noted, socio-political movements (like Kamalise) must confront the challenge of reflecting the multiple identities of those they represent, as well as negotiating a dual relationship with the State that includes both resistance and claim-making on behalf of their constituents.

Despite these cautionary notes, however, adaptive management frameworks for reconstructed conservation science and practice will increasingly be situated in locally-evolved socio-political movements which should not be ignored by conservation and adaptive management advocates. In the uplands of Banawa-Marawola in particular, the combined effect of political-economic agendas and the environmental orthodoxy associated with ecological transformation as constructed by different groups with different agendas and interests, has encouraged external interests to identify dramatic interventions such as resettlement, restrictions on use and property rights, and exclusionary protection. Efforts to democratize the identification of social-ecological issues and the resulting management of externally real biophysical processes is a pressing need (see Batterbury et al., 1997). Yet the theory and practice of adaptive management inadequately accounts for, or explicitly encourages recognition of, these new socio-political realities. A reflexive institutional-organizational framework for adaptive management practice is thus required that represents local agendas, while drawing on the knowledge and resources of the State, civil society, experts and the international community (see Figure 9.2).

> *The challenge, then, is not just to construct a more informed and democratized explanation of externally real biophysical change; but also to ensure that this knowledge is used to influence policy at various spatial scales to enable practical and equitable environmental management (Batterbury et al., 1997:130).*

As Zimmerer (2000:358) notes, conservation science and practice must "...be blended with the efforts of ....people to transform traditional power relations into politics that are more responsible and accountable". Adaptive management should play a critical role in this regard. An adaptive approach to conservation science and practice, therefore, necessitates the maintenance of ecologically sound and culturally appropriate resource management practices and supporting institutions (like those identified in the Banawa-Marawola region) where they still exist. Where they have been undermined, devalued or degraded by internal and external processes of socio-cultural, political and economic change, efforts should focus on their reconstruction. The challenge for an adaptive approach to conservation science and practice is, and will continue to be, to identify and develop the institutional and organizational mechanisms that can link traditional ecological knowledge systems and resource management practices with monitoring and management of the coastal and upland systems. The challenge for adaptive management in the "new" socio-politics of conservation science and practice, therefore, is to address the issue of how local institutions or "rules-in-use" can become embedded in just and equitable forms of decision-making and governance. There are no clear mechanisms in which to address this challenge for policy and practice. However, efforts to enhance the likelihood of effective adaptive management practice include building understanding of and capacity to operationalize the approach, such as rebuilding the traditional (*adat*) knowledge framework and resource management practices identified in Chapter 9; and, focusing on the development of reflexive institutional and organizational frameworks which support formal and non-formal adaptive management practice, social learning, and which address issues of power and justice. Such actions will only begin to be accomplished if legitimate mechanisms for public consultation and collaboration (e.g., working groups, workshops, public forum, etc.) are implemented which involve local groups in the coastal and upland zones, along with government agencies, NGOs and other relevant stakeholders.

10.3 A new orthodoxy for planning and management?.....Or avenues for further research

As implied by the conclusions and recommendations outlined above, issues of power and hegemony have influenced the planning, management and use of natural resources in Central Sulawesi. Yet the power structures and hegemonic practices that have shaped policy narratives and resource management in the coastal and upland zones of Banawa-Marawola are being challenged; new power relationships in the region are required that engender collaborative decision making, and flexible institutional and organizational frameworks. In contrast to the conventional process of the linear, top-down conservation planning approach used in the region, elsewhere "post-normal" planning and management models are increasingly in demand –

planning models that are anticipatory and adaptive, pluralistic, integrative and synthetic, cognizant of uncertainty and inherent unpredictability. Local, district and regional planners and managers must recognize the source of these demands, the reasons for their emergence and act accordingly. The conceptual and analytical frameworks utilized in this dissertation encourage that recognition by offering a critical analysis of upland and coastal systems in the region, as well as the potential mechanisms to link analysis with policy, planning and management.

Although guided by a similar set of principles and constructs (see Table 5.3), each of the conceptual and analytical frameworks integrated for this research enables a different perspective. For example, complex systems interpretations (e.g., cross-scale and nested interactions of different types, uncertainty, unpredictability, etc.) resonate well with political ecological interpretations that illustrate how ecological, institutional and socio-political factors coalesce in often unpredictable ways. Thus, political ecology interpretations offer a more explicit focus on the socio-political relationships that influence multiple interactions and inter-relationships. Moreover, cultural ecological insights, similar to adaptive management, place additional emphasis on how individuals, communities and societies may respond to uncertainty and change, and learn from those responses in the process. Combined, these conceptual approaches offer an emergent framework for analysis which helps to challenge conventional conservation theory and practice.

Batterbury et al. (1997) have argued, however, that the search to challenge convention, orthodoxy and the mainstream narratives that guide current policy discourse and practice will be counterproductive if real problems of environmental degradation are denied. The point of this analysis, therefore, has not been only to challenge orthodoxy in order to deny perceived threats of environmental change, but to open new avenues for policy, practice and research that are innovative, realistic and focused on system resilience. As a result, the findings, conclusions and recommendations emerging from this analysis suggest numerous entrées for additional research. Indeed, there are still inadequately tested assumptions about causality among socially just, decentralized, and autonomous approaches to conservation practice, and the expectations of improved outcomes for biodiversity, ecological integrity and sustainability. Detailed case analyses and comparative studies are required to provide, as appropriate, the empirical basis for such claims. Thus, several important areas for additional research in the Banawa-Marawola region of Central Sulawesi are identified below (in no special order of importance):

1. Research in both coastal and upland areas to explore the capacity of emerging socio-political movements (e.g., Kamalise) to create and foster new community-state power relationships in the control and management of natural resources (e.g., possibly in the form of co-management regimes);
2. Community-specific participatory action research in the coastal zone is necessary to generate ideas and options for mangrove forest restoration where desired, and to address key issues of property rights, resource access and control;
3. Applied research is necessary to work directly with local resource users in both the coastal and upland zones in order to identify possible mechanisms in which local knowledge can be integrated with formal, scientific knowledge to monitor processes of ecological change, and how that can be linked to resource management strategies. In the uplands in particular, such monitoring could help to clarify how the traditional agroecological system supports or hinders opportunities for ecological resilience, and ideally, could be compared with other agroecological systems emerging in the highlands (e.g., permanent cocoa plantation) in order to generate important conservation policy insights;

4. Further study and analysis of the uplands are required, using an historical ecological framework linked to complex systems understanding. This will enable a better understanding of the dynamics of vegetation change in the Banawa-Marawola uplands and the implications for conservation policy and management models;
5. More detailed anthropological and agroecological research on upland communities (e.g., the Da'a) is required. In particular, a household survey and/or ethnographic research would be useful in order to develop more detailed understanding of the various practices identified in Table 9.1. As previously mentioned, there is very limited research on the Da'a and other upland groups in the region; and .
6. Exploratory and applied research is required to illustrate the potential links between the temporally sensitive spatial articulation of nature-society interaction supported by traditional resource management practices in the area, and the implications for conservation science and practice guided by a complex adaptive systems theoretical framework.

10.4 Final Thoughts....

At several points throughout this dissertation, I suggested that the "science" of conservation is not an issue of analytical technique, or a matter of advancing by seeing the unseen. Rather, the challenge of synthesis and integration - both decidedly political processes - is the locus for reconstructed conservation science and practice. The focus on methodology in this dissertation has, I believe, been justified given that methodology is the likely meeting ground for the philosophical and pragmatic issues such innovative conservation strategies will inevitably engender (Woodhill and Rõling, 1998). At their most basic, conservation science and practice are about the struggle to locate the ever-shifting point of balance between relativism and determinism. As the philosopher and historian Isaiah Berlin (1998) concluded, relativism should act as a reminder of our limitations of knowledge. Beyond that, Berlin (1998:180) concluded, relativism relies on spurious logic and the specious interpretation of experience. Determinism, in contrast, can help indicate specific obstacles to management opportunities and choices. Beyond that, determinism becomes "mythology and metaphysical dogma of grand design" (Berlin, 1998:180).

Like any map, therefore, the approach, analysis and insights offered in this dissertation provide an approximate, rather than an explicit, description of biophysical and social reality. Further tests and explorations of the perspectives and insights outlined in this dissertation should be guided not by an interest in chasing facts, but in constructing the integrated understanding of complex sociobiophysical systems - understanding that is necessary for adaptation to the inevitable uncertainty and turbulence of nature-society interactions. This dissertation, therefore, contributes to an increasing literature which seeks to challenge the conventional theories upon which current conservation science and practice are based, and offers an example of the application of a synthetic theoretical and conceptual framework for conservation and sustainable development policy. It is evident that the philosophical, epistemological and conceptual framework guiding current conservation science and practice is evolving for the task ahead. Conservation and development advocates will need to continue moving beyond the Cartesian influence on conservation science and practice to better understand critical social-ecological system dynamics, incorporate indigenous knowledge and management practices, promote collaborative social learning among a broad range of stakeholders, and create flexible institutional and decision-making conditions. We must continually ask ourselves if our adherence to conventional worldviews, approaches and policies for conservation science and practice has staying power because they are too strong to dispute.....or do we simply lack the conviction and political will to hasten their departure?

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12.0 ENDNOTES

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[1] A cursory review of Global Environmental Facility (GEF) Project Appraisal documents indicates a uniform approach to most terrestrial biodiversity conservation projects across continents and contexts.

[2] This Banawa-Marawola area of Central Sulawesi was chosen as the site for my research for several reasons. The opportunity to undertake research through the UCE project in Indonesia was brought to my attention by my advisor, Dr. Bruce Mitchell. Based on his recommendation, and in consideration of the nature of the research I was interested in doing, the Banawa region and the Environmental Study Centre at Tadulako University (UNTAD PSL) in Palu was suggested as a potentially suitable location. Following discussions with a fellow graduate student from Palu (Achmed Rizal) a decision to focus my research in the region was made. Within Banawa-Marawola region, two key systems were quickly identified for their significance: the coastal system where mangrove forest has been converted to fishpond and the widespread swidden agricultural and resource management system in the uplands.

[3] Tansley (1935) is often credited with popularizing the term "ecosystem", although underlying concepts such as hierarchical organization of populations and communities, and the functional connections between biota and their environments are evident in the work of earlier researchers (e.g, Mobius (1877), Forbes (1887), Cowles (1899), and Clements (1916), etc.) (see Christensen et al., 1996).

[4] Slocombe (1993a) provides a more detailed account of the development of ecosystem science (e.g., the role of E.P Odum and H.T. Odum, the work of the International Biological Programme, and Man and Biosphere Programme).

[5] Non-linear in this sense refers to the fact that systems behave as a whole and cannot be understood by disaggregating components or attributes or by recombining them (Kay, 2001).

[6] More specifically, ecological integrity involves three issues: (1) the current well-being of the system or its "health" or "vigour"; (2) the resiliency of the system or its ability to re-organize in response to stress and disturbances that may cause the system to flip into another state; and (3) the potential of the system to continue self organizing; that is, the systems ability to develop, regenerate (sensu Holling's four phase ecosystem model), and evolve under normal environmental circumstances (emergent complexity) (see: Kay, 1991; Kay 2001; Kay et al., 1999)

[7] Thanks to Prof. James Kay, University of Waterloo for introducing me to Weinberg's "Law of Medium Numbers", and for helping to clarify the subtle differences and technical meanings of various concepts and terms associated with complex systems.

[8] See Rosenhead (1998) for a counter argument on why analysis and analytical methods have an important role to play even in the context of "complex systems".

[9] Rosenhead (1998) challenges the empirical validity of transferring complex system concepts from the natural to social / management realms. As well, he makes a distinction between "metaphor" and "analogy". A metaphor, while valuable, has limited prescriptive weight. Its influence on policy will depend on the clarity of the metaphor and plausibility of the inferences for practice the metaphor implies. An analogy asserts similarities or differences between corresponding elements in two different systems and makes an assertion about the causal links operating within each system (see Rosenhead, 1998). The requirements to be considered an analogy are more stringent than those for metaphor.

[10] In discussing linear systems, Weinberg (1975:232) notes that they possess a property called "superposition"; if two linear systems are put together they maintain their linearity. Likewise, a linear system can be decomposed into systems that also retain the property of linearity.

[11] Complex social-ecological systems (i.e., self-organizing, hierarchical and open systems as described by Kay et al. (1999)) exhibit sets of behaviours which are organized and coherent. The focal point of this organization and coherence is referred to as the system "attractor" (Kay et al., 1999). Different attractors exist within different ecosystem types (e.g., clear water/rich submered vegetation and turbidity/loss of submerged plants represent two attractors for lake ecosystems) (see Scheffer et al., 2001 for examples in a range of ecosystem types).

[12] Kay et al. (1999) actually use the term "self-organizing, holarchic, open" system or SOHO system.

[13] Kay et al. (1999) provide a more detailed technical description as follows: "Self-organizing dissipative processes emerge whenever sufficient exergy is available to support them. Dissipative processes restructure the available raw materials in order to dissipate the exergy. Through catalysis, the

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information present enables and promotes some processes to the disadvantage of others. The physical environment will favour certain processes. The interplay of these factors defines the context for (i.e. constrains) the set of processes which may emerge. Once a dissipative process emerges and becomes established it manifests itself as a structure. These structures provide a new context, nested within which new processes can emerge, which in turn beget new structures nested within which.....The canon of the SOHO system is the complex nested interplay and relationships of the process and structures, and their propensities, that give rise to coherent, self-perpetuating behaviours, that define the attractor.

[14] Adaptive ecosystem management, adaptive management, and adaptive environmental planning and management, are terms that will be used interchangeably throughout this dissertation, but will refer to the same approach.

[15] Holling (1978) cites examples from Venezuela and Argentina, although there have been no explicit case studies from these regions. The use of adaptive management in developing country contexts is emerging, however. For example, ESSA (a consulting firm) has been active in Asia for approximately 15 years, while a Cornell University research program in Nusa Tengara, Indonesia, is focusing on protected areas, conflict resolution and adaptive management (L. Fisher, pers. comm., 1999).

[16] Interestingly, recent social changes in some southeast Asian countries may modify certain social customs and invalidate institutional structures that limit the potential for bounded conflict (see Nakayama, 1998).

[17] The distinction between substantive and procedural constraints is not always clear; however, an attempt has been made to differentiate between the two in order to facilitate organization.

[18] Based on comments provided by Dr. P. Eagles, University of Waterloo, Waterloo, Ontario, November, 2000.

[19] This concept of cultural adaptation is similar to the theory of punctuated equilibrium that explains significant leaps in the fossil record from one major organism type to another (see Raup, 1989), and dissipative structures that explain the potential for abrupt changes in physical system states (see Kay et al., 1999) (Hardesty, 1986).

[20] Fiorino (1995) provides a brief overview of several public policy models including the systems, institutional, net benefits and group process models, as well as an account of bounded rationality and incrementalism.

[21] Roe (1991, 1994) outlines the narratives associated with the tragedy of the commons; land registration and increased agricultural productivity; systems analysis and sectoral integration; and repetitive budgeting by national governments.

[22] According to Vandergeest et al. (1999), political ecology is an integration of cultural/human ecology and political economy. However, Berkes (1999) points out that political ecology is different from political economy which tends to reduce all things to social constructions, excluding to a large extent ecological relationships in political, economic and institutional analyses.

[23] Brackish ponds have been used for aquaculture production in Indonesia since the 1400s, and as early as several hundred years ago in South Sulawesi, although it is a much more recent activity in the study area.

[24] Major components of water discharge waste from aquaculture developments include nutrients, organic solids, chemicals and bacteria (Flaherty and Karnjanakesoran, 1995; DeWalt et al, 1996).

[25] Intensive shrimp culture, for example, requires an average water exchange of approximately 5-10% of the total pond volume per day in the early stages of growth and 30-40% of the total pond volume per day during the later stages (Flaherty and Karnjanakesoran, 1995)

[26] It is difficult to offer unambiguous empirical evidence to support such an assertion, although perceptions of corruption are widely held by local individuals I spoke with during the course of this research project, and reaffirmed by personal experience.

[27] In Indonesia, however, the success of markets and commodities such as those associated with fish pond production are a result of bureaucratic expansion into all sectors of the domestic and export economy, rather than through a reduction of state market influence as neoliberal economic theory proscribes (see Lowe, 2000)

[28] Such assertions need to be understood as well in the broader Indonesian context in which ethnic tension between Indonesians of Chinese and Malay descent are long standing.

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[29] The process of allocation and acquisition of property rights for aquaculture production was an issue raised by several individuals participating in the focus group discussions and workshops undertaken in the Banawa Selatan area as part of this research project.

[30] The term "slash and burn" and "shifting cultivation" will not be used here to describe the upland agroecological system of the Da'a because of their pejorative nature. Although the Da'a do "slash" and "burn", for example, these terms do not adequately describe the complexity of the Da'a land use system. Nevertheless, the terminology of slash and burn is still widely used in the development planning literature and much of the environmental literature usually because it is associated with calls for its modification and/or eventual elimination.

[31] Myers (1992) seeks to distinguish between traditional shifting cultivators and non-traditional shifting cultivators (i.e., those forced to new locations because of land scarcity in their own areas). However, numerous historical and political factors make such a distinction difficult and make, in my opinion, such conclusions suspect. More importantly for the argument here, policy makers tend not to account for such a distinction, perceiving shifting cultivation generally as destructive, and thus contributing to the general narrative of the degrading influence of local resource management practice.

[32] Although the focus of this analysis is on the agroecological system of the Da'a and its implications for conservation and development, reasonable inferences to the other Kaili groups in the area can be made based on this understanding.

[33] This information is based on the results of focus groups, interviews and a review of literature from similar contexts. However, it is recognized that a detailed household survey of upland swidden farmers is required to verify these findings and to develop detailed household-level data on the amount of land used for swiddens and their respective fallow periods.

[34] Detailed historical evidence on fallow length in the Banawa-Marawola uplands is not available. However, based on trends identified in other jurisdictions (Henley, 2000) it is likely that the length of fallows has decreased in the region (particularly in the eastern portion of the uplands where there is a greater trend towards cocoa production). It is important to keep in mind, however, that the cause of decreased fallow periods is not simply a result of increasing populations but a result of a number of diverse factors coalescing to undermine a resilient and sustainable strategy for its context.

[35] The cycle of clearing and renewal associated with upland swidden practice is a practical example of Holling's (1994, 1995) four-phase ecosystem development concept (see section 3.2). The small-scale disturbance created by a swidden patch eventually regenerates and leads to reorganization and renewal. At this small scale, resilience and integrity are maintained.

[36] In other words, the *mompepoyo* ritual would fall into the domain of certainty, predictability and control, all of which is counterintuitive to the belief system of local groups which is partly premised upon a belief and/or recognition that natural systems cannot be controlled and that to do so will inevitably falter.

[37] The term "mature" is used here because even when swidden farmers express a desire to clear what is typically interpreted to be "primary" forest, it is unlikely to be forest that has not experienced some previous form of human disturbance.

[38] It should also be pointed out that this analysis does not account for the condition of secondary forest and is further influenced by classification error.

[39] I would like to stress (as I indicate in the main text) that the Fragstats™ analysis undertaken is preliminary. As a result, there are two primary limitations associated with the data and subsequent analysis. First, without comparative longitudinal data, inferences about change are difficult. Second, the methodology and protocol followed were "rudimentary". In other words, I used an "unsupervised" classification scheme with a limited number of ground control points used for verification purposes. As a result, the results are simply intended to provide a preliminary or "first-cut" analysis which offer an initial baseline from which additional, more detailed RS/GIS analysis can begin.

[40] The selected landscape metrics used to illustrate conditions in the Banawa-Marawola uplands include several basic FragstatsTM measures. A description or definition for each follows (adapted from Bridge et al., 2000): (1) Total Core Area and Total Cores Area as a percent of Class: the area within an individual class that is greater than 200m from the edge or calculated as the sum of all core areas in a class, along

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with the percent of core area within each class (the more core area within a class the less fragmented the class is likely to be); (2) Mean Patch Size: the arithmetic mean of all patch sizes within an individual class (e.g., mature forest); (3) Mean Nearest Neighbor: the average distance (in metres) between the edge of each patch and the edge of the nearest neighbor in the same class (the shorter the mean distance, the less isolated the patches); (4) Total Edge: the total amount of edge for each class (in metres) representing a measure of inherent diversity and the degree of disturbance); (5) Shannon's Evenness Index: measures (from "0" to "1") how evenly the total landscape area is divided among the various patch types. A value close to zero would suggest a very uneven distribution of class types (one class type dominates, such as secondary forest).

[41] It is essential to note that the 200 metre buffer criteria actually comes from boreal ecosystems in the context of forest management planning requirements (Bridge et al., 2000). However, it is used here as a proxy criteria in the absence of a more suitable buffer requirement for the tropical forest ecosystems found in Central Sulawesi.

[42] Gunderson (1999) uses a similar propositional analytical approach to evaluate adaptive management more generally.

[43] Decentralization is an often used but rather vague term. According to Manor (1999), three forms of decentralization can be identified: (i) deconcentration (or administrative decentralization) involves the dispersal of central or higher level government agents into lower government levels; (ii) fiscal decentralization involves downward fiscal transfers in which higher government levels pass on authority over budgets and financial decisions to local or lower government levels; and (iii) devolution (or democratic decentralization) refers to the transfer of resources and power to lower level authorities for the most part independent of central government authorities and which are themselves democratic in their structure and function. Indonesia is attempting to promote the latter model, although the role of central government authorities is still significant.

[44] The Consultative Group on Indonesia (CGI) is composed of key donors, the World Bank, International Monetary Fund and the Government of Indonesia.

[45] For descriptive examples of village governance in the Indonesian context (albeit in Bali and not Sulawesi), see Mitchell (1995) and Gertler (1995)

[46] The Canadian International Development Agency (CIDA) through the University of Guelph implemented the Sulawesi Regional Development Project in which the promotion of bottom-up, participatory planning in provincial government agencies was a primary objective (see for example, Ferrazi et al., 1993).

[47] Ficus is considered "sacred" in many areas throughout Asia (F. Berkes, personal communication, December 5th, 2001; see also Gadgil et al., 1993)

[48] *Ngata* is a term also used to identify an entire territory or village

[49] In turn, such government sponsored official spatial planning exercises are often ignored or circumvented due to inadequate regulation, enforcement and/or corrupt practices (B. Mitchell, pers. comm., 2001).

[50] See Schelhas and Greenberg (1996) for a more complete discussion of the positive and negative elements of mature regenerating forest patches in tropical contexts.

[51] Based on observations during fieldwork in 2000, there were few examples of large standing trees in recently cleared lands. Given that few traditional swidden cultivators possess gas-powered chainsaws, the extent to which local sawmill operators are influencing the removal of larger trees needs to be better determined, although their capacity to create a significant localized impact is substantial.

[52] I have not clearly understood the seeming contradiction between *ramaiya* and the *mompepoyo* ritual, but it is likely a factor in specific types of land.

[53] Transgressions have historically been "monitored" on an informal basis by community members. No sanctioned "regulators" were identified although they may exist. This particular issue was beyond the scope of this dissertation.

[54] See Dove (1993) for discussion of decline of *adat* among the Kantu of Kalimantan.

[55] The people of the *Kamalise* movement are named after Gunung Gawalise (Mt. Gawalise) and cover most of the uplands of Banawa and Marawola.

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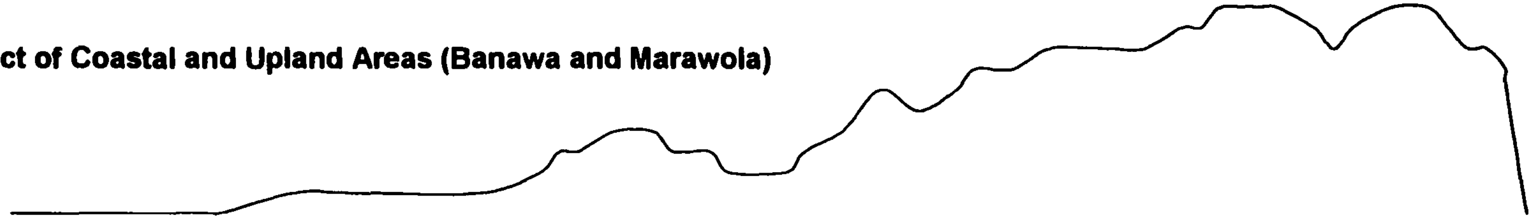
[56] I would just reiterate that the intention of the critique of the formal administrative bureaucracy in Central Sulawesi is not intended to single out the limitations of government in that particular region, nor suggest fundamental inadequacies in institutions and organizations in developing countries in the absence of a detailed treatment of historical socio-political and economic influences. Rather, the intent of the analysis is to raise awareness and understanding in an explicit manner of the limitations (and opportunities) that do influence opportunities for adaptive management in Central Sulawesi. A reader may be inclined to argue that the same limitations are as likely to exist in Ontario as they are in Central Sulawesi (e.g., entrenched power inequities among system actors complicate resource decision making). However, while this may be true in a general sense, the specific manner in which the limitations and opportunities for adaptive management unfold in any two jurisdictions are in my opinion very different, *likely* to be more acute in places like Central Sulawesi, and therefore, require explicit analysis.

[57] Although the potential for an increasing loss of older-growth forest and late successional fallow lands is not necessarily protected against in this conceptualization of multiple steady state land use configurations, opportunities for the maintenance of system integrity and resilience are much greater than they would be if lands are converted to permanent estate crops (e.g., cocoa). As well, local users are more likely to sustain the conditions in which traditional agroecological strategies can be continued given the links to the socio-cultural identify of local people.

[58] The current district spatial master plan is considered incomplete because it was prepared prior to the implementation of Law 22/1999 and was only based on input from mainline governmental agencies. As a Bappeda representative explained, a revised plan must be prepared that incorporates community desires and aspirations. The incorporation of such aspirations into the spatial plan would eliminate ongoing sources of conflict between local groups and transmigrated "outside" communities (although the conflict is more likely based on the support which governmental agencies give to transmigrant communities). Consequently, communities must produce specific recommendations for incorporation into the spatial master plan. However, a few issues are associated with this perspective. First, although community aspirations are to be incorporated into the planning process, there has been no identification of the mechanisms to ensure participation and relevant input. More strategically, the discourse inherent in the Bappeda perspective is that the adat resource management systems and insights must be adapted to fit into the formal, top-down planning process. There is no recognition at Bappeda of the value of utilizing adat frameworks as the basis for spatial scaling, and therefore, planning and building on local knowledge systems.

[59] This process is also connected to renewed debates regarding the "political resurgence of the commons" (Goldman, 1998).

Annex I: Transect of Coastal and Upland Areas (Banawa and Marawola)



Zone	Coastal	Uplands (middle hills)	Uplands (inner hills)
Rainfall and Climate	Seasonal (bi-modal) rainfall; continuous humidity	Seasonal (bi-modal) rainfall; continuous humidity	Seasonal (bi-modal) and frequent rainfall; dense and continuous cloud cover, fog and mist; cool evenings
Soils	Fluvisols and regisols	Regisols, podzols and lithosols	Podzols and lithosols
Vegetation	Grass, bush, mangrove forest, light secondary forest	Light secondary forest, grass, bamboo, scattered primary forest remnants	Secondary and primary forest, bamboo, grasses
Wildlife	Limited	Endemic wild pig, civet cat, babirusa, anoa, macques	Endemic wild pig, civet cat, babirusa, anoa, macques
Primary Land Use	Fish pond, mixed agriculture (estate crop plantation, e.g., cocoa, coconut, clove; secondary food crops, e.g., corn, banana, etc.)	Mixed agriculture (estate crops and secondary food crops, e.g., corn, cassava, banana, etc.)	Swidden agriculture (corn and rice, along with secondary food crops, such as cassava, taro, banana, sweet potato, etc.)
Other Resource Extraction and NTFP Use	Fuelwood, charcoal, copra, fish, fruit tree crops	Bamboo, timber, sago, river shrimp, durian, langsat	Bamboo, rattan, timber, wild pig, sago, durian, langsat
Ethnic Composition	Buginese, Mandarese, Torajanese, Ledo, Unde	Unde, Da'a	Da'a
Religion	Islam	Christian	Christian
Key Environment and Development Issues	Mangrove forest conversion; intensification of estate crop production, fishery decline	Timber extraction, forest concessions, forest cover change, cultural change and settlement of swidden cultivators, transmigration	Timber extraction, forest concessions, forest cover change, cultural change and settlement of swidden cultivators, transmigration

MBUWU VILLAGE
Protecting and Improving Environment and Forest

(Results from workshop in the Bantaya, Uedepu (Mbuwu); 06/10/2000)

I. ROLES AND RESPONSIBILITIES:

(i) Aparat Desa / LKMD (village government)

- ✓ Provide information to people about the importance of maintaining forest

(ii) Masyarakat (community: farmers, fisherman, etc.)

- ✓ Agree not to cut forested areas but instead be involved in protecting the resource
- ✓ Only cultivate available land and/or ova – not open new lands for cultivation
- ✓ Learn new methods for intensive cultivation that maintain soil fertility

(iii) Lembaga Adat (traditional institutions)

- ✓ Adat laws/regulations must play a central role in village development
- ✓ Although weak at present, can still provide a basis for better decision making; therefore, adat leaders and institutions should play a central role in all decision making
- ✓ Adat leaders and institutions should be allowed to participate; the traditional process of Nolibu should be used
- ✓ Apply sanctions when adat regulations are broken

(iv) Pemda (regional government)

- ✓ Provide information and knowledge on how to cultivate estate crops (e.g., cocoa); provide practical farmer extension. If farmers received this information they would be able to let more land return to forest
- ✓ Provide an improved road and assistance to improve housing
- ✓ Strengthen and support adat laws/regulations

(v) GEMABANGDESA

- ✓ lack of awareness of meaning and intent and therefore not recognized as having a role

LALOMBI VILLAGE
Protecting and Improving Environment and Forest
(Results from workshop in the Village Office; 4/10/2000)

I. ROLES AND RESPONSIBILITIES:

(i) Aparat Desa / LKMD (village government)

- ✓ Full responsibility for mangrove forest preservation and lead planning and organization process
- ✓ Raise community awareness about importance of mangrove forest protection
- ✓ Determine boundaries and develop zoning for mangrove area that identifies areas for protection, harvest, conversion; send results to Bupati for approval
- ✓ Take a lead role in granting permission for resource harvesting activities
- ✓ Help administer sanctions

(ii) Masyarakat (community: farmers, fisherman, etc.)

- ✓ Protect mangrove by:
  - ✓ providing information to adat leaders
  - ✓ providing suggestions and proposals on how to protect mangrove forest
  - ✓ cooperate with various institutions
  - ✓ keep an eye on things

(iii) Lembaga Adat (traditional institutions)

- ✓ determine local regulations for protection and sustainable use of the mangrove forest
- ✓ determine sanctions, set fines, and apply sanctions (not necessarily money, but could be livestock, etc.)
- ✓ reconstruct and regenerate adat regulations within the community (e.g., ombo)

(iv) Pemda (regional government)

- ✓ maintain current role in permitting, licensing; however, Pemda should make decisions based on the desires of individual communities
- ✓ strengthen role of adat regulations and then use adat regulations as a basis for decision-making
- ✓ responsible for disseminating information and raise awareness
- ✓ provide financial assistance to communities for protection/restoration initiatives

(v) GEMABANGDESA

- ✓ lack of awareness and understanding of role of GEMABANGDESA
- ✓ some individuals indicated that GEMABANGDESA could be focal point for leading mangrove forest protection/restoration (pioneer)

II. ACTION PLAN

Key activities	**Responsibility**	**Timeframe**
1. Musyawarah	✓ Aparat Desa ✓ LKMD ✓ Masyarakat	✓ November (dengan MusBangDes)
2. Spatial Plan (zoning and boundary delimitation)	✓ Masyarakat ✓ Assistance from external groups (e.g., LSM)	✓ To be determined
3. Develop strategic plan for required actions (detailed plan of action)	✓ Masyarakat ✓ LKMD ✓ LMD (with Adat)	✓ To be determined
4. Implement key activities (planting seedlings, seedling protection)	✓ Masyarakat	✓ To be determined
5. Maintenance (weeding, seedling maintenance, physical maintenance)	✓ Masyarakat	✓ To be determined
6. Supervision, monitoring an enforcement	✓ Pemda for regulations; awareness raising ✓ Masyarakat	✓ To be determined
7. Reporting	✓ LKMD ✓ LMD	✓ To be determined

TOLONGANO VILLAGE

Protecting and Improving Environment and Forest

(Results from workshop in the Village Office; 11/10/2000)

I. ROLES AND RESPONSIBILITIES:

(i) Aparat Desa / LKMD (village government)

- ✓ hold a village meeting to determine plan of action
- ✓ identify mangrove forest locations to be improved and protected
- ✓ confirm status of the izin for tambak owners (**if discrepancy, than extra tambak area should be reclaimed)
- ✓ provide results to Pemda
- ✓ Apply APPKD to tambak owners (15,000 Rp/ha/harvest)
- ✓ Increase the power of the Tokoh Adat within the LMD

(ii) Masyarakat (community: farmers, fisherman, etc.)

- ✓ Determine if there are locations where mangrove forest can be planted and protect the remaining areas of mangrove forest
- ✓ Masyarakat should be involved not only in implementing activities but in planning them as well
- ✓ Tax tambak owners and give percentage to village, not have all go to Pemda Tingkat II

(iii) Lembaga Adat (traditional institutions)

- ✓ Provide knowledge and information to masyarakat and help plant around edges of tambak areas
- ✓ Reconstruct and return to adat regulations/laws that previously existed (community members will be more willing to follow adat law)
- ✓ Pemda should agree to promote and support adat law

(iv) Pemda (regional government)

- ✓ Check the izin of all tambak owners and take land back if there are discrepencies
- ✓ Pemda should refer to results from MusBangDes when making policy or granting izin to outsiders
- ✓ Provide awareness about how to improve environmental management
- ✓ Construct a wall along the coast to help prevent coastal abrasion

(v) GEMABANGDESA

- ✓ lack of awareness and understanding of role of GEMABANGDESA
- ✓ there is a need to socialize the community about the role of Gemabangdesa
- ✓ should facilitate the relationship between various levels of government, different agencies and the village

II. ACTION PLAN

Key activities	Responsibility	Timeframe	Results and Hopes
8. Musyawarah	✓ Kades	✓ Januari (dengen MusBangDes)	✓ Village decision to improve and protect mangrove forest
9. Field survey of conditions	✓ LKMD ✓ Aparat Desa	✓ To be determined	✓ Recognize and address the need for planning
10. Develop a village master/spatial plan	✓ LMD ✓ Aparat Desa ✓ Pemda	✓ To be determined	✓ Obtain ownership data ✓ Obtain data on natural resources and land use
11. Implement key activities	✓ LKMD ✓ Masyarakat	✓ To be determined	✓ Improvement in the situation; in the environment ✓ Improvement in situation of coastal abrasion