Evaluation of a Spatial Habitat Suitability Model for the Northern Goshawk (*Accipiter gentilis*) in West-central Alberta

by

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"Goshawks were Hamlet, were Ludwig of Bavaria. Frantic heritors of frenetic sires, they were in full health more than half insane."

T.H. White. 1951. *The Goshawk.*

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Abstract

The current era of forest management has expanded the array of values, spatial dimensions and temporal horizons beyond those formerly considered in the planning process. The desire to evaluate the impact of various management scenarios on biodiversity has prompted the development of tools such as habitat suitability models. The implicit but frequently untested assumption in the application of these models is that their outputs accurately reflect real-world habitat use.

As part of the Biodiversity Assessment Project, Millar Western Forest Products Ltd. developed spatially-explicit habitat supply models for 17 wildlife species. The objective of this study was to evaluate the performance of the previously untested habitat suitability model for the Northern Goshawk (*Accipiter gentilis*).

The model was first reviewed for agreement with current literature in terms of computational methods and outputs across forest cover-types. A sensitivity analysis of the model directed field studies and illustrated that forest cover-type was the most influential variable within the nesting component of the model.

Field investigations revealed the model's inability to identify goshawk nesting habitat correctly. Identified goshawk nest sites (n = 15) had an average nesting suitability value of only 0.25 (on a scale of 0 to 1). A negative correlation between modelled nesting suitability values and actual habitat use was also observed.

Improvements to the nesting component of the model were made in regard to forest cover-type, canopy closure, and proximity to roads. A modification to the method used to calculate foraging habitat was also suggested. These modifications improved model performance with respect to known nest sites, but only within the limits of input data. Discrepancies between forest inventory and field data were frequent as field-collected data commonly reported trembling aspen cover where the forest inventory did not. These discrepancies resulted in model modifications improving nesting scores for known sites from 0.25 to 0.45 using inventory data and from 0.35 to 0.94 using data collected directly from nest sites.

Model outputs were examined across a 200-year planning horizon using three forest-management scenarios to test the relative impact of model alterations. Results from this procedure illustrated similar trends within and between scenarios using both the original and modified models. Consequently the modified model would be unlikely to alter management decisions under a system where scenarios are evaluated in relation to each other.

1 Introduction

1.1 Project Overview

The current era of sustainable forest management has expanded the array of values, spatial dimensions and temporal horizons previously considered in forest management (Van Damme *et al.* 2003). The need to accommodate changing social values across North America is illustrated in the continued evolution of environmental policy, legislation, and certification systems (Patton 1992, Doern and Conway 1994, Fedkiw 1998, Burton *et al.* 2003). Similarly, computer modelling tools and decision support systems have grown to address the complexity of information and values now addressed in the forest management planning process (Messier *et al.* 2003).

Habitat models represented one of the more common forms of models used to aid in the forest management planning process (Van Horne and Wiens 1991, Patton 1992, Brooks 1997, Morrison *et al.* 1998). The use of species-specific habitat models (i.e., fine-filter) in conjunction with broader ecosystem diversity and landscape configuration analysis (i.e., coarse-filter) has been promoted as an effective and efficient means to evaluate the potential impacts of various forest management alternatives (Hunter 1990, Duinker *et al.* 2000).

Habitat models, like all models, are simplified representations of reality and are created to describe, analyse, understand, or predict behaviour (Hall and Day 1977, Morrison *et al.* 1998, Messier *et al.* 2003). In some manner, the simplified composition of models is similar to the general nature of scientific theory. As Kenneth Waltz (cited in Kuehls 1996) suggested:

The Northern Goshawk was one of the species for which a BAP habitat model was created. Provincially, only one thorough study of the species had been conducted (Schaffer 1998), and consequently the model relied upon this single study and habitat-relationships described in other ecosystems (Higgelke and MacLeod 2000). The relative rarity of the species, its potential sensitivity to forest management activities, its status on the provincial Yellow B list, and the general scarcity of information on the species within the boreal forest all highlighted the need for further study (Crocker-Bedford 1990, Schaffer 1998, Blancher 2003).

1.2 Project Objectives

There were four main objectives in this research project:

1. Review the model with respect to current literature, model outputs across forest cover types, and computational methods to determine if the model was in agreement with all literature and produced reasonable results across forest cover types;
2. Conduct a sensitivity analysis of the model to determine the degree of model sensitivity and to direct field studies toward the most uncertain and influential aspects of the model;
3. Conduct field studies to evaluate the ability of the model to identify suitable nesting habitat accurately, with specific attention to the variable(s) identified above as most sensitive. It was hypothesised that search effort would illustrate a positive correlation between modelled nesting suitability values and observed goshawk habitat use and that located nest sites would have a high modelled nesting value; and

2 Literature Review

2.1 Northern Goshawk

2.1.1 Taxonomy and Range

Though containing a relatively large number of species globally, the Accipiter genus is represented by only three species in North America (American Ornithologists' Union 1957). The Northern Goshawk (*Accipiter gentilis*) is largest of the North American accipiters, with the Cooper's Hawk (*Accipiter cooperii*) and Sharp-shinned Hawk (*Accipiter striatus*) comprising the other species found on the continent (American Ornithologists' Union 1957). Two subspecies of goshawk are officially recognized in North America: the widespread *atricapillus* subspecies occupying the entire range of the species in North America, except for the Queen Charlotte Islands which contain the *laingi* subspecies (American Ornithologists' Union 1957, Squires and Reynolds 1997).

The goshawk is discernible from other birds of prey through several distinctive characteristics such as size, shape, and unique plumage. Adult birds are approximately raven-sized (male length = 55 cm, wingspan = 98-104 cm; female length = 61 cm, wingspan = 105-115 cm), and maintain the general accipiter characteristics of a comparatively short wingspan and long tail (Squires and Reynolds 1997). Like all accipiters, goshawks exhibit reversed sexed-sized dimorphism with adult males weighing 631-1,099 g and the larger females ranging from 860 to 1,364 g (Squires and Reynolds 1997). Adult plumage is unique with upperparts of uniform gray or slate-gray and underparts of pale-gray with fine barring (Sibley 2000, Figure 1). Adults also have a dark-capped head with a prominent white stripe over the eye. Juvenile birds are more difficult to identify as the first-year plumage of goshawks and other accipiters is quite

States to Mexico (Squires and Reynolds 1997) (Figure 2). It is estimated that more than 25% of the global population of Northern Goshawks inhabit the boreal forest of Canada (Blancher 2003). Throughout its breeding range, the goshawk is commonly a year-round resident though large winter migrations from northern habitats can occur during periods of low prey availability. Particularly, in parts of the range where the species is reliant on snowshoe hare, populations are known to migrate in large numbers at ten-year intervals corresponding to the hare cycle (Erdman *et al.* 1998).

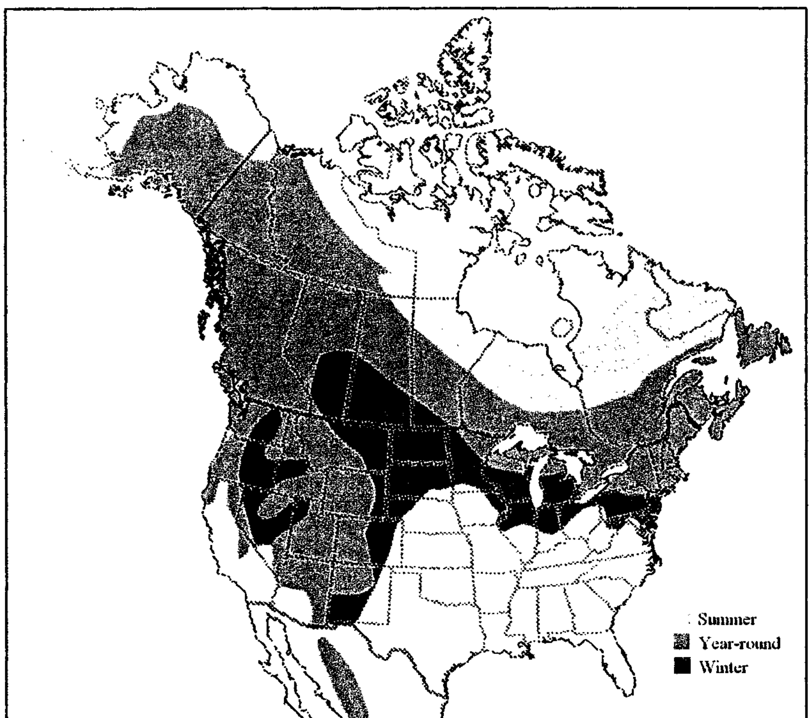

Figure 2. Northern Goshawk distribution in North America (adapted from Sibley 2000).

2.1.2 Breeding Chronology and Success

Goshawks in central Alberta typically select their nesting site in early March and, with successful breeding, remain within the territory until late August (Squires and Reynolds 1997, Shaffer 1998, Figure 3). The annual breeding cycle commences with the

2.1.3 Habitat Use and Preferences

Nesting Habitat

Early goshawk studies commonly consisted of qualitative descriptions of behaviour and the immediate habitat of a limited number of nesting pairs (e.g. Dixon and Dixon 1938). Later studies focused more on quantitative accounts of habitat characteristics at the nest site and nest stand (e.g. Speiser and Bosakowski 1987, Squires and Ruggiero 1996). Research interest further expanded to consider habitat selection at scales of the post-fledging area (Kennedy *et al.* 1994, Daw and DeStefano 2001) and home range (Hargis *et al.* 1994, Penteriani and Faivre 1997, Penteriani *et al.* 2001, Tornberg and Colpaert 2001). Concurrent with an interest in habitat selection at varying scales was concern over the species' response to forest management (Crocker-Bedford 1990, Penteriani and Faivre 2001) and the development of management guidelines for the protection of the species (Reynolds 1983, James 1984, Reynolds *et al.* 1992).

Goshawks appear to exhibit preferences for nest-tree species based on the particular region in question. For example, goshawks most commonly nest in American beech (*Fagus grandifolia*) and black birch (*Betula lenta*) in New York and New Jersey (Speiser and Bosakowski 1987), in white birch (*Betula papyrifera*) in Alaska (Iverson *et al.* 1996), and lodgepole pine (*Pinus contorta*) in Wyoming (Squires and Ruggiero 1996) and British Columbia (Mahon *et al.* 2001). In Alberta, goshawks most commonly nest in mature trembling aspen (*Populus tremuloides*) (Todd 1991, Schaffer 1998). In addition to species preference, the specific nest tree utilised is generally one of the largest existing within the stand (Reynolds *et al.* 1982, Speiser and Bosakowski 1987, Squires and

Table 1. Summary of Northern Goshawk nest area characteristics from other studies in North America (adapted from Bosakowski 1999).

Location (State/Province)	Sample Size	Basal Area (m^2/ha)	Mean dbh (cm)	Canopy Closure (%)	Tree Density (stems/ha)	Nest Tree Height (m)	Nest Tree dbh (cm)	Nest Height (m)	Source
California	12	-	27.1	77	749	34.4	74	16.8	Saunders 1982
California	12	90	58	88	279	43	91	21	Hall 1984
Idaho	26	28.5	31	75	-	26	43	14	Patla 1997
Montana-Idaho	17	40.6	-	80	1135	26	50	12.5	Hayward and Escano 1989
New Mexico	11	-	22	-	959	25.9	57	16.9	Kennedy 1988
New York	12	25	-	-	-	24	46	15	Allen 1978
New York-New Jersey	16	32.2	27	90	540	24.1	32	12	Bosakowski *et al.* 1992
Oregon	7	-	27.4	60	482	33.5	82	16.2	Reynolds *et al.* 1982
Oregon	34	51.9	22.1	-	1007	-	-	-	Moore and Henny 1983
Oregon	12	-	-	81	-	34	65	15	Bull and Hohmann 1994
Utah	25	-	23.8	63	-	-	34	12.6	Hennessy 1978
Utah	10	-	27.5	68	720	22.4	43	11.3	Fischer 1986
Washington	7	-	43.1	64	-	27	-	15.7	Fleming 1987
Washington	12	-	48.3	60	-	32	-	19.2	Fleming 1987
Wyoming	39	50.8	-	67	-	21.4	32	11.9	Squires and Ruggiero 1996
British Columbia	8	35.5	22.8	52	701	20.9	35	12.3	Bosakowski and Rithaler 1997
Alberta	17	-	19.7	77	-	22.6	30	14.9	Schaffer 1998

then habitat alteration of these components could result in the decline of the species even though nests themselves are protected (Hargis *et al.* 1994).

Bosakowski and Speiser (1994) reported that two macro-habitat variables (distance to paved roads and elevation) were useful in predicting goshawk nest sites. These variables reduced the total area of suitable habitat by eliminating those stands which met the micro-habitat requirements of stand structure, but did not fulfill macro-habitat constraints. Grubb *et al.* (1998) believed that roads may be a factor in the suitability of nest sites, but that at distances greater than 400 m the existence of roads is likely not a significant factor.

Foraging Habitat

Though the majority of goshawk studies have focused on the analysis of nest-site attributes, some researchers believe that the nest site is of secondary importance compared to foraging habitat and prey availability (Janes 1985, Klopfer and Ganzhorn 1985). However, due to the difficulty in collecting data on foraging habitat use and prey consumption, the foraging behaviour and habitat requirements for the species are not as well documented as the characteristics of nesting habitat. Considerable debate exists as to which of the intertwined factors of prey abundance (e.g. Reynolds *et al.* 1992) or prey availability with respect to forest structure (e.g. Widen 1989, Beier and Drennan 1997, Good 1998) most influences populations.

Goshawks typically focus their hunting activities to the forest interior where they use a short-duration "sit and wait" technique of perching and searching for prey and then moving to a new perch after several minutes if prey is not located (Kenward 1982). The

dump. Snyder *et al.* (1994) reported that a female goshawk killed several Thick-Billed Parrots at a reintroduction release site in Arizona and continued to visit the area for at least a month after all birds were recaptured. These studies also indicate that foraging habitat is significantly different than random habitat on the landscape, with goshawks preferentially foraging in mature forests devoid of openings (Beier and Drennan 1997, Good 1998, Tornberg and Colpaert 2001).

The "Management Recommendations for the Northern Goshawk in the Southwestern United States" (MRNG) (Reynolds *et al.* 1992) adopted the approach that the requirements for goshawk foraging are best achieved through the provision of abundant populations of prey species. Accordingly, the MRNG proposed a mixture of seral stages and small openings interspersed throughout the home range. Beier and Drennan (1997) presented results contradictory to the MRNG assumptions by showing that goshawk foraging habitat was not selected on prey abundance, but rather by the structure of the forest. Beier and Drennan (1997) found goshawks selecting foraging sites that had higher percentage canopy closure, greater tree density, and greater density of large trees than random contrast points. While prey abundance and availability are inexorably related, Beier and Drennan (1997) presumed that as long as prey numbers are above a certain threshold, goshawks will select foraging areas based on the structural characteristics that best favour their hunting strategies rather than seek areas where prey densities are the greatest (Beier and Drennan 1997).

south-western United States sought protection for the Northern Goshawk through the two federal policy channels of the Endangered Species Act (ESA) and the National Forest Management Act (NFMA). Several petitions to list the goshawk as an endangered species were made, though all petitions were eventually ruled unwarranted (Peck 2000). Petitions were also made through the NFMA during the same time period. A request by environmental groups to halt all timber-harvest operations until the long-term survival of the species could be assured was rejected. Due to the range of Northern Goshawk in the western United States (e.g. west of the 100^{th} meridian), these petitions had the potential to be of greater impact than those surrounding the infamous spotted owl (McGrath *et al.* 2003). These protests and concerns did result in the formation of review committee that ultimately produced new forest management guidelines for the goshawk (Reynolds *et al.* 1992). However, the goshawk controversy in the south-western United States has been used to illustrate weaknesses in both the ESA and NFMA (Peck 2000).

2.1.5 Management Guidelines

Several guidelines have been developed to provide for goshawk habitat protection at the nest-site (Reynolds 1983, James 1984) and home-range scales (Reynolds *et al.* 1992). Management recommendations variously encompass simple nest buffering (James 1984), stand-level silvicultural guidelines (Lilieholm *et al.* 1993, Penteriani and Faivre 2001, Finn *et al.* 2002a), and landscape-level approaches focused on the provision of prey habitat in addition to nest-site requirements (Reynolds *et al.* 1992).

No-cut buffers are the simplest approach to the protection of goshawk habitat, but their effectiveness has been questioned by Crocker-Bedford (1990) who found dramatic

In Alberta there is currently no province-wide, regulated level of protection provided to stick nests during forest operations as each Forest Management Agreement holder formulates ground rules specific to its management area (Alberta Environmental Protection 1994).

2.2 Habitat and Habitat Modelling

The association between specific bird species and unique habitat conditions has long been recognized (Cody 1985). The mobility of birds allows them to exercise a degree of habitat selection beyond those of most species, and has led the study of habitat selection by birds to be an expansive area of research (Cody 1985). While such study has recognized that most bird species are not inflexibly tied to a single, specific habitat type (Klopfer and Ganzhorn 1985), the limits of flexibility must be fixed within morphological constraints (Cody 1981). The approach of habitat suitability index (HSI) models utilizing suitability index (SI) graphs is in general agreement with the idea that a species is likely to have thresholds of upper or lower habitat characteristics, but within these limits changes in the habitat feature may make little difference (Andrewartha and Birch 1984, Van Horne and Wiens 1991).

The methods used to discern the association of species to their environment are diverse. Describing the relationship between species and environmental variables has been conducted through a range of methods depending on the research question, availability of data, and structure of the measured variables. Methods include multiple regression, logistic regression, discriminant analysis, and principal component analysis (Morrison *et al.* 1998). Similarly, various types of habitat models have been developed ranging from highly empirical and quantitative forms to those which are more theoretical

appear as final versions rather than a representation of the best current working knowledge (Van Horne and Wiens 1991).

Habitat models are frequently created for prediction purposes such as impact assessment, but they often remain untested against real-world data because of logistical constraints (Morrison *et al.* 1998). Hundreds of HSI models have been developed in North America, yet very few have undergone field testing (e.g. Cook and Erwin 1985, Thomasma *et al.* 1991, Naylor *et al.* 1994a, Jones *et al.* 2002). Particularly sparse is peer-reviewed literature on HSI models and their validation (Brooks 1997). Results from studies that have tested the validity of habitat suitability models have often illustrated the need for model modification (Thomasma *et al.* 1991, Roloff and Kernohan 1999, Jones *et al.* 2002). These findings raise serious questions as to the appropriateness of using untested models (Van Horne and Wiens 1991, Roloff and Kernohan 1999).

Logically, the confidence in model results increases as the model progresses through development to testing against actual habitat use. This calibration process decreases the level of uncertainty associated with the model's predictions. Similarly, the level of risk in using a model decreases as the model is developed and model outputs are shown to reflect real-world habitat use (Figure 4). However, absent from Figure 4 is the idea that risk is also a function of model application. For example, applying model results to influence immediate research strategies is arguably a less risky process than using the model to direct long-term management strategies at the regional or provincial scale. Similarly, the evaluation of risk or comfort with uncertainty will vary between groups such as regulators, academics, and industry (Haas 2003). Therefore, the "risk"

range smoothing" approach used by the Biodiversity Assessment Project (BAP) model (Higgelke *et al.* 2000). The BAP goshawk model is the focus of this thesis, and is described in greater detail below.

2.3 BAP Northern Goshawk Habitat Supply Model

The HSM for the Northern Goshawk was created from expert opinion and a review of goshawk habitat use described in available literature. At the time of the model's creation, only one intensive examination of goshawk habitat use in Alberta had been conducted (Schaffer 1998). Literature based on research in the western United States (e.g. Hayward and Escano 1989, Hargis *et al.* 1994), eastern United States (e.g. Speiser and Bosakowski 1987, Erdman *et al.* 1998), and Scandinavia (e.g. Widen 1989) was also drawn upon.

The goshawk HSM follows the general envirogram form initially suggested by Andrewartha and Birch (1984), and further promoted by Van Horne and Wiens (1991). The model considers goshawk habitat in terms of both nesting and foraging requirements. Within each of these life requirements, three elements were considered to be vital to the determination of habitat quality (Figure 5). Foraging habitat is reported at the home-range scale (2,000 ha), while nesting habitat is calculated at both the nest-site (12 ha) and home-range scales (2,000 ha) (Table 2).

space in the understory to allow for the pursuit of prey, and 3) a high percentage of canopy closure to allow for concealment (Figures 6 a-c). As all of these elements are considered equally important for suitable hunting habitat, no compensation is allowed between them in the suitability equation (Figure 5).

The need for tall trees with suitable perches (Sf_l) is the first requirement for foraging habitat considered in the model. Though they may use stands with average tree height greater than 8 m, a height of 16 m is considered to be preferred, and greater than 24 m is thought to be optimal (Figure 6a).

The second variable included in the foraging model is understory manoeuvrability or free-flying space. This component of the model aims to balance the need to access prey with the potential disadvantages of a too-open understory. Highly entangled areas receive a low score as it is assumed prey will be inaccessible in these conditions. A very open understory may provide conditions more suitable for other raptors, and as a result these areas also receive a low value. Porous to obstructed understories are considered optimal and are assigned a value of 1.0 (Figure 6b).

The final variable included in the foraging model is canopy closure percentage. Specifically, areas with greater than 60% closure are considered optimal, though suitability decreases in areas with greater than 90% closure (Figure 6c).

the management area with centres one radius (2,525 m) apart. Within each circle, all foraging values are averaged together with the resulting mean value applied to the entire circle to give an indication of the area's overall foraging suitability.

2.3.2 Nesting Habitat

The nesting component of the habitat model considers the need for suitable tree species and age (Sn_1), canopy closure (Sn_2), and distance from roads (Sn_3). Because each aspect is considered equally important as nesting habitat, no compensation is given between them in the suitability equation (Figure 5).

A habitat table is used to assign values to the first nesting variable which considers the need for suitable nest trees. Appropriate nest trees are expected to be present in mature and overmature hardwood-dominated mixedwood stands (Table 3). Less suitable are mature and overmature pure hardwood areas. All other forest types are considered unsuitable.

the management area. Within each square, the maximum nesting value is selected and applied to the square. These values are considered to represent the best nesting opportunities located a sufficient distance from each other. Similar to the home-range-smoothing calculation used in the foraging component of the model, a circle of 2,000 ha moves over the management area with centres one radius (2,525 m) apart. Within each circle, the top four values from the 500 m^2 grids are averaged to give a representation of the four best nesting sites within the home range that would be a suitable distance from each other. The complete model document is included in Appendix I.

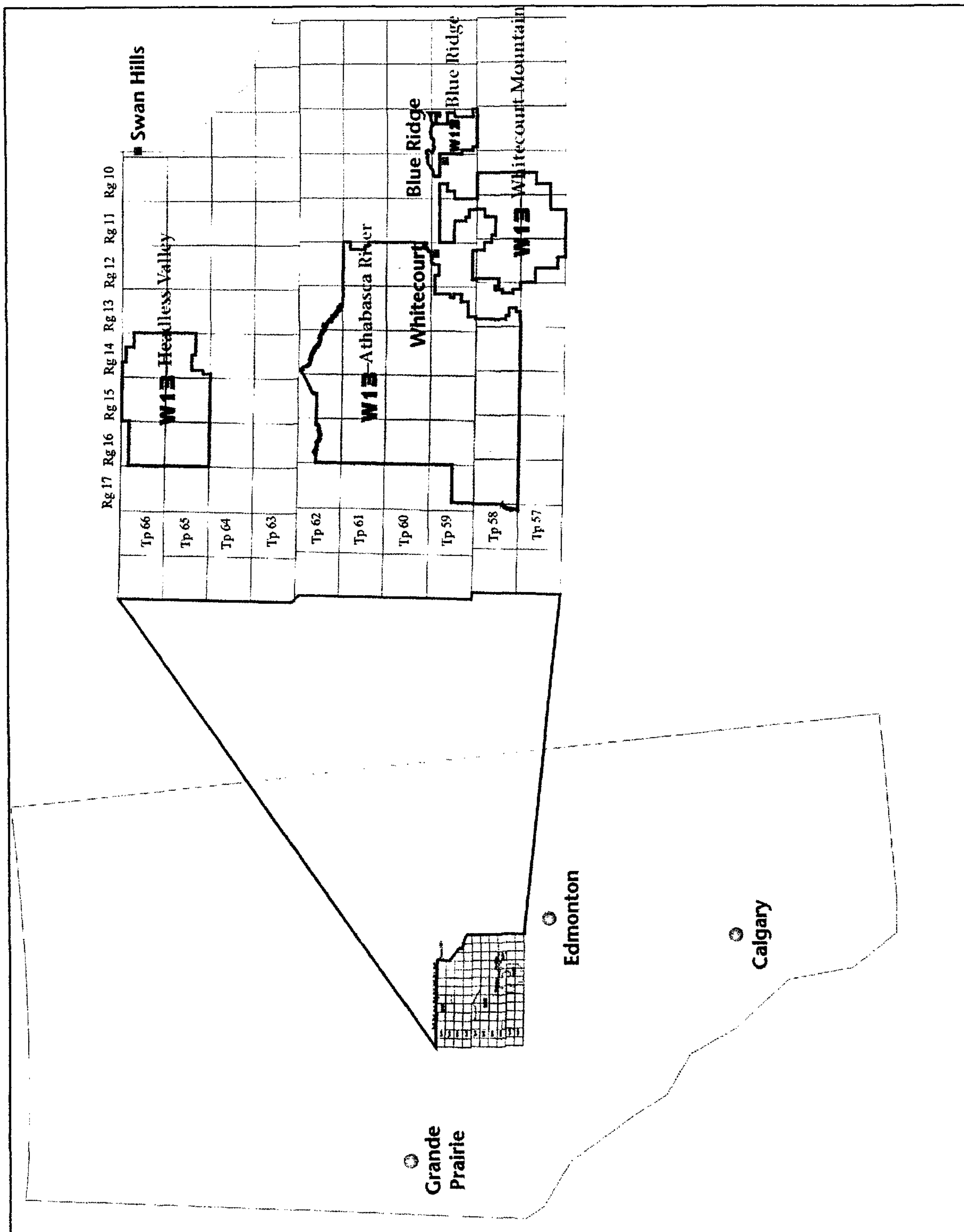

Figure 7. Location of the Millar Western Forest Products FMA area in Alberta (source: Millar Western Forest Products Ltd. 2000a).

assumption of the 500 m grid equating to areas being greater than 500 m apart may be invalid (Figure 8). The assumptions of this method would be legitimate if a small block of suitable habitat were to fall only into one of the 500 m cells, or a larger block of suitable habitat spanned the 500 m grid.

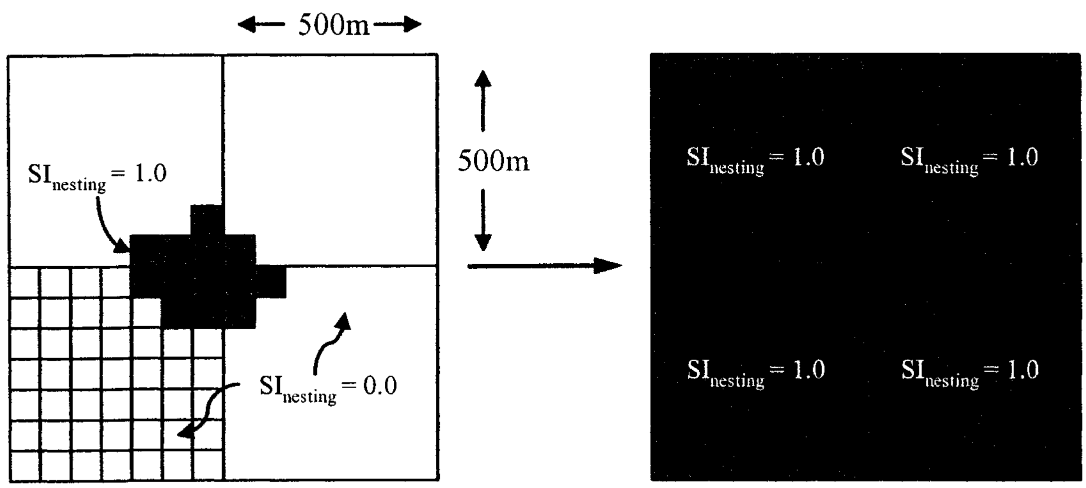

Figure 8. Illustration of how a home range may receive an artificially high nesting suitability value as the true distance between high quality nesting areas is less than 500 m. (Note: small cells represent 25 m x 25 m pixels and are not drawn to scale).

A program consisting of linear equations was created to investigate the possible extent and impact this potential miscalculation. The program consisted of a routine to sort all pixel values in a home-range circle. From this sorted list, the top value was selected as the first of the four highest values. The next value from the remaining list was then selected and tested to see if the distance between the values was greater than 500 m. If the distance criterion was fulfilled, this value was selected as the next most suitable site. If the distance criterion was not met, the next value in the list was tested. This process continued until four values were selected that each fulfilled the criterion of being greater than 500 m apart from the others. The average of these four values was then calculated and applied to the home-range centre. The overall results from this program

was considered a potential minimum and maximum value based on the literature. Within the realm of biological reasoning, these values were considered to represent the most conservative or lenient form the model could take. Thus, the amount of change represented by the maximum and minimum analysis varied for each variable. For the tabular cover-type variable (Sn_1), a similar minor and major change was applied by adding and subtracting more or less habitat types into the realm of suitable habitat. Overall, this "minimum and maximum" approach to change illustrated the model's response to relatively small alterations as well as potentially large deviations from current values. The percentage change between the mean FMA nesting and foraging scores was calculated between the original model and each sensitivity run. In total, twenty-four modifications (four modifications to each of the six model variables) were made to the model to test for sensitivity (Appendix III).

3.4 Search Effort

Sensitivity-analysis results (see Section 4.2) indicated that forest cover type was the variable that most influenced model results. In addition, studies in surrounding regions frequently report nesting in conifer-dominated areas (Bosakowski 1999, Mahon *et al.* 2001, Finn *et al.* 2002b). For these reasons, the discounting of conifer-dominated stands in the habitat model presented itself as one of the most likely variables requiring adjustment with potentially large changes to model output resulting from its refinement.

Search effort for goshawk nests was divided to search approximately equal areas of low (0 - 0.3), medium (0.4 - 0.7) and high (0.8 - 1.0) nesting-suitability scores. Search effort was similarly stratified between areas of coniferous-dominated and deciduous-dominated areas to allow analysis of cover type to be conducted, and test the hypothesis

searching was conducted in a 300 m radius surrounding the initial response site and any last point of contact. When an active nest was found, the surrounding 300 m was searched for alternate nests. Individual responses from mimics were not recorded, but commonly included the Gray Jay (*Perisoreus canadensis*) and Yellow-bellied Sapsucker (*Sphyrapicus varius*). Broadcasts also elicited infrequent responses from Broad-wing hawks (*Buteo platypterus*), Sharp-shinned hawks (*Accipiter striatus*), and Piliated Woodpeckers (*Dryocopus pileatus*).

Search area was quantified from the screen-digitizing of search area delineated on 1:15,000 Alberta Vegetation Inventory (AVI) field maps. Sightings of all raptors and stick nests were recorded, as were all sightings of other HSM species.

A presentation made to Millar Western staff on May 25, 2001, described the current knowledge of the Northern Goshawk in regard to habitat use, impacts from forest management, the HSM, and identification tips. Field staff personnel were asked to report any possible sightings of goshawks or goshawk nests.

3.5 Data Collection and Analysis

The primary objective of data collection was to relate observed nesting habitat with the variables used in the nesting component of the HSM. Field data were collected from the area directly surrounding the nest tree and four additional plots surrounding the nest tree. One 0.04 ha (r = 11.3 m) plot was centred on the nest tree with four surrounding plots located 30 m away in the cardinal directions (Figure 9). Located at the centre of the 0.04 ha plot was a 0.004 ha (r = 3.6 m) plot used to record finer habitat elements (e.g. shrub cover). This field layout has been used in other goshawk studies (Hargis *et al.* 1994, Schaffer 1998) and is believed to be effective as it captures data from a relatively

At each 0.004, ha plot the percentage of shrub cover was estimated within each of six height classes (0.00-0.25, 0.26-0.50, 0.51-1.00, 1.10-2.00, 2.10-3.00, and greater than 3 m). These height classes correspond to the values used in the Special Habitat Element (SHE) model for shrub cover (Doyon and MacLeod 2000).

Using the raw data collected from the plots, additional statistics were calculated and included total live-tree basal area (m^2/ha), tree density by diameter class (stems/ha), relative dominance of species (percentage of total live-tree basal area/species), and average live-tree dbh (cm). The tree-species composition of the nest sites was of particular interest given its strong influence on model output as illustrated through sensitivity analysis. In stands containing multiple alternate nests, the distance between all nests and the overall average distance between nests were calculated.

Using the AVI forest inventory and Geographic Information System (GIS), the proximity of each nest to water, roads, and clearings was calculated. Using the HSM outputs, the nesting and foraging suitability of each nest was recorded.

A preference index score was calculated for three HSM classes (0.0-0.3; 0.4-0.7; 0.8-1.0) to evaluate model performance. The index provides an account of actual habitat use with a standardization based on search effort, and has been used in other habitat-model validation exercises (Thomasma *et al.* 1991). A positive correlation between preference index score and habitat model classes would be expected and help corroborate the model (Thomasma *et al.* 1991).

$$\text{Preference Index} = \frac{(\%\ \text{goshawk nest sites within an SI class})}{(\%\ \text{area searched within an SI class})}$$

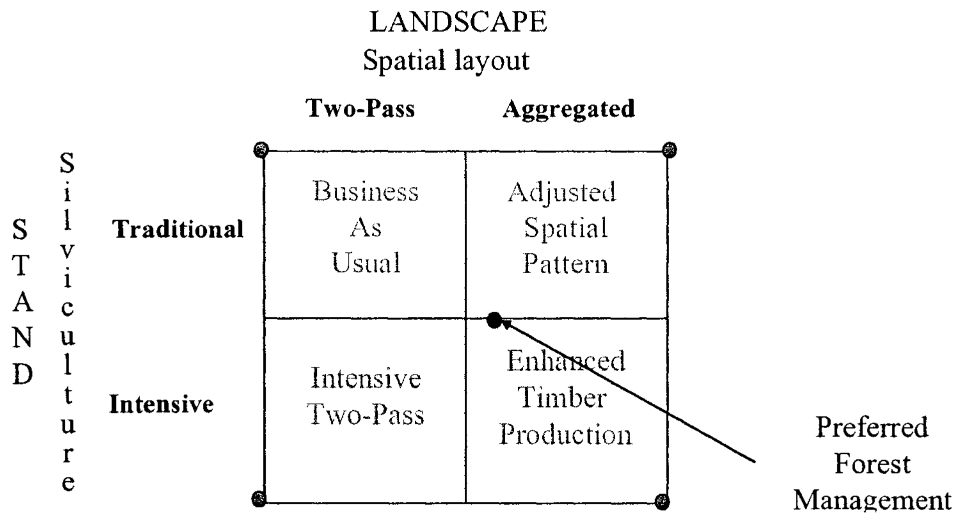

Figure 10. Matrix of forest management scenarios used in model analysis (Source: Millar Western Forest Products Ltd. 2000b).

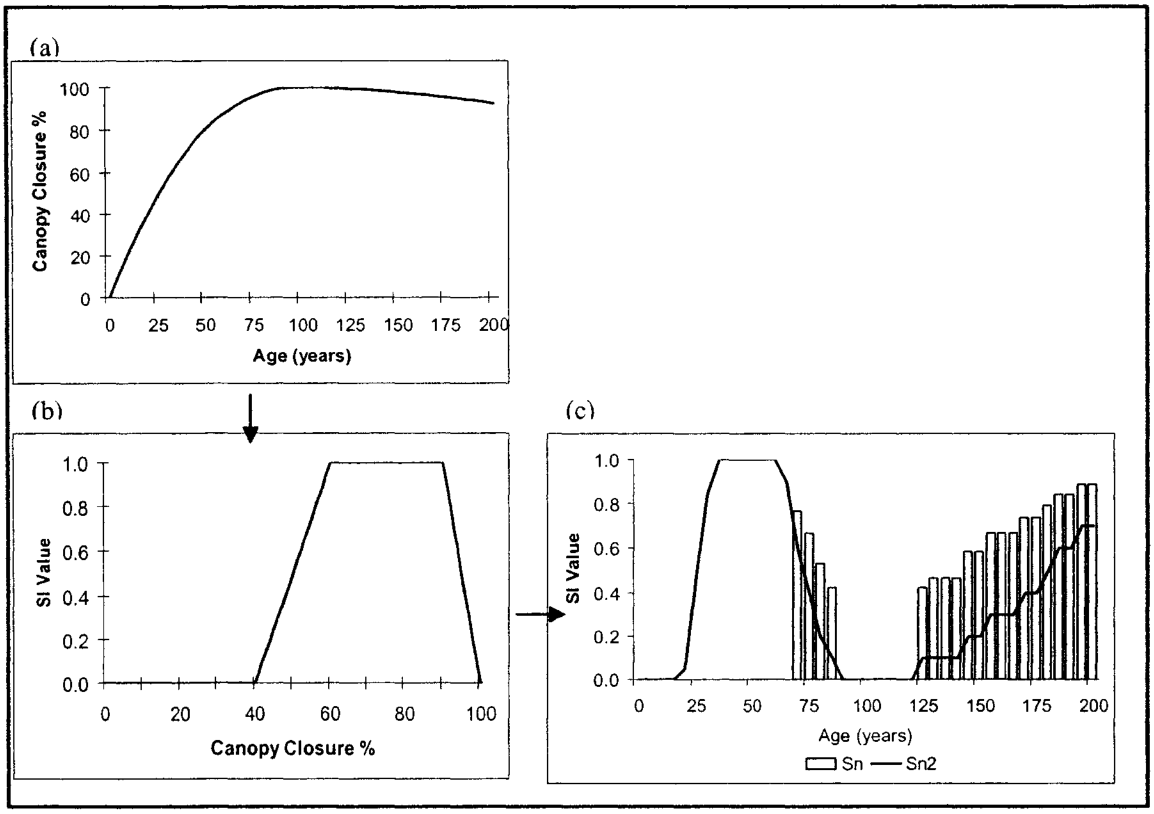

Figure 11. Nesting suitability of a mixedwood forest type (good site class) through time (c), based on modelled canopy closure values (a) and HSM suitability scores (b). (Note: S_n score assumes proximity to road (S_{n3}) equals 1.0).

The comparison of the model's blocking method of calculating the home-range-level HSM scores versus the linear-equation method illustrated little difference between the two methods. There was a minor reduction (7.1%) in the amount of 1.0 and 0.9 habitat values reported with the blocking method, with a comparable increase (7.7%) in the amount of 0.7 and 0.8 habitat scores using the linear program (Figure 12). The average HSM home-range nest score for the entire FMA only changed from 0.70 with the original method to 0.69 using the program of linear equations. Also, the spatial pattern of habitat values did not change dramatically between the two methods (Figure 13), further suggesting that the two methods yielded similar results. Overall, the minute difference

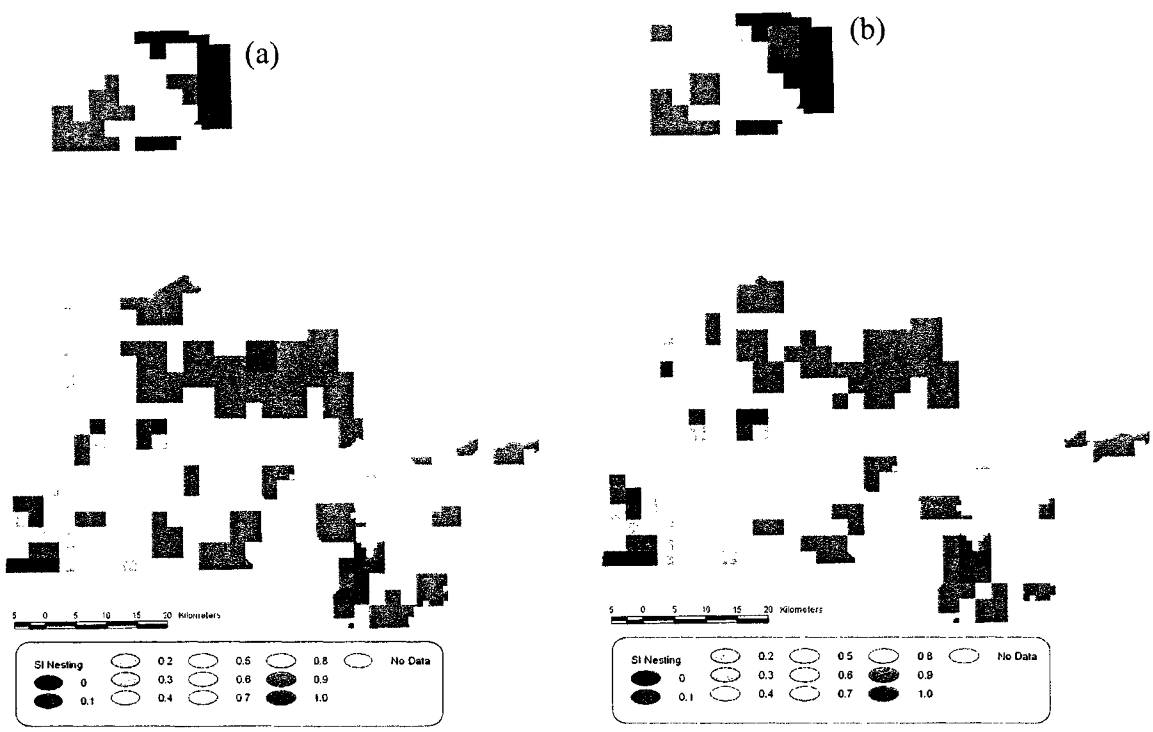

Figure 13. Comparison of nesting home range results based on blocking (a) and linear equation (b) methods (Scenario: PFM 1998).

4.2 Sensitivity Analysis

Sensitivity analysis results for the nesting portion of the model illustrated that cover type (Sn_l) was the variable that most influenced model results (Table 4). The maximum alterative indicated an approximately doubling (102%) of the mean FMA area nesting score (0.402 versus 0.198). Similarly, the other Sn_l sensitivity tests illustrated the most dramatic changes compared to the other variables. Indeed, four of the five greatest differences in the sensitivity tests were from the cover-type alterations. This result was not surprising as these sensitivity tests allowed coniferous-dominated areas to receive positive HSM scores. As over 55% of the FMA is comprised of coniferous-dominated areas, the inclusion of mature conifer areas in the model naturally led to significant impacts on the outputs.

Sensitivity results regarding the foraging component of the model all yielded similar results (Table 5). The greatest change was associated with the free-to-manoeuvre-flying-space variable (Sf_2) with the -10% and minimum change scenarios both reducing overall results by 24% (0.566 to 0.430). The majority of differences were small with nine of 12 alternatives producing results less than 0.1 in absolute change, and eight of 12 resulting in differences of less than 10% in relative terms. These results suggested that the model is relatively stable in regard to foraging variables.

Table 5. Results of foraging habitat sensitivity analysis.

	Percent Change		
	Sf_1	Sf_2	Sf_3
Maximum	4.3	7.5	5.1
+10%	3.4	4.1	4.5
-10%	-7.5	-24.0	-4.9
Minimum	-20.9	-24.0	-10.4

Overall, sensitivity results indicated that cover type was the most sensitive variable of the nesting component of the model. This result, coupled with literature suggesting that coniferous-dominated stands were used for nesting in neighbouring regions, directed field sampling efforts to include cover type as a main factor for investigation.

opportunistically during searching. Nests that were unoccupied were evaluated for signs of possible goshawk use (e.g. size, shape and composition of the nest; large prey remains on the ground; and the existence of multiple nests).

In the second season, nine new nest sites and 14 goshawk nests were found. Search efforts commenced on May 5, 2002 and concluded on July 28, 2002. Known goshawk sites from the first season were revisited to check for occupancy. Additionally, unoccupied sites from the first season that appeared to be possible goshawk sites were checked for goshawk use. In total over the two seasons, 15 goshawk nest sites and 27 individual nests were located (Figure 16).

Nest sites and individual nests were labelled using a system combing their general location within the FMA area and a sequential alpha-numeric tag as needed (Figure 15). The first part of the label denotes the general location within the FMA area using the compartment boundary names used by Millar Western Forest Products Ltd. (e.g. WWF = West Windfall). Unique nest sites within the same compartment boundary were labelled sequentially in the order of their discovery (e.g. WWF-1, WWF-2, WWF-3). Similarly, each nest within a nest site was labelled in the order of their discovery (e.g. WWF-3A, WWF-3B, and WWF-3C).

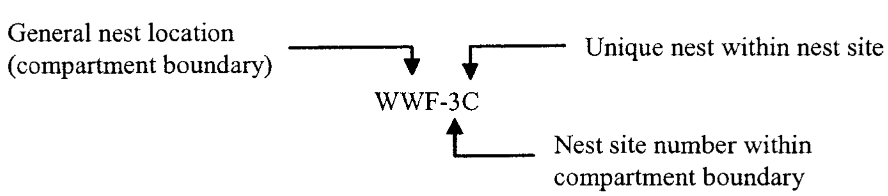

Figure 15. Labelling convention used for goshawk nest sites.

locating goshawk sites, the frequent use of opportunistic findings in other goshawk studies (Speiser and Bosakowski 1987, Squires and Ruggiero 1996, Erdman *et al.* 1998, Schaffer 1998, Daw and DeStefano 2001, Finn *et al.* 2002b, McClaren *et al.* 2002), and reports suggesting that opportunistic locations do not necessarily bias results (Daw *et al.* 1998). As two of the sites were in conifer-dominated areas and two in deciduous-dominated areas, it was felt that these results were not slanting results toward one type of forest cover.

In total, approximately 14,900 ha was searched over the two field seasons. This area was divided between areas of low (5,300 ha), medium (5,200 ha) and high (4,400 ha) nesting suitability scores. Nearly equal amounts of deciduous-dominated (6,000 ha) and coniferous-dominated (5,500 ha) forest were searched with the remainder (3,400 ha) in mixedwood conditions. The relative lack of mixedwood searching compared to pure stand conditions was largely a result of the paucity of these sites on the landscape.

Overall, search effort produced approximately one nest site/1,000 ha. However, this includes the four nests found either opportunistically or through refined searching of areas reported by forest workers. Removing these areas, my search results more realistically produced one nest site/1,350 ha. Other studies have reported goshawk responses to broadcasts from a low of one response per 4,700 ha of searching in Alaska (Iverson *et al.* 1996) to as much as one response per 350 ha in Arizona (Joy *et al.* 1994).

Reaction to broadcasts commonly followed a pattern of response (vocal or visual) and retreat in the direction of the nest with continued vocal protest. As I followed the direction of flight, birds could usually be relocated and would commonly respond with an alarm call when re-spotted if an active nest was present (Figure 17). Continued flights

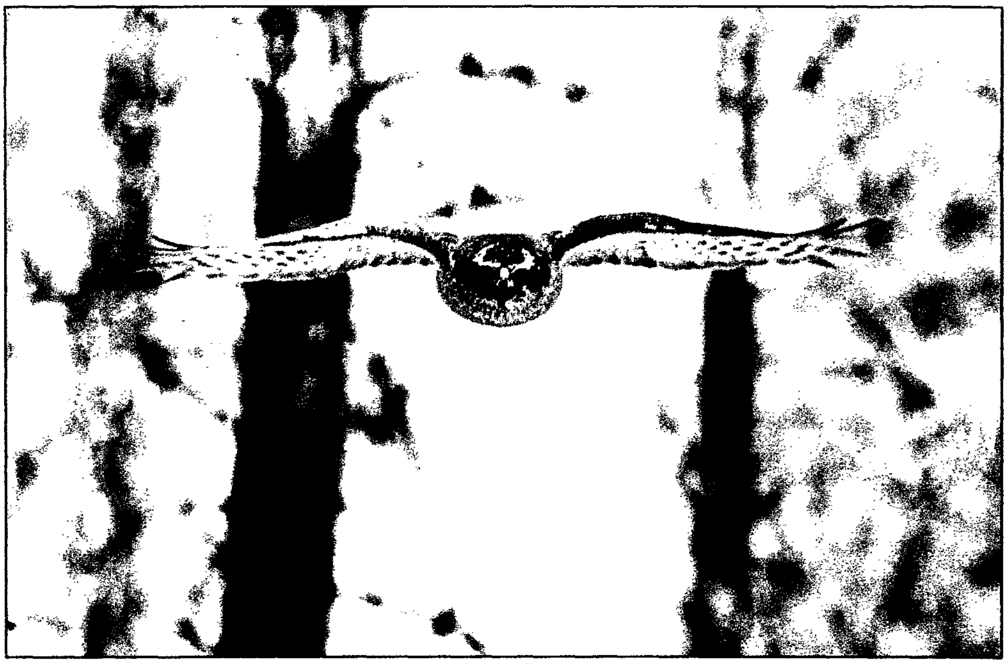

Figure 18. Adult Northern Goshawk defending its nest. (Photo: K. Hautala).

The distance between my location at the time of response to the broadcast calls and the active nest varied from 60 to 700 m (Appendix V). Several nests were located at a substantial distance (greater than 300 m) from the point of first contact. These response distances were as much as four times greater than anticipated or accounted for in the survey protocol. The responses thus illustrate that one needs to be cognisant of potential long-distance responses when conducting surveys in this manner.

Five areas searched produced unquestionable goshawk responses on one or more occasions, but did not result in my locating a nest site. Several other sightings or vocal responses were believed to be possible goshawks, but where visual confirmation could not be made, these responses were not tallied. There are several possible explanations as to why all responses did not result in the locating of active nests:

- Identified goshawks may have been non-breeding (*i.e.*, lacking a partner and nest site);

Figure 19. Typical goshawk nest located in the primary fork of a mature trembling aspen. Note the number and size of supporting branches. (Photo: K. Hautala)

Nest trees were large and averaged 39 cm dbh, and 23 m in height (Table 6). Nest trees consistently represented some of the largest in the area (92nd percentile of dbh, Figure 20). The smallest dbh of a nest tree was 26 cm (white spruce), while the smallest of the aspen nest trees was 31 cm. All nest trees were 20 m in height or greater. The largest of the nest trees was, for this region, a sizeable 61 cm dbh and 25 m in height.

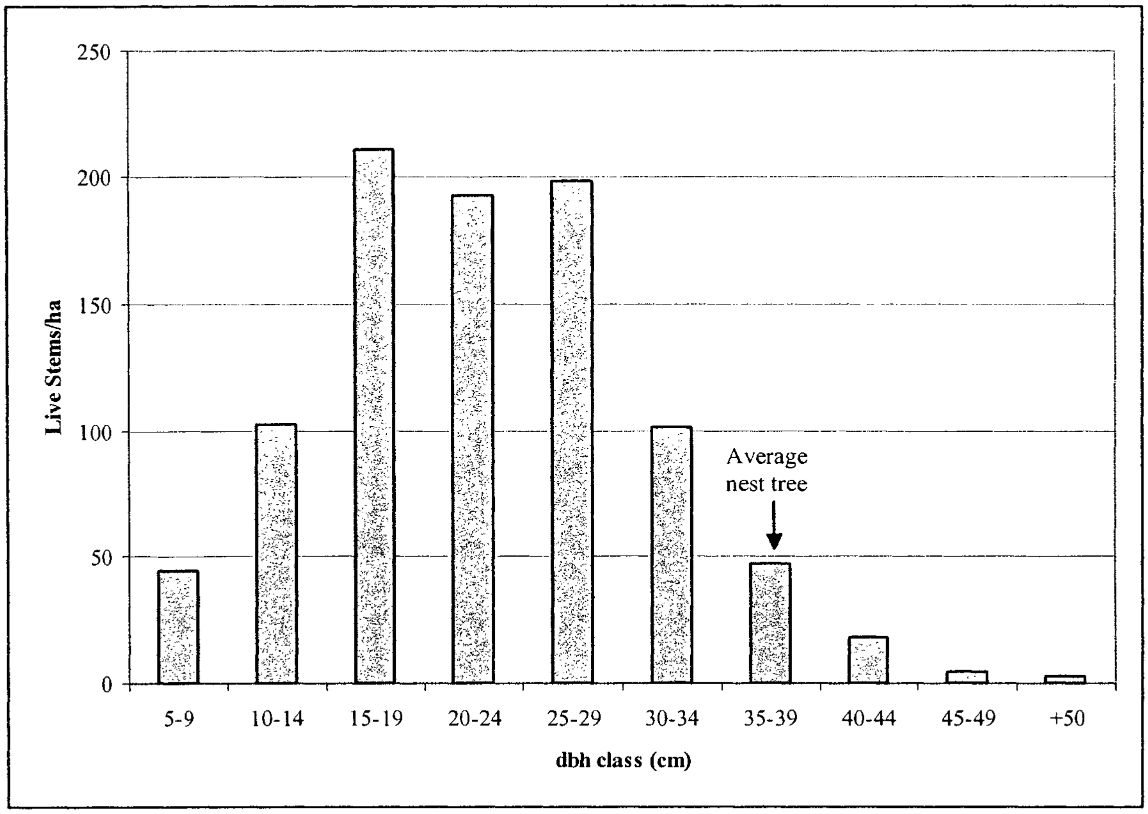

Figure 20. Average dbh class distribution of nest-site stands.

In nest areas where more than one nest was located (n = 5), the mean distance between nests was 196 m. At three nest sites, alternate nests were simultaneously occupied by Great Gray Owls (*Strix nebulosa*, n = 2), and Great Horned Owls (*Bubo virginianus*, n = 1). These nests were 143-358 m away from the active goshawk nest. The use of alternate nests by other raptor species in such relative proximity to active goshawk nests during the same breeding season is a unique result. Though it is accepted that goshawk nest sites are often used by other species, this is commonly reported to occur only when goshawk nest sites are abandoned. The simultaneous use of nest sites suggested that nesting habitat, and namely available nests for owls, may be limited in the area. It also illustrated the need to search beyond a nest occupied by other raptor species

Table 7. Characteristics of Northern Goshawk nest areas on the Millar Western FMA.

	Nest Area					
Nest Label	Broad Cover	Species Composition*	Mean Tree Height(m)	Mean Live dbh(cm)	Canopy Closure(%)	Total Basal Area(m^2/ha)
BL-1A	DM	$Aw_6Sw_3Pl_1$	22.0	27	71	48.8
BL-1B	D	Aw_8Sw_2	25.2	28	73	56.7
BL-2A	DM	$Aw_5Sw_3Pl_2$	21.8	22	69	53.9
BL-3A	CM	$Sw_5Aw_3Pl_2$	21.1	19	71	46.4
BL-4A	DM	$Aw_5Sw_2Pl_2Pob_1$	25.0	23	64	48.7
OC-1A	CM	$Pl_7Sw_2Aw_1$	22.7	25	73	47.1
PE-1A	D	Aw_8Pob_2	21.6	26	71	44.2
SC-1A	C	Sw_8Aw_2	21.9	19	67	39.6
SC-1B	C	Sw_9Pob_1	23.0	23	66	36.2
SC-1C	C	Sw_9Aw_1	23.0	23	67	42.1
TC-1A	D	Aw_{10}	24.0	22	66	26.6
TC-2A	DM	Aw_6Sw_4	23.6	24	61	46.9
TH-1A	C	Pl_8Aw_2	25.2	24	73	50.8
TH-1B	CM	$Pl_6Aw_3Sw_1$	24.0	23	73	45.8
TH-1C	C	$Pl_6Sw_3Aw_1$	24.3	22	72	50.2
TH-1D	C	Pl_8Aw_2	23.3	22	72	42.8
TH-1E	C	Pl_9Aw_1	22.0	24	69	54.4
TH-2A	CM	$Pl_7Aw_2Sw_1$	24.4	28	70	59.3
TH-3A	CM	$Pl_7Aw_2Sw_1$	22.2	24	74	48.7
WWF-1A	C	Pl_8Aw_2	24.4	24	73	54.4
WWF-1B	C	Pl_9Aw_1	24.0	18	70	40.7
WWF-1C	CM	$Pl_6Aw_3Sw_1$	24.4	24	74	54.0
WWF-2A	C	$Pl_7Aw_2Sw_1$	21.2	26	75	41.7
WWF-3A	C	$Pl_7Sb_2Aw_1$	21.0	20	60	36.2
WWF-3B	D	$Aw_4Pl_4Sb_2$	21.4	22	75	56.9
WWF-3C	C	$Pl_7Aw_2Sb_1$	21.0	21	66	44.2
WWF-3D	CM	$Pl_6Aw_3Sb_1$	21.4	22	64	38.0
Average (all nests, n=27)			22.9	23	70	46.5
Average/nest site (n=15)			22.9	24	70	46.5

D = deciduous-dominated; DM = deciduous-dominated mixedwood; C = coniferous-dominated; CM = coniferous-dominated mixedwood

Aw = trembling aspen; Pl = lodgepole pine; Pob = balsam poplar (*Populus balsamifera*) Sb = black spruce; Sw = white spruce

* Species composition calculated from field data

latitude areas, it is possible that neither significantly cooler nor warmer microclimates associated with aspect are beneficial to goshawk nesting. Another factor may be the limited area of significant slope in this region compared to areas where the extent and degree of slope may be more extreme, producing more discernable and significant microclimate differences.

Two nest sites (seven nests) were located in stands that had been commercially thinned. All seven nests were located along forwarder trails that provided an unobstructed flight path to and from the nest (Figure 22). Nesting near flight corridors such as footpaths has been noted in other studies (Penteriani and Faivre 1997). The high tree density in these areas prior to thinning (Table 8) represent site conditions that were likely too constricted for goshawk nesting. For this reason, these sites were believed not to be occupied by goshawks prior to the thinning treatments.

Early habitat recommendations for the goshawk suggested that thinning of stands would be detrimental to habitat quality (Reynolds 1983, James 1984). Later recommendations by Reynolds *et al.* (1992) and Finn *et al.* (2002a) suggested that thinning may be beneficial in creating nesting habitat. However, little evidence exists to illustrate the compatibility of thinning and goshawk habitat, and the relationship between the two remains largely speculative. The two nest sites located in thinned areas provide some evidence of the compatibility of thinning and nesting habitat, and the potential of thinning to produce nesting habitat in areas that may otherwise be unsuitable.

approximately 3.5 km (mean 723 m). This relatively short distance to tertiary roads is a reflection of the high-density road network on the management unit. Distance to water ranged from 95 to 1,620 m (mean 675 m).

Given the Northern Goshawk's preference for trembling aspen as a nest tree, this discrepancy produced doubt in the ability of the forest inventory to identify suitable nesting habitat correctly. However, it is important to note that field results were taken from a relatively small area (0.2 ha) compared to the scale of the forest inventory and associated photo-interpretation exercises. Forest stands are delineated at a scale and in a manner that is sufficient, but biased, towards an assessment of timber. However, with the increase in values considered in forest planning, the forest inventory has been called upon to perform tasks (e.g. habitat assessment) beyond which it was intended. This "functionality creep" is problematic in that substantially different results may be produced if the base data were derived with its end purpose in mind (e.g. a "wildlife forest inventory" may be much different in composition (attributes and resolution) than our current forest inventories). As field plots were not structured to validate the accuracy of the AVI, it is not possible to conclude which of the field data or AVI is most accurate at the stand level.

While some inventory inaccuracies inevitably exist and produce errors at the stand level, in strategic planning at the FMA-area level, it is possible that forest inventory errors may effectively balance themselves (Naylor *et al.* 1994a). Additionally, the habitat model is used primarily to evaluate management scenarios through a 200-yr planning horizon. Thus, erroneous assumptions surrounding forecasted silviculture prescriptions, timber growth and yield, and forest succession may be more important than anomalies in the current forest description.

data. Model performance was still poor (mean nest value = 0.35) as many sites were considered conifer-dominated, and consequently received a Sn_1 score of zero (Table 10).

Table 10. Average habitat model scores for Northern Goshawk nest sites.

Source of Habitat Information	**Sn_1**	**Sn_2**	**Sn_3**	**Sn $=(Sn_1 * Sn_2 * Sn_3)^{1/3}$**
Mean Nesting Suitability (AVI)	0.18	0.98	0.97	0.25
Mean Nesting Suitability (Field Data)	0.25	0.98	0.97	0.35

Similar to average nest-site scores, model performance was poor in regard to the preference index. Nests were located in high, medium and low nest-site scores, 13%, 20%, and 67% of the time, respectively. Search effort was relatively constant across habitat scores with 29% in 0.8-1.0, 35% in 0.4-0.7, and 36% in 0.0-0.3. This resulted in a counterintuitive negative correlation between modelled nesting scores and actual habitat use (Figure 23). In other words, with standardization for search effort, more nest sites were located in the poorest habitat according to the habitat model.

otherwise (Reynolds *et al.*1992, Bright-Smith and Mannan 1994, Hargis *et al.* 1994, Schaffer *et al.* 1999, McGrath *et al.* 2003).

Average foraging suitability scores were high (0.86) at identified goshawk nest sites. Mean foraging values decreased with increasing distance from nest sites as the increased plot sizes encompassed more-heterogeneous cover, including unsuitable foraging habitat (Figure 24). At the home-range scale, the average foraging suitability was 0.65 (range = 0.42-0.88). The average amount of highly suitable (0.8-1.0) foraging area in the 2,000 ha surrounding known nest sites was 1,060 ha (53%). These results suggest that the entire home range need not be comprised of optimal foraging habitat.

It is important to note that this analysis assumed that the model equation accurately reflects actual goshawk foraging habitat, and that the use of circular 2,000 ha circles sufficiently approximates the true home range of a given nesting pair. Actual home range size of a nesting pair is known to shift based on habitat quality (Kenward 1982) and time of the season (Hargis *et al.* 1994). However, the use of circular plots has been used in other raptor studies and is considered to provide a reasonable approximation of habitat use (Ripple *et al.* 1991, Lehmkuhl and Raphael 1993, Hunter *et al.* 1995, Finn *et al.* 2002b).

requirements. The model currently requires an optimal home range to consist entirely of optimal foraging habitat, while field results suggest this is not likely a condition for goshawk habitat.

6.2 Suggested Model Alterations

6.2.1 Nesting Habitat

The most substantial difference between habitat predicted by the model and actual habitat use was the use of conifer and conifer-dominated mixedwood stands. Other studies in the region (Shaffer 1998) and the habitat supply model considered conifer-dominated stands to be unsuitable habitat. This discrepancy between predicted and actual habitat use was the single largest factor in poor model performance.

To align the HSM better with observed habitat use, methods to account for nesting in conifer-dominated stands were investigated. However, the current model's use of broad forest cover posed a problem because I believe that this system lacks the appropriate resolution to define suitable nesting habitat. Specifically, cover type categories could no longer be used because conifer stands should only be considered suitable if aspen constitutes a component of the stand. Using the original model's forest cover categories (Table 3) would require assigning a positive value to pure conifer stands (i.e. conifer > 70%) irrespective of the species in the remaining portion of the stand (e.g. aspen or otherwise). Analysis of the forest inventory revealed that for areas designated as pure lodgepole pine, 44% of the area (approximately 30,000) lacked an aspen component, while the remaining 56% of the area had at least 10% aspen cover. Thus, approximately half of this category would be suitable habitat, while the other half would not. To overcome this shortcoming, it was suggested that the model component (Sn_1), which

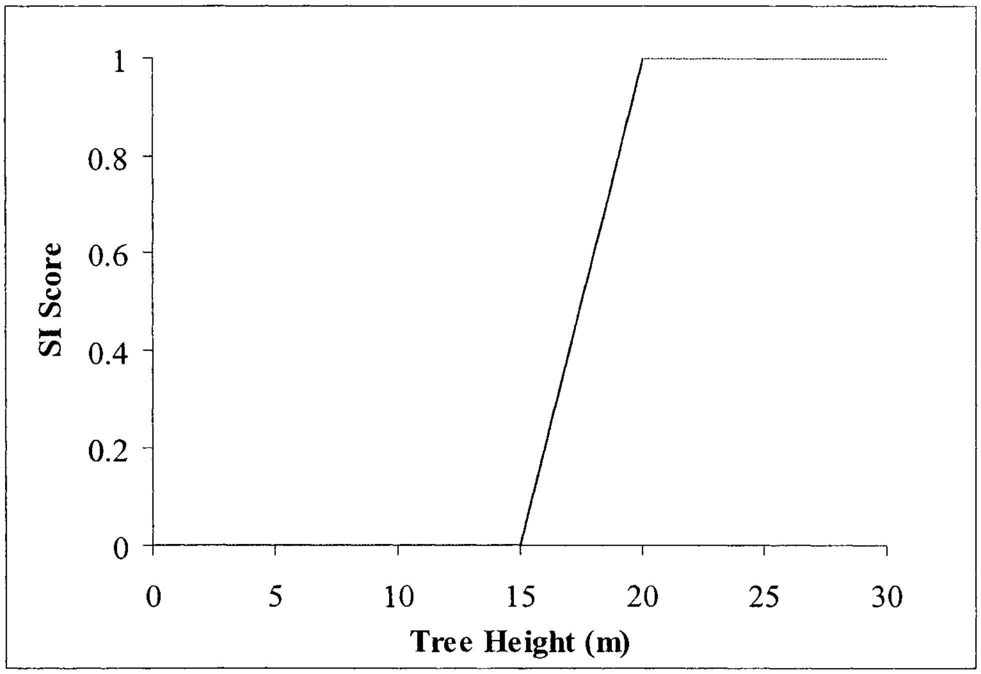

Figure 26. Nesting suitability in relation to tree height.

The SI curve for aspen cover was created with consideration for the observed nesting in low-percentage aspen cover (*i.e.*, 10-20%). Values of 10% were given a 0.5 while aspen percentages between 20 and 80% were considered optimal. Because only three nests were found in pure aspen areas, suitability was reduced for areas with greater than 80% aspen cover. The decreased suitability of pure hardwood stands supports findings from other studies that suggest mixedwood areas may be most suitable due to stable microclimates and the increased hiding cover provided by conifer trees especially prior to leaf flush (Bosakowski 1999).

Optimal nesting habitat was considered to require trees at least 20 m in height as no nest trees were shorter than this. These results match those of Shaffer (1998) who reported an average goshawk nest height of 22 m in the region. While no nest trees were shorter than 20 m, it is likely that a smaller tree would be capable of supporting a nest. My observations suggest that trees would need to be taller than 15 m to be capable of

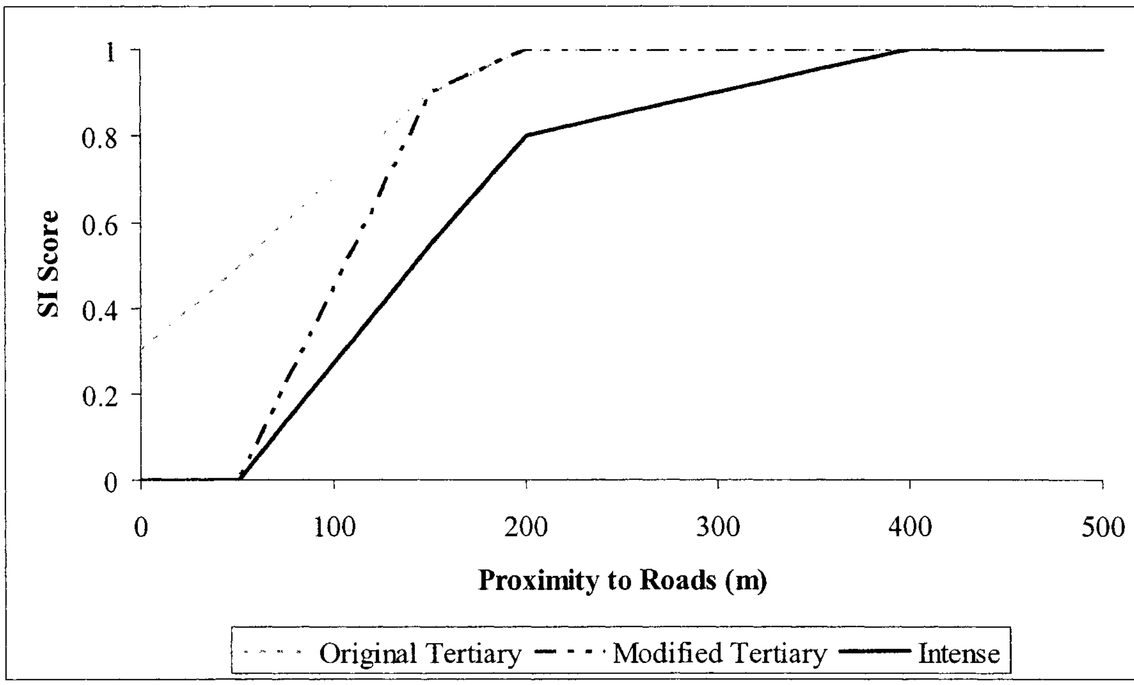

Figure 27. Revised nesting suitability in relation to proximity to roads.

The relatively closed canopy conditions observed in this study support results of other studies (Hayward and Escano 1989, Hargis *et al.* 1994, Squires and Ruggiero 1996, Speiser and Bosakowski 1987, Schaffer 1998) and the overall belief that canopy closure is one of the most universal goshawk habitat requirements (Squires and Reynolds 1997, Bosakowski 1999). Nest sites in this study average 70% closure with a range of 60-75%. To align the model better with field results, the minimum requirement for canopy closure was increased by 10% (Figure 28). To account for the likelihood that nesting habitat is not reduced with higher percentage canopy closure conditions (*see* 4.1 Model Verification), the model was altered to equate these conditions with optimal habitat.

range consist of 40-60% mature forest cover (*i.e.,* suitable foraging habitat) (Reynolds *et al.* 1992). To align model output better with field results, the average of the top 60% of the home range should be used to represent the foraging suitability of a potential home range.

6.3 Results of Model Alterations

6.3.1 Known Nest Site Scores

Model scores for known nest sites were recalculated using the proposed changes to the model. These results indicated that the average HSM nesting score for nest sites improved with the modifications. However, results were still considered poor as the average nest score for known sites was only 0.45 (Table 11). This low average was largely a result of the low percentage of trembling aspen (S_{n1}) reported in the AVI for stands containing known nest sites. As described above (*see* 6.1.1 Nesting Habitat), the AVI frequently reported no percentage of aspen at nest sites, and consequently the revised model produced S_{n1} values of zero at seven nest sites.

To evaluate model performance better, without the propagation of errors produced by the AVI, model scores were recalculated using field-data-derived species composition and height. This process illustrated significant improvements in model performance, as average nest scores at known sites increased from 0.35 using the original model to 0.94 using the suggested alterations (Table 11). Thus, alterations to the model substantially improved nesting scores for known nest sites, but only within the limits of the input data.

within the FMA area remained relatively constant between the original and modified models (Figure 30).

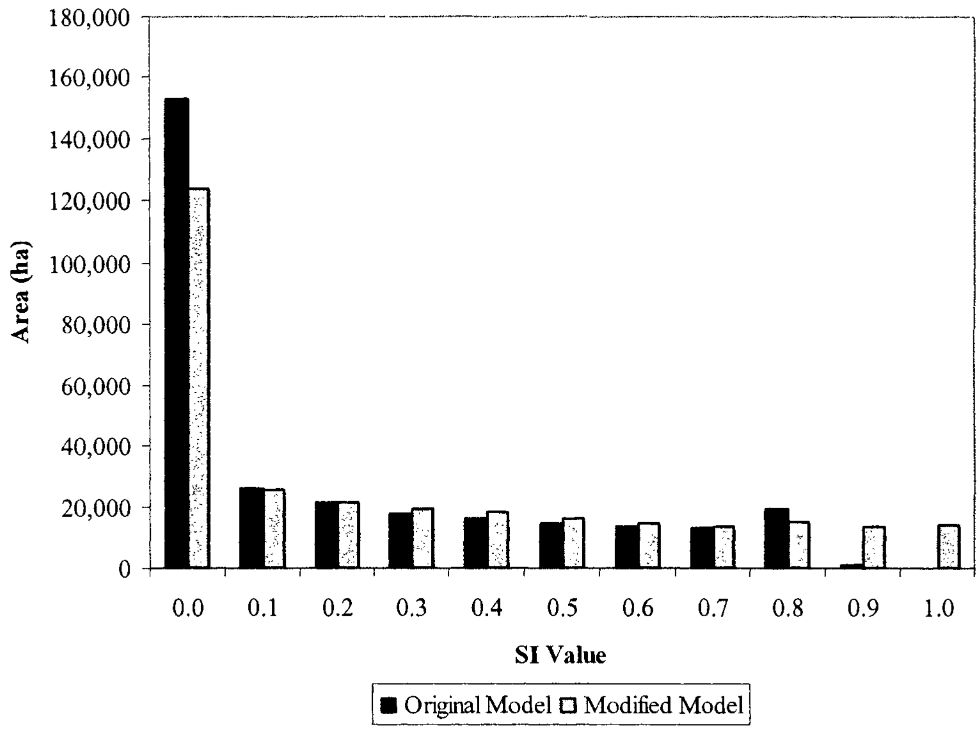

Figure 29. Comparison of nest site suitability between the original and the modified models (Year = 1998).

0.13), and the same downward trend in habitat suitability through time was evident in each scenario.

The analysis of scenarios during forest management plan development concluded that while “some wildlife habitat quality indices are affected by management in the near term (20 to 40 years)...it does not appear that any of the indicators of wildlife habitat quality are negatively affected in the current planning term” (Millar Western Forest Products Ltd. 2000c). These same trends were noted with the modified model, and suggest that the same conclusions would be drawn.

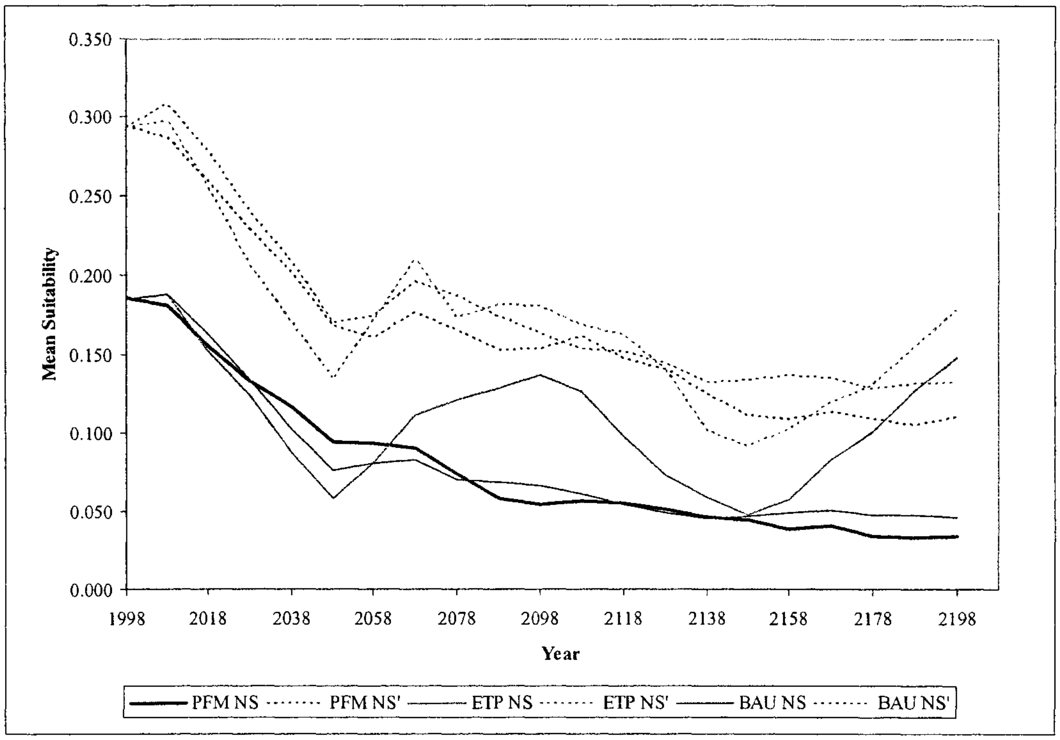

Figure 31. Comparison between FMA area average nest site suitability scores between scenarios using the original and modified habitat model (PFM = preferred forest management scenario, ETP = enhanced timber production scenario, BAU = business-as-usual scenario. NS = original model, NS’ = modified model).

from the current condition (e.g. Naylor *et al.* 1994b), then changes to the model may be more likely to produce a minimal impact on the decision-making process. Conversely, if outputs act as a surrogate for population-level targets, as inputs into population-persistence models (Calkin *et al.* 2002), or as absolute numeric targets, then the inaccuracies contained in untested models become cause for greater concern. This is not to suggest that research to improve the performance of models is not important, but rather that in decision systems where relative scores are considered, the negative impact of using untested models may be less than expected as a result of relative rankings being insensitive to model alterations. In situations where the absolute value of model outputs is evaluated, then logically more attention must be given to model validation, and outputs from unvalidated models must be used with caution.

In analyzing model outputs across scenarios, it was noted that differences between the scenarios was not substantial, and as such, the utility of the goshawk model as an indictor in strategic planning may be questionable. However, the scenarios created during plan development were within a relatively narrow spectrum of options (i.e., silviculture intensities, harvest levels, and spatial arrangements). Furthermore, the lack of differences between scenarios may simply reflect the reality that forest management activities produce relatively constant impacts at the FMA level regardless of spatial arrangements or silviculture treatments for a number of wildlife species.

Figure 33. Example of a small radius buffer applied to a goshawk nest.

The suggested size of the buffer typically corresponds to the nest site scale (8-12 ha). A buffer size of 12 ha (radius = 200 m) would likely be more effective in protecting sites and ensuring the re-occupancy of nests. Field results indicated that the 12 ha surrounding nests was comprised nearly entirely of mature or overmature forest cover (93%). Additionally, the frequency with which goshawk territories contain multiple nests suggests that when an active nest is located, the surrounding area should also be searched for alternate nests so that they may also be afforded protection. Field results suggested an average distance between nests of approximately 200 m. An appropriate operating procedure would require searching within a 200 m radius of active nests and applying a 200 m radius buffer to any alternate nests as well.

Little empirical evidence exists regarding the effectiveness and appropriate size for nest buffers. Crocker-Bedford (1990) found even the largest buffers in his study (200 ha)

The importance of macro-habitat conditions in the selection of nest sites and the success of breeding should also be an area of research for the boreal forests of Canada. Work in the United States (e.g. McGrath *et al.* 2003) and Scandinavia (e.g. Krüger and Lindström 2001) have illustrated the existence of habitat selection criteria beyond that of the nest stand, and the existence of density-dependent habitat selection such that not all occupied nest sites should be viewed as equally suitable (Krüger and Lindström 2001). These broader-scale habitat selection processes have important implications for habitat modelling, the variables considered within the models, and the scale(s) at which they operate.

This project and others in the region (Shaffer 1998) suggest a no-harvest nest buffer size of 12 ha surrounding goshawk nests. This suggestion is based largely on recommendations in other jurisdictions, observations of the percentage of mature forest surrounding nest sites at this scale, and a limited number of observations of apparently unsuccessful buffers of smaller size. This suggested buffer size should be considered a starting point for an adaptive management program to test the effectiveness of no-harvest buffers for Northern Goshawk nests and those of other raptors. A long-term project, such as that of Mahon *et al.* (2001), designed to test the occupancy and productivity of nests in response to various buffer sizes, can provide an accurate assessment of these protective measures. Suitable goshawk habitat consists of more than the immediate nest site, and the effectiveness of a strategy designed to protect only this element of habitat must be investigated to ensure these measures are truly effective in maintaining productivity.

Frequent discrepancies were noted between the tree species composition calculated from field data and that reported in the forest inventory. This disagreement may be the

The model demonstrated an inability to identify goshawk nesting habitat as known nest sites had a low average modelled nesting score (0.25 using AVI data and 0.35 using field data), and a negative correlation between modelled nesting scores and actual habitat use was discovered. This poor performance, along with sensitivity and verification exercises, resulted in the following recommendations for the model:

1. Cover type should be revised to account for nesting in areas with a low percentage (10-50%) of trembling aspen. The model's use of cover-types was considered too broad to identify nesting habitat accurately, and dividing this aspect of the model into variables for aspen cover and tree height was considered to be the best solution;
2. Nesting in close proximity (<60 m) to roadway was not observed. Observations of nesting at a distance from roads and findings from other studies supported the suggestion to alter the SI curve of this variable;
3. The closed-canopy conditions noted at nest sites in this and other studies, as well as counterintuitive results from verification exercises, suggested that nesting habitat should be considered optimal under 90-100% canopy closure conditions; and
4. The home-range-level calculation of the foraging component of the model should not require the entire home range to be comprised of optimal foraging habitat in order to receive an optimal value. Results from nest sites in this study, and management recommendations in other jurisdictions, suggest that 60% of the 2,000 ha surrounding nests need be suitable foraging habitat. To align the model output better with field results, it was suggested that the average

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Appendix I: Northern Goshawk Habitat Supply Model

NORTHERN GOSHAWK

(Accipiter gentilis atricapillus)

Source: Salt and Salt (1976)

Prepared for Millar Western Forest Products' Biodiversity Assessment Project

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within a closed canopy stand (Reynolds and Meslow 1984; Janes 1985; Beier and Drennan 1997). Goshawks generally find habitat containing these required elements in mature or old deciduous-dominated mixedwood forests.

Since different forest management practices influence the tree species composition and age-class structure of the forest in different ways, foresters must be aware of the conditions considered optimal for this species if its habitat is to be protected or enhanced. Research by Crocker-Bedford (1990) revealed that the birds abandoned their nesting sites in response to selective harvesting. For this reason, the author recommended that the entire range used during the sensitive breeding, nesting, and post-fledging family times (~ 2,000 ha) be withdrawn from forest management activities (Crocker-Bedford 1990).

It is vital that appropriate prey species are both available and accessible. Prey is most easily accessed in mixedwood stands with relatively clear understories, allowing the goshawks to quickly pursue prey. In addition, competing open-forest raptors with lesser agility and manoeuvrability are discouraged from foraging in the area (Crocker-Bedford 1990; Reynolds *et al.* 1992a; Austin 1993; Bright-Smith and Mannan 1994; Hargis *et al.* 1994; Beier and Drennan 1997). Hunting occurs within stands of canopy closure between 60 and 89%, with a strong aversion to areas with less than 40% cover. Observation in Alberta has revealed that goshawks tend to forage in mature to old aspen-dominated mixedwood forests (Lilieholm *et al.* 1993; Schaffer 1995).

Recent clearcuts and dense young stands are thought to be unsuitable as goshawk foraging habitat for three reasons: 1. tall trees are not available as perches; 2. thick canopy cover is not present for concealment; and 3. the understorey is too thick for efficient movement.

The high nutritional requirement of young goshawks during the first few weeks of life means that the area surrounding the nest, termed the post-fledging family area, must contain excellent foraging habitat. In fact, Newton (1976) and Ward and Kennedy (1996) suggested that the breeding success of the Northern Goshawk may be limited by food availability.

Based on the above discussion, the characteristics contributing to good foraging habitat include:

- Mixedwood, preferably aspen-dominated forest;
- Relatively clear understorey;
- Tall trees for use as perches; and
- Canopy closure of 60 to 89%.

2.2 Cover Requirements

Northern Goshawks are forest dwellers (Palmer 1988) and have the ability to utilise a wide variety of forest ages, structural conditions, and successional stages (Francis and Lumbis 1979; Reynolds *et al.* 1992a; Reynolds *et al.* 1992b) for most of the year. During nesting, their habitat requirements become more demanding. These requirements will be discussed in the following section.

The Northern Goshawk's position high in the food web limits its predators to large birds such as the Great-Horned Owl and carnivorous mammals such as the Fisher (Crocker-Bedford 1990; Reynolds *et al.* 1992b; Erdman *et al.* 1998). Canopy closure for protection from predators and concealment from prey is necessary particularly during the nesting season.

2.3 Reproduction Requirements

Monogamous Northern Goshawk pairs of central Alberta move to their nesting territory in early March and remain within the post-fledging family area until late August (Schaffer 1998). At this time, they will either select a pre-existing platform nest (Godfrey 1986; Semenchuk 1992) that they may use for up to five subsequent years (Crocker-Bedford 1990) or will establish a new nest (Knopf 1977). Stick nests are approximately 1 m in diameter and are built 5 to 23 m above the ground (Godfrey 1986; Semenchuk 1992).

Some biologists believe that Northern Goshawks prefer to establish their nest sites in overmature coniferous stands (Dubois *et al.* 1987). Others argue that appropriate cover conditions can be provided by mature stands of any species composition (Widen 1989; Squires and Ruggiero 1996) as long as sufficient canopy cover exists to protect young from predation and conceal foraging adults from prey (Hennessy 1978; Forsman 1980; Moore 1980; Shuster 1980; Hall 1982; McCarthy *et al.* 1987; Crocker-Bedford and Chaney 1988; Hayward and Escano 1989;

2.5 Landscape Configuration Requirements

It has been suggested by Schaffer (pers. comm. 1999) that future research efforts should be directed at determining the placement of goshawk nest sites with respect to other landscape features such as water bodies, roadways, and different types of clearings. In addition, work must be done to discover the macrohabitat characteristics most influential in goshawk habitat selection (stand composition, interspersion of stand types, area and shape of habitat patches, Schaffer 1998).

The presence of streams, trails, and small natural clearings may be important due to the supposed desire of the goshawk to build nests near natural paths of flight (Godfrey 1986; Semenchuk 1992). Since this idea has not yet been confirmed and did not receive support from goshawk researchers in western Canada, it will not be considered further in this HSM.

2.6 Sensitivity to Human Disturbance

It is thought that Northern Goshawks are sensitive to timber harvesting (Crocker-Bedford 1990), forest fragmentation (Erdman *et al.* 1998), and human disturbance around the nesting site (LeFranc and Millisap 1984). In fact, loud human voices can be enough to keep hawks from their nests and even short absence can lead to loss of eggs or nestlings to predation (Call 1979). In addition, it has been shown that the birds experience limited breeding success when human activities are carried out in the vicinity during this sensitive time (Reynolds *et al.* 1992b; Kennedy and Stahlecker 1993). In areas where human activities were not sufficiently restricted around nests, the recorded rate of nest occupancy was 75 to 80% lower and nestling production was 94% lower (Crocker-Bedford 1990).

It is recommended that human interference be minimised within at least 50 m of a goshawk nest (Schaffer 1995; Erdman *et al.* 1998). Based on the research of Jones (1979), Richardson and Millar (1997) suggested that it would be preferable to place a buffer of 450 m around Northern Goshawk nests. Reynolds *et al.* (1983) recommended that timber harvesting activities be restricted within the entire ~2,000 ha area used by the hawks for post-fledging foraging during the post-fledging family period while other human activities that do not alter the habitat structure could continue.

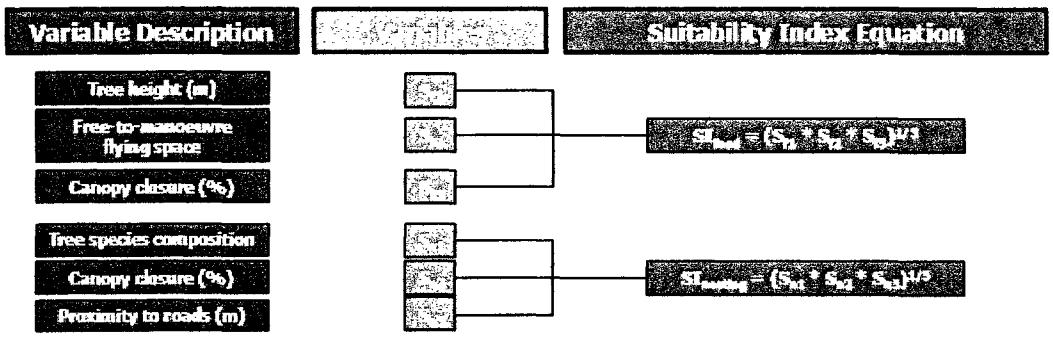

Figure 3. HSM structure for the Northern Goshawk within Millar Western's FMA area.

The SI_{food} consists of an evaluation of the stand's capability to satisfy the bird's hunting requirements: appropriate manoeuvrability as well as the presence of tall trees for use as perches, and canopy closure for concealment. As all of these variables are required for successful hunting, no compensation is allowed between them.

The $SI_{nesting}$ consists of the tree species composition and degree of canopy closure of the stand. It also takes into account the proximity of the potential nesting site to roads. Goshawks are likely to find suitable nest sites in large deciduous trees. In particular, trees greater than 40 cm dbh make the best nest sites. As previously mentioned, a density of at least six large deciduous trees per ha will likely suffice. We expect that an appropriate number of nest trees will readily be found in mature hardwood, old hardwood, and old hardwood-dominated mixedwood stands. Goshawks may also be successful in finding nest sites in mature hardwood-dominated mixedwood stands. Research has indicated that the birds seem to prefer mixedwood stands over pure deciduous stands as shelter. In addition, a nesting site is considered most suitable if it is distant from roads.

3.4 Habitat Variable SIs

Food

Successful foraging will occur where prey is accessible. The variable, S_{f1}, considers the goshawks' need for tall trees or snags as perches by taking into account the average height of the trees in the stand. Although they may inhabit stands of height > 8 m, 16 m mean height is generally preferred by the birds, and > 24 m is considered optimal (Figure 4). Variable S_{f2}, manoeuvrability, assigns a suitability index of 0.5 for a clear understorey since the competitive pressure exerted on the goshawks by other raptors may result in reduced suitability of the habitat. An entangled understorey is not appropriate for goshawk foraging and, therefore, receives a value of 0 and porous to obstructed habitats, which are considered optimal, are given a value of 1.0 (Figure 5). To hide itself from prey as it hunts, the goshawk requires significant canopy closure (S_{f3}, Figure 6). In particular, it prefers stands with canopy closure of at least 60%. Suitability declines, however, in stands with > 90% canopy closure.

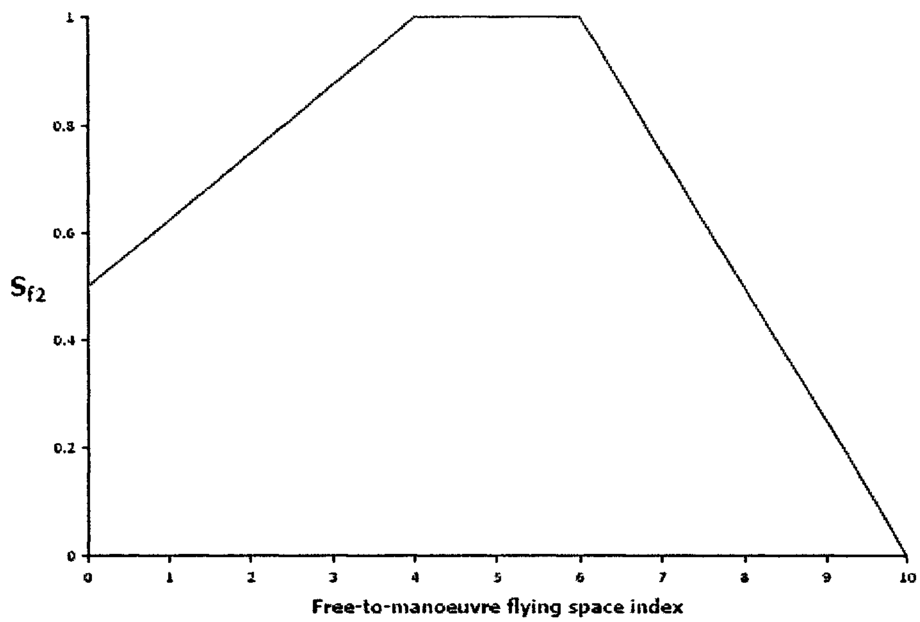

Figure 5. Northern Goshawk foraging habitat suitability in relation to flying space within Millar Western's FMA area. 0 = clear, 10 = entangled, > 0 and < 10 = porous to obstructed.

Table 1. Northern Goshawk nesting habitat suitability ratings, by habitat type.

		Opening	Developing		Forest		Old
Broad	Specific	Clearcut	Regenerating	Young	Immature	Mature	Old
Hardwoods	Aspen					0.5	0.5
	Poplar					0.5	0.5
	White birch					0.5	0.5
Hardwood Mixed	Aspen-Pine					0.75	1
	Aspen-White spruce					0.75	1
	Aspen-Black spruce					0.75	1
	Poplar-Pine					0.75	1
	Poplar-White spruce					0.75	1
	Poplar-Black spruce					0.75	1
Softwood Mixed	Pine-Poplar						
	Pine-Aspen						
	White spruce-Poplar						
	White spruce-Aspen						
	Black spruce-Poplar						
	Black spruce-Aspen						
Conifers	Pine						
	White spruce						
	Black spruce						
	Larch						

3.5 Computation

Our goal is to create HSMs that allow the user to identify potential impacts of proposed forest management strategies on foraging and nesting habitats. Therefore, the outputs of the SI_{food} and $SI_{nesting}$ calculations are considered individually to display trends in habitat availability.

Foraging Habitat Index

The ability of each pixel of forested habitat to provide foraging opportunities is measured. The following equation is solved for each pixel:

$$SI_{food} = (S_{f1} * S_{f2} * S_{f3})^{1/3}$$

Nesting Habitat Index

One of the variables, S_{n3}, included in $SI_{nesting}$ requires calculation of the distance of each pixel from roadways of varying intensity. To apply a suitability rating for this variable to each pixel, all roads are buffered to a distance of 400 m. Each pixel within the buffer receives a suitability rating based on the distance-dependent relationship shown in Figure 7. All pixels outside of the buffered areas receive a suitability rating of 1.

The value of each pixel as nesting habitat is then assessed by the following equation:

$$SI_{nesting} = (S_{n1} * S_{n2} * S_{n3})^{1/3}$$

Since the hawks require nesting sites of at least 12 ha in size, the $SI_{nesting}$ values are averaged within a moving window of 12 ha. In this way, each pixel is given a suitability rating for nesting that takes into account the suitability of the surrounding 12 ha of habitat. A home range generally contains a number of alternate nesting sites. These sites should not be too close together since the birds may be required to move to another site if the first becomes disturbed. We estimate that nesting sites should be at least 500 m apart for the birds to be offered viable nesting options in the face of disturbance. To identify potentially suitable nesting sites, the FMA area is divided into non-overlapping squares of length 500 m. The maximum $SI_{nesting}$ value within each square is found. These are considered the best nesting sites located an acceptable distance apart.

Home Range Smoothing

A pair of goshawks use an area of approximately 2,000 ha to forage as they raise their young during post-fledging family time. Because extensive clearings are detrimental to goshawk habitat, contiguous forest is optimal. Therefore, to identify the total value of each potential home range within Millar Western's FMA area as goshawk habitat, the SI_{food} and $SI_{nesting}$ ratings are averaged within a circle the size of one home range. A circle of radius 2,525 m (2,000 ha) moves over the grid with centres 2,525 m (one full radius) apart. All of the SI_{food} ratings are averaged together within the 2,000 ha circle to give an indication of the value of the entire home range as foraging habitat. In addition, since the birds require a choice of nesting sites in case of disturbance, we average the highest four nesting suitability ratings as derived above. This provides an estimate of the suitability of four alternate nesting sites within the home range. The two average values (food and nesting SIs) are applied to the pixel at the centre.

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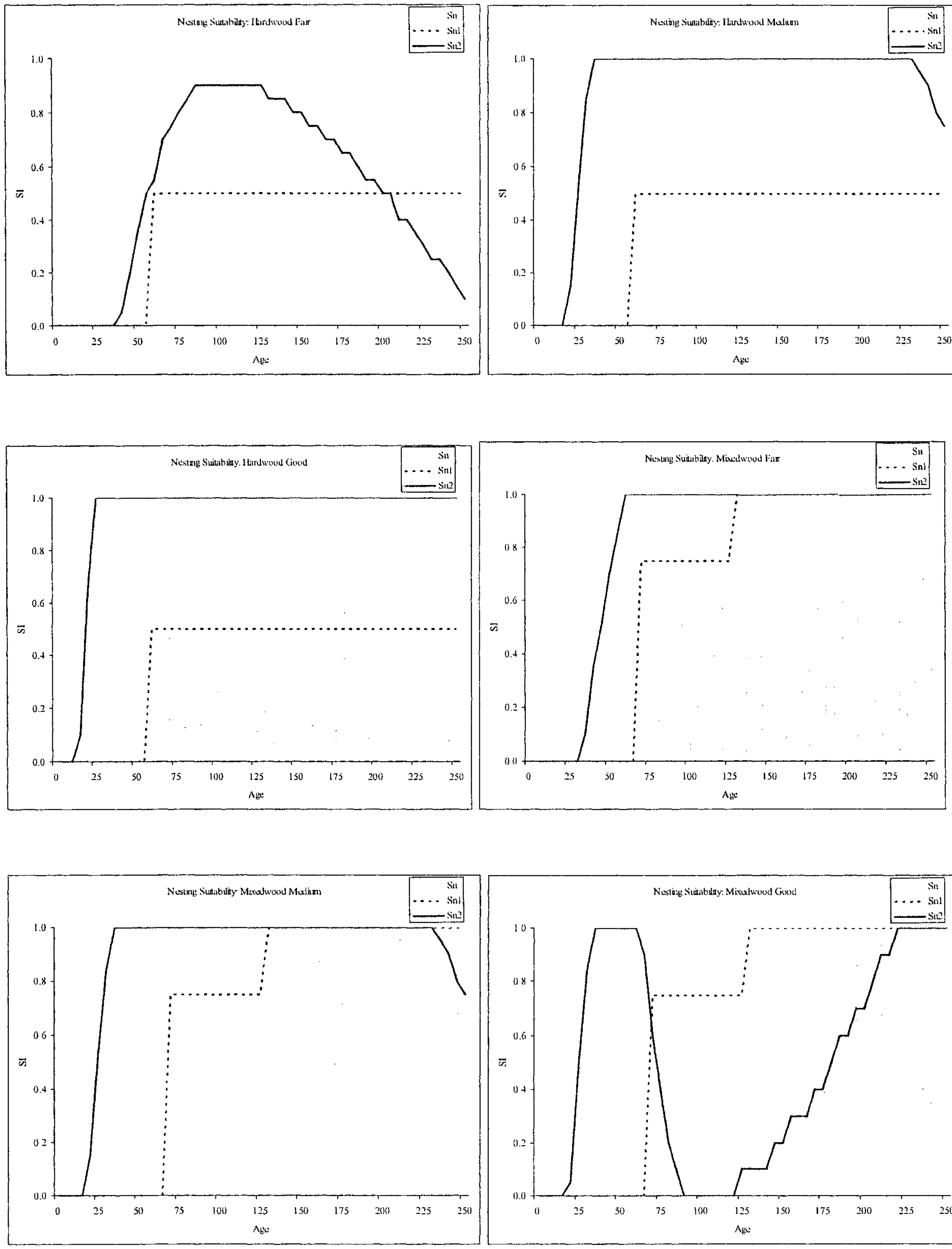
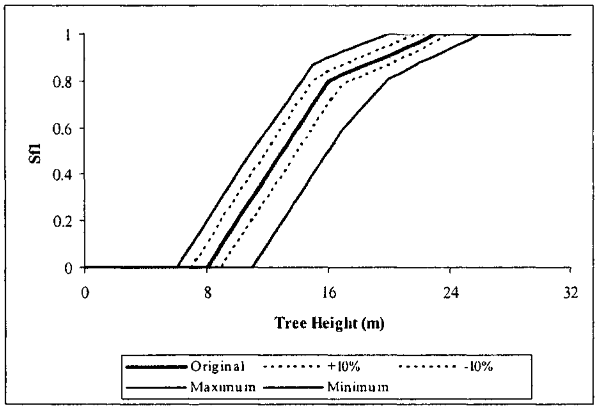
Appendix II: Model Verification Results

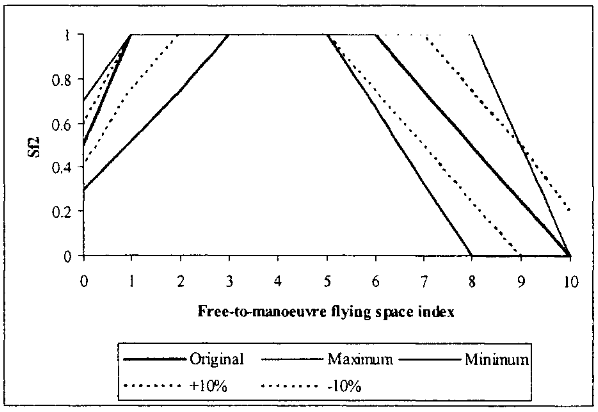
Appendix II-1

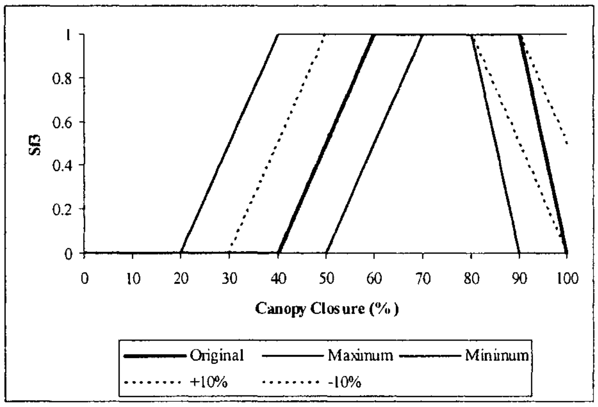


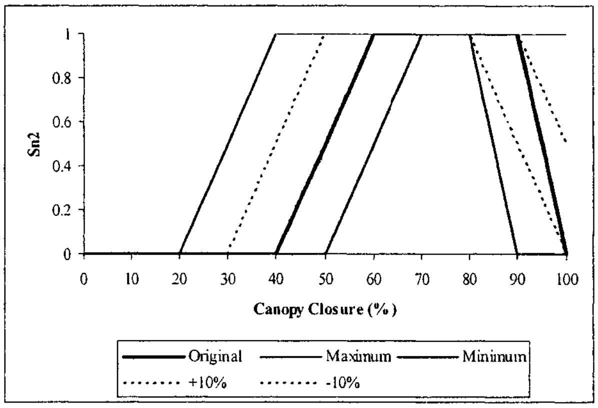
Appendix III: Variable Alterations Used in Sensitivity Analysis

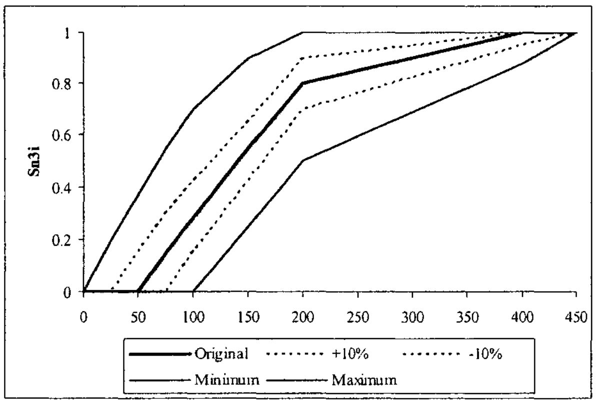
Appendix III-1

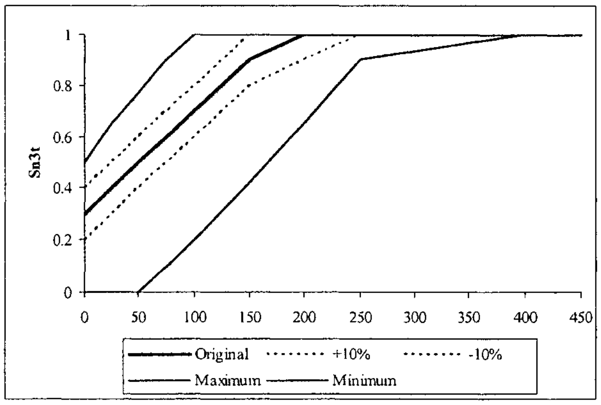












Appendix IV: Habitat Variables Collected at Field Plot

Appendix IV-1

Location	Variable
Nest Tree	Location (UTM)
	Slope
	Aspect
	Ecosite
	Broad Cover Type
	Specific Cover Type
	Developmental Stage
	Nest Tree Species
	Nest Tree DBH (cm)
	Nest Tree Height (m)
	Nest Tree Crown Height (m)
	Nest Tree Condition (healthy/leaf-needle loss/dieback)
	Nest Tree Damage
	Nest Height (m)
	Nest Direction (degrees)
	Nest Distance from truck (m)
	Nest Size
	Flight Corridor [absent/present(type, distance from nest)]
	If obvious from ground, otherwise from GIS: Distance to road (m); Distance to clearing(m); Distance to water (m)
0.04 ha Plots (r = 11.3m)	Live Trees (=> 5cm DBH): Species; DBH
	Standing Dead Trees: >5m, DBH; <5m, DBH
	Canopy Closure (%)
	Mean Tree Height (m)
	Free-to-manoeuvre-flying-space
0.004 ha plots (r = 3.56m)	% Shrub Cover (in height classes)

Appendix V: Dates and Response Types from Northern Goshawk Broadcast Surveys

Appendix V-1

Date	Initial Response*	Approximate Distance to Nest	Comment
May 16/01	Vocal	225 m	TH-1 nest site.
June 1/01	Vocal and visual	N/A	Two sightings. No nest found.
June 9/01	Vocal	150 m	WWF-1 nest site.
June 27/01	Vocal and visual	80 m	SC-1 nest site. Sighting reported by forestry worker.
July 2/01	Vocal and visual	100 m	TC-1 nest site. Sighting reported by forestry worker.
July 4/01	Vocal and visual	175 m	PE-1 nest site.
July 19/01	Vocal and visual	N/A	One sighting. No nest found.
May 9/02	Visual	60 m	Opportunistic finding (sighting from road). WWF-3 nest site.
May 27/02	Vocal and visual	N/A	Sighting reported by other researcher. Four sightings. No nest found.
June 3/02	Vocal	80 m	WWF-2 nest site. Sighting reported by forestry worker.
June 9/02	Vocal	350 m	OC-1 nest site.
June 15/02	Vocal and visual	50m	BL-1 nest site.
June 22/02	Vocal and visual	N/A	Two sightings. No nest found.
June 27/02	Vocal	100 m	TH-2 nest site.
July 2/02	Vocal	180 m	TC-2 nest site.
July 9/02	Vocal	700 m	BL-2 nest site.
July 12/02	Vocal and visual	600 m	BL-3 nest site.
July 15/02	Vocal	N/A	One sighting. Vocal response occurred several minutes after last broadcast.
July 16/02	Vocal and visual	N/A	Two sightings. Rebroadcast of July 15 area. No nest found.
July 19/02	Vocal and visual	180 m	TH-3 nest site.
July 26/02	Vocal	125 m	BL-4 nest site.

* Initial response indicates if individual was first seen, heard or both simultaneously.