THE EFFECTS OF FOREST MANAGEMENT, WEATHER, AND LANDSCAPE PATTERN ON FURBEARER HARVESTS AT LARGE-SCALES

by

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ABSTRACT

Savage, D.W. 2003. The effects of forest management, weather, and landscape pattern on furbearer harvests at large-scales. 109 pp. Advisors: U.T. Runesson and I.D. Thompson.

Key Words: beaver (*Castor canadensis* (Kuhl)), fisher (*Martes pennanti* (Erxleben)), forest management, geographic information system (GIS), landscape pattern, logging, lynx (*Lynx canadensis* (Kerr)), marten (*Martes americana* (Turton)), natural disturbance, Ontario, scale, weather.

Over the past 50 years, Ontario's forest landscape has changed due to ever increasing natural resource management. The natural vegetation pattern, forest composition, and the fire regime have been altered. Maintaining wildlife species diversity is an important goal of current forest management. However, little is understood about the impacts of large-scale land use and landscape scale processes that influence wildlife. This project used trapline harvest statistics from 1972-1990 to identify broad-scale effects of forest management, weather, and landscape structure on furbearers (marten, beaver, fisher, and lynx).

Spatial variables for logging and fire disturbance, forest cover type, weather, spatial pattern, and road density were compiled in a geographic information system (GIS) and standardized by trapline. Regression models were created for each species and analysed at five spatial scales ranging from the Ontario Ministry of Natural Resources (OMNR) district (5000 sq. km) to the 'provincial' (800,000 sq. km) scales. The models were then compared temporally and spatially for consistency in variable contribution to the regression models. Forest cover type, weather, and spatial pattern variables accounted for the greatest variation in furbearer harvest, while disturbance and road density variables accounted for little variation. Model predictive capability ranged from 10 to 55% for all species. Marten models had the greatest predictive power (r^2) at the 'OMNR District' scale, while fisher and beaver models had the highest r^2 values at the 'Hills site region' and 'provincial' scales, respectively. Lynx models were inconsistent with relatively low predictive power at all scales.

The models suggest that disturbance from forest management is not affecting furbearer harvests. Landscape scale variables such as forest cover type, weather, and landscape pattern account for a relatively high proportion of marten, beaver, and fisher harvests. These variables and the predictive power of the models reveal the influence that broad landscape factors have on wildlife.

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Arnold Rudy (KBM Forestry Consultants) helped me develop the skills to compile all of the provincial level spatial databases. Bonson Law showed me the process to develop an Access database and completed the initial species queries. Keith Hautala was a good friend to discuss ideas with and develop new methodologies. My family has provided constant support for my academic career, no matter how long it takes.

This project was funded directly through the Sustainable Forest Management Network (NCE) and the Ontario Ministry of Natural Resources provided the data. Both of these organizations contributed greatly to this project.

INTRODUCTION

In Ontario, much of the forest landscape has been managed for forest products over the past 50 to 60 years. The area disturbed by logging has tripled since the 1950s, while the area burned has decreased slightly over the same period (Perera and Baldwin 2000). Intensive fire management in populated and economically important zones has changed the natural fire regime of many areas. The boreal forest is adapted to fire and dependent on it for controlling species composition, age class structure and the pattern of vegetation, as well as initiating forest succession (Li 2000).

Although managers are currently trying to emulate forest compositional patterns resulting from natural disturbance in their planning, the disturbance pattern created in the past by clearcutting differs from that caused by natural disturbances (mostly fire) (Perera and Baldwin 2000). From 1970-1991, the spruce and mixed softwood tree species groups decreased in area by 14% and 8%, respectively, while deciduous forest types have concurrently increased (Hearnden *et al.* 1992). Intensive fire management has altered the fire regime by increasing the fire cycle and reducing the mean fire size. The total area burned in these intensive fire management zones has also decreased (Li 2000).

White and Harrod (1997) suggested that wildlife species presence and abundance will be affected by changing the disturbance regime of the landscape. By altering the disturbance regime, species that are dependent on the conditions created by fire can be reduced and possibly extirpated.

In Ontario there has been concern about the impacts of forest management on species such as marten (*Martes americana* (Turton)) (Watt *et al.* 1996), as well as fisher

(*Martes pennanti* (Erxleben)) and lynx (*Lynx canadensis* (Kerr)). In contrast, beaver (*Castor canadensis* (Kuhl)), an early successional species, may benefit from increased timber harvesting that creates younger forests suitable for beaver foraging. All four latter species are economically important for trappers and widely harvested across the province. As well, all four species have been suggested as ecological indicators of different habitat types at the forest (1000-10,000 ha) and landscape (10,000-1,000,000 ha) scales (McLaren *et al.* 1998). Long-term data sets of population estimates for these species do not exist due to the complexity involved with the data collection. However, there are long-term data sets of trapper harvests that were recorded by the Ontario Ministry of Natural Resources (OMNR) for each registered trapline across the province. Trapper harvest data cannot be reliably used as a proxy for population estimates because trapper effort may be dependent on socio-economic factors on an inter-annual basis (Weinstein 1977, Smith *et al.* 1984). However, by controlling for trapping effort, harvest data can be used to compare the effects of environmental variables on the relative furbearer population over time and space. The general hypothesis is that if timber harvesting is having a large-scale impact on furbearer populations, then there should be a relationship between forest disturbance variables and trapper harvests at one or more spatial scales. Alternatively, population change over time as indicated by trapper harvests might be better correlated with other variables such as weather.

Disturbance processes on the landscape influence an ecosystem at multiple spatial and temporal scales (Lertzman and Fall 1998). As a result, ecosystems operate at many scales (both spatially and temporally) as well, and rarely have a single correct or optimal scale of measurement or observation (Gardner 1998). Spatial scale is also important for identifying the habitat elements that are important for wildlife populations (Kolasa and Waltho 1998). Determining and measuring the most appropriate scale for the analysis of landscape effects is a key ecological problem (Goodwin and Fahrig 1998). Hierarchy theory defines a hierarchical structure with upper level processes constraining lower level processes and the resulting phenomena observed. Climate, a broad spatial process, constrains forest cover type, succession, and micro/meso scale disturbances at a lower level in the hierarchy, thus influencing wildlife at multiple spatial and temporal scales (Voigt *et al.* 2000).

This study used fur harvest statistics from the 1970s and 1980s to examine the association among several landscape scale variables on the densities of marten, fisher, lynx and beaver. The analysis was also expected to determine the optimum scale for measuring these associations. There were two primary goals for this project:

1. To determine whether forest management, natural disturbance, weather, and landscape pattern affected furbearer densities. Logging disturbance was used to measure the direct effects of forest management, while species composition and the spatial pattern of young and mature forest were indirect effects.

2. To establish the optimum spatial scale at which these effects might be identified and predicted.

The analysis was expected to provide insight into which landscape variables influenced trapline harvests.

LITERATURE REVIEW

BIOLOGY OF MARTEN, FISHER, BEAVER AND LYNX

Marten (*Martes americana*)

Distribution

Marten are found throughout the forested regions of Canada. Habitat loss due to land clearing and over-trapping in the Great Lakes region in the 1800s caused extirpation throughout much of the southern part of their range (Strickland and Douglas 1987).

Population Density

In the late winter, an unharvested population of marten in Algonquin Park has a resident density of approximately 0.6 marten/sq. km. An influx of juvenile and transient marten increases the summer density to approximately 1.2-1.9 marten/sq. km (Strickland and Douglas 1987). Thompson (1994) found that marten densities were 88-95% higher in uncut forests compared to logged areas. The age difference in marten between uncut and cut areas was also different in the winter with a greater number of mature marten inhabiting uncut forest areas (Thompson 1994)

Habitat

Marten can tolerate a wide range of forest habitats if food and cover are present. However, they seem to prefer mature conifer dominated or mixedwood forests (Strickland and Douglas 1987). Spencer (1987) found that marten tended to use trees, snags, stumps, and logs for non-subnivean (above snow) resting sites. During periods of continuous snow cover, subnivean resting sites were used exclusively and were associated with logs, stumps, and snags (Spencer 1987). Marten prefer large snags, rock crevasses, and large logs for natal dens. Dens are located primarily near the ground and offer some security from predators (Ruggiero *et al.* 1998). Many studies have looked at marten home range sizes using an array of techniques including mark-recapture and telemetry methods. These techniques provide a variety of home range estimates that vary from 0.1 to 15.7 sq. km. Male home range sizes, in general, are 1.3 to 3 times larger than female home ranges (Strickland and Douglas 1987). Thompson and Colgan (1987) found that in years during food shortages marten home ranges will increase in size. Female marten are especially sensitive to food shortages and can increase their home ranges 1.5-2 times.

Food Habits

Marten are omnivores consuming a variety of plant and animal materials that are located predominantly in their preferred habitat (Strickland and Douglas 1987). Clem (1977) found marten diets were variable during the winter, although snowshoe hare (*Lepus americanus*) constituted 20-40% of their diet, throughout the season. Red-backed voles (*Clethrionomys gapperi* (Vigors)), ruffed grouse (*Bonasa umbellus* (L.)), gray jay (*Perisoreus canadensis* (L.)), red squirrel (*Tamiasciurus hudsonicus* (Erxelehen), deer mice (*Peromyscus maniculatus* (Wagner)), and redhorse sucker (*Moxostoma spp.*) were all consumed by marten from November to February (Clem 1977). Raine (1987) found similar results for the winter season with a large proportion of the marten's diet composed of snowshoe hare (58.9%), microtines and shrews (20.5%), red squirrels

(15.9%), and birds (17.8%). Thompson and Colgan (1990) suggested that marten primarily forage for large prey (snowshoe hare) and consume smaller species incidentally in winter. As well, they predicted that marten diet selection would expand during declines in large prey abundance.

Response to Disturbance

Large-scale clearcutting and severe fire disturbances reduce habitat suitability for marten, depending on the intensity of disturbance and rate of regeneration (Strickland and Douglas 1987). Thompson (1994) found that marten density indices are 88-95% higher in uncut mature mixedwood forest compared to logged areas up to 40 years old. Using closed canopy forests for predator avoidance and greater success in prey capture may have contributed to the overall habitat preference (Thompson and Colgan 1994). Similar studies (Potvin *et al.* 2000) have suggested that marten use of logged landscapes in the winter can be variable. They also found that marten selected mixedwood stands. Potvin *et al.* (2000) recommended that forest management retain greater than 50% of the forest on the landscape in an uncut condition and the forest be greater than 30 years of age. After forest harvesting has occurred, 15 to 23 years of regeneration is considered adequate for providing suitable habitat for marten (Strickland and Douglas 1987). However, other studies suggest that greater stand development is required over a longer period of time (Snyder and Bissonette 1987). One consequence of logged landscapes is increased mortality due to predation and commercial trapping (Thompson 1994).

Fisher (*Martes pennanti*)

Distribution

Fisher occurs throughout most of the forested regions of Canada, excluding some of British Columbia (B.C.). Its original range included B.C., the northern boundary of the Pacific Northwest and the northeastern area of the U.S. including the Great Lakes region. Land clearing, over-trapping and the use of strychnine as a harvest and predator control have reduced their range since the early 1900s. The fisher's range has been restored in several parts of North America through protective legislation, habitat improvement, and reintroductions (Douglas and Strickland 1987).

Population Density

Although density is difficult to measure, estimates from trapping records and radio-telemetry methods have been made. Densities ranging from 1 fisher/3.9-7.5 sq. km to 1 fisher/18.9 sq. km have been reported (Douglas and Strickland 1987).

Habitat

Powell (1994) found that fishers selected habitat for foraging and resting sites at multiple scales. Foraging habitat for fisher in their home range was comprised of pine and lowland-conifer habitats with relatively small amounts of upland-hardwood habitat. Lowland-conifer sites were used more often as resting sites, while the upland-hardwood habitats in close proximity to foraging habitat were avoided (Powell 1994). Overhead forest cover provides concealment, access to prey, denning sites and escape. Areas of increased edge tend to have more fisher activity due to high prey availability than interior habitat. Fishers seem to adapt better than marten to early successional stages of forest growth. Fishers use a variety of resting sites including; hollow logs, tree cavities, brushpiles, rockpiles, burrows, dens of other animals and snow dens. Home ranges for fisher vary from 15 to 39 sq. km for males, and 3.6 to 20 sq. km for females (Douglas and Strickland 1987).

Food

Fishers are somewhat opportunistic feeders that prey on species associated with their habitat (Douglas and Strickland 1987). Raine (1987) found that fishers consumed hares most often (84.3%), with birds (8.2%) and martens (5.0%) as secondary sources of food in Manitoba. Fishers have also been observed consuming carrion, fruits, nuts, and berries. Fisher consumption of small mammals has been shown to increase during declines in hare populations. Porcupines (*Erethizon dorsatum* (L.)), a species with few predators, are also a primary food source for fishers (Douglas and Strickland 1987).

Response to Disturbance

Severe disturbance reduces habitat value for fishers by removing overhead concealment and allowing snow to accumulate and inhibit movement (Raine 1987). Low intensity disturbances may provide habitat diversity for improved prey densities and denning sites (Douglas and Strickland 1987).

Relationship Between Marten and Fisher

Studies indicate that some interaction between marten and fisher populations occurs. These two species are sympatric and may compete for food resources (Clem 1977, Strickland and Douglas 1987, Raine 1987). The theory of competitive exclusion suggests that species cannot fill the same role in a community (Elton 1927) or a similar subdivision of the environment (Grinnell 1917). Both marten and fisher have large diet requirements that are common to several species. However, marten may prey more frequently on smaller mammals and birds, as opposed to fishers preying on larger species, such as porcupines (Clem 1977, Strickland and Douglas 1987). Marten and fisher both hunt on the ground, although marten use areas under the snow (subnivean) and frequent trees (arboreal) more often. Both require similar denning sites (Strickland and Douglas 1987). Clem (1977) compared the diets of marten and fisher trapped in Algonquin Park and found the diets differed until winter when an overlap in prey occurred. The overlap in prey studied by Clem (1977) and Raine (1987) was not a stress for either species. Raine (1987) also found that marten made up approximately 5% of the fisher's diet. However, Strickland and Douglas (1987) suggested this phenomenon was uncommon.

A study conducted in Maine by Krohn *et al.* (1995) tried to find evidence of marten and fisher interactions. They found indications that there are weather variables conducive to marten (snowfall) that negatively affect fisher and precluded their range from certain parts of Maine. Marten were not present in southern Maine and it is hypothesized that interactions with a dense fisher population is preventing expansion. Weather factors in this region that enable fisher to thrive may prevent marten from expanding its distribution (Krohn *et al.* 1995).

Beaver (*Castor canadensis*)

Distribution

Beavers are distributed throughout North America and are limited primarily by food and stream availability. They are not found north of the treeline, in peninsular Florida, some parts of the Midwest U.S. and arid regions. A reduced beaver distribution throughout Canada and the U.S. can be attributed to over-trapping in the early 1900s. Current management of beaver has allowed the species to repopulate most of its former range (Novak 1987).

Population Density

Population density is dependent on several factors including habitat, mortality and behaviour. The number of families and the average number of individuals per family will give an estimate of the total beaver population. Surveys have indicated a range in densities from 0.15 families/sq. km to 4.6 families/sq. km. Individual colonies are also variable in size ranging from 3 to 8 beavers per family. Family size has been shown to vary over several seasons but there is no evidence that beaver populations are cyclic (Novak 1987).

Habitat

Beavers inhabit a wide variety of habitats. They colonize ice-free ponds, permanent water systems in the arid southwestern U.S., arctic and sub-arctic areas with nine months of ice cover and montane regions above 3400 m. Water is the most important component of beaver habitat, but it cannot fluctuate severely between seasons or flow too quickly. Ponds, small lakes and meandering streams with muddy bottoms are ideal for beavers. Beaver home ranges vary from 0.6 to 0.9 km of stream. Studies have shown that when beaver densities are low, home ranges can be up to 2.2 km of stream (Novak 1987).

Food

Beavers are strictly herbivores and consume approximately 30% of their diet in cellulose and 44% in protein. The number of vegetative species consumed by beaver increases from north to south. In Mississippi, beavers were found to eat 42 species of trees, 36 genera of herbaceous plants, and four types of woody vines. Beavers in all regions of North America cut conifer tree species. However, beavers are dependent on deciduous species and shrubs (Novak 1987). Barnes and Mallik (2001) found that trembling aspen (*Populus tremuloides* (Michx.)), a preferred food species, did not regenerate significantly after 12 years of initial dam construction and colonization. Slough and Sadleir (1997) considered trembling aspen to be an essential component of beaver diet and that population health was dependent on it.

Canada Lynx (*Lynx canadensis*)

Distribution

Canada Lynx are found throughout most of Canada in the boreal forest zone. Its range extends southward along the Rocky Mountains into Colorado. Lynx populations declined in the first half of the 1900s until they were fully extirpated from the northern U.S. and parts of southern Canada because of overtrapping. Throughout the 1960s and

1970s population growth occurred and they reclaimed some of their former range throughout Canada and several areas through the northern U.S. (Anon. 1988). Lynx were placed on the U.S. Threatened Species list in 2000 (Anon. 2002).

Population Density

The population density is variable across Canada and can reach highs of 1 lynx/5-10 sq. km or can be as low as 1 lynx/50-70 sq. km. Generally, the density is thought to fall within the range of 1 lynx/15-25 sq. km. Habitat quality and availability of prey are factors contributing to the variability in lynx density across the country (Quinn and Parker 1987).

Habitat

Lynx habitat requirements are not well-documented and require more research. Selection of habitat is thought to be based on their primary food source, snowshoe hare. Studies of snowshoe hare have determined that a diversity of forest types including conifer swamp are preferred for cover with alternating shrubby openings for feeding. Openings of approximately two to four ha within conifer-dominated sites are considered ideal. In studies of lynx habitat selection, successional forests and open mature conifer stands were selected more often than mature mixedwood sites (Quinn and Parker 1987). Lynx have also been observed in fragmented agricultural landscapes. Their persistence in this habitat is based on a minimum quantity of forest cover and the availability of prey (Anon. 1988). Home ranges for lynx are approximately 16 to 29 sq. km, but can vary by as much as 12 to 243 sq. km. Many factors including habitat quality and prey abundance likely contribute to the high variability in recorded home ranges for lynx (Quinn and Parker 1987).

Food

Lynx prey primarily on snowshoe hare that constitute 60% of their winter diet and 40% of their summer diet. Lynx also prey on mice (*Peromyscus* spp.), voles, red squirrels, ruffed grouse and ptarmigan (*Lagopus* spp.) when hare populations are declining. Predation on larger mammals is not common for lynx but does occur on deer (*Odocoileus* spp.) fawns, caribou (*Rangifer tarandus* (L.)) fawns, moose (*Alces alces* (L.)) calves, but very rarely on adult deer or caribou. Lynx in Newfoundland commonly preyed on caribou calves and can be a limiting factor to the caribou population when hare populations are declining (Quinn and Parker 1987).

Response to Disturbance

Little is known about the response of lynx to forest disturbances, but the early-to-mid-successional conditions created by fire and clearcutting should produce prime habitat for snowshoe hare and therefore lynx, as well (Quinn and Parker 1987).

Lynx and Snowshoe Hare Cycles

Snowshoe hare populations follow a regular interval of abundance and decline in an eight to 11-year cycle throughout the boreal forest. No clear consensus can be reached on whether predation of snowshoe hare is the driving factor behind its decline or simply a contributor. Most researchers agree that predation by lynx is a driving force behind the decline and may in fact cause the population to decrease more than normal and for a longer period of time (O'Donoghue *et al.* 1998).

Poole (1994) studied lynx populations during the first year of a snowshoe hare decline and determined that kitten survival and the overall density was unchanged from the previous year. The following year however, showed no kitten recruitment, home ranges increased, dispersal intensified and mortality increased. By late winter of that same season no lynx were detected on the study area.

MONITORING FURBEARERS AND REGULATING HARVESTS

Monitoring

Several methods have been studied to accurately monitor and estimate populations of furbearers. Thompson *et al.* (1989) used 1 km track transects as an index of the relative abundance of several species in winter. Live trap captures of marten, hare, and red squirrel were highly correlated with the abundance of tracks recorded. To use this method as a monitoring system, Thompson *et al.* (1989) recommended installing four or more permanent 1 km transects, in two different sites that are proportional in size to the occurrence of habitats on the landscape. This system would be adequate for monitoring the relative abundance of ermine, marten, hare and red squirrel. Depending on home range size and population levels, a longer transect may be required to ensure that sample size is large enough for other species such as red fox (*Vulpes vulpes*) (Thompson *et al.* 1989).

In California sooted track plates with bait have been studied as a method for indexing population change in marten and fisher. Zielinski and Stauffer (1996) stratified the landscape into broad regions based on the variation in occurrence of marten and fisher and then sampled for the presence or absence of the two species. The detection ratio (number of stations visited divided by the total number of stations) was used as the relative measure of abundance. Power analysis was performed to determine the number of samples required to detect different levels of decline in the population. These tests were only able to detect declines in the index and not increases, due to the large sample size requirements. This method of non-lethal monitoring may be more socially accepted in the future (Zielinski and Stauffer 1996).

Trapping records are commonly used as a measure of species abundance but are subject to variation by other factors. The price of fur, access to the traplines, and the availability of other employment for trappers are all factors contributing to the density-independent variation observed in catch totals (Thompson 1988). Weinstein (1977) and Smith *et al.* (1984) criticized trapline harvest data as an indicator of furbearer abundance based on changing capture probabilities among years and socio-economic factors. Similar studies have shown that by controlling trapping effort, the overall variation in effort can be reduced and an accurate population estimate made. McDonald and Harris (1999) used trapper questionnaires combined with harvest records to make population size estimates in England. They found that total catches were directly related to trapping intensity and alone did not reflect population trends. To monitor populations using this method McDonald and Harris (1999) suggested it would be necessary to record the number of traps set in each month, the total catches, and the sex of each animal.

Marten and Fisher Management

To properly manage marten and fisher, an estimate of the population size and its rate of change are required. Based on this population estimate a proportion of the animals are allocated for harvest. Population size for both of these species is very difficult to measure and therefore obtaining an accurate estimate is economically impractical. Managers have resorted to population indices to measure the performance of each species on the landscape (Douglas and Strickland 1987).

The trapping vulnerability of males compared to females, and juveniles compared to adults, is reflected in the sex and age ratios of marten trapped. Juveniles that lack a home range tend to constitute a large proportion of the fall harvest, approximately 67% in some years. By February, the proportion of juveniles trapped decreases to approximately 37% partly due to the large harvest in the fall. The proportion of marten in a certain sex and age group can be used as a tool for identifying the harvest intensity in the population. When harvest intensity is low, juvenile males are more susceptible to being trapped and constitute the primary demographic from the population being harvested (Strickland and Douglas 1987, Thompson and Colgan 1994, and Hodgman *et al.* 1994). However, when the population is declining or being over-harvested adult females become more susceptible to harvest and will be an increasingly large component of the harvest. To combat the effects of over-harvest, quotas are imposed on a trapline to ensure the population is not devastated (Strickland and Douglas 1987). A quota imposes a maximum harvest level on a species to ensure its trapped on a sustained yield basis (Novak 1987).

Fishers experience similar disparities in the trapped ratios of males compared to females and juveniles compared to adults within the population. Male fishers have a larger home range size and are therefore more susceptible to being trapped than females. Population indices and the sex-to-age ratios have been monitored to ensure over-trapping does not occur (Douglas and Strickland 1987).

Fryxell *et al.* (2001) used cohort analysis to determine the age structure of a marten population harvested from 1972 to 1990 in Algonquin Park, Ontario. The total harvest and corresponding ages were used in a backward recursion formula to estimate the minimum population sizes present in the past. Monte Carlo simulations were then used to calculate the expected maximum yield from the estimated population. This procedure estimated a marten harvest proportion of 36% would be the maximum biological potential of the population. Trappers were actually removing 34% of the population. The near maximum yield harvest was attributed to trapper/manager cooperation and active participation by trappers in the age determination program. The ability to adjust harvest levels when fluctuations were observed in the proportion of marten trapped was considered an overriding factor (Fryxell *et al.* 2001).

Lynx Management

Fluctuating lynx populations (or cycles) influence the number of animals trapped each year. Quotas based on trapping history for an area are generally employed to prevent over-harvesting, but do not achieve an optimum yield. Documented and predictable cycles within the population are used to aid managers in setting quota limits. Areas of high intensity trapping should be monitored closely to ensure populations are not over-harvested especially on the declining portion of the lynx cycle. Monitoring programs that record the sex and age of harvested lynx can be used to detect the onset of a decline. One indicator of a population decline is the harvesting of primarily older lynx; this signifies a lack of yearlings within the population (Quinn and Parker 1987). To offset the effects of a declining population, Quinn and Thompson (1987) and Poole (1994) suggested eliminating lynx trapping for several seasons until populations begin to increase again. This measure ensures high adult lynx survival when the population cycle restarts.

Beaver Management

To accurately regulate beaver harvests, estimates of population size are required. Aerial surveys are carried out to determine the number of active beaver families in an area and the size of food caches that are being stored for winter. The surveys are generally carried out in the autumn after leaf-fall to enhance the detection of colonies and because food caches are usually completed. Knowing the total number of families on a trapline does not give an accurate estimate of the total population unless the mean number of animals per family is known. Studies have found that large, medium, and small food caches support 9.0 animals, 7.1 animals, and 3.7 animals, respectively. Formulas have also been derived based on the number of kits, and non-breeding adults within a colony (Novak 1987).

Beaver harvests throughout Ontario are regulated by a quota system. Quotas can vary greatly depending on region and site type. In the past, quotas of 40 to 70% were considered excessive. Ontario, through research and years of trial and error, has adopted a standard catch quota of 30% of the total estimated population (Novak 1987).

A DESCRIPTION OF ONTARIO'S ECOLOGY, CLIMATE, AND NATURAL PROCESSES

Ecological Land Classification

The primary ecological land classification for Ontario was derived by Hills (1959) (Figure 1). This system is based on a hierarchy of ecological units where landform is the smallest unit, site district is an intermediate classification and site region is the largest unit. The landform unit is the initial building block of the system. Each level is based on the level below it, site districts are an assemblage of landform units and site regions a grouping of site districts. Landform units are based on broad soil and topographical features, as well as vegetation succession patterns. The landform units are then combined to form site districts. As Hills' hierarchical land classification moves to a larger spatial scale, climate is the next controlling factor for ecological processes across the landscape. Climatic gradients are used to combine the site districts into site regions (Perera and Baldwin 2000).

Recently Mackey *et al.* (1996) studied Hills' ecological land classification and attempted to quantify the site region boundaries using several climatic elements including minimum temperature, maximum temperature and precipitation. Using these broad climatic measurements, eight climate variables were created. The variables used in the analysis were degree days, length of growing season, minimum temperature of coldest month, maximum temperature of warmest month, precipitation of warmest quarter, and

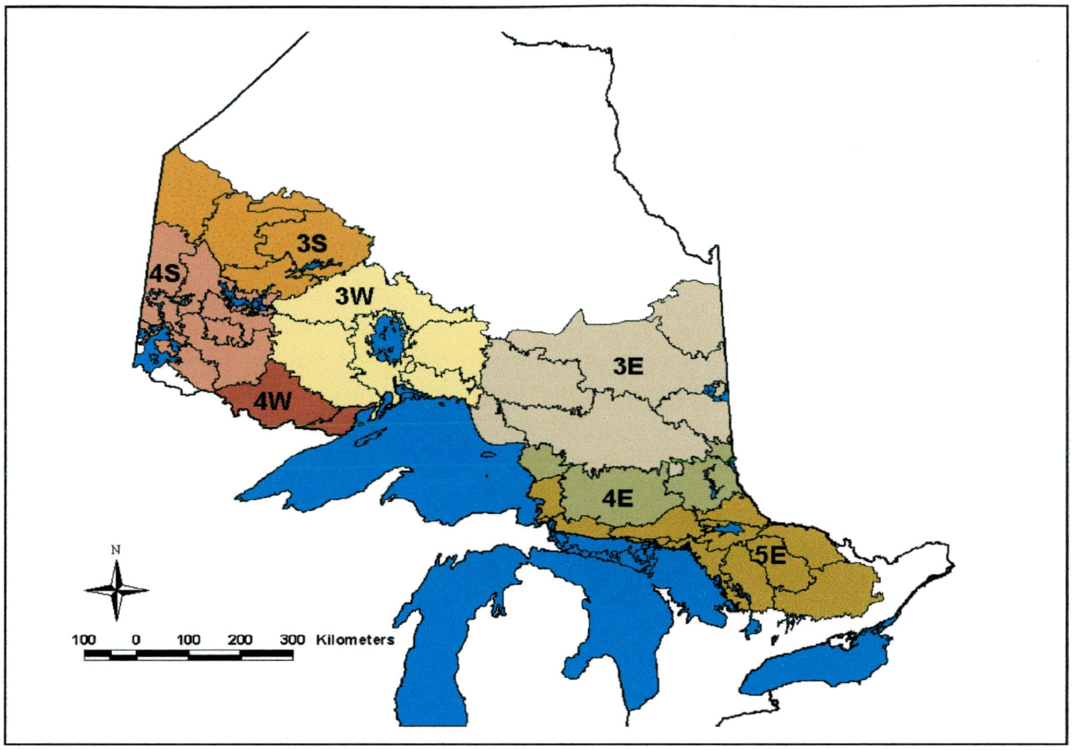


Figure 1. Hills site region land classification.

temperature of warmest quarter. As well, two precipitation variables for different periods were included. The eight spatial climate variables were then analyzed to identify climatic trends using an agglomerative classification procedure. Results showed that temperature is the climatic factor driving the north-south gradient in Hills' classification, while summer precipitation is the factor contributing to the east-west split. Overall, many of Hills' site regions were similar to climatic gradients modeled. However, some of the boundaries clearly did not coincide with significant climatic gradients, which may be due to improved climate modeling and analysis (Mackey *et al.* 1996).

Climate

Most of Ontario is dominated by a humid continental climate, which is influenced by cold, dry polar air from the north, Pacific polar air from the prairies and warm, moist, subtropical air from the Atlantic Ocean and Gulf of Mexico. Temperature follows a north-south gradient but is affected by Hudson Bay and James Bay which reduces the number of growing degree days over an extensive area. Continental conditions from the prairies influence the northwestern part of Ontario, while warm air in summer from the southwest U.S. brings warm dry conditions to the western shores of Lake Superior. These conditions increase the number of growing degree days (Baldwin *et al.* 2000). Precipitation throughout the province increases generally from the northwest to the southeast but can be altered significantly by large bodies of water. In the winter, precipitation and snow accumulation are highly variable and can be influenced by the high-pressure zones in the northern and eastern parts of the province. Low-pressure moist air accompanied by winds from the southwest deposit precipitation on the colder landmass. Precipitation throughout the summer is localized away from bodies of water and tends to be highest in central Ontario (Baldwin *et al.* 2000)

Species Distribution

The distribution of vegetation in Ontario is directly associated with climatic patterns across the province. Vegetation structure and function are linked to climate and the associated weather through temperature and precipitation (Flannigan and Weber 2000). Vegetation is also influenced by weather indirectly through disturbance and permafrost. The minimum temperature in winter is recognized as a major factor in determining tree species distribution. Most deciduous species cannot tolerate temperatures below -40°C, while conifer species use a different strategy to prevent damage in cold weather and can withstand temperatures of –70° to –80°C (Flannigan and Weber 2000). Although minimum temperature limits the distribution of species, a minimum growing season temperature is also required to initiate growth and germinate seeds. Mechanical damage to vegetation can also occur due to snow accumulation. Although most areas are characterized by mean temperature and precipitation, variability within these weather attributes can have consequences to the landscape (Flannigan and Weber 2000).

Species richness in Ontario is distributed along a gradient that increases from north to south and is maximized in the Algonquin Park region. This area contains about 110 species of forest birds, 49 mammal species, and 22 forest dwelling amphibian and reptile species. Southern Ontario shows lower species richness due to increased agriculture and urbanization. The entire province contains approximately eight species of reptiles, 14 species of amphibians, 60 species of mammals, and 150 species of birds that use forests for breeding (Thompson 2000a).

At broad provincial scales species richness corresponds to the forest's net primary productivity, which has a similar north-south gradient throughout Ontario. Climate is a controlling factor in forest productivity (Thompson 2000a).

Although species distributions have changed over the last 50 years, documenting the degree of change is difficult. In general, climate change combined with deviations in weather and habitat alteration caused by forest management are thought to be factors in several documented changes in wildlife distribution (Thompson 2000a). Fisher has shown the most dramatic shift in range, which began from 1964 to 1975 in a province-wide decline followed by a recovery over the past 5-7 years (Thompson 2000a). The decline in the west was not as severe but the fisher did reduce its range. Western Ontario experienced a slight change in distribution while the decline in eastern Ontario was more severe. In north central Ontario the fisher range declined from White River, Manitouwadge and Geraldton. The population further declined from Cochrane to a southerly limit near Kirkland Lake (Thompson 2000a).

Pattern of Clearcut and Fire Disturbance in Ontario

Perera and Baldwin (2000) state that approximately 20% of the landscape was disturbed by fire and timber harvest, in the forest management zone of Ontario from 1951 to 1995 (≈0.5%/year). Forest fires were more spatially clustered (Figure 2) while timber harvesting (Figure 3) was distributed evenly across the landscape (Perera and Baldwin 2000). Site regions 2W, 2E, and 5E show very little disturbance by either fire or timber harvesting. The site region encompassing Red Lake (4S) had the greatest disturbance, 15% from fire and another 25% from timber harvesting. Site region 3S exhibited the greatest area burned by forest fires (17%) while 3E, which encompasses Timmins, Cochrane, and Hearst had the most timber harvesting (24%). Edge created by timber harvesting has increased greatly throughout the forest management zone, while the quantity of edge created by fire has remained constant. The increasing amount of edge was partly caused by an increase in timber harvesting from 0.5 million ha from 1951 to 1960 to 2.0 million ha from 1981-1990. A decrease in clearcut size has further confounded the problem by creating a landscape with many small disturbance patches (Perera and Baldwin 2000). The mean patch size of clearcuts has decreased from 939 ha in the 1960s to 105 ha in the 1990s, while the number of clearcuts has increased from 1,141 to 15,934 over the same period (Table 1) (D. Savage, unpub.).

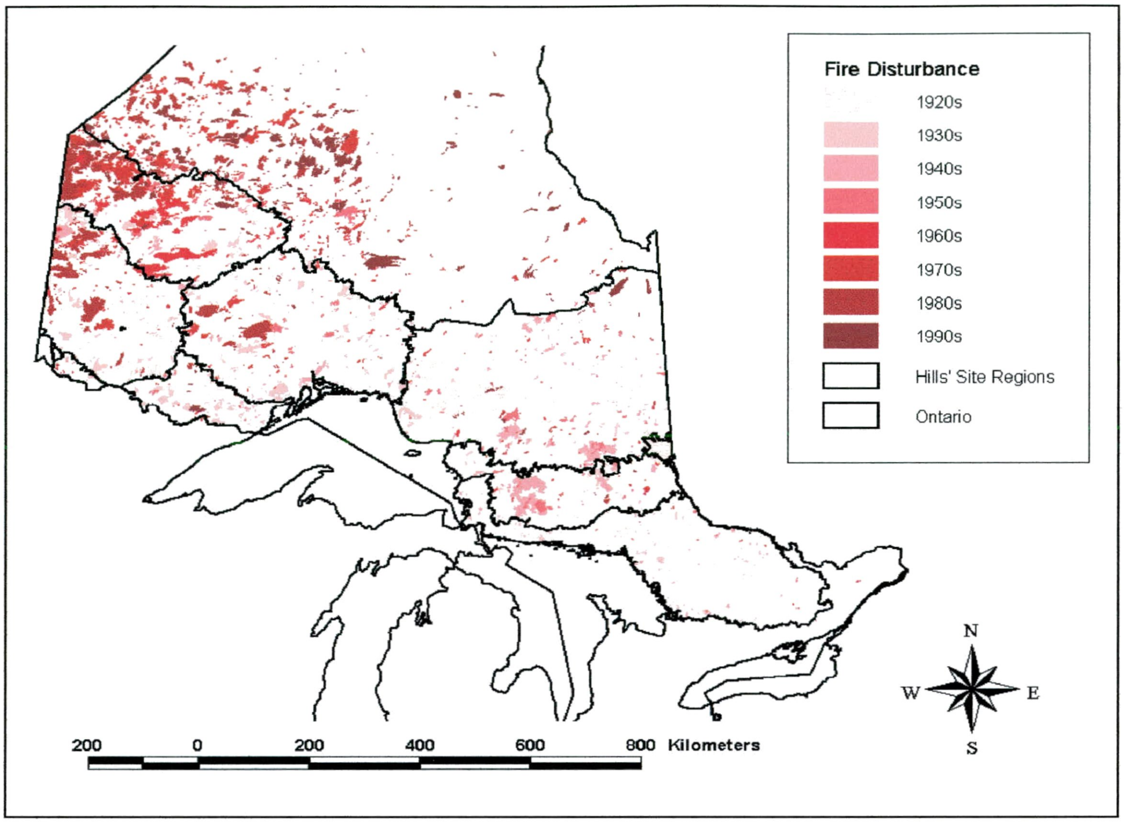


Figure 2. Fire Disturbances in Ontario and Hills site region land classification.

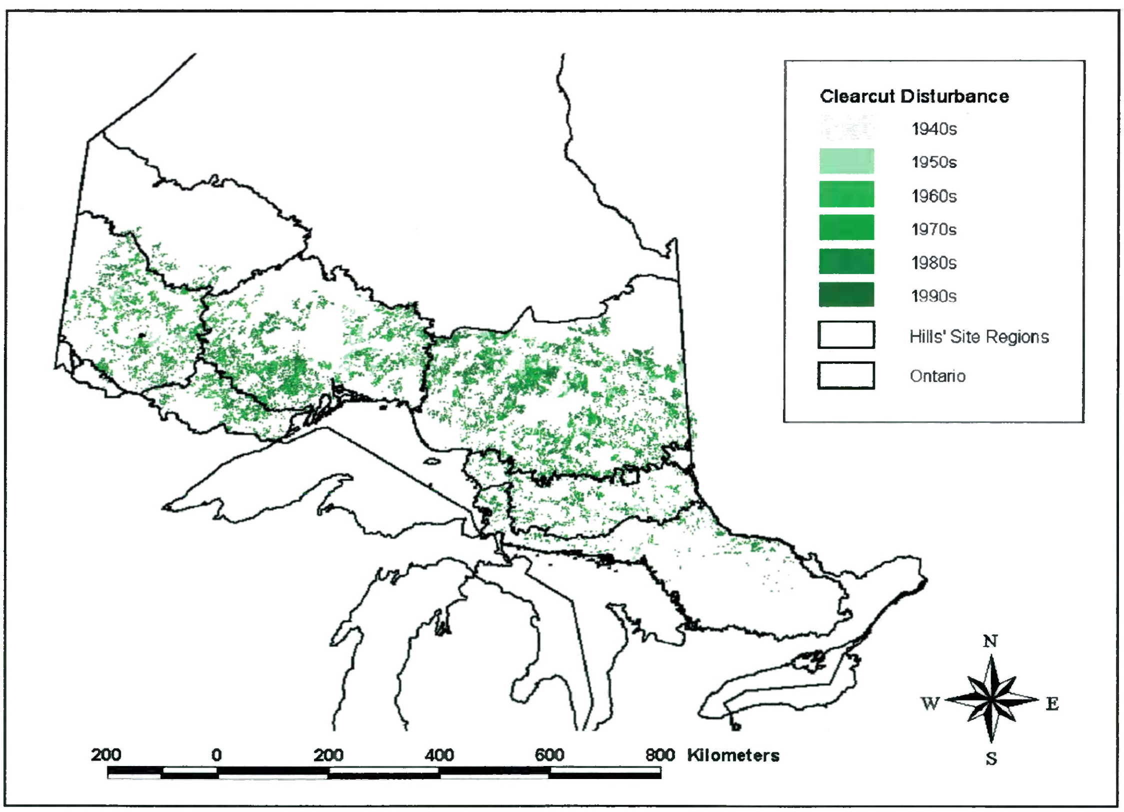


Figure 3. Clearcut Disturbances in Ontario and Hills site region land classification.

Table 1. A summary of logging disturbances for Ontario from 1940 to 1995.

Decade	Total Clearcuts	Average Clearcut Size (ha)	Standard Deviation of Clearcut Size	Total Area Harvested (ha)
1940s	141	1,558	4697	219,677
1950s	377	1,381	3574	520,564
1960s	1,141	939	2337	1,071,784
1970s	2,060	711	2034	1,465,321
1980s	8,398	244	889	2,045,633
1990s	15,934	105	466	1,670,809

Gluck and Rempel (1996) analyzed both fire and clearcut disturbed landscapes to identify key differences in spatial pattern. Landscape metrics were chosen that describe composition, size, shape and interspersion. The clearcut landscape tended to have larger more variable patches at lower densities with greater irregularities in shape. Edge densities between fire and clearcut were not different in recent disturbances. However, they were different in older disturbances. The mean core area size for areas burned was greater in recent disturbances. Interspersion of fire disturbances was greater in the fire-dominated landscape for both recent and older disturbances (Gluck and Rempel 1996). This study was conducted north of Fort Frances and does not necessarily represent the conditions found throughout the boreal forest.

Forest Composition

The boreal forest is dominated by a limited number of tree species including jack pine (*Pinus banksiana* (Lamb.)), black spruce (*Picea mariana* ((Mill.) B.S.P.)), white spruce (*Picea glauca* ((Moench) Voss)), white birch (*Betula papyrifera* (Marsh)), trembling aspen, balsam poplar (*Populus balsamifera* (L.)) and balsam fir (*Abies balsamea* ((L.) Mill.)). These species are found in several associations across the landscape producing both conifer and mixedwood stands. Topography plays an important role in forest composition by either limiting or enhancing the growing conditions for certain species. Poorly drained lowland areas are dominated by homogeneous stands of black spruce, with small proportions of cedar (*Thuja occidentalis* (L.)) and larch (*Larix laricina* (Du Roi) K. Koch). Dryer sites with greater productivity tend to have more diverse stand composition with increased productivity (Thompson 2000b).

The Great Lakes-St. Lawrence Forest Region is situated in central and southern Ontario and to the east and west of Lake Superior. This region contains a greater diversity of vegetation than the boreal forest and is characterized by primarily mixedwood and deciduous forests. Some common hardwood species found in this region are: sugar maple (*Acer saccharum* (Marsh.)), yellow birch (*Betula alleghaniensis* (Britt.)), beech (*Fagus grandifolia* (Ehrh)), trembling aspen and red oak (*Quercus rubra* (L.)). White pine (*Pinus strobus* (L.)) that was located throughout most of the Great Lakes-St. Lawrence Forest Region in the 1700s, is currently found in much smaller densities because of over-harvest (Thompson 2000b).

Fire Regime

Since the 1920s improved fire detection and suppression technologies have influenced fire disturbance dynamics across the landscape (Li 2000). Fire in the boreal forest is highly variable in intensity, frequency and spatial extent. Small, frequent fires of less than 100 ha are most common in the boreal forest. However, high intensity crown fires that disturb tens of thousands of hectares occur as well. These large disturbances are primarily responsible for vegetation patterns at the landscape scale. In general, a small proportion of fires are responsible for the majority of disturbed areas (Thompson 2000a). The fire cycle in pre-suppression history is estimated to be between 20 and 135 years with a mean of 60 years. The fire cycle across Ontario is not uniform but is instead influenced by a number of factors including weather, topography, fire events, and fuel conditions (Li 2000). Eastern Ontario generally has a longer fire cycle due to increased moisture and a low summer temperature from the influence of Hudson's Bay (Thompson 2000a).

The Great Lake-St. Lawrence forest region rarely experiences large stand-destroying fires, but instead is disturbed by low intensity ground fires that influence understory succession. These fires cause individual tree mortality and create small to large openings in the canopy (Thompson 2000a).

A qualitative comparison of three fire management zones in the OMNR Red Lake District found that several key components of the fire regime had been altered by human interactions on the landscape (Li 2000). The total number of fires, mean fire size, percentage of total area burned, percentage of the mean annual burn, and the fire cycle were compared for intensive, measured, and extensive fire management areas. Intensive fire management zones are located in areas with greater population densities and therefore had an increased incidence of human-caused fires. Fires caused by lightning strikes dominated extensive areas. As a result of increased forest activity in intensive areas, fire suppression efficiency is greater, thus decreasing the percentage of total area burned and the mean fire size. The mean fire size was 182 ha, 353 ha and 1,993 ha for the intensive, measured, and extensive management areas, respectively. The fire return cycle has also been altered and ranged from 51 years in the extensive fire zone to 135 years in the intensive fire management zone (Li 2000).

CLIMATE AND WEATHER

Climate is defined as the variation in weather over a specific time period in a certain location. It is usually measured over 30 years and can represent many different variations of weather that occur. Mean temperature and precipitation are common variables used in climate studies. However, the extreme variations (i.e., minimum/maximum temperatures) in weather that occur may offer more evidence to processes that will affect vegetation and the landscape (Flannigan and Weber 2000).

Generating a Weather Model

Mackey *et al.* (1996) used a smoothing thin-plate spline interpolation technique to generate climatic surfaces for the province of Ontario. These surfaces were used to characterize the climate for each of Hills' site regions. The thin-plate smoothing spline algorithm offers several advantages to other geostatistical techniques. This method does not require initial subjective estimates to generate the surfaces (Mackey *et al.* 1996). A surface produced using the thin plate smoothing spline also passes exactly through the measurement points and will have a smooth interpolation (ESRI 2001). Flannigan and Wotton (1989) did a comparison of interpolation techniques for generating fire weather index (FWI) surfaces, and suggested that a thin-plate smoothing spline algorithm was optimal for estimating the fire rating between stations.

HABITAT AND CLIMATE

Habitat and climate are not mutually exclusive factors for wildlife but instead interact, in part, to form the landscape where populations succeed (survive, reproduce, feed, etc.). The spatial and temporal composition, structure, and productivity of forest ecosystems are in part determined by climate. Vegetation and wildlife are also influenced by these climatic gradients (Mackey *et al.* 1996). In theory, habitat has three components; cover, food and water. Cover has been further divided into habitat requirements and escape cover. There are two components of vegetation that are important for wildlife habitat: the forest landscape structure and the taxa of the plants, or floristics (Morrison *et al.* 1998). The vegetation structure and habitat configuration (size, shape, distribution of vegetation) was thought to be more important than floristics for determining patterns of habitat occupancy. However, species composition of the forest is now also widely recognized as an important factor in determining habitat occupancy. (Morrison *et al.* 1998).

Weather patterns can influence wildlife populations at small spatial scales for short periods of time. Severe winter conditions can affect ungulate populations by limiting food availability resulting in increased predation rates (Voigt *et al.* 2000). Fishers also respond negatively to increasing snow depths, which reduce their fitness, by decreasing recruitment, survival, or a combination of the two (Krohn *et al.* 1995).

DISTURBANCE

Disturbance is defined as "a discrete event, either natural or human-induced, that changes the existing conditions of an ecological system; … an allogenic disturbance is the result of external factors such as fire, drought, and wind" (Perera *et al.* 2000). In Ontario, the fire regime can be described through several variables including size, intensity, and frequency. The fire regimes can be classified according to intensity and frequency of occurrence. A combination of short and long-term fire frequencies, along with varying intensities of surface and crown fires can be classified into approximately six classes of fire regime (Li 2000).

From an ecological point of view, fire disturbance is important to boreal tree species, which have become adapted to varying fire intensities and frequencies. Fire dictates species composition, the spatial pattern of vegetation and successional processes occurring on the landscape (Li 2000).

NATURAL DISTURBANCE AND WILDLIFE HABITAT

All types of disturbances have some influence on wildlife depending on the scale, frequency and intensity. Landscape disturbances such as fire and windstorms can change habitat suitability by altering the structure, composition and function of the forest. Herbivory, considered a small-scale disturbance, can also affect wildlife by modifying species composition of both forests and herbaceous vegetation over time. Disturbances that are infrequent but high in intensity can have drastic effects on forest structure. An example of a rare but intense disturbance was the 1998 ice storm that struck eastern Ontario. Wildlife that are dependent on older forest conditions may find it difficult to find these patches in landscapes with high frequency disturbances (i.e., fire, windstorm, and clearcutting). Fire and windstorm disturbances that are common in the boreal forest can be highly variable in their extent and intensity (Voigt *et al.* 2000). All types of disturbances interacting at multiple scales, intensities and frequencies are important factors influencing wildlife habitat.

ECOLOGICAL BASIS FOR ANALYSIS AT MULTIPLE SCALES

Scale functions both temporally and spatially across a given landscape. Scale is defined as a change in pattern related to temporal and/or spatial attributes that are of interest and can be measured (Gardner 1998). There are two measured components of scale: grain and extent. Grain is the resolution or unit measured when sampling. In a spatial sense, grain is the plot or pixel size. The spatial domain over which measurements are made is referred to as the extent and is the geographic area of observation (Goodwin and Fahrig 1998). A species response and perception of habitat are functions of scale and resolution of interpretation. Wildlife species of different sizes that occupy the same spatial area will interpret the landscape at different scales thus influencing interactions and functions among species (Kolasa and Waltho 1998). Wildlife populations can be characterized by both an upper and lower spatial scale. The smallest spatial scale of a species is defined by the individual and is characterized by the area that an individual occupies during non-dispersal activities. The global population is recognized as the largest spatial scale and encompasses the distribution of a species (Goodwin and Fahrig 1998).

Choosing the appropriate scale for sampling and analysis of population dynamics can be very difficult. In the past, cost and logistical constraints have been major factors in choosing the scale for ecological studies. Human interpretations of habitat structure and species requirements have also been a method used for choosing scale. Elements of the landscape that are simple to delineate such as clearcuts, agricultural fields or urban areas, may not encompass the local or regional populations thus giving researchers an incomplete understanding of the true population dynamics. A third method for choosing the appropriate scale of study is to observe the population at its inherent local, regional, or global population scales and match the study to one of these scales. This method requires species distribution and rates of dispersal information that are extremely costly and often difficult to collect, making this method very difficult to use. Wildlife population dynamics cannot be understood at any single scale and should be explored at multiple scales to accurately identify factors that control population dynamics (Goodwin and Fahrig 1998).

HIERARCHY THEORY

Hierarchy theory is a method for observing different levels of organization that are ordered based on their interaction strength and frequency. The focal level (L) is composed of a system of elements that are at a lower level (L-1), while at the same time is a single component of a higher system in the hierarchy (L+1) (King 1997). Level L is the focal scale at which a certain biological phenomenon is being measured. If the phenomenon is collective then the components of the system fully explain level L. However, if the system is emergent, a higher level of information (L+1) is required to explain the variation in the phenomenon. As a system is observed at successive levels in the hierarchy, functional relationships at the focal level may show qualitative differences or variability at higher levels; this phenomenon is known as transmutation. To understand processes at the focal level, a reductionist will look for explanations at a lower level (L-1). However, the move from one level of organization to the next will involve variability that cannot be explained and this variability is transmutation (Bissonette 1997). Boundary conditions are external influences that constrain the behaviour and dynamics of a system at higher levels of organization. Factors that are abiotic such as climate, topography, and soils, are classified as extra-hierarchical boundary conditions (King 1997). Habitat specialists and generalists are defined by their habitat requirements and are a good example of species using different levels in the hierarchy to meet their needs. Specialists occupy lower levels in the hierarchy by using a more specific component of the habitat on the landscape than generalists. Generalists are defined by the broad type of habitat elements used and therefore exploit a higher level in the hierarchy (Kolasa and Waltho 1998). Habitat specialists and generalists operate at many spatial scales and are not restricted to a specific scale because of their place in the hierarchy.

MATERIALS AND METHODS

DATA

Data for this project were obtained primarily from the Ontario Ministry of Natural Resources (OMNR) and have a variety of temporal and spatial extents (Table 2). Most of the data sets were spatial in nature when they were obtained. However, the fur harvest database and the Canadian Daily Climate Data were developed into a spatial data set using a geographic information system (GIS). The spatial data were represented by both vector and raster data types and had a provincial extent.

Table 2. Summary of data sets used in this study

Data Set	Data type	Thematic Structure	Time Period	Source
Fur Harvest Database	Aspatial	N/A	1972-1990	OMNR
Fire Disturbance	Spatial	Vector	1920-1990	OMNR
Clearcut Disturbance	Spatial	Vector	1940-1990	OMNR
Provincial Road Coverage	Spatial	Vector	2002	OMNR
Provincial Stream Coverage	Spatial	Vector	2002	OMNR
Landcover 28	Spatial	Raster	1996	OMNR
Canadian Daily Weather Data	Aspatial	N/A	1970-1990	Environment Canada

HARDWARE AND SOFTWARE

Environmental Systems Research Institute (ESRI) software was used for the GIS. ARC/INFO and ArcView were used primarily for spatial analysis of the data sets. Patch Analyst (Elkie *et al.* 1999), an OMNR ArcView extension, was used to calculate spatial statistics. ERDAS Imagine was used for some of the raster analysis and data conversion.

For data compilation and organization, Microsoft Access and Excel were used. SPSS and Datadesk were used for the statistical analyses.

The methods had two distinct components. The first component involved database standardization, variable generation, and spatial data compilation. The second was the statistical analysis of the compiled data sets and involved a variety of parametric tests to assess alternative hypotheses.

SPATIAL SCALES OF ANALYSIS

The trapline was the fundamental spatial unit used in the analysis. All spatial variables (disturbance (fire and clearcut), percentage forest cover type, weather (1970s and 1980s), spatial statistics, road density and stream density) were compiled in the GIS to provide an estimate for each trapline. Furbearer harvests were analysed at five spatial scales. These scales of analyses changed the spatial extent or grouping of the traplines while maintaining each trapline as an individual sample unit. At different scales the variation in the spatial variables and the subsequent furbearer trapping densities changed. Each scale was comprised of spatial extents that encompassed the entire geographic area of that scale. At the largest scale, i.e., the entire province of Ontario, all of the traplines were included in the analysis with only one spatial extent (Figure 4). As the scale of the analysis decreased to the 'forest biome' scale, traplines located in the boreal forest were grouped and analysed together while traplines in the Great Lakes-St. Lawrence forest east and west were grouped and analysed separately for a total of three spatial extents at this scale (Figure 5). The analysis continued to decrease in spatial scale (smaller and smaller classifications) to the 'sub-boreal' scale (two spatial extents), 'Hills site region' scale (seven spatial extents), and the 'OMNR District' scale (30 spatial extents) (Figures 6-10). As the scale decreased, the geographic area of each classification also became smaller, theoretically decreasing the spatial variation across the landscape. This multi-scaled analysis of furbearer harvest data identified factors that affected trapline harvests, first at the 'provincial' scale and then at subsequently smaller classifications of the landscape. This analysis method was expected to reduce the variation in the landscape variables and furbearer harvests caused by individual landscape processes such as fire, timber harvesting, and weather because at large scales these processes were highly variable and decreased in variation at subsequently smaller scales.

Each scale and its spatial extents could be represented by both its total spatial area on the landscape and the total trapline area that was contained within that scale (Table 3). In some cases, the OMNR District boundaries were administrative and no longer existed (i.e., area reorganization) and therefore the total district areas were not presented, only the total trapline area.

Table 3. A summary of the five spatial scales, their total spatial area and total trapline area.

Scale	Number of Traplines	Area (sq. km)	Area on Traplines (sq. km)
'Provincial'	1397	≈ 800,000	227,877
'Forest biome'			
Boreal Forest	764	≈ 500,000	168,193
GSL West	202	≈ 43,000	23,547
GSL East	431	≈ 155,000	36,137
'Sub-Boreal'			
Boreal West	411	≈ 360,000	110,677
Boreal East	353	≈ 140,000	57,516
'Hill's Site Region'			
Site Region 3S	97	≈ 66,000	45,163
Site Region 4S	236	≈ 59,000	36,967
Site Region 4W	66	≈ 20,000	8,644
Site Region 3W	196	≈ 89,000	40,110
Site Region 3E	347	≈ 137,000	57,224
Site Region 4E	126	≈ 41,000	14,681
Site Region 5E	329	≈ 74,000	25,088
'OMNR District'			
Arnprior	42		3,961
Atikokan	20		2,539
Bancroft	37		1,357
Blind River	63		5,668
Bracebridge	27		1,944
Cochrane	34		5,905
Chapleau	47		7,428
Dryden	27		3,818
Espanola	12		1,507
Fort Frances	33		4,854
Geraldton	24		5,397
Gogama	22		3,315
Hearst	36		7,946
Huronia	9		180
Ignace	16		3,105
Kapuskasing	50		10,851
Kirkland Lake	67		6,375
Minden	45		1,236
North Bay	51		5,405
Nipigon	60		14,081
Parry Sound	52		3,041
Red Lake	78		32,247
Sioux Lookout	87		29,131
Sault Ste. Marie	41		3,516
Thunder Bay	97		15,291
Temiskaming	22		2,237
Timmins	39		5,858
Terrace Bay	51		8,560
Wawa	88		12,610
Kenora	120		10,676

Figure 4 shows the 'provincial' scale and gives an overview of the traplines available before the minimum trapping effort constraints were applied (see below). Each polygon was a trapline while the colour grouping represented different OMNR Districts (spatial extents). Figures 5 and 6 show the 'forest biome' and the 'sub-boreal' scales, and a map of the 'Hills site region' (Hills 1960) scale is presented in Figure 7. The 'OMNR District' scale is shown in Figures 8-10.

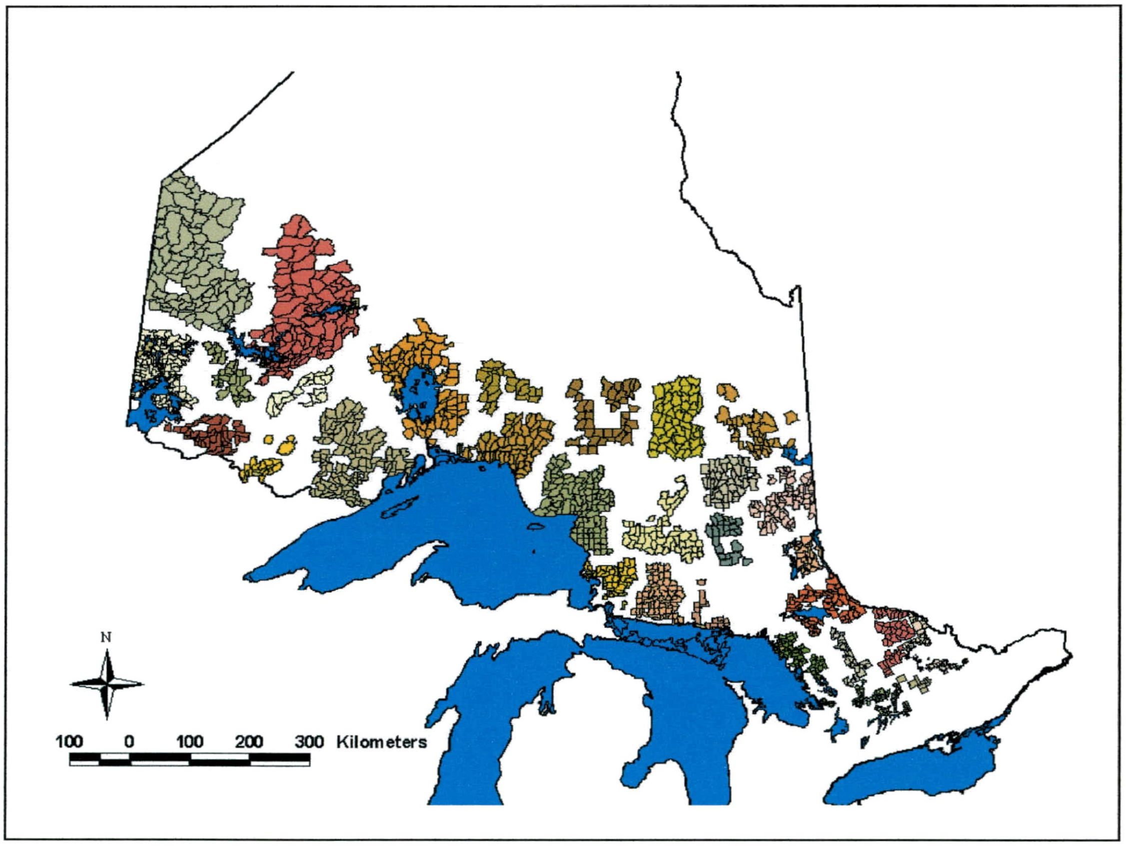


Figure 4. Provincial overview of registered traplines used in the study.

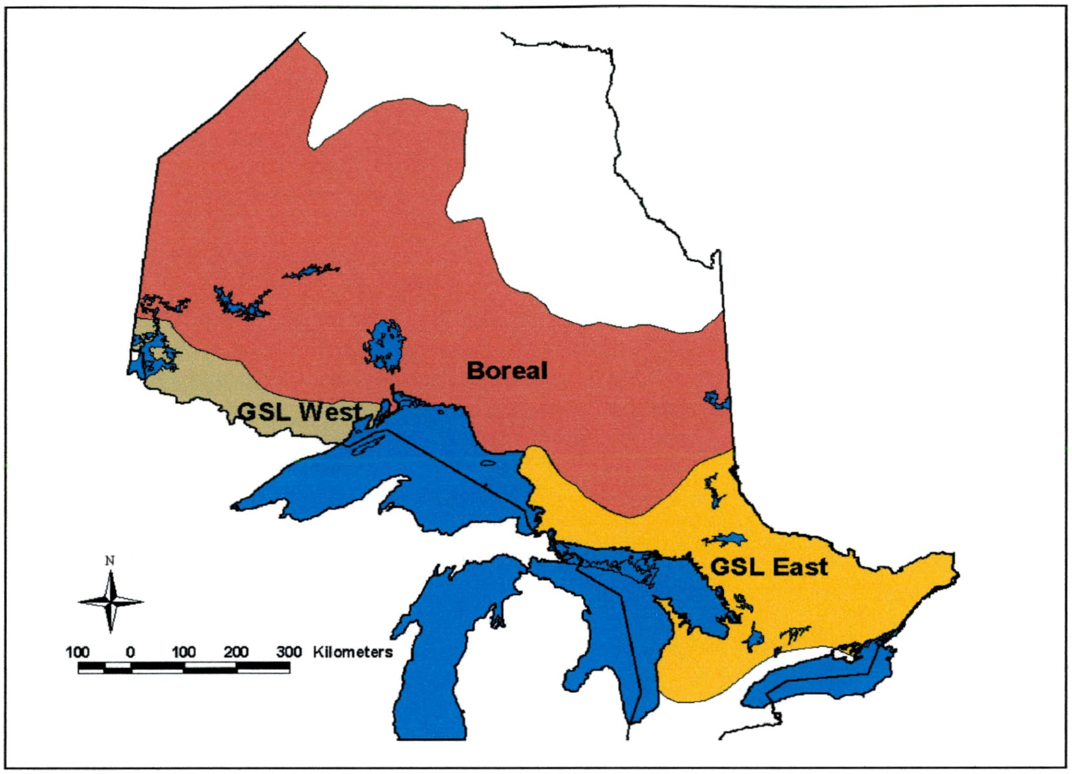


Figure 5. 'Forest biome' scale

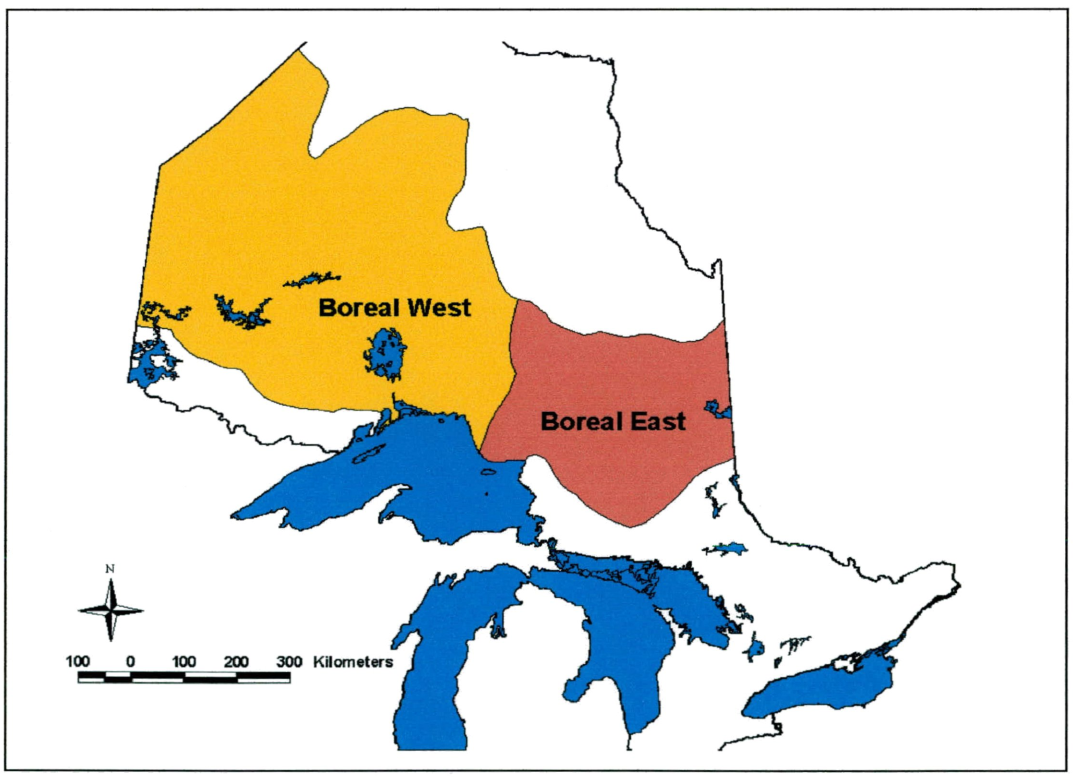


Figure 6. 'Sub-boreal' forest scale

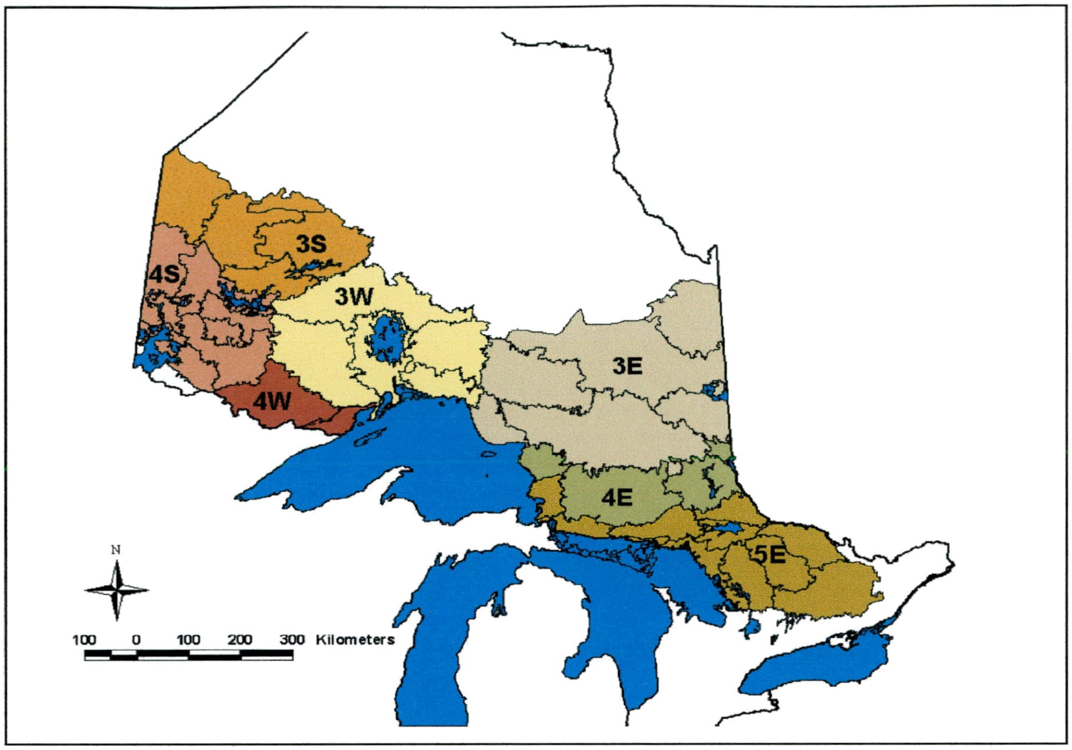


Figure 7. 'Hills site region' scale

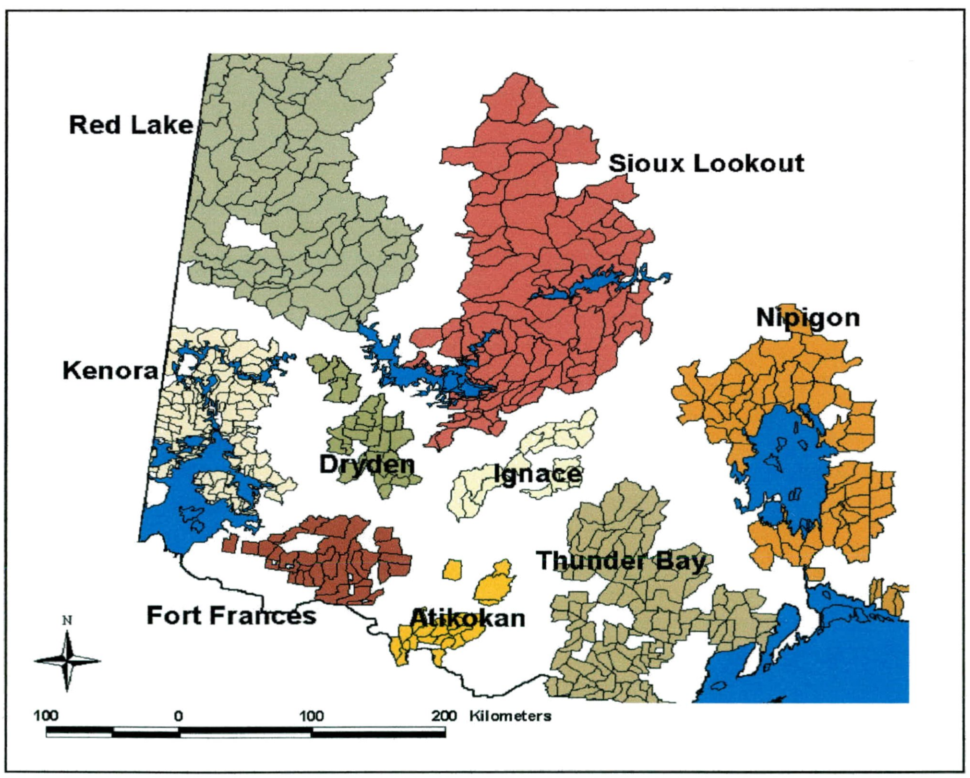


Figure 8. Northwestern Ontario traplines used in the study.

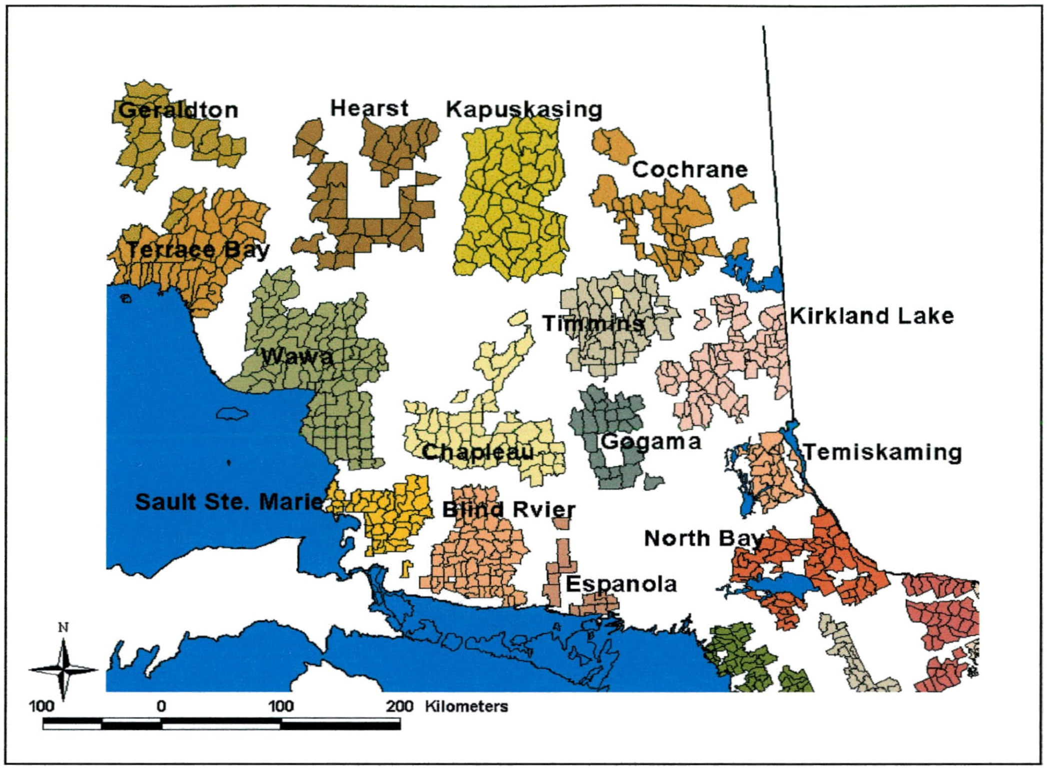


Figure 9. Northeastern Ontario traplines used in the study.

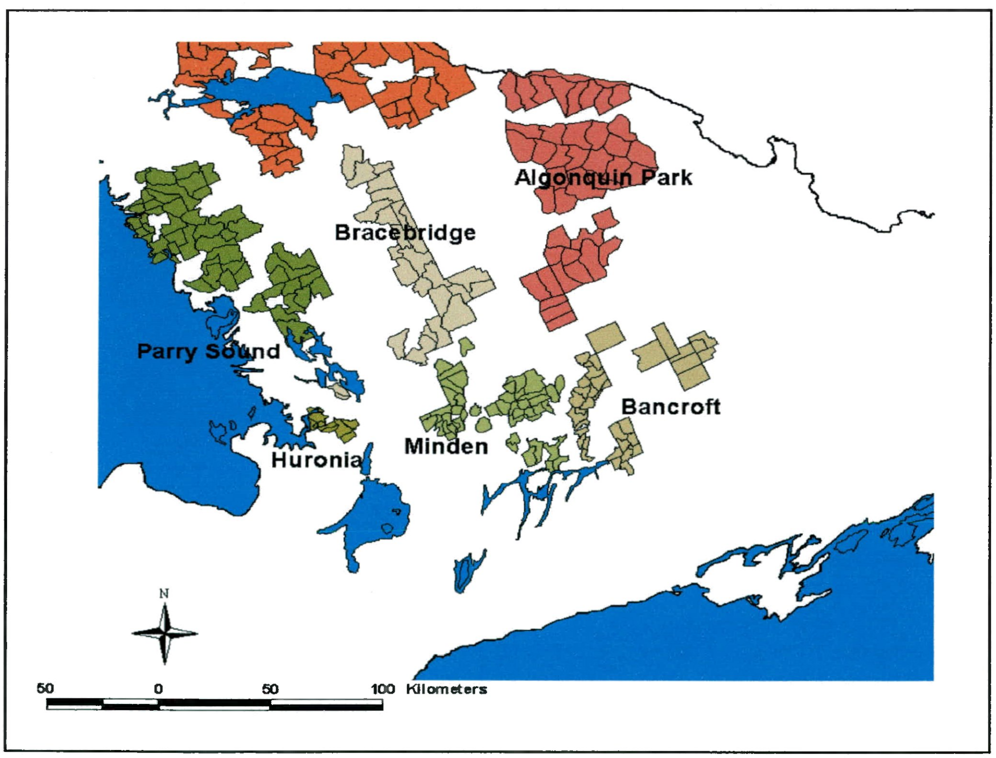


Figure 10. Southern Ontario traplines used in the study.

DATA COMPILATION

Aspatial and spatial data were used for analyses. The fur harvest data set was used as the dependent variable in the analysis. This data set was aspatial and required standardization and compilation. All of the independent variables were spatial and needed to be compiled by trapline and converted to an aspatial, tabular format for analysis (see flowchart - Figure 11).

Compilation of the Trapline Fur Harvest Data

The fur harvest database contained an annual total catch of each furbearer species harvested from each registered trapline across Ontario. The temporal extent of the fur harvest data set was 19 years, from 1972 to 1990, with three years missing in that period (1975, 1986, 1989) for marten, fisher, beaver and lynx. To ensure consistency in trapline identification, the database was first converted to a standardized label format with a two-letter district indicator and a three number trapline identifier (TB = Thunder Bay District, 001 = trapline number, trapline label = TB001). The 20 years of data were then divided into four, five-year periods (1972-1974, 1975-1979, 1980-1984 and 1985-1990), each to be analysed separately. Periods 1, 2, 3, and 4 refer to these time periods: 1972-1974, 1975-1979, 1980-1984 and 1985-1990, respectively. The data were analysed individually by period to control for some of the variation in furbearer harvest potentially caused by pelt value among years and to allow a qualitative temporal comparison of the variables that accounted for the greatest variation in furbearer harvests.

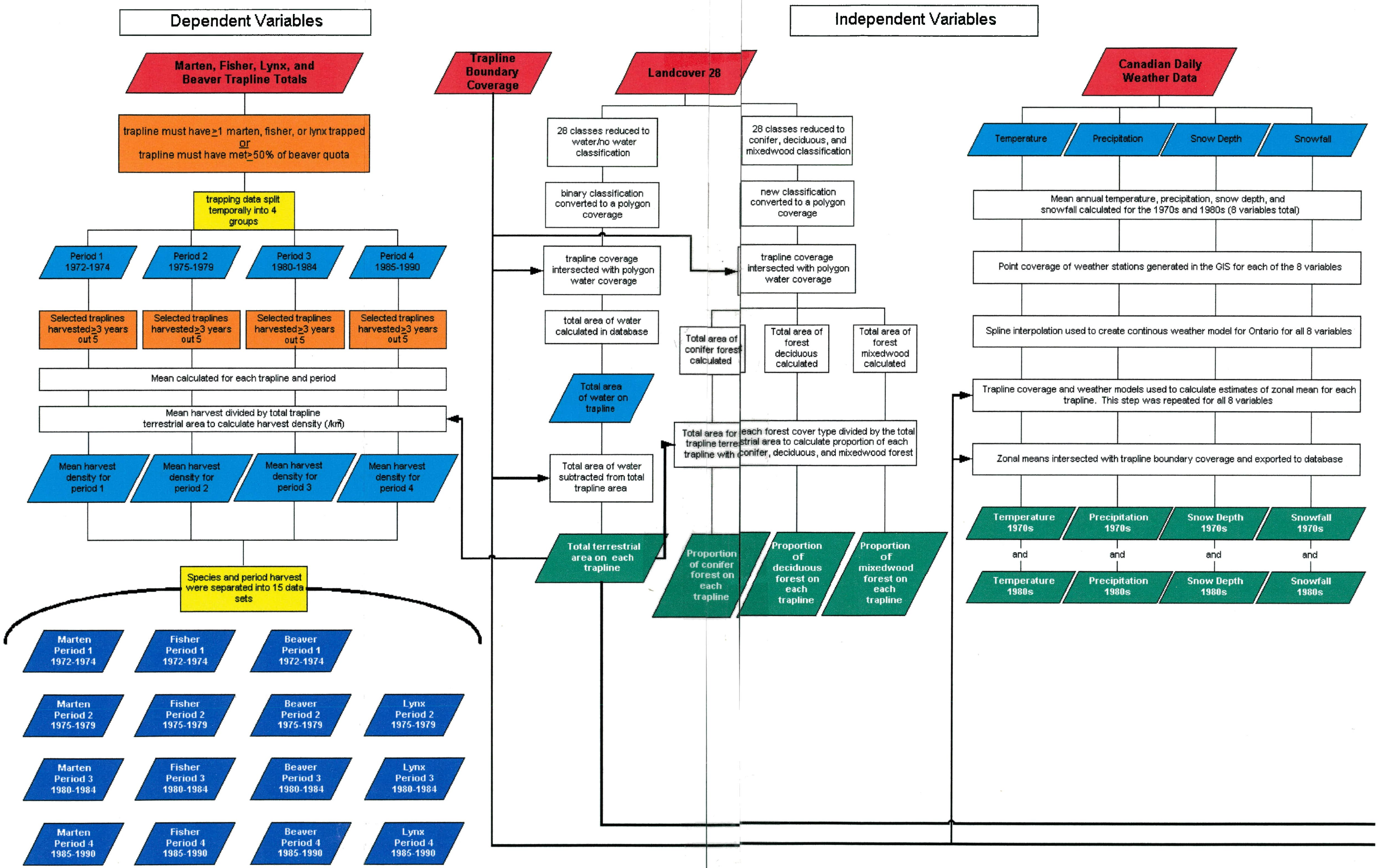
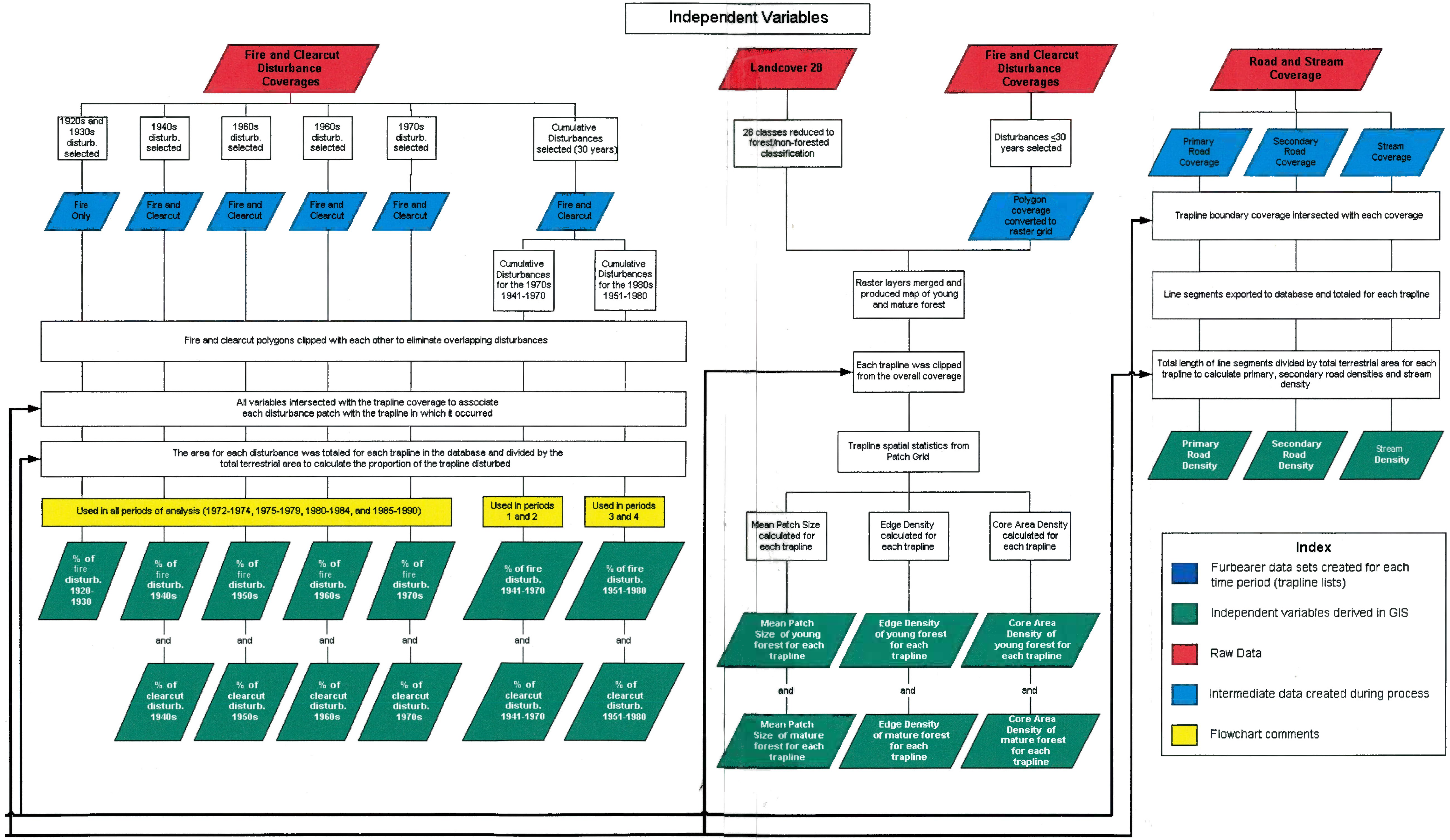


Figure 11. An overall summary of data compilation



Independent Variables
Fire and Clearcut Disturbance Coverages
1920s and 1930s disturb. selected
1940s disturb. selected
1960s disturb. selected
1960s disturb. selected
1970s disturb. selected
Cumulative Disturbances selected (30 years)
Fire Only
Fire and Clearcut
Fire and Clearcut
Fire and Clearcut
Fire and Clearcut
Fire and Clearcut
Cumulative Disturbances for the 1970s 1941-1970
Cumulative Disturbances for the 1980s 1951-1980
Fire and clearcut polygons clipped with each other to eliminate overlapping disturbances
All variables intersected with the trapline coverage to associate each disturbance patch with the trapline in which it occurred
The area for each disturbance was totaled for each trapline in the database and divided by the total terrestrial area to calculate the proportion of the trapline disturbed
Used in all periods of analysis (1972-1974, 1975-1979, 1980-1984, and 1985-1990)
Used in periods 1 and 2
Used in periods 3 and 4
% of fire disturb. 1920-1930
% of fire disturb. 1940s
% of fire disturb. 1950s
% of fire disturb. 1960s
% of fire disturb. 1970s
% of fire disturb. 1941-1970
% of fire disturb. 1951-1980
and
% of clearcut disturb. 1940s
% of clearcut disturb. 1950s
% of clearcut disturb. 1960s
% of clearcut disturb. 1970s
% of clearcut disturb. 1941-1970
% of clearcut disturb. 1951-1980
Landcover 28
28 classes reduced to forest/non-forested classification
Fire and Clearcut Disturbance Coverages
Disturbances ≤30 years selected
Polygon coverage converted to raster grid
Raster layers merged and produced map of young and mature forest
Each trapline was clipped from the overall coverage
Trapline spatial statistics from Patch Grid
Mean Patch Size calculated for each trapline
Edge Density calculated for each trapline
Core Area Density calculated for each trapline
Mean Patch Size of young forest for each trapline
Edge Density of young forest for each trapline
Core Area Density of young forest for each trapline
Mean Patch Size of mature forest for each trapline
Edge Density of mature forest for each trapline
Core Area Density of mature forest for each trapline
Road and Stream Coverage
Primary Road Coverage
Secondary Road Coverage
Stream Coverage
Trapline boundary coverage intersected with each coverage
Line segments exported to database and totaled for each trapline
Total length of line segments divided by total terrestrial area for each trapline to calculate primary, secondary road densities and stream density
Primary Road Density
Secondary Road Density
Stream Density
Index
Furbearer data sets created for each time period (trapline lists)
Independent variables derived in GIS
Raw Data
Intermediate data created during process
Flowchart comments

Controlling for Trapping Effort

To reduce the variability in furbearer harvest and the effects of trapping effort, several constraints were imposed on the data set to ensure that the traplines selected were representative of ones that were actively and consistently harvested. An issue within the database was determining whether low catches were the result of minimal trapping effort or other factors. A restriction of 'minimum effort' was placed on the selection of traplines to ensure that a trapper harvested at least one animal per year. A trapline must have maintained the minimum trapping effort ($\geq$1 animal) for at least three years in each of the previously-noted five-year periods. The mean number of animals harvested for the five-year period for each trapline was then calculated. This procedure was used for marten, fisher, and lynx.

Beaver harvest in Ontario was subject to a quota (a minimum harvest). Therefore by measuring success in relation to the quota by trapline, a level of confidence in trapping effort could be achieved for this species. If a trapper met 50% of the quota for three years in a five-year period, the trapline was considered to be representative of a consistently trapped trapline. If not, the line was deleted. Once the traplines were selected for analysis, a five-year mean was calculated for each trapline. This procedure was repeated for the four periods of analysis (1972-1974, 1975-1979, 1980-1984, and 1985-1990) for marten, fisher, beaver, and lynx. This procedure created a list of traplines that met the expressed criteria. Altogether, 16 lists of traplines were created, four for each species (four species total). Lynx trapping success was low in the period from 1972-1974 and therefore this data set was not used in the analysis, leaving 15 data sets for the analysis (four marten data sets, four fisher data sets, four beaver data sets, and three lynx data sets).

Trapline sizes were variable throughout the province and therefore the number of furbearers harvested was standardized to trapline size. The number of furbearers was divided by the trapline area to calculate the number of furbearers harvested per square kilometre.

Spatial Data Compilation

Registered Trapline Boundary Data

The trapline boundary data set was a polygon coverage of registered traplines within the province. Although this data set did not require compilation, many traplines had boundaries that had been changed over the time period of this study, which would have caused errors in the analysis. The most common change in trapline boundaries was the union of adjacent traplines. Amalgamating traplines occurred because of insufficient animal harvest or for administrative purposes (Helen Milne, OMNR Peterborough, Personal Communication, July 24, 2001). The GIS coverage was compared with the official maps located in Peterborough, Ontario. Traplines that had changed during the period of analysis were eliminated to ensure furbearer harvest totals and areas were consistent across all traplines. Traplines that bordered OMNR District boundaries were also eliminated because of changes that have occurred to these district boundaries through time. Tracking these changes would have been very difficult, especially with inconsistencies in trapline numbering systems for some districts.

Water Data

To calculate furbearer densities, stream and road densities as well as the percentage of land in different disturbance classes and forest types, the quantity of terrestrial land was required (i.e., without significant water-bodies). The water classification in Landcover 28 was used to calculate the total area for lakes by trapline. Landcover 28 was a raster data set and was reclassified from 28 classes to a simple binary data set (water/no water). Due to limitations in ARC/INFO, the binary data set could not be converted directly to a polygon coverage and it was therefore subdivided into OMNR Districts using a clip procedure within an arc macro language (AML) script. The individual districts were then converted to a polygon coverage. Each district polygon was intersected with the trapline boundary map to associate each lake with its respective trapline. A database was used to sum the total lake area by trapline. The lake area was subtracted from the total trapline area to obtain an estimated terrestrial area.

Disturbance Variables

Disturbances within the fire data set were classified on a yearly basis, whereas the clearcut disturbances were labeled by decade. To ensure that a comparison between the two types of disturbances could be made, the fire disturbances were reclassified by decade. The first task was to classify the disturbances into temporal periods for analysis. Fires were classified into seven classes and the clearcuts into six disturbance classes for analysis (Table 4).

Table 4. Disturbance classes used in the analysis and corresponding years.

Disturbance Type			
Fire	Clearcut	Time Period	Temporal Extent
Burn 1970s	Cut 1970s	1971-1980	10 years
Burn 1960s	Cut 1960s	1961-1970	10 years
Burn 1950s	Cut 1950s	1951-1960	10 years
Burn 1940s	Cut 1940s	1941-1950	10 years
Burn 1920s-1930s	Not Available	1921-1940	20 years
1970s Cumulative Burns	1970s Cumulative Cuts	1941-1970	30 years
1980s Cumulative Burns	1980s Cumulative Cuts	1951-1980	30 years

Each class was considered a separate variable for the analysis and represented the time since disturbance. For both the fire and clearcut variables, a cumulative disturbance variable was created that represented 30 years of total disturbance. Thirty years was chosen as the estimated average age at which forests change from early successional structure to a more mature successional structure. Two separate variables were created for both disturbances, each variable was used in the analysis. The first cumulative variable was analyzed with the furbearer harvest data in the first two periods (1972-1974, 1975-1979) and extended from 1941 to 1970 and the second cumulative variable (analysis of periods 3 and 4) extends from 1951 to 1980. Therefore, when the trapline harvest data were analyzed in the four temporal periods (1972-1974, 1975-1979, 1980-1984, and 1985-1990), there were two cumulative disturbance variables, one for the 1970s and another for the 1980s, each spanning 30 years. The decadal disturbance variables were used to test whether a specific time since disturbance was influencing furbearer harvests. The cumulative variables tested whether the affects of disturbance persisted beyond 10 years and continued to affect the furbearer population.

The lakes coverage was first clipped from the fire and clearcut coverages to account for inaccuracies in disturbance boundary that occurred in the mapping process. A further inspection of the GIS database showed that some disturbances overlapped spatially (both fire and clearcut). These overlapping disturbances would have provided incorrect estimates of the quantity of area disturbed for each decade by disturbance type. Since the disturbance variables were surrogates of age classes on the landscape, the most recent disturbances were considered the most important for measurement. Therefore, in areas where multiple disturbances occurred on the same site, the most recent disturbance was considered correct. An older disturbance on an overlapping disturbance site would not have provided an accurate estimate of the proportion of the trapline in that age-class. An AML script was written to clip the most recent disturbance polygons from older disturbance polygons to ensure that recent disturbances took priority in the analysis. As well, the fire and clearcut disturbances were clipped from each other to account for areas that may have been salvage logged and for new plantations that may have burned. Once the coverages were clipped, each layer was intersected with the trapline boundary coverage to assign trapline identifiers to each disturbance. The attribute tables were then exported from ARC/INFO to Microsoft Access and the total disturbance by trapline was calculated. To standardize the amount of disturbance per trapline, the total disturbance was divided by the trapline area to obtain the percentage of disturbance by trapline.

Weather Variables

Weather Station Measurements

Environment Canada had a network of 1380 weather stations across Ontario. The database contained daily measurements of three principal weather variables: temperature, precipitation and snow depth (Anon. 1999). Ordinary stations recorded the maximum temperature in a 24-hour period, while some stations recorded the minimum temperature, as well. Environment Canada computed a mean temperature for each day (Anon. 1999).

Rain, drizzle, freezing rain, freezing drizzle and hail are considered precipitation and were measured using the standard Canadian rain gauge. The precipitation was funneled into the rain gauge, which is a cylindrical container 40 cm in length and 11.3 cm in diameter. The precipitation measurement was the water equivalent of all types of precipitation. Snowfall, a specific type of precipitation was measured on the ground. Environment Canada averaged the snow depth for ordinary weather stations at several locations and then divided by ten to calculate the equivalent quantity of water. Principal weather stations measured snowfall by melting the precipitation that collects in a specialized collection system called a Nipher gauge. This method was more accurate than the 10 to 1 technique where 10 cm of snowfall equals 1 cm of precipitation. This method was utilized by smaller weather stations for calculating snowfall. Snow depth was measured at several representative points around the weather station and then averaged (Anon. 1999).

Weather Model

To examine the association of weather on furbearers, four continuous weather surfaces were produced by interpolation for the province and used in the statistical analysis. The weather station data were obtained from Environment Canada's Canadian Daily Climate Data (Anon. 1999). Temperature, precipitation, snowfall and snow depth were calculated for both the 1970s and 1980s. Data from individual weather stations (Figures 12 and 13) were compiled by decade to produce mean estimates of the four variables. Monthly means (i.e., a mean for the months of January, then a mean for the months of February, etc.), and a decadal mean were calculated. The monthly means were used to offset the effects of missing months within the data set, otherwise a single missing month (which was common in the data) would have provided an incorrect estimate of the mean yearly temperature. Due to some inconsistencies in weather station measurements (missing months/years) a minimum of five years of data were required from a weather station for it to be used in the analysis. Once a weather station met the minimum requirement and the variable was calculated, the latitude and longitude, and the weather estimate were entered into a spreadsheet. The spreadsheet was then exported into a comma delimited file to be used in ARC/INFO. This process was repeated for all four variables in both decades.

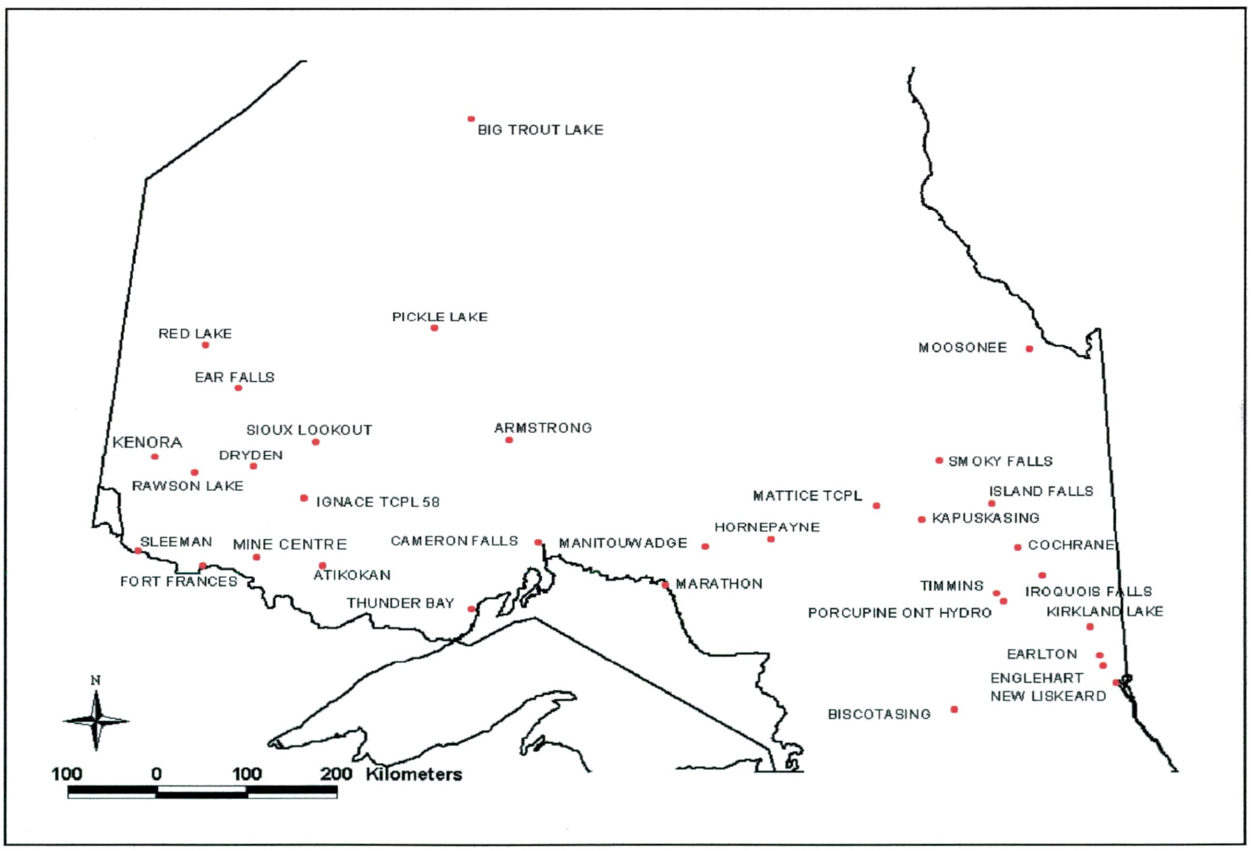


Figure 12. Weather station locations throughout Northern Ontario.

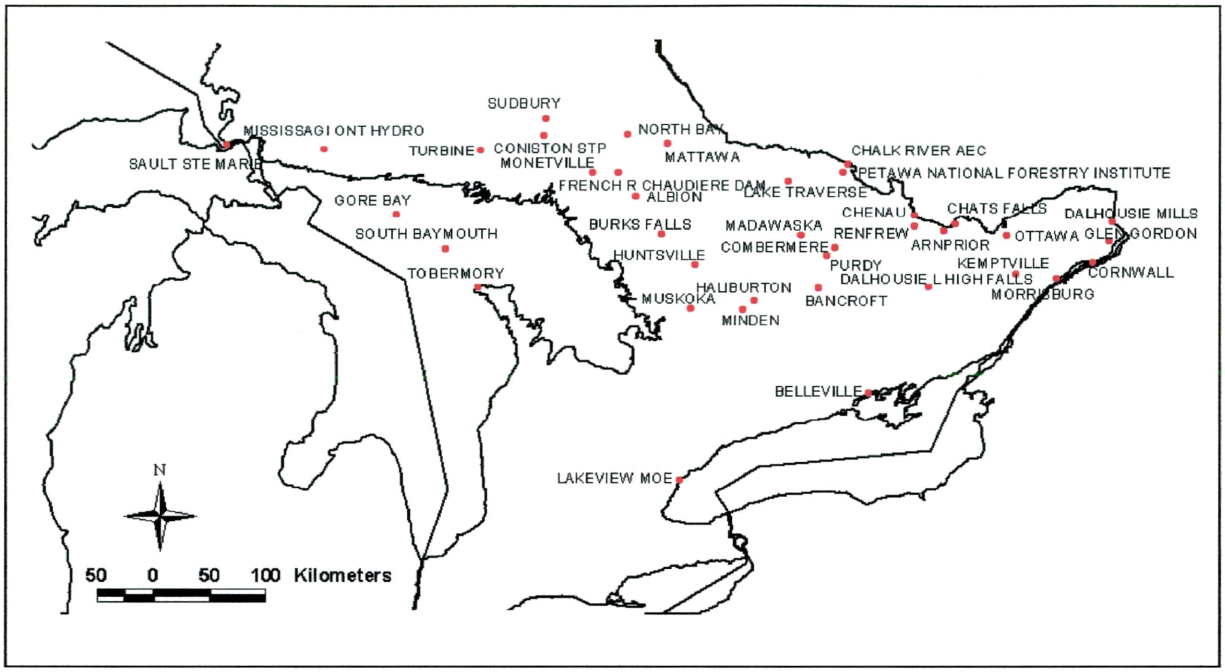


Figure 13. Weather station locations throughout Southern Ontario

Using the 'generate' command in ARC/INFO, a point coverage was created from the latitude and longitude locations. Estimates for the four weather variables were stored in the coverages attribute table. To use this point coverage with the other data sets required re-projection to a standardized Lambert projection used by the OMNR. An AML script was written to re-project all four variables in both decades to a compatible projection.

The GRID module in ARC/INFO was used to create a continuous weather model of the province and to compile individual weather observations by trapline. The surface was generated using a spline interpolation algorithm. The grid was interpolated to a grain of 1 km and the tension option within the software was set to 10. A tension value of 10 was typical according to ESRI (2001) and ensured the values interpolated in the surface corresponded to the weather station point data. Using the trapline boundary coverage and the weather surface, a 'focalmean' procedure produced a neighbourhood mean for each trapline. A 'zonalcentroid' procedure was then used to create a grid of individual cells that represented the mean weather value for each trapline, the cells were located at the centre of each zone (trapline). The trapline centroids were then converted to a point coverage and intersected with the trapline boundary coverage to ensure correct identification of each weather variable. Mean annual temperature, mean annual precipitation, mean annual snowfall, and mean annual snow depth were calculated in each trapline for the two decades (1970s and 1980s). The weather values for each trapline were exported to a Microsoft Access database.

Spatial Forest Age Structure Variables

Ontario did not have a provincial forest age data set. However, using the fire and clearcut data sets to represent the majority of disturbance (windthrow, insects, and pathogens account for the majority of the remaining disturbance types, but few data are available), patches of young and mature forest were identified. Landcover 28 was reclassified to a forested/non-forested binary data set and integrated with the disturbance layers to generate spatial variables. Disturbance patches from 1960-1990 were selected from both the fire and clearcut coverages. The two types of disturbances were combined to represent young forest. This data set was then converted to a 25 m raster coverage for use with Landcover 28. Landcover 28 was used to distinguish between areas of forested and non-forested land (Table 5). The 28 classes were reclassified to a three-class data set, two forest classes (unknown age forest and recent disturbance forest) and non-forested. A recent disturbance class that was identified within Landcover 28, was classified as a second young forest class. Using the forested areas from the Landcover 28 with unknown age, the fire and clearcut disturbance data were combined to identify areas of forest <30 years of age. With the disturbance data and Landcover 28 combined, the entire data set was reclassified a final time to produce a young forest class (<30 years), a mature forest class (>30 years), and a non-forested class.

To use this data set in the statistical analysis component of the project, spatial statistics (i.e., landscape indices/landscape metrics) were required for each trapline. An AML script was written to clip all of the traplines from the overall derived data set, into individual raster data sets.

Once the three data sets were combined, and each trapline was clipped and spatial statistics were calculated. Each trapline was considered a separate data set and analyzed using Patch GRID (Elkie *et al.* 1999), an OMNR extension designed for ArcView. Approximately 300 raster data sets (traplines) could be analyzed at once for a variety of spatial attributes. The extension calculated approximately 50 spatial statistics divided into several classes including metrics for: area, patch density and size, edge, shape, diversity and interspersion and core area. Simple statistics that measure basic landscape patterns were calculated (Table 6). Mean patch size, edge density, and core area density were chosen, calculated for both the young and mature forest in Patch Grid, and were then exported into a database and associated with its respective trapline number.

Table 5. Reclassification table for broad species classes and coarse age classes

Landcover 28 Classification	Broad Species Classification	Broad Forest Age Classification
Water	Non-Forested	Non-Forested
Coastal Mudflats	Non-Forested	Non-Forested
Intertidal Marsh	Non-Forested	Non-Forested
Supertidal Marsh	Non-Forested	Non-Forested
Freshwater Coastal Marsh	Non-Forested	Non-Forested
Deciduous Swamp	Non-Forested	Non-Forested
Conifer Swamp	Non-Forested	Non-Forested
Open Fen	Non-Forested	Non-Forested
Treed Fen	Non-Forested	Non-Forested
Open Bog	Non-Forested	Non-Forested
Treed Bog	Non-Forested	Forested (>30 yrs)
Tundra Heath	Non-Forested	Non-Forested
Dense Deciduous Forest	Deciduous Forest	Forested (>30 yrs)
Dense Coniferous Forest	Coniferous Forest	Forested (>30 yrs)
Coniferous Plantation	Coniferous Forest	Forested (>30 yrs)
Mixed Forest, Mainly Deciduous	Mixed Forest	Forested (>30 yrs)
Mixed Forest, Mainly Coniferous	Mixed Forest	Forested (>30 yrs)
Sparse Coniferous Forest	Coniferous Forest	Forested (>30 yrs)
Sparse Deciduous Forest	Deciduous Forest	Forested (>30 yrs)
Recent Cutovers	Non-Forested	Forested (<30 yrs)
Recent Burns	Non-Forested	Forested (<30 yrs)
Old Cuts and Burns	Non-Forested	Non-Forested
Mine Tailings, Quarries, Bedrock	Non-Forested	Non-Forested
Settlement and Developed Land	Non-Forested	Non-Forested
Pasture and Abandoned Field	Non-Forested	Non-Forested
Cropland	Non-Forested	Non-Forested
Alvar	Non-Forested	Non-Forested
Unclassified	Non-Forested	Non-Forested

Table 6. Definitions of spatial statistics calculated.

Landscape Structure	Definition
Mean Patch Size (MPS)	The average patch size (forest <30 yrs. and forest >30 yrs.) in a specified area (trapline) for an individual class (forest type) or the landscape. MPS is measured in hectares (Elkie *et al.* 1999).
Edge Density (ED)	The quantity of edge habitat expressed over a relative area (trapline) for an individual class (forest type) or the landscape. ED is measured in metres/hectare (Elkie *et al.* 1999).
Core Area Density (CAD)	The total number of unconnected core areas over an area (trapline) and is a measure of their distribution for an individual class (forest type) or the landscape (Elkie *et al.* 1999).

Species Composition Variables

The percentage of conifer, deciduous and mixedwood forest on each trapline was determined from the Landcover 28 data set. The data set was first reclassified from 28 classes to four, three of which were forested and one that was a non-forested class (Table 5).

Using ARC/INFO, each OMNR District was clipped from the overall raster data set and then converted to a polygon coverage. Limitations in the software (ARC/INFO) prevented the entire data set from being processed in a single procedure and therefore the landscape was divided into smaller subsets (districts) to be processed individually. An intersect command was used to associate each patch of the three forest types with the respective trapline in which it occurred. The percentage forest cover type data sets were then exported into Microsoft Access and queried to determine the total area for each of the three forested land types in each trapline. To standardize the data set for different trapline areas, the total area of each forest type was divided by the total terrestrial area to obtain a percentage forest cover by trapline.

Road Density Variables

Primary, secondary and tertiary road coverages were obtained for the province. All of the coverages were transformed to a common Lambert projection. Upon inspection, the tertiary roads data were eliminated from the analysis due to inconsistencies. In northern Ontario, companies used different road classification systems and the tertiary roads data were incomplete (Len Hunt, OMNR, CNFER, Thunder Bay, Personal Communication, Oct. 22, 2001). The primary and secondary roads were then intersected with the trapline boundary map in the GIS to associate each segment of road with its respective trapline. The data were then exported to a database and the linear segments were totaled by trapline. To standardize the quantity of primary and secondary road for each trapline, the total road length was divided by the total terrestrial area to determine road density (m/ha).

Stream Density Variables

The stream data set had a similar format and structure to the road data set and was therefore compiled in the same manner. All streams were intersected with the trapline boundary coverage and the total stream length for a given trapline was related to the record for that trapline. This variable was also standardized to account for different trapline areas and was divided by the total terrestrial area to obtain a stream density (m/ha) by trapline.

Database Construction

The final step was the amalgamation of the data sets into a common database. Using the minimum furbearer harvest constraints ($\geq$ 1 animal harvested in three years out of five-years), a list of available traplines was created for each of the four time periods (1972-1974, 1975-1979, 1980-1984, and 1985-1990) and for each of the four furbearers (marten, beaver, fisher and lynx). Fifteen data sets (lists of traplines) were created in this procedure (four marten data sets, four fisher data sets, four beaver data sets, and three lynx data sets). Microsoft Access was used to associate the disturbance (fire and clearcut), percentage forest cover type, weather (1970s and 1980s), spatial statistics, road density and stream density variables with the respective traplines from each of the fifteen data sets.

STATISTICAL ANALYSIS

Descriptive statistics were calculated for all of the independent variables (disturbance (fire and clearcut), percentage forest cover type, weather (1970s and 1980s), spatial statistics, road density and stream density) at all scales of analysis. The mean at each scale, the standard deviation, the standard error, and minimum and maximum values were calculated for all of the traplines throughout Ontario. Each variable in the data set was evaluated for normality, and variability using histograms and box-plots to ensure they satisfied assumptions of the parametric tests that were performed. Most variables required a transformation. Logarithm, square root, and cube root transformations were most commonly used (Appendix IV, Table 54, Table 55, Table 56, Table 57).

Principal Components Analysis

Principal components analysis (PCA) was used to reduce the overall number of variables to be analyzed in subsequent procedures. A PCA was performed at each scale, for all four furbearer species for all four periods of analysis. Principal components (PC) that accounted for $\geq$10% of the total variation among unit variability in the data set were used to subdivide the variables. This rule removed PCs that accounted for little variation of the landscape variables in the data set. The majority of the analyses summarized among trapline variation in the first three PCs, although in some cases two or four PCs were used when $\geq$10% of the variation was explained. PCs were interpreted using the component loading factors to assess the contribution of each variable to the individual PC. The eigenvectors were only comparable within each PC, but not among PCs (Johnson 1998). Variables with the greatest contribution to the PC were retained for further analysis. Approximately 14 to 18 variables were selected from each model.

To determine whether any relationship existed between the dependent variable and the PC score, correlation analysis was done. This test gave some insight into whether the variables being selected by the PCA were in fact accounting for some of the variation in the furbearer harvest data.

Stepwise Multiple Regression Analysis

Using the variables selected by the PCA, forward stepwise multiple regression procedures were used to identify those variables that explained the majority of the variation in the furbearer harvest data among sampling units at the various scales. The spatial variables developed in the GIS were used as the independent variables in the Multiple Linear Regression and the furbearer harvest data was used as the dependent variable. The analyses were run for each species at each of four time periods and for each of the spatial extents at the various scales. The regression analysis had two purposes: 1) to build models that accounted for the greatest variation in furbearer harvest data and; 2) to identify variables that repeatedly explained variation in furbearer harvests within and among scales and among the time periods. Using the forward stepwise automatic variable selection procedure, an entry probability of 0.05 and a removal probability of 0.10 was used. Johnson (1981) suggested that a minimum of 20 samples was required for multivariate analysis plus an additional three to five samples per variable in the model. A minimum of 25 samples was required for each model developed in this project.

The regression model was considered significant if $\alpha \leq 0.05$. Each variable that accounted for variation in the furbearer harvest data was then evaluated to ensure the slope was not equal to 0 ($\alpha \leq 0.05$) and therefore significantly contributed to the model. Multicollinearity could occur when correlation among the predictor variables was high and may cause imprecise estimates of regression coefficients. The variance inflation factor (VIF), a statistic that can identify potential multicollinearity among variables, was used to assess all regression models (Neter *et al.* 1996). Neter *et al.* (1996) suggested a VIF <10 was acceptable. However, a conservative value of 5 was chosen, although in most cases the VIF was <2. As the multicollinearity between two or more variables increases so does the VIF. Once an interaction between two or more variables was detected, a Pearson Correlation was calculated, and if the correlation was ≤ 0.70, the multicollinearity was considered acceptable. A Pearson Correlation of 0.70 was chosen as a reasonably conservative maximum association between two variables to ensure that the relationship between some of the landscape variables did not influence the regression models. The Pearson Correlations were performed on the data sets used in the PCA and the Multiple Linear Regression and therefore had sample sizes greater than 25. A final diagnostic evaluated the distribution of the residuals to ensure that they were randomly distributed. This statistical procedure was repeated for each spatial extent at the five scales of analysis, over four time periods, and for the four species of furbearer (Table 7). Not all spatial extents were analysed at each scale due to insufficient sample sizes (i.e., not enough traplines met the minimum trapping effort requirement in some spatial extents). The variables that accounted for the greatest variation in furbearer harvest data within the regression models were then compared for consistency, within and among scales and time periods. The r^2 values for all models were also compared for consistency in the variation in furbearer harvest explained, within and among scales and time periods.

Table 7. Summary of the number of regression models developed for each species, time period, and scale.

		Number of Spatial Extents Analysed/Regression Models Developed*			
Time Period	Scale	Marten	Beaver	Fisher	Lynx
1	'provincial'	1	1	1	0
	'forest biome'	2	2	2	0
	'sub-boreal'	2	0	0	0
	'Hills site region'	2	1	2	0
	'OMNR District'	2	1	1	0
	Sub-Total	9	5	6	0
2	'provincial'	1	1	1	1
	'forest biome'	3	3	3	1
	'sub-boreal'	2	2	1	2
	'Hills site region'	7	7	3	2
	'OMNR District'	13	10	2	1
	Sub-Total	26	23	10	7
3	'provincial'	1	1	1	1
	'forest biome'	3	3	3	2
	'sub-boreal'	2	2	2	2
	'Hills site region'	7	7	4	3
	'OMNR District'	16	13	4	2
	Sub-Total	29	26	14	10
4	'provincial'	1	1	1	1
	'forest biome'	3	3	3	1
	'sub-boreal'	2	2	1	2
	'Hills site region'	7	7	2	1
	'OMNR District'	14	7	5	0
	Sub-Total	27	20	12	5
	TOTAL	91	74	42	22

*One regression model developed for each spatial extent analysed. Each spatial extent had $\geq$25 traplines (sample units) to be analysed.

RESULTS

DESCRIPTIVE STATISTICS

Descriptive statistics were calculated for each variable at all five spatial scales and most are presented in Appendix III. Several variables that demonstrated important trends have been represented graphically below to illustrate relationships that were detected.

The variability in the percentage of fire disturbed area was low in the 1970s among traplines, across all scales (Appendix III, Table 21). However, two 'OMNR Districts' (Ignace and Red Lake) had traplines where the percentage of disturbance ranged from 50-80% in the 1970s. The percentage of fire-disturbed area from 1921-1940 was highly variable among traplines (Appendix III, Table 25). At the 'OMNR District' scale, nine of the districts had traplines with >80% of their area disturbed by fire and six had <30% fire disturbance. Variability in the proportion of traplines disturbed by fire decreased from the 1940s to the 1960s (Appendix III, Tables 22-24). The mean and standard deviation for the percentage of traplines disturbed by fire for the 'provincial', 'forest biome', 'sub-boreal', and 'Hills site region' scales was calculated for the decades 1921-1940, 1940s, 1950s, 1960s, and 1970s (Figure 14). There was a decrease in the mean proportion of area disturbed by fire per trapline from the 1920s to the 1970s, as well as a decrease in the variability of the percentage of area disturbed by fire. At the 'OMNR District' scale, the percentage of fire-disturbed area per trapline was highly variable both spatially and temporally (Appendix III, Tables 21-25, Figure 32). The mean percentage of cumulative fire disturbances (1951-1980 and 1941-1970) was variable spatially and temporally (Appendix III, Tables 26-27). Cumulative fire disturbances from 1951-1980 and 1941-1970 were higher in northwestern Ontario, and central Ontario, respectively when compared to the other parts of the province (Appendix III, Figures 33-34).

The variability in the percentage of each trapline that was clearcut increased from 1940-1970, while the variability of trapline area disturbed by fire decreased through time (Appendix III, Tables 28-31). In the 1970s, twelve districts at the 'OMNR District' scale contained traplines with maximum harvests of >30% of their area, while seven districts had traplines with <1% of their area harvested. The districts with the highest harvest levels were found throughout northern Ontario. There was an increase in the mean harvest area of traplines at the 'provincial', 'forest biome', 'sub-boreal' and 'Hills site region' scales (Figure 15). The mean percent area disturbed by logging for traplines at the 'OMNR District' scale increased from the 1940s to the 1970s (Appendix III, Tables 28-31, Figure 35). Cumulative logging disturbances from 1951-1980 and 1941-1970 were higher in 'Hills' site regions' 3W and 3E for both time periods when compared to the other parts of the province (Appendix III, Tables 32-33, Figures 36-37). The percentage of disturbance on traplines increased through time and shifted from fire to clearcut disturbances. The variation in area disturbed on traplines also changed through time with greater variation from logging than fire occurring on traplines.

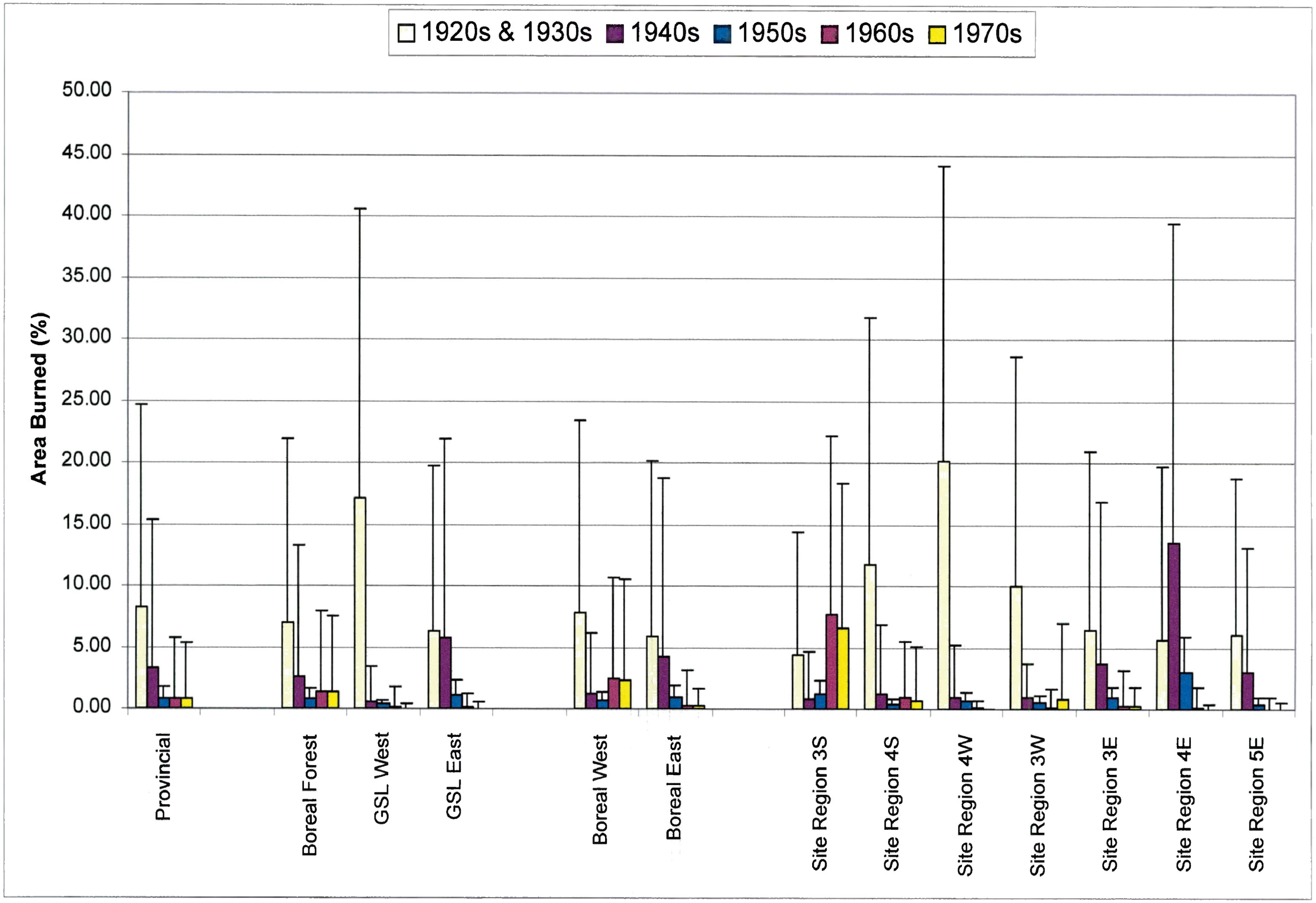


Figure 14. A comparison of the mean and standard deviation of the fire disturbed area by trapline at the 'provincial', 'forest biome' and 'Hills site region' scales.

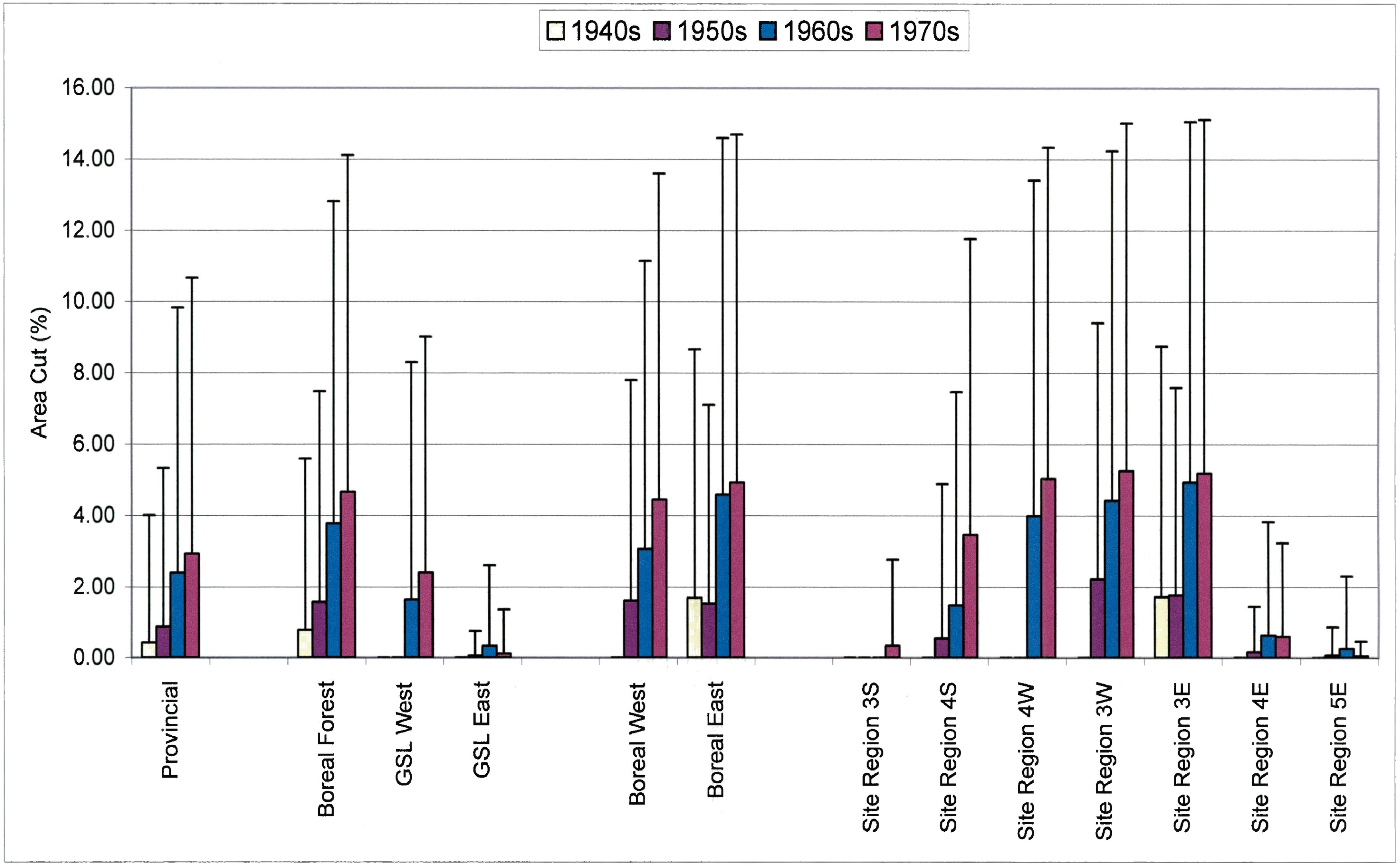


Figure 15. A comparison of the mean and standard deviation of the clearcut disturbed area by trapline at the 'provincial', 'forest biome' and 'Hills site region' scales.

Across Ontario the mean annual temperature in the 1970s and 1980s was higher in southern districts and showed low variability in temperature across all scales (Figure 16). In general, there was an increase in the mean annual temperature throughout the province between the 1970s and 1980s.

Mean annual precipitation increased from west to east across Ontario in the 1970s and 1980s (Appendix III, Tables 36 and 37), and this is a typical provincial pattern (Thompson 2000b). ‘Hills’ site regions’ 3S and 4S in the northwest received consistently less precipitation than ‘Hills’ site regions’ 4E and 5E in eastern and southern areas of Ontario (Appendix III, Figure 38). Throughout the province the mean annual snowfall decreased from the 1970s to the 1980s, but only minimally (Appendix III, Figure 39). In the Parry Sound, Temiskaming, and Kirkland Lake districts, the mean snowfall increased from the 1970s to the 1980s. Mean annual snow depth was greater in the 1970s than the 1980s throughout the province (Appendix III, Tables 40 and 41). A north-south gradient of decreasing snow depth was identified in the 1970s data (Appendix III, Figure 40). The variability in mean annual snow depth among traplines was low. Weather conditions throughout Ontario were highly variable with obvious changes across the landscape occurring between the 1970s and the 1980s.

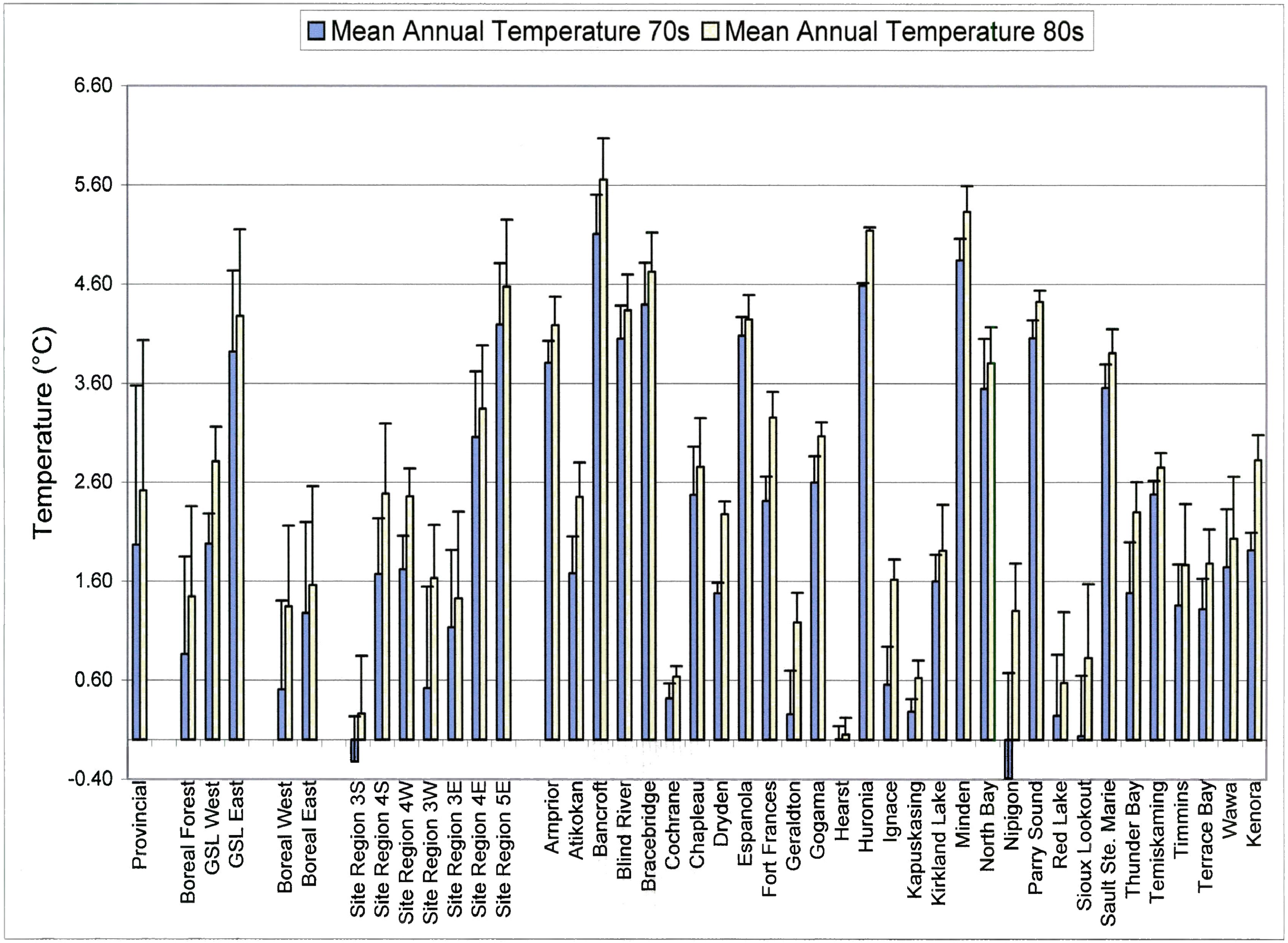


Figure 16. A comparison of the mean annual temperature and standard deviation for the 1970s and 1980s at all scales.

The mean patch size for young forest decreased on a north-to-south gradient and was variable among traplines. Northwestern Ontario had smaller patches of mature forest than the other parts of the province and was highly variable among traplines. A comparison of mean patch sizes for mature and young forest revealed that patches of young forest were much smaller than mature forest patches across the landscape at all scales (Figure 17).

In general, the edge density of young forest decreased from north to south but was highly variable among traplines (Appendix III, Figure 41). The edge density for mature forest showed no clear pattern across the province, but was lowest in 'Hills site region' 4S (Red Lake). 'Hills site region' 5E (southern Ontario) had the highest mean edge density for mature forest and had the most variability among traplines.

There was no consistent pattern for core area density of young and mature forest across the province. However, both were highly variable among traplines (Appendix III, Figure 42). Generally, mature forest had a greater core area density than did young forest but the inverse occurred in 'Hills' site regions' 3S and 4E.

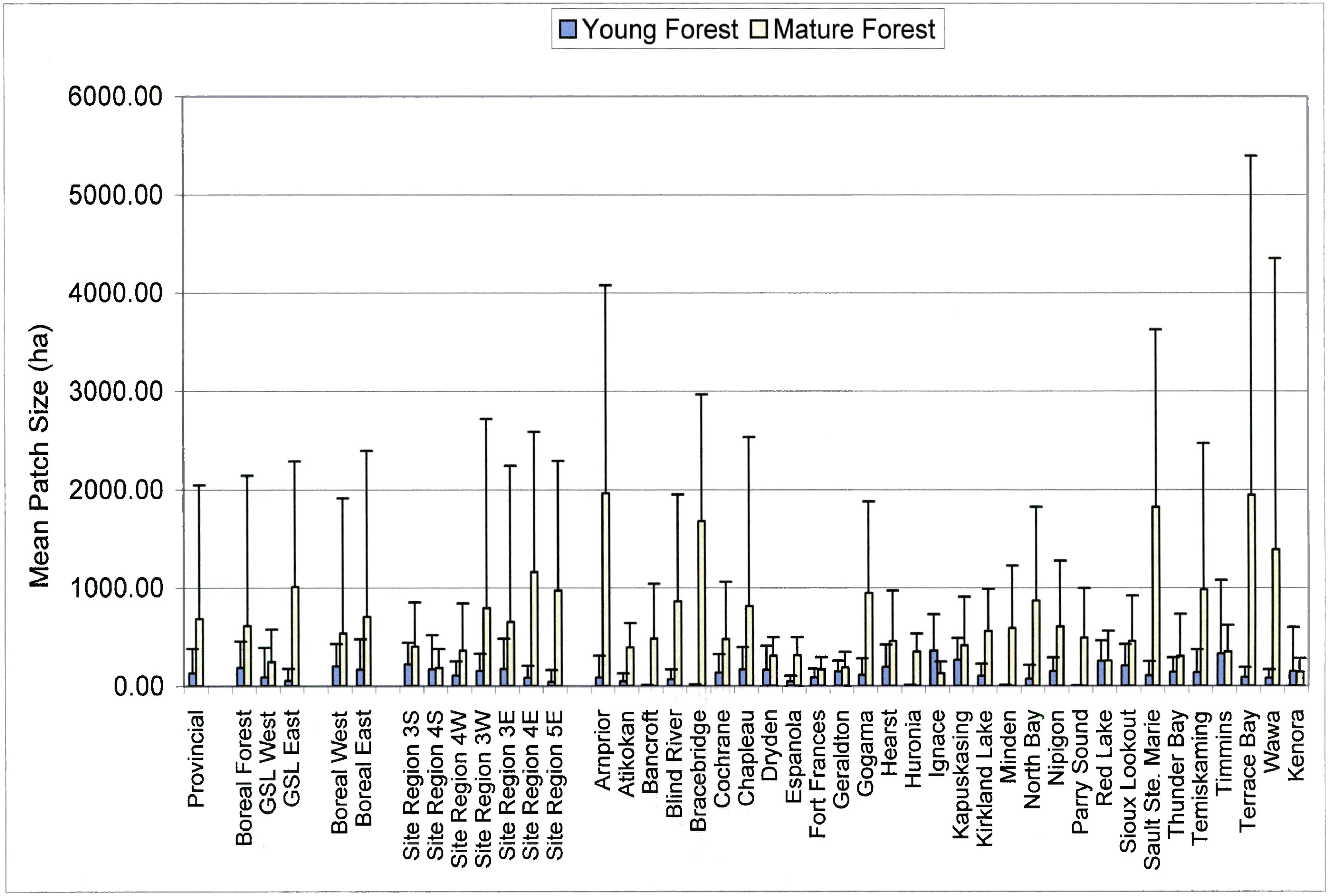


Figure 17. A comparison of the mean and standard deviation in mean patch size for young and mature forest.

The percentage of forest cover types on each trapline fluctuated spatially throughout the province (Appendix III, Tables 48-50). In general, mixedwood forest covered a higher proportion of area than conifer or deciduous forests, except in 'Hills site region' 3S, where conifer forest occurred in higher proportion than the other two cover types. Variability among forest cover types was high in individual traplines (Appendix III, Figures 43-44).

In northwestern Ontario, stream densities were lower than eastern and southern parts of the province (Appendix III, Figure 45). Among traplines stream densities were variable (Appendix III, Table 51). There was little change in the primary and secondary road densities throughout the province at the 'Hills site region' scale, except for 3S (Red Lake) where road densities were lower (Appendix III, Tables 52-53). At the 'OMNR District' scale, the variability in mean road density among traplines was high and fluctuated among districts (Appendix III, Figure 46).

SPECIES ANALYSIS

Factor loading tables and PC score correlations were used to reduce the overall number of variables and are presented in Appendices V and VI, respectively. As well, regression model coefficients and diagnostics are presented in Appendices VII and VIII. The complete SPSS output is in Appendix IV. The variables used in the initial analyses are presented in Table 8.

Table 8. Summary of all variables examined prior to principal components analysis.

Variable	Description	Broad Variable Classes
Burn 1970s	Percentage of trapline disturbed by fire from 1971-1980.	Fire Disturbance Variables
Burn 1960s	Percentage of trapline disturbed by fire from 1961-1970.	Fire Disturbance Variables
Burn 1950s	Percentage of trapline disturbed by fire from 1951-1960.	Fire Disturbance Variables
Burn 1940s	Percentage of trapline disturbed by fire from 1941-1950.	Fire Disturbance Variables
Burn 1920s-1930s	Percentage of trapline disturbed by fire from 1921-1940.	Fire Disturbance Variables
1970s Cumulative Burn	Percentage of trapline disturbed by fire from 1941-1970.	Fire Disturbance Variables
1980s Cumulative Burn	Percentage of trapline disturbed by fire from 1951-1980.	Fire Disturbance Variables
Cut 1970s	Percentage of trapline disturbed by logging from 1971-1980.	Logging Disturbance Variables
Cut 1960s	Percentage of trapline disturbed by logging from 1961-1970.	Logging Disturbance Variables
Cut 1950s	Percentage of trapline disturbed by logging from 1951-1960.	Logging Disturbance Variables
Cut 1940s	Percentage of trapline disturbed by logging from 1941-1950.	Logging Disturbance Variables
1970s Cumulative Cuts	Percentage of trapline disturbed by logging from 1941-1970.	Logging Disturbance Variables
1980s Cumulative Cuts	Percentage of trapline disturbed by logging from 1951-1980.	Logging Disturbance Variables
Conifer Forest Cover	Percentage of conifer forest cover on each trapline.	Forest Cover Type Variables
Deciduous Forest Cover	Percentage of deciduous forest cover on each trapline.	Forest Cover Type Variables
Mixedwood Forest Cover	Percentage of mixedwood forest cover on each trapline.	Forest Cover Type Variables
Mean Temperature	Mean annual temperature from the 1980s on each trapline.	Weather Variables
Mean Precipitation	Mean annual precipitation from the 1980s on each trapline.	Weather Variables
Mean Snow Depth	Mean annual snow depth from the 1980s on each trapline.	Weather Variables
Mean Snowfall	Mean annual snowfall from the 1980s on each trapline.	Weather Variables
Mean Patch Size – Young Forest	The mean patch size of forest $\leq$30 yrs of age on each trapline.	Spatial Pattern Variables

Table 8. (Continued)

Variable	Description	Broad Variable Classes
Edge Density – Young Forest	The edge density of forest ≤30 yrs of age on each trapline.	Spatial Pattern Variables
Core Area Density – Young Forest	The core area density of forest ≤30 yrs of age on each trapline.	Spatial Pattern Variables
Mean Patch Size – Mature Forest	The mean patch size of forest >30 yrs of age on each trapline.	Spatial Pattern Variables
Edge Density – Mature Forest	The edge density of forest >30 yrs of age on each trapline.	Spatial Pattern Variables
Core Area Density – Mature Forest	The core area density of forest >30 yrs of age on each trapline.	Spatial Pattern Variables
Primary Road Density	The density of primary roads (m/ha) on each trapline.	Road Density Variables
Secondary Road Density	The density of secondary roads (m/ha) on each trapline.	Road Density Variables
Stream Density	The density of streams (m/ha) on each trapline.	Stream Density Variable

<u>Marten</u>

Marten harvest density was the dependent variable in the analyses and a subset of variables selected through the PCA procedure and compiled in the GIS were the independent variables. Variables that contributed significantly to regression models in the stepwise regression procedure for all four periods were compared spatially and temporally (Table 9). Darkly shaded boxes in Table 9 correspond to positive correlations between the independent variables and marten harvests in the regression models at different scales, while lightly shaded boxes indicate negative correlations. Empty boxes in this table represent variables that did not contribute significantly ($\alpha \leq 0.05$) to the regression models (Table 9). The corresponding r^2 values from each model were also compared with models that had sufficient sample sizes but no significant independent variables contributing to the model. The models without significant independent

Table 9. Variable compilation for marten models at all scales.

	Mixedwood Forest Cover				Deciduous Forest Cover				Mean Temperature				Mean Precipitation			
	Period*				Period				Period				Period			
SCALE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Provincial		+	+												-	-
Boreal Forest		+	+	+												
GSL West											-					+
GSL East						+	+	+		+		-			-	+
Boreal West		+	+			+					+			+		-
Boreal East			+	+							-			-		
Site Region 3S			+													
Site Region 4S			+	+												
Site Region 4W		+						-								
Site Region 3W			-													
Site Region 3E			+	+							-			-		
Site Region 4E				+								-				
Site Region 5E						+	+	+								
Red Lake														+	+	+
Kenora											+					
Fort Frances				+												
Sioux Lookout																
Thunder Bay							+									
Terrace Bay																
Hearst		+	+													+
Kapuskasing											+				-	-
Cochrane		+	+		-				+		+					
Wawa																
Chapleau																
Timmins												+				
Sault Ste. Marie																
Blind River																
Gogama																
Kirkland Lake			+													
North Bay				+								-				
Bracebridge																
Algonquin Park										+	+					

*Period refers to the 5 year analysis periods (1972-1974, 1975-1979, 1980-1984, and 1985-1990)

Table 9. (Continued)

	Mean Snow Depth				Mean Snowfall				MPS* - Mature Forest				ED** - Mature Forest			
	Period				Period				Period				Period			
SCALE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Provincial	+		+	-		+										
Boreal Forest						+		-			-	-				
GSL West					+									+		
GSL East		+														
Boreal West			+											+		
Boreal East			+				-					-				
Site Region 3S				+				-		+					+	
Site Region 4S																
Site Region 4W		+								-						
Site Region 3W																
Site Region 3E												-				
Site Region 4E																
Site Region 5E		+								+						
Red Lake																
Kenora											-					
Fort Frances				-												
Sioux Lookout							-				+					
Thunder Bay		+												+		
Terrace Bay														+		
Hearst																
Kapuskasing																
Cochrane			-											+	+	
Wawa																
Chapleau																
Timmins																
Sault Ste. Marie																
Blind River																
Gogama																
Kirkland Lake		-				-										
North Bay																
Bracebridge																+
Algonquin Park																

*MPS = Mean Patch Size

**ED = Edge Density

Table 9. (Continued)

	CAD*** - Mature Forest				R-squared (%)			
	Period				Period			
SCALE	1	2	3	4	1	2	3	4
Provincial		+	+		4.8	6.6	4.8	2.0
Boreal Forest		+	+		NM	15.0	7.3	5.6
GSL West					21.2	4.6	6.8	5.6
GSL East		-				20.7	11.6	11.3
Boreal West			+		NM	22.0	23.3	4.7
Boreal East					NM	13.4	15.1	5.8
Site Region 3S						42.7	44.8	36.2
Site Region 4S						15.3	17.8	9.2
Site Region 4W						26.9	NM	26.2
Site Region 3W					14.7	4.5	6.6	2.5
Site Region 3E					NM	15.4	8.4	5.9
Site Region 4E						NM	NM	25.0
Site Region 5E						26.5	18.0	5.4
Red Lake						47.4	29.0	25.5
Kenora							26.8	NM
Fort Frances							NM	58.0
Sioux Lookout						29.6	67.0	
Thunder Bay					13.5	13.6	3.7	
Terrace Bay						47.1		NM
Hearst						24.2	15.1	19.9
Kapuskasing		-				36.6	33.8	7.5
Cochrane					27.5	66.7	63.5	NM
Wawa							15.2	23.7
Chapleau							NM	
Timmins						NM	20.5	19.1
Sault Ste. Marie						NM	23.7	13.7
Blind River						NM	NM	20.0
Gogama								
Kirkland Lake						31.9	8.9	15.7
North Bay						38.5	28.4	28.9
Bracebridge								56.2
Algonquin Park						23.2	29.9	
***CAD = Core Area Density								

variables are represented in this table as no model (NM) (Table 9). Periods 1, 2, 3, and 4 correspond to the years 1972-1974, 1975-1979, 1980-1984, and 1985-1990, respectively. For period 1, a lack of trapping effort produced an insufficient number of cases for most of the districts at the 'OMNR District' scale and spatial extents at the 'Hills site region' scale.

The percentage of forest cover types on the landscape, were positively correlated with marten harvests at the 'provincial' and 'forest biome' scales and consistently contributed to the regression models at these two scales (Table 9). The percentage of mixedwood and deciduous forest were positively correlated with marten harvests for time periods 2, 3 and 4. At the 'forest biome' scale the percentage of mixedwood forest variable accounted for the greatest variability in furbearer harvest in the boreal forest, and the percentage of deciduous forest contributed significantly to regression models in the Great Lake-St. Lawrence forest. At the 'Hills site region' scale, the percentage of mixedwood forest contributed significantly to the regression models in seven of the 23 possible models. The proportion of mixedwood forest variable at the 'OMNR District' scale was positively and negatively correlated with marten harvests among these models for the various districts. However, the percentage of mixedwood forest was positively correlated with marten harvests in northeastern Ontario for Hearst, Cochrane, Kirkland Lake, and North Bay Districts, at the 'OMNR District' scale. The percentage of conifer forest cover on a trapline was not a significant variable in the regression models at any scale and was positively and negatively correlated with marten harvests in several districts at the 'OMNR District' scale (Appendix VII).

Road density variables across the landscape were not significant and contributed inconsistently to explaining the variation in marten harvests at any of the scales (Appendix VII). The primary road density variable was positively correlated with marten harvests in several boreal districts (Sioux Lookout, Nipigon, and Terrace Bay), but did not contribute to the regression models consistently either temporally or spatially. The secondary road density variable was positively and negatively correlated with marten harvests at several scales as were a variety of spatial extents within those scales.

Fire disturbance variables were significant in few regression models and contributed inconsistently at all scales or for any time period (Appendix VII). Burn variables were positively and negatively correlated with the marten harvest in the 1970s and 1950s. Variables representing fire disturbance in the period 1921 to 1940 and the cumulative disturbance variables were negatively correlated with marten harvests but did not contribute consistently to the regression models among time periods in six of the 78 models.

The logging disturbance variables, as a group, were negatively correlated with marten harvests (Appendix VII). However, no single variable contributed consistently to the regression models at any scale or time period. Logging disturbance variables from the 1970s contributed to regression models in Timmins District, and at the 'forest biome' scale in the eastern Great Lake-St. Lawrence forest. Logging disturbances from the 1960s contributed significantly to regression models from the western Great Lake-St. Lawrence forest at the 'forest biome' scale in period 1, and Thunder Bay and Terrace Bay Districts at the 'OMNR District' scale in period 2 and 3.

Weather variables contributed to the regression models for marten more often than any other variable (Table 9). Precipitation, snow depth, and snowfall accounted for variation in marten harvests at the 'provincial' and 'forest biome' scales. Precipitation, snow depth, and snowfall variables were not consistent in their influence among models (both positively and negatively correlated). Temperature consistently accounted for variation in marten harvests at the 'forest biome', 'Hills site region' and 'OMNR District' scales, but was positively and negatively correlated with the trapping data in separate models among scales and spatial extents throughout Ontario. Overall, weather variables contributed to many of the regression models, but their relationship to the marten harvest data was not consistent.

Variables representing the spatial pattern of young forest did not contribute to the regression models consistently at any scale or time period (Appendix VII). The correlation among these variables and marten harvest was positive and negative. The positive and negative correlations occurred in separate models among scales and among spatial extents throughout Ontario. The spatial pattern of mature forest accounted for variation in marten harvests in more models than young forest (Table 9). Mean patch size contributed to regression models at the 'forest biome' and 'Hills site region' scales. However, MPS was not a consistent influence on marten harvests (both positively and negatively correlated). The edge density of mature forest accounted for variation in marten harvests in the regression models and was positively correlated with marten harvests at several spatial scales and showed temporal consistency for one district at the 'OMNR District' scale. Core area density contributed to regression models primarily at the largest spatial scales and was positively correlated with marten harvests, for most models.

The total amount of variation in marten harvest accounted for in each regression model was highly variable (Table 9). However, in general, as the spatial scale decreased the r^2 values increased. At the 'provincial', 'forest biome', and 'sub-boreal' scales, the r^2 values ranged from 0-20%. The variability in marten harvest explained by the models increased slightly at the 'Hills site region' scale from 15-35% and at the 'OMNR District' scale the r^2 values ranged from approximately 25-50%. The smallest scale ('OMNR District') had the most variability in marten harvest explained. Most regression models had two to four variables, with the models for the largest spatial scales containing the most variables.

Beaver

Regression models with beaver harvest as the dependent variable for the four periods of analysis were compared (Table 10). Periods 2, 3, and 4 were trapped more intensively than period 1 and therefore had a greater number of regression models for comparison. Most regression models contained two to four variables, with the greatest number of variables contributing to regression models at the 'provincial' and 'forest biome' scales.

The percentage forest cover variables contributed to the regression models at the 'forest biome' and 'Hills site region' scales and were predominant in many of the models (Table 10). The proportion of mixedwood forest cover on each trapline was positively correlated with beaver harvests in two of the 11 models at the 'forest biome' scale and four of the 19 models at the 'Hills site region' scale. The proportion of mixedwood forest cover consistently accounted for variability in beaver harvests in 'Hills site region' 3E and at the 'OMNR District' scale for Kirkland Lake District. The percentage of deciduous forest cover for each trapline was positively correlated with beaver harvests in three of the six models at the 'sub-boreal' scale and five of the 19 regression models at

Table 10. Variable compilation for beaver models at all scales.

	Mixedwood Forest Cover				Deciduous Forest Cover				Conifer Forest Cover				Mean Temperature				Mean Precipitation				Mean Snow Depth			
	Period				Period				Period				Period				Period				Period			
SCALE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Provincial										-	-	-	+	+	+	+			+			+		
Boreal Forest				+						-														
GSL West				-										+	+				-			+		
GSL East		+						-								+		+	+				-	
Boreal West						+	+												-			+		+
Boreal East			+			+												-					-	-
Site Region 4S										-	-	-				+								
Site Region 4W						+												+						
Site Region 3W						+	+	+															+	+
Site Region 3E		+	+	+														-				+		
Site Region 4E			+			+																		
Site Region 5E								-														-	-	
Kenora																		+						
Thunder Bay						+	+					-												
Nipigon																								
Hearst																								
Kapuskasing																								
Timmins										-	-	-												
Blind River																		-						
Kirkland Lake		+	+	+																		+		
North Bay														+										
Parry Sound																								
Bracebridge			-				-																	
Algonquin Park			-																					
Minden												-						+						
Bancroft																								

Table 10. (Continued)

	Mean Snowfall				MPS - Young Forest				ED - Young Forest				CAD - Young Forest				ED - Mature Forest				R-squared (%)			
	Period				Period				Period				Period				Period				Period			
SCALE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Provincial	-	-								-	-	-					+	+	+	+	57.0	58.0	50.5	37.9
Boreal Forest						-	-											+				15.3	4.7	2.7
GSL West	-			-													+				52.6	43.1	48.1	45.0
GSL East				-						-					-			+	+	+	44.6	50.0	52.9	35.8
Boreal West		-		-						-												36.4	16.1	25.1
Boreal East			+	+			-					-						+				20.7	29.8	11.8
Site Region 4S																		+				42.7	54.0	44.6
Site Region 4W			-															+				49.6	32.1	12.1
Site Region 3W		+				-																34.9	19.6	23.0
Site Region 3E							-					-						+				35.4	23.7	15.7
Site Region 4E												-										20.0	49.2	21.1
Site Region 5E		+												-	-	-		+	+	+	44.6	51.4	48.3	30.3
Kenora						-																52.4	57.5	
Thunder Bay			-					-										+			NM	42.2	23.3	28.7
Nipigon																							18.1	
Hearst																							15.7	
Kapuskasing								-															31.8	14.6
Timmins								+										+	+			53.9	36.1	47.1
Blind River				+																		28.4		36.3
Kirkland Lake							-	-		-								+				34.3	53.1	49.5
North Bay			-								-											33.2	29.4	NM
Parry Sound			-																			NM	15.8	
Bracebridge																						54.8	83.6	
Algonquin Park																							54.3	
Minden																			+			17.4	16.9	13.5
Bancroft										-	-											66.1	53.5	

*MPS = Mean Patch Size **ED = Edge Density ***CAD = Core Area Density the 'Hills site region' scale. The percentage of conifer forest cover contributed to regression models at the 'provincial' (three of the four models), 'Hills site region' (three of the 19 models), and 'OMNR District' (five of the 31 models) scales and was negatively correlated with beaver harvests.

Primary and secondary road density variables were negatively correlated with beaver harvest at all scales (Appendix VII). Stream density was negatively correlated with beaver harvests in five of the 68 models and showed no spatial consistency. No temporal consistency across the four periods was identified among these variables.

Fire disturbance variables contributed to three of the 68 regression models across all scales (Appendix VII). Disturbances from 1921 to 1940 accounted for significant variability in beaver harvests in 'Hills site region' 4W and the cumulative burn variable contributed to two models in 'Hills' site regions' 4S and 3W. However, there was no consistency either spatially or temporally in the contribution of the fire disturbance variables to the regression models. Three logging disturbance variables (cut 1970s, cut 1960s, and cumulative cut) contributed significantly to eight of the 68 models from all of the scales. Cuts in the 1960s, 1970s, and the cumulative cut variables were not consistent in the regression models either spatially or temporally. The models were also positively and negatively correlated with beaver harvests.

Weather variables contributed to many of the regression models and were most prominent at the 'provincial', 'forest biome' and 'Hills site region' scales (Table 10). Mean temperature consistently contributed to the models at the 'provincial' and 'forest biome' scales and was positively correlated with beaver harvests. Precipitation, snow depth, and snowfall were temporally and spatially consistent as a source of variability in beaver harvests for many of the models at the various scales. However, the variables were positively and negatively correlated with beaver harvests at different scales and for different spatial extents. At the 'OMNR District' scale there was no consistency among weather variable contributions to the regression models.

In general, the spatial pattern of young forest was negatively correlated with beaver harvests in most models (Table 10). Mean patch size of young forest was not consistent in the regression models either spatially or temporally, but was negatively correlated with beaver harvests. The edge density of young forest contributed to 12 of the 68 models and was spatially consistent at the 'provincial' scale (three of the four models), and for the 'OMNR District' scale at Bancroft District (two of two models). For 'Hills site region' 5E the core area density of young forest contributed to regression models in periods 2, 3 and 4. The mean patch size and edge density of mature forest contributed to several models. Mean patch size was negatively correlated with beaver harvests at the 'provincial' scale, and edge density was positively correlated also at the 'provincial' scale (Appendix VII). Edge density also contributed consistently to regression models at the 'forest biome' and 'Hills site region' scales in southern Ontario (Table 10). Core area density contributed to very few regression models and did not have a consistent influence (positive and negative correlations) on beaver harvests (Appendix VII).

At the 'provincial' scale, various variables contributed to the regression models and accounted for approximately 50% of the variation of the beaver harvests (Table 10). Similar r^2 values were seen at the 'forest biome' and 'Hills site region' scales. However, the regression models at the 'forest biome' scale, specifically in the 'boreal forest', accounted for less variation in beaver harvests. At the 'OMNR District' scale, the amount of variation in beaver harvests explained was variable, but was highest in the extreme east and west of the province (Kenora and Timmins Districts), and for parts of southern Ontario (Bancroft, Bracebridge, and Algonquin Park Districts).

Fisher

Regression models with fisher as the dependent variable were compared for the four periods of analysis (Table 11). The percentage of forest cover in each trapline contributed to four of the 42 models across all the scales and showed no consistency spatially, temporally, or in their influence on fisher harvests (positively and negatively correlated) (Appendix VII). Secondary road densities were negatively correlated with fisher harvests in two of the four models at the 'provincial' scale, three of the 11 models at the 'forest biome' scale, and three of the 11 models at the 'Hills site region' scale (Table 11). Fire disturbance variables only contributed to two fisher models and showed no consistency in scale (Appendix VII). Both fire variables were negatively correlated with fisher harvest at the 'provincial' scale and for Kenora District. Three clearcut disturbance variables were statistically significant in the regression models, cuts in the 1970s, 1960s, and the cumulative cut variables, but were not consistent in all temporal periods. Cuts in the 1960s were positively correlated with fisher harvests in one regression model at the 'sub-boreal' scale. However, cuts in the 1970s and the cumulative cut variables were negatively correlated with fisher harvests in six of the 42 models at the 'provincial', 'sub-boreal', 'Hills site region', and 'OMNR District' scale.

Table 11. Variable compilation for fisher models at all scales.

	Secondary Road Density				Mean Temperature				Mean Snow Depth				Mean Snowfall				MPS - Mature Forest				ED - Mature Forest			
	Period				Period				Period				Period				Period				Period			
SCALE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Provincial	-	-				+	+	+			-		-	-				-	-	-		+		
Boreal Forest						+																		
GSL West	-		-				+											-	-					
GSL East	-					+	+															+	+	+
Boreal West		-						+			-			-										
Boreal East																								
Site Region 3S																								
Site Region 4S		-	-			+	+	+			-	-							-					
Site Region 3E																								
Site Region 5E	-					+	+															+	+	+
Red Lake		-																						
Kenora																								
North Bay																								
Algonquin Park																								
Parry Sound				+																			+	+
Bracebridge																								
Minden																								

*MPS = Mean Patch Size **ED = Edge Density ***CAD = Core Area Density

Table 11. (Continued)

	CAD - Mature Forest				R-squared (%)			
	Period				Period			
SCALE	1	2	3	4	1	2	3	4
Provincial					29.3	36.3	46.3	39.1
Boreal Forest						18.7	9.9	16.7
GSL West	+				42.2	18.4	55.4	18.2
GSL East					12.0	41.0	48.3	26.9
Boreal West						26.9	8.0	26.9
Boreal East							32.4	
Site Region 3S						47.6	NM	
Site Region 4S	+	+			48.4	45.3	62.2	41.7
Site Region 3E							12.4	
Site Region 5E					12.0	37.5	49.4	24.8
Red Lake						23.1	NM	
Kenora		+				36.6	49.5	21.1
North Bay								NM
Algonquin Park							48.4	
Parry Sound					NM		28.5	35.1
Bracebridge								79.4
Minden								21.0

Weather variables contributed most often to the regression models at the 'provincial', 'forest biome' and 'Hills site region' scales (Table 11). Mean temperature was positively correlated with fisher harvests in all regression models, and consistently contributed to models at the 'provincial', 'forest biome' and 'Hills site region' scales. Precipitation variables were not consistent in the regression models, either spatially or temporally and were positively and negatively correlated with fisher harvests at the different scales (Appendix VII). Snow depth and snowfall were both negatively correlated with fisher harvests and contributed significantly to regression models at the 'Hills site region' and 'provincial' scales (Table 11).

Mean patch size, edge density, and core area density of young forest were negatively correlated with fisher harvests at all scales (Table 11). At the 'provincial' scale, mean patch size of young forest consistently contributed to the regression models, while the edge density contributed at the 'Hills site region' scale (Appendix VII). The core area density of young forest consistently accounted for variability in fisher harvests at the 'forest biome' scale. The mean patch size of mature forest was negatively correlated with fisher harvests at the 'provincial' and 'forest biome' scales (Table 11). Conversely, edge density and core area density of mature forest were positively correlated with fisher harvests at the 'provincial', 'forest biome', 'Hills site region', and 'OMNR District' scales. The edge density of mature forest consistently contributed to models at the 'forest biome' and 'Hills site region' scales in eastern Ontario, while core area density accounted for variability in fisher harvests in 'Hills site region' 4S.

At the 'provincial' scale, regression models explained 30-45% of the variability in fisher harvests (Table 11). Variables in the boreal forest of the 'forest biome' scale were only able to account for 10-20% of the variation in fisher harvest. In the Great Lake-St. Lawrence forest at the 'forest biome' scale, the r^2 values increased up to 50%. Regression models in 'Hills' site regions' 3S and 4S, in northwestern Ontario, accounted for approximately 40-55% of the variability in fisher harvest.

Lynx

Variables that contributed significantly to the regression models for lynx and the corresponding r^2 values for all four periods were compared spatially and temporally (Table 12). Regression models were developed for lynx at all scales. However, many traplines were not able to meet the minimum trapping effort requirement and therefore the number of regression models produced within each scale was low compared to the other three species. Low harvest values for the period 1972 to 1974 resulted in this period being excluded.

The percentage of mixedwood and conifer cover types on a trapline were positively correlated with lynx harvests and accounted for variability in lynx harvests at the 'provincial' and 'forest biome' scales (Table 12). The proportion of deciduous forest cover was not a significant variable in the regression models (Appendix VII). The primary road density variable contributed to one model at the 'sub-boreal' scale and was positively correlated with lynx harvests. Fire disturbance from the 1970s and 1960s accounted for variability in lynx harvests for the Red Lake District, at the 'OMNR District' scale. The fire disturbance variables contributed to two of the 22 regression models and were negatively correlated with lynx harvests for the Red Lake District. Logging disturbance variables from the 1950s, 1960s, and 1970s were all negatively correlated with lynx harvests. At the 'sub-boreal' scale, logging in the 1960s and 1970s contributed to two regression models consistently in relation to the time since disturbance.

Temperature and snow depth contributed to the regression models and were positively correlated with lynx harvests at the 'provincial' and 'sub-boreal' scales (Table 12). Temperature accounted for variability in lynx harvests for periods 2 and 3 at the 'provincial' scale. Snow depth only contributed to one regression model at the 'sub-boreal' scale and precipitation and snowfall variables were not significant in the regression models for lynx.

Table 12. Variable compilation for lynx models at all scales.

SCALE	Mixedwood Forest Cover			Mean Temperature			Mean Snow Depth			MPS - Young Forest			R-squared (%)		
	Period			Period			Period			Period			Period		
	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
Provincial		+		+		+				-	-		17.3	12.4	12.6
Boreal Forest		+	+								-		19.9	9.1	8.3
GSL East														NM	
Boreal West	+			+		+			+				17.6	4.2	26.6
Boreal East					+								18.1	9.8	NM
Site Region 4S											-			30.2	
Site Region 4W															
Site Region 3W										-	-		17.8	7.8	
Site Region 3E													18.6	3.6	NM
Red Lake													26.9	9.6	
Timmins														NM	
*MPS = Mean Patch Size **ED = Edge Density ***CAD = Core Area Density															

The mean patch size of young forest consistently contributed to regression models at the 'provincial' and 'Hills' Site' Region' scales and was negatively correlated to lynx harvests (Table 12). The edge density of young forest accounted for variability in lynx harvests in two regression models but showed no temporal consistency (Appendix VII). The spatial pattern of mature forest contributed to two regression models for lynx. The mean patch size was negatively correlated with lynx harvests at the 'provincial' scale, while edge density was positively correlated with lynx harvests in the Red Lake District, at the 'OMNR District' scale.

DISCUSSION

This study examined the association of several forest landscape scale variables, weather, and access on furbearer harvests at large scales ranging from 'provincial' (e.g., 1:1 million) to the 'OMNR District' scale (e.g., 1:100,000). There were three important aspects for discussion: 1) data quality and the limitations in detecting landscape-scale associations; 2) landscape-scale habitat and climate changes that influenced furbearer harvests through time; 3) and the implications of the results. This study examined the potential to use trapline harvest statistics as measures of broad landscape changes on furbearer populations at multiple scales.

DATA QUALITY AND VALIDATION

Data Resolution and Scale

The resolution, or grain, of the spatial variables influenced the scale at which the data were associated with furbearer harvests. The forest cover type variables had a grain, or pixel size, of 25 m. However, this classification was a broad representation of forest species across the landscape and likely should not be used below the scale of a trapline (≈ 100-1500 sq. km). Logging and fire disturbances had a broad range of disturbance sizes with upper ranges of 200-390 sq. km and 1000-1500 sq. km, respectively, for older disturbances. These phenomena may have been most appropriate at the 'OMNR District' scale where only a few of these very large-scale disturbances have occurred and the majority of disturbances were much smaller.

Weather variables were generated from approximately 40-60 weather stations across Ontario. The weather estimates were coarse and the variability inherent in weather would suggest that this variable had the most influence at the 'Hills site region', 'forest biome', and 'provincial' scales. The pattern of forest age (young vs. mature) incorporated disturbances from both logging and fire. These disturbances would cause a broad pattern across the forest at scales larger than the 'OMNR District' scale, making this variable most meaningful at the 'Hills site region', 'forest biome', and 'provincial' scales.

Trapline Data

The use of trapline harvest statistics for monitoring furbearer populations was criticized by several authors including Weinstein (1977) and Smith *et al.* (1984). Their criticism focused on socio-economic and probability of capture issues that may have influenced the number of animals trapped. Trapper employment and pelt value were the primary socio-economic factors and contributed to the effort a trapper expends. McDonald and Harris (1999) conducted trapper surveys and found that trapping totals were highly variable depending on the amount of trapping effort.

Controlling the effects of variation in trapping effort among traplines and years reduced variability in the Ontario fur harvest database by selecting traplines that were harvested *a priori* with a specified minimum effort. The trapping effort condition used gave conservative estimates of harvest densities and ensured a minimum trapping effort was applied to all traplines. The four, five-year periods of analysis were used to select consistently harvested traplines, and also to reduce the variability in effort among years.

Although pelt value influences trapping effort, this effect was likely to have been constant and proportional to effort across the province due to a fixed pelt value for all trappers for any given year. With the effect of trapping effort removed, fluctuations in trapline harvests may be attributed to relative changes in environmental conditions. The temporal comparisons were also unaffected because each period was considered a discrete, relative qualitative comparison.

One factor that may have prevented the association of forest management on furbearers from being always detectable was the grain or sample unit size (trapline) used. Across the province, traplines varied in size from 100-1400 sq. km, with the largest occurring in the north. The large area of the northern traplines may have allowed trappers to change the focus of their trapping effort among years and to move to areas with less disturbance, greater access, or that were unharvested for several years thereby masking the predicted association between logging and trapping. By reducing trapline size and reducing options for trap relocation, forest management effects may be more pronounced. Areas in southern Ontario with smaller traplines were not subjected to large-scale clearcutting that occurred in the north, and would probably not be affected to the same degree by trapper prerogative.

Forest Age Data

This forest age classification, developed from the spatial fire and forest harvest databases combined with Landcover 28, did not take into account widespread disturbances caused by wind, insects, and pathogens. Insect disturbances have been widespread, occurring across most of the province in both boreal and Great Lake-St.

Lawrence forest biomes. Though the extent of this disturbance has been mapped, the forest mortality and intensity of disturbance to the forest landscape pattern has not been quantified. Many of the disturbance types interact, for example insects and fires, or salvage logging associated with extensive insect and wind disturbances. These disturbances also result in a range of successional stages for different forest types (Fleming *et al.* 2000). Although the association of wind, insects and pathogens were not quantified, fire and clearcut disturbances provided a broad representation of the spatial pattern of forest age. The pattern of forest age was expected to account for variation in furbearer harvest and to be important for species dependent on habitat configuration.

FOREST LANDSCAPE CHANGE AND COMMUNITY STRUCTURE

Ontario's forest landscape has been altered by forest management, in three primary ways: 1) through changes to species composition (Hearnden *et al.* 1992, Carleton 2000), 2) altered spatial vegetation pattern (Perera and Baldwin 2000), and 3) modification of the province's fire regime (Li 2000). Andren (1994) and Fahrig (1997) predicted that the presence of wildlife on the landscape would be affected by both the loss of habitat and alteration of habitat configuration. Changes to the disturbance regime of a landscape have been shown to affect the wildlife species that are present (White and Harrod 1997). Boutin and Hebert (2002) suggested that forest managers should focus on maintaining habitat quantity, while habitat configuration will have greater importance only at a minimum threshold. Forest management and timber harvesting have undoubtedly influenced wildlife across the province through habitat loss and changes to spatial configuration (Voigt *et al.* 2000). The scale of observation is another important factor that must be considered when examining ecological dynamics. For example, using inappropriate or arbitrary scales of analysis might reveal misleading patterns and/or processes on the forest landscape and may produce ambiguous results (Wiens 1989).

Although the forest landscape is being altered through intensive management, climate changes have consequences for wildlife as well. A warmer climate will have a direct impact on species distribution and growing season across the province, but will also indirectly affect vegetation dynamics through an altered fire regime. The new fire regime is predicted to have a shorter return interval, with larger fires, of greater intensity. These changes may affect species distributions, landscape structure, and the overall age distribution of the forest (Thompson *et al.* 1998). With all of the changes that were occurring on the landscape the prediction of wildlife response is likely to be difficult. Nevertheless, to maintain biodiversity, the interaction of multiple landscape factors must be studied.

EFFECTS OF LANDSCAPE VARIABLES ON FURBEARER SPECIES

The furbearer harvest database offered a unique opportunity to identify large-scale trends in trapline harvests across a range of sizes (spatial scales) of selected landscapes. There were many factors that contributed to the variability in trapline harvests including socio-economic factors, environmental or biological responses by individual furbearer species to disturbance and weather, and the effect of trapper site selection on individual traplines. Variables selected in the stepwise regression procedure therefore represented a range of factors over space and time, including biologically significant associations and the influence of trapper site selection.

General Trends

The proportion of forest cover, weather and spatial pattern variables at the 'provincial', 'forest biome' and 'Hills site region' scales contributed to the regression models and accounted for the greatest variation in trapline harvests for each of the four species. Habitat is a combination of resources and environmental conditions; in general, vegetation and weather are necessary components for species survival (Morrison *et al.* 1998). The four species examined each have different forest cover type requirements and distribution patterns that have been influenced by weather. The spatial patterns of young and mature forest have influenced furbearer harvests by causing a biological response in the species and/or affecting trapper site selection. Primary and secondary road densities were used to determine if improved access enhanced overall trapping success. However, this variable was not a significant factor for harvest of any of the species. Disturbance variables did not occur consistently in the regression models and accounted for little of the variation in furbearer harvests. The disturbance variables also did not consistently contribute to the regression models, either spatially or temporally, and so showed little evidence of influencing animal harvests at large-scales.

The scales used in this study were not based on prior knowledge of either the local or regional populations. Levin (1986) suggested that population predictability would be highest at the scale of the global population and lowest at the scale of the individual. Individuals in a population have been affected by many factors that function at small scales (Spencer 1987). These influences would likely not be obvious or detectable by human observation of a species at the scale of the individual. In contrast, a global population may have been influenced by factors at much larger scales, that humans can observe, measure, and attempt to interpret. As the scale of analysis increased, the variation explained (r^2) also increased for beaver and fisher harvests possibly indicating that the appropriate scale to observe these two species was used. 'Hills site region' and 'forest biome' scales may have been the optimum scales at which to measure the association of landscape variables on fisher because the variation explained in furbearer harvest was relatively high compared to marten and lynx harvests and the variables contributing to the regression models were consistent at these scales. Regression models at the 'provincial' scale accounted for the most variation in beaver harvests. Goodwin and Fahrig (1998) suggested that population predictability increased when the sampling scale matched either the local or regional population scales. The 'forest biome' and 'Hills site region' classifications were used to reduce variability in climate and vegetation patterns that were being influenced at these large-scales. Climate and vegetation patterns were used initially to derive Hills' site regions (Perera and Baldwin 2000) and therefore this scale was predicted to be appropriate to reduce variability in climate and vegetation processes among sample units on the landscape.

Morrison *et al.* (1998) suggested that habitat models could likely only account for 50% of the variation in wildlife densities, because many other factors on the landscape influences species, such as predator/prey relationships, competition, and small scale vegetation influences. For example, a habitat suitability index for fisher (Thomasma *et al.* 1991) accounted for 46.6% (r-value) of the variation in fisher occurrence on different sites, and a similar model for pronghorn sheep (*Antilocapra americana* (Ord)) was able to account for 39-70% of the winter habitat densities in the northwestern U.S.A. (Cook and Irwin 1985). The variation in furbearer harvest densities explained by the regression models in this study showed similar results. Although, marten and lynx regression models were comparatively weaker in the variation that they explained, the beaver and fisher models were successful in explaining 40-50% of the variation in furbearer harvests. With all of the factors that influenced the harvest of these species (trapping effort, landscape processes, trapline access, etc.), the ability to account for this level of variation in furbearer harvest established that trapline harvest data, especially beaver and fisher harvests, may be useful for identifying broad landscape factors that affect these furbearers.

Hierarchy theory defines a hierarchical structure of processes on the landscape that function at multiple spatial and temporal scales. Processes at broad spatial scales, such as climate and weather, have been shown to constrain processes at smaller spatial scales such as forest cover type distribution, succession, and natural disturbance (Voigt *et al.* 2000). A similar pattern of influence has been shown in the contribution of the landscape variables to the regression models at the scales analysed here. The weather variables contributed to regression models at all scales for marten, beaver, fisher, and lynx. However, weather variables had the greatest consistency and variability at the 'forest biome' and 'provincial' scales. The proportion of forest cover type and the spatial pattern of young forest compared to mature forest were similarly found at all scales but were most consistent in regression models for the four species at the 'forest biome', 'sub-boreal', and 'Hills site region' scales. The pattern of hierarchical structure within the variables that influenced furbearer harvests provided some evidence to support the hypothesis that wildlife species are influenced by broad-scale climate and habitat factors

(Voigt *et al.* 2000) and require a multi-scale approach for future modeling and management.

Marten

The proportion of mixedwood, and deciduous forest, covers on a trapline were positively correlated with marten harvests at the 'forest biome' scale in the boreal forest and Great Lakes-St. Lawrence forest biome, respectively. Strickland and Douglas (1987) and Potvin (1999) have suggested marten prefer mixedwood forest. The contribution of deciduous forest cover variables in the regression models was in opposition to reported habitat preferences for marten of conifer and mixedwood forest cover types and may have resulted from other processes occurring on the landscape, such as juvenile dispersal or trapper site selection. As well, in the Great Lakes-St. Lawrence forest biome at the 'forest biome' scale, the percentage of conifer cover type on each trapline was much lower than the boreal forest biome with a mean of approximately 6%, while deciduous forest covered approximately 26% of traplines in the Great Lakes-St. Lawrence forest biome. The amount of conifer forest cover did not vary markedly among traplines and so may have affected the value of this variable to account for variation in marten harvests.

Weather variables accounted for substantial variation in marten harvests in many of the regression models. Marten harvests were clearly influenced by weather but were influenced inconsistently spatially and temporally. A direct association among weather and marten was expected from snowfall and snow depth, which could have influenced trapline access and trap site selection. Temperature may also have been a limiting factor, affecting marten survival. At very large-scales, weather may have affected marten harvests indirectly by influencing tree species distributions and fire disturbance over time (Flannigan and Weber 2000). Weather variables undoubtedly influenced marten harvests. However, the interpretation of their direct association was made difficult by the spatial and temporal scales at which these variables operated and in some cases the scales did not correspond.

The spatial landscape pattern variables for young forest (<30 years) did not contribute consistently to the regression models spatially or temporally. The mean patch size (MPS), edge density (ED), and core area density (CAD) for mature forest (>30 years) accounted for a small proportion of the variation in marten harvests. The regression models revealed that as MPS decreased, marten harvests increased, possibly indicating the influence of trap placement by trappers. This relationship was opposite to the goal of current forest management guidelines that attempt to increase the overall patch size distribution and prevent further species and age-class fragmentation from occurring in the forest (Watt *et al.* 1996). However, the MPS of mature forest in the traplines was large with a mean area of 614 ha and a standard deviation of 1529 ha. The association of MPS and marten harvest on mature forest was likely having little effect. Edge density was positively correlated with marten harvests at several scales. Marten use of edge habitat was limited and they do not respond positively to disturbance (Snyder and Bissonnette 1997, Thompson 1994, Potvin *et al.* 2000). Therefore this result was not expected. Regression models with ED for mature forest did not have a higher quantity or greater variability of ED than other regression models thus causing difficulty in interpretation. The positive correlation of CAD with marten harvests suggested that as the number of core areas in a trapline increased (i.e., interior contiguous areas not influenced by edge), marten harvests (and presumably marten population) increased as well. Current forest management practices attempt to create these types of habitat conditions with large core areas (Watt *et al.* 1996).

Strickland and Douglas (1987), Thompson and Colgan (1994), and Hodgman *et al.* (1994) found that a high proportion of marten harvests in the fall consisted of young, dispersing juveniles that do not maintain home ranges. As a result, dispersing juveniles may not have been representative of the habitat that they were trapped in, in the sense that they probably do not live where they are caught, and may have confounded results by increasing the variation in harvest totals through the use of sub-optimal habitat.

Regression models at the 'provincial', 'forest biome', and 'Hills site region' scales for marten harvests accounted for less variation (r^2 = 5-25%) than did regression models at the 'OMNR District' scale, where approximately 25-45% of the variation in marten harvests was explained. Individual models for several individual 'OMNR Districts', and for 'Hills site region' 3S, accounted for more variation (≈50-65%) in marten harvests than other models at these scales. The proportion of forest cover type, weather, and the spatial pattern of young compared to mature forest contributed consistently to the regression models for marten. These variables explained the most variation in marten harvests and provided an indication of landscape processes that may have affected marten populations. However, low r^2 values in the majority of the models indicated that there were other important influences within the system that affected marten harvests, but that were not accounted for in these models. Marten trapline harvests appeared generally to be a poor index of marten densities, and hence habitat quality.

Beaver

The proportion of mixedwood and deciduous forest cover types were consistently positively correlated with beaver harvests at the 'Hills site region' scale. Deciduous species in these two forest covers were a main food source and therefore an essential component of habitat for beaver (Novak 1987). The proportion of conifer forest cover contributed to regression models at the 'provincial', 'Hills site region', and 'OMNR District' scales and indicated that with an increasing proportion of conifer forest, the number of beavers harvested decreased. Beavers may feed on conifer species across their range but these species were not preferred (Novak 1987).

At the 'Hills site region', 'forest biome' and 'provincial' scales, weather variables accounted for variation in beaver harvests in many of the regression models. However, mean temperature was the only variable that contributed consistently to these models, and was positively correlated with beaver harvests at the 'provincial' scale. Temperature may have been a limiting factor for beavers in Ontario because longer and colder winters in the north may have limited food availability, as well as the distribution of favoured tree species (Flannigan and Weber 2000). Precipitation, snowfall, and snow depth explained a significant proportion of the variation in beaver harvests in many models at the 'Hills site region', 'forest biome', and 'provincial' scales. However, these variables were correlated positively and negatively with beaver harvests. In places where snowfall and snow depth were high, access to the trapline was expected to be low resulting in these variables being negatively correlated with beaver harvests. This relationship was in fact observed for the boreal east spatial extent of the 'sub-boreal' scale where the mean annual snow depth was greater than other parts of the province and the snow depth variable was negatively correlated with beaver harvests. Thermal protection provided by snow cover may have been another factor that influenced beaver harvests. Shallow beaver ponds in Alberta have been shown to freeze completely when snow levels are low, and when the ponds were completely frozen, beavers could not access food piles, causing the population to be affected over broad areas (Suzanne Bayley, Professor of Biological Sciences, University of Alberta, Personal Communication, November 13, 2002).

Stream density was a habitat characteristic that was expected to contribute to regression models for beaver harvests. However, the large area that each trapline encompassed and the low variability in stream density among traplines, may have excluded this variable from being an important factor for beaver harvests.

The spatial pattern of young and mature forest contributed consistently to regression models at the 'Hills site region', 'forest biome', and 'provincial' scales. Young forest variables were consistently negatively correlated with beaver harvests. Beavers have been shown to cut and use large diameter, early successional tree species (Donkor and Fryxell 1999) that are characteristic of mature forests. Traplines with a high proportion of young forest, regardless of spatial arrangement would therefore likely have low beaver harvests. However, due to riparian management guidelines in the province of Ontario, a minimum 30 m "area of concern" buffer (OMNR 1988) is applied to all streams. This area is protected from logging and therefore timber harvesting may not have influenced beaver harvests negatively. On the other hand, the protection of riparian areas may also have a negative impact on beavers by promoting late successional species, which are not optimal for beaver habitat (Barnes and Mallik 2001). The ED of mature forest was positively correlated with beaver harvests suggesting mature forest and the associated edge with young disturbed forest was important habitat for beavers seeking early successional forest conditions.

Models for beaver explained more variation in harvest than the marten models, with consistently 50% of the variation in harvest data explained at the 'provincial' scale, and slightly less explained at the 'forest biome' and 'Hills site region' scales. The variation in beaver harvests explained by the regression models was similar in magnitude (≈50%) to that found in studies by Thomasma *et al.* (1991), Cook and Irwin (1985) and research by Morrison *et al.* (1998) and indicated that other factors, possibly at smaller scales, were also influencing beaver harvests such as vegetation dynamics or predator prey relationships.

Fisher

At the 'provincial', 'forest biome', and 'Hills site region' scales secondary road densities were negatively correlated with fisher harvests. This relationship was not expected because road density was anticipated to be an indicator of trapline access and increased harvest. Roads may have influenced fishers biologically by decreasing the amount of core area, reducing patch size, increasing edge, and causing habitat fragmentation (Reed *et al.* 1996). Mean temperature was positively correlated with fisher harvests at the 'forest biome' scale in the Great Lake-St. Lawrence forest biome and may have been a factor that limited fisher's range throughout Ontario. Snowfall and snow depth were negatively correlated with fisher harvests at the 'Hills site region', 'forest biome', and 'provincial' scales. Snowfall was shown by Voigt *et al.* (2000), Krohn *et al.* (1995), Raine (1983) to negatively affect fisher by reducing their mobility and foraging success. Snowfall and snow depth may have also reduced access to the trapline and decreased trapper success. The spatial pattern variables for mature forest contributed consistently to regression models at the 'Hills site region', 'forest biome', and 'provincial' scales. MPS was negatively correlated with fisher harvests at the 'provincial' scale and in the western Great Lakes-St. Lawrence forest biome of the 'forest biome' scale. The negative correlation of fisher harvests with MPS and the positive correlation with ED suggested that fisher required habitat in the early stages of stand development. Younger forest may have promoted snowshoe hare populations (Quinn and Parker 1987) through a diversity of habitats created by disturbance (Douglas and Strickland 1987). Therefore the early stages of stand development created by logging and the diversity of species regenerated may have promoted snowshoe hare populations and possibly could have been a positive influence on fisher harvests.

The variability explained in the fisher harvests was not consistent at any scale. However, greater variability was accounted for within the Great Lake-St. Lawrence forest biome than in the boreal forest biome of the 'forest biome' scale, with approximately 25-50% of the variation in the fisher harvest data explained. The regression models with the highest explanatory power corresponded to areas where fishers have their highest densities throughout northwestern and southern Ontario (Thompson 2000a). Models for the boreal forest biome, where fisher densities were lower than the Great Lake-St. Lawrence forest biome of the 'forest biome' scale, accounted for approximately 10-20% of the variation in fisher harvests.

Lynx

Lynx models had relatively low explanatory power with r^2 values ranging from 10-25%. However, the proportion of mixedwood forest cover type contributed to four of the 22 regression models and was positively correlated with lynx harvests at the 'forest biome' and 'provincial' scales. Young mixedwood forest was a main component of lynx habitat and its main prey, snowshoe hare (Quinn and Parker 1987). Mean temperature and lynx harvests were positively correlated, possibly indicating that temperature may have been a limiting factor in their distribution. Temperature may have affected lynx directly through decreased survival in colder temperatures or indirectly by influencing snowshoe hare and their associated habitat. The MPS of young forest was negatively correlated with lynx harvests at the 'Hills site region', 'forest biome', and 'provincial' scales. This relationship may have indicated a preference by lynx for mature forest or small openings, as suggested by Quinn and Parker (1987).

CONCLUSIONS AND RECOMMENDATIONS

Furbearer harvests have been influenced by broad landscape factors such as forest cover type, weather, and landscape pattern. These three broad variables accounted for approximately 30-50% of the variation in marten, beaver, fisher, and lynx harvests using regression models. Although it was difficult to interpret some of the associations among the landscape variables, it was important to recognize that habitat was only one component that influenced these species. Throughout the landscape other factors at smaller scales (e.g., predator/prey relationships) and possibly even larger scales (continental climate patterns) may be affecting the distribution and harvests of these species.

The main hypothesis was that forest management influenced the population and hence the harvests of marten, beaver, fisher, and lynx. The direct influence of logging does not appear to affect the harvests of these animals at the 'trapline' scale. However, traplines in northern Ontario, which were subject to large-scale logging activities may have been of sufficient in size to accommodate both forestry and trapping activities. As logging occurred within a trapline, trappers may have been able to move their furbearer harvesting efforts to areas not subject to forestry activities, especially as these were made more accessible from new logging roads. Indirectly, logging has been shown to influence the forest cover type, and therefore forest managers should be cautious about altering forest stand composition on the landscape. The spatial pattern of young forests was another indirect effect of forest management. Marten in particular do not prefer early stand conditions and forest management therefore should try to maintain areas of contiguous mature forest habitat for this species. Beaver, fisher, and lynx may respond well to a diversity of stand developmental stages for their foraging activities. Beaver harvests would likely be affected negatively in the short-term by timber harvesting. However, the early successional conditions created would increase beaver habitat in the long-term. Lynx and fisher may benefit from the early successional forest conditions through increased prey abundance and hence improved foraging. Road density variables explained very little variation in furbearer harvests, although forest management activities were a primary factor in the level of access available to trappers.

Several improvements in data collection and provincial spatial data sets would improve results of the analysis. An accuracy associated with the provincial landcover (Landcover 28) data set would improve user confidence in the reliability of the broad forest cover types. Spatial information on other disturbance processes such as wind and insects would diversify the range of effects on the landscape that may have been influencing furbearer harvests. Furbearer ages from the trapline harvests would be beneficial to understanding the dynamics of the animals harvested (especially for marten) and provide more insight for interpretation. A measure of trapper effort would also provide useful data for analysis and interpretation of changes to furbearer harvest levels.

The harvest of marten, beaver, fisher, and lynx was clearly influenced by broad landscape variables. Some of these variables, such as forest cover type and landscape pattern were indirectly affected by forest management and should be an important consideration for future resource managers. Weather variables, that influence furbearers directly and their habitat indirectly will be difficult to anticipate in the future under current predictions of climate change. Resource managers trying to conserve furbearers for the future will have the difficult task of incorporating habitat dynamics occurring at many scales with current forest management policy while realizing that uncontrollable global and local processes are also influencing the landscape.

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