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An evaluation of furbearer harvest statistics and breeding bird atlas data to assess the effects of forest management at large landscape scales in Ontario

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An evaluation of furbearer harvest statistics and breeding bird atlas
data to assess the effects of forest management at large landscape
scales in Ontario

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ABSTRACT

Over the past 50 years, Ontario's forest landscape has changed as a result of forest resource management. The natural vegetation pattern, forest composition, and the fire regime have all been altered by management efforts. During the past 20 years, maintaining wildlife species diversity has become an important goal in forest management. To accomplish this goal, the impacts of large-scale land use and landscape scale processes that influence wildlife must be better understood, as habitat selection by many vertebrate species occurs at least partially at these scales. This project used trapline harvest statistics from 1972-1990 as a dependent variable to examine possible broad-scale effects of forest management and weather on selected furbearers, including marten, beaver, fisher, and lynx. As well, 21 avian species with distributional data from the "Breeding bird atlas of Ontario" were used to identify changes to breeding bird communities relative to large-scale habitat variables.

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 (ca. 5000 km²) scale, to the 'provincial' (ca. 800,000 km²) scale. This resulted in several models at each of the spatial scales. Further, 4 temporal periods were also analysed independently. Within each of the scales examined, results were then examined for consistency in the independent variables that entered the models. Forest cover type, weather, and spatial pattern variables accounted for the greatest variation in the furbearer harvest, and forest disturbance and road density variables accounted for little variation. Predictive capability of the models ranged from 10 to 55% among the species, and these were consistently best for beaver. 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' scale and 'provincial' scale, respectively. Lynx models were inconsistent and had low predictive power at all scales. The regression models suggested that disturbance by forest management did not affect furbearer harvests, and that landscape-scale variables such as forest cover type, weather, and landscape pattern accounted for a relatively high proportion of marten, beaver, and fisher harvests.

Data on selected birds from the Ontario breeding bird atlas were analysed by Universal Transverse Mercator (UTM) square (ie., sample unit = 100 km²). Canonical correspondence analysis (CCA) was used to determine the association among avian species and different levels of disturbance on each of the UTM squares. Most CCA models at the spatial extents examined were not significant, and only a small proportion of the variability in species presence was explained by the disturbance variables in significant models, ranging from 6-28%. Bi-plot graphs produced for the significant CCA models showed a poor relationship among avian species and the disturbance variables. The results suggested that other factors were apparently influencing bird species presence/absence probably acting at smaller scales.

INTRODUCTION

In Ontario, much of the forest landscape has been managed for wood products over the past 50-60 years. In particular, the area disturbed by logging has tripled since the 1950s and the area burned decreased slightly over the same period (Perera and Baldwin 2000). As a result, the landscape has been changed in several ways including smaller patch size, more edge, and altered tree species composition (Perera and Baldwin 2000, Thompson 2000a). From 1970-1991, the upland spruce (*Picea* spp.) and mixed softwood tree working groups decreased in area by 14% and 8%, respectively, while deciduous forest types have concurrently increased (Hearnden *et al.* 1992).

In Ontario there has been concern about the impacts of forest management on furbearer species such as marten (*Martes americana*) (Watt *et al.* 1996), fisher (*Martes pennanti*), and lynx (*Lynx canadensis*). In contrast, beaver (*Castor canadensis*), an early successional species, may have benefitted from increased timber harvesting that creates younger mostly deciduous forests suitable for beaver foraging. These 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 in Ontario (McLaren *et al.* 1998). Unfortunately, long-term population data for these species do not exist. However, there are long-term data for trapper harvests for each species that were recorded by the Ontario Ministry of Natural Resources (OMNR) for each registered trapline in the province. Trapper harvest data cannot necessarily be a reliable estimate of populations because trapper effort may be biased and dependent on socio-economic factors that regularly vary (Weinstein 1977, Smith *et al.* 1984). However, by controlling for trapping effort, harvest data could be used to compare the effects of environmental variables on the relative harvest over time and space.

The “Atlas of the breeding birds of Ontario” (Cadman *et al.* 1987) was an existing large-scale survey with provincial extent and with data collected from 1981-1985. Species presence and breeding activity was recorded for 10 x 10 km Universal Transverse Mercator (UTM) squares. This landscape survey was used successfully by Venier *et al.* (1999) to identify broad climatic variables that were important to the distribution of five warbler species. Trzcinski *et al.* (1999) used the breeding bird atlas survey data to test the proportion of forest cover and the effects of forest fragmentation in an agricultural landscape of southern Ontario. In that study he detected no forest fragmentation effects, but the proportion of forest cover in a UTM square was an important factor explaining species presence.

The general hypothesis in our study was: if timber harvesting is having a large-scale impact on furbearer and avian populations, then there should be a relationship between amount of forest disturbance and trapline harvests, and for breeding bird communities at one or more spatial scales. The alternate hypothesis was that furbearer harvests and avian species presence might be better predicted with other large-scale variables such as weather, or perhaps only with smaller-scale factors (i.e., stand-level changes).

Our study used fur harvest statistics from the 1970s and 1980s and the breeding bird atlas of Ontario data to examine the relationship of several landscape scale variables on the densities of marten, fisher, lynx, beaver, and 21 avian species. The analysis was also expected to determine the optimum spatial extent for measuring these effects. There were two primary objectives for the project:

1. To determine whether forest management, natural disturbance, weather, and landscape pattern affected furbearer harvest densities. Logging disturbance (area) 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. For avian species the associated, species presence and amounts of logging and fire were tested.
2. To establish the optimum spatial scale (extent) at which these effects might be identified (i.e., at which they act) and predicted.

We expected that our analysis would provide insight into whether landscape-scale variables influenced furbearer harvests and avian species presence across the landscape.

METHODS

SPATIAL SCALES OF ANALYSIS

Furbearer Harvest Statistics

The trapline was the fundamental spatial unit used in the analysis of furbearer harvest statistics. 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 estimated values for each trapline. Furbearer harvests were analysed at five spatial scales (Figure 1). These scales of analysis changed the extent or grouping of the traplines but maintained each trapline as the individual sample. At different scales, the variation in the spatial variables and the subsequent furbearer harvest densities changed. Each scale was comprised of spatial extents that encompassed the entire geographic area of the study. However, at the largest scale, the entire province of Ontario, all of the traplines were included in the analysis with a single spatial extent. As the scale (extent) 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, providing three spatial extents at the biome scale. The analyses were continued with decreased spatial scale (smaller and smaller extents) to the ‘sub-boreal’ scale (two spatial extents), ‘Hills site region’ scale (seven spatial extents), and the ‘OMNR District’ scale (30 spatial extents). As the scale decreased, the spatial extent of each classification also became smaller, theoretically decreasing the spatial variation across the landscape. This multi-scaled analysis of furbearer harvest identified factors that affected trapline harvests, first at the ‘provincial’ scale, and then at each subsequent

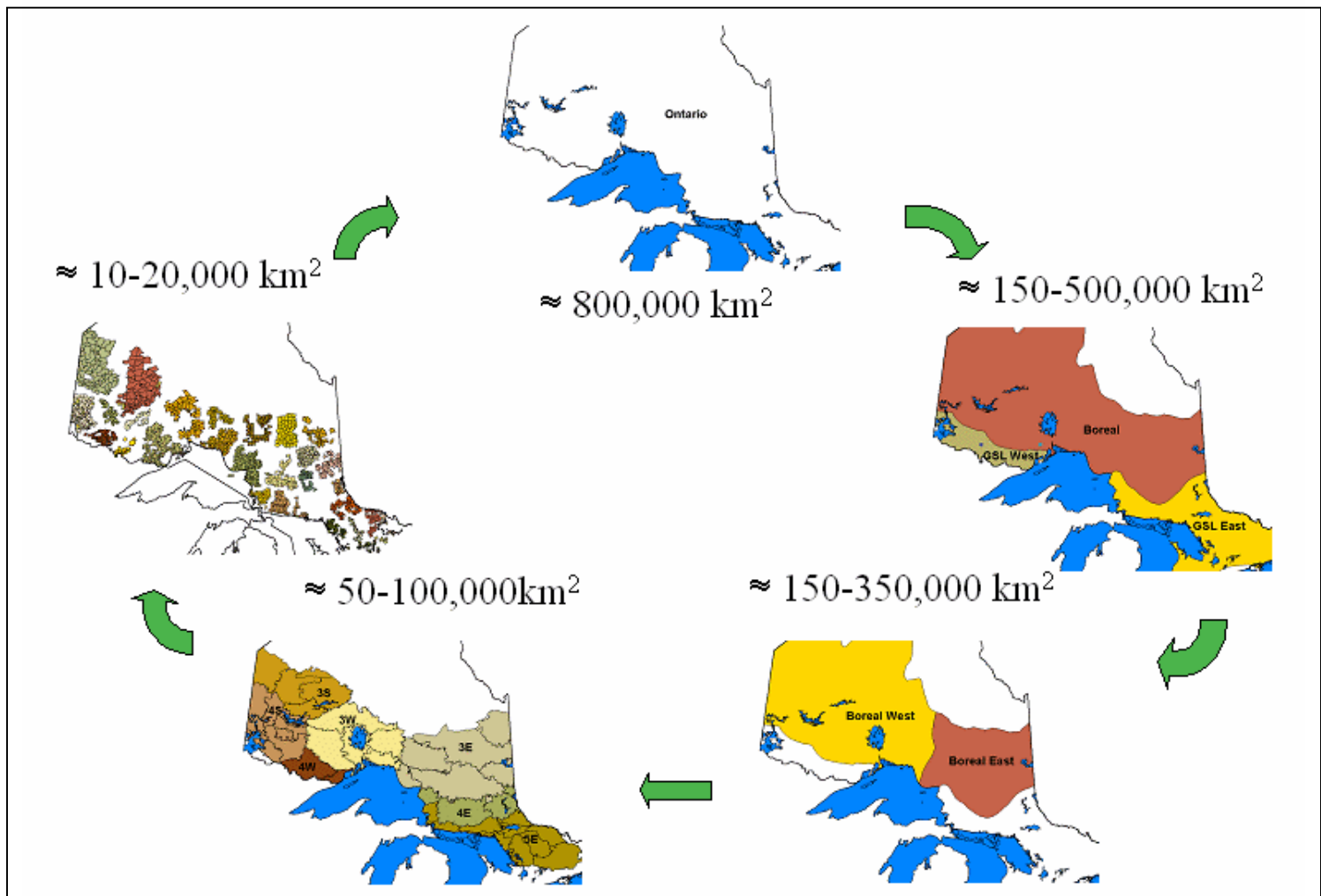


Figure 1. Spatial scales (extents) used in furbearer harvest analysis.

smaller classification of the landscape. This analysis method was expected to reduce variation caused by individual landscape processes such as fire, timber harvesting, and weather because at large scales these processes were highly variable and were expected to show decreased variation at smaller scales.

Breeding Bird Atlas

The multi-scale classification system for extent used in the furbearer analysis was applied to the breeding bird atlas component of our study, with a few exceptions: the UTM square was the basic sample unit, and there were four scales at which the breeding bird communities were analysed, 'provincial', 'forest biome', 'Hills site region', and 'Hills site district'.

COMPILATION OF WILDLIFE DATA

Compilation of the Furbearer Harvest Data while Controlling for Trapping Effort

The fur harvest database contained an annual total of each furbearer species harvested from each registered trapline in Ontario. The temporal extent of the fur harvest data set was 20 years, from 1972 to 1990, with three years missing in that period (1975, 1986, 1989) for marten, fisher, beaver, and lynx. The 20 years of data were subdivided into four 5-year periods (1972-1974, 1975-1979, 1980-1984 and 1985-1990, referred to as periods 1-4 respectively), and each was analysed separately. The data were analysed individually by period to remove some of the variation 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.

To reduce variability 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 harvested. An issue within the database was determining whether low catches were the result of minimal trapping effort or environmental factors. A restriction of 'minimum effort' was placed on the selection of traplines to ensure that a trapper harvested at least 1 animal/year. Further, we only used data from traplines where the minimum trapping effort (≥ 1 animal) had been maintained for at least 3 years during each of the 5-year periods. The mean number of animals harvested for the 5-year period for each trapline was then calculated 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 3 years in a 5-year period, the trapline was considered to be representative of a consistently trapped trapline, and if not, the line was deleted. Once the traplines were selected for analysis, a 5-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 the four species. 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) by time

period. Lynx trapping success was low in the period from 1972-1974 and therefore we did not use this data set 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). Finally, trapline size was variable and therefore the number of furbearers harvested was standardized by trapline size to furbearers harvested per km².

Breeding Bird Atlas Survey

The breeding bird atlas of Ontario was surveyed by volunteers who collected information on bird presence for each UTM square throughout southern Ontario. In the north, the sampling intensity was decreased because of poor access and difficult terrain. The landscape was divided into 100 x 100 km blocks and a subset of 10 x 10 km UTM squares were sampled less intensively (Cadman *et al.* 1987). Approximately 16 hours was defined as the minimum sampling period to obtain 75% of the species present in a square, and the larger blocks in northern Ontario were sampled for longer periods of approximately 50 hours. Species presence, breeding evidence, and approximate abundance were recorded for all squares. Breeding evidence was classified into four broad categories including: species observed, possible breeding, probable breeding, and confirmed breeding (Cadman *et al.* 1987). The last three categories were considered positive evidence of breeding activity (presence), while the first category was not considered breeding evidence. Trzcinski *et al.* (1999) speculated that abundances found within the breeding bird atlas were extremely coarse and offered little information beyond the presence/absence of a species. Therefore, we classed these data as presence/absence for our analysis.

In the analysis, only squares surveyed were used in the analysis. Many UTM squares in northern Ontario were not surveyed due to poor access and therefore have not been included in our analysis. The limited sampling intensity in the north decreased the overall data set (Figure 2). Each UTM square was then classified based on its location into its respective spatial domain (extent) for each of the three ecological land classifications, for the subsequent multi-scaled analysis. We also compared the proportion of surveyed UTM squares with and without disturbance to the overall proportion of UTM squares on the total landscape with and without disturbance, to determine whether a sampling bias occurred in relation to disturbance.

COMPILATION OF SPATIAL LANDSCAPE VARIABLES

Furbearer Harvest Statistics

The landscape variables that we used were generated from six main data sets and resulted in 31 variables (Table 1). The fire and logging disturbance data sets were further divided into several temporal periods by decade. Roads were classified according to structure, either primary or secondary. We used the 'Landcover 28' satellite image classification to calculate the quantity of conifer, deciduous, and mixedwood forest types on each trapline. We interpolated eight surfaces from the Canadian Daily Weather Data including mean

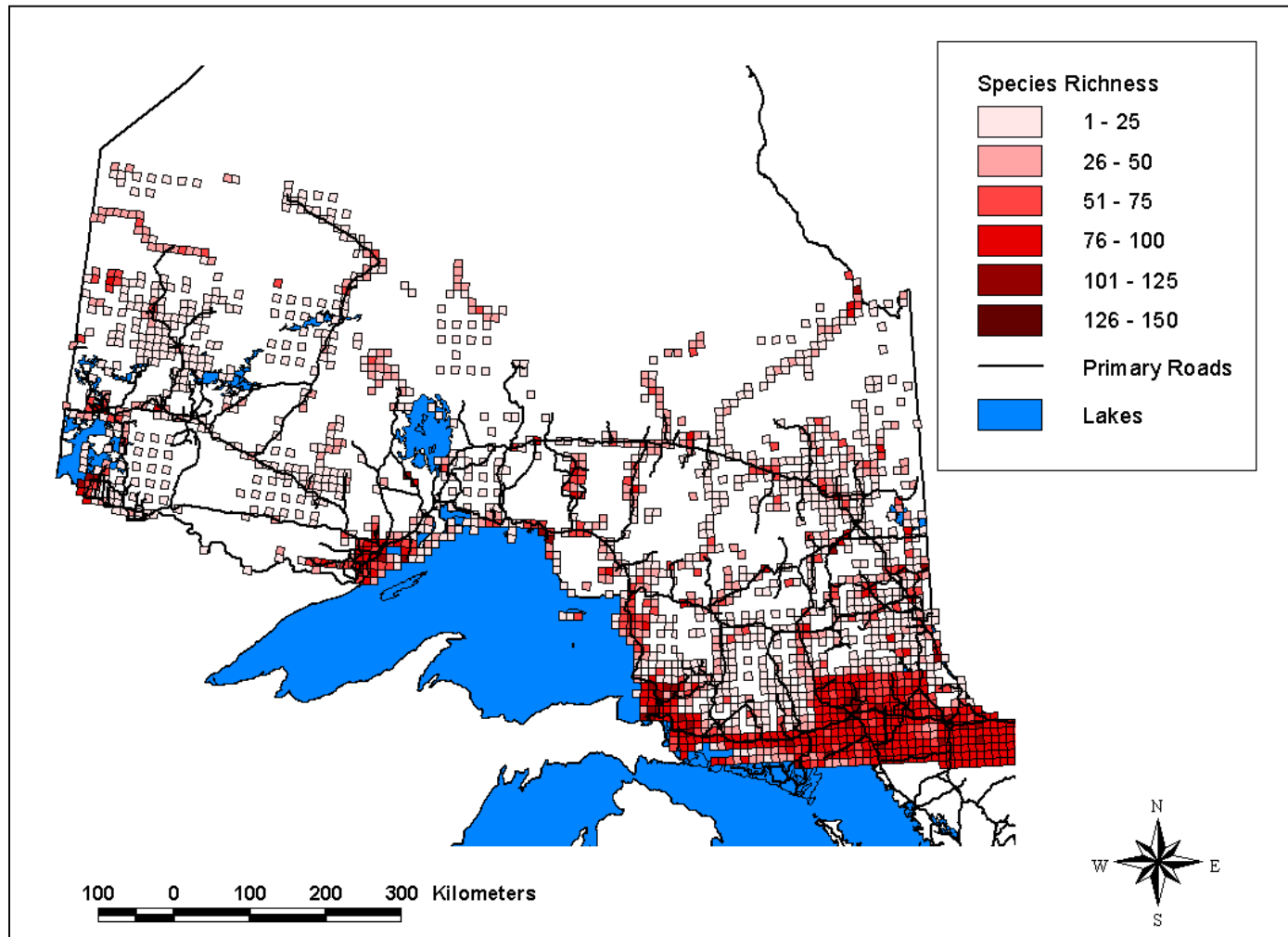


Figure 2. UTM squares sampled by the breeding bird atlas in northern Ontario.

annual temperature, mean annual precipitation, mean annual snowfall, and mean annual snow depth, for the 1970s and 1980s. To examine the association between trapline harvest and the spatial pattern of young forest (≤ 30 years of age) and mature forest (> 30 years of age), we combined logging and fire disturbances with Landcover 28 to identify forested areas ≤ 30 years of age and > 30 years of age. We used these combined data sets to calculate three spatial landscape metrics: mean patch size, edge density, and core area density for young and mature forest.

We compiled all spatial data set in the GIS. To obtain estimates for the 31 variables that we used in the analysis, all spatial variables were intersected with the trapline boundary coverage in GIS. The associated value from each variable, for each individual trapline was then compiled in a database with each trapline being a separate record or sample unit. Traplines throughout Ontario vary in size and therefore all variables including the furbearer harvest data were standardized to density measurements (variable/km²) or to a proportion (%) measurement. The final step was to amalgamate the data sets into a common database. Using the minimum furbearer harvest constraints, we created a list of available traplines for each of the four time periods, for each of the four furbearer species. Microsoft Access was used to associate the disturbance (fire and clearcut), percentage forest cover type, weather, spatial statistics, road density and stream density variables with the respective traplines from each of the fifteen data sets.

Breeding Bird Atlas

Each UTM square was considered a sample unit in the analysis and therefore we compiled the disturbance variables for each UTM square that had been surveyed. We combined fire and logging variables to generate a total disturbance variable because the total disturbance in some of the large UTM squares was low. The database for the breeding bird atlas was constructed in a similar manner to the furbearer harvest data set, except that all 21 avian species were included in the database with the combined fire and logging disturbance variables. We made some *a priori* predictions about broad forest age-class associations expected for each of the 21 species based on published literature and our own experience. We then predicted which disturbance variables might be associated with each species. (Further analyses will identify other landscape variables (e.g., forest cover type) influencing breeding bird communities.)

STATISTICAL ANALYSIS

Furbearer Harvest Statistics

We used principal components analysis (PCA) to reduce the number of variables to be analyzed in subsequent procedures. A PCA was performed at each scale, for all four furbearer species and for all four periods of analysis. Principal components (PC) that accounted for $\geq 10\%$ of the total variation in the data set were used to subdivide the variables. This rule removed PCs that accounted for little variation in the data set. The majority of the analyses summarized among trapline variation in the first three PCs,

Table 1. Summary of independent variables used to assess impacts on furbearer harvests

Data Set	Time Period	Variables Generated
Fire Disturbance	1920-1990	Burn 1970s Burn 1960s Burn 1950s Burn 1940s Burn 1920s-1930s Cumulative Burns 1941-1970
Logging Disturbance	1940-1990	Cut 1970s Cut 1960s Cut 1950s Cut 1940s Cumulative Cuts 1941-1970
Provincial Road Coverage	2002	Primary Roads Secondary Roads
Provincial Stream Coverage	2002	Provincial Streams
Landcover 28	1996	Conifer Forest Deciduous Forest Mixedwood Forest
Canadian Daily Weather Data	1970-1990	Mean Annual Temperature 1970s Mean Annual Precipitation 1970s Mean Annual Snowfall 1970s Mean Annual Snow Depth 1970s Mean Annual Temperature 1980s Mean Annual Precipitation 1980s Mean Annual Snowfall 1980s Mean Annual Snow Depth 1980s
Fire Disturbance + Logging Disturbance + Landcover 28	1996	Mean Patch Size – Young Forest Edge Density – Young Forest Core Area Density – Young Forest Mean Patch Size – Mature Forest Edge Density – Mature Forest Core Area Density – Mature Forest

although in some cases two or four PCs were used when $\geq 10\%$ of the variation was explained. Variables were selected from the PCs, using the component loading factors to

assess the contribution of each variable to the individual PC. Variables with the greatest contribution to the PC were retained for further analysis. Approximately 14 to 18 variables were selected from each model.

Using the variables selected by the PCA, we conducted forward stepwise multiple regression procedures to identify those variables that explained the majority of the variation in the dependent variable, furbearer harvest, at the various scales. We conducted analyses 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.

This statistical procedure was repeated for each spatial extent and time period for the four species of furbearer. 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 within the regression models were then compared for consistency in relationship to the furbearer harvest data, within and among scales and time periods. We compared the r^2 values for all models for consistency in the variation explained, within and among scales and time periods.

Breeding Bird Atlas

The presence/absence structure of the breeding bird atlas and the four predictor variables (total disturbance in the 1970s, 1960s, 1950s, and 1940s) were analysed using canonical correspondence analysis (CCA). This statistical method is a constrained ordination technique that allows direct gradient analysis of species and environmental data (Ter Braak 1986) and permitted analysis of all avian species in a single procedure. The method used a primary matrix of species abundances (or presence/absence data) and a secondary matrix of environmental data (disturbances).

We calculated eigenvalues and used them to evaluate the first three axes of the CCA, as this statistic was considered a better evaluation criteria than the Pearson species and environment correlation by McCune (1997). To test the null hypothesis that no linear relationship existed between the two matrices, we used a Monte Carlo randomization technique with 100 iterations. A probability was calculated for each axis to determine the proportion of eigenvalues that were greater than, or equal to, the observed eigenvalue for that axis (McCune *et al.* 2002). The p value was the probability of a type I error and was considered significant if it was ≤ 0.10 . The weighted averaging (WA) scores were graphed in a bi-plot with the species scores and vectors for the four environmental variables. This plot showed the relationship between the species and environmental variables in two-dimensional space. Within the bi-plots, we classified the avian species into broad forest age classes in which they are known to occur most frequently (defined as young, mature, and old forest).

The closer that two disturbance variable vectors were (similar direction and similar magnitudes), the higher was the correlation between the two variables. We expected avian species that relied on ‘young forest’ conditions to have been within close proximity to the disturbance vectors that represented ‘young forest’ conditions (i.e., disturbance in the 1950s, 1960s, and 1970s). Breeding bird species that required ‘mature forest’ conditions should have been negatively correlated with ‘young forest’ variables, or in close proximity to disturbance variables from the 1940s. Finally, we expected breeding bird species that required ‘old forest’ conditions to be negatively correlated with all of our disturbance variables.

RESULTS

FURBEARER HARVEST STATISTICS

The analysis of the furbearer harvest statistics resulted in 229 regression models for the four species at five spatial scales and during four time periods. All of the regression models developed have been reported in Savage (2003). Here, we present a summary of the consistent associations between furbearer harvest by species and the independent landscape variables (Table 2). Certain landscape variables (Table 2) were consistently associated with furbearer harvests among spatial scales (e.g., ‘provincial’, ‘forest biome’, ‘sub-boreal’, etc.) and/or among time periods.

The proportion of mixedwood forest cover and the core area density of mature forest was positively related to marten harvests at the ‘provincial’ scale. At the ‘forest biome’ and ‘Hills site region’ scales the proportion of mixedwood forest cover and deciduous forest cover were positively correlated with marten harvests. Beaver models were influenced by forest cover type, weather, and certain spatial pattern variables at the ‘provincial’ scale. The proportion of conifer forest cover and edge density of young forest was negatively associated with beaver harvests, while mean annual temperature and edge density of mature forest were positively correlated with beaver harvests. At the ‘Hills site region’ scale, the proportion of conifer forest cover and edge density of mature and young forest were associated with beaver harvests. However at the ‘Hills site region’ scale, the proportion of mixedwood and deciduous forest cover were positively associated with beaver harvests. At the ‘provincial’ scale, fisher harvests were associated with secondary road density (negatively), mean annual temperature (positively), and the mean patch size of mature forest (negatively). At the ‘Hills site region’ scale, secondary road density and mean annual temperature were, respectively, negatively and positively associated with fisher harvests. Snowfall and snow depth, although not consistently associated with fisher harvests either spatially or temporally, were negative factors in most of the fisher regression models. Variables selected in the regression models for lynx were not consistent at any scale or for any time period. However, the proportion of mixedwood forest (positive), mean annual temperature (positive), and the mean patch size of young forest (negative) were associated with lynx harvests.

The variation accounted for in furbearer harvests by the regression models was generally inconsistent. Regression models for marten harvests accounted for

Table 2. Summary of landscape variables influencing furbearer harvests.

Variables Contributing Consistently to Regression Models, their Association with Furbearer Harvests, and their Spatial Extent on the Landscape				
Scale	Marten	Beaver	Fisher	Lynx
'Provincial'	Mixedwood Forest Cover (+)	Conifer Forest Cover (-)	Secondary Road Density (-)	Mixedwood Forest Cover (+)
	CAD ¹ – Mature (+)	Mean Annual Temperature (+)	Mean Annual Temperature (+)	Mean Annual Temperature (+)
		ED ² – Young (-)	MPS ³ – Mature (-)	MPS – Young (-)
		ED – Mature (+)		
'Forest Biome'	Mixedwood Forest Cover (+) (boreal forest)	ED – Mature (GSL east)	ED – Mature (GSL east)	
	Deciduous Forest Cover (+) (GSL east)			
'Hills site region'	Mixedwood Forest Cover (+) (4S and 3E)	Mixedwood Forest Cover (+) (4S and 3E)	Secondary Road Density (-) (4S)	
		Conifer Forest Cover (-) (4S)	Mean Annual Temperature (+) (4S)	
		Deciduous Forest Cover (+) (3W)		
		ED – Young (-) (5E)		
		ED – Mature (+) (5E)		
'OMNR District'	Mean Annual Precipitation (+) (Red Lake)	Conifer Forest Cover (-) (Timmins)		
Note:	Associations are based on regression model coefficients show positive and negative correlations of furbearer harvest with landscape variables.			
	CAD ¹ – Core Area Density	ED ² – Edge Density	MPS ³ – Mean Patch Size	

Table 3. Summary of CCAs for avian species in relation to forest disturbances for each scale.

SCALE	% of Eigenvalue Variance Explained			Total Variance Explained	Pearson Correlation - Spp*Envt			Eigenvalue Probability		
	Axis 1	Axis 2	Axis 3		Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
Provincial	0.4	0.1	0.1	0.5	0.218	0.121	0.104	0.01	0.09	0.06
FOREST BIOME										
Boreal	0.3	0.2	0.2	0.7	0.221	0.216	0.182	0.45	0.04	0.07
GSL West	2.1	1.8	1.2	5.2	0.464	0.452	0.393	0.48	0.06	0.06
GSL East	0.8	0.5	0.3	1.5	0.269	0.267	0.183	0.02	0.01	0.02
HILLS' SITE REGION										
Site Region 3S	7.0	5.7	2.8	15.6	0.832	0.722	0.636	0.05	0.01	0.01
Site Region 4S	3.3	2.3	2.1	7.7	0.679	0.691	0.525	0.39	0.15	0.01
Site Region 4W	7.2	5.1	2.2	14.5	0.678	0.695	0.510	0.07	0.01	0.04
Site Region 3W	3.4	1.1	0.6	5.1	0.563	0.456	0.318	0.01	0.25	0.56
Site Region 3E	0.9	0.4	0.2	1.5	0.393	0.277	0.202	0.01	0.18	0.30
Site Region 4E	0.9	0.6	0.3	1.9	0.357	0.305	0.227	0.05	0.01	0.17
Site Region 5E	1.0	0.3	0.2	1.4	0.261	0.186	0.156	0.09	0.80	0.48
HILLS' SITE DISTRICT										
Site District 3S-1	14.0	8.8	3.0	25.7	0.913	0.795	0.708	0.11	0.05	0.33
Site District 4S-1	5.9	4.4	2.3	12.7	0.810	0.612	0.652	0.81	0.48	0.36
Site District 4W-2	8.6	4.4	3.0	15.9	0.783	0.581	0.562	0.18	0.20	0.06
Site District 3W-2	4.0	1.1	0.6	5.7	0.630	0.454	0.356	0.15	0.53	0.66
Site District 3E-1	2.1	1.0	0.7	3.8	0.486	0.465	0.334	0.13	0.55	0.33
Site District 3E-2	5.8	3.7	2.5	12.0	0.790	0.652	0.661	0.04	0.02	0.01
Site District 3E-5	4.1	1.6	0.7	6.5	0.757	0.450	0.310	0.03	0.03	0.40
Site District 3E-6	6.2	3.2	2.0	11.3	0.665	0.689	0.626	0.21	0.42	0.36
Site District 4E-3	1.9	1.1	0.7	3.6	0.439	0.425	0.337	0.10	0.07	0.06
Site District 4E-4	3.0	1.6	0.8	5.4	0.494	0.524	0.448	0.18	0.16	0.33
Site District 5E-4	2.7	0.7	0.5	3.9	0.456	0.343	0.242	0.32	0.98	0.96
Site District 5E-5	3.3	1.2	NA	4.6	0.471	0.380	NA*	0.23	0.36	NA
Site District 5E-6	5.7	4.1	0.8	10.6	0.724	0.498	0.426	0.31	0.10	0.96
Site District 5E-13	15.0	4.9	3.1	23.0	0.879	0.609	0.534	0.11	0.23	0.14

*NA denotes no axis calculated

*Highlighted scales denote models that accounted for $\geq 5\%$ of the variation and were significant.

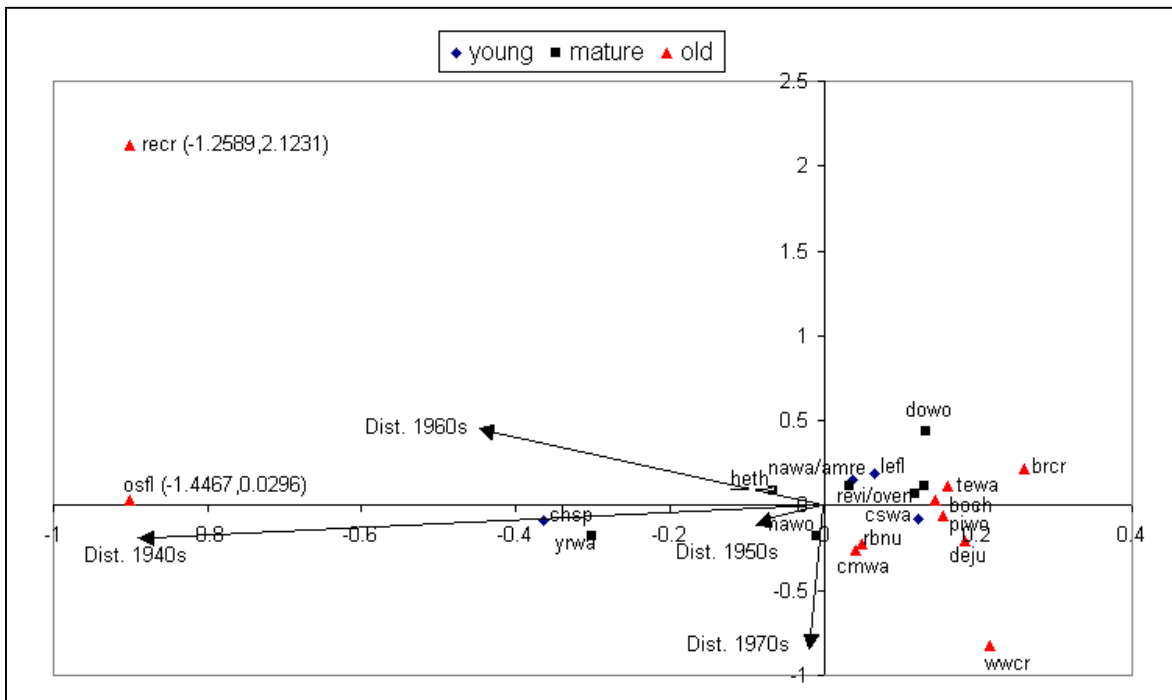


Figure 3. An example of a canonical correspondence analysis bi-plot for songbirds and environmental factors (see appendix for bird acronyms), for ‘Hills site district’ 3E-2. Young, mature, and old are broad forest habitat designations for each species used to aid interpretation of communities.

approximately 15-45% of the variation, with the best models resulting at the ‘OMNR district’ scale. Regression models for beaver and fisher were best (i.e., explained most variation) at the ‘provincial’ and ‘Hills site region’ scales, respectively. Regression models for beaver accounted for approximately 40-55% of the variation in beaver harvests, while fisher models accounted for 40-66% of the variation in fisher harvest. Regression models for lynx accounted for the least variation of the four species and generally explained 10-25% of the variation in lynx harvests.

BREEDING BIRD ATLAS

Many of the CCA models were not significant at all spatial extents (Table 3). Six out of 24 models were significant, with two of these models occurring at the ‘Hills site region’ scale, and four significant models occurring at the ‘Hills site district’ scale. At the ‘Hills site region’ scale, the significant CCA models accounted for approximately 15% of the variation in avian species presence, and the models at the ‘Hills site district’ scale accounted for approximately 6-25% of the variation in avian species presence.

The CCA bi-plots suggested generally weak relationships among the 21 avian species and the four disturbance variables (Figure 3). In most, many of the avian species were grouped near the centres of the bi-plots, as a result of weak correlations among

Table 4. Summary of individual avian species that were correlated with expected disturbance variables at the ‘Hills site district’ scale.

Hills Site District	Predicted Broad Forest Age-class		
	Young Forest	Mature Forest	Old Forest
3S-1	Least Flycatcher* Chipping Sparrow* Chestnut-sided Warbler*	Downy Woodpecker* Hermit Thrush*	Pileated Woodpecker* Dark-eyed Junco* Boreal Chickadee* Olive-sided Flycatcher
3E-2		Downy Woodpecker* Ovenbird Red-eyed Vireo* Yellow-rumped Warbler	Pileated Woodpecker* Dark-eyed Junco* Boreal Chickadee* Brown Creeper* Tennessee Warbler*
3E-5		Downy Woodpecker* Hairy Woodpecker*	White-winged Crossbill Dark-eyed Junco*
5E-13	Least Flycatcher* Chipping Sparrow* Chestnut-sided Warbler*	Downy Woodpecker* Hairy Woodpecker* Hermit Thrush* Red-eyed Vireo*	Pileated Woodpecker* Dark-eyed Junco* Boreal Chickadee* Brown Creeper* Tennessee Warbler* Red-breasted Nuthatch
*Avian species that were consistently correlated with the disturbance variable indicative of their broad forest class.			

avian species and the disturbance variables, resulting in difficulty in interpretation. Generally, cavity nesters were negatively associated with ‘young forest’ disturbance variables (1950s-1970s), suggesting some relationship with older forest conditions within the UTM squares. Similarly several mature and old forest species appeared related to the lack of disturbance or to the oldest disturbances. However, these relationships were not consistent throughout all the CCA models. As an example of the interpreted results of the CCA for individual species, several bird species by broad forest age group were associated with expected disturbance variables especially at the ‘Hill’s site district’ (Table 4). Notable is the number of cavity-nesters in the old forest and mature forest group that were correctly predicted by the CCA models.

DISCUSSION

FURBEARER HARVEST STATISTICS

Marten

The proportion of mixedwood, and deciduous forest cover, were positively related to marten harvests at the ‘forest biome’ scale in the boreal forest and in Great Lakes-St.

Lawrence forest biomes, respectively. Strickland and Douglas (1987) and Potvin (1999) suggested marten preferred mixedwood forest. The contribution of deciduous forest cover variables to the regression models was opposite to generally reported habitat preferences for marten, and may have resulted from other processes occurring on the landscape, such as juvenile dispersal or trapper site selection. The result may also reflect FRI forest typing from aerial photography that cannot detect an understory conifer component in forest stands.

Weather variables accounted for substantial variation in marten harvests in many of the regression models. While marten harvests were clearly influenced by weather, the effects were inconsistent spatially and temporally. A direct effect of weather was expected from snowfall and snow depth that could have influenced trapline access and trap site selection. 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). The interpretation of the direct effect of the various weather variables was made difficult by the spatial and temporal scales at which these variables operated.

The spatial landscape pattern variables for young forest (<30 yrs) 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 yrs) accounted for a small proportion of the variation in marten harvests. The regression models revealed that as MPS decreased, marten harvests increased. This relationship was opposite to the goal of current forest management guidelines that attempts to increase the overall patch size distribution and prevent further species and age-class fragmentation from occurring in the forest (Watt *et al.* 1996). Edge density was positively correlated with marten harvests at several scales. However, marten use of edge habitat is limited and they do not respond positively to disturbances (Snyder and Bissonette 1997, Thompson 1994, Potvin *et al.* 2000). Therefore it is likely that the positive influence of edge in the models reflected trapper use of edges for trapping as opposed to any positive selection by marten, other than for travelling and especially for dispersing juvenile animals. 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 in Ontario attempt to create these types of habitat conditions with large core areas (Watt *et al.* 1996).

Regression models at the 'OMNR District' scale accounted for approximately 25-45% of the variation in marten harvests. 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 which were not accounted for in these models. Marten trapline harvests appeared generally to be a poor index of marten density, and hence habitat quality. Strickland and

Douglas (1987), Thompson and Colgan (1994), and Hodgman *et al.* (1994) found that a high proportion of marten harvests consisted of young, dispersing juveniles that do not maintain home ranges. Habitats used by dispersing juveniles may not have been representative of habitats that are selected by adult resident marten. High juvenile harvest rates may have confounded our results by causing variation in harvest totals through regular capture of the animals in sub-optimal habitats.

Beaver

The proportion of mixedwood and deciduous forest cover types was consistently and positively correlated with beaver harvests at the 'Hills site region' scale. Deciduous species in these two forest covers are 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 suggested that with an increasing proportion of conifer forest, the number of beavers harvested decreased. Although beavers may also feed on conifers across their range, these species are not preferred foods (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 related to beaver harvests at the 'provincial' scale. Temperature may have been a limiting factor for beavers in Ontario because the long cold winters may limit the availability favoured food tree species (Flannigan and Weber 2000). Precipitation, snowfall, and snow depth explained a significant proportion of the variation in beaver harvests in many of the models at the 'Hills site region', 'forest biome', and 'provincial' scales. Unfortunately, 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 a negative correlation between these variables and beaver harvests. This relationship was in fact observed in regressions for the 'eastern boreal forest', where the mean annual snow depth was greater than in other parts of the province. Thermal protection provided by snow cover may have also positively influenced beaver harvests. For example, on occasion, shallow beaver ponds in Alberta have frozen completely when snow levels were low and beavers could not access food piles, resulting in a reduced population (S. Bayley, Univ. Alberta, pers. comm.).

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 likely combined to exclude this variable as an important factor related to beaver harvests in Ontario forests.

The spatial pattern of young and mature forest contributed consistently to regression models at the 'Hills site region', 'forest biome', and 'provincial' scales for beavers. The young forest variables were consistently negatively correlated with beaver

harvests. Beavers have been found to cut and use large diameter, early successional tree species (e.g., 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 wide ‘area of concern’ buffer (OMNR 1988) is applied to all streams. This area is protected from logging and therefore timber harvesting may not necessarily have influenced beaver harvests directly. On the other hand, the protection of riparian areas may have a negative impact on beavers by maintaining late successional species, which are not optimal as beaver forage (Barnes and Mallik 2001). The edge density of mature forest was positively related to beaver harvests, suggesting mature forest and the associated edge with young disturbed forest was important habitat for beavers seeking early successional forest conditions.

Beaver models explained more variation in harvest than did the marten models, with consistently 50% or more 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 ($\approx 50\%$) to that found in studies by Thomas *et al.* (1991), Cook and Irwin (1985), and Morrison *et al.* (1998), for various wildlife species. 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 related to fisher harvests. This relationship was unexpected 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, and may have been a factor that limited the distribution of fisher 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. Mean patch size (MPS) was negatively related to fisher harvests at the ‘provincial’ scale and at the ‘western Great Lakes-St. Lawrence’ forest biome scale (i.e., Rainy River-Ft. Frances). The negative correlation of fisher harvests with MPS and the positive correlation with edge density suggested that fisher require extensive habitat in the early stages of stand development. For example, young forest may have promoted snowshoe hare populations (Quinn and Parker 1987) through a diversity of habitats created by disturbance (Douglas and Strickland 1987) that could have been a positive influence on fisher population and harvests.

The variability in fisher harvest explained by the landscape variables was not consistent at any scale. However, greater variability in fisher harvest was accounted for within the Great Lake-St. Lawrence forest biome (25-50%) than in the boreal forest biome (10-20%). The regression models with the highest explanatory power corresponded to areas where fishers have their highest densities in Ontario (Thompson 2000b), and hence where the data were the most consistent.

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 is a main component of lynx habitat and its main prey, snowshoe hare (Quinn and Parker 1987). Mean temperature and lynx harvests were also positively correlated, possibly indicating that temperature may have been a limiting factor to 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).

Breeding Birds

The CCA models did not test the hypothesis that breeding bird communities may have been affected by forest management directly, but instead allowed an assessment of whether the presence/absence of avian species, as a community, were associated with various amounts of disturbance at the scale of the UTM square (10 x 10 km) or larger. The effects of forest management were difficult to detect in the breeding bird atlas data, for most species that we studied. Approximately 12 out of 21 species studied, appeared to show some positive associations with broad forest age-classes on the landscape. Sampling bias towards areas of access (i.e., areas with forest disturbance) was a factor that may have confounded avian habitat relationships.

In general, the variation in species presence explained in the models was not consistently greater at either the ‘Hills site region’ or ‘Hills site district’ scales. This suggested that the spatial extent of analysis did not influence the variation explained by the disturbance variables between these two scales. As well, the proportion of broad forest age-classes at the scale of the UTM square (grain) was not an important factor predicting the presence of most species. Our results suggested that the variables influencing bird distribution did not act at very large scales. For example, avian habitat characteristics at stand scales (e.g., snags, DWD, canopy structure) are not detected by the coarse UTM grain, but will influence species presence on the landscape, and may be much more important to birds than large landscape structure.

Nevertheless, we found significant relationships in the CCA bi-plots for many of the cavity-nesters at large scales. Cavity nesters require snags as a primary component of their habitat for nesting and feeding (Schiek *et al.* 1995; Hobson and Bayne 2000). Imbeau *et al.* (1999) found woodpeckers (*Picoides spp.*) in black spruce forests >120 years old and in post-fire early successional stands. They concluded that snag availability in older forests and post disturbance areas were responsible for the species presence and abundance. Setterington *et al.* (2000) recorded black-backed woodpeckers (*P. arcticus*) only in old forests in Newfoundland and related this to a high density of large snags. Cavity nesters as a guild may perceive the landscape at a much larger scale than other bird species, especially those species seeking large burned areas or old conifer forests. The CCA results suggested that disturbance at the scale of the UTM square (grain) may affect communities of cavity nesters associated with certain levels of forest in specific age-classes.

No other guild showed any clear and consistent relationship. However, certain results suggested that several species may have been responding individually at scales that were sufficiently coarse for the UTM square data to be useful. For example, chestnut-sided warblers (*Dendroica pensylvanica*) and ovenbirds (*Seiurus aurocapillus*) were positively correlated with ‘young forest’ and ‘mature forest’ disturbance variables, respectively (Hobson and Bayne 2000). Olive-sided flycatcher (*Contopus borealis*), boreal chickadee (*Parus hudsonicus*), hermit thrush (*Catharus guttatus*), and dark-eyed junco (*Junco hyemalis*) showed a common correlation with ‘old forest’ disturbance (or lack of disturbance) variables. However, stronger association in the data set among avian species classified as requiring ‘old forest’ and ‘mature forest’ and the disturbance variables may have been limited by the relatively short temporal span of the disturbance data. Logging and fire disturbances have been mapped reliably since the 1940s in Ontario. Better prediction for avian species that require ‘old forest’ or ‘mature forest’ conditions may require disturbance data from the mid-to-late 1800s to identify positive correlations among broad forest age-classes and avian species. The results suggested that the UTM square grain of 10 x 10 km was too coarse to detect the effects of broad forest age-classes on most breeding bird species.

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 50% of the variation in marten, beaver, fisher, and lynx harvests using regression models, although there was some inconsistency among scales and time periods. Although it was difficult to interpret some of the associations among the landscape variables, it was important to recognize that smaller-scale variables also influenced these species. Other factors at smaller scales (e.g., predator/prey relationships, stand-level variables) and possibly even larger scale effects (continental climate patterns) may also be affecting the distribution and harvests of these species.

Our primary 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. This may be because traplines in northern Ontario, which were subject to large-scale logging activities were often 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 either not subjected to forestry activities, or to areas that had been logged but which had returned as habitat. Logging may have made these latter areas more accessible.

The change in spatial pattern of young forests was an 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-development 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 longer 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 analyses such as ours. 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 insect infestations, would diversify the range of effects on the landscape that may influence 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 harvests of marten, beaver, fisher, and lynx were 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, which 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.

We can provide no clear conclusion about the effects of forest management on breeding bird communities based on the breeding bird atlas and disturbance data. Cavity nesters were the only avian guild that showed consistent associations with disturbance variables. Several other individual avian species were also fairly consistently correlated with their expected forest age-class. However, while the observed relationships in this study do not advance our knowledge of avian species, they do provide some insight into the use of the breeding bird atlas data. These results revealed that the breeding bird atlas

has too coarse a grain (10 x 10 km) to adequately monitor most species on the landscape relative to forest disturbances that act at smaller scales. Overall, the inconsistency in CCA model significance and the inability to detect the effects of broad forest age-classes for many of the species, demonstrates the limited value of the breeding bird atlas beyond broad predictions of species distribution across Ontario. An improved sampling design in collecting atlas data that is not biased by access, and instead is based on representative forest types would improve the value of such data for spatial analyses.

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Appendix 1. Acronyms for bird species used in figure 3.

Bird Species	Acronym
Hairy Woodpecker	hawo
Brown Creeper	brcr
Red-breasted Nuthatch	rbnu
Boreal Chickadee	boch
American Robin	amro
Hermit Thrush	heth
Least Flycatcher	lefl
Red-eyed Vireo	revi
Olive-sided Flycatcher	osfl
Yellow-rumped Warbler	yrwa
Nashville warbler	nawa
Ovenbird	oven
Downy Woodpecker	dowo
Tennessee Warbler	tewa
Chestnut-sided Warbler	cswa
Cape May Warbler	cmwa
Chipping Sparrow	chsp
Red Crossbill	recr
White-winged Crossbill	wwcr