Evaluating the Importance of Marten Cores to Trapper Harvests: Final Report for Phase 1

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Summary - We investigated the relationship between marten harvest, trapper effort, access, climate and habitat supply using data from 197 traplines in the boreal forest of northeastern Ontario, 156 traplines from the boreal forest of northwestern Ontario, and 140 traplines from the transition forest of central Ontario. Relative marten harvest (controlling for variation among years) was significantly related to indices of trapper effort (% of beaver quota filled) and access (density of roads) in all 3 regions. Relative marten harvest was also significantly related to mean January temperature and total annual precipitation in 2 of the 3 regions. When effort, access, and/or climate variables were controlled, relative marten harvest was significantly related to the total (non-spatial) supply of suitable habitat on traplines in all 3 regions. The best predictor of relative marten harvest was either the total area of suitable habitat or the area of suitable habitat in patches > 500 ha. In the latter case, one hectare of suitable habitat in core-sized patches (> 3000 ha) did not yield more captures than one hectare in 500-3000 ha patches. The supply of suitable habitat in forest management units (FMU) surrounding traplines had a significant or marginally significant effect on relative marten harvest in 2 of 3 regions. However, when FMU-scale results were significant, there was no indication that the supply of suitable habitat in core-sized patches had more influence on relative marten harvest than the supply in smaller patches. Overall, our results do not support the hypothesis that suitable habitat must occur in core-sized patches to support high trapper harvest of martens. However, we acknowledge that our best models only explained about 25% of the variation in relative marten harvest; we hope that better information on the age and sex of the harvest, as well as on trapper effort, will permit us to develop models with more predictive power (focus of Phase 2).

Introduction

The American marten (*Martes americana*) is an economically valuable furbearer in Ontario (Novak 1987). It is also viewed as an indicator of the sustainability of forest management practices because it is considered to be a species associated with large patches of mature and old coniferous and mixed forest (McLaren et al. 1998). In the boreal and transition forests of Ontario, forest management operations are modified to maintain habitat for martens. Retention of mature and old coniferous and mixed forest in large patches (3000-5000 ha) termed cores is one requirement of the current guidelines (Watt et al. 1996).

There is a large volume of information on the habitat requirements of martens. Much is known about the characteristics of den and rest sites used (e.g., Martin and Barrett 1991, Gilbert et al. 1997, Raphael and Jones 1997, Porter et al. 2005), the composition, age, and structural characteristics of forest stands preferred by martens (e.g., Thompson et al. 1989, Bowman et al. 1996, Bowman and Robitaille 1997, Payer and Harrison 2000), and the influence of landscape pattern at the scale of individual or multiple home ranges (e.g., Chapin et al. 1997, Hargis and Bissonette 1997, Potvin et al. 2000, Fuller and Harrison 2005). However, with the exception of some conceptual models (e.g., Thompson and Harestad 1994) and simulation models (e.g. Schneider 1997), there is little empirical information to suggest how habitat should be distributed across large (100s to 1000s of km^2) landscapes.

A recent thesis by Savage (2003) suggested that trapper harvest data might have some utility in evaluating the influence of large landscape scale patterns on the abundance of martens. He found a significant but weak relationship between trapper harvest and the amount and pattern of certain cover types identified by satellite imagery. Unfortunately, Savage did not classify habitat using suitability models currently available (Elkie et al. 1999, Naylor et al. 1999, Holloway et al. 2004), nor did he attempt to model the relationship between trapper harvest and the supply of habitat in core-sized patches.

Building on Savage's work, our study was designed to investigate the relationship between the supply of habitat in core-sized patches and trappers' harvest of martens. If core-sized patches of habitat are necessary to support high trapper harvest, we hypothesized there should be a positive relationship between trapper harvest and the area of suitable habitat in patches that are at least 3000 ha in size; as a corollary, there should be no (or a weak) relationship between trapper harvest and the area of habitat in patches smaller than 3000 ha.

This report summarizes results from Phase 1 of this project which tests our hypothesis using past harvest records. Phase 2 of this project tests our hypothesis using more detailed harvest information (on effort and harvest by age and sex) from a smaller sample of traplines. Both studies are part of a larger marten research program that is a collaborative effort involving the University of Guelph, the Canadian Forest Service, the Ontario Ministry of Natural Resources, and Ontario's forest industry (as represented by the Forest Ecosystem Science Co-operative Inc.).

Study Areas

This report focuses on data collected from 197 traplines in 14 forest management units (FMUs) in the boreal forest of northeastern Ontario (70 and 30% of traplines from site regions 3E and 4E, respectively), 156 traplines from 15 FMUs in the boreal forest of northwestern Ontario (46, 36, 13, and 5% of traplines in site regions 3W, 4S, 4W, and 2W, respectively), and 140 traplines from 5 FMUs in the transition forest of central Ontario (56 and 44% of traplines from site regions 4E and 5E, respectively) (Fig. 1). FMUs in site region 4E were considered boreal or transition based on their location relative to the lower boundary of the boreal forest as delineated by Rowe (1972).

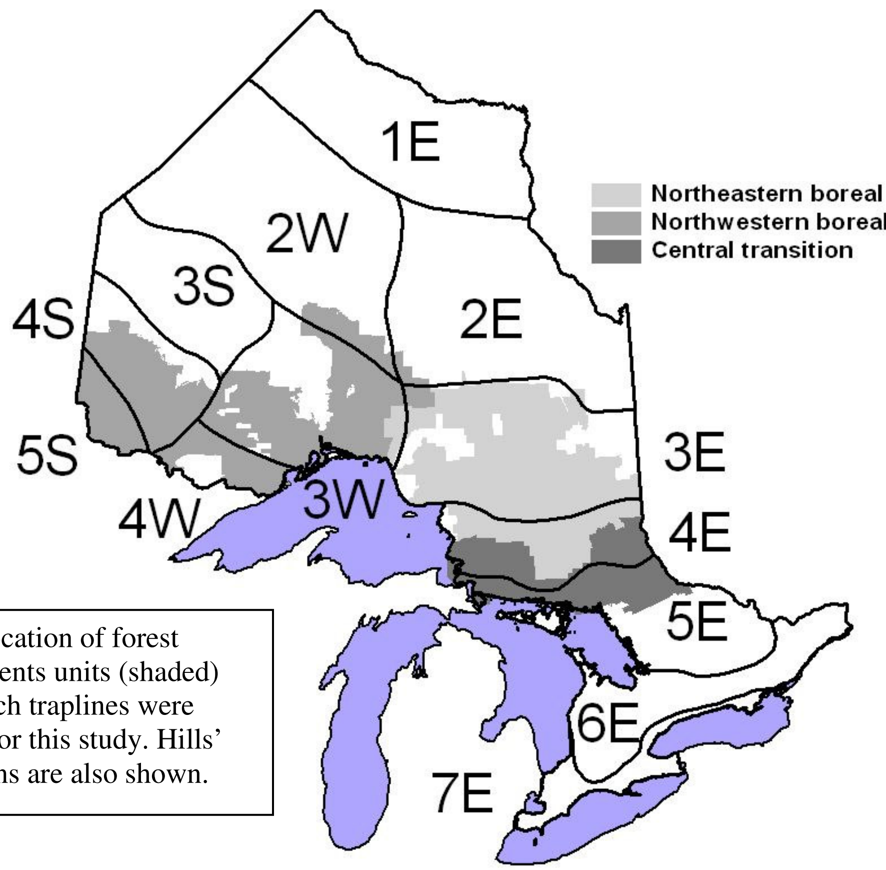

Fig. 1. Location of forest managements units (shaded) from which traplines were selected for this study. Hills' site regions are also shown.

The physiography, climate, and vegetation of each study region are well described by Baldwin et al. (2000), Mackey et al. (1996), and Rowe (1972).

In summary, both boreal regions are characterized by extensive forests of black spruce (*Picea mariana*), white spruce (*P. glauca*), jack pine (*Pinus banksiana*), balsam fir (*Abies* balsamea), trembling aspen (*Populus tremuloides*), and white birch (*Betula papyrifera*). Physiography is dominated by morainal deposits. The northeastern boreal region has extensive deep lacustrine deposits and small scattered outwash deposits. The northwestern boreal region has large areas of lacustrine and outwash deposits with some extensive areas dominated by bedrock. Mean annual temperature is about -1 to 3°C in the northwest and 0 to 3°C in the northeast. Total annual precipitation ranges from < 550 to 900 mm in the northwest and 700 to 1050 mm in the northeast.

In contrast, the central transition region is warmer (mean annual temperature 1 to 5°C) and wetter (total annual precipitation 750 to > 1100 mm) than the boreal regions. Its physiography is also dominated by morainal deposits; there are only small isolated areas of lacustrine and outwash deposits but some large areas dominated by bedrock. The forest cover is a mixture of boreal-like communities and those dominated by species characteristic of the Great Lakes – St. Lawrence forest such as sugar maple (*Acer saccharum*), red maple (*A. rubrum*), yellow birch (*Betula alleghaniensis*), white pine (*Pinus strobus*) and red pine (*P. resinosa*).

Methods

Marten harvest data

In Ontario, fur harvest is regulated through a registered trapline system (Novak 1987). We accessed the provincial Fur Management Information System to acquire harvest records for all traplines in the 3 study regions. This database provides a record of the reported harvest by year, but does not provide information on trapper effort or the age or sex of the catch. We selected all non-aboriginal registered traplines for study that had complete harvest information for 3 years bracketing the vintage of the forest resources inventory (FRI) data we had to characterize habitat supply (see below). We excluded traplines that had not caught at least 1 marten to avoid including traplines where trappers did not harvest martens. We also excluded very small traplines (< 5000 ha). Finally, a small number of traplines with very high harvests of martens (> 4X the regional annual average) that behaved as outliers in subsequent analyses were excluded from analysis. Marten harvest was averaged across the 3 years and then divided by the total trapline area to yield an estimate of catch per km^2 of trapline.

Marten harvest varies considerably among years across Ontario (Novak 1987), at least partly in response to changes in prey availability (Fryxell et al. 1999). For example, average harvest varied from 0.06 martens/km^2 (2001) to 0.18 martens/km^2 (1999) for 238 traplines in the northeastern boreal forest that had complete harvest data for the 10 year period from 1994-2003. In the northwestern boreal forest, harvest varied from 0.07 martens/km^2 (2001) to 0.19 martens/km^2 (1997) for 216 traplines with complete harvest data for the same time period. To control for annual variation in harvest, the 3 year harvest average for each trapline was scaled by dividing it by the appropriate 3 year regional moving average. All analyses are based on this measure of relative marten harvest.

Harvest records were linked to a digital map of registered traplines extracted from an OMNR database created in 2001. Although this map does not coincide with the vintage of all our FRI data, discussions with OMNR district staff suggested there were few known changes to trapline boundaries that would have affected the results of our study.

Characterizing habitat supply

FRI data were acquired for the area depicted in Fig. 1. FRI databases provided a digital inventory of the forested landscape, depicting forest stands and non-forested features such as lakes, rivers, and wetlands. Attribute data for individual forest stands included overstory species composition, age, height, stocking (density), and site class (site quality)(see OMNR 2001). The vintage of FRI data used varied from 1995 to 2002.

Habitat supply was assessed in a two step process. First, individual forest stands were rated using a non-spatial habitat suitability model. Then patches of suitable habitat in 3 size classes: small (less than the size of a male's home range - 500 ha), medium (at least the size of a home range but smaller than a core - 500 to 3000 ha), and large (at least the size of a core - 3000+ ha) were delineated using the core-building algorithm in the Ontario Wildlife Habitat Analysis Models (OWHAM) software package (Naylor et al. 1999). This algorithm identifies patches of forest that meet a minimum size threshold and contain at least 75% suitable marten habitat. The core-sized patches identified through this process were not necessarily those delineated as cores by forest management planning teams. Thus, the core-sized patches identified represent potential cores. We believe this analysis provided a reasonable index of the supply of habitat in large patches on traplines.

Habitat suitability of individual stands was assessed using 3 different models. In the northeastern boreal forest, we rated suitability based on the model in OWHAM (Table 1). In the northwestern boreal forest, we rated suitability based on the model in the Ontario Marten Analyst (OMA; Elkie et al. 1999) (Table 1). In the transition forest, we rated suitability based on the model in Holloway et al. (2004) (Table 1). OWHAM has a third suitability class termed 'marginal'. Marginal forest is generally poor marten habitat. Preliminary analyses suggested that the supply of marginal habitat had little effect on marten harvest and was subsequently excluded from further analysis.

Habitat supply was modeled for each FMU separately. We appreciate that modeling at this scale may miss some large patches of suitable habitat that cross FMU boundaries. However, we felt it was appropriate to model at this scale since marten cores are identified by planners at this scale. The area of different classes of habitat within each trapline was then identified by overlaying digital trapline and habitat supply maps. Habitat supply was expressed as the percent of the trapline in different habitat classes. We omitted traplines from analysis if > 5% of their area had missing FRI data or > 20% was private, park, or federal land. We excluded traplines when these conditions were met because we were concerned that estimates of the supply of habitat or the harvest of martens could be biased.

Other variables influencing marten harvest

We measured other variables that previous research or expert opinion had suggested might influence marten harvest.

Table 1. Description of habitat suitability classes used in the northeastern boreal, northwestern boreal, and central transition forests.

Habitat suitability class	**Definition**
Northeastern boreal forest	
Guideline suitable	%[1] Sb+Sw+Bf+Ce (%SFC) ≥ 40% and stand height (HT) ≥ 15.0 m and conifer canopy closure ≥ 50% and mature or old growth development stage (DS)
Suitable	Not guideline suitable but %SFC ≥ 30% and HT ≥ 12.0 m and total canopy closure ≥ 50% and mature or old growth DS
Northwestern boreal forest	
Good suitable	HT ≥ 14.99 m and stocking (STKG) > 50% and age > 79 years AND ((% Sw+Sb+Bf+Ce+Pj+Pr+Pw > 40% and Pj ≤ 40% and Sb ≤ 70% and Bf ≤ 80% and Pr ≤ 50% and Pw ≤ 70% and La = 0%) OR (Sb+Pj > 60% and Sb ≤ 80% and Pj ≤ 80% and Sb≥Pj and La = 0%))
Fair suitable	Not good suitable but HT ≥ 14.99 m and STKG > 50% and age > 79 years AND ((Sw+Sb+Bf+Ce+Pj+Pr+Pw > 40% and Pj ≤ 70% and Sb ≤ 70% and Bf ≤ 80% and Pr ≤ 50% and Pw ≤ 70% and La ≤ 20%) OR (Sb+Pj > 60% and Sb ≤ 80% and Pj ≤ 80% and Pj≥Sb) OR (Sb > 80% and site class = X, 1, 2, or 3))
Central transition forest	
Preferred	Ecosites[2] 11, 13, 16, 18, 20-22, 28, 30-34 and mature or old growth DS
Used	Ecosites 12, 14, 15, 17, 19, 27, 29, 35 and not presapling or sapling DS

[1] Percent of overstory comprised of various tree species: Bf = balsam fir; Ce = cedar; La = larch; Pj = jack pine; Pr = red pine; Pw = white pine; Sb = black spruce; Sw = white spruce.
[2] Ecosites define common forest communities; a description of the ecosites of central Ontario can be found in Chambers et al. (1997). For this analysis, ecosite was estimated by OWHAM.

Trapper effort may obscure the relationship between marten harvest and habitat supply. Unfortunately, we had no direct measure of trapper effort, such as number of traps set or number of days traps were set. Instead, we hypothesized that the % of the beaver quota filled might be a reasonable index of trapper effort. In Ontario, trappers are given a beaver quota based on the estimated size of the beaver population on their trapline and are required to harvest at least 75% of this quota (Novak 1987). We assumed that trappers that were unable to fill their quota in a given year due to some factor such as illness or injury would also not be expending much effort trapping martens.

Most trappers use roads built by the forest industry to gain access to their traplines and marten harvest may be positively influenced by road density (Soukkala 1983, Hodgman et al. 1994, Thompson 1994). For each trapline, we measured the density of roads (km/km^2 of trapline) based on the current (2004) provincial digital inventory of roads. We appreciate that this may not include all roads and trails that provide access for trappers, and may not coincide with the vintage of all our FRI data, but we believe it was a reasonable index of access on our study traplines.

Both temperature and snowfall are known to influence the behaviour of martens in winter (Thompson and Colgan 1994, Wilbert et al. 2000) and climatic variables have been linked to variation in marten harvest, both within and among years (Savage 2003). We identified the Environment Canada weather station that best represented the broad climatic zone (Mackey et al. 1996) in which each trapline was situated. Mean January temperature and total annual precipitation from the appropriate weather station were then averaged for the 3 years used to estimate marten harvest (see above).

Data analysis

All spatial analyses were conducted within the ArcView® environment. SPSS® was used for most statistical analyses.

For each of the 3 study regions, our analyses proceeded in the following manner. We first explored the relationship between relative marten harvest on individual traplines and indices of effort, access, and climate using correlation analysis and by developing a suite of regression models based on all possible combinations of independent variables. We then developed a suite of models to explore the relationship between relative marten harvest and the total (non-spatial) supply of suitable/guideline suitable (northeastern boreal) or fair suitable/good suitable (northwestern boreal) or used/preferred habitat (central transition) on traplines, while controlling for effort, access, and/or climate. This helped us identify what was functioning as suitable habitat. To evaluate our hypothesis, we then developed a suite of models relating relative marten harvest to the supply of functionally suitable habitat in small, medium, and large patches, controlling for effort, access, and/or climate. In all cases, we used an information theoretic approach (Akaike's Information Criterion - AIC) to select the most parsimonious models (Anderson et al. 2000). Most data were SQRT- or ARCSIN-transformed to meet assumptions of statistical tests.

To explore the influence of habitat supply at a scale greater than the individual trapline, we first estimated the amount of suitable habitat in patches > 0 ha (total supply), > 500 ha (supply in home range-sized and larger patches), > 3000 ha (supply in core-sized and larger patches), > 5000 ha (supply in patches larger than the upper end of the range prescribed for marten cores), and > 10000 ha (supply in patches > twice the largest size prescribed for marten cores) within each FMU. We then modeled the relationship between relative marten harvest on each trapline and the supply of suitable habitat within the surrounding FMU while controlling for habitat, effort, access, and/or climate variables used in the best trapline-scale predictive models (described above).

To investigate functional relationships, we used the best trapline-scale regression models to predict relative marten harvest from habitat supply. To control for effort, access, and/or climate, we set these variables in the regression models to their regional means. Confidence intervals for predicted values were generated using Statistix®.

Results

Influence of effort, access, and climate on relative marten harvest

Relative marten harvest was positively correlated with our index of trapper effort in the northeastern boreal (r = 0.143, P = 0.045), northwestern boreal (r = 0.247, P = 0.002), and central transition (r = 0.190, P = 0.025) forests.

Relative marten harvest was at least marginally correlated with the density of roads in the northeastern boreal (r = 0.120, P = 0.094), northwestern boreal (r = 0.172, P = 0.032), and central transition (r = 0.238, P = 0.005) forests.

Relative marten harvest was negatively correlated with mean January temperature (r = -0.257, P = 0.000) in the northeastern boreal forest but not in the northwestern boreal (r = -0.069, P = 0.390) or the central transition (r = -0.002, P = 0.979) forests. Relative marten harvest was not correlated with total annual precipitation in the northeastern boreal (r = -0.027, P = 0.705), northwestern boreal (r = -0.026, P = 0.752), or central transition (r = -0.124, P = 0.145) forests.

In the northeastern boreal forest, AIC analysis suggested the best predictor of relative marten harvest was the model with all variables except density of roads (53% likelihood). This model was highly significant (F = 11.135, P = 0.000) and explained about 15% of the variation in relative marten harvest. A model with all 4 variables also had a high (44%) likelihood of being the best predictor. Moreover, multi-model inference suggested a 46% chance that the best model would consider density of roads. Thus, in all subsequent analyses of the northeastern boreal data, we control for all 4 variables.

In the northwestern boreal forest, AIC analysis suggested that the best model included the index of trapper effort and density of roads. This model was highly significant (F = 7.275, P = 0.001) but only explained about 9% of the variation in relative marten harvest. Moreover, the AIC score for this model was low (33%) and other models may have been equally valid. For example, there was a 21% chance that the model containing the index of trapper effort, density of roads, and mean January temperature was the best predictor. However, multi-model inference suggested the likelihood that the best model would include the index of trapper effort, density of roads, mean January temperature, and total annual precipitation was 98%, 75%, 38%, and 28%, respectively. Thus, we only control for trapper effort and density of roads in all subsequent analyses of the northwestern boreal data.

In the central transition forest, AIC analysis suggested the best predictor of relative marten harvest was either the model with all 4 variables (23% likelihood) or with the index of trapper effort and density of roads only (25% likelihood). These models were highly significant (P’s < 0.001) and explained about 9-12% of the variation in relative marten harvest. While the latter model is more parsimonious, multi-model inference suggested > 50% chance that the best model would consider mean January temperature and total annual precipitation. Thus, in all subsequent analyses of the central transition data, we control for all 4 variables.

Influence of habitat supply in the boreal forest of northeastern Ontario

Non-spatial supply of habitat

Relative marten harvest appeared to be related to the supply of both suitable and guideline suitable habitat (Table 2). The model containing both variables explained about 19% of the variation in relative marten harvest. Although the regression coefficient for guideline suitable habitat (0.00704±0.00359) was about 1.3 times greater than that for suitable habitat (0.00538±0.00400), the difference was not close to being significant (t = 0.267, P = 0.790), suggesting that each hectare of suitable habitat and guideline suitable habitat had a similar influence on relative marten harvest. Overall, AIC analysis suggested that the most parsimonious predictor of relative marten harvest was the model containing the single variable representing the pooled supply of suitable and guideline suitable habitat (47% likelihood). Thus, we consider the pooled supply of suitable and guideline suitable habitat in subsequent analyses.

Table 2. Summary statistics for regression models predicting relative marten harvest from 197 traplines in the boreal forest of northeastern Ontario based on the supply of suitable and guideline suitable habitat. Suitability is based on definitions in OWHAM. All models control for an index of trapper effort (see text), density of roads, mean January temperature, and total annual precipitation.

Model	**Habitat variables**[1]	**Model F**	**Model P**	**Model R^2**	**AIC_c weight**
No habitat variables		8.821	0.000	0.155	0.03
Area of suitable habitat	++	8.057	0.000	0.174	0.08
Area of guideline suitable habitat	++	8.546	0.000	0.183	0.23
Area of suitable habitat Area of guideline suitable habitat	NS +	7.453	0.000	0.191	0.20
Pooled area of suitable and guideline suitable habitat	+++	8.887	0.000	0.189	0.47

[1] Significance and slope of habitat variables: NS = not significant (P > 0.10); + = marginally significant (P < 0.10) and positive; ++ = significant (P < 0.05) and positive; +++ = highly significant (P < 0.01) and positive.

Influence of patch size

The model including all 3 patch size variables was highly significant and explained about 18% of the variation in relative marten harvest (Table 3). The regression coefficient for large patches (0.00388±0.00224) was not significantly different from the regression coefficients for small (-0.00147±0.00692) (t = 0.922, P = 0.358) or medium patches (0.00254±0.00381)(t = 0.354, P = 0.724). However, the magnitude of the regression coefficients suggests that habitat in medium and large patches may have had a greater influence on marten harvest than habitat in small patches. This possibility is supported by the AIC analysis. The most parsimonious predictor of marten harvest was either the model that contained the variable representing the pooled area of habitat in small, medium, and large patches (45% likelihood) or the model containing the variable representing the pooled area of habitat in medium and large patches (38% likelihood). There was only a 13% chance that the model based on the area of habitat in large patches only was the best predictor.

Table 3. Summary statistics for regression models predicting relative marten harvest from 197 traplines in the boreal forest of northeastern Ontario based on the supply of suitable and guideline suitable habitat in small (< 500 ha), medium (500 – 3000 ha) and large (3000+ ha) patches. Suitability based on definitions in OWHAM. All models control for an index of trapper effort (see text), density of roads, mean January temperature, and total annual precipitation.

Model	**Patch variables[1]**	**Model F**	**Model P**	**Model R^2**	**AIC_c weight**
No habitat variables		8.821	0.000	0.155	0.02
Area of small patches Area of medium patches Area of large patches	NS NS +	5.948	0.000	0.181	0.02
Pooled area of small, medium, & large patches	+++	8.887	0.000	0.189	0.45
Area of medium patches Area of large patches	NS ++	6.966	0.000	0.180	0.00
Pooled area of medium & large patches	+++	8.801	0.000	0.187	0.38
Area of large patches	++	8.296	0.000	0.178	0.13

[1] Significance and slope of patch size variables: NS = not significant (P > 0.10); + = marginally significant (P < 0.10) and positive; ++ = significant (P < 0.05) and positive; +++ = highly significant (P < 0.01) and positive.

Thus, in the northeastern boreal forest, there is little evidence to support our hypothesis that large patches of habitat by themselves are necessary for high marten harvest. Relative marten harvest was best predicted by either the pooled supply of habitat regardless of patch size or the pooled supply in medium and large patches. When considering only medium and large patches, 1 hectare of habitat in large patches did not produce more martens than 1 hectare in medium patches.

FMU-scale analysis

Adding variables representing the supply of suitable and guideline suitable habitat in patches up to > 10000 ha in size within the surrounding FMU did little to improve the predictive capability of the best model from Table 3. None of the variables was close to being significant (P's > 0.4) and the amount of additional variation explained ranged from 1 to 2% (Table 4).

Table 4. Summary statistics for regression models predicting relative marten harvest from 197 traplines in the boreal forest of northeastern Ontario based on the supply of suitable and guideline suitable habitat in patches > 0 ha, > 500 ha, > 3000 ha, > 5000 ha, and > 10000 ha within the surrounding forest management unit. Suitability based on definitions in OWHAM. All models control for an index of trapper effort (see text), density of roads, mean January temperature, total annual precipitation, and total supply of suitable and guideline suitable habitat on each trapline.

Model	**FMU variable[1]**	**Model F**	**Model P**	**Model R^2**	**AIC_c weight**
No FMU-scale variables		8.887	0.000	0.189	0.33
Area of habitat in patches > 0 ha	0.427	7.497	0.000	0.191	0.15
> 500 ha	0.563	7.436	0.000	0.190	0.13
> 3000 ha	0.579	7.431	0.000	0.190	0.13
> 5000 ha	0.631	7.415	0.000	0.190	0.13
> 10000 ha	0.640	7.412	0.000	0.190	0.12

[1] P-value for FMU-scale habitat variable.

Influence of habitat supply in the boreal forest of northwestern Ontario

Non-spatial supply of habitat

Relative marten harvest was highly related to the supply of both fair suitable and good suitable habitat (Table 5). The model containing both variables explained about 19% of the variation in relative marten harvest. Although the regression coefficient for good suitable habitat (0.01397±0.00435) was about 1.3 times greater than that for fair suitable habitat (0.01100±0.00348), the difference was not close to being significant ($t = 0.544$, $P = 0.587$), suggesting that each hectare of fair suitable habitat and good suitable habitat had a similar influence on relative marten harvest.

Table 5. Summary statistics for regression models predicting relative marten harvest from 156 traplines in the boreal forest of northwestern Ontario based on the total supply of fair suitable and good suitable habitat. Suitability is based on definitions in OMA. All models control for an index of trapper effort (see text) and density of roads.

Model	**Habitat variables[1]**	**Model F**	**Model P**	**Model R^2**	**AIC_c weight**
No habitat variables		7.275	0.001	0.087	0.00
Area of fair suitable habitat	+++	8.017	0.000	0.137	0.00
Area of good suitable habitat	+++	8.122	0.000	0.138	0.00
Area of fair suitable habitat Area of good suitable habitat	+++ +++	8.956	0.000	0.192	0.12
Pooled area of fair suitable and good suitable habitat	+++	12.775	0.000	0.201	0.88

[1] Significance and slope of habitat variables: NS = not significant (P > 0.10); + = marginally significant (P < 0.10) and positive; ++ = significant (P < 0.05) and positive; +++ = highly significant (P < 0.01) and positive.

Overall, AIC analysis suggested that the most parsimonious predictor of relative marten harvest was the model containing the variable representing the pooled supply of fair suitable and good suitable habitat (88% likelihood). Thus, we consider the pooled supply of fair suitable and good suitable habitat in subsequent analyses.

Influence of patch size

The model including all 3 patch size variables was highly significant and explained about 23% of the variation in relative marten harvest (Table 6). The regression coefficient for large patches (0.0107± 0.00243) was marginally greater than the coefficient for small patches (-0.000474± 0.00758) (t = 1.670, P = 0.097) but was not different from the coefficient for medium patches (0.0127± 0.00457) (t = -0.423, P = 0.673). AIC analysis suggested that either the model containing the variable representing the pooled area of habitat in medium and large patches (44% likelihood) or the individual variables representing the area of habitat in medium and large patches (36% likelihood) was the best predictor of relative marten harvest; there was only a 2% chance that the model based on area of habitat in large patches only was the best predictor.

Table 6. Summary statistics for regression models predicting relative marten harvest from 156 traplines in the boreal forest of northwestern Ontario based on the supply of fair suitable and good suitable habitat in small (< 500 ha), medium (500 – 3000 ha) and large (3000+ ha) patches. Suitability based on definitions in OMA. All models include an index of trapper effort (see text) and density of roads.

Model	**Patch variables**[1]	**Model F**	**Model P**	**Model R^2**	**AIC_c weight**
No habitat variables		7.275	0.001	0.087	0.00
Area of small patches Area of medium patches Area of large patches	NS +++ +++	8.908	0.000	0.229	0.12
Pooled area of small, medium, & large patches	+++	12.775	0.000	0.201	0.07
Area of medium patches Area of large patches	+++ +++	11.208	0.000	0.229	0.36
Pooled area of medium & large patches	+++	14.314	0.000	0.220	0.44
Area of large patches	+++	11.703	0.000	0.188	0.02

[1] Significance and slope of patch size variables: NS = not significant (P > 0.10); + = marginally significant (P < 0.10) and positive; ++ = significant (P < 0.05) and positive; +++ = highly significant (P < 0.01) and positive.

Thus, in the northwestern boreal forest, there is little evidence to support our hypothesis that habitat must occur in large patches to support a high marten harvest. The area of fair suitable and good suitable habitat in medium and large patches pooled was the best predictor of marten harvest and 1 hectare of habitat in large patches did not produce more martens than1 hectare in medium patches.

FMU-scale analysis

Adding variables representing the supply of fair suitable and good suitable habitat in patches up to > 10000 ha in size within the surrounding FMU improved the predictive capability of the best model from Table 6. All variables were significant; the amount of additional variation explained ranged from 2 to 3% (Table 7). AIC analysis suggested a 96% likelihood that the best predictive model included a variable describing the supply of habitat in the surrounding FMU. The model considering the FMU-scale supply of habitat in patches > 500 ha had the highest R^2 value and AIC weight. However, models considering the FMU-scale supply of habitat in patches > 0 ha or > 3000 ha were equally likely to have been the best predictors.

Table 7. Summary statistics for regression models predicting relative marten harvest from 156 traplines in the boreal forest of northwestern Ontario based on the supply of fair suitable and good suitable habitat in patches > 0 ha, > 500 ha, > 3000 ha, > 5000 ha, and > 10000 ha within the surrounding forest management unit. Suitability based on definitions in OMA. All models control for an index of trapper effort (see text), density of roads, and supply of fair suitable and good suitable habitat in patches > 500 ha on each respective trapline.

Model	**FMU variable[1]**	**Model F**	**Model P**	**Model R^2**	**AIC_c weight**
No FMU-scale variables		14.314	0.000	0.220	0.04
Area of habitat in patches > 0 ha	0.020	12.436	0.000	0.248	0.21
> 500 ha	0.015	12.626	0.000	0.251	0.28
> 3000 ha	0.019	12.481	0.000	0.248	0.22
> 5000 ha	0.031	12.180	0.000	0.244	0.14
> 10000 ha	0.037	12.085	0.000	0.242	0.12

[1] P-value for FMU habitat variable.

Influence of habitat supply in the transition forest of central Ontario

Non-spatial supply of habitat

Relative marten harvest was highly related to the supply of both used and preferred habitat (Table 8). The model containing both variables explained about 24% of the variation in relative marten harvest. Regression coefficients for used habitat (0.02613± 0.00570) and preferred habitat (0.02227± 0.00568) were not significantly different (t = 0.946, P = 0.346), suggesting that each hectare of used habitat and preferred habitat had a similar influence on relative marten harvest. Overall, AIC analysis suggested that the most parsimonious predictor of relative marten harvest was the model containing the variable representing the pooled supply of used and preferred habitat (89% likelihood). Thus, we consider the pooled supply of used and preferred habitat in subsequent analyses.

Table 8. Summary statistics for regression models predicting relative marten harvest from 140 traplines in the transition forest of central Ontario based on the total supply of used and preferred habitat. Suitability is based on definitions in Holloway et al. (2004). All models control for an index of trapper effort (see text), density of roads, mean January temperature, and total annual precipitation.

Model	**Habitat variables**[1]	**Model F**	**Model P**	**Model R^2**	**AIC_c weight**
No habitat variables		4.476	0.002	0.117	0.00
Area of used habitat	++	4.830	0.000	0.153	0.00
Area of preferred habitat	NS	3.669	0.004	0.120	0.00
Area of used habitat Area of preferred habitat	+++ +++	7.014	0.000	0.240	0.11
Pooled area of used and preferred habitat	+++	8.967	0.000	0.251	0.89

[1] Significance and slope of habitat variables: NS = not significant (P > 0.10); + = marginally significant (P < 0.10) and positive; ++ = significant (P < 0.05) and positive; +++ = highly significant (P < 0.01) and positive.

Influence of patch size

The model including all 3 patch size terms was highly significant and explained about 17% of the variation in relative marten harvest (Table 9). The regression coefficient for large patches (0.01049± 0. 0.00372) was not significantly different from the regression coefficients for small patches (0.01334± 0.00521) (t = 0.963, P = 0.337) or medium patches (0.00623± 0.00391) (t = 1.300, P = 0.196).

Table 9. Summary statistics for regression models predicting relative marten harvest from 140 traplines in the transition forest of central Ontario based on the supply of used and preferred habitat in small (< 500 ha), medium (500 – 3000 ha) and large (3000+ ha) patches. Suitability based on definitions in Holloway et al. (2004). All models control for an index of trapper effort (see text), density of roads, mean January temperature, and total annual precipitation.

Model	**Patch variables**[1]	**Model F**	**Model P**	**Model R^2**	**AIC_c weight**
No habitat variables		4.476	0.002	0.117	0.00
Area of small patches Area of medium patches Area of large patches	++ NS +++	3.831	0.001	0.169	0.00
Pooled area of small, medium, & large patches	+++	8.967	0.000	0.251	1.00
Area of medium patches Area of large patches	NS NS	3.238	0.005	0.127	0.00
Pooled area of medium & large patches	NS	4.085	0.002	0.132	0.00
Area of large patches	NS	3.915	0.002	0.127	0.00

[1] Significance and slope of patch size variables: NS = not significant (P > 0.10); + = marginally significant (P < 0.10) and positive; ++ = significant (P < 0.05) and positive; +++ = highly significant (P < 0.01) and positive.

Moreover, AIC analysis suggested that the model containing the variable representing the total supply of used and preferred habitat (small, medium, and large patches pooled) was clearly the best predictor of relative marten harvest (100% likelihood).

Thus, in the transition forest of central Ontario, there is little evidence to support our hypothesis that habitat must occur in large patches to support a high marten harvest. The total area of used and preferred habitat (regardless of patch size) was the best predictor of marten harvest and 1 hectare of habitat in large patches did not produce more martens than 1 hectare in small or medium patches.

FMU-scale analysis

Adding variables representing the supply of used and preferred habitat in patches up to > 10000 ha in size within the surrounding FMU had a weak effect on the predictive ability of the best model from Table 9. Only 1 variable was even marginally significant and the amount of additional variation explained was < 2% (Table 10). However, AIC analysis suggested a 84% likelihood that the best predictive model included a variable describing the FMU-scale supply of habitat. The model including the FMU-scale supply of habitat in patches > 500 ha had the highest R^2 value and AIC weight. However, models considering FMU-scale supply of habitat in patches > 3000 ha, > 5000 ha, and > 10000 ha were equally likely to have been the best predictors.

Table 10. Summary statistics for regression models predicting relative marten harvest from 140 traplines in the transition forest of central Ontario based on the supply of used and preferred habitat in patches > 0 ha, > 500 ha, > 3000 ha, > 5000 ha, and > 10000 ha within the surrounding forest management unit. Suitability based on definitions in Holloway et al. (2004). All models control for an index of trapper effort (see text), density of roads, mean January temperature, total annual precipitation, and the total supply of used and preferred habitat on each trapline.

Model	**FMU variable[1]**	**Model F**	**Model P**	**Model R^2**	**AIC_c weight**
No FMU-scale variables		8.967	0.000	0.251	0.16
Area of habitat in patches > 0 ha	0.500	7.519	0.000	0.253	0.07
> 500 ha	0.097	8.036	0.000	0.266	0.22
> 3000 ha	0.127	7.943	0.000	0.264	0.18
> 5000 ha	0.127	7.941	0.000	0.264	0.18
> 10000 ha	0.123	7.953	0.000	0.264	0.19

[1] P-value for FMU habitat variable.

Functional relationships

In all 3 regions, there was a positive relationship between the supply of suitable habitat and relative marten harvest. In the northwestern boreal forest, the influence of habitat supply was greatest when suitable habitat occurred in medium and large patches, but we could detect little difference between the value of medium and large patches. Is suitable habitat arranged in medium and large patches always better?

To investigate this question, we illustrate the functional relationship between relative marten harvest and either the supply of fair suitable and good suitable habitat regardless of patch size or the supply of fair suitable and good suitable habitat in medium and large patches only (Fig. 2). When the supply of suitable habitat on traplines was low, concentrating habitat in medium and large patches appeared to produce a higher harvest of martens. However, the curves in Fig. 2 eventually converge. The functions themselves intersect when there is about 70% suitable habitat on traplines; there is considerable overlap of confidence intervals when traplines contain > 30% suitable habitat.

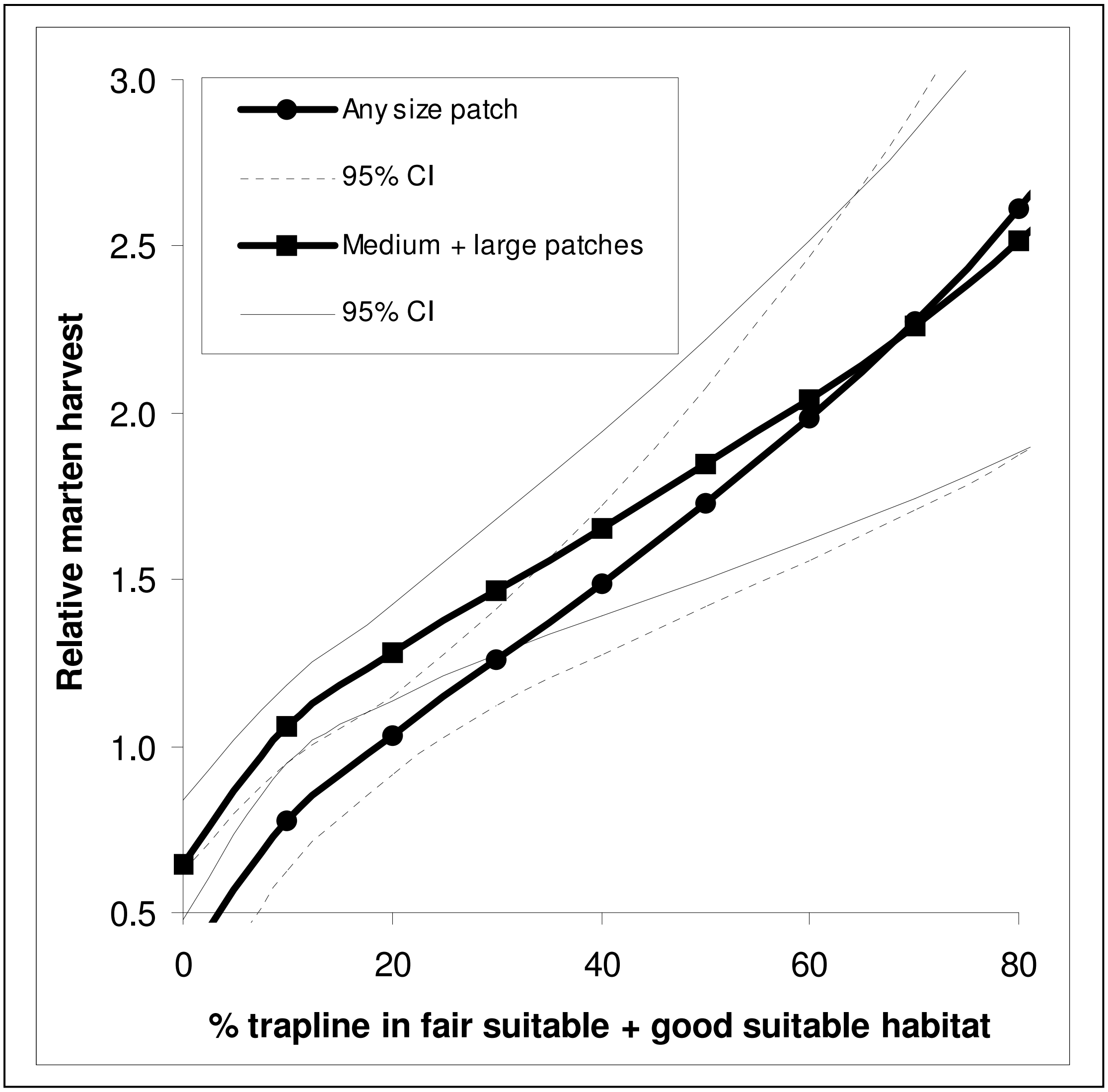

Fig. 2. Functional relationship between relative marten harvest and % of trapline in fair suitable and good suitable habitat in either any size patch or medium and large patches only for 156 traplines in the boreal forest of northwestern Ontario.

How much habitat is enough? In the northwest, Fig. 2 suggests traplines should yield a harvest about the annual regional average (# martens/km^2) with as little as 20% fair suitable and good suitable habitat (all patch sizes) or 10% in medium and large patches.

Discussion

Influence of habitat supply on harvest of martens

The amount of suitable habitat (suitable and guideline suitable in the northeastern boreal, fair suitable and good suitable in the northwestern boreal, used and preferred in the central transition) on traplines was a significant predictor of marten harvest in all 3 regions. However, the importance of habitat supply relative to other variables such as trapper effort, access, and climate varied among regions; adding habitat terms increased the % of variation explained by base models by as little as 22% in the northeastern boreal forest to as much as 263% in the northwestern boreal forest.

In the boreal regions, each hectare of high quality suitable habitat (guideline suitable or good suitable) appeared to have about 1.3 times the effect on marten harvest as each hectare of low quality suitable habitat (although these differences were not significant). These results at least partly validate the non-spatial habitat suitability models currently used in OWHAM and OMA (see also Bowman and Robitaille 2005). In contrast, in the central transition forest, there was no suggestion that preferred habitat was more likely to yield higher catches of martens than was used habitat. This supports a recent study in Algonquin Park which suggests that some aspects of the non-spatial habitat suitability model developed for the Great Lakes – St. Lawrence and transition forests need to be revised (Gelok 2005).

Concentrating suitable habitat into home range-sized and larger patches appeared to increase marten harvest in the boreal forest (at least in northwestern Ontario). However, our results do not support our hypothesis; 1 hectare of suitable habitat in large patches did not produce a greater yield of martens than 1 hectare of suitable habitat in medium patches. This result is consistent with research from managed forests in Maine which suggests that martens may need patches of suitable habitat that are only about the size of individual home ranges (Chapin et al. 1998).

The importance of patch size to marten harvest appeared to be influenced by the overall supply of suitable habitat on traplines. When traplines contained a large amount of suitable habitat (more than about 30%), concentrating habitat into patches had little effect on yield. This is consistent with emerging theory on the relative importance of amount versus pattern of habitat at landscape scales. Some authors suggest that habitat pattern influences the diversity and/or abundance of various taxa only when suitable habitat occupies less than 20 to 30% of a landscape (see review by Fahrig 2003).

In contrast to the boreal regions, there was little suggestion that suitable habitat needed to be concentrated in patches in the transition forest. This may reflect the different nature of the forest mosaic in the boreal and transition forests. In the boreal forest, suitable habitat tends to occur as ‘islands’ within a matrix of less suitable habitat; traplines in the northeastern and northwestern boreal forests averaged 27% and 24% suitable habitat, respectively. In contrast, in the transition forest, unsuitable habitat tends to occur as 'islands' within a matrix of largely suitable habitat; traplines averaged 74% suitable habitat in central Ontario.

Generally, more than half the martens caught by trappers are juveniles and juvenile martens disperse widely during the fall and early winter when most trapping is conducted (Strickland and Douglas 1987). Thus, many of the martens caught on our traplines were likely not residents or even juveniles produced on those traplines. It is thus possible that some large core areas may be necessary at larger landscape scales to sustain populations and produce a supply of dispersing juvenile martens that can subsequently be caught on adjacent traplines. Results of our FMU-scale analyses suggested that habitat supply within a larger landscape did have some influence on marten harvest on individual traplines. However, there was no clear indication that habitat at the FMU-scale had to occur in core-sized patches to influence harvest on individual traplines.

In the northwestern boreal forest, traplines with at least 10 to 20% suitable habitat appeared to yield at least as many martens as the annual regional average. This is not out of line with others who have suggested that between 20 and 25% of small to large landscapes should be maintained in suitable habitat conditions to sustain marten populations (Soutiere 1979, Thompson and Harestad 1994).

Modeling using trapper harvest data

While marten harvest could be significantly predicted by habitat supply, trapper effort, access, and climate, our best models only explained about 25% of the variation. We believe the following factors may have contributed to the low predictive ability of our models.

We used marten harvest data collected from 1994 to 2003. The procedure for collecting data on harvest by trappers changed circa 1999 (Chris Heydon, pers comm. 2005). This change in approach may have influenced the precision of the harvest data we used.

Trapper effort clearly has the potential to have a large influence on marten harvest but our index of effort (% of beaver quota filled) was imprecise. Standards for reporting beaver harvest often vary among OMNR districts (Chris Heydon, pers comm. 2005). Moreover, effort spent harvesting beavers is not necessarily directly correlated with effort spent harvesting martens. A more precise estimate of trapper effort (number of traps set for martens and length of time traps were set) is being examined in Phase 2 of this project.

Our index of access on traplines was imprecise. Our data on roads were not necessarily the same vintage as our FRI data. Moreover, many old roads and trails that are frequently used to access traplines were not part of our roads database.

Our measures of climatic factors that may affect marten harvest were imprecise. Climatic data from relatively large areas were assigned to each trapline. Collection of climatic data on each trapline (or use of climate surface models) may have improved the predictive ability of our models.

Finally, our estimates of habitat supply were imprecise. FRI data formed the basis of our estimates of habitat supply. FRI is based largely on air photo interpretation and is considered to be imprecise, especially at the scale we used it. Moreover, habitat supply was interpreted using habitat suitability models that have recently been validated with varying levels of success (see Bowman and Robitaille 2005, Gelok 2005).

In interpreting our results, we have assumed that marten harvest reflects relative abundance of martens on traplines, which in turn is an indicator of the quantity and quality of habitat on traplines. Are these assumptions valid?

Is harvest related to abundance? Marten harvest may be affected by numerous factors that are unrelated to abundance such as trapper effort, access, climate (see above), and even variation in marten behaviour (Thompson and Colgan 1987). We have attempted to control for some of the variation contributed by these variables. Moreover, despite the variation introduced by these factors, marten harvest at large geographic scales appears to be positively correlated with marten abundance (see Fryxell et al. 2001). Thus, we believe that marten harvest was a reasonable index of abundance on traplines.

Does abundance necessarily reflect the quantity and quality of habitat on traplines (*sensu* Van Horne 1983)? Abundance might be a misleading indicator of habitat supply if juvenile martens are forced to disperse to poor habitats where they reach high densities during the trapping season. There are agonistic interactions between territorial and juvenile martens, likely inducing dispersal (Strickland and Douglas 1987). However, there is little evidence that juvenile martens 'fill up' poor habitats in the fall and winter. At large geographic scales, the literature suggests that good habitat has more martens than poor habitat at all times of the year, and that good and poor habitats have a similar % of juveniles in the fall and winter (see Soutiere 1979, Thompson 1994, Potvin and Breton 1997). Abundance might also be a misleading indicator of habitat supply if it is not positively associated with productivity and survival. However, high abundance of martens is typically associated with high survival and/or high productivity (Thompson 1994, Potvin and Breton 1997). Thus, we believe that marten harvest was a reasonable indicator of the quantity and quality of habitat on traplines.

We hope to be better able to evaluate these assumptions during Phase 2 of this project, when we will have information on harvest effort and the sex and age of captures.

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