An assessment of expert-based marten habitat models used for forest management in Ontario

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ABSTRACT

We used marten snow tracking data and a previously developed empirical habitat model from northeastern Ontario to validate a number of expert-based, non-spatial marten habitat models. In particular, we tested the non-spatial Ontario Wildlife Habitat Analysis Model, the Boreal East Habitat Suitability Matrix (including tests of both standard forest units and development stages), and Allen's (1982) HSI model. Marten habitat use as measured by tracks in the snow was consistent with predictions of all the expert-based models, suggesting that these models correctly characterized the stand-level forest cover selected by marten in winter. Suitability ranks for individual stands derived from standard forest units and development stages also were consistent with their use by marten. The empirical model was consistent with the expert-based models in that it considered suitable forest stands to be those with tall trees dominated by spruce (*Picea* spp.) and balsam fir (*Abies balsamea*) trees, with a large amount of coarse woody debris, and high canopy closure. Our findings suggested that the expert-based models were able to characterize stand structure used by marten despite some of the models using only inputs available from stand inventories. This was accomplished because stand structural elements such as coarse woody debris were integrated into OWHAM and HSM indirectly, through relationships with stand age and species composition.

Key words: boreal forest, forest inventory, habitat, habitat suitability, guidelines, Forest Ecosystem Classification, landscape, *Martes americana*, resource selection, snow tracking, spatial autocorrelation, stand structure

RÉSUMÉ

Nous avons utilisé des données de pistes sur neige de martre et un modèle de qualité de l'habitat empirique existant du nord-est de l'Ontario pour valider quelques modèles non-spatiaux d'habitat de la martre et basés sur la littérature (experts). En particulier, nous avons testé le Modèle non-spatial d'Analyse de l'Habitat pour la Faune de l'Ontario, la Matrice de Qualité de l'Habitat Boréal Est (incluant les tests des unités forestières standard et des stades de développement), et le Modèle IQH d'Allen (1982). La distribution des pistes sur neige de martre correspondait aux prévisions de tous les modèles experts, ce qui suggère que ces modèles ont caractérisé correctement le couvert forestier des peuplements choisis par la martre à l'hiver. Les rangs de qualité des peuplements individuels dérivés des Unités Forestières standard ainsi que les stades de développement correspondaient également à leur usage par la martre. Le modèle empirique correspondait aux modèles experts en ce qu'ils considéraient les peuplements forestiers de qualité s'ils étaient constitués de grands arbres et d'une grande quantité d'épinettes (*Picea* spp.) et de sapins baumiers (*Abies balsamea*), de débris ligneux et d'une canopée fermée. Nos résultats suggèrent que les modèles experts étaient capables de caractériser la structure des peuplements utilisés par la martre en dépit du fait que certains de ces modèles utilisaient seulement les données d'inventaire de peuplement. Ceci a été possible parce que les éléments structuraux des peuplements tel que le débris ligneux ont été intégrés aux modèles OWHAM et HSM indirectement, via les relations avec l'âge et la composition en espèces.

Mots-clés : forêt boréale, aménagement forestier, habitat, qualité de l'habitat, lignes directrices, classification de l'écosystème forestier, paysage, martre, *Martes americana*, suivi de pistes sur neige, sélection des ressources.

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Introduction

The marten (*Martes americana*) is a provincially featured species in Ontario for the purposes of forest management, and as such, a guide has been developed for the provision of marten habitat in managed forests (Watt *et al.* 1996). Marten have been identified as a featured species, due to the perception that they require mature or older coniferous and mixed forest habitat for successful denning, resting, and foraging (Thompson 1991).

The focus on marten as a featured species has resulted in the development of numerous non-spatial marten habitat models, both in Ontario and elsewhere. An early example of such a model was the Habitat Suitability Index (HSI) model

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for marten developed by Allen (1982) for the United States Fish and Wildlife Service. This, and other, similar models relate the suitability of a forest stand for marten to the characteristics of the stand, which ideally are described using information available in stand inventories. Stand suitability can then be forecast along with wood supply, and in essence, these become habitat supply models. Such models often are "expert-based" (rather than empirical, for example), since the models tend to be developed through literature review and consensus.

In northeastern Ontario, there are currently two main expert-based marten habitat models being used in forest management. There is a Boreal East Habitat Suitability Matrix (HSM) which assigns suitability for marten to a matrix of standard forest units and development stages (Holloway *et al.* 2004). A standard forest unit (hereafter forest unit) is a group of forest stand types that have similar vegetation communities and succession pathways and can thus be aggregated during forest planning (Holloway *et al.* 2004). Development stage is simply age assigned to five classes: presapling, sapling, young, mature, and old. There also is the Ontario Wildlife Habitat Analysis Model (OWHAM), which contains a non-spatial marten model (Naylor *et al.* 1999). These two models (HSM and OWHAM) are similar in that they characterize stands using information obtained remotely from stand inventories.

We have previously developed an empirical model of marten habitat use in northeastern Ontario (Bowman and Robitaille 1997) using snow tracks to identify sites used by marten. Vegetation structure at used and random sites was statistically compared to derive the model. We also have tested an earlier version of the expert-based HSM (D'Eon and Watt 1994) for northeastern Ontario (Bowman *et al.* 1996). However, we have not evaluated how these two modelling approaches were related (that is, how the two models performed on a set of the same stands), and we believe that this step is important to consider, as it would demonstrate the relationships that exist between the expert-based model and our field measurements of stand structure related to marten. Also, we felt that it would be useful to revisit these models because the HSM of D'Eon and Watt (1994) has been replaced by one that ranks suitability based on forest units and a revised definition of development stage (Holloway *et al.* 2004). The Ontario Wildlife Habitat Analysis Model also has been developed since our earlier work. Finally, reassessing these models is timely because the Ontario Ministry of Natural Resources is in the process of reviewing its forest management guides and the relevant planning models.

Our objectives were to assess Ontario's expert-based models by testing how they relate both to our empirical model and to observations of marten snow tracks. We also assessed Allen's (1982) original HSI model. Finally, we compared the inputs and outputs of all these stand-level models in order to assess their differences, similarities, and overall performance.

Methods

Development of empirical model

The empirical model has been fully described in Bowman and Robitaille (1997). Briefly, we conducted snow tracking in the Clay Belt (Rowe 1972) near Timmins, Ontario, during winter 1994 and divided tracked transects into 100-m segments with and without marten tracks. In summer 1994 and 1995, segments were revisited and a circular plot was established within each to measure and inventory stand structure. Discriminant function analysis was conducted to develop a model of the posterior probability of any 100-m segment containing a marten track. We followed the statistical methods of Brennan *et al.* (1986). We used 565 plots to develop the model, and 293 different plots to test the model. The 565 model-development plots were spread across 25 transects, which created a potential problem of pseudoreplication and spatial autocorrelation among the transect segments in measuring marten habitat use. Spatial autocorrelation would incorrectly reduce confidence intervals, and would therefore result in overestimating significance of effects. However, we tested our model on an external validation set to minimize this problem (Bowman and Robitaille 1997), and have subsequently tested for spatial autocorrelation in the occurrence of 100-m segments with tracks and found that it was not significant (Table 1). Our reason for carrying out the analysis at this scale was that we were interested in stand-level habitat use. We recognize that marten make decisions at larger scales about where to locate home ranges, etc., and that finer scale decisions will be constrained by these larger scale patterns. For the purpose of comparing outputs among different stand-level models, we do not believe that sub-sampling transects presents a problem, since we were merely interested in local vegetation structure as measured by the various models.

Table 1. Mean autocorrelation coefficients (r) and 95% upper and lower confidence limits (Bonferroni corrected) for the presence of a marten track in 100-m segments of longer transects (N = 25 transects)

Distance (m)	LCL	Mean	UCL
100	-0.01082	0.164493	0.33982
200	-0.05984	0.077198	0.21424
300	-0.14121	-0.02094	0.099338
400	-0.08602	0.057524	0.201071
500	-0.15702	-0.06515	0.026718
600	-0.18954	-0.08232	0.024902
700	-0.22769	-0.12937	-0.03105
800	-0.2287	-0.08782	0.053058
900	-0.24797	-0.12643	-0.00489
1000	-0.2861	-0.1352	0.0157

Our final empirical model, the probability of any 100-m segment containing marten tracks, was given by:

$$P = \frac{1}{1 + 2.33 \bullet e^{-x}} \qquad [1]$$

where x = [0.0259 • spruce or fir (%)] + [0.0814 • median tree height (m)] + [0.1231 • number of downed logs] + [0.0140 • canopy closure (%)] – 3.7021 (Table 2).

Derivation of standard forest units and habitat units

During our field surveys in June to August of 1994 and 1995, we determined the northeastern Ontario Forest Ecosystem Classification site types (NE-FEC) of each of the 565 model development plots (Bowman *et al.* 1996). We characterized

Table 2. Some non-spatial marten habitat models either used in, or developed for, Ontario's boreal forest

Model[a]	Input[b]	Output[c]	Source[d]
Habitat Suitability Index	1) Spruce or fir (%) 2) Canopy closure (%) 3) Successional stage 4) Coarse woody debris (%)	0 to 1	1
Ontario Wildlife Habitat Analysis Model	1) Spruce, fir, or cedar (%) 2) Canopy closure (%) 3) Development stage 4) Tree height (m)	0 to 3	2
Boreal East Habitat Suitability Matrix	1) Standard forest unit 2) Development stage	0 to 2	3
Standard Forest Units[e]	1) Standard forest unit	0 to 2	3
Development Stage[e]	1) Development stage	0 to 2	3
Empirical Model	1) Spruce or fir (%) 2) Canopy closure (%) 3) Tree height (m) 4) Coarse woody debris (amount)	0 to 1	4

[a]All except empirical model are based on literature review and expert opinion.
[b]Spruce (*Picea* spp.); Fir (*Abies balsamea*); Cedar (*Thuja occidentalis*).
[c]For all models, 0 indicates the lowest quality habitat.
[d]1 Allen (1982); 2Naylor et al. (1999); 3 Holloway et al. (2004); 4 Bowman and Robitaille (1997).
[e]Standard Forest Units and Development Stage are the inputs that are combined to estimate the Boreal East Habitat Suitability Matrix probability.

site types based on the classification of McCarthy *et al.* (1994). Since that time, the NE-FEC scheme has been revised (Taylor *et al.* 2000). However, we were able to update our assessments to the new scheme based on linkages provided in Taylor *et al.* (2000). We then used a matrix from Holloway *et al.* (2004) to translate our site types into forest units.

The HSM assigns putative suitability to forest stands for a range of species, including marten (Holloway *et al.* 2004). The HSM value for any stand is a combination of the assigned suitabilities of the development stage of that stand and the suitability of its forest unit (Table 2). The suitability of both development stage and forest unit varies between 0 (low) and 2 (high). Overall HSM scores are calculated as the product of development stage and forest unit suitabilities where product ≥ 3 then HSM = 2 (preferred), product ≥ 1 and < 3, then HSM = 1 (used), product = 0 then HSM = 0 (not used). Since we had classified each of our 565 plots into NE-FEC site types, and these could be translated to forest units, we were able to assign marten suitabilities to each forest unit for each of our plots (see Holloway *et al.* 2004). We then inferred development stage from tree height using the rules: median tree height < 5 m then development stage suitability = 0, height ≥ 5 m and ≤ 10 m then suitability = 1, height > 10 m then suitability = 2. Overall HSM score could then be calculated for each of the 565 sampled plots.

Derivation of OWHAM scores

The Ontario Wildlife Habitat Analysis Model (Naylor *et al.* 1999) is a tool used in forest management that contains both a spatial and a non-spatial marten habitat suitability model for the eastern boreal forest. We tested the non-spatial model by calculating model scores for each of our 565 segments and comparing model scores to marten use of the plots and to empirical model scores for the plots. Non-spatial habitat suitability in OWHAM is estimated based on four variables: amount of spruce, balsam fir, or eastern white cedar (*Thuja occidentalis*); stand height; canopy closure; and maturity class (development stage) (Table 2). Each of these varies from 0 (poor) to 3 (optimal), and the variables are combined such that the stand in question is assigned a suitability equal to the minimum suitability value of any of the four variables. Therefore, overall OWHAM suitability varies between 0 and 3, and a value of 3 means that all four variables are assigned a suitability of 3. We were able to directly score the first three variables from our plots using the rules provided by Naylor *et al.* (1999), and we used the same rule as our assessment of the HSM to score the fourth variable (development stage).

Derivation of Allen model scores

Allen (1982) produced an HSI model for marten that has been heavily relied on in Ontario (Watt *et al.* 1996) and elsewhere (e.g., Fecske *et al.* 2002), as a basis for including marten habitat values in forest management. The HSI contains non-linear relationships that vary between 0 (poor) and 1 (optimal) for four variables: canopy closure, amount of spruce or fir (where fir is *Abies* spp. or *Pseudotsuga menziesii*), successional stage (similar to development stage), and amount of downed woody debris (Table 2). We scored our plots according to Allen's model (0 to 1) by creating translations based on his suitability curves for each of the four variables: for canopy closure, < 25% = 0, 25–50% = 0.50, and > 50% = 1; for amount of spruce and balsam fir 0 = 0.20, < 25% = 0.4, 25–50% = 0.75, and > 50 = 1; for successional stage, < 5 m median tree height = 0.3, tree height 5–10 m = 0.67, and tree height > 10 m = 1; for downed woody debris, 0% = 0.50, < 25% = 0.75, 25–50% = 1, and > 50 % = 0.75. In our field work, we counted downed wood, rather than % amounts as the HSI used, so we derived % values by using the plot with the most logs as the denominator and expressing other plots as a percent of this value. We combined values for the four variables to produce an overall HSI score for each of our 565 plots.

Since the HSI scored stand suitability as a continuous variable, where the other expert-based models were categorical, we classified the HSI output into four categories (< 0.25 = 0, < 0.50 = 1, < 0.75 = 2, < 1.0 = 3) to allow comparison among the models. We also compared the empirical model to the HSI using the raw scores since both of these models produced continuous output.

Statistical analyses

For each of the expert-based models, we assessed whether marten used transect segments with different model scores in proportion to their availability. We conducted chi-square analyses of the relationships between the presence and absence of marten tracks in segments and the categorical suitability scores of the segments. Significant relationships were tested using the methods of Byers *et al.* (1984) with $\alpha = 0.05$. The HSI, OWHAM, and HSM models, as well as the forest unit and development stage suitability ranks, were tested using this approach.

We used analysis of variance to explore the distribution of empirical model scores in segments with different categorical scores for the HSI, OWHAM, and HSM models, as well as for the forest unit suitability ranks. The relationship between the continuously distributed scores of the HSI and the empirical model was assessed with a Spearman rank correlation.

Results

Comparison among expert-based models

The HSI of Allen (1982) differed from the other expert-based models in that it required an input, % coarse woody debris (CWD), that was not directly available from typical stand inventories (Table 2). Other differences between the OWHAM and the HSI were that the OWHAM included eastern white cedar with spruce and fir as suitable tree species, and contained inputs for both tree height and stand development stage (successional stage in the HSI). The HSM was the simplest and most different of these expert-based models in that it required only two inputs: forest unit and development stage (Table 2).

Comparison of expert-based models with occurrence of marten tracks

The use of forest stands by marten, as determined by tracks in the snow, was consistent with predictions by all three of the expert-based models, as well as for the forest unit and development stage suitability ranks. In general, tracks were disproportionately less abundant in stands that were considered poor marten habitat by the models (OWHAM, $\chi^2 = 28.1$, P < 0.0001, Phi = 0.22; Forest unit, $\chi^2 = 5.5$, P = 0.064, Phi = 0.10; HSI, $\chi^2 = 45.5$, P < 0.0001, Phi = 28.4; HSM, $\chi^2 = 16.1$, P < 0.0001, Phi = 0.17; Development stage, $\chi^2 = 16.5$, P < 0.0001, Phi = 0.17) (Fig. 1).

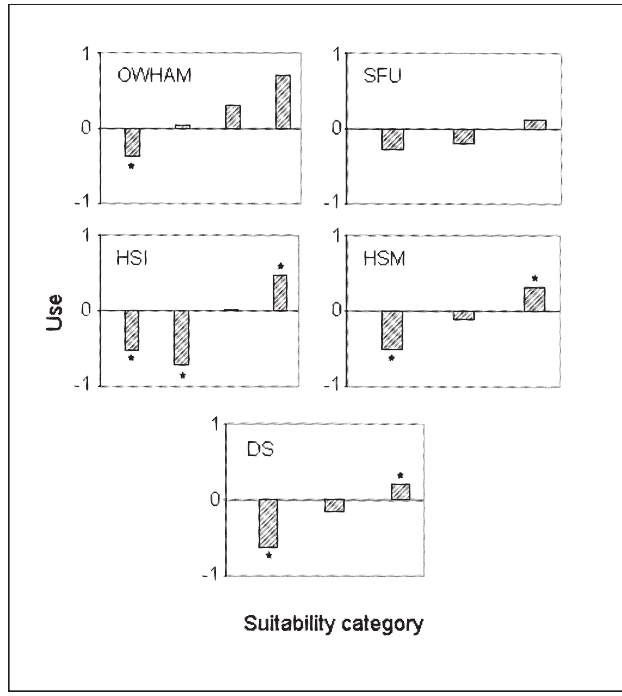

Fig. 1. Distribution of marten (*Martes americana*) snow tracks among 565 forest plots in northeastern Ontario with different marten habitat suitability scores according to five different non-spatial models: the Ontario Wildlife Habitat Analysis Model (OWHAM); Standard Forest Units (SFU); Allen's (1982) HSI (HSI); the Boreal East Habitat Suitability Matrix (HSM); and Development Stage (DS). Bars show use by marten [(obs-exp)/exp]. Stars indicate Bonferroni-corrected significance ($\alpha = 0.05$). Suitability categories vary between 0 (low) and 2 (high) (SFU, HSM, DS) or between 0 (low) and 3 (high) (OWHAM, HSI).

Comparison of expert-based models with empirical model

The empirical model was most similar in structure to the HSI, containing the same four inputs, with the exception that tree height was used in the empirical model as a measure of development stage. The OWHAM differed from the empirical model in that it included eastern white cedar as a suitable tree species, and included both tree height and development stage as model inputs. The empirical model had the fewest similarities in model structure to the HSM (Table 2).

The distribution of empirical model scores was consistent with scores from each of the expert-based models (OWHAM, F = 156.6, df = 3, 561, P < 0.0001; Forest unit, F = 13.7, df = 2, 562, P < 0.0001; HSI, F = 220.3, df = 3, 561, P < 0.0001; HSM, F = 96.5, df = 2, 562, P < 0.0001) (Fig. 2). A Spearman correlation demonstrated a significant, positive relationship between Allen's HSI model (with a continuous data output) and the empirical model ($r_s = 0.804$, N = 565, P < 0.0001) (Fig. 3).

Discussion

The distribution of marten snow tracks was consistent with predictions of all of the expert-based models, suggesting that these models correctly characterized the stand-level forest cover selected by marten in winter. Generally, the models suggested that marten should prefer late seral stands with high canopy cover, a large amount of downed wood, and a large proportion of softwood. The characterization of marten

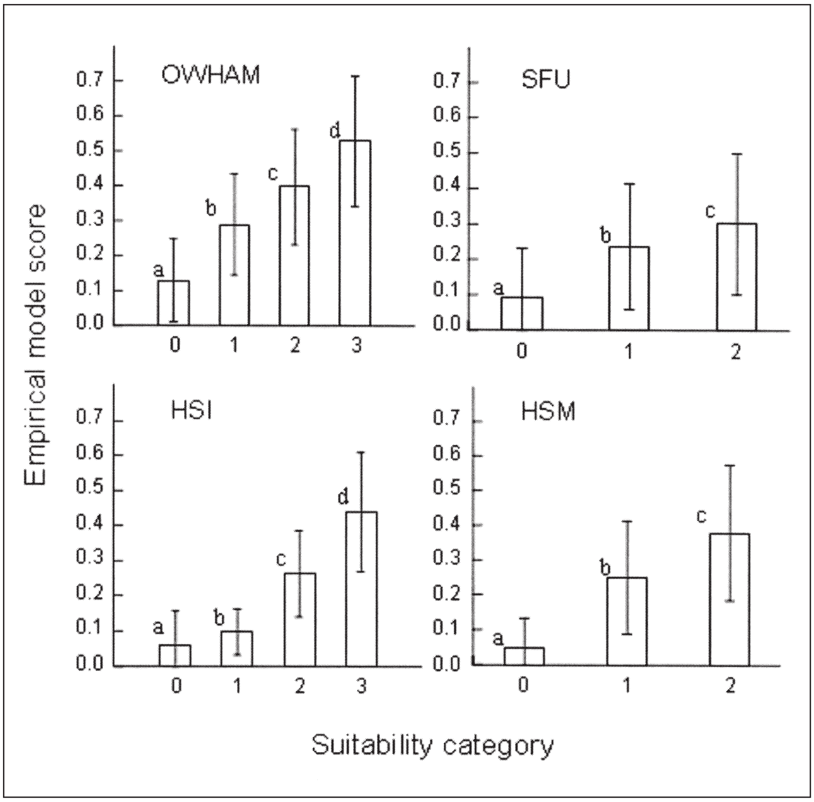

Fig. 2. Comparison of marten (*Martes americana*) habitat suitability scores (mean ± 1 SD), from 565 plots in northeastern Ontario, between an empirical model (Bowman and Robitaille 1997) and four expert-based models: the Ontario Wildlife Habitat Analysis Model (OWHAM); Standard Forest Units (SFU); Allen's (1982) HSI (HSI); and the Boreal East Habitat Suitability Matrix (HSM). Suitability categories that were demonstrated to be different from one another by analyses of variance are labelled with different letters (a–d).

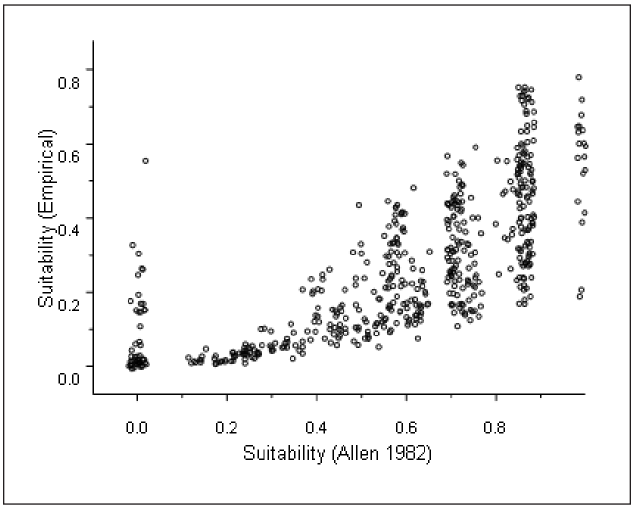

Fig. 3. Scatterplot between an empirical marten (*Martes americana*) habitat model (Bowman and Robitaille 1997) and an expert-based marten habitat suitability index (HSI) model (Allen 1982) for 565 forest plots in northeastern Ontario (r_s = 0.804, P < 0.0001; Spearman rank correlation).

habitat in these expert-based models was largely from literature review (using primary sources such as Hawley and Newby 1957, Koehler and Hornocker 1977, and Soutiere 1979). The empirical model, based on regression relationships between marten tracks and field measurements of stand structure, resulted in similar conclusions by suggesting that marten tracks were positively related to four stand descriptors: canopy closure, downed logs, spruce or balsam fir trees, and tree height (a proxy for age).

Although the expert-based and empirical models reached similar conclusions, they are not interchangeable from the perspective of forest planners in Ontario. For example, the utility of the Allen (1982) HSI model is limited because it includes an input, CWD, which is not available in the province's forest inventories. Coarse woody debris is perceived to be an important component of marten habitat, since it creates subnivean structure for denning, resting, and foraging (Thompson 1988). The OWHAM and HSM models have tried to indirectly integrate CWD through the inclusion of development stage and species composition inputs. Older stands tend to have more CWD, as do stands consisting largely of boreal softwoods (e.g., Sturtevant *et al.* 1997). The empirical model scores suggest that the OWHAM and HSM models do a reasonably good job of capturing components of stand structure that are important to marten, despite these expert-based models including only inputs that can be derived from stand inventories. For all of the expert-based models, empirical model scores were positively related to rank scores, with significant differences between ranks (Fig. 2).

The poorest fitting expert-based model to both the snow tracks and the empirical model was the forest unit suitability rankings. This result is not surprising, since on their own, forest units do not contain information about stand developmental stage. These units are merely categorical descriptions of a stand's community (Holloway *et al.* 2004). Even with this limitation, there was still a consistent trend between use of forest unit types by marten and the suitability ranks of those types assigned by planners.

Our empirical model, based on field research in northeastern Ontario, closely resembled the expert-based HSI model of Allen (1982), which was developed for use in the United States. Essentially, the same four variables were selected during the empirical model building procedure (Bowman and Robitaille 1997) as were selected through a literature survey 15 years earlier by Allen (1982). An area of disagreement between these models was that stands with < 25% canopy closure were assigned 0 habitat suitability in the HSI model, whereas the suitability of these stands in the empirical model would depend on the value of the other model inputs. Thus, there were a number of stands with suitability = 0 in Allen's model but > 0 in our empirical model (Fig. 3).

It is worth noting that the OWHAM included eastern white cedar among the suitable tree species, whereas the HSI did not. Cedar was included as a candidate species in the development of the empirical model, but its inclusion did not improve model fit. Consequently, like the HSI, the empirical model included only spruce and fir species. OWHAM also contained inputs for both stand height and development stage. These characteristics are highly correlated, and having both inputs introduces some redundancy to the model. This was especially true in our field test of OWHAM, since we actually used stand height to infer development stage.

There were some other limitations to our approach to evaluating these habitat models. First, tracks in the snow do not reflect the entire habitat use pattern of marten, because they spend time resting and travelling both below the snow and in trees (Raine 1983, Hargis and McCullough 1984). However, this is an objective way to assess habitat use, and has been widely used by other researchers (e.g., Raphael 1994). Second, there was no consideration of fitness in our approach. We merely related the distribution of snow tracks to forest cover characteristics. Indeed, non-spatial, stand-level habitat models will not adequately reflect marten fitness (e.g., Thompson 2004), since these carnivores range over territories much larger than one forest stand. The composition and configuration of forest landscapes (i.e., multiple stands) may contribute importantly to marten fitness (e.g., Dunning *et al.* 1992). Nonetheless, non-spatial, stand-level habitat models, along with larger scale spatial models, are used in marten habitat management, both in Ontario and abroad, and our objectives were to assess the stand-level models. It is these non-spatial models that form the building blocks of the larger scale, landscape-based marten models.

In summary, we observed that the expert-based, non-spatial models used in Ontario to describe marten habitat were consistent with our stand-level findings of marten habitat use, as measured both by tracks in the snow and by our empirical model. Our results suggested that despite including only inputs that are available in stand inventories, both the OWHAM and HSM models characterized stands that were used by marten. This was likely accomplished because structural attributes, such as CWD, were included in these models indirectly through relationships with stand age and species composition. Our finding supports the use of habitat models that are based only on stand inventory attributes for characterizing forest stand structure that is used by marten.

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