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Research Article

Modelling habitat suitability for deciduous forest focal species – a sensitivity analysis using different satellite land cover data

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Abstract

We explored the usefulness of three satellite land cover data sets available to land managers in south-central Sweden for conservation planning using four deciduous forest focal resident bird species with different habitat requirements. Habitat suitability models using empirical species-specific habitat parameters and a Geographic Information System were applied to evaluate and compare the degree of consistency among three different land cover data sets. The study area encompassed 10,000 km^2 in a landscape mosaic of managed boreal forests and is within the distribution range of all four focal species. Although the three land cover data sets indicated similar total amounts of deciduous forest, the habitat suitability models showed that different land cover data yielded inconsistent results regarding the amount and distribution of suitable habitat within 5×5 km grid cells. Given this sensitivity to the choice of land cover data sets, the habitat suitability models showed positive relationships among the selected focal species for each land cover data set separately. As expected, decreasing amounts of suitable habitat were identified for species with higher specialisation. Thus, because habitat suitability models are an appropriate way to gain insight into the functionality and connectivity of habitat networks, land cover data must be carefully evaluated and if necessary combined with other landscape information for effective conservation planning.

Introduction

The world's natural resources are being utilised intensively, resulting in many environmental issues such as the loss of biodiversity at multiple spatial scales (Young 2000; Gergel and Turner 2002). Intensive management of forests is one example of resource use negatively affecting biodiversity, through a reduction in natural forest components (Hansson 1997; McComb and Lindenmayer 1999; Larsson and Danell 2001; Korpilahti and Kuuluvainen 2002). At the stand scale, studies in northern European forest history gradients show dead wood amounts have declined by more than 95% (Siitonen 2001; Angelstam et al. 2004a) and the proportion of deciduous tree species has declined by up to 90% (Mikusiński and Angelstam 1999; Shorohova and Tetioukhin 2004). At the landscape scale the amount of old forests, which provide suitable habitats for both specialised and area-demanding species, have diminished (Esseen et al. 1997). As a consequence species specialising on natural forest structures have declined (Mikusiński and Angelstam 1998) and important abiotic and biotic processes have been altered (Angelstam et al. 2004c).

In response to these developments negatively affecting biodiversity a range of international and national policies related to the maintenance of the compositional, structural and functional elements of biodiversity have been initiated (Liaison Unit in Lisbon 1998; Larsson 2001). Forest and woodland policies in Europe make explicit reference to the concept of 'naturalness' (Peterken 1996; Rametsteiner and Mayer 2004). Over the last decade throughout Europe more nature friendly management approaches have been proposed and to some extent also applied (Angelstam and Pettersson 1997; Raivio et al. 2001).

This development may help to secure viable populations, but only if a sufficient amounts of habitat with functional spatial and temporal connectivity of suitable habitat stands can be sustained (Dytham 1995; Opdam et al. 1995; Angelstam and Andersson 2001). However within this nature friendly development there are many conflicting actions when implementing strategic environmental goals (Store and Jokimäki 2003). This can be detrimental to the new efforts of conservation placed on forest management: e.g., non-industrial private forest land holders restrict the management of the spatial arrangement and connectivity of forest stands.

In areas of the boreal forest where the history of forest and land management is long, coniferous forest types have been promoted at the expense of deciduous stands (Jansson and Angelstam 1999; Mikusiński et al. 2003). Sweden's managed forests provide an excellent example. Today's Swedish forest composition is estimated to comprise on average 17% (timber volume) of deciduous trees, with 11% consisting of Birch (*Betula* spp.) (Anonymous 2002a). Moreover the deciduous forest component is dominated by young trees which are harvested long before their biological maturity as host for specialised species. This provides Sweden with a homogeneous forest structure dominated by two conifer species [Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*)] and small scattered deciduous stands, usually of cultural origin (Esseen et al. 1997; Mikusiński and Angelstam 1999, Mikusiński et al. 2003). In contrast, unmanaged forests at the same latitude in Eastern Europe where land use history is short, the proportion of deciduous trees in young stands after stand-replacing disturbance is 70% and 50% of timber volume in mature and old growth stands, respectively (Shorohova and Tetioukhin 2004). The present challenge is to revise the traditional forest management methods and to establish functional conservation area networks (Angelstam and Andersson 2001; Angelstam et al. 2004). Thus, the implementation of biodiversity policies requires tools for cost-efficient decisions and spatially explicit zoning regarding the protection, management and restoration of deciduous forest networks.

Habitat Suitability Index (HSI) modelling (Scott et al. 2002) for focal species (e.g., Lambeck 1997, 1999) is one tool that can be utilised to guide forest planning (Angelstam et al. 2003a, b, 2004b; Gibson et al. 2004). To combine empirical data regarding species' requirements with land cover data, spatially explicit computer models can be used to produce habitat suitability maps (Store and Jokimäki 2003). Usually Geographic Information Systems (GIS) play key roles in environmental planning (e.g., Gurnell et al. 2002; Gibson et al. 2004) and can be used to spatially predict species distribution and their habitat from land cover data (Guisan and Zimmermann 2000). Specifically focusing on the scale of landscapes and regions, creation of land cover data using remote sensing is a necessary prerequisite (Young and Sánchez-Azofeifa 2004). This is feasible as satellite remote sensing based land cover data is being applied in forest management, aiding in the planning and monitoring of timber exploitation (Reese et al. 2003) and environmental management (Holmgren and Thuresson 1998).

This paper compares different spatially explicit land cover data sets by using the quantitative requirements of focal species through spatially explicit Habitat Suitability Index models. We attempt to evaluate the effects of varying data quality on practical conservation planning using spatially explicit HSI modelling. In particular, we measure functional connectivity of deciduous forests using four resident focal species with increasing demands on the degree of naturalness of the different stages in the deciduous succession (Angelstam et al. 2004b). The selected species were Hazel Grouse (*Bonasa bonasia*), Long-tailed Tit (*Aegithalos caudatus*), Lesser Spotted Woodpecker (*Dendrocopos minor*) and the White-backed Woodpecker (*Dendrocopos leucotos*).

Study area

The area selected for the analyses was a matrix of managed forests surrounding a series of protected conservation areas and one national park (Färnebofjärden) in south-central Sweden (60° N, 16° E). The study area encompasses a 100 by 100 km square (map sheets 12–13 and G–H in the Swedish national grid with the south–western corner located at 6650 km N and 1500 km E, and the outer boundaries being near the cities of Uppsala, Gävle, Falun and Fagersta (Figure 1)). The study area is located on the boundary of the hemiboreal and southern boreal forest ecoregions (Nordic Council of Ministers 1983) and is known for being one of the last remaining southern boreal forests in Sweden still providing an authentic species pool with respect to birds, lichens, wood-living fungi and insects (Holmstedt 1996; Anonymous 1999). The area has a mixture of deciduous and coniferous forest types, which are needed to host populations of the selected focal species, assuming the quality of forest stands and resulting habitat networks are sufficient. The size of the study area (i.e. 10,000 km^2) is in the order of magnitude required to host a viable local population of the White-backed Woodpecker, the most area-demanding focal species selected (Angelstam et al. 2004b).

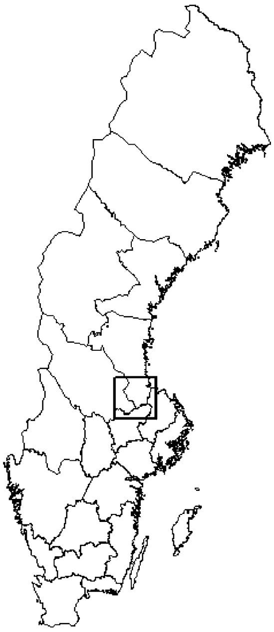

Figure 1. The study area in southern-central Sweden (60° N, 16° E), covering 10,000 km^2.

Methods

Habitat suitability models require three components (Store and Jokimäki 2003; Angelstam et al. 2004b): (1) knowledge about the habitat variables and parameter values describing the requirements of a species at the level of individuals and populations, (2) landscape data with a thematic resolution that represents the relevant habitat variables, and (3) GIS to conduct the spatial analyses. The resulting habitat models are sensitive to errors in all three components.

Focal bird species – habitat requirements and ecology

The focal species approach (e.g., Lambeck 1997, 1999) is based on the idea that conservation of specialised and area-demanding species can contribute to the protection of many naturally co-occurring species (Lambeck 1997; Hess and King 2002; Angelstam et al. 2003a; Roberge and Angelstam 2004). It is similar to the umbrella species approach (e.g., Fleishman et al. 2000).

The selected focal species are resident deciduous forest specialists dependent on higher proportions of deciduous forest (Hazel Grouse and Long-tailed Tit), or both higher proportions of deciduous forest and large amounts of dead wood of different dimensions and stages of decay (Lesser Spotted Woodpecker and White-backed Woodpecker) (e.g., Wiktander et al. 1992; Angelstam and Mikusiński 1994; Martikainen et al. 1998; Olsson 1998; Carlson 2000; Jansson and Andrén 2003; Angelstam et al. 2004b). With this selection of focal species the winter conditions are of critical importance when selecting habitat variables (Store and Jokimäki 2003). The study area is well within the distribution range of all four focal species (SOF 1990).

Hazel grouse
A herbivore dependent on dense rich mixed forests containing coniferous trees (mainly Norway spruce) for shelter as well as deciduous trees for food supply (Swenson 1995; Åberg et al. 2003; Jansson et al. 2004). Complete snow cover forces this species to forage on catkins and buds of deciduous tree species (Swenson 1995). Hazel Grouse are found in multi-layered stands ranging from young to old growth (> 20 years) in natural and managed forests. They avoid open areas and are particularly vulnerable to fragmentation of forests (Åberg et al. 1996). The habitat requirements can be defined as forest stands with a minimum size of 15 ha and a critical threshold minimum of 20% suitable habitat in a 1 km^2 area (Jansson et al. 2004). Forest stand age alone has little impact on the species, however at a landscape scale, loss and isolation of habitat may dramatically reduce the occurrence of Hazel Grouse (Jansson et al. 2004).

Long-tailed tit
As an insectivore, because deciduous trees contain a higher abundance of insects (Bleckert 1991), this species requires middle aged to old deciduous forest stands of 5–15 ha (Gaston 1973; Jansson and Angelstam 1999). The critical threshold level for minimum suitable habitat is estimated at 20% in 1 km^2 (Jansson and Angelstam 1999). Flocks form throughout the year, except for the breeding season in spring to early summer (Nakamura 1969; Gaston 1973; Snow and Perrin 1998). According to Jansson and Angelstam (1999) a forest rotation time of three to four decades should be suitable for the species, as long as there is adequate management of deciduous stands.

Lesser spotted woodpecker
Europe's smallest woodpecker forages for surface living arthropods on the foliage of deciduous trees during the summer, whilst in winter they focus on food resources found in dead wood (Cramp 1977–1994; Olsson 1998). This species has a preference for open woodland forests with deciduous trees > 60 years old and high proportions of dead wood (Cramp 1977–1994; Wiktander et al. 2001). According to Wiktander et al. (2001) this species has a minimum habitat patch size requirement of 1 ha per pair with a minimum critical threshold of 20% suitable forest in 2 km^2 (Wiktander et al. 2001).

White-backed woodpecker
One of the most endangered species in Sweden. At present there are approximately 20 active territories known, of which two are located inside the Färnebofjärden study area, around the lower river Dalälven (K. Stighäll, Swedish Conservation Society, personal communication). The White-backed Woodpecker is a deciduous forest specialist that relies heavily on food resources (insects) located mainly in dying, dead and decaying deciduous trees (Aulén 1988; Carlson 2000). Recent studies have indicated that an area of 50–100 ha in deciduous stands with an age of 50–90 years is required for one pair, while the suitable habitat minimum critical threshold is 15% in 20 km^2 (Aulén 1988; Carlson 2000). High amount of coarse deadwood is an important requirement of this species and according to Hogstad and Stenberg (1994) and Angelstam et al. (2002); stands on average should contain a minimum of approximately 15% of timber volume ($\sim$20 m^3 ha^{-1}) in the form of dead wood.

Land cover data

For the selected study area three potentially useful spatially explicit land cover databases are available to forest managers and conservation planners in Sweden: (1) the Sverigeklassning, (2) wRESEx and (3) the kNN (for a detailed technical description see Table 1). All three land cover data sets were derived with use of remote sensing and attempt to describe the spatial distribution of forest stands with spatial resolution of 25 m which is suitable to identify forest stands (Heywood et al. 2002).

Habitat suitability index models and different land cover data

As each land cover data set was created using different methods (Table 1), it was important to critically evaluate any differences among the land cover data describing the deciduous forest. Firstly, using each of the land cover data sets we compared the forest area amounts of the whole study area. Secondly, we calculated the deciduous amount of

Table 1. Characteristics of the three different land cover databases used in the analyses.

Land cover data	Satellite sensor	Method	Verification	Accuracy for deciduous component	Thematic resolution	Produced by whom and when	Reference
Sverige Klassning	Landsat 5 TM[a] and SPOT XS[b]	Pixelbased, supervised (Maximum Likelihood) multi-spectral classification,	Infrared aerial photos and ground verification for deciduous component	Producer's accuracy 63% User's accuracy 79%	3 forest types	Swedish Space Corporation; 1990–91	Anonymous 1992; Anonymous 2002b; Mikusiński et al. 2003
wRESEx	Landsat 5 TM1	Nonparametric multispectral and multitemporal classification, based on the nearest neighbour method, wavelet transforms and information theory	Field data and digital topographic and forest maps	Insufficient to define low proportions of deciduous trees (0–20% basal area)	33 forest types divided into tree species and age	Swedish University of Agricultural Sciences Umeå; 2002	Ranneby and Yu 2003
kNN	Landsat 7 ETM[c]	*K*-Nearest Neighbour algorithm	Field data from a separate set of GPS-located plots from National Forest Inventory (NFI)	Data concerning deciduous component is generally not very accurate – details not specified	Multiple ages and classes of forest can be selected	Swedish University of Agricultural Sciences Umeå; 2003	Franco-Lopez et al. 2001; Holmström 2001; Reese et al. 2003

[a] Landsat 5 Thematic Mapper (6 spectral bands between blue and SWIR with 30 m spatial resolution plus a thermal band with 120 m resolution).

[b] System Pour l'Observation de la Terra (3 spectral bands at 0.50–0.59, 0.61–0.68, 0.79–0.89 μm with 20 m resolution).

[c] Landsat 7 Enhanced Thematic Mapper (multispectral bands at 0.45–0.52, 0.52–0.60, 0.63–0.69, 0.76–0.90, 1.55–1.75, 2.08–2.35 μm with 30 m resolution + plus thermal band 10.4–12.5 μm + panchromatic at 15 m resolution).

forest contained within the forest area. We used a minimum proportional value of 50% to define the 25×25 m deciduous forest pixels.

Habitat suitability index models were made for the four focal bird species using GIS (Arc view 3.2a, ERSI 2000) as described in Angelstam et al. (2003a). Spatially explicit data including habitat variables and parameter values (Angelstam et al. 2004b as summarised above) were used to produce habitat suitability models. These incorporated several forest cover classes to model the habitat of a particular focal species (Table 2).

Specifically, the creation of habitat suitability index models using the three different remote sensing data sets involved three main steps. Firstly, we selected suitable forest vegetation types at the pixel level, for example a certain age class of deciduous forest required by the focal species. Secondly, we identified stands, which provide sufficient area amounts of the relevant forest vegetation type to meet the requirements of the focal species. Finally, we identified forest tracts with concentrations of suitable habitat where the species-specific critical thresholds are satisfied. Technically this is produced by determining a neighbourhood window size based on the range of local movement for the selected focal species, giving a key indication of the species-specific connectivity of stands at the landscape scale (e.g., Fahrig 2002; Villard and Taylor 1994). The habitat suitability modelling procedure thus identifies suitable habitat in three steps, commencing with the suitable forest areas, reducing this amount to suitable forest stands and further reducing this to suitable habitat tracts for the species.

To compare the proportion of the local landscape satisfying the requirements of a particular species using the three different data sets within 5×5 km grid cells (n = 400 cells), a Pearson correlation analysis of the amount of suitable habitat among the four focal species and the three data sets was made. This grid cell size was used because: (1) it represents an area in the order of magnitude that may encompass a local population of each of the four focal species selected, and (2) it is a common basic geographical unit in the national grid for environmental monitoring in Sweden, for example the national Swedish bird atlas used this grid cell size (Svensson et al. 1999).

Table 2. Variables and parameter values of focal bird species used for creation of the habitat suitability models. Note that the selection of forest vegetation type varies due to the selection available in the land cover data; the kNN data provided the closest vegetation required by the focal species. Resource density refers to the suitability of the stand for the species (e.g., optimal stands have the resource density set at 1 while suboptimal at 0.5) (Dec. – Deciduous, y – Years).

Forest type	Focal species	Selection of forest vegetation types			Resource density	Patch requirements	Minimum threshold and neighbourhood window size
		Sverige Klassning	wRESEx	kNN			
Mixed Forest	Hazel Grouse	71-Dense coniferous	Spruce > 70%, 40–70 y,	Spruce > 60%, > 40 y	1	15 ha	20% (1 km^2)
		73-Dec.	Dec. > 20%, > 40 y	Dec. > 20%, > 40 y	1		
					1		
Deciduous Forest	Long-tailed Tit	73-Dec.	Dec. > 20%, > 40 y	Dec. > 25%, > 40 y	1	7 ha	20% (1 km^2)
	Lesser Spotted Woodpecker	73-Dec.	Dec. > 50%, 70–110 y	Dec. > 35%, > 60 y	1	1 ha	20% (2 km^2)
			Dec. > 20%, > 110 y		1		
			Dec. 20–50%, 70–110 y		0.5		
	White-backed Woodpecker	73-Dec.	Dec. > 50%, > 40 y	Dec. > 35%, > 50 y	1	1 ha	15% (20 km^2)
			Dec. > 50%, > 110 y		0.5		

Table 3. The total amount of forest and forests dominated by deciduous trees in the whole study area (10,000 km^2) as revealed by the three different sets of land cover data.

Data set	Total forest area		Total deciduous forest area	
	km^2	Area %	km^2	Area %
Sverigeklassning	5525	55.2	869	15.7
wRESEx	6037	60.3	832	13.8
kNN	6418	64.1	791	12.3

Results

Amount of habitat in the landscape

The initial analyses of the three land cover data sets indicated similar amounts of total forest cover within the study area, with the largest difference between the Sverigeklassning and the kNN data sets, corresponding to a 9% share of the study area (Table 3). The deciduous forest cover differed by a 3% share with the Sverigeklassning indicating the largest area amount of deciduous dominating forest (Table 3).

Habitat suitability modelling at the local scale

The results at the scale of 5×5 km grid cells obtained from habitat suitability index modelling for the focal species showed significant variations in the amount of suitable habitat indicated by the three types of land cover data. The total area of suitable tracts for the species differed considerably among models based on the different land cover data sets. An Analysis of Variance (ANOVA) showed that the differences were significant (Hazel Grouse: $F = 319.8$; DF $= 2$; $p < 0.001$; Long-tailed Tit $F = 168.8$; DF $= 2$; $p < 0.001$; Lesser Spotted Woodpecker $F = 421.4$; DF $= 2$; $p < 0.001$; White-backed Woodpecker $F = 265.5$; DF $= 2$; $p < 0.001$ (Figure 2)). For all species the relative level of functionality of the habitat patch network measured by the amount of suitable forest stands and suitable forest tracts was lower than the total amount of habitat (Figure 3a–d). The Sverigeklassning data identified in most cases the greatest amount of suitable habitat in the data sets followed by the wRESEx and kNN data.

The area of suitable habitat expressed at the scale of 5×5 km grid cells showed a relatively low agreement among different land cover data for a given species (Pearson *r* was on average 0.25, Table 4). In contrast we found that correlation coefficients among species within the same type of land cover data showed stronger relationships (Pearson *r* was on average 0.68, Table 4). This indicates a clear relationship amongst the species, but poor relationships among the three land cover data sets.

Discussion

Evaluation of land cover data sets

At the scale of the whole study area the three land cover data sets portrayed similar amounts of total forest land cover as well as the amount of deciduous forest. However, when describing the

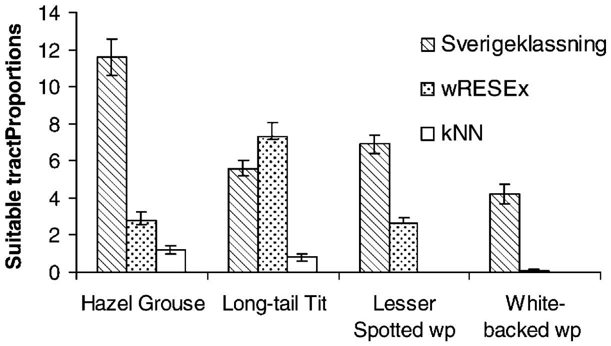

Figure 2. Estimated mean area proportion and 95% confidence intervals of suitable forest tracts within the study area (10,000 km^2) based on three types of land cover data. Note that according to kNN data there are no suitable habitat tracts for the studied woodpecker species.

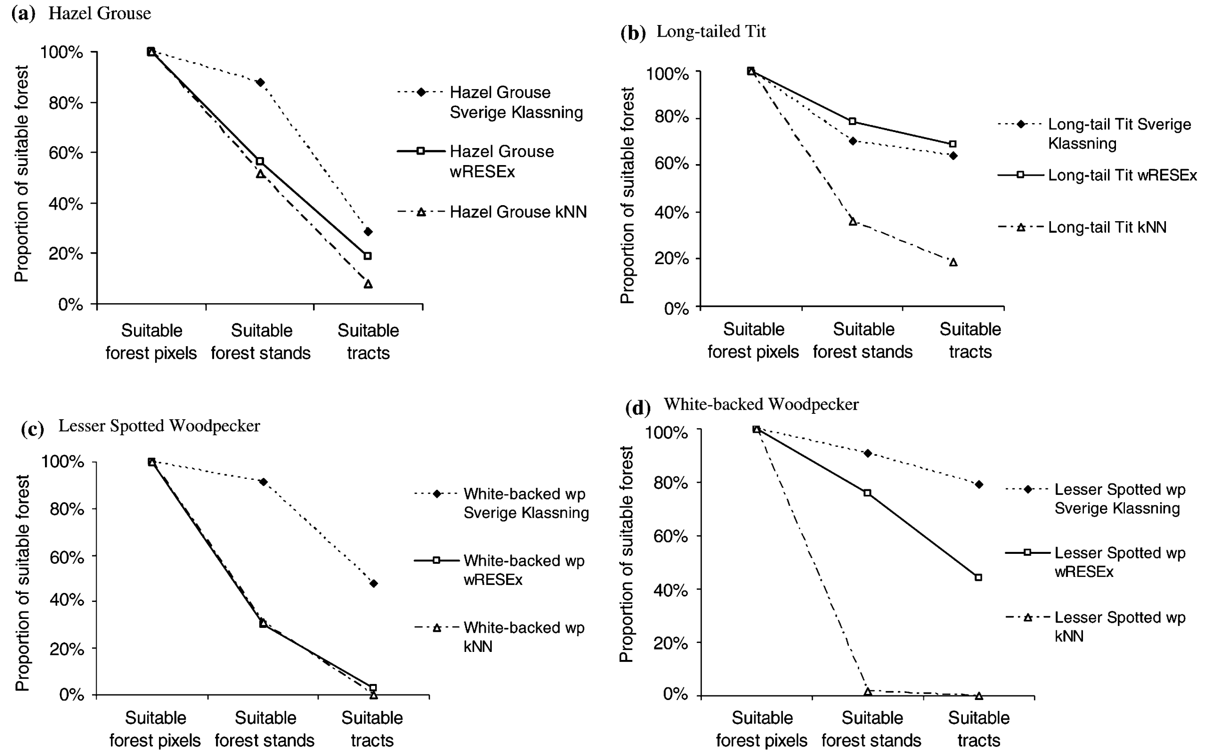

Figure 3. (a–d) Proportions of suitable forest pixels, suitable forest stands and suitable forest tracts indicated by the different habitat suitability index models for each of the four focal species using the three data sets.

deciduous forest cover using habitat suitability modelling for four focal species at the local scale (5×5 km grid cells); the results indicated large variations in the amount and spatial distribution of the respective deciduous forest networks.

The correlation analysis showed low spatial concordance among the three data sets for the habitat models within a given species. In contrast to the GIS-models' sensitivity to the choice of land cover data, we found a strong line of order related to the degree of specialisation as indicated by the habitat selection of the different focal species. For example, suitable habitat was consistently more available for the Hazel Grouse and the Long-tailed Tit in all models. However, when considering the more demanding specialist species such as the Lesser Spotted Woodpecker and White-backed Woodpecker, the models based on different land cover data were clearly inconsistent. Interestingly enough, however, nearly all models identified the Båtfors Nature Reserve and its surrounding area. According to the national Swedish bird atlas data (Svensson et al. 1999) this area is a prominent hotspot for species specialising on different types of deciduous forest.

Several factors may have influenced the outcome of the habitat suitability models using similar focal species parameters with different land cover data. The resource definitions, e.g., deciduous forest, vary in each database. Firstly, the data describing the deciduous component has various thematic resolutions. Both the wRESEx and kNN data integrate satellite image information with field observations using a network of points and objects in order to estimate forest variables. In contrast, a simple supervised classification of satellite images with training areas derived from aerial photos was used in the Sverigeklassning. As a result, the Sverigeklassning provides only one deciduous class describing the forest with canopy cover dominated by deciduous trees. The wRESEx classification has several age and volume combinations that describe the composition of forests. Finally, the kNN estimations allowed for classification based on age and volume that can be

Table 4. Pearson correlation analysis of the amount of suitable habitat among the four focal species and the three data sets based on 400 cells of 5×5 km (HG = Hazel Grouse, LT = Long-tailed Tit, LW = Lesser Spotted Woodpecker, WB = White-backed Woodpecker; SK = Sverigeklassning data set, wR = wRESEx data set, KNN = kNN data set).

	HG–Sk	HG–wR	HG–kNN	LTT–Sk	LTT–wR	LTT–kNN	LSWP–Sk	LSWP–wR	LSWP–kNN	WBWP–Sk	WBWP–wR	WBWP–kNN
HG–Sk	1.00											
HG–wR	0.20*	1.00										
HG–kNN	0.45*	0.29*	1.00									
LTT–Sk	0.92*	0.13**	0.44*	1.00								
LTT–wR	0.28*	0.80*	0.31*	0.22*	1.00							
LTT–kNN	0.35*	0.16*	0.50*	0.39*	0.20*	1.00						
LSWP–Sk	0.90*	0.12*	0.42*	0.98*	0.21*	0.38*	1.00					
LSWP–wR	0.22*	0.64*	0.29*	0.14*	0.84*	0.21*	0.13**	1.00				
LSWP–kNN	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	1.00			
WBWP–Sk	0.79*	0.08	0.43*	0.85*	0.18*	0.40*	0.82*	0.14*	0.00a	1.00		
WBWP–wR	0.21*	0.12*	0.13**	0.21*	0.19*	0.15*	0.18*	0.29*	0.00a	0.22*	1.00	
WBWP–kNN	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	1.00

N = 400; * Correlation is significant at 0.05; ** Correlation is significant at 0.01.

a. 0.00 correlation results using the WB_KNN and LW_KNN is due to results of no suitable habitat indicated for these species using the kNN data.

adjusted more precisely to the requirements of the modelled species.

Since forest age is not indicated in the Sverigeklassning data, deciduous pixels may often represent younger phases of succession not suitable for most of the studied species. Deciduous stands that are outside of forest land are not indicated in the kNN and wRESEx databases. Using the Sverigeklassning, Mikusiński et al. (2003) showed that a substantial number of deciduous stands occur on officially non-forested land such as wooded meadows or succession on former agricultural land. In addition, the Sverigeklassning represents the distribution of deciduous forest approximately 15 years ago, while the two other data sets have been derived from satellite images with in the last 5 years.

Several factors thus indicate the possibility that higher amounts of suitable habitat will be identified by the Sverigeklassning data compared to the other land cover data sets due to the insufficient resource definition and better landscape coverage. When considering the wRESEx and kNN data, we expected there to be a high resemblance in spatial distribution and the amount of suitable habitat. This high resemblance is expected due to the similarities in resource definition, data age and methods of classification by the kNN and wRESEx data.

These differences among the three different land cover data sets were not unexpected given the characteristics of the three databases (Table 3). Recently, also Lawler et al. (2004) reported the influence of thematic resolution on the outcome of predictive habitat models by testing two different land cover classifications. However, most users are unaware of the technical details linked to the production of the commonly available land cover data sets that can be used for conservation planning. To ensure high quality conservation planning, we strongly suggest that different thematic themes should be cross-validated against each other and against field measurements. These validations need to be performed at a number of spatial scales. The accuracy of forest classifications with high thematic resolution usually declines with spatial resolution. For instance, producers of the kNN estimates are aware of very low accuracy at the pixel level but higher accuracy at the stand level (Reese et al. 2003).

Improving landscape data with ancillary information

Remote sensing based land cover data is often proposed as an easy way to gain insight into the forest cover of landscapes and is often useful at continental or national levels, unless a lower thematic resolution is required (Meyer and Werth 1990). However, Holmgren and Thuresson (1998) showed the thematic resolution of remote sensing data available for general application in planning agencies and forest companies may not be sufficient for forestry applications. Our study thus supports the notion of being cautious when using land cover data also in conservation planning. Recent improvements obtained in the field of remotely sensed extraction of forest parameters may provide much better data for development of habitat models (Thies et al. 2004). More precise forest stands parameters on the local scale can be already obtained from high resolution satellite data (Ikonos, Quickbird) or airborne, high resolution laser data that allows the identification of species of individual trees (Holmgren and Persson 2004). However, these promising data is available only for limited areas while conservation planning often requires landscape data covering major regions or watersheds. Even if future databases describing the amount, distribution and quality of forest stands are improved, there will still be some habitat characteristics that are difficult to derive from remotely acquired information and which can be made available at low cost to managers.

Implementation of habitat suitability models using GIS provides greater insight in planning conservation areas as the inherent complexity of the natural environment can be best explored using these spatial analysis tools (Young and Sanchez-Azofeifa 2004; Burnett and Blaschke 2003). However, there are many factors limiting the implementation and use of habitat suitability models. For example, the models identify suitable areas for a few individuals or a local population, but not a whole viable population. Also many important forest variables such as dead wood and foliage diversity are not indicated by remote sensing based land cover data (Woodhouse et al. 2000; Store and Jokimäki 2003).

It is therefore often necessary to complement remote sensing data with information layers based on field surveys and other spatially explicit data. The use of Digital Elevation Models for obtaining relevant information on topography and hydrology that affects forest structure and composition have already been demonstrated useful in habitat modelling (Mackey et al. 1999). Landscape history as depicted by historic maps may also be very helpful in improving satellite-based land information (Angelstam et al. 2003c). An interesting method providing information on dead wood that may be used for further GIS evaluation, is the recently researched relationship analysis between transport infrastructure and the amount of dead wood (Angelstam et al. 2004a). This research has demonstrated the negative role that infrastructure plays on dead wood and biodiversity, further illustrating the need of ancillary data to obtain relevant habitat suitability index modelling maps for conservation planning (Angelstam et al. 2004a).

Habitat models and conservation planning

To maintain viable populations of species it is important to consider the requirements of focal species, and to identify priority conservation areas across entire landscapes (Woodhouse et al. 2000). If the identified areas are sufficiently connected as a functional network there is then a need to protect or manage the total area that will accommodate a viable population (Gergel and Turner 2002; Margules and Pressey 2000). Habitat Suitability Index models are frequently used as planning tools for highlighting potential conservation areas (e.g., Scott et al. 2002; Suchant and Braunisch 2004). However, before employing such models in the decision-making process their predictions need to be evaluated by comparing models with field data.

Conservation and restoration of habitat networks at the landscape scale are complex activities where a strategic balance between knowledge and action is required. For the protection of areas identified as having high conservation value, there is a need to integrate efforts at the levels of government, private and non-private actors across whole landscapes. Obtaining a functional habitat network requires involvement of different policies, stakeholders, and actors, something that may bring forth a variety of conflicts and challenges depending on different scales and interest levels. Only once these problems have been solved, can conservation policies be considered as implemented (Margules and Pressey 2000). We argue that habitat suitability modelling is a tool that can help to resolve a wide range of barriers when managing landscapes for the maintenance of biodiversity.

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