COMBINING RESOURCE SELECTION FUNCTIONS AND DISTANCE SAMPLING: AN EXAMPLE WITH WILLOW PTARMIGAN

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Abstract: Today, with a continuously changing landscape, one of the main issues for wildlife management is to describe the association between wildlife and their habitat. Such an association may be used to interpret the effects of habitat disturbance. The development of new technology such as satellite images and extensive computer software has simplified the methodology to get this kind of information. Our approach here has primarily been tentative, combining the data from satellite information with line transects (i.e. distance sampling) of willow ptarmigan (*Lagopus lagopus*) in a resource selection function (RSF). Habitat parameters described from satellite data are a cost-efficient way of sampling large areas. Hence, the combination of satellites with RSF may give valuable insight on the distribution of game over large areas. We describe here how we chose parameters from the large amount of data available in satellite images and how we interpreted this information. Further, we modeled a RSF by combining the data of actually used units with available units chosen at random. Availability data was chosen according to the detection function created by the distance sampling analyses. We have chosen two different spatial scales of analyses that suggest that we mainly observe willow ptarmigan in areas with rich bogs. However, within these areas willow ptarmigan prefer to be located close to thickets. This result has been implemented in a map showing the expected distribution of willow ptarmigan in the study area.

Key words: distance sampling, resource selection, satellite images, willow ptarmigan, *Lagopus lagopus*, Norway.

INTRODUCTION

Human activities are to an increasing extent changing the landscape and habitats for wildlife (Forman and Godron 1986, Meffe and Carroll 1994) often with detrimental or unknown consequences for those inhabiting the areas, as their resource selection is unknown. Hence, a crucial aim for wildlife management today is to identify factors that explain the presence of animals. One approach to this problem is to describe the resource selection function (RSF) for the species in question (Manly et al. 2002). To increase the use of RSF in wildlife management there is a need for methods that can sample the parameters needed for modeling the RSF in a cost-efficient way over large areas. The development of aerial sensors, especially in satellites, has improved the accessibility of detailed habitat data.

There are several ways to sample observational data on the presence of a species to be used as a response in the modeling of the RSF (Byron et al. 2002). Distance sampling, based on transect lines or points (Buckland et al. 1993, 2001), has been frequently used in wildlife management to estimate the abundance of species (Thompson et al. 1998, Schwarz and Seber 1999). However, to implement data on the utilization of habitat in the RSF there is a need also to have point estimates of the presence of wildlife. So far, distance sampling has seldom been applied to estimate the RSF (but see Hedley et al. 2000, Borchers and Buckland 2002). Recently Manly (2002) has elaborated a theory combining data from line transects with habitat data.

Manly's (2002) approach is to model the search pattern of observations fromline transects, where the detection probability of an observation decline as a function to the distance from the line. The available units are selected randomly within a study area, as usual. This concept requires that the lines are sampled representatively for the study area.

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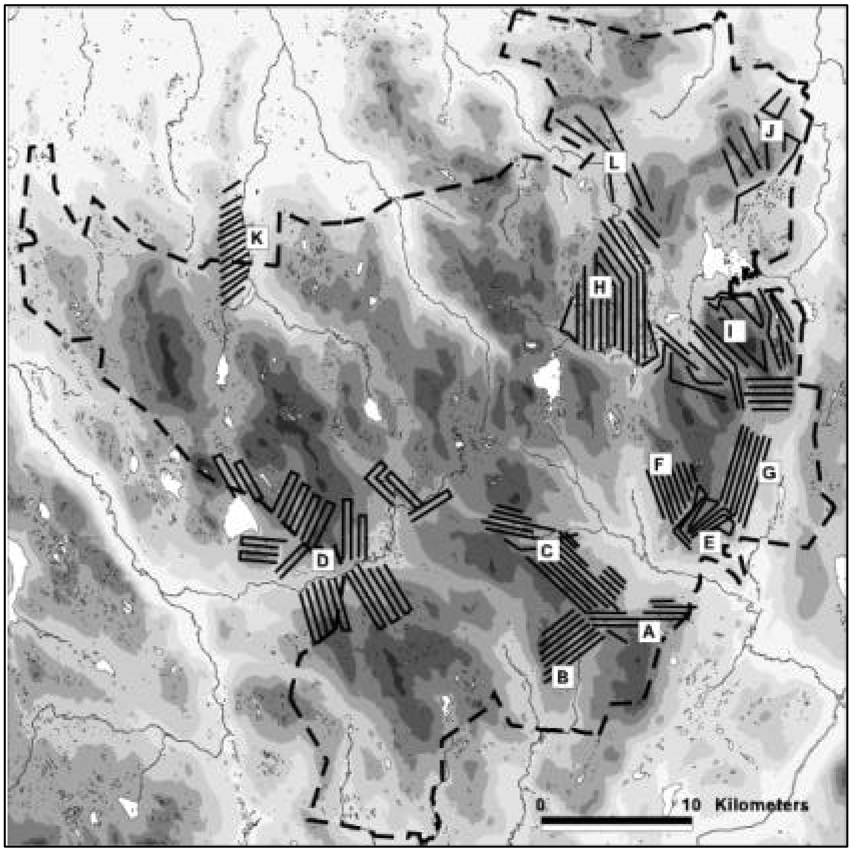

Figure 1. The distribution of lines and hunting areas within the Forollhogna National Park and adjacent areas superimposed on a terrain model. The letter-marks refer to information on Table 1.

We describe here another method where we combine information of used units from a line transect sample with available units sampled according to the detection function calculated with the DISTANCE program. In the present study we have a situation where lines are put out randomly within hunting areas. These lines are censused every year by local hunters. Sample size of used units, will therefore increase every year, but the effort are not the same among years. Due to different causes (weather, illness, shortage of counters etc.) some lines will drop out, so not exactly the same set of lines will be sampled each year.

In our approach the available set of data is randomly selected according to the probability of the detection function for each area (see Figure 1) and year. This makes the approach flexible in relation to the sampling scheme of lines (or points). Here we have studied to what degree habitat parameters measured from the IRS-satellite can explain habitat use of willow ptarmigan (*Lagopus lagopus*). This is our first tentative approach to combine the extensive information existing in satellite images with computer intensive methods of analyses. Below we will elaborate on distance sampling, the interpretation of information from satellite images, as well as the modeling of the RSF.

STUDY AREA

The study area is mostly within the Forollhogna National Park, covering some 2000 km² in Sør-Trøndelag and Hedmark Counties, Norway (62° 15' - 63° 00' N, 10° 15' - 11° 15' E) (Figure 1). Mountain birch (*Betula pubescens*) forest is found in all censused areas. However, most of the study area is found in the low alpine zone, characterized by vegetation dominated by dwarf birch (*B. nana*), heather (*Vaccinium* spp.) and willows (*Salix* spp.). The climate is relatively continental, 200-220 days with precipitation amounting to 500-1000 mm annually. The bedrock consists of precambrian and cambro-silurian rock, partly converted and covered by glacifluvial material (Moen 1998). The total area is considered prime willow ptarmigan habitat. Spring density varies both among years and among different parts of the total study area. During the years of data collection for this paper, August numbers have varied from 13 to 79 willow ptarmigan/km².

METHODS

Observational Data

Counts of willow ptarmigan using line transect methodology have been done in Forollhogna since 1996 (Table 1). Lines are positioned systematically within a set of randomly chosen hunting areas (Figure 1). In seven hunting areas, counts have been done regularly since 1996. In 2002 counts were done in four additional areas. Each line were sampled by two persons and one free running pointing dog, a common method used for counting Galliforme game birds (Myrberget 1976). We have earlier done a test to see if the critical assumptions (Buckland et al. 2001) of using distance sampling are achieved when using a free running pointing dog (Pedersen et al. 1999). The study showed that both the assumption of observing all objects on the line and at their initial location, without any directional movement in response to the observers, is fulfilled.

The perpendicular distance was either measured by a measuring tape or with a laser ranging system. The counters either marked the spot where they observed the birds on a detailed map, or by recording it on a GPS-receiver. Abundance of willow ptarmigan was estimated using the DISTANCE program (Thomas et al. 1998). If the detection functions were not statistically different among areas or years the data were pooled before estimating the detection probability.

Selection of Available Units

Both for evaluating the habitat definitions derived from satellite data and to model the RSFs (see below) we selected availability according to the detection probability function of each area each year. Hence, we drew a coordinate (A_i) at random along each line, with the maximum distance from the line given by the cut point from the detection probability function. For each coordinate chosen we estimated the probability that it should be sampled according to the detection probability function of that line. We then selected a probability p between 0 and 1 at random, and accepted the chosen coordinate (A_i) as an availability unit if the probability estimated by the detection function was higher than p (Figure 2). Hence, the available units were selected with the same probability distribution as the distance distribution of the utilized units observed.

The number of availability data for each transect line was chosen on a yearly basis according to the effort (i.e. the length of the line that had been surveyed). A total of 8 329 points out of 20 000 where accepted as availability units according to the distance function (Table 1). We do not have any knowledge of the probability that a unit in use is sampled. Hence, we cannot correct for variations in the probabilities of sampling used and available units (see Manly 2002).

Use of Buffer Areas

Each pixel in the satellite data gives information of only one type of habitat. Hence, at the pixel level all habitat classes will consist of only presence/absence data with a large surplus of zeros. Furthermore, it is doubtful that the willow ptarmigan responds to such a small area. Here we have therefore chosen to derive habitat information from circular buffers with 50 m and 500 m radius around the used and available points, much in the same way as Erickson et. al (1998) did in their moose study. The choice of radius was done arbitrarily, but in a way also to have extreme values. Furthermore, we cannot decrease the size of the radius too much as this would give little useful distributions of the habitat variables (i.e. a large number of zeros). We believe that with our choice of radius we may be able to evaluate what general type of habitat the willow ptarmigan selects (i.e. 500 m radius), and within this type of habitat what small-scale selection it has (i.e. 50 m radius).

Habitat Data

The vegetation map was made from an unsupervised classification of the IRS satellite data from August 1999, using a classification system describing vegetation communities in Norway (Fremstad 1997). Reference data (ground truth) for the classification were based on field visits and visual interpretation of aerial photos. The photos were taken with a small-format digital camera which had a four-band sensor (RGB and NIR) with spectral response similar to satellite sensors like Landsat TM or SPOT (Lieng et al. 2002). The possibility to switch between a view of ordinary RGB-colour and near-infrared colour made these images suitable for vegetation identification.

Table 1. Sampling period and sample size for the different hunting areas. The values for the effective search width (ESW) varied between 63 and 125 meters.

Area	Code[1]	Period	# Years	Effort (km)	# Observations	# Available points
Rabblia/Dalfjellet	A	1997-2002	5	115	74	848
Vingelen	B	2002	1	28	37	210
Dalfjellet/Vestfeltet	C	1997-2002	4-5	254	57	1532
Kvikne	D	2002	1	114	173	645
Åslia	E	1997-1999	3	91	87	617
Mastukåsa	F	1997-2002	5	96	184	631
Kjurrudalen	G	2002	1	34	53	251
Middagskneppen	H	1996-2002	6	354	310	1552
Berghøgda	I	1996-2002	6	395	336	1844
Båttjønndalen	J	2002	1	16	12	77
Risknappan	K	2002	1	24	26	98
Fjesetfjell/Nekjadalen	L	2002	1	6	7	24
TOTAL				1527	1546	8329

[1] Refers to the hunting areas in figure 1.

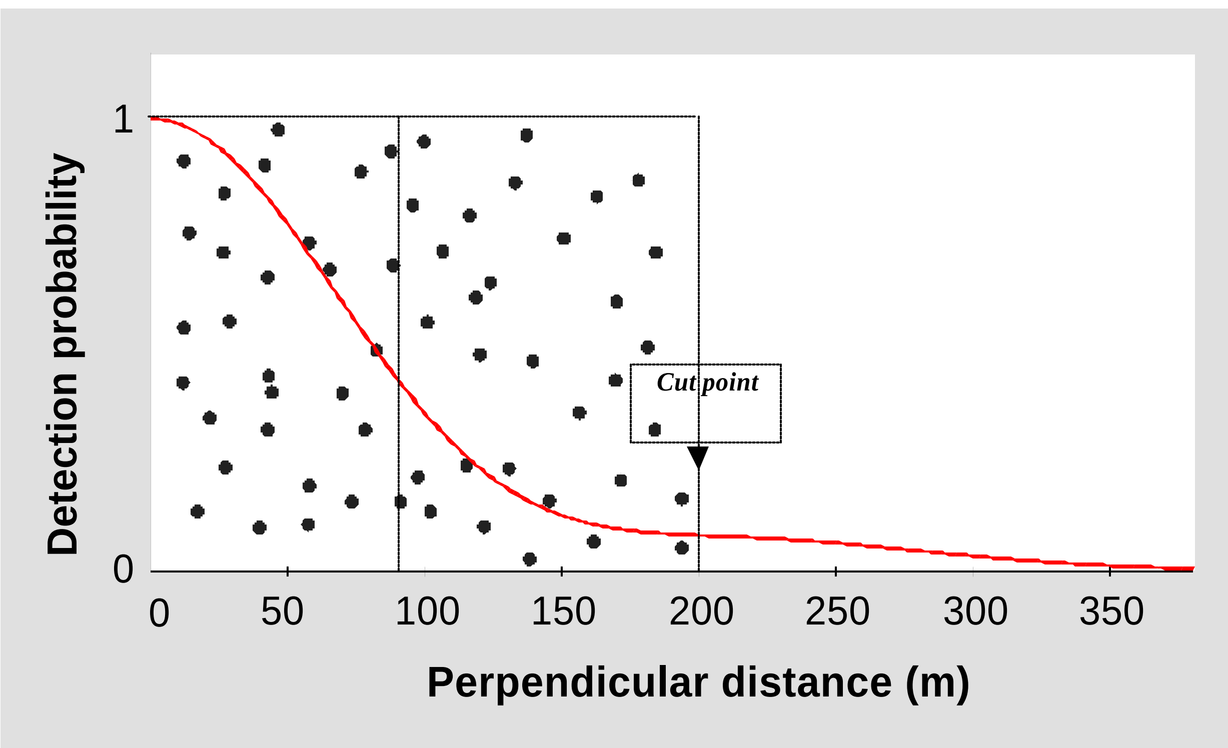

Figure 2 The available units were selected according to the detection probability by selecting out only those randomly chosen coordinates that had a randomly chosen probability (p) less then estimated by the detection function.

We used the Isodata clustering algorithm (Tou and Gonzales 1974) in ERDAS imagine software to reduce the spectral information into 250 clusters. Based on the ground truth information we identified 74 vegetation types from the clusters. From these 74 types we removed edges and cultivated fields (classes 71 and 72), as these were not present in the availability data within a radius of 500 m. Furthermore, we removed shadows and clouds (classes 73 and 74), as these have no biological interpretation and were seldom included in the picture (median=0%, max<0.002%).

Many of the 70 vegetation types are not really differentiable in practice in the field. To further evaluate a reduction of classes we combined the 70 vegetation types in a Principal Component Analysis (PCA) to see how they were associated and if their association was reasonable. The PCA showed that structural nearby vegetation types was clumped together, so we feel quite confident that the interpretation of the satellite image had been successful. We further used the PCA as guidance in combining the vegetation types into 13 habitat classes naturally belonging together (Table 2). Before we pooled vegetation types into habitat categories, we scanned through all 70 correlations between willow ptarmigan presence and habitat to avoid combining vegetation types that had strong opposite correlations.

For each of the remaining habitat categories we estimated the proportion of the area (within the 50 m and 500 m buffers) covered by the habitat both for the used and availability sample. In addition to the proportion of pixels inside each circle containing the various habitat classes we obtained the following variables: The *standard deviation* of the 70 vegetation types as an expression of small-scale mosaic or habitat diversity. An index of *solar radiation* (Parker 1988) as an expression of the extent that the slope of the area was exposed to sun. The index was calculated from a digital elevation model with a pixel size of 25 meter. Length of *bog edges* and *bog area* from topographic maps of scale 1:50 000. *Median* and *range* of elevation from a 25 m digital elevation model. *Distance to water* was taken from the topographical map.

Modeling the Resource Selection Function

From our own personal field experience and known willow ptarmigan biology (Myrberget 1988, Myrberget and Pedersen 1993) we predict *a priori* what variables that will enter into the RSF at two different scales of observation; i.e. the habitat described at 50 m and 500 m radius around the point of observation, and the sign of the coefficients (Table 2). We expected that willow ptarmigan would be attracted to areas generally (500 m circle) covered with medium high vegetation such as tall-herb meadows, willow scrub, dwarf birch and thicket fens, in addition to open fens. As we have separated between rich and poor fens and dwarf birch areas, we expected the rich areas to be more attractive to willow ptarmigan. Further we expected willow ptarmigan to avoid heaths, forests or low elevations (forests is associated with low elevations). At a local scale (50 m circle) we expected to find willow ptarmigan close to cover vegetation (e.g. birch forest, dwarf birch, willow scrub).

We used generalized linear mixed models (GLMM) implemented in the GLIMMIX macro in SAS version 8 (see Little et al. 1996) to model the RSF. The presence (used) /absence (availability) data of willow ptarmigan was used as a response implied in the GLMM with binomial error and a logit link function. Both year and area may be interpreted as a random sample of available years and areas. We therefore included both year and area as random effects in the models with no further purpose of interpreting these effects. Hence our models is of the form:

$$w(x) = \frac{e^{(a + ß_1 \cdot X_1 + ß_2 \cdot X_2 + ß_3 \cdot X_3 + \ldots + ß_n \cdot X_n)}}{1 + e^{(a + ß_1 \cdot X_1 + ß_2 \cdot X_2 + ß_3 \cdot X_3 + \ldots + ß_n \cdot X_n)}},$$

where X_i are the various habitat variables selected in the model, n the number of habitat variables selected and Y = 0 for availability data and 1 in the sample of observed willow ptarmigan.

Habitat variables may also have a non-linear association with the presence of a species, i.e. that an intermediate value is selected or avoided by the species in question. Hence, we also scanned through all non-linear associations (i.e. X_i^2) between number of willow ptarmigan observed and each of the categorized habitat variables before starting to select a model for the RSF. We attempted to enter any possible squared association into the model. However, we found no such association.

We used an exploratory procedure primarily based on our experience and knowledge of the data structure to selection our RSF models. Both a backwards and a forward selection was applied ending up with some variables that either alone or additive with others seemed to give significant contributions to improve the model (p< 0.10) (see also

Table 2. Our prediction on how the various habitat categories correlate with the abundance of willow ptarmigan in the two spatial scales chosen. The expected sign of the correlation coefficient is denoted by -, 0 and + for negative, no or positive correlations respectively. Increasing number of – or + indicates both the strength of the correlation and our confidence in the prediction.

Habitat category	**Prediction**	
	50 m	500 m
Coniferous forest	0	-
Birch forest	+	0
Dwarf birch	+	0
Polar willow	+	++
Tall-herb meadow	+	++
Heath	0	0
Hummock	0	0
Fen	+	++
Thicket fen	+	++
Wet bog	0	0
Water	-	-
Snow	--	--
Impediments	--	--

Burnham and Anderson 1998). The structure of these continuous data did not actually allow for crossed habitat components (interactions) in the model. We then tried all possible combinations of models using these variables and ended up with a few models with similar AIC values (Akaike 1973). We then included habitat variables that we *a priori* expected to be highly positively or negatively associated with the number of willow ptarmigan and were not already in the model. If they did not improve the fit of the model they were again removed. If some of the habitat variables that entered the models were highly correlated ($r > 0.60$) with another habitat variable not in the mo del we also tried to exchange between these two habitat variables to see if we got a better fit of the model. We choose the final model according to the AIC criteria. We attempt to do model averaging (Burnham and Anderson 1998), but according to the AIC-criteria there was no competing models to the selected model (i.e AIC-values for alternative models had AIC-values > 5 higher than the selected model).

Implementation of the RSF

We implemented the model result into a map of Forollhogna by putting out a systematic grid of hexagons with an area equal to that of a circle with 200 m radius. At the center point of each hexagon we calculated the model values from parameters measured within the buffer distances of 50 and 500 meters. The calculated values were added to the hexagons and presented as a hexagon map (Figure 3).

RESULTS

We made separate models for the 50 m and 500 m buffers as well as combined models (Table 3). The model for 50 meter showed that there is the highest probability to find ptarmigan close to rich dwarf birch, rich fens and thicket fens, but not in areas with a high proportion of water. In addition, the variation of habitat variables and the elevation have a positive association with the probability of observing willow ptarmigan. The positive correlation between willow ptarmigan and elevation could be interpreted as an avoidance of forest in the lower parts surrounding the study area. Actually we would have expected a squared association between willow ptarmigan observations and elevation as willow ptarmigan are known also to avoid high elevations without any vegetation. However, forest areas and these high elevations were not surveyed. Hence the elevation variable just says that there is a higher probability of finding willow ptarmigan at higher elevation in a zone above the forest border and below the mid-alpine zone.

The 500 m model showed an additive effect of rich dwarf birch, rich fens and heath (negatively associated to probability of willow ptarmigan observations). When we combined both models into the additive model, the rich dwarf birch areas that were highly correlated at the 50 m and 500 m scale, were removed from the 50 m buffer.

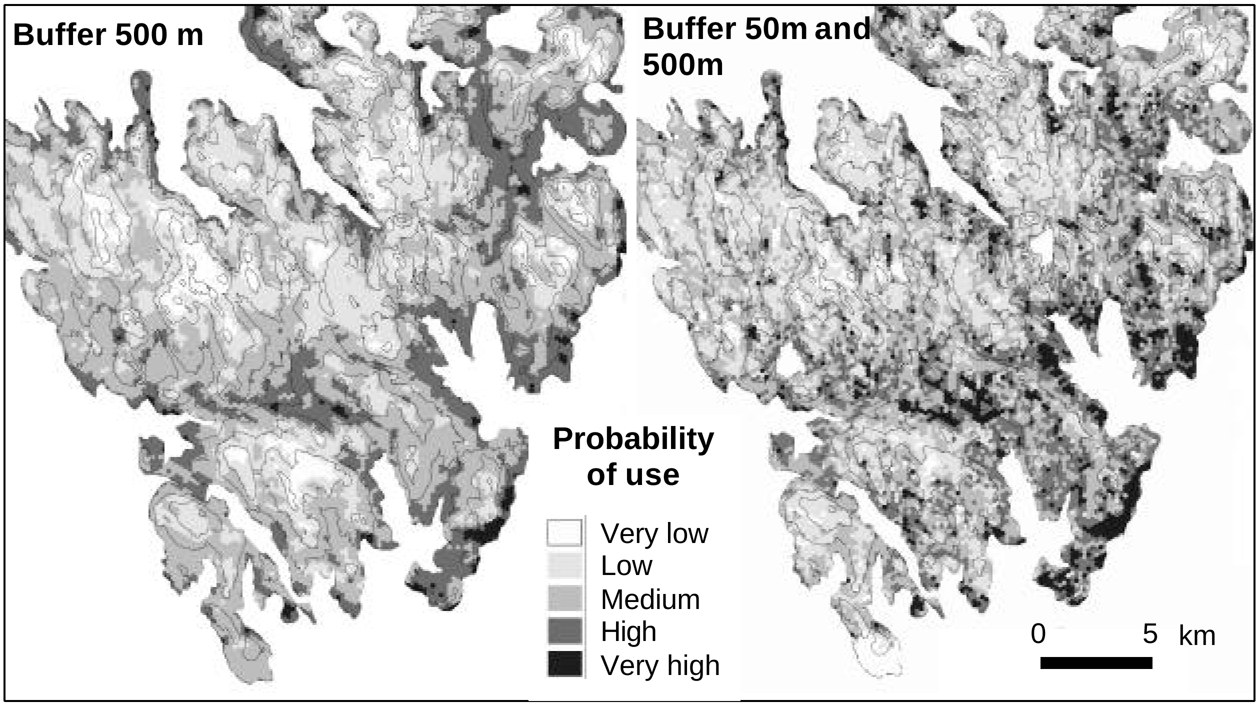

Figure 3. Maps of Forollhogna showing the results of the model with buffer distance 500 meter and a model combining 50 meter and 500 meter buffers. Since no lines were sampled in the forest, the result are only valid for areas above the tree-line. The forested areas are removed from the model.

Table 3. Coefficients of the estimated RSF for habitat selection of Willow Ptarmigan in Forollhogna National Park and adjacent areas.

Variables	Coeff. 50 meter model	Coeff. 500 meter model	Coeff. combined model
Constant	-4. 032	-1.960	-4.623
Std.dev.of vegetation type	0.047		0.042 (50m)
Dwarf birch	4.671	12.724	15.178 (500m)
Rich bog	0.954	2.571	0.530 (50m)
Water	-1.711		-1.605 (50m)
Thicket bog	2.130		1.730 (50m)
Elevation median	0.001		0.002 (50m)
Heath		-3.528	-2.651 (500m)
Rich bog$_{500}$			1.305 (500m)

Our final combined model thus suggests that willow ptarmigan prefer to inhabit large rich areas consisting of fens and dwarf birch, but avoid large open, dry and poor areas like heath. Within this general area they will be close to thickets and local areas with a high variation of habitat types.

DISCUSSION

Our approach to combining cost efficient satellite information of habitat and linear sampling of willow ptarmigan was quite successfull as it to some extent resembled our expectations from known willow ptarmigan biology. In contrast to Manly et al. (2002) who incorporate the detection probability function directly into the RSF modeling, we modified the available sample units adjusting for the detection probability as a function of distance. However, the variance associated with the detection function has not been included in our modeling of RSF. This could have been accomplished by bootstrapping techniques (Efron and Tibshirani 1993): resampling the transects with replacement, refitting the detection function, generating the available units and refitting the model. This rather time consuming procedure that has to be repeated thousands of times has not as far been been subjected to our study.

Management Implications

For active management we have shown the possibility of combining cost efficient methods with computer intensive procedures. RSFs may thus be derived from presence data of species sampled in a logistically feasible study area, and with satellite information of habitat applied over larger areas. Planned changes in the landscape, for instance due to road construction, may be implemented in the background habitat map and changes in species distribution visualized before alterations of the landscape is performed. However, these methods are quite computer intensive and require the knowledge of several areas of expertise, e.g. statistics and GIS. The applicability of such methods therefore requires interdisciplinary cooperation and possibly also the development of software that can automate some of the analysis and presentation procedures.

There might also be other factors than habitat distribution that predicts the spatial distribution and abundance of a species. Knowledge of the factors contributing to the temporal dynamics of a species could preferably also be included in the RSF to get a more realistic visualization of the effects of altered landscapes.

CONCLUSION

This is a first tentative approach to combining cost efficient satellite images and line transect surveys to implement the RSF with large amount of satellite information. Our methods to combine distance sampling with RSF gave both interpretable and expected results.

Our approach here lacks data on habitat variables at the landscape level, such as for instance patch size. Landscape variables might very well be important for the willow ptarmigan. Our next approach will thus be to include such variables in the selection of the RSF. It is also demanding to test the predictability of the model, for instance by applying the model to other areas. Future studies should, however, also evaluate the effects of the spatial scale for describing the habitat and the predictability of the RSF.

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