A RESOURCE SELECTION PROBABILITY FUNCTION FOR THE NORTHERN SPOTTED OWL IN PLUM CREEK'S CENTRAL CASCADE HABITAT CONSERVATION PLAN, WASHINGTON STATE

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Abstract: Plum Creek Timber Company is one of the largest private owners of forested habitat occupied by the northern spotted owl (*Strix occidentalis caurina*) in the United States. Plum Creek's ownership in the central Cascades Mountain in Washington State is in a checkerboard pattern of alternating square mile sections intermingled with land administered by the U.S. Forest Service. At the time of the federal listing of the spotted owl in 1990, 107 spotted owl nest sites had been located within the intermingled ownership. To facilitate the management of the spotted owls and address the economic impacts that the federal listing of the species had created, Plum Creek began the development of a Habitat Conservation Plan (HCP). This is a process under the Endangered Species Act which allows private landowners to obtain a permit to incidentally "take" a listed species or its habitat under otherwise lawful activities in accordance with an approved plan which specifies actions to mitigate and minimize the anticipated impact on the listed species. The HCP area is 418,690 acres in size, including 140,300 acres of Plum Creek property plus land managed by others. The resource selection function fulfills two roles in the HCP. The first is to assess the likelihood that habitat retained in the plan, or projected to grow over the 50 year life of the plan, would have a low, medium, or high probability of occupancy by spotted owls. The second role is to provide estimates of the carrying capacity of the area under different management scenarios, where this is defined as the maximum number of spotted owl nest sites than could be accommodated in the planning area.

Key words: Carrying capacity, habitat conservation plan, forestry management, northern spotted owl *Strix occidentalis caurina*

The northern spotted owl (*Strix occidentalis caurina*), is the largest of the three subspecies of spotted owl inhabiting western North America (Gutierrez et al. 1995). The species was listed as threatened by the United States federal government under the Endangered Species Act (ESA) in 1990 on the basis of three findings by the U.S. Fish and Wildlife Service (USDI 1990): (1) suitable forest habitat was declining throughout its range, (2) populations showed declining trends, and (3) existing regulatory mechanisms were not adequate to protect the owl.

Plum Creek Timber Company is one of the largest private owners of forested habitat occupied by the northern spotted owl in the United States, which is located in the central Cascades Mountain range of Washington State. Plum Creek's ownership is in a checkerboard pattern of alternate square mile sections intermingled with land administered by the U.S. Forest Service. At the time of the federal listing of the northern spotted owl in 1990, 107 spotted owl nest sites had been located within the intermingled ownership (Herter et al. 1995). To facilitate the management of the spotted owls and address the economic impacts that federal listing of the species had created, Plum Creek initiated an intensive spotted owl inventory and radio-tracking study from 1990-1995. The company also began development of a Habitat Conservation Plan (HCP). This is a process under the ESA which allows private landowners to obtain a federal permit to incidentally "take" a listed species or its habitat under otherwise lawful activities in accordance with an approved plan which specifies actions to mitigate and minimize the anticipated impact on the listed species (U.S. Department of the Interior and U.S. Department of Commerce 1996 , Plum Creek Timber Company 1996). The HCP planning area is 418,690 acres in size, and includes 140,300 acres of Plum Creek property plus lands managed by others including the U.S. Forest Service, the Washington State Department of Natural Resources, the Washington State Department of Fish and Wildlife, and some small private owners.

Studies of habitat use have indicated that northern spotted owls generally use mature and old-growth forest as much or more than expected, and early seral stage forest less than expected (Forsman 1980, Forsman et al. 1984, Solis and Gutierrez 1990, Sisco 1990, Meyer et al. 1998, Carey et al. 1990, 1992). A resource selection function (RSF) analysis was

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carried out to better quantify these and other aspects of the use of habitat by the owls. Initially, spotted owl nest sites were located in the HCP project area using standard survey protocols (Herter and Hicks 2000). The selection of a 0.7-mile radius circle around these sites as the unit for describing the habitat followed the process described by Irwin and Hicks (1995), with similar methods used by by Meyer et al. (1998), Swindle et al. (1999) and Franklin et al. (2000). Forest habitat designations followed the protocol established by Oliver et al. (1995) and are described further in the HCP (Plum Creek Timber Company 1996).

An initial version of the RSF (Irwin and Hicks 1995) attempted to fulfill two functions in the HCP. The first was the development of a method to assess the likelihood that habitat retained in the plan or projected to grow over the 50-year life of the plan would have a low, medium or high probability of occupancy by spotted owls. The second was to use the RSF to provide estimates of the carrying capacity of the area under different management scenarios, with the carrying capacity defined to be the most reasonable maximum number of spotted owl nest sites that could be accommodated in the planning area. This latter feature of the RSF is an important monitoring component of the HCP because it makes it possible to evaluate the effectiveness of the plan after several years of implementation. In 2001 the RSF was revised making use of the extensive data then available in the geographical information system (GIS) database for the HCP project area. We focus on the revision for the remainder of this paper.

CHOICE OF VARIABLES TO USE IN THE RESOURCE SELECTION FUNCTION

Initially the revised RSF was estimated from a comparison between 92 sites known to be used by owls, and 51 randomly selected unused sites. Later the number of available sites was increased to 170 to improve the accuracy of the estimated function (Figure 1). In order to ensure that unused sites really were unused, their circles were not permitted to overlap more than 50% with the circles for any sites in the used sample.

The major difficulty with determining the RSF was in the choice of the variables to include in the function. There were 100 variables available in the GIS and it was thought from the start that no more than ten of these should be used. Looking at all possible combinations of 100 variables was not realistic because the number of possible models is huge. Furthermore, the variables were in 13 groups (Table 1), where in some cases all of the variables in a group should either be in or out of the equation. This made automatic stepwise selection procedures difficult to apply. For these reasons it was decided that an initial screening process was necessary to select biologically meaningful variables.

For the initial screening two multivariate tests were carried out on each of the 13 groups of variables to see whether there were significant mean differences between the unused and used samples. Because of the highly non-normal data for many of the variables, two randomization tests were used. The first of these was the sum of log(F) statistic, and the second was Romesburg's E-statistic (Manly 1997a, Section 12.3). A significant result on one of these tests indicates that at least one of the set of variables being considered has a mean that is different for used and unused sites. The calculations were carried out using the computer program RT (Manly 1997b). In addition, the initial screening process involved graphically comparing the distributions of variables for used and unused resource units.

Based on the multivariate tests and graphs, an initial assessment of the groups of variables in terms of their likely value in the RSF was made (Table 1). At this stage it appeared that the important variables were likely to be contained within the Slope, Habitat Type, Stand Structure, and Riparian/Upland groups.

Following the initial screening, a RSF was fitted separately for each group of variables using logistic regression (Manly et al. 2002, p. 99). The value of each of the 13 equations was assessed using Akaike's information criterion (AIC), with small values of this criterion being preferred to large values in terms of the compromise between keeping the number of variables in the equation as small as possible and fitting the data well (Burnham and Anderson 1998). It was anticipated that the results obtained from this procedure would confirm the assessments shown in Table 1.

One complication was that the variables in eight of the 13 variable groups add to 991 (the number of acres in a 0.7 mile radius circle). This means that when fitting a logistic regression function one of the variables had to be omitted in each of the variable groups in order to define the 'standard' conditions (Manly et al. 2002, p. 89). For example, with the first group (Land Type) there are ten variables that add to 991 for each resource unit. One of these ten variables must therefore be left out when doing the logistic regression. Usually the last variable was omitted, but in a few cases other choices of what to leave out were also considered, to see what effect this had on the coefficients of included variables.

As well as using the AIC values, the importance of individual variables was also determined by testing whether the coefficient were significantly different from zero at the 5% level in the fitted functions, using t-tests (Table 2, models 1 to 15). The Habitat Type variables, the Riparian/Upland Habitat variables and the GAP-PRIM variables were found to be the most useful from this analysis, which is broadly in agreement with the results in Table 1. These groups all achieved AIC values of less than 170. However, the Stand Structure variables were investigated further because of their relative ease of measurement, and it was found that a reduced set of these plus the total riparian acres, the elevation range, and the Site Index minimum produced an equation with a low AIC value of 151.1. This equation was chosen as the final one to use because all of the variables are standard and relatively easily measured.

Figure 1. The study area for the Plum Creek Timber Company spotted owl HCP, central Cascade Mountains, Washington State. the circles depict 92 known owl nest sites and 170 unused random potential sites.

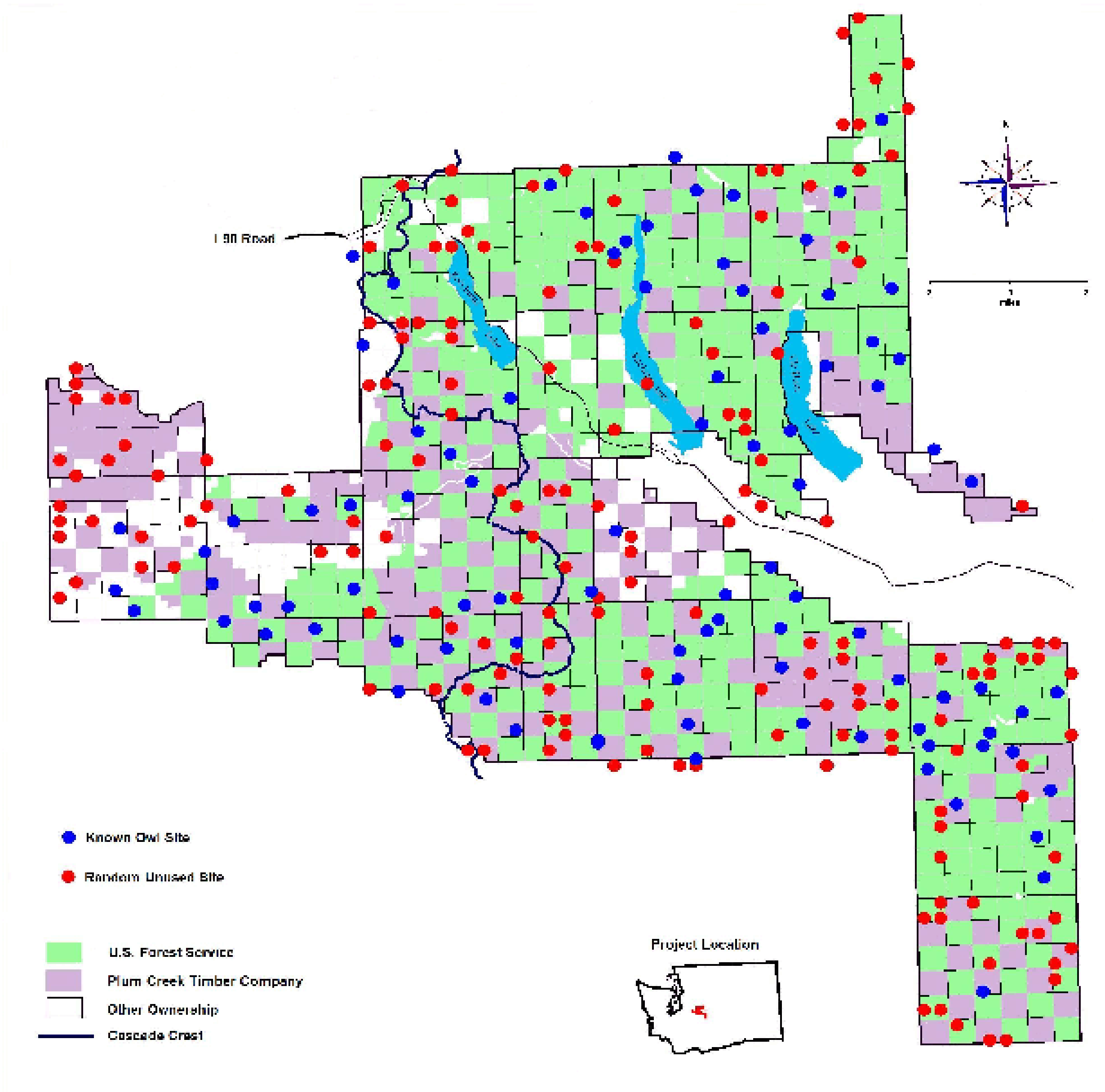


Table 1. The 13 groups of variables available for use in the RSF and a ranking of their likely usefulness, with high ranks for variables judged to be important. Test 1 uses the sum of log(F) statistic and Test 2 uses Romesburg's E statistic. More explicit descriptions of the variables are provided by Manly (2000).

Group	Variables	Variable/Group Name	Test 1 significance	Test 2 significance	Ranking	Use
1	1-10	Land Type Class	5%	5%	3	Maybe
2	11-14	FMAZ Class	NS	NS	0	Drop
3	15-20	Distances to Streams	NS	5%	2	Maybe
4	21-23	Elevation - Min, Max, Std Dev	5%	1%	4	Maybe
5	24-28	Slope Class	5%	0.01%	5	Keep
6	29-36	Aspect Class	NS	NS	0	Drop
7	37-39	Habitat Type Class	0.01%	0.01%	7	Keep
8	40-48	Stand Structure Class	0.01%	1%	6	Keep
9	49-56	Riparian/Upland[2]	0.01%	0.01%	7	Keep
10	57-69	Precipitation Zones Class	NS	5%	2	Maybe
11	70-87	GAP - Primary Land Cover Class	0.01%	NS	1	Maybe
12	88-96	GAP - Primary Zone Class	NS	NS	0	Drop
13	97-100	Site Index	1%	5%	4	Maybe

[1]The Land Type variables sum to 991 acres, the total area of the study site. Therefore, one of the variables had to be omitted for most analyses. This also applied with all of the other Class variables.
[2] Totals were not used.

During the fitting of the logistic regression equations it was decided to replace the standard deviation of elevation with the range of elevation (ELEVH - ELEVL as defined in Table 1) because this was easier to calculate in the GIS. A plot of the standard deviation against the range of elevation indicated, as might be expected, that the relationship between these variables is close to linear.

DERIVING THE FINAL RESOURCE SELECTION PROBABILITY FUNCTION

At this stage the estimated logistic regression equation selected for use was

$$\hat{P} = \exp(z)/\{1 + \exp(z)\}, \quad (1)$$

where

$$z = -8.213 + 0.003126X_{45} + 0.003307X_{46} + 0.008530X_{47} + 0.01124X_{52} + 0.003351X_{23} + 0.05669X_{97}), \quad (2)$$

and (with the variable numbering from Table 1): X_{45} = the number of MF (mature forest), acres X_{46} = the number of MOG (managed old growth) acres, X_{47} = the number of OG (old growth) acres, X_{52} = the total riparian acres, X_{23} = the maximum - minimum elevation in metres, and X_{97} = the minimum site index in feet. To assess the fit of the equation, the Hosmer and Lemeshow (2000, p. 147) goodness of fit test for logistic regression was carried out. This gave a non-significant result (chi-squared = 0.94 with 4 degrees of freedom, p = 0.92) indicating that the model was a good fit to the data.

Equations (1) and (2) do not give the final resource selection probability function selected for use. First of all, the coefficients in equation (2) were only based on a random sample of 51 unused resource units, which was considered to be too small to be satisfactory. Therefore, an extra 119 random unused units were subsequently selected and the logistic regression was refitted. This yielded

$$z = -5.810 + 0.002550X_{45} + 0.002531X_{46} + 0.002942X_{47} + 0.006225X_{52} + 0.001676X_{23} + 0.03286X_{97}) \quad (3)$$

to replace equation (2). The standard errors associated with the estimated constants -5.810 to 0.03286 in order are 1.190, 0.0009616, 0.0008307, 0.001044, 0.001412, 0.00173 and 0.01264, respectively. As a result, the t-values $b_i/SE(b_i)$ for testing whether the coefficients of the X-variables are significantly different from zero are significant at the 5% level except for the coefficient of X_{45} (t = 1.74 with 255 degrees of freedom, p = 0.082). As this coefficient is nearly significant this was not considered to be of concern. A Hosmer and Lemeshow test shows a reasonable fit of the logistic model to the data (chi-squared = 13.04 with 8 degrees of freedom, p = 0.11).

Table 2. Equations fitted by logistic regression to relate northern spotted owl nest sites to habitat variables.

Model	Variables included in the equation with underlining indicating a significant coefficient based on a t-test																	AIC	Comment
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
0																		188.3	The null model with no resource selection
Fitting of 13 Groups of Variables																			
1	1	2	3	4	5	6	7	8	9									189.1	The Land Type variables LT1 to LT9
2	11	12	13															189.3	The FMAZ Zone variables FMAZ2 to FMAZ5
3	15	16	17	18	19	20												190.9	The Distance to Streams variables ST1 to MDS
4	21	22	<u>23</u>															179.0	The Elevation variables ELEVL, ELEVH and ELEVSD
5	24	25	26	27														179.2	The Slope Class variables SLOPE1 to SLOPE4
6	25	26	27	28														179.2	The Slope Class variables with SLOPE1 omitted instead of SLOPE5
7	29	30	31	32	33	34	35											188.1	The Aspect Class variables ASP1 to ASP8
8	<u>37</u>	<u>38</u>																167.5	The Habitat Type variables HAB1 and HAB2
9	41	42	43	<u>44</u>	<u>45</u>	46	<u>47</u>	48										179.6	The Stand Structure variables STDST2 to STDST9
10	<u>49</u>	<u>50</u>	51	<u>53</u>	54													156.0	The Riparian/Upland Habitat variables excluding totals and RIPUP7
11	<u>52</u>																	165.3	TOTRIP (total riparian acres) only
12	58	59	60	61	62	63	64	65	66	67	68	69						193.0	The Precipitation Zones variables PREC2 to PREC13
13	<u>71</u>	72	<u>73</u>	74	<u>75</u>	76	77	78	79	80	<u>81</u>	<u>82</u>	<u>83</u>	<u>84</u>	<u>85</u>	<u>86</u>	<u>87</u>	167.6	The GAP-PRIM variables GAPP1 to GAPP18
14	89	90	91	92	93	94	95	96										196.4	The GAP-Zone variables GAPZ2 to GAPZ9
15	<u>97</u>	98	99	100														184.6	The Site Index variables SI1 to SI4
Equations fitted with Various Changes and Combinations of Variables																			
16	<u>23</u>																	184.3	The Elevation variable ELEVSD changed to the range of elevation*
17	<u>44</u>	<u>45</u>	<u>46</u>	<u>47</u>														174.9	A reduced set of Stand Structure variables
18	44	<u>45</u>	46	<u>47</u>	<u>52</u>													159.5	The reduced Stand Structure variables plus the riparian total acres
19	44	<u>45</u>	46	<u>47</u>	<u>52</u>	18												161.1	As above plus the distance to stream type 4 (ST4)
20	44	<u>45</u>	<u>46</u>	<u>47</u>	<u>52</u>	23												158.9	As above but with ST4 replaced by the elevation range
21	44	<u>45</u>	<u>46</u>	<u>47</u>	<u>52</u>	23	<u>97</u>											151.6	As above plus the minimum Site Index variable SI1
22	<u>45</u>	<u>46</u>	<u>47</u>	<u>52</u>	<u>23</u>	<u>97</u>												151.1	As above but with STDST5 (DF acres) removed
23	<u>45</u>	<u>46</u>	<u>47</u>	<u>52</u>	23	<u>97</u>	27											151.8	As above plus SLOPE4 (acres with 31-40% slope)
24	45	46	47	<u>52</u>	23	<u>97</u>	<u>37</u>	38										149.3	As above but with SLOPE4 replaced by Habitat Type variables HAB1 and HAB2
25	<u>45</u>	46	<u>47</u>	<u>52</u>	<u>23</u>	<u>97</u>	88	94	95	96								155.7	As above but with the Habitat Type variables replaced by GAP-Zone variables
26	<u>45</u>	46	<u>47</u>	<u>52</u>	<u>23</u>	<u>97</u>	89	90	91	92	93							156.2	As above but with other GAP-Zone variables
27	<u>45</u>	46	<u>47</u>	<u>52</u>	23	<u>10</u>												154.7	Seeing whether variable 97 (SI1) can be replaced by variable 100 (SI4) in model 22

*The maximum minus minimum site elevation (ELEVH - ELEVL) was used as a proxy for the standard deviation of elevation because of the difficulty in calculating the standard deviation.

Equation (1) with the linear combination shown in equation (3) can be converted to a resource selection probability function (RSPF) by adding $\log_e(P_a/P_u)$ to the constant term, where P_a is the sampling fraction for unused resource units, and P_u is the sampling fraction for used resource units (Manly et al. 2002, p. 104). The difference between a resource selection function and a resource selection probability function is that the RSPF is intended to give the probability of a potential nest site being used, whereas the RSF only gives this probability multiplied by an arbitrary constant. Generally a RSPF is preferred to a RSF if the conversion from relative to absolute probabilities can be made.

For the used resource units the sampling fraction is straightforward to calculate. There are assumed to be 104 northern spotted owl nests in the study area, of which 92 were used for the estimation of the logistic regression equation. This gives $P_u = 92/104 = 0.885$.

For the unused units it is not so simple to decide what the sampling fraction is. One reasonable approach is to base the calculation on the number of owl sites that could be fitted into the study area with the amount of overlap between sites that is observed to exist for the 92 known sites. The total area covered by the 92 sites is 87,564.7 acres, which is an average of 951.79 acres per owl. There are 418,690 acres in total in the study area. It therefore appears that 418,689/951.79 . 440 owl sites would fit into the area. Of these 104 already exist, suggesting that the potential number of unused sites is 440 - 104 = 336. This gives the sampling fraction $P_a = 170/336 = 0.505$.

From these calculations the correction term for changing the logistic regression equation into the estimated RSPF is

$$\log_e(P_a/P_u) = \log_e(0.505/0.885) = -0.559.$$

The estimated RSPF then becomes

$$\hat{w}^* = \exp(z^*)/\{1 + \exp(z^*), \quad (4)$$

where

$$z^* = -6.369 + 0.002550X_{45} + 0.002531X_{46} + 0.002942X_{47} + 0.006225X_{52} + 0.001676X_{23} + 0.03286X_{97}). \quad (5)$$

APPLICATION OF THE RESOURCE SELECTION PROBABILITY FUNCTION

The estimated RSPF can be used with the data from the logistic regression analysis to calculate an expected number of owl nest sites in the study area. First, the 92 sampled used sites are assumed to represent all 104 used sites. The expected number of owls in these sites, E(owls|used), is 104 times the average estimated value of the RSPF for the 92 used sites. Next, the 170 unused sites are assumed to represent all 336 unused sites. The expected number of owls in these sites, E(owls|unused), is 336 times the average estimated value of the RSPF for the 170 unused sites. The total expected number of owls is then

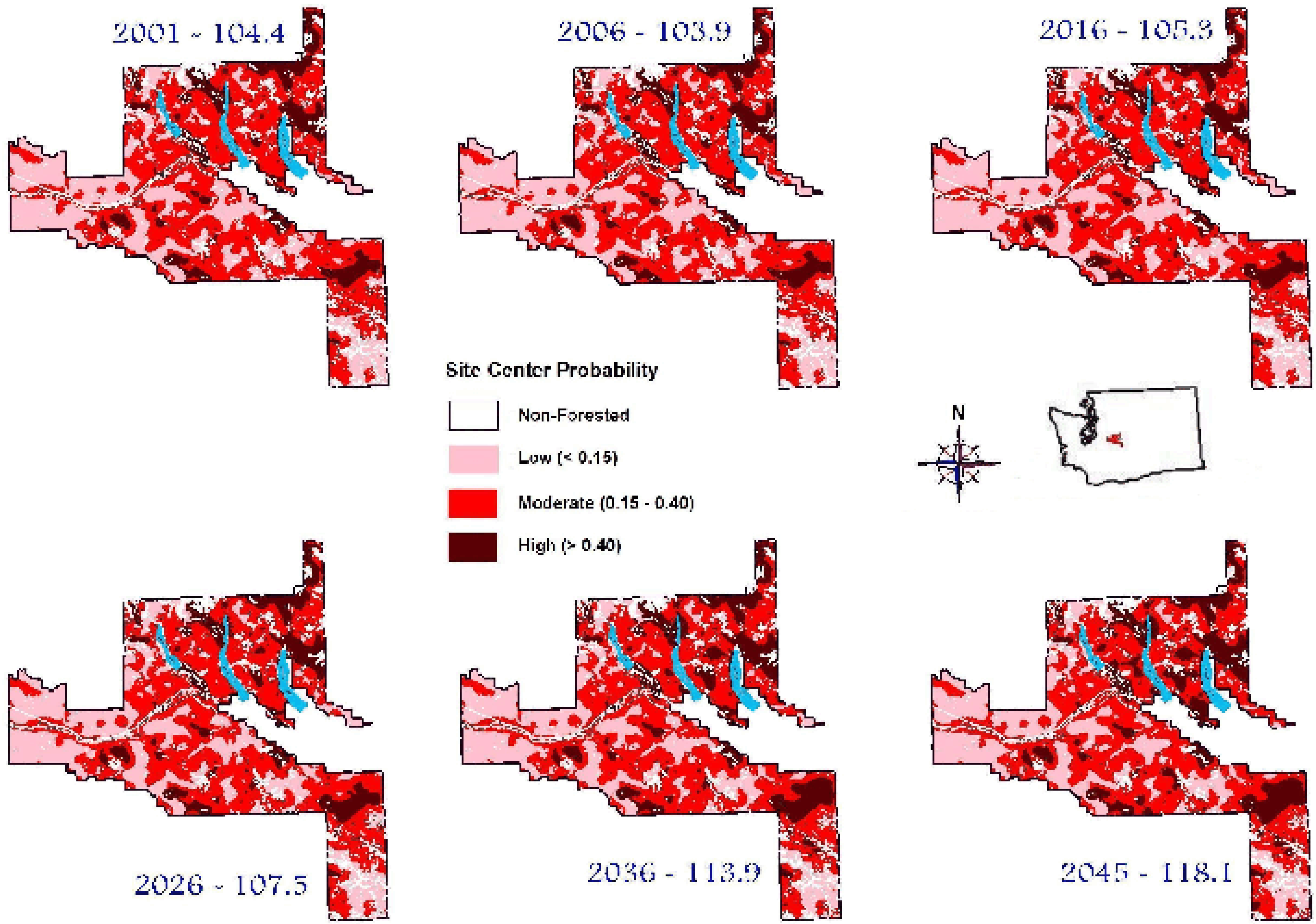
$$\begin{aligned} E(\text{owls}) &= E(\text{owls}|\text{used}) + E(\text{owls}|\text{unused}) \\ &= 104\times0.346 + 336\times0.203 \\ &= 104.2. \end{aligned}$$

One of the most useful aspects of the analysis is that it can be extended using the habitat distribution that is expected to exist in the future as a result of the logging and regrowth of trees. This logging and regrowth is modeled in the GIS using standard forestry methods, and then the carrying capacity can be predicted at different times in the future (Table 3 and Figure 2). The carrying capacity of owl nests in the HCP project area is projected to increase with the planned cutting regime up to year 2045.

Table 3. Projected carrying capacities in the HCP project area based on the planned logging regime and the natural growth of the forest.

Year	2002	2006	2016	2026	2036	2045
Carrying Capacity	104	104	105	108	114	118

Figure 2 Map of estimated values from the RSPF for the HCP project area for the present (2002) and as projected for 2045. These maps were produced by evaluating the value of the RSPF for every pixel in the GIS and plotting them with white for non-forested areas to dark for pixels with the highest probabilities of use. Map headings are the year, followed by the estimated carrying capacity in the year.



DISCUSSION

This study has illustrates the common aspects of the use of resource selection functions to describe the selection of habitat by animals. First, there is the need to define the units of selection. The units chosen for the owls were 0.7 mile radius circles centered on nests or potential nest sites, with the radius chosen because previous studies in the HCP planning area had indicated that habitat configurations within this radius had the highest correlation with nest site occupancy by spotted owls (Irwin and Hicks 1995). When there is concern that the conclusions from a study may depend on the size being assumed for resource units it may be desirable to try several different sizes to see what effects this has (Erickson et al. 1998).

Once resource units are defined, the next step is to decide on a set of variables to use to describe the habitat within units. With modern GIS systems the problem here is often that there is so much choice that it is difficult to decide what to use. With the case study there were initially 100 variables, but by grouping these and doing some initial screening for differences between used and unused resource units it became possible to consider far fewer variables as candidates for inclusion in the RSPF. Some process like this is recommended whenever there are initially a large number of variables that could be used in the RSPF.

Having estimated the RSPF in the case study it was used to predict changes in the carrying capacity of the study area based on planned logging and the natural growth of the forest. This type of application was recommended by Boyce and McDonald (1999), with some controversy resulting (Mysterud and Ims 1999, Boyce et al. 1999). At issue is the question of whether it can be assumed that the RSPF remains constant when the amounts of different types of habitat changes. In general, it can be expected that large changes in the availability of different types of habitat are likely to result in changes in the way that animals select the habitat, and hence in the RSPF. However, with the case study the nature of the habitat in the study region is not expected to change substantially in the near future (Figure 2) so that the assumption of a constant RSPF seem reasonable. The fact is that to predict the effects of habitat changes on the northern spotted owls some assumptions have to be made. We think that the approach used here based on a RSPF is probably the most reasonable one available, although there is scope for debate about the details of how this approach is carried out.

When the carrying capacity of an area remains constant or increases this does not mean that the number of animals will also necessarily increase. In fact, there is evidence that the number of spotted owls in the Cascades HCP region has declined in the last five years while the available habitat has hardly changed. This decrease in spotted owls has been matched with an increase in the number of barred owls (*Strix varia*) in the region (Herter and Hicks 2000). It seems likely that competition for habitat with the barred owls is responsible for the decline in spotted owls numbers, suggesting that in future the RSPF should be modified to account for the presence or absence of barred owls as a feature of the habitat.

ACKNOWLEDGEMENTS

We thank two referees for their helpful comments on earlier versions of this paper that helped us to improve the presentation considerably.

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