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RESOURCE SELECTION FUNCTION MODELS AS TOOLS FOR REGIONAL CONSERVATION PLANNING FOR NORTHERN GOSHAWK IN UTAH

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Abstract. Because the Northern Goshawk (*Accipiter gentiles*) has a relatively large home range size and low density, data on regional-scale habitat configuration is a critical element of conservation planning for the species. We built a resource-selection-function model to predict goshawk occurrence based on 565 nest-site locations surveyed from 1992–2002 on USDA Forest Service lands throughout Utah. Potential explanatory variables included regional-scale geographic information system (GIS) data on vegetation type, MODIS satellite imagery metrics, topography, climate, and road density. The final model included variables for the tasseled-cap indices of brightness, greenness, and wetness derived from satellite imagery, elevation, slope, aspect, and coefficients for eight vegetation classes. Habitat variables show greater predictive power at the scale of a core or post-fledgling area (~ 1.7 km^2) scale than at stand or home range scales. The model had an area under the receiver-operator-characteristic curve (ROC) of 0.874, indicating a useful to highly accurate model. Comparison using a separate validation data set of the performance of the RSF model and an expert-based ranking of the habitat value of potential vegetation types showed that both models were significant predictors of goshawk distribution, with a slight advantage to the RSF model. We compared predicted goshawk habitat distribution with that of other biodiversity targets incorporated in an ecoregional plan for the Utah high plateaus region. RSF values for goshawk were positively correlated with habitat value for wolf (*Canis lupus*) and black bear (*Ursus americanus*) but negatively correlated with rare plant locations. Use of these modeling techniques may strengthen currently planned national goshawk surveys by allowing assessment of regional habitat distribution and stratification of primary and secondary habitat across multiple land ownerships and jurisdictions.

Key Words: *Accipiter gentilis*, conservation planning, focal species, habitat model, resource selection function, spatial analysis.

MODELOS DE SELECCIÓN DE FUNCIÓN DE RECURSO, COMO HERRAMIENTAS PARA LA PLANEACIÓN DE LA CONSERVACIÓN DEL GAVILÁN AZOR EN UTAH.

Resumen. Debido a que el Gavilán Azor (*Accipiter gentilis*) tiene un rango en el tamaño del hogar relativamente grande y una baja densidad, información sobre la configuración del hábitat a escala regional es un elemento crítico en la planeación para la conservación de la especie. Construimos un modelo de selección de función de recurso para predecir la ocurrencia del gavilán, basado en 565 localidades de sitios de nidos, estudiadas de 1992–2002, en tierras del USDA Servicio Forestal por todo Utah. Potenciales variables explicativas incluyeron datos de tipo de vegetación en sistemas de información geográfica (SIG) de escala regional, imágenes de satélite métricas MODIS, topografía, clima y densidad de caminos. El modelo final incluyó variables para los índices de brillo, verdor y humedad derivados de la imagen satelital, elevación, pendiente, aspecto y coeficientes para ocho clases de vegetación. Variables del hábitat muestran mayor poder de predicción a la escala del centro o en el área de post-volantón (~ 1.7 km^2), que en el grupo de árboles o en escalas de los rangos de hogar. El modelo tuvo un área bajo la curva recibidor-operador-característica (ROC) de 0.874, indicando que este modelo es útil y altamente preciso. La comparación, utilizando un grupo de datos de validación distinta del desempeño del modelo RSF y una clasificación basada-en-experiencia del valor del hábitat de los valores potenciales de la vegetación, mostró que ambos modelos fueron pronósticos significativos de la distribución del gavilán, con una pequeña ventaja en el modelo RSF. Comparamos la distribución pronosticada del hábitat del gavilán con la de otros blancos de biodiversidad incorporados en un plan ecoregional para la región alta de la meseta de Utah. Los valores RSF para el gavilán fueron positivamente correlacionados con el valor del hábitat para el lobo (*Canis lupus*) y el oso negro (*Ursus americanus*), pero negativamente correlacionados con localidades de plantas raras. La utilización de este tipo de técnicas de modelación podría fortalecer estudios nacionales sobre el gavilán actualmente planeados, permitiendo la evaluación de la distribución del hábitat regional y la estratificación del hábitat primario y secundario a través de múltiples propietarios y jurisdicciones.

Until recently, conservation planning in the US has been species-based, due to the prevalent interpretation of the Endangered Species Act (USDI Fish and Wildlife Service 1997, 1998a) and other legal mandates. Because knowledge and resources are insufficient to manage for all species individually, land-management agencies increasingly have advocated ecosystem-level regional planning (USDA and USDI 1994). Although the concept of management indicator species, as often applied, has been questioned (Landres et al. 1988, Noss 1990), the broader notion that the population status of a species can be used to assess ecological integrity in conjunction with landscape or ecosystem-level metrics remains useful. Population viability analysis of well-selected focal species allows us to evaluate the effectiveness of conservation strategies in a way not possible with composite indicators of ecosystem function (Carroll et al. 2003a). Lambeck (1997) suggested linking conservation of species and ecosystems by focusing on a few focal species that are most sensitive to changes in key landscape processes (e.g., fire). The Northern Goshawk (*Accipiter gentilis*) may fall into two of four categories of focal species (Lambeck 1997)—it is area-limited, with a home range size that may be >20 km^2, and may be resource-limited by its association with large trees that are used for nesting or to facilitate hunting (Reynolds et al. 1992, Beier and Drennan 1997, Squires and Reynolds 1997).

Many potential focal species occur at low densities due to their high trophic position. This makes collecting accurate survey data difficult and expensive. Although planning for the goshawk benefits from the availability of long-term demographic data in a few portions of the species' range (Reynolds and Joy 1998, Ingraldi 1999), population parameters from intensive demographic studies may provide ambiguous information on declining viability without information on regional-scale trends in habitat (Doak 1995). Coordinated planning across multiple ownerships is necessary for insuring viability of area-limited or wide-ranging species. Although legal mandates have resulted in more complete data on goshawk distribution than is available for most species (Graham et al. 1999b, USDA Forest Service, unpubl. data), data collection is primarily focused on federal lands with timber or other development activities. Our knowledge of goshawk distribution and abundance on other public and private lands is still relatively poor. In order to develop an estimate of goshawk habitat value across the entire region of interest (the Utah high plateaus (UHP) ecoregion (Fig. 1), we developed a resource selection function (RSF; see Appendix 1 for definitions of terminology) (Manly et al. 1993, Boyce and McDonald 1999) based on a multivariate analysis of correlations between known goshawk nest locations and regional-scale habitat variables. We then compared RSF model results with those from an expert-based assessment of goshawk habitat quality (Graham et al. 1999b).

The use of particular focal species in developing regional conservation plans (Carroll et al. 2001) complements two other major tracks of conservation planning; special elements and ecosystem representation (Noss and Cooperrider 1994, Noss et al. 2002). The special elements approach concentrates on occurrences of imperiled species, rare plant communities, and other rare natural features, as are found in the databases of the conservation data center (CDC) network maintained by state and non-governmental organizations (Groves et al. 2003). The level of threat to, and hence the conservation attention merited by a species, is based on the heritage ranking system developed by the CDCs rather than on federal or agency mandates (such as endangered or sensitive species; Groves et al. 2003). Focal species are distinct from special elements in that they are meant to be a representative subset of those species whose persistence is dependent on broader-scale habitat configuration and thus would be inadequately protected by managing only those sites with recorded occurrences. The representation approach seeks to capture examples of all geoclimatic or vegetation types in a network of protected areas. These vegetation types occur at a broader scale than those localized plant communities evaluated as special elements (Groves et al. 2003).

We used model predictions to assess the degree of overlap between areas of high priority for goshawk conservation and for conservation of other focal species and the broader special element conservation goals. For this step, we used habitat models and special elements data developed in a cooperative federal and non-governmental organization (USDA Forest Service (USFS) and Nature Conservancy (TNC)) planning process for the UHP ecoregion, which covers approximately 46,000 km^2 in the states of Utah and Colorado (Tuhy et al. 2004; Fig. 1). The UHP ecoregion is a series of plateaus that rise steeply from the north-south trending valleys that separate them. Common vegetation types include conifer forests of spruce (*Picea* spp.), fir (*Abies* spp.), pine (*Pinus* spp.), and Douglas fir (*Pseudotsuga menziesii*), as well as aspen (*Populus tremuloides*), grassland, montane shrubs, and big sagebrush (*Artemisia*

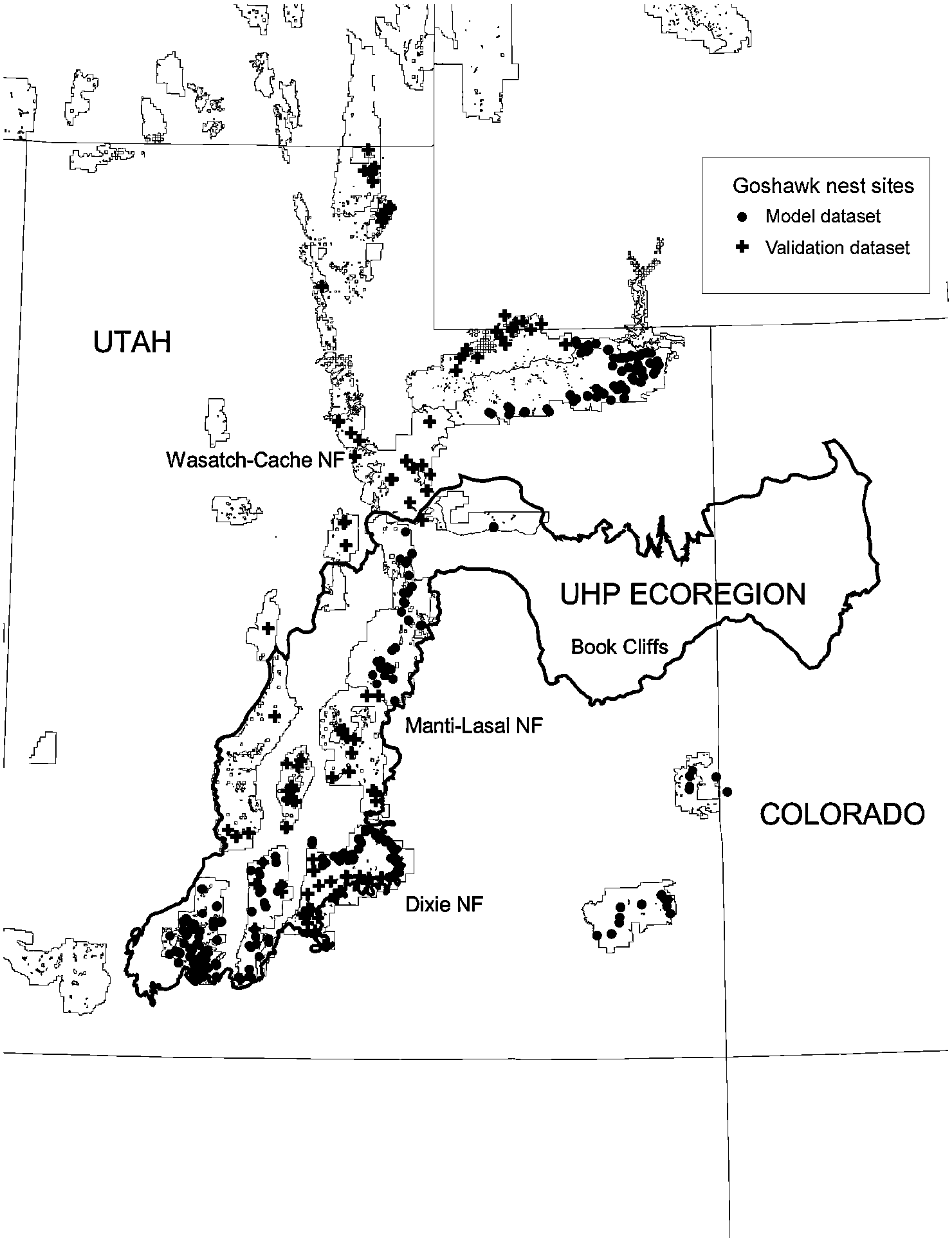

FIGURE 1. Locations of Northern Goshawk nest sites on USDA Forest Service lands in Utah. Dots mark nest locations used in development of the resource selection function (RSF) model. Crosses mark nest locations used for model validation.

tridentata). Precipitation ranges from 375–900 mm annually and annual temperature averages 0–8 C (USDA Forest Service, unpubl. data). The ecoregion encompasses portions of four national forests, several Bureau of Land Management (BLM) field offices, Ute tribal land, and state and private lands. The UHP ecoregional planning process combines methods for ecological assessments used by the USFS with the ecoregional planning methods developed by TNC (Tuhy et al. 2004). Because the ecoregional plan is intended as a decision support tool rather than as a management decision as defined under the National

Environmental Policy Act (NEPA), the plan and its associated data may be applied independently by the USFS and TNC. But because the process uses information on the distribution of biodiversity on all land ownerships within the ecoregion, it will allow public land management decisions such as forest plan revisions to better include information on the biological context of public lands.

Work groups composed of agency biologists and other experts chose three species for in-depth analysis as the focal species component of the UHP plan: the gray wolf (*Canis lupus*), black bear (*Ursus americanus*), and Northern Goshawk. The wolf has recently dispersed into Utah from adjacent populations in Wyoming and Idaho, and has been the focus of a recent state management planning process designed to anticipate and reduce conflicts with livestock and sport hunting (Utah Division of Wildlife Resources 2005). The black bear was selected due to its association with semi-arid vegetation communities and the hypothesized sensitivity of populations in portions of the UHP ecoregion to high rates of sport harvest and control associated with livestock depredation. Due to their relatively large area requirements, these three species may all be expected to be dependent on habitat configuration at regional scales. It was hypothesized that habitat and population viability requirements differ between the species in such a way as to provide contrasting and complementary information to the planning process. Although the impact of factors such as regional habitat connectivity on goshawk populations is poorly known in comparison to the two terrestrial species, field data suggests that a significant proportion of dispersal distances exceed 100 km (Wiens et al. 2006b) and thus a regional-scale perspective on habitat distribution is informative.

The objectives of the goshawk analysis thus spanned multiple spatial scales and management contexts to include the following goals:

1. Provide a multi-ownership assessment of goshawk distribution for use in ecoregional planning.
2. Subsequently inform decisions at the national forest and project level as to the relative importance of a project area for goshawks.
3. Provide initial estimates of regional habitat distribution and potential sampling strata (primary and secondary habitat) for potential use in broad-scale regional surveys (Hargis and Woodbridge, *this volume*).
4. Suggest general hypotheses concerning factors and spatial scales of habitat influencing goshawk distribution that could be tested by future surveys.

METHODS

RESOURCE SELECTION FUNCTION MODEL

An RSF model (Manly et al. 1993) was constructed to predict goshawk nest site occurrence based on regional-scale GIS data such as vegetation type, satellite imagery metrics, topography, climate, and road density variables (Table 1). Satellite imagery was transformed into the tasseled-cap indices of brightness, greenness, and wetness (Crist and Cicone 1984), a standardized means of representing the three principal axes of variation in the values of the six moderate resolution imaging spectrometer (MODIS) spectral bands that are equivalent to those in the older thematic mapper (TM) imagery (Appendix 1; Wharton and Myers 1997). Pseudo-habitat variables that are derived directly from unclassified satellite imagery are correlated to varying degrees with ecological factors such as net primary productivity and thus abundance of prey species and have proved useful in modeling wildlife distributions (Mace et al. 1999, Carroll et al. 2001). However, interpretation of changes in these metrics is complex. The cover type class (e.g., forest versus grassland) and topographic position of a site will affect the manner in which the metric changes in response to changes in ecological attributes such as productivity. Forest stands may first increase and then decrease along the tasseled-cap axes as they age (Cohen et al. 1995). Closed hardwood-conifer forest typically has higher greenness than pure conifer stands. Brightness often corresponds to the amount and reflectivity of exposed soil. Greenness, as its name suggests, is often a correlate of primary productivity. Wetness, however, does not necessarily reflect the presence of water. Wetness is often highest in young conifer stands, with hardwoods and older conifers having lower wetness (Cohen et al. 1995). We also assessed whether we could improve the model by addition of variables representing expert-based habitat rankings for nesting, foraging, or overall habitat value based on potential vegetation type for the state of Utah (Graham et al. 1999b).

Three moving-window sizes were used to approximate hypothesized scales of goshawk habitat selection: 1 km^2 nest site or stand, 1.7 km^2 core or post-fledgling area, and 22 km^2 breeding-season home range (Graham et al. 1994, 1999b). Imagery from two seasonal dates in 2001 was used—May to represent nest establishment and July to represent the height of the growing season. The following number of nest-site locations from USFS lands throughout Utah, dating from 1991–2002, were used in model

TABLE 1. DATA LAYERS EVALUATED IN THE DEVELOPMENT OF THE RESOURCE SELECTION FUNCTION MODEL FOR NORTHERN GOSHAWK IN UTAH.

Data layer	Resolution	References
Vegetation variables		
Potential vegetation type	>5 ha MMU	Graham et al. 1999b
Existing vegetation type—GAP	5 ha MMU	Edwards et al. 1995
Satellite imagery metrics		
July leaf area index (LAI)	1 km	Wharton and Myers 1997
July enhanced vegetation index (EVI)	1 km	Wharton and Myers 1997
May brightness	1 km	Crist and Cicone 1984
May greenness	1 km	Crist and Cicone 1984
May wetness	1 km	Crist and Cicone 1984
July brightness	1 km	Crist and Cicone 1984
July greenness	1km	Crist and Cicone 1984
July wetness	1 km	Crist and Cicone 1984
Topographic variables		
Elevation	90 m	USGS unpubl.
Slope	90 m	USGS unpubl.
Aspect (transformed)	90 m	Beers et al. 1966
Climatic variables		
Average annual snowfall	2 km	Daly et al. 1994
Average annual precipitation	2 km	Daly et al. 1994
May precipitation (mean, min., max., range)	2 km	Daly et al. 1994
July precipitation (mean, min., max., range)	2 km	Daly et al. 1994
Average annual temperature	2 km	Daly et al. 1994
May temperature (mean, min., max., range)	2 km	Daly et al. 1994
July temperature (mean, min, max, range)	2 km	Daly et al. 1994
Human-impact associated variables		
Road density	1:100,000	USGS unpubl.

development: Dixie National Forest (excluding the Escalante Ranger District)—208, Manti-Lasal National Forest—70, Ashley National Forest—138, for a total of 416. Because nest-site data spanning 11 yr were compared with a single year of satellite imagery, we cannot represent the inter-annual variability in the environment at nest sites, e.g., due to drought. The 416 nest locations comprised 199 territories. Although nests were assigned to territories by field personnel based on proximity, territory membership is not known with certainty. To avoid bias due to uneven survey effort over time, nest locations were weighted in the model-fitting by the inverse of the number of nest sites in the territory. These used locations were compared with 1,687 available locations randomly selected from within the boundaries of the forests listed above. All habitats within USFS lands were included as available habitat, including vegetation types that might have been classified as unsuitable by an expert-based model. Our goal was to evaluate goshawk occurrence probability over a geographic region, rather within specific habitat types. Extrapolation of our model to adjacent ownerships for which little survey data exists can be expected to be more problematic than its application on USFS lands. However, because ecoregions are delineated based on similarities in biological, edaphic and climatic characteristics (Groves et al. 2003), and our results were intended for use in multi-ownership eco-regional planning, we expanded our scope of inference to the eco-region as a whole.

Model predictions, especially on non-USFS lands, should therefore be seen as map-based hypotheses to be validated with new field data (Murphy and Noon 1992, Carroll et al. 1999). The model predictions should also be seen as hypotheses because the multiple logistic regression analysis was not restricted to a limited set of a priori models. Comprehensive sets of candidate models are difficult to construct a priori when evaluating variables such as satellite imagery metrics whose functional relationship to biological processes is poorly known. Alternate models were compared using AIC and BIC (Appendix 1), diagnostic statistics that penalize for overfitting (Akaike 1973, Schwarz 1978). AUC, the area under the receiver operating curve (ROC), was used as a measure of model performance. AUC is similar to but more informative than alternate model diagnostics such as correct classification rate or confusion matrices (Manel et al. 2001).

One hundred and forty-nine nest locations from areas not included in the original data set (Fishlake National Forest—40, Dixie National Forest Escalante Ranger District—40, Uinta National Forest—34, and Wasatch-Cache National Forest—35) were withheld for use in model validation and compared in this step with 1,516 random points distributed throughout these validation areas. We compared our RSF model results with the habitat value predicted by an expert-based ranking of goshawk habitat for the state of Utah (Graham et al. 1999b) by comparing the AIC of two univariate models predicting validation data class (nest or random) from either RSF or expert-based habitat values, and by a t-test for significant difference in means in predicted habitat values between nest and random sites in the validation area. Categorical class values from Graham et al. (1999b), which integrate expert-based rankings of nesting and foraging habitat, were assigned a numerical value as follows:

6. Optimum—nest value and all prey values are high.
5. High—nest value and at least one prey value are high.
4. Medium—at least one of nest and three prey values are high.
3. Medium-low—nest value and at least one prey value are medium.
2. Low—all values are medium or low.
1. Non-habitat.

Although the expert-based model (Graham et al. 1999b) was limited to Utah, summary figures for the final RSF model encompass the entire UHP eco-region lying within both Utah and Colorado.

Comparison Of Goshawk Habitat With Other Eco-regional Planning Targets

The planning process for the UHP eco-region identified special element targets by considering species with heritage ranks of G1 (critically imperiled globally) to G3 (vulnerable globally), and then added other species of concern due to factors including declining populations or status as an endemic, disjunct, or vulnerable population (Tuhy et al. 2004). The goals for special elements sought to include a set proportion of the known occurrences of each species or community type within priority areas identified in the eco-regional plan. All occurrences of the rarest elements were targeted. For more common species, the goal was the proportion of the known occurrences thought to be sufficient to insure viability of the population (Groves et al. 2003).

We assessed the degree of spatial overlap between goshawk habitat and other elements of biodiversity by comparing the RSF model results for the goshawk with predicted habitat value for the remaining two UHP focal species (wolf and black bear) and with the rare plant special element data. We focused the latter comparison on rare plants because that category forms the majority of special element data in the UHP ecoregion (1,438 of 2,299 locations; Tuhy et al. 2004). The wolf model was a RSF model developed from wolf territory data for the Yellowstone region (Wyoming) and extrapolated to Utah and Colorado (Carroll et al. 2003b). The black bear model was an expert-based ranking of the habitat value of vegetation types in Utah for black bear (UDWR 2000), which we then extrapolated to western Colorado. Further details of the RSF model for wolf (Carroll et al. 2003b) and the expert-based model for black bear (Utah Division of Wildlife Resources 2000), as well as analysis of concordance between this species-based data and ecosystem representation goals are treated in the UHP eco-regional plan (Tuhy et al. 2004).

We measured the value of the goshawk-, wolf-, and black bear-predicted habitat models at 1,438 rare plant locations and 5,859 random locations within the UHP eco-region. The resulting data were then analyzed with Spearman rank correlations and principal components analysis (PCA; Insightful Corp. 2001, McCune et al. 2002). Although the taxa evaluated here can be expected to show contrasting spatial scales of habitat selection that is not depicted in the PCA, PCA biplots remain useful for visual assessment of patterns of habitat similarity between species that aids interpretation of the correlation coefficients (Carroll et al. 2001). We also evaluated spatial overlap between conservation targets by assessing the proportion of rare plant locations that would be included within the 20% of the eco-region with highest RSF values for goshawk.

RESULTS

Resource Selection Function Model

The resource selection function took the form:

$$
\begin{aligned}
w(x) = {} & \exp(-42.60564 + (0.3779376 \times \text{JULGRN}) + \\
& (-0.02276473 \times \text{JULGRN}^2) + (0.175529 \times \\
& \text{JULWET}) + (-0.03550869 \times \text{MAYBRT}) + \\
& (0.02652771 \times \text{ELEVLAT}) + \\
& (-0.000004058102 \times \text{ELEVLAT}^2) + \\
& (-0.1311468 \times \text{SLOPE}) + (6.678469 \times \\
& \text{TRANSASP}) + (-0.1057033 \times \text{VCLASS1}) + \\
& (0.9648604 \times \text{VCLASS2}) + (-1.63612 \times \\
& \text{VCLASS3}) + (1.74222 \times \text{VCLASS4}) +
\end{aligned}
$$

(0.7659255 × VCLASS5) + (0.4041541 ×
VCLASS6) + (-0.3272406 × VCLASS7) +
(-0.5334307 × VCLASS8) + (-0.0006313316 ×
JULGRN × JULWET) + (-0.001929468 ×
TRANSASP × ELEVLAT) + (-2.077283 ×
RDDEN))

where JULGRN is July MODIS greenness, JULWET is July MODIS wetness, MAYBRT is May MODIS brightness, ELEVLAT is latitude-adjusted elevation (m), SLOPE is slope in degrees, TRANSASP is transformed aspect, and the eight vegetation classes (VCLASS) are 0 (base class)—barren, 1—true fir, 2—Douglas-fir, 3—pinyon-juniper, 4—lodgepole pine, 5—ponderosa pine, 6—aspen, 7—grassland and sagebrush, and 8—montane shrub. As elevation and greenness show convex quadratic functions in the RSF, their effect is highest at moderate values. RDDEN is a variable derived from road density for which road density values less than 0.6 km/km^2 are assigned a value equal to ((-1 × road density) + 0.6). This is interpreted as a nuisance parameter reflecting survey bias against areas of difficult access, and therefore is set to zero when predicting actual goshawk distribution (Carroll et al. 2001). All variables were as averaged by a moving window of 1.7 km^2 in size, except for the MODIS variables, which due to their coarser original resolution (1 km^2) were averaged over 3 km^2. Deviance (-2LL) equaled 899, with $\chi^2 = 372$, df = 19, and $P < 0.001$. Pseudo-r^2 equaled 0.441, while a pseudo-r^2 corrected through cross-validation equaled 0.416. The area under the ROC curve equaled 0.874, indicating a useful model (AUC >0.7), and nearly reaching the highly accurate class (AUC >0.9 [Swets 1988]). Excluding the vegetation types, all individual variables were significant at $P < 0.001$, except for ELEVLAT (0.74), JULGRN × JULWET (0.01), and TRANSASP × ELEVLAT (0.01). ELEVLAT is retained because of the significance of its quadratic term. Only two of the eight vegetation variables (pinyon-juniper and lodgepole pine) showed individual significance of $P \leq 0.05$. However, the vegetation type factor as a whole was highly significant and improved AIC and model generality; therefore, it was retained in the model.

Comparison of the performance of the RSF model and expert-based model (Graham et al. 1999b) using the validation data showed that both models were highly significant predictors of goshawk distribution, but the RSF model performed somewhat better in terms of its AIC value (940.3) than did the expert-based model (946.9). For a t-test of significant difference in means between nest and random sites for the RSF model, t = 10.47, df = 1,663, $P < 0.001$, for nest sites $\bar{x} = 0.077$ (SD = 0.094), for random sites 0.026 (0.052). For a t-test of significant difference in means for the expert-based model, t = 7.69 (df = 1,663, $P < 0.001$), for nest sites $\bar{x} = 2.283$ (SD = 0.901), and for random sites $\bar{x} = 1.529$ (SD = 1.161).

Although both models showed similar predictive power for the validation data set, they showed strong contrasts in predicted habitat value in several areas of Utah (Fig. 2). The RSF model undervalued habitat in comparison to the expert-based model on the Wasatch-Cache National Forest and northern Manti-La Sal National Forest, while overvaluing habitat in comparison to the expert-based model on the Dixie National Forest, Escalante Ranger District, in the western Book Cliffs, and in extreme northcentral Utah (Fig. 2). The areas overvalued by the RSF model appear to be generally more xeric than those it undervalues. Based on the RSF model, and subject to the uncertainties attendant on model extrapolation beyond USFS lands, general public lands in the UHP eco-region have 80% higher habitat value than do private lands. Within the Utah portion of the UHP eco-region, general public lands have 26% higher expert-based habitat value (Graham et al. 1999b) than do private lands.

RSF values for goshawk were positively correlated with habitat value for wolf and black bear (Spearman's correlation coefficient or rho = 0.39 and 0.41, respectively, with $P < 0.001$, df = 8,156 for both), but negatively correlated with rare plant locations (rho = -0.10, $P < 0.001$, df = 8,156). Goshawk nest locations were found at higher elevations than rare plants (mean elevation 2,704 vs. 2,269 m, t = -16.71, $P < 0.001$, df = 1,798; mean elevation of the UHP eco-region is 2,277 m). Protection of the 20% of the UHP eco-region with highest goshawk RSF values would protect 15.11% of rare plant locations. Results of the principal components analysis show that on the first two axes, which account for 64.54% of total variation in the data, the distribution of goshawk habitat is most similar to that of wolf habitat, slightly less similar to that of black bear habitat, and most dissimilar to the distribution of rare plants (Fig. 3).

DISCUSSION

Empirical distribution models such as those developed here are an important initial stage in development of a multi-ownership monitoring program (Hargis and Woodbridge, *this volume*) that can place local habitat and population trends within the context of the regional metapopulation (Carroll et al. 2001). However, initial models must be seen as

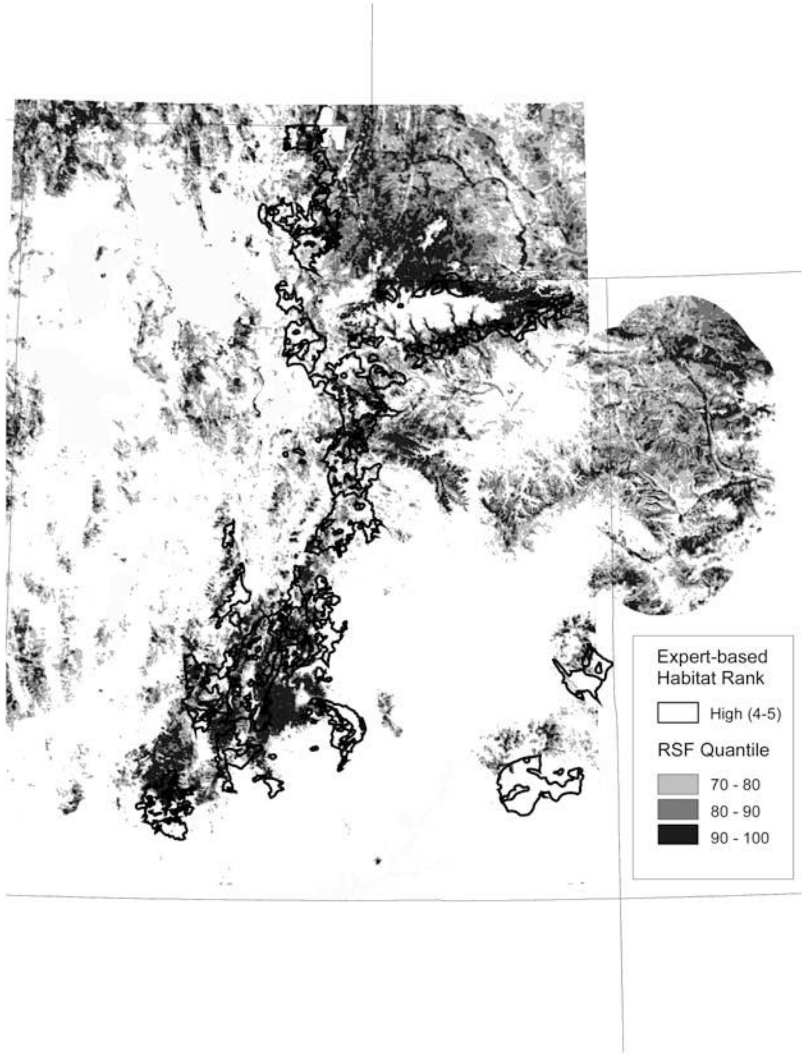

FIGURE 2. Comparison of areas rated as high value habitat in the expert-based Northern Goshawk model (Graham et al. 1999b) and the resource selection function (RSF) model.

map-based hypotheses which can refined with new field data (Murphy and Noon 1992, Carroll et al. 1999). While ideally the geographically extensive data necessary for building such models are collected through standardized surveys, such efforts only have recently been proposed as part of agency monitoring programs (Hargis and Woodbridge, *this volume*). The goshawk distribution data used here, although greatly superior to non-verifiable occurrence data such as sightings, nevertheless may show sampling bias that must be evaluated during the analysis process. Although we might expect the distribution of survey effort would bias goshawk occurrence towards more productive, low-elevation forests, Daw et al. (1998) found that goshawk habitat was characterized similarly by both non-systematic and systematic datasets. However, Daw et al. (1998) compared habitat at a finer spatial scale (0.4 ha) than considered here. Our habitat evaluation is similar to most goshawk studies in that it ignores winter habitat distribution, which may be distant from breeding season habitat. The combination of multiple explanatory variables (e.g., vegetation) with varying levels of error in a GIS also leads to spatial error propagation and increased levels of uncertainty (Heuvelink 1998). Despite problems of survey bias, regional habitat models built from the non-systematic survey data can provide initial estimates of species

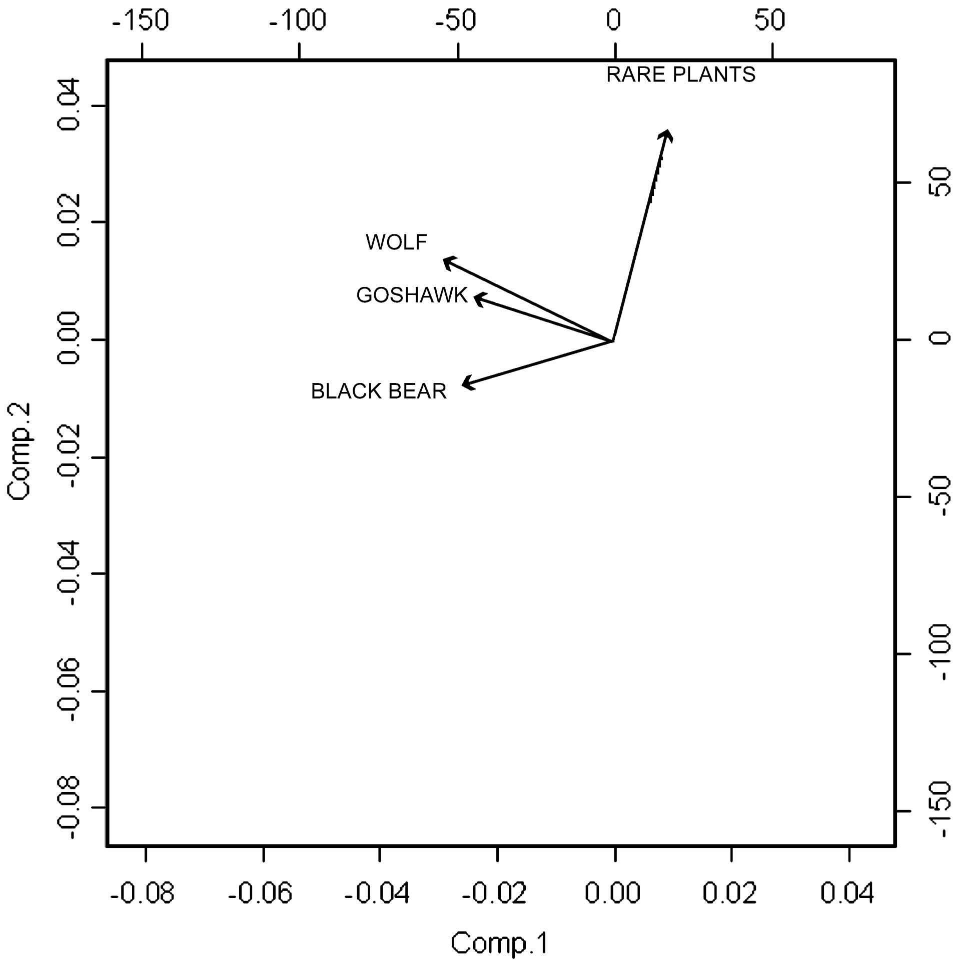

FIGURE 3. Biplot of results from principal components analysis (PCA) of predicted habitat value for goshawk (RSF model), wolf, and black bear at 1,438 rare plant locations and 5,859 random locations within the Utah high plateaus (UHP) eco-region. The biplot shows the first and second PCA axes, which together encompass 64.5% of the total variation in the data.

distribution and abundance as averaged over coarse spatial and temporal scales (Carroll et al. 2001).

Interpretation of Coefficients of the RSF Model

Interpretation of individual coefficients in regression models must be done with caution due to correlation between coefficients, but may be informative in suggesting new hypotheses as to important habitat factors. Goshawk occurrence peaks in vegetation of moderate greenness, which may indicate avoidance of both non-forested areas with low greenness and young forest or other forest types with high greenness. Areas of high brightness (low cover) are avoided. The positive association with July wetness may indicate association with mesic forest types. The inclusion of the July tasseled-cap indices suggest that summer vegetation characteristics may the best seasonal coarse-scale predictors of goshawk occurrence. However, the negative coefficient for May brightness suggests avoidance of areas with late season snow cover. The coefficients of the topographic variables (elevation, slope, and aspect) suggest association with mid-elevation areas (adjusted for latitude), areas of low slope, and areas with northeast aspects. As elevation increases, there is less selection for mesic aspects, as would be expected due to the effect of elevation on temperature and precipitation. Although no climatic variables entered into the model, spatial variation in climate may be partially represented by factors included within the effects of elevation and the tasseled-cap indices. Among the vegetation classes, avoidance of pinyon-juniper and association with lodgepole pine were significant in the RSF model. This agrees with vegetation cover type associations found in earlier analyses (Graham et al. 1999b). A model without vegetation type variables tended to overpredict occurrence in pinyon-juniper due to that vegetation type's high greenness. Habitat variables show greater predictive power at the scale of a core or post-fledgling area (~ 1.7 km^2) scale than at stand or home range scales. This agrees with results from other habitat models for other birds with high trophic positions (e.g., California Spotted Owl [*Strix occidentalis occidentalis*]; Carroll 1999), but is a finer spatial scale than that identified in habitat models for mammalian carnivores (Carroll et al. 1999). This could suggest contrasts in scale of habitat selection between the taxa, but could also arise from use of nest sites (birds) versus the less informative foraging sites (mammals) in the models, or from contrasts in underlying landscape heterogeneity between study regions.

Value and Limitations of Non-systematic Survey Data

Due to sampling bias, we might expect the RSF model to accurately predict goshawk distribution within the extent of the survey data used in model creation but to have low generality outside that region. However, the validation results suggest that the RSF model performs slightly better than the expert-based model when tested with new data. The habitat estimates provided by both types of models are essential complements to the original nest site location data in that they allow conservation planning to occur across multiple jurisdictions that differ in survey effort. However, validation with new data from non-USFS ownerships would be a useful test of the level of extrapolation error that might be expected in multi-ownership planning. The variables used in the RSF model, such as the tasseled-cap indices, are somewhat more difficult to interpret in terms of the biological requirements of the species than are the potential vegetation types used to build the expert model (Graham et al. 1999b). Therefore the RSF results might best be used in combination with more conceptual (expert-based) models to suggest new factors that may influence goshawk distribution. RSF model development is potentially more rapid than expert-based habitat assessment over large regions, which may be useful for broad-scale monitoring programs that need an initial rapid assessment of habitat distribution to delineate sampling strata (primary and secondary habitat) and semi-discrete populations or management units (Hargis and Woodbridge, *this volume*). Because the variables in RSF models may be more easily updated and replicable than expert-based models, they may also help in assessing whether changes in frequency of goshawk occurrence are linked to changes in habitat. At a finer scale than that of the bioregional surveys, the models were successful in providing a multi-ownership assessment of goshawk distribution for use in the UHP ecoregional plan (Tuhy et al. 2004) and providing data that can inform forest and project-level management decisions as to the relative importance of project areas for goshawks. Basing such decisions on known nest site locations alone not only sacrifices habitat in poorly-surveyed jurisdictions but also ignores the importance of unoccupied but suitable habitat for metapopulation persistence (Lande 1987).

Integrating Goshawk Conservation Priorities with other Biodiversity Goals

Land managers increasingly need information on how to combine conservation measures for well-studied, high-profile species with a broader mandate for protection of large numbers of poorly known taxa (Groves et al. 2003). The Utah high plateaus eco-regional planning process allowed us to assess this question in the context of a mountainous region with strong physical gradients in aridity and vegetation type. In this environment, we see some overlap within our mammalian and avian focal species but little overlap between this group and broader biodiversity targets such as rare plants. Amongst the three focal species analyzed in the UHP ecoregional plan, goshawk and wolf appear closest in habitat associations in the principal components analysis (Fig. 3). Both species select mesic, high productivity forest types that occur at moderate to high elevations in the region. In contrast, the black bear, an omnivore, is found at high densities in more xeric, lower elevation woodlands that contain mast-producing species such as Gambel oak (*Quercus gambelii*). Because rare plant locations occur in dissimilar habitats to all three of the focal species (Fig. 3), it appears that conservation measures focused on protecting high-value habitat for goshawk and other focal species would be poor at protecting rare plants. This effect is likely in part an artifact of the tendency of special element databases to be biased towards more easily surveyed areas with high human access (Carroll et al. 2003a). However, much of the contrast between rare plants and wide-ranging focal species in the UHP ecoregion is due to the association of rare plants with barren substrates whose low tree cover is due to edaphic or erosional processes (Tuhy et al. 2004).

Although not a surrogate for broader biodiversity goals, inclusion of wide-ranging species such as goshawk in regional conservation planning efforts addresses factors that would be missed in a plan based exclusively on special-element data (Carroll et al. 2003a). In addition to showing contrasting site-level habitat associations (Fig. 3), the three focal species may also respond to habitat availability at contrasting spatial scales. In the context of Utah and the larger Great Basin, the UHP eco-region has a disproportionate importance for terrestrial species such as the wolf because it is predominantly higher-elevation, productive habitat and connects the mainland of widespread montane habitat in the northern Rocky Mountains with more isolated habitat patches to the south (Carroll et al. 2006), forcing the planning process to address this species in an inter-regional context (Tuhy et al. 2004). Demographics of the goshawk, as well as the wolf and black bear, show the effect of the high environmental stochasticity (year-to-year variation) in fecundity in the semi-arid ecosystems typical of the Utah study area (Reynolds and Joy 1998, Costello et al. 2001). Levels of interpopulation connectivity may strongly influence persistence of metapopulations characterized by high environmental stochasticity (Lande et al. 2003). Although we know little as to what constitutes population connectivity in goshawks as compared to terrestrial mammals, the species' long-distance dispersal ability (Wiens et al. 2006b) suggests that development of regional-scale distribution models, as well as broad-scale monitoring programs (Hargis and Woodbridge, *this volume*), are necessary initial steps in the development of effective conservation strategies.

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APPENDIX 1. Definition of terms.

AUC—a measure of model performance based on the area under a receiver-operating characteristics (ROC) curve. Because the ROC curve measures model sensitivity and specificity across the full range of probabilities, the AUC statistic, unlike the correct classification rate, is independent of any arbitrary threshold for classifying a species as present or absent.

AIC—Akaike information criterion, a model-fitting statistic that incorporates penalties for the addition of variables

BIC—Bayesian information criterion, a model-fitting statistic that is similar to AIC but with larger penalties for overfitting

Eco-regional plan—A plan consisting of documents and spatial data, usually developed by a land management agency or conservation organization, that seeks to evaluate the relative importance of areas for conservation of biological diversity at the scale of an eco-region. Importance is often evaluated in terms of special elements, ecosystem representation, and focal species viability. Eco-regions are defined by shared environmental and biogeographical factors.

Focal species—Species subject to in-depth habitat or viability analysis in eco-regional planning. They may be especially sensitive to key ecosystem processes and are meant to be a representative subset of those species whose persistence is dependent on broader-scale habitat configuration and thus would be inadequately protected by managing only those sites with recorded occurrences (i.e., as special elements).

MODIS—Moderate resolution imaging spectrometer, a satellite-based sensor launched on the Terra satellite that provides multispectral images of the earth at low spatial but high temporal and spectral resolution.

RSF—resource selection function, a function that is proportional to the probability that a resource unit, such as an area of habitat, will be used by an animal.

Special element—Rare and localized species and communities and other ecological features that are evaluated in eco-regional planning based on records of their occurrence at specific sites that are generally small in size.

Tasseled-cap transformation—A transformation of the six of the reflectance bands of satellite imagery (e.g., TM or MODIS) into three indices—brightness, greenness, and wetness—that represent the major axes of variation in TM data. This transformation is similar to a principal components transformation except that the axes are fixed for all data rather than dependent on a particular data set.

TM—Thematic mapper, a sensor on the Landsat series of satellites that records seven spectral bands at high spatial but low temporal resolution.