Modeling Critical Habitat for Flammulated Owls (*Otus flammeolus*)

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Abstract.—Multiple logistic regression analysis was used to produce a prediction model for Flammulated Owl (*Otus flammeolus*) breeding habitat within the Kamloops Forest Region in south-central British Columbia. Using the model equation, a pilot habitat prediction map was created within a Geographic Information System (GIS) environment that had a 75.7 percent classification accuracy. Factors were identified indicating the quality of the modeling process; several limitations were also detected. Maps derived from the pilot model will be ground-truthed in coordination with field inventories. New habitat identified from the field investigations will be used to refine models in an ongoing, iterative process.

BACKGROUND AND RATIONALE

Operational planning requirements of the Forest Practices Code of British Columbia Act and the corresponding Regulations include the protection of critical habitat for species at risk within resource development plans (Ministry of Forests 1995). Geographic Information Systems (GIS) may be used to efficiently map critical habitat features allowing for integrative mapping and analysis within logging and development plans. Unfortunately, collecting adequate data to detect and map habitat for all species at risk would be an exhaustive process.

British Columbia has the highest level of biodiversity of any province in Canada (Harding and McCullum 1994, Pojar 1993). The Kamloops Forest Region is representative of the Province's diversity. The Biogeoclimatic Ecosystem Classification (BEC) system of British Columbia has divided the province into 14 broad zones, 10 of which are present in the Kamloops Forest Region (Lloyd *et al.* 1990). These 10 zones span the climatic spectrum from dry, hot desert climate to pockets of high elevation, coastal rain forest. Inherent in the diversity of ecosystems is the diversity of wildlife. Increasing human disturbance in these ecosystems has led to a significant number of species recognized as being at risk (Harding and McCullum 1994).

Using traditional methods for mapping habitat over extensive regions is costly, time consuming, and labor intensive (StefanoviC and Wiersema 1985). The difficulty of the task in the Kamloops Forest Region is exacerbated by steep and complex terrain and extensive dense forests. Predictive habitat modeling has been recognized as a practical alternative to traditional surveys for some time (Anderson *et al.* 1980, Carneggie 1970, Carneggie *et al.* 1983, Christie and Low 1996, Hunter 1990). Star and Estes (1990) described GIS as the only practical method for predictive habitat modeling for rare, threatened and endangered species in California. Potential critical wildlife habitat in British Columbia may be modeled using GIS database variables such as forest cover characteristics, terrain, and juxtaposition of critical habitat features. Models could be used to produce maps of potential habitat which may efficiently guide field inventory studies.

Several factors have delayed the acceptance of predictive habitat modeling over a planning area as large as the Kamloops Forest Region (6.7 million ha (Watts 1983)). First, legislated requirements for critical habitat mapping applied consistently over the entire region and to all resource planners did not, until recently, exist. Second, the scope of many early GIS-based habitat modeling studies was often restricted by data limitations such as inappropriate data resolution (scale), data cost, and data quality and precision (Herr and Queen 1993, Lyon 1983, Pétrie 1990, StefanoviC and Wiersema 1985). These limitations, combined with inadequate budgets, consequently

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*Adult Flammulated Owl (*Otus flammeolus*).*

produced moderately successful results. Finally, failing to weight different habitat variables relative to their importance to a species was also cited as a reason for limited success in habitat modeling (Lyon 1983).

Recent studies have met with more favorable results. Pereira and Itami (1991) modeled habitat for the endangered Mt. Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) in Arizona using various abiotic (terrain) and biotic (vegetation) variables. The model successfully classified 90 percent of squirrel habitat and only misclassified 27 percent of the non-habitat. Duncan *et al.* (1995) used multi-temporal data to validate their Florida Scrub Jay (*Aphelocoma coerulescens coerulescens*) habitat suitability model. Habitat prediction modeling for wolves (*Canis lupis*) in Peter Lougheed Provincial Park, Alberta, also produced excellent results (Waters 1996). Sperduto and Congalton (1996) used the results of chi-square analysis to weight habitat variables and increase the modeling accuracy for a rare orchid *(Isotria medeoloides)* in New Hampshire and Maine. All project teams benefited from combined GIS and wildlife expertise. Unfortunately, results of these studies are only applicable to the study areas in question due to the use of site-specific data.

Hunter (1990) suggested that plans based on GIS and remote sensing data require careful scrutiny by wildlife managers to recognize the deficiencies of the modeling process. Conversely, wildlife managers who venture into GIS modeling must also seek the scrutiny of GIS experts. Too often, habitat models have failed to produce adequate results because they were developed either by wildlife biologists with inadequate GIS experiences or GIS modelers with insufficient knowledge of wildlife and wildlife habitat.

STUDY SITE AND SPECIES DESCRIPTION

The Flammulated Owl (*Otus flammeolus*) is a neotropical migrant and summer resident in British Columbia where it nests primarily in woodpecker cavities in ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) snags (Cannings *et al.* 1987, Howie and Ritcey 1987, van Woudenberg unpubl. data). At 15 to 18 cm tall and weighing approximately 55 grams, it is the second smallest owl in North America (McCallum 1994). The owl is nocturnal and secretive, foraging in small grassy openings for Lepidopterans, Othopterans and Coleopterans.

Wheeler Mountain was the trial study site where Flammulated Owl habitat research had been conducted from 1989 to 1996 (fig. 1). The forest is mature to old growth (80-200+ years), with Douglas-fir as the dominant species and ponderosa pine as a subdominant on xeric, south aspect sites of the Mountain (van Woudenberg, unpubl. data). Predominant species in the shrub layer include Saskatoon

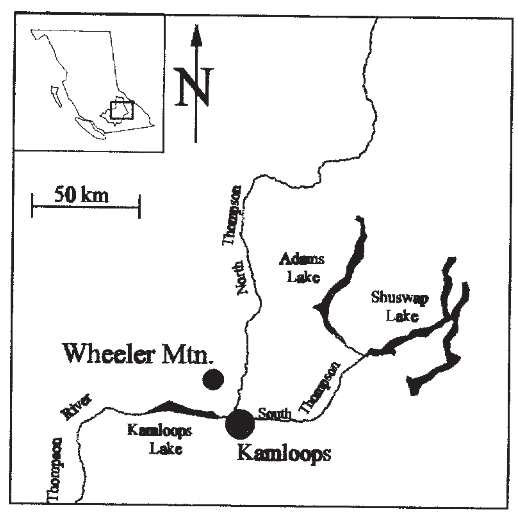

Figure 1.—*Location of Wheeler Mountain pilot study site, British Columbia, Canada.*

(*Amelanchier alnifolia*), birch-leaved spirea (*Spirea betulifolia*), common snowberry (*Symphoricarpos albus*) and soopolalie (*Shepherdia canadensis*). Kinnikinnick (*Arctostaphylos uva-ursi*) is the dominant forb, and pinegrass (*Calamagrostis rubescens*), rough fescue (*Festuca scabrella*), and blue-bunch wheatgrass (*Agropyron spicatum*) are the dominant graminoids.

The transition between mesic and xeric sites, where large ponderosa pine snags are found near stands of Douglas-fir regeneration and small grassy openings, is optimal habitat for the Flammulated Owl (van Woudenberg, unpubl. data). The Douglas-fir regeneration provides foraging opportunities and security cover, the openings provide foraging opportunities and snags are used as nest sites. Douglas-fir snags are used more often for nesting in mesic sites where ponderosa pine is minimal or absent. Where ponderosa pine is scarce, suitable nesting may be the limiting habitat type for Flammulated Owl populations. In xeric sites, where ponderosa pine snags are more common, security cover may be the limiting habitat feature. This may be mitigated by reduced risk of predation on xeric sites (van Woudenberg, unpubl. data). Generally, nest cavities in ponderosa pine are created by Pileated Woodpeckers (*Dryocopus pileatus*) and cavities in Douglas-fir are created by Northern Flickers (*Colaptes auratus*).

METHODS

The first stage of research focused on the pilot study site, an approach recommended by Star and Estes (1990) for two reasons. First, field data collected from the study site would allow preliminary testing of proposed methods and experimental design. Second, the relevance of different data types may be investigated during the trial study before committing to large data acquisitions.

The Ministry of Environment supplied 1:20,000 scale Terrain Resource Information Management (TRIM) digital map data to be used as the base. A Triangulated Irregular Network (TIN) Digital Elevation Model (DEM) was created from TRIM spot elevation data. The Kamloops Region Ministry of Forests (MoF) provided 1:20,000 scale forest cover maps and database files. All nest site locations collected from the pilot site were derived using differential Global Positioning System (GPS). A CMT MC5-GPS unit (Corvallis Microtechnology Inc. 1995) was used for field data collection.

TerraSoft V.10.03 (Digital Resource Systems Ltd. 1991) was used for GIS input and analyses. A combined theme containing polygons with all variables was created through theme overlay processes. Thirty-five nest sites, found between 1989 and 1995, were used for model calibration. A total of 29 polygons were used as some polygons contained multiple nest sites. Due to the large number of eligible polygons (approx. 20,000) in the Flammulated Owl habitat database and the small number of polygons with owl nests, a case-control sampling with complete sampling of cases and random sampling of controls was performed. The significant contributions of each variable to characterize habitat was tested by comparing polygons containing documented habitat features with randomly chosen polygons without known habitat features.

The independent variables considered were slope, elevation, aspect, primary, and secondary tree species and their respective percentages, age class, crown closure (percent), and site index (forest productivity). A filter was applied to select only polygons with Douglas-fir as the primary species for two reasons. First, all polygons with nests had Douglas-fir as the primary species. Second, this filter excluded non-forested and water feature polygons from the modeling process. Polygons were also filtered to exclude erroneous polygons with elevations less than the lowest elevation on the source map.

After completing the univariate analyses, variables were selected for multivariate analysis. The problem with the univariate approach is that it ignores the possibility that a collection of variables that may be weakly associated with the outcome can become an important predictor when considered together. Due to the complexity of the problem in this study, it was decided that the stepwise logistic regression would be used to select variables for the final model. The technique used in the stepwise logistic regression was forward variable selection with a test for backward elimination. The following hypotheses was tested for the pilot model:

H_0: There is no significant lack of fit of the model.

H_A: There is a significant lack of fit of the model.

79To test this hypotheses, the final model was tested for goodness of fit within a 95 percent confidence interval using the Hosmer-Lemeshow goodness of fit test (Hosmer and Lemeshow 1989). The model was then used to query the database for polygons with predicted habitat suitability; a map identifying those polygons was produced.

RESULTS

Polygons containing nest sites ranged in elevation from 850 to 1,150 m, 10 to 50 percent slope, and all aspects were represented except north. The dominant tree species for all polygons was Douglas-fir and percentage cover was from 55 to 100. Ponderosa pine was the secondary species for 19 nest sites and it ranged in percentage cover from 3 to 45; lodgepole pine (*Pinus contorta*) was the secondary species for two nest sites where it comprised 5 and 40 percent, respectively. There were no secondary species for the remaining 14 nest sites. The age class ranged from 5 to 8, crown closure from 30 to 50 percent, and site index from 8.5 to 15.6.

The significant predictor variables included ELEV_01, a binary variable for elevation (ELEV_01 = 0 if <900m and >1,100m, ELEV_01=1 if >= 900m and <= 1,100m). The other significant predictor variables were AGE_CLASS, specifically older stands, and CROWN_CLOS, typically 40-50 percent, or that of an older stand. P-values for each significant variable were well below the 0.05 significance level.

The final model equation was;

$$Y = -11.63 + 2.22*ELEV\_01 + 0.58*CROWN\_CLOS + 0.11*AGE\_CLASS$$

The probability of finding a nest in the predicted forest polygon was calculated by:

$$p = 1/[1 + EXP(-Y)]$$

Using the model equation, a pilot habitat capability map was created within the GIS environment having a 75.7 percent classification accuracy (optimum probability limit of 0.35) (fig. 2). The coefficients and standard errors of final model variables are shown in table 1.

Table 1.—*Coefficients and standard errors of final model predictor variables*.

Variable	Coefficient	Standard error
Intercept	-11.6341	2.9527
ELEV_01	2.2197	0.7849
AGE_CLASS	0.5822	0.2420
CROWN_CLOS	0.1083	0.0360

DISCUSSION

Several factors indicated the quality of the modeling process. The higher standard deviation values for the randomly selected polygons without confirmed nesting indicated that a broad range of non-nested or control polygons were used to generate the prediction model. Because the coefficient values are all greater than zero, each variable was positively associated with habitat suitability. The predictor variables derived through development of the model were available from forest cover and TRIM maps, and were therefore readily available for all areas of concern. Furthermore, the independent variables selected to derive the habitat suitability prediction model were biologically meaningful to Flammulated Owl nesting habitat and were highly associated with this habitat.

The small sample size of polygons with nest sites (n=33) affected the power of the multivariate analysis. For example, the variables that were excluded from the prediction model, site index and slope, may be important features for owl nests but were not analytically detected in the few polygons with documented nests. As the nest inventory work continues on Wheeler Mountain and surrounding sites, more samples will be available for the modeling process. For example, the 1996 project detected 13 new nest sites whose locations are now available for habitat modeling, bringing the sample size to 46. After each year of inventory, and with expanded inventory sites, the efficiency of the model should improve.

Since the nesting data used to derive the model was extracted using a point in polygon overlay, it is questionable whether this data is a good representation of the species' home range. Most polygons are considerably smaller than the estimated 3.0 ha home range size on Wheeler Mountain (van Woudenberg, unpubl.

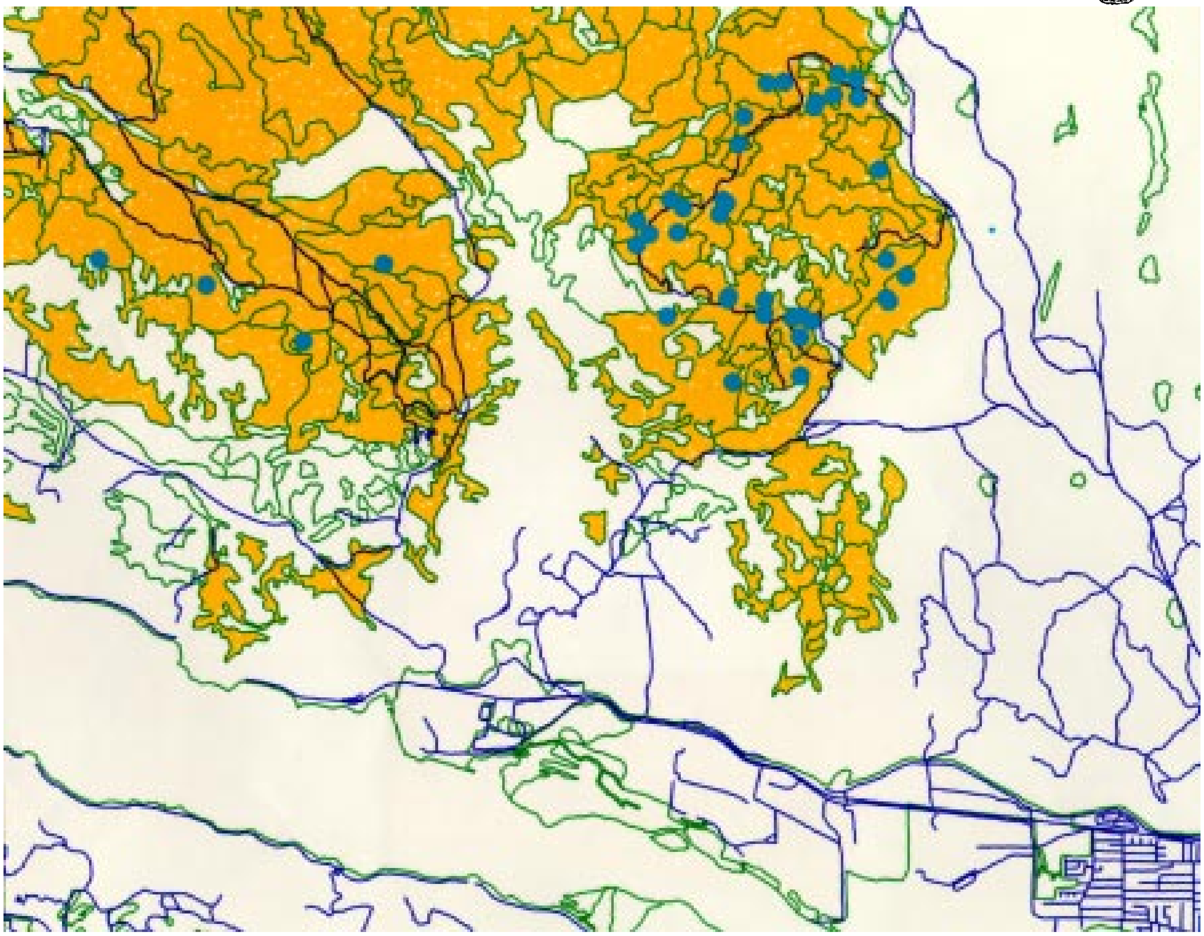

Figure 2.—*Predicted habitat for Flammulated Owls for the 1:20,000 scale forest cover map which encompasses the Wheeler Mountain study site, British Columbia. The shaded forest cover polygons are areas of predicted habitat. Circles represent documented nest site locations. The map also shows the northeastern outskirts of the city of Kamloops in the lower right corner.*

data). It would therefore be wise to refine the model using polygon overlays that are more representative of the home range. This would likely improve model accuracy by ensuring that adjacent polygons are not used as non-nesting polygons during model development and testing.

The data analysis used to generate the model did not include spatial relationships such as distance between nest sites which may be indicative of the owl's home range size. The distance between nest sites and water bodies and large openings may also be important. The owls tend to avoid large water bodies and riparian areas, likely due to their intolerance of humidity (McCallum 1994). The owls also seem to avoid nesting within several hundred meters of large openings (>1 ha), probably to reduce the risk of predation. Using a GIS buffering operation, buffers could be placed around riparian areas and large openings to exclude these features from predicted habitat.

The superiority of the Triangulated Irregular Network (TIN) elevation model for representing irregular terrain surfaces has been well documented (Burrough 1986, Peucker *et al.* 1978). For terrain modeling purposes, the collection of spot elevation data points should be dictated by the relief of the surface being modeled. TRIM map spot elevations were collected in a uniform grid pattern which did not reflect the terrain complexity of the mapping area. This terrain mapping will suffice for some purposes but may be inadequate for representing subtle terrain conditions that indicate the presence of critical habitat features. This has necessitated the investigation of surrogate elevation data sources.

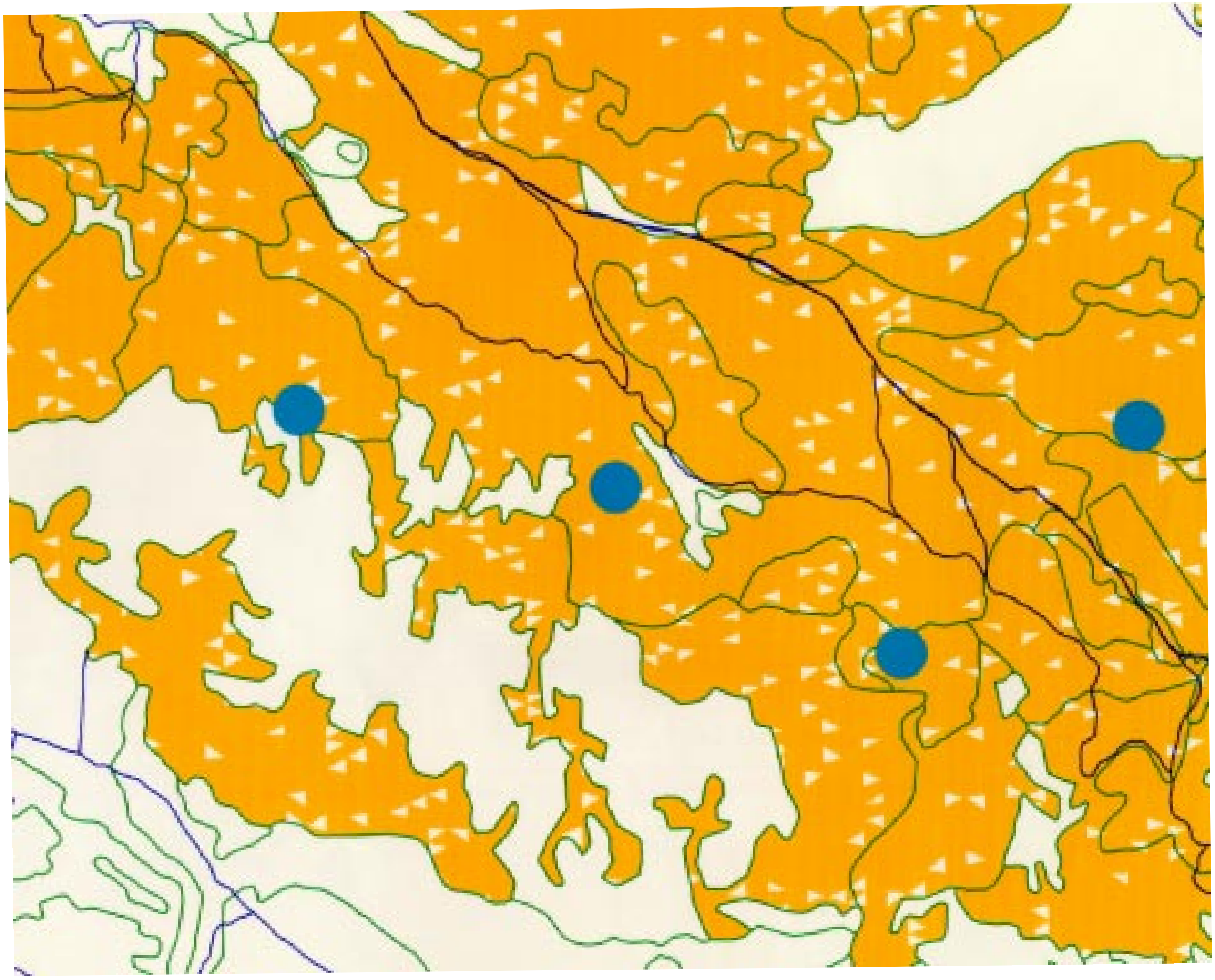

Figure 3.—*This portion of the pilot map shows an overgeneralized forest cover polygon at the Wheeler Mountain study site, British Columbia. This polygon contains the second nest from the left (circle). This nest site is located in a Douglas-fir dominated portion of the polygon while the remainder of the polygon is dominated by lodgepole pine unsuitable as habitat for Flammulated Owls. The triangles within polygons are also unsuitable Flammulated Owl habitat.*

Perusal of the final map identified problems with overgeneralized forest cover polygons based on the modeler's knowledge gained from field surveys in those sites. For example, one forest cover polygon covered a very large area and incorporated a variety of distinct stands of trees (fig. 3). The polygon was classed as 40 percent lodgepole pine cover. The area within the polygon where nesting occurred was large enough to constitute a separate polygon and contained 100 percent Douglas-fir cover. The polygon had been overgeneralized, perhaps by an inability of the photointerpreter to detect the differences in the forest cover. The problem is unavoidable for forest cover mapping when map makers lack field knowledge of the area and conditions being mapped. The problem may be ameliorated by relevant practical knowledge by the modeler or modeling team.

Temporally static data (sampled from a single period in time) is a potential downfall of many wildlife habitat models (Pereira and Itami 1991, Hodgson *et al.* 1987). Data collection replicated through time is necessary for proper identification of annual and seasonal habitat differences and occurrence of periodic fluctuations which affect a species' choice of habitat. Vernier *et al.* (1993) addressed the danger of classifying habitat based on one year's potentially atypical data. For example, Flammulated Owls in the Kamloops area may have responded to outbreaks of western spruce budworm (*Choristoneura occidentalis*) as an opportunistic food supply (van Woudenberg, unpubl. data). Sampling habitat during a single year of heavy outbreak may lead to classifying habitat that can be less productive in non-outbreak years. Productive habitat and habitat types shift with changing conditions, something that is impossible to detect without long-term studies.

Although habitat data has been collected from the Wheeler Mountain site for 6 years, the majority of the nest sites found to date were located between 1994 and 1996 (34 of 46 or 74 percent). The summer of 1994 was extremely hot and dry in the Kamloops area. The spring of 1995 was unseasonably mild and the summer was wetter than normal; the spring and summer of 1996 were colder and wetter than most recorded years (Dave Low, pers. comm.). These differences affected both the spatial distribution of nesting and the nesting success of the owls. It could be a costly mistake to assume that the sites detected in these years are completely representative of Flammulated Owl habitat use over time. Data collected over a longer time frame is necessary to obtain a range of habitat use over time.

Measuring habitat during one season may fail to detect habitat that is critical during other seasons. Van Horne (1983) identified social interactions within wildlife populations as a potential habitat classification problem. For some population structures, dominant breeding animals exclude more numerous, sub-dominant, non-breeding animals from highest quality habitat. Classification of habitat based solely upon density of animals, such as results from aural census for Flammulated Owls, would result in a model which identifies sub-optimal habitat as critical at the exclusion of optimal habitat. Protecting only sub-optimal habitat would negatively influence the breeding success and overall stability of the population.

The 75.7 percent classification accuracy of the Flammulated Owl habitat model was surprising because the model relied almost exclusively on forest cover variables. The absence of slope and aspect in the regression model was highly conspicuous. Terrain is perhaps the most significant determinant of wildlife habitat (StefanoviC and Wiersema 1985), particularly for areas with high relief. Pereira and Itami (1991) found slope, elevation and aspect to be statistically significant variables for their Mt. Graham red squirrel habitat model. The predominance of terrain variables occurred even though an equal number of vegetation variables were tested. Pereira and Itami suspected that the vegetation variables, determined to be critical from field research, were not detectable at the coarse resolution of the surrogate data used to model them. The importance of data resolution for detecting critical habitat features was also discussed by StefanoviC and Wiersema (1985) for their Ibex (*Capri ibex*) habitat model in the European Alps.

There is no explicit information regarding the spatial distribution of trees within forest cover polygons, although limited information may be implied from stocking density, volume, etc. Critical habitat variables that were too small to warrant classification as separate polygons, and were consequently grouped into a generalized polygon, present difficulties for modeling. Satellite imagery may also be used to supplement forest cover data for the Flammulated Owl habitat model. Stands with unique forest cover textures, where Flammulated Owl nest sites were most often found during nest site surveys, have been detected using aerial photographs. This texture, lost within a forest cover polygon, represents dense forest patches interspersed by openings <1 ha. The thicket and opening pattern indicates the juxtaposition of critical foraging and security habitat for the owl (van Woudenberg, unpubl. data). The introduction of RADARSAT's Synthetic Aperture Radar (SAR) 10 m resolution imagery to the modeling process should facilitate the detection of the small forest opening and dense patch pattern indicating Flammulated Owl habitat.

For an area as large as the Kamloops Forest Region, remotely sensed data is the only practical approach to uniform data collection. Data suitable for wildlife habitat modeling may be interpreted from aerial photographs or derived from satellite imagery (StefanoviC and Wiersema 1985). Remotely sensed variables may be used as surrogates for desired, high resolution variables if statistical correlations are established (Burrough 1986). Several other new data sources are now available such as 1 m resolution multispectral satellite imagery, sub-meter resolution aerial multispectral imagery and aerial laser topographic imagery.

High resolution digital orthophotographs are another possible source of data which are ideal for many GIS applications (Star and Estes 1990). While this data is more expensive to acquire per unit area, its possible utility for various different planning purposes should make it cost effective at the detailed planning level.

Habitat selection is a species-specific process where habitat features are chosen to meet life requisites. For example, a Flammulated Owl may, as first priority, select suitable foraging habitat before searching for a suitable snag or tree for nesting (van Woudenberg, unpubl. data). Lyon (1983) used separate sub-models to represent different biotic variables and their spatial relationships relative to habitat selection by American Kestrels (*Falco sparverius*) in Oregon. These sub-models were weighted according to their relative importance to the habitat being selected. Equal weighting of variables does not priorize habitat features according to life requisites and will inevitably lead to reduced model accuracy. In summary, Lyon (1983) suggested several conditions necessary for successful modeling of wildlife habitat:

1. model components [variables] must be quantifiable and have biological significance for the species to be studied;
2. the contribution of each sub-model must represent the relative importance of each habitat characteristic for the species;
3. field data must be available to develop the weights (train the model), and for verifying model sensitivity with the known characteristics of the species-preferred habitat; and
4. the land-cover types important to the species must be detectable from the remotely sensed data employed for the study.

The need for sub-models will be determined in part by the species' home range size and by the heterogeneity of its habitat. Flammulated Owl home range size at its northern range limit is relatively small, approximately 3.0 ha (van Woudenberg, unpubl. data), allowing nesting, foraging and security habitat to be modeled as one unit. If a species uses distinctly different habitat types over a large home range then it may be necessary to create several sub-models for that species' habitat. Careful consideration should also be given to infrequently used habitats which, although utilized for less than a few weeks out of the year, may be critical for the long-term sustainability of the species.

CONCLUSIONS

The pilot Flammulated Owl habitat prediction model was completed with promising results. A project team has been assembled with the relevant expertise, training, and experience to contribute to further success of the model. Several model limitations were identified and potential solutions will be applied to future models. The need to detect seasonal and annual variations in habitat and habitat selection necessitate a multi-year project duration. For habitat models to be effective they must address habitat as a dynamic entity. These models must possess the flexibility to adapt to both the habitat they represent and the growing body of habitat knowledge. The essence of this concept has been expressed by Harding and McCullum (1994) in *Biodiversity in British Columbia: Our Changing Environment*:

> "We have been reminded again and again of how much there is yet to learn about the biodiversity of our province. And even as we learn, identifying new species and tracing ecological relationships, the ecosystems around us are changing."

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