A Sensitivity Analysis of a Map of Habitat Quality for the California Spotted Owl (*Strix occidentalis occidentalis*) in Southern California

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Abstract.—Using a Geographic Information System (GIS), a sensitivity analysis was performed on estimated mapping errors in vegetation type, forest canopy cover percentage, and tree crown size to determine the possible effects error in these data might have on delineating suitable habitat for the California Spotted Owl (*Strix occidentalis occidentalis*) in southern California. The maps were developed as part of a project to map existing vegetation for the USDA Forest Service in southern California using Landsat Thematic Mapper satellite data, and GIS modeling. The research area is the San Bernardino National Forest, the largest contiguous area of spotted owl habitat in southern California, with a large and thoroughly surveyed spotted owl population. Map error was estimated using error matrices based on comparing the final map output to expert photointerpretation of a number of locations. The simulation of map uncertainty resulted in an increase in suitable habitat area with changes in vegetation classification. There was no significant increase in the number of actual known spotted owl locations found with modeled areas of suitable habitat. Fragmentation analysis of the additional patches showed a possibility that the additional patches were too small and fragmented to be useful as actual habitat areas. This research will generate different map realizations for a population model being developed for the USDA Forest Service.

The population of the California Spotted Owl (*Strix occidentalis occidentalis*) in southern California is declining and the cause is not known (Anderson and Mahato 1995, LaHaye et al. 1994, Verner et al. 1992). Even if this decline is temporary, Lehaye et al. (1994) believe that the southern California metapopulation could be extinct within 40 years. Both the Northern and Mexican Spotted Owls (*S. o. caurina* and *S. o. lucida*) have been given the status of threatened by the U.S. Fish and Wildlife Service because of population decline due to loss of habitat (LaHaye et al. 1994, Verner et al. 1992). However, the California owl, which inhabits the Sierra Nevada and the Peninsular ranges of southern California, is listed as sensitive under the Endangered Species Act (LaHaye et al. 1994), and as a species of Special Concern by the State of California (Gutierrez et al. 1995). While not protected by law in the same manner as a threatened or endangered species (Greif 1995), this classification still describes the danger of a population in severe enough decline that extinction is a possibility if current management trends continue (Roberts 1993).

Although the California Spotted Owl does not require as large a territory as the Northern Spotted Owl, the amount of range the owl does require in southern California is in conflict with urban and residential expansion (Verner and Taylor 1992).

In the Hearing of the Subcommittee on National Parks, Forests, and Lands of the 104th Congress, the fact that the California Spotted Owl was classified as sensitive rather than endangered led politicians to argue that the management of this species was expensive, unnecessary, and politically dangerous (California Spotted Owl Recovery Plan Hearing 1994). The vigorous debate which seemingly

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pits politicians and economists against ecologists and academics could be seen as a test of the values which have guided our resource management agencies in recent years (Gutierrez et al. 1995, Yaffee 1994). The intensity of political debate has overshadowed the fact that much still needs to be learned about the life history and ecology of the owl in order to develop a plan for the conservation of this species (Gutierrez et al. 1995, Verner et al. 1992). Explicit characterizations of habitat requirements for the California Spotted Owl still must be assumed. These assumptions could make the conclusions of habitat models cur-rently being developed highly suspect, and possibly too general for the critical habitat designation of a sensitive or possibly threatened species (Heinen and Lyon 1989, Verner and Taylor 1992). Isolating the variables, whether based on owl life history, environmental factors, or human interference, which are critical to the California Spotted Owl, is now essential for the owl's survival. Population simulation models, designed to investigate the influence of these variables, have been used to examine the viability of Spotted Owl populations (Doak 1989, Lande 1988, Schumaker, in press).

The focus of our research is aimed at one of the pitfalls of computer simulation modeling, especially the modeling of habitat in large ecosystems. Simulation approach models are "...only as good as the data on which they are based" (Moffat 1994). Problems of data availability can be avoided in these population models, provided there is a thorough analysis of the sensitivity of the results to changes in model parameters (Durant and Mace 1994). This can also be true for the error inherent in data analysis and classification based on combining Geographic Information Systems (GIS) and remote sensing mapping procedures. When using these procedures to model habitat suitability, the errors created by mapping processes, especially data classification, can effect the model critically, and some measure of this uncertainty should be known (Goodchild 1994). We attempted to characterize this uncertainty by ascertaining how sensitive habitat suitability predictions might be to reasonable assumptions of mapping process error. This knowledge can be used to more accurately isolate the importance of population model parameters.

John Stephenson (pers. comm.) suggested three map classification criteria that are supposed to be the most important in the delineation of California Spotted Owl habitat: vegetation type, forest canopy cover percentage, and tree crown size. We chose an area in southern California (the San Bernardino Mountains) with a large, well-documented population of owls (LaHaye and Gutierrez 1994, Stephenson 1991). Estimating reasonable error in the mapping procedures, we then performed a sensitivity analysis to ascertain the resulting differences in delineation of habitat suitability areas using a GIS map overlaying procedure. Differences were evaluated based on comparisons with known owl locations and by other criteria. In this way, the susceptibility of the habitat suitability map to data error was quantified, and different realizations of the habitat areas with corrections based on estimated map inaccuracies were made available for the population modeling process being done for the owl by the USDA Forest Service.

The Nature of Wildlife Habitats and Habitat Models

There has been an increase in wildlife habitat modeling recently, but it has been noted that empirical testing of these models has been neglected (Chalk 1986, Stoms et al. 1992). Predictive wildlife habitat models, often created deductively by using expert opinions of relationships and variables, can potentially lead to erroneous conclusions. When the model wrongly predicts species presence, and the species is absent, this is a Type I error. If the model is used to purchase, or set aside land for habitat, this could be costly. When the model wrongly predicts absence, and the species is present, or a Type II error, this can be more critical, for example, when the model is being used to predict impacts on habitats for endangered or threatened species (Morrison et al. 1992).

In summary, wildlife habitat models examine a complex system. An attempt must be made to identify all the important components of this system with as much accuracy as possible and relate them to one another. They must be well understood and evaluated for accurate prediction of future events (Anderson and Gutzwiller 1994).

Evaluating the Sensitivity of Habitat Suitability Models

In complex decision-making, sensitivity analysis for modeling land use suitability is originally an urban planning concept, an experiment that involves a systematic manipulation of variables or factors within a study to see how other variables are affected. This can ensure that criteria are relevant and reduce uncertainty, testing the robustness, or imperviousness to perturbation of the decision model (Alexander 1989).

Lodwick et al. (1990) describe a sensitivity analysis using a GIS. The analysis is defined as "...the study of the effects of imposed perturbations (varia-tions) on the inputs of a geographical analysis on the outputs of that analysis." The ability of a GIS to perform a task "...repetitively with unchanging precision makes it an effective tool for this type of modeling" (Lowry et al. 1995).

Stoms et al. (1992) estimated the sensitivity of habitat models to uncertainty in input data for the endangered California Condor (*Gymnogyps californianus*). He concluded, that for GIS, there is a need to acknowledge and quantify uncertain-ties and "...increase our confidence that GIS-based analysis provides us with a reasonable model...of (wildlife) habitat."

Habitat Fragmentation

Error in mapped habitat variables not only affect their total estimated area, but the estimated spatial arrangement of habitat patches as well. The size, shape, spatial distribution, and density of patches create the degree of habitat fragmentation within a landscape (Ripple et al. 1991). Habitat fragmentation was used in this research as a tool to analyze the effects of the sensitivity analysis model on output habitat patches. Fragmentation can be defined by its actions, a reduction in habitat area, and an increase in the isolation of habitat patches (Morrison et al. 1992, Wilcove 1985).

Fragmentation can lead to the isolation of a population causing increased risk from natural catastrophes, genetic inbreeding depression, or demographic variability. It has been shown that for species associated with forest interiors, especially populations associated with a specialized forest stand type, such as the Spotted Owl, the degree of fragmentation will cause a corresponding decline in population (Hunter et al. 1995, Morrison et al. 1992, Usher 1987). The idea of fragmentation also addresses such issues as the effects of habitat patch size and connectivity on Spotted Owl population stability. Gutierrez and Pritchard (1990) predict that the ability of juvenile owls to find vacant habitat will be critical to the health of populations in managed forests.

THE CALIFORNIA SPOTTED OWL

Geographic Range of the Spotted Owl in Southern California

The entire range of the California Spotted Owl is from the southern Cascades through the Sierra Nevadas, throughout the mountain ranges of southern California, and into the central Coast Ranges into Monterey county (Beck and Gould 1992). Gutierrez et al. (1995) extend the range south to Sierra San Pedro Martir in northern Baja California. In southern California, the Spotted Owl is found on 11 major mountain ranges (fig. 1). The majority of Spotted Owl populations in southern California are on National Forest lands, including the Angeles, San Bernardino, Cleveland, and Los Padres National Forests (Beck and Gould 1992).

Patterns of Habitat Use

California Spotted Owls occur in three distinct forest types in southern California. The distribution of these types is generally divided by elevation, with a riparian hardwood habitat below 1,200 m, Douglas-fir (*Pseudotsuga menziesii*)/live oak woodland (*Quercus* ssp.) forest between 900 and 1,800 m, and mixed conifer between 1,500 and 2,400 m. Forty-one percent of the owl sites in southern California occur in the big-cone Douglas-fir/live oak woodland community. The patches of forest they inhabit are dense and mature, requiring between 200 and 1,000 ha of forest per pair of birds (Verner et al. 1992).

California Spotted Owls are intolerant of high temperatures, seeking cool, shaded, thick (greater than 70 percent canopy cover) nesting sites. They avoid grasslands, chaparral, and open-canopied habitats (Gutierrez and Pritchard 1990, Verner et al. 1992). Nesting trees are usually large, with a diameter at breast height

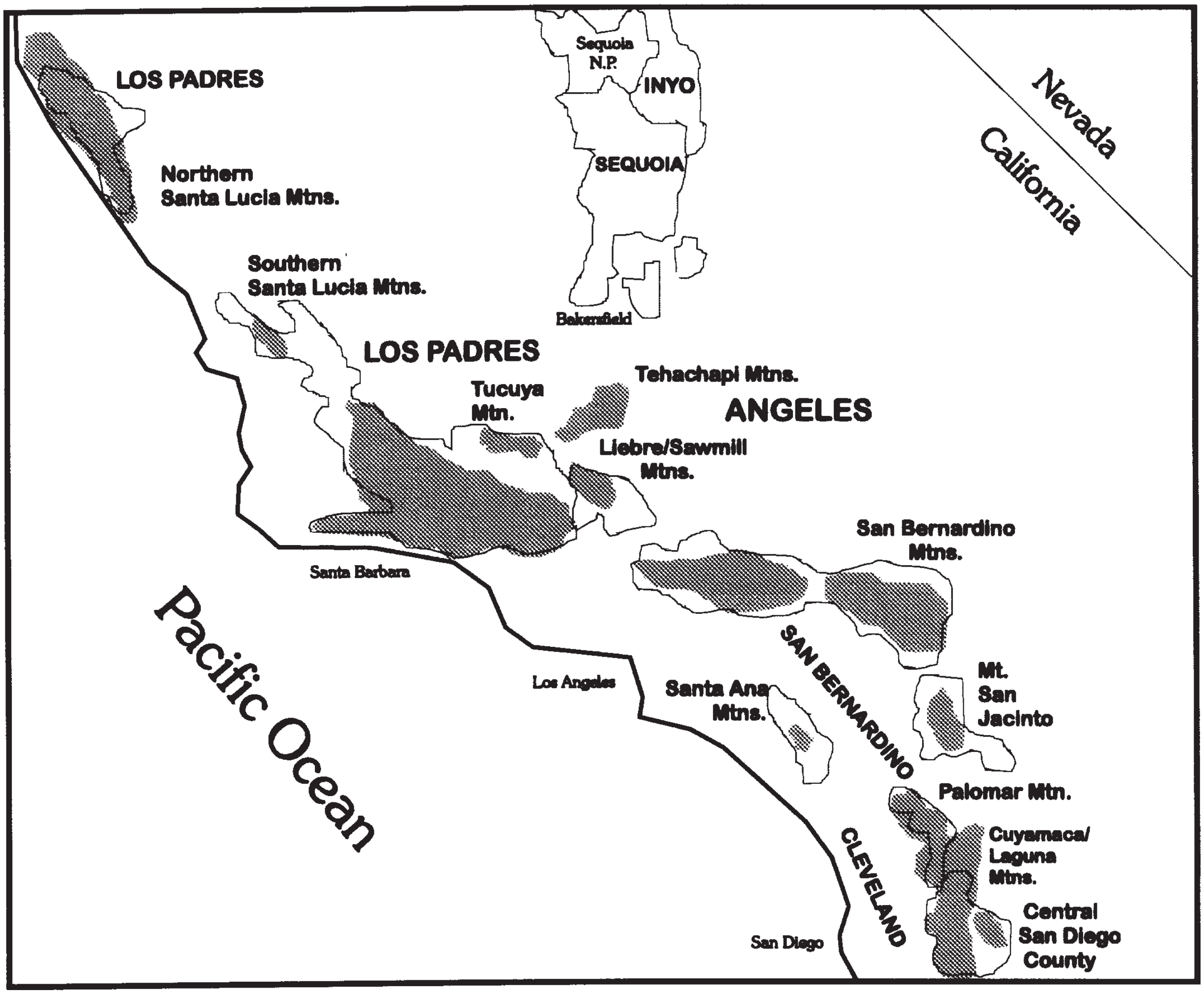

Figure 1.—Shaded areas show islands of population for the southern California Spotted Owl in Cailifornia. Source: Verner et al. (1992).

of around 94 cm. Foraging areas are similar, but usually have lower canopy cover, usually 40 to 70 percent. The forest structure is usually complex, with trees in different diameter classes, but with a uniform presence of large trees greater than 90 cm diameter at breast height (Verner et al. 1992).

There are gaps between the isolated mountain ranges that constitute owl habitat in southern California that may restrict movement. The separation of suitable habitat by areas of urban development, major highways, and hot, dry lowlands is a major problem for owl dispersal. A primary concern is that this isolation will worsen. Major threats to southern California habitats include increased areas of urbanization and recreation, wildfires, and groundwater extraction. There are considerable private land holdings within National Forest boundaries which include heavily trafficked, rapidly developing recreational areas (Beck and Gould 1992). For example, in the San Bernardino National Forest, if these present trends continue, including the rapid growth of mountain resorts like Lake Arrowhead, the owl population is expected to decline by 50 percent in 4 years (LaHaye and Gutierrez 1994, Noon and McKelvey 1992, Stephenson 1991). It is becoming clear that the most important habitat variable for spotted owls in southern California is the distribution and shape of contiguous areas of suitable habitat (Gutierrez and Pritchard 1990, Lamberson et al. 1994).

METHODS

Description of the Study Area and Owl Sighting Data

The area used for this study is the San Bernardino Mountains, which are contained within the San Bernardino National Forest (fig. 2). Seventy km (43 miles) east of Los Angeles, these mountains are the largest contiguous area of suitable California Spotted Owl habitat in southern California (LaHaye and Gutierrez 1994). The Spotted Owl population here is also the largest in the southern California region, and the most thoroughly surveyed (Stephenson 1991). Since 1987, LaHaye and Gutierrez have made yearly population surveys. This area (1,890 km^2) is bounded on the north, east, and south by the National Forest boundary, and on the west by Interstate Highway 15 (LaHaye and Gutierrez 1994). This population is large enough (145 known territories) for demographic studies, but at the same time, small enough to monitor.

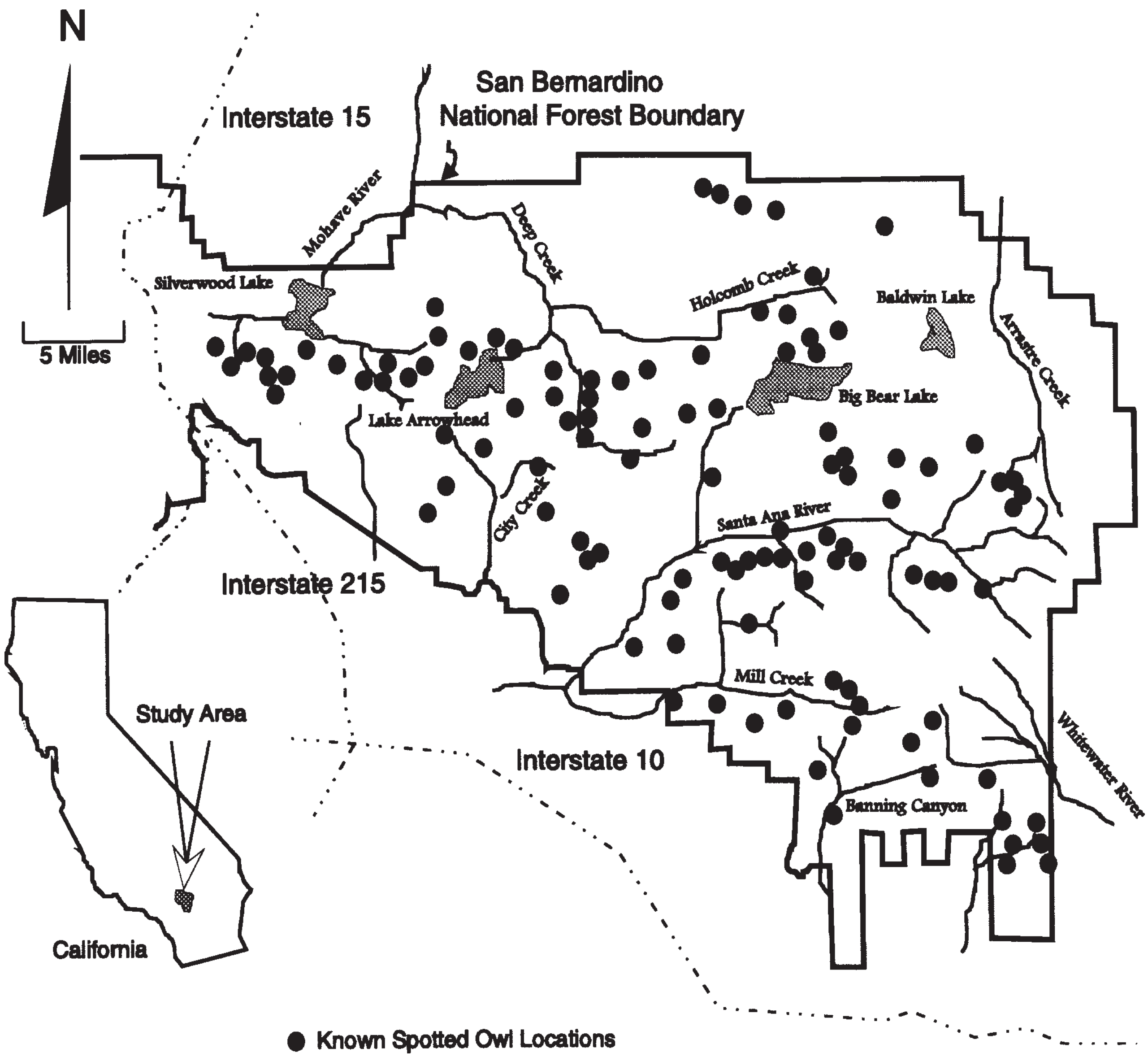

Figure 2.—The San Bernardino mountains Spotted Owl study area, southern California. Source: LaHaye and Gutierrez (1994).

This research uses 629 known owl sightings documented by LaHaye and Gutierrez (1994). The locations of each sighting were recorded in UTM coordinates, and digitized into an Arc/Info point coverage. This point coverage was then converted into a Grid raster coverage with 25 x 25 m pixels for analysis. Due to overlapping locations within pixels, there are 428 pixels in the Grid raster coverage that contain owl locations.

Description of Vegetation Data

The data used in this study to represent mapped habitat variables are the result of a project utilizing remotely sensed data and GIS-modeling to map existing vegetation in the National Forests of Southern California for the USDA Forest Service. These maps provide a digital database of existing vegetation and forest cover and structure for land cover inventory, ecosystem management planning, and timber inventory of National Forest lands (Franklin and Stephenson 1996, Franklin and Woodcock 1997). The software used included Image Processing Workbench, and ARC/INFO Grid as a GIS. The Calveg vegetation classification system was used. This is a standard statewide vegetation classification system developed by the USDA Forest Service (Forest Service, Region 5, 1994). The attributes of these vegetation maps included vegetation classes, as well as estimates of canopy cover and tree crown size, and they were in a GIS database.

Accuracy Analysis of Map Data

The reference data used to estimate the accuracy of vegetation classification, canopy cover percentage, and crown size class were gathered as training sites by Harry L. Bowlin, a professional forester and consultant for the mapping project. He photointerpreted stands of designated vegetation classes, and estimated canopy percentage and crown size class for each stand. We created error matrices (Jensen 1996) by comparing the vegetation class and attributes of each stand (126 conifer stands, 97 hardwood stands) to the classes and values for the same stands in the digital maps. Based on the resulting error matrices, estimates were then made of the approximate error in the map labels.

Description of Sensitivity Analysis

The maps used in the sensitivity analysis were derived from the final map products delivered to the Forest Service (figs. 3, 4, and 5). These were produced in ARC/INFO Grid format with 25 m pixels, and a subarea was selected to represent the major owl habitat area.

To implement the changes in the maps which would represent the estimated mapping errors in vegetation class, canopy cover, and crown size found in the error matrix, programs were written in Arc Macro Language (AML) to mask ARC/INFO Grid pixels into the original polygons, and then randomly choose a specified percentage of pixels from the segments of each class, and change them into another class.

The percentages of pixels to be reassigned among the different classes were derived from the error matrices and inserted into the AML programs, which were then used to assign randomly located changes in class labels in a series of 10 replications each for the vegetation, canopy cover, and crown size maps of the area. Then the resulting maps were combined into six combinations of map change scenarios for a total of 60 iterations. The map classes were given scores of habitat value (1 through 99) using a score assessment developed by John Stephenson (pers. comm.). We then chose, in consultation with Stephenson, a threshold value of 27 to distinguish between suitable and unsuitable habitat. The area of vegetation types important as spotted owl habitat (Douglas-fir, mixed conifer, black oak (*Quercus kelloggii*), and live oak (*Quercus* ssp.) woodland) were compared with the original forest map. Also areas of canopy cover and crown size classes were compared with values in the unchanged map. The ability of these simulated corrections to significantly alter the resulting habitat suitability map was analyzed. A Wilcoxon signed rank non-parametric test was used for all significance tests, and the null hypothesis of no difference was rejected when $p < 0.05$.

Binary maps were then created from the 60 altered maps and the original unchanged map of either acceptable (1) or unacceptable (no data) areas for owl habitat based on a threshold value of 27 for suitable habitat. The area of

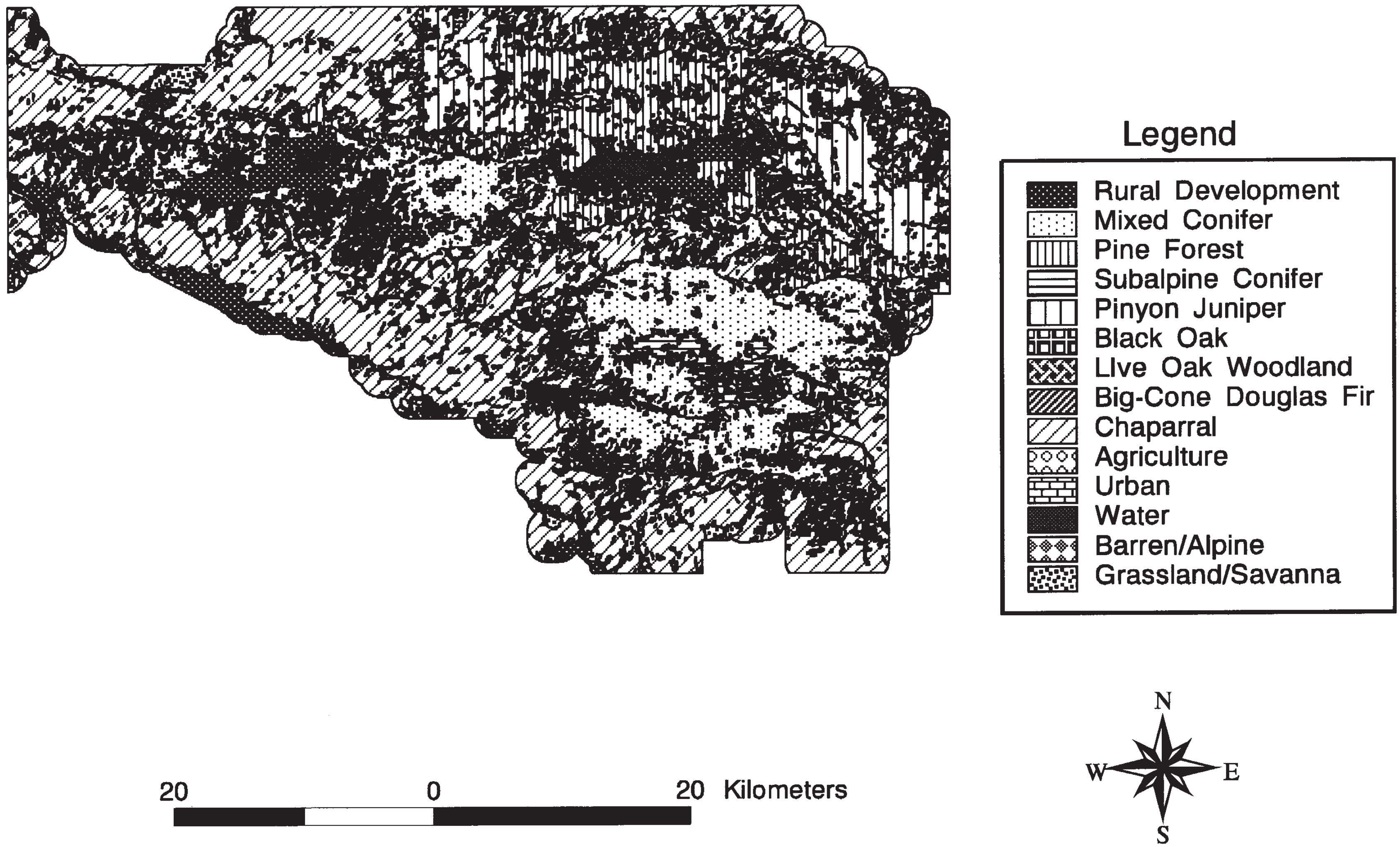

Figure 3.—Vegetation map of the San Bernardino National Forest, California, including 1.6-km (1-mile) buffer around the forest boundary. Source: U.S. Forest Service, Region 5.

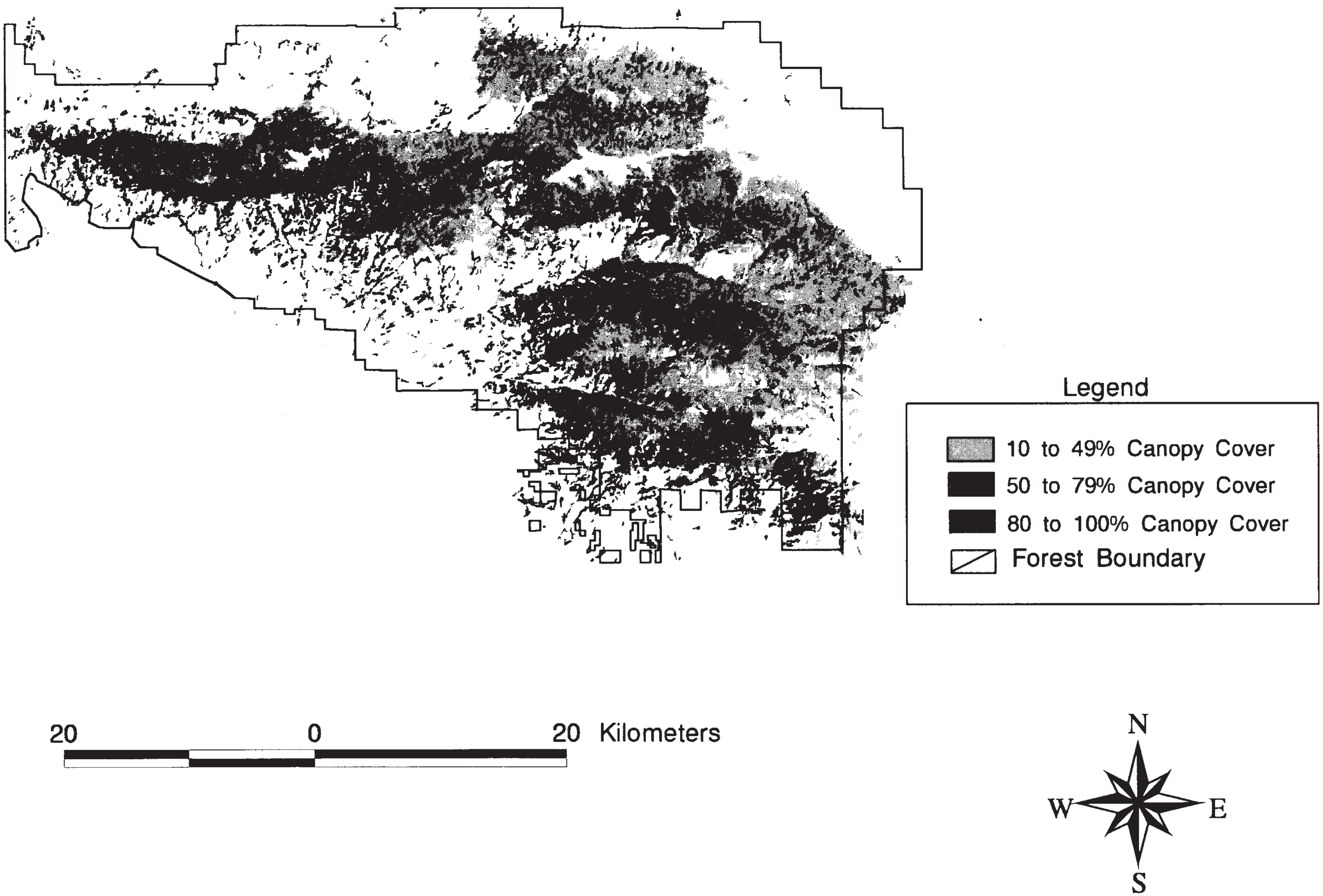

Figure 4.—Canopy cover class map of the san Bernardino National Forest, California. Source: U.S. Forest Service.

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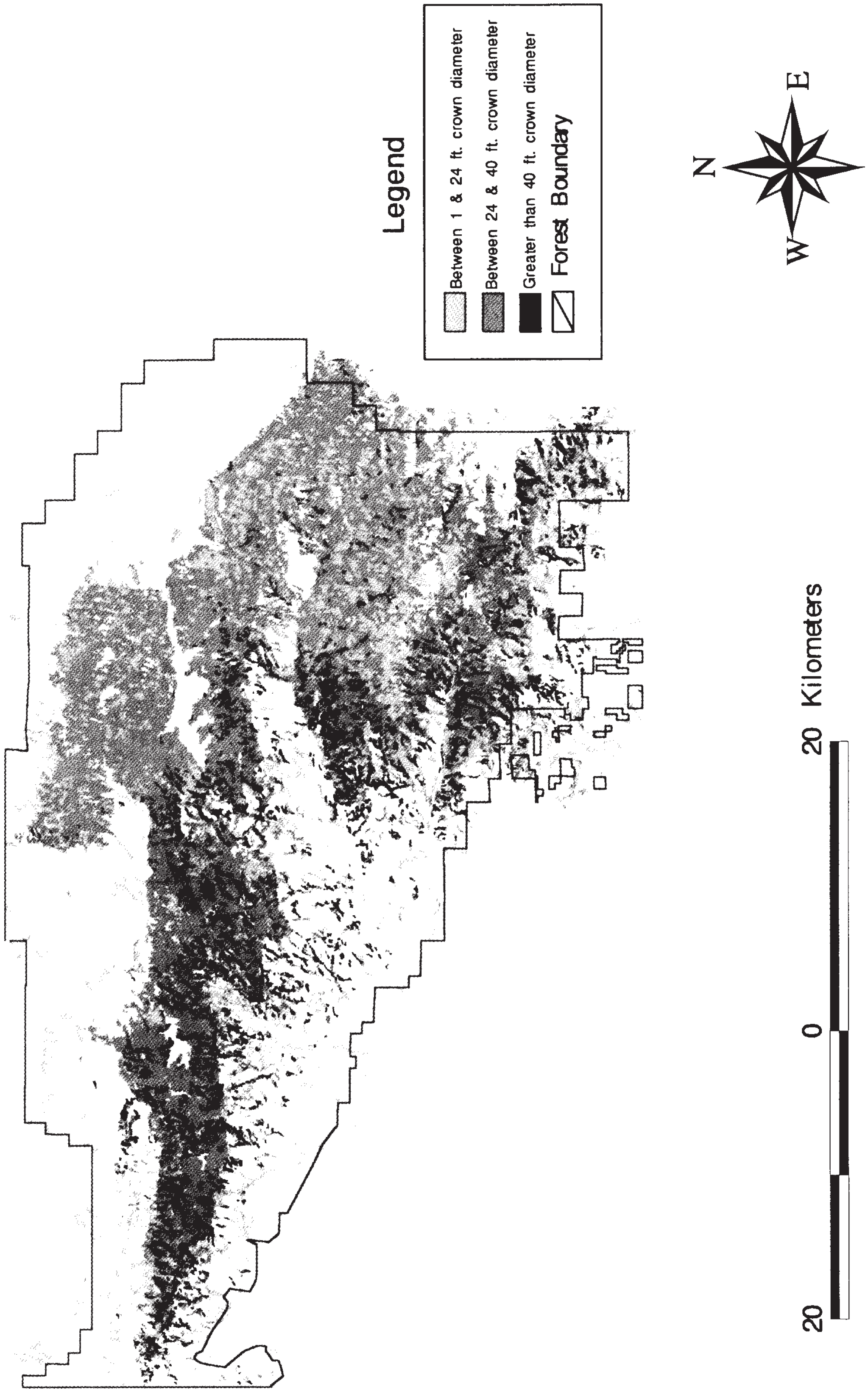

Figure 5.—*Crown size map of the San Bernardino National Forest, California. Source: U.S. Forest Service.*

Figure 5.—Crown size map of the San Bernardino National Forest, California. Source: U.S. Forest Service.

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acceptable habitat in each of the 60 binary maps was compared with the original map. We then compared the difference in the ability of the original habitat suitability map and those with simulated corrections to capture the actual documented owl sighting locations.

Analysis of the Effects of Simulated Map Error on Landscape Patterns of Habitat

The landscape pattern analysis software FRAGSTATS was used to evaluate the effect of simulated map corrections on spatial patterns in the predicted owl habitat (McGarigal and Marks 1994). The 60 binary maps of habitat/non-habitat were evaluated using seven landscape indices chosen to best represent the changes in the spatial pattern of the habitat and the landscape. More detailed explanations of those specific indices can be found in McGarigal and Marks (1994), and Ripple et al. (1991). As in Ripple et al. (1991), the measures chosen were related to the size, shape, distribution, and density of habitat patches. For each index, the mean values for each combination of changed maps were then compared to the values for the original map.

RESULTS

Estimating Map Uncertainty and Creation of the Sensitivity Model

Table 1 shows a sample of the error matrices created to assess the accuracy of the vegetation types, as mapped for both conifer and hardwood species. The overall accuracy for vegetation classes sampled was 73 percent. Based on the error matrix, decisions were made concerning the directions and percentages of changes for each vegetation class concerned.

Here is an example of how the resulting rules were used to create the input maps for the sensitivity model. The rules were mostly formulated by using the net omission and commission errors within each category. For example, 21 percent of the samples mapped as black oak were photointerpreted to be live oak woodland, while 3 percent of the live oak woodland stands in the map were photointerpreted as black oak. Therefore, in the simulation, we designated that 18 percent of the black oak pixels would be changed to live oak woodland in the map replicates. In the same manner, 17 percent of mixed conifer pixels were changed to black oak, 16 percent of Douglas-fir to live oak woodland, 7 percent of subalpine conifer to mixed conifer, and 4 percent of mixed conifer to live oak woodland.

Since chaparral is so extensive in the San Bernardino forest area, some of the chaparral pixels, if chosen randomly by the model and assigned a forest vegetation type, would land in totally improbable habitat areas. Since southern California Spotted Owls are known to prefer riparian areas, we created a 200 m buffer around streams (John Stephenson, pers. comm.), and the chaparral pixels within that restricted area were used to simulate labeling errors between chaparral and forest classes. Based on estimated commis-sion and omission errors, we estimated a 10 percent net error. The amount of pixels in-cluded in the stream buffer was approximately 50 percent of the

Table 1.—Error matrix of vegetation class accuracy for the San Bernardino National Forest, California, showing the true class membership of training sites based on photointerpretation, versus the label received in the original map.

	N=227	MAPPED							
		Black oak	Live oak woodland	Mixed conifer	Jeffrey pine	Douglas fir	Subalpine conifer	Chaparral	Row total
TRUE CLASS	Black oak	22	1(3%)	8(17%)				2	33
	Live oak woodland	6(21%)	29	2(4%)	0	5(16%)	0	(31%)19	61
	Mixed conifer	0	0	30	2(6%)	0	0	0	32
	Jeffrey pine	0	0	2(4%)	30	0	0	0	32
	Douglas fir	0	0	1(2%)	0	27	0	(13%)4	32
	Subalpine conifer	0	0	3(7%)	0	0	27	7	37
	Column total	28	30	46	32	32	27	32	227

Percent Training Sites Correctly Classified = 165/227 = 72.69%

total pixels for chaparral, so 5 percent of the buffered chaparral pixels were randomly changed to live oak woodland, and another 5 percent to Douglas-fir.

For canopy cover and crown size, the overall accuracy showed poor agreement, particularly for the hardwood species. Specific biases were noted towards class 2 in conifer cover, class 4 in conifer size, and class 3 in hardwood size. Similar vegetation mapping projects have also shown that especially the size estimates derived with these methods are unreliable (Woodcock et al. 1994). Also, the sample size per class was quite small, even to develop rough estimates of the direction and magnitude of map error. Therefore, for both canopy and size, it was decided to first add an increase of one class to 10 percent of randomly selected pixels in each class, and then subtract a class from 10 percent of the pixels in each class.

Implementation of the Sensitivity Model

After the habitat value scores were applied to the 60 simulated maps, binary maps were created for each one showing the number and pattern of acceptable habitat pixels using the threshold habitat score of 27. Figure 6 depicts the variation in class area among map iterations as compared to the original number of pixels for mixed conifer, black oak, live oak woodland, and bigcone Douglas-fir. For canopy cover and crown size, the differences are not as great because we changed fewer pixels. Table 2A summarizes the results of these significance tests. The p-value in each case shows that the differences were significant.

In the binary maps of suitable/non-suitable habitat, the simulations added to the number of acceptable habitat pixels in the original map (fig. 7). This is due to the nature of the errors

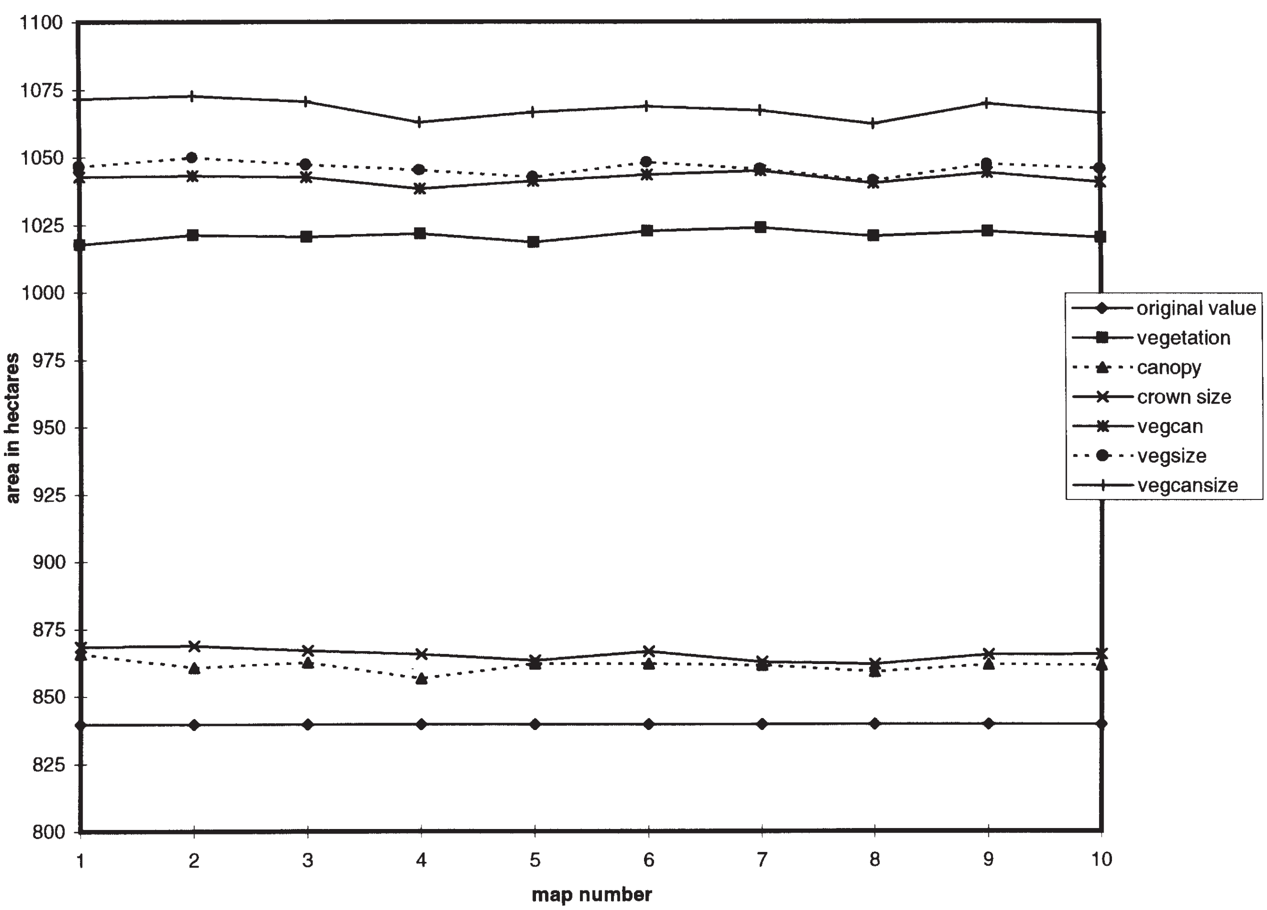


Figure 6.—Results of sensitivity analysis, San Bernardino National Forest, California: Suitable habitat areas for each corrected change category: Vegetation, canopy cover, and crown size changes; changes in vegetation and canopy cover (vegcan); in vegetation and crown size (vegsize); and in vegetation, canopy cover, and crown size (vegcansize).

Table 2.—Sensitivity analysis results, San Bernardino National Forest, California: (A) Changes in areas of single map categories; (B) Changes in combinations of map categories; (C) The difference in numbers of known owl locations falling within suitable habitat with different types of map corrections (number of pixels with a suitable habitat score ≤ = 27). Original value = 233 pixels. Note: All values are in pixel counts.

Variable	Original Value	Mean	Standard Deviation	p-value 95% confidence interval
mixed conifer changes	726487	597603	1084	0.0022
black oak changes	27959	146064	923	0.0022
live oak woodland changes	103259	188888	1367	0.0022
bigcone douglas fir changes	83758	108466.4	828	0.0022
canopy category 10 changes	353770	361334	673	0.0059
canopy category 20 changes	539994	550838	487	0.0022
canopy category 30 changes	548286	529776	521	0.0059
size category 1 changes	283867	304190	855	0.0022
size category 2 changes	874865	864175	866	0.0059
size category 3 changes	283318	273686	309	0.0022

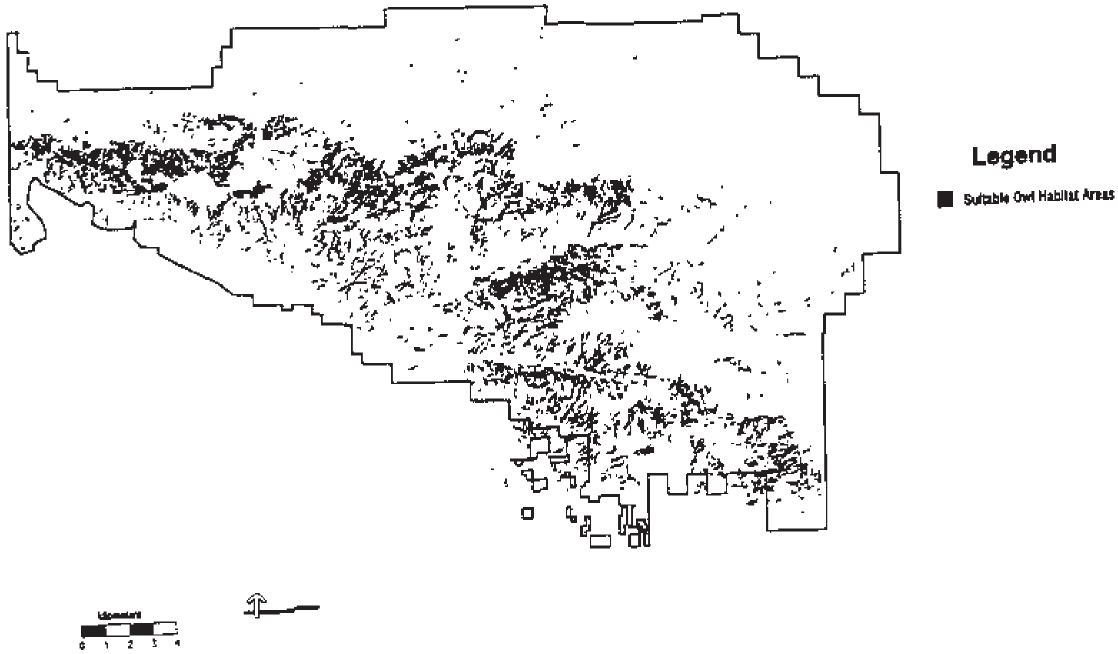
(A)

Variable	Original Value	Mean	Standard Deviation	p-value 95% confidence interval
veg-class changed	335819	408376	717	0.002
canopy % changed	335819	344515	903	0.002
crown size changed	335819	346205	870	0.002
veg & canopy changed	335819	416850	756	0.002
veg & size changed	335819	418354	962	0.002
veg & canopy & size changed	335819	427113	1308	0.002

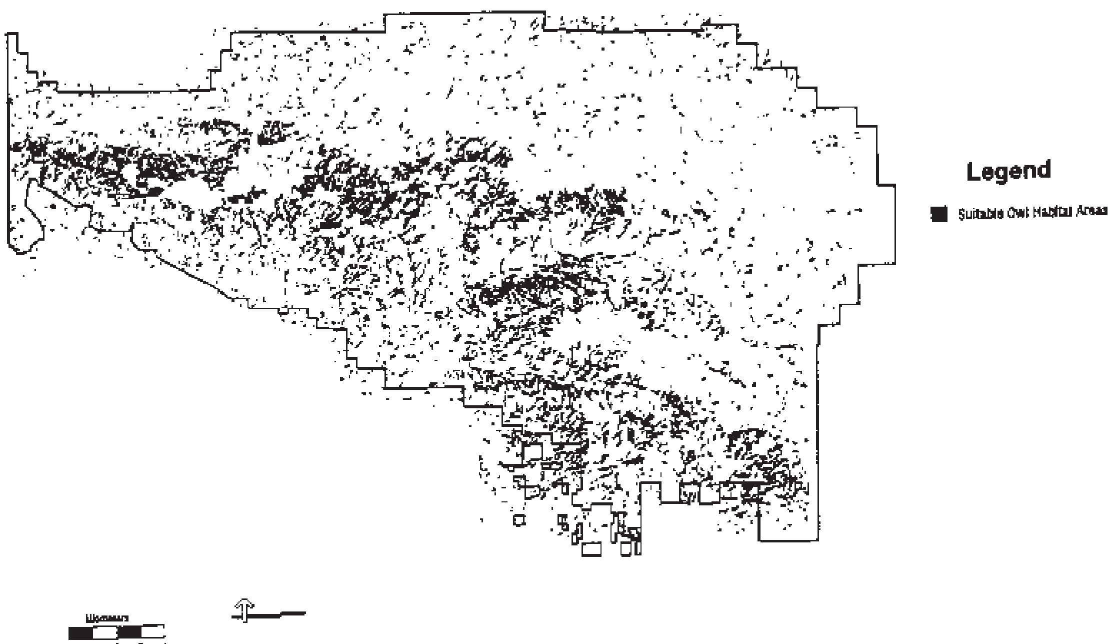
(B)

Variable	Mean	Standard Deviation	p-value 95% confidence interval
veg-class changed*	233.5	3.35	0.5239
canopy % changed*	234.1	2.59	0.2309
crown size changed*	235.7	2.28	0.0126
veg & canopy changed*	234.2	4.42	0.4738
veg & size changed*	235.4	3.93	0.0577
veg & canopy & size changed*	235.6	5.18	0.2198

(C)



(A)



(B)

Figure 7.—Results of sensitivity analysis: Comparison of binary maps of suitable habitat area (pixels with a suitable habitat score HS ≤ 27). (A) Suitable habitat in original map; (B) Suitable habitat in map resulting from all combinations of map changes.

in the original map that consisted of omissions from important habitat types. For changes only in canopy cover, this amounted to around 25 ha, with size changes adding slightly more. Changes in vegetation classes consistently added more pixels, with just vegetation class simulations adding at least 175 ha, and increasing with further changes, adding almost 25 more ha per map when all three attributes were altered. Table 2B shows significant differences due to these changes.

We then examined the number of actual owl sighting locations contained in predicted areas of suitable habitat to see if the different combinations of map changes had a significant effect on the number of those locations. The results were not statistically significant in all instances except changes in crown size (table 2C).

Summary of Landscape Pattern Measurements

The various map simulations affected the fragmentation indices significantly, in all of the combinations of vegetation changes (table 3). Only canopy and crown size changes for Patch Size Standard Deviation and canopy changes for the Double Log Fractal Dimension did not change the fragmentation indices significantly. This is interpreted as resulting from the methods employed in this research: we changed fewer pixels for canopy and crown size than for vegetation classes.

DISCUSSION AND CONCLUSIONS

Changes in vegetation class labels, especially combined with changes in canopy and crown size, created landscapes with a greater number of patches, smaller, closer together, with greater variation of size, and less complicated shapes. In weighing these factors, some, such as a greater number of patches that are closer together, and in less complicated shapes, seem to denote a landscape area with a more favorable configuration of Spotted Owl habitat. At the same time, these smaller patches, with less uniform size, seem to suggest an actual pattern of habitat that is more fragmented and possibly unsuited for the long-term survival of the species.

Figure 7 is a binary map of suitable habitat area from the original map as compared to the same showing pixels added by all combined change combinations. The maps show that much of the suitable habitat area added in the simulations is outside of the higher mountainous areas and in the riparian buffer in the chaparral zone. The vegetation class labels were changed to correct estimated map errors, and therefore the majority of pixels added were to black oak, live oak woodland, and Douglas-fir classes. Pixels were lost from higher elevation conifer categories such as mixed conifer and subalpine conifer. This possible incorrect assignment of vegetation classes in the original, or unchanged, forest map could have been caused by the criteria used for life form classification by the USDA Forest Service. The rule that conifer stands were defined as having ≥10 per-cent of conifer cover (Franklin and Woodcock 1997) caused mixed conifer/hardwood stands to have a primary vegetation class label corresponding to a small percentage of conifer com-position.

While riparian areas suitable for Spotted Owl habitat were added in the simulations, the correspondence between numbers of known Spotted Owl locations, and the number predicted from the habitat map, was not significantly increased by adding these areas. Scale could have been a factor in the number of known Spotted Owl locations captured in both the original and corrected, or simulated, maps. Hunter et al. (1995) found that spatial scale was a critical factor in finding land cover types that include Spotted Owl nests. The minimum mapping unit of the vegetation map for this research, as represented by the size of each polygon, may have been too large for the accurate measurement of small narrow riparian areas used as potential owl nesting sites. The generalization of vegetation classification within each polygon can miss detecting small topographic features within the landscape that are important as suitable habitat areas. Bowser (1996) concluded that the resolution of GIS map layers can impose an unrealistic decision-scale when representing the ecological restraints of an animal. In a case such as this, where the minimum mapping unit of the map is suspected of not identifying potentially important habitat features, further testing could be done. A sample area could be chosen, and the automated polygon delineation redone at a smaller scale before the life form classification. Then the mapping process could be completed and the sensitivity analysis redone. A smaller minimum mapping unit, however, may introduce cost or computer space constraints due to increases in computer usage.

Table 3.—Sensitivity analysis results: differences in landscape fragmentation indices between original and corrected maps with different types of map changes.

Variable	Original Value	Type of Map Correction	Mean	Standard Deviation	p-value 95% confidence interval
SIZE					
Mean Patch Size		vegetation	10.13	0.13	0.0022
		canopy	17.68	0.16	0.0025
	18 hectares	size	17.51	0.16	0.0022
		veg-can	10.12	0.14	0.0022
		veg-size	10.13	0.14	0.0022
		veg-can-size	10.12	0.15	0.0022
Patch Size Standard Deviation		vegetation	55.80	3.38	0.0022
		canopy	87.32	1.71	0.7695
	87 hectares	size	86.01	4.25	0.7695
		veg-can	55.97	3.02	0.0022
		veg-size	56.36	4.00	0.0022
		veg-can-size	56.49	3.30	0.0022
SHAPE					
Double Log Fractal Dimension		vegetation	1.40	0.00	0.0025
		canopy	1.47	0.00	0.4124
	1.468	size	1.47	0.00	0.0461
		veg-can	1.40	0.00	0.0025
		veg-size	1.40	0.00	0.0025
		veg-can-size	1.40	0.00	0.0025
DISTRIBUTION					
Mean Nearest-Neighbor Distance		vegetation	156.03	3.20	0.0022
		canopy	161.46	2.03	0.0137
	159.58 meters	size	170.84	4.38	0.0022
		veg-can	156.21	3.55	0.0039
		veg-size	156.22	2.53	0.0039
		veg-can-size	154.85	2.80	0.0039
Nearest -Neighbor Standard Deviation		vegetation	212.30	5.90	0.0022
		canopy	296.85	7.93	0.0022
	365.38 meters	size	324.15	29.76	0.0059
		veg-can	203.97	6.60	0.0022
		veg-size	204.37	7.15	0.0022
		veg-can-size	197.12	5.99	0.0022
DENSITY					
Number of Patches		vegetation	2519.40	31.19	0.0059
		canopy	1218.10	9.07	0.0059
	1159	size	1235.90	11.06	0.0059
		veg-can	2575.00	34.04	0.0022
		veg-size	2582.10	33.39	0.0022
		veg-can-size	2637.90	35.65	0.0022
Patch Density		vegetation	9.87	0.13	0.0022
		canopy	5.66	0.05	0.0059
	5.52 per 100 hectare	size	5.71	0.05	0.0022
		veg-can	9.88	0.14	0.0022
		veg-size	9.88	0.13	0.0022
		veg-can-size	9.88	0.14	0.0022

Also, image classification may not be able to resolve forest type and structure at this finer scale, and time-consuming and costly photo-interpretation would be required to refine the more detailed habitat map.

If the maximum amount of habitat areas predicted were preserved, based on the corrections made for estimated map errors in vegetation, canopy cover, and crown size class, the effect on the long-term survival of metapopulations of the Spotted Owl in this area is not known. The smaller patches shown in the corrected maps, closer together, and in greater density (as shown by the fragmentation statistics), still might be valuable as marginal habitat, and possibly useful for dispersal. They could be big enough for nesting, surrounded by small areas valuable for foraging. Previously, we mentioned the variability in researchers' determinations of ideal territory size for the California Spotted Owl, with an overall estimation of 200-1,000 ha depending on elevation and prey density (Verner et al. 1992). While the importance of forest composition and structure are known (Verner et al. 1992), the effect of habitat fragmentation, both present and projected, is the subject of ongoing research using population model simulations being developed by Schumaker (in press) and Stephenson (Master's thesis in progress).

The changes made in the sensitivity analysis attempted to correct error in map classification by reassigning specified percentages of pixels among classes. This should have made the resulting corrected maps more accurate both in themselves, and in the estimation of possible habitat area. The map replications represented different possible realizations of the spatial distribution of map classes. The magnitude and direction of error assessed for the original map indicates that owl habitat area is underestimated, specifically in representing marginal habitat. The simulated corrections indicate that this additional habitat is in small patches outside the core habitat area, but this may be due to one of the assumptions made in generating the map changes (randomly choosing stands or segments for label reassignment). This may not have been a reasonable assumption. Errors in a mapping process tend to be spatially autocorrelated, and would occur along ecotonal boundaries, potentially forming larger, more clustered habitat patches. This could be simulated by making vegetation class changes based on parameters related to the distribution of these classes, such as the combination of slope, aspect, and elevation used in predicting the forest cover type from terrain rules, or proximity to known owl locations. To implement this suggestion, we would recommend that: (1) the gradient models be used to alter the probability of the location of the addition or subtraction of pixels in the sensitivity model for different vegetation types; and (2) buffers be created around ecotonal boundaries, thus creating an area for possible habitat corrections more reflective of realistic error possibilities.

An additional method, based on proximity to known spotted owl locations, would be to develop a trend surface model to describe the locational trends in spotted owl habitat use (Periera and Itami 1991). This could be used to revise the probabilities of a pixel being suitable for owl habitat based on prior knowledge of spotted owl habitat preferences. As we stated above, the eventual consequences of these differences in the estimated habitat area and patterns on population viability can only be explored via population modeling, and are especially critical because of controversy about habitat requirements and configuration.

The utility of this study could also be improved by increasing the percentage of change for canopy and crown size, and making those among-class changes reflective of the estimated errors. Changing 10 percent of each class may have been too conservative for the low accuracy of the data found in the original canopy and crown size maps, and did not reflect the labeling bias that was observed. Therefore, the results of the simulations for size and cover labels are less useful than those for vegetation class changes.

There is a gap between the subjectivity found in decision-making processes based on this kind of map data, and the objectivity needed for scientific methods. Sensitivity analysis can be a useful framework within which to re-scale and re-weigh the various factors involved. Geographic Information Systems are increasingly being used in conservation biology and wildlife management for habitat modeling, population simulation modeling, and reserve design, and are appropriate for the repetition and reassessment of the changes produced from a sensitivity analysis model. Different realizations of mapped distributions can be both visually and statistically compared and *adjusted as needed. Careful research based on the output of these simulations is a further step in closing that gap.*

While GIS is an efficient and "...virtually error-free system for manipulating map data, the data being processed are often of variable precision" (Openshaw 1989). Models of error need to be developed and used routinely or the usefulness of GIS will be compromised (Chrisman 1989, Veregin 1989). User awareness as to the extent of error in spatial databases needs to be improved, and policy-makers whose decisions are based on products of data transformation processes should have a more accurate estimate of their reliability (Lanter and Veregin 1992, Openshaw 1989). Management decisions made about species such as the California Spotted Owl are critical to its survival, and must often be made before its habitat associations can be fully determined. Sensitivity analysis can be further developed to supply a knowledge of the reliability of the assumptions that must be made.

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