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The Contribution of Federal and Non-Federal Habitat to Persistence of the Northern Spotted Owl on the Olympic Peninsula, Washington: Report of the Reanalysis Team

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Cover Photo

"The Olympic Peninsula From Space," a panoramic view of this region, was produced from digital data gathered by Landsat 5 satellite, which orbits Earth at an altitude of 435 miles.

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Abstract

Holthausen, Richard S.; Raphael, Martin G.; McKelvey, Kevin S.; Forsman, Eric D.; Starkey, Edward E.; Seaman, D. Erran. 1995. The contribution of Federal and non-Federal habitat to persistence of the northern spotted owl on the Olympic Peninsula, Washington: report of the Reanalysis Team. Gen. Tech. Rep. PNW-GTR-352. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 68 p.

We analyzed likely patterns of distribution and persistence of northern spotted owls (*Strix occidentalis caurina*) on the Olympic Peninsula. Analysis focused on the effects of Federal habitat under provisions of the Northwest Forest Plan; additional benefits to the owl population of different levels of habitat retention on non-Federal lands; effects of establishing a habitat connection between the Olympic Peninsula and other parts of the owl's range; the likely rate of habitat regrowth in the National Forest and its effect on the owl population; and the likely effect of a worst-case fire. We used a spatially explicit population model for northern spotted owls for the analysis and also reviewed current information on demographics and likely owl population numbers on the Olympic Peninsula. We concluded that it is likely, but not assured, that a stable population of northern spotted owls would be maintained in portions of the Olympic National Forest and the Olympic National Park in the absence of any non-Federal contribution of habitat, and that the retention of non-Federal habitat would make a biologically significant contribution to the maintenance of the population. Finally, we concluded that a habitat connection across southwestern Washington, based on the design proposed by the Northern Spotted Owl Recovery Team, would have little effect on the status of the owl population on the peninsula if that population was stable or nearly stable.

Keywords: Northern spotted owl, simulation model, spatially explicit population model, population dynamics, land management, Olympic Peninsula.

Summary

The analysis in this paper was requested by the U.S. Fish and Wildlife Service to provide background for development of a section 4(d) rule under the Endangered Species Act (ESA) that might authorize incidental "take" of some northern spotted owls from non-Federal forests on the Olympic Peninsula, Washington. The analysis describes likely patterns of distribution and persistence of owls on the Olympic Peninsula (fig. 1) under the provisions of the Northwest Forest Plan, benefits to the owl population of various levels of habitat contribution from non-Federal lands, and possible effects of establishing habitat connections between the Olympic Peninsula and other parts of the owl's range. Updated information about spotted owl habitat, population status, and birth and survival rates for the Olympic Peninsula were summarized, and much of the analysis focused on simulations of spotted owl populations under alternative scenarios. The analytical work provided useful insights, and our final conclusions, summarized below, represent a synthesis of those insights. We concluded that it is likely, but not assured, that a stable population of owls would be maintained within portions of the Olympic National Forest and the core area of the Olympic National Park in the absence of any non-Federal contribution of habitat. The lack of non-Federal habitat would make it unlikely, however, that an owl population would be maintained in the western coastal strip of the National Park, and it could result in fewer areas of remaining Federal land having high occupancy by owls. Our judgment that the maintenance of a stable population was not assured was based on significant uncertainty about the interpretation of demographic results; variability observed in simulations using different assumptions; and the effect of eliminating up to 64 600 hectares (159,700 acres) of suitable habitat on non-Federal lands. There also is uncertainty about the increase in the barred owl population and resulting competition and hybridization with spotted owls. Our confidence in the maintenance of a stable population on the peninsula would improve if the uncertainties in knowledge were resolved and indicated a favorable outcome, or the conditions on the peninsula became significantly more robust with respect to these uncertainties.

We concluded that the retention of non-Federal habitat could result in a biologically significant contribution to the maintenance of a stable population of spotted owls distributed across currently occupied portions of the Olympic Peninsula. Our conclusion was based, to a large extent, on the results of the model simulations. The simulations consistently showed increases in the numbers of pairs of owls maintained over time and in the rate of occupancy of owl territories on Federal lands when non-Federal habitat was added to Federal habitat. Retention of non-Federal habitat in the western special emphasis area, under consideration as an alternative in the 4(d) rule process, could be particularly significant as this area contains the greatest concentration of habitat remaining on non-Federal land. The retention of this habitat likely would increase the chances of maintaining a population in the coastal strip of the Olympic National Park. Finally, non-Federal lands may provide the majority of low-elevation habitat, which is poorly represented on the Federal lands and might be of higher quality than higher elevation habitat.

Although we concluded that retention of non-Federal habitat would significantly improve the projected status of the population, we do not believe that it would fully resolve the uncertainties about the future of spotted owls on the Olympic Peninsula. Therefore, although the retention of habitat on non-Federal land could be significant, we did not conclude that it would alter the basic uncertainties sufficiently to assure the maintenance of a population distributed across currently occupied portions of the peninsula.

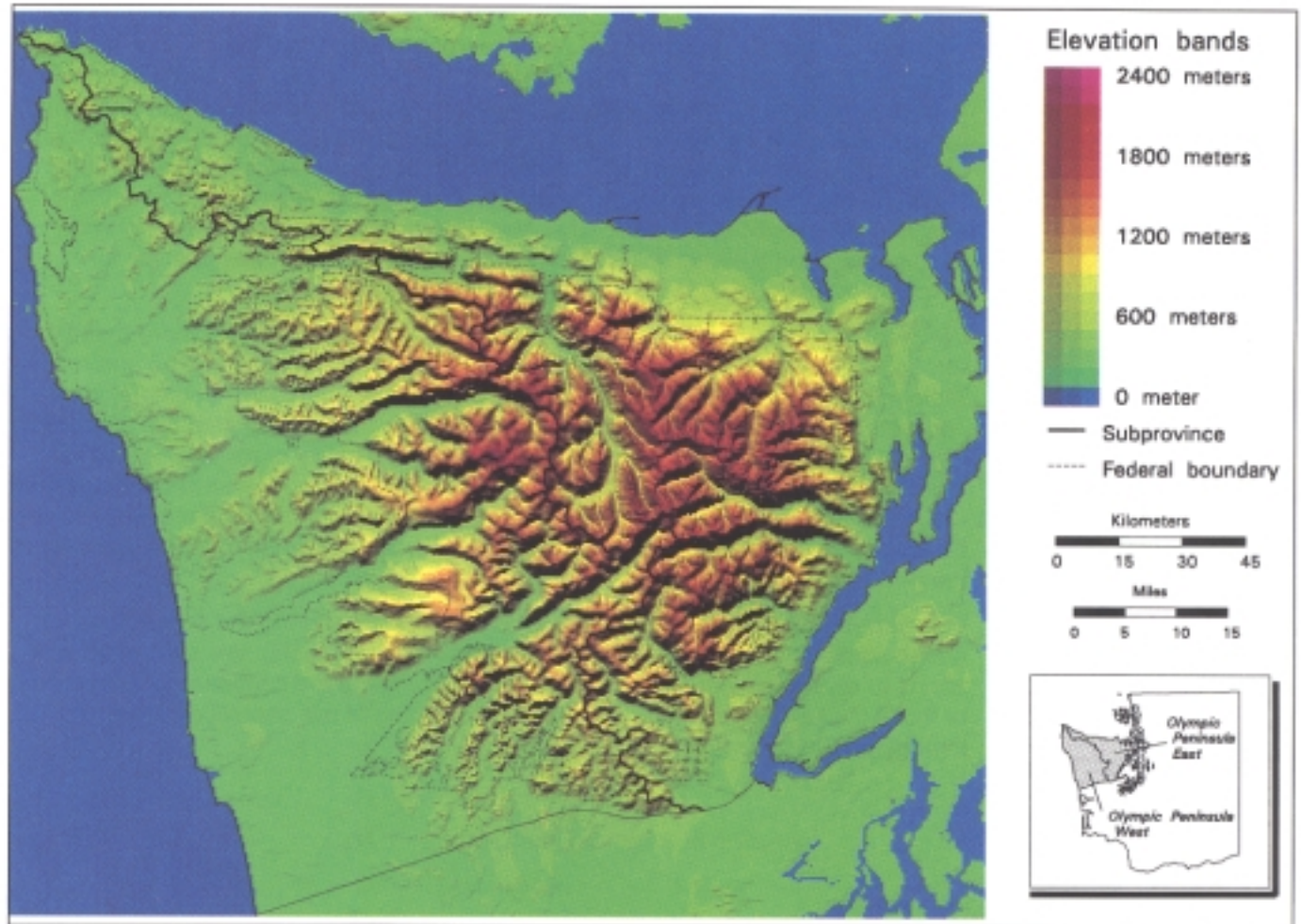


Figure 1-Topographic projection of the Olympic Peninsula, from U.S.G.S. digital elevation model (U.S. Geological Survey 1990).

Our analyses also suggested that a habitat connection across southwestern Washington (from the design proposed by the Northern Spotted Owl Recovery Team) would have little effect on the demographic status of the owl population on the peninsula. It should be noted that the habitat connection described by the Northern Spotted Owl Recovery Team was constrained by feasibility and the high cost of developing habitat in this heavily harvested landscape. Other more ambitious designs likely would have significantly greater effects on the status of the Olympic Peninsula population, but their implementation would be increasingly unrealistic. The habitat connection would clearly have significant effects on the likelihood of maintaining owls in southwestern Washington, but those effects were outside the scope of this analysis. Additionally, the analysis does not address the need for or utility of dispersal habitat between relatively closely spaced reserves. It was specific to the role of corridors connecting reserves separated by large distances. The results do not imply that dispersal habitat in intervening areas between more closely spaced reserves is unimportant.

These conclusions should not be extrapolated to other portions of the range of the northern spotted owl. Each portion of the range represents a different situation and different relationship between Federal and non-Federal lands. The Olympic Peninsula is unique because of the large block of relatively unfragmented habitat in the Olympic National Park, the relative isolation of the Olympic population from owls in the rest of the range, and the presence of suitable habitat on non-Federal land adjacent to a late-successional reserve on Federal land. Thus, the insights gained from this analysis are specific to the peninsula. Also, this assessment has focused only on spotted owls and their habitat. It does not address effects on other species for which there are legal, social, or biological concerns.

We recommend that the techniques used in this analysis be applied more broadly throughout the owl's range as plans for owls continue to be implemented and refined. Although the results are not definitive, they help clarify the relative contributions that could be made by Federal and non-Federal lands to maintain spotted owl populations. One of the prerequisites for such analyses is the availability of reliable habitat information for both Federal and non-Federal lands. Additional cooperative efforts between the states and the Federal government could help generate this information, and participation by private landowners in such efforts would greatly improve the reliability of the results.

This analysis also emphasizes the need to continue monitoring owl populations and to continue demographic studies as part of that monitoring. We support current efforts to review owl demographic studies and to ensure the continuance or expansion of those studies that are critical to our understanding of owl population dynamics throughout the range.

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Introduction

Conservation of the northern spotted owl (*Strix occidentalis caurina*) has been a focal point in the debate over forest management in the Pacific Northwest for at least the last decade (Thomas and others 1990, USDA and USDI 1994, USDI 1992). Spotted owls use large home ranges and nest, roost, and forage in predominantly older forests. Thus, maintenance of their habitat was not consistent with the rates of timber cutting that occurred on Federal and non-Federal lands through at least the decades of the 1970s and 1980s. Major milestones in the effort to manage forest lands for owls have included the plan developed by the Interagency Scientific Committee (Thomas and others 1990); listing of the owl as threatened (USDI 1990); development of a final but unsigned recovery plan (USDI 1992); development of a series of options for ecosystem management on Federal forest lands by the Forest Ecosystem Management Assessment Team (FEMAT 1993); and adoption of one of those options as a strategy for managing late-successional and old-growth forests on Federal forest lands in the range of the owl (USDA and USDI 1994). That strategy is termed the "Northwest Forest Plan" throughout this paper.

Adoption of the Northwest Forest Plan put in place a set of land allocations (table 1) and management standards and guidelines that were judged adequate for the Federal contribution to the recovery of northern spotted owls under the Endangered Species Act (ESA) (USDA and others 1994: app. G). Conservation measures for Federal forests under this plan are stronger in many areas (USDA and USDI 1994) than the recommendations made in the "Final Draft Recovery Plan for the Northern Spotted Owl" (USDI 1992). The Northwest Forest Plan does not, however, contain any specific recommendations concerning owl habitat in non-Federal forests. The supporting supplemental environmental impact statement (SEIS; USDA and others 1994) simply notes that there are areas of concern where non-Federal contributions remain important to recovery of owls. For purposes of analysis, the SEIS assumes that owls will continue to be protected in those areas of concern, but it defers further consideration of non-Federal lands to a series of potential actions to be pursued by the U.S. Fish and Wildlife Service (FWS) in compliance with the ESA.

One of the actions being considered by the FWS is adoption of a special rule under section 4(d) of the ESA that addresses the conservation of northern spotted owls while reducing the prohibition against incidental take of owls in the course of timber harvest and related activities on non-Federal lands. A notice of intent was published on 29 December 1993 that identified a series of special emphasis areas (SEA) where the FWS believed that maintenance of non-Federal habitat was necessary. The FWS is further evaluating those areas and additional alternatives to develop a proposed 4(d) rule.

The analysis in this document was requested by the FWS to provide additional background for development of the 4(d) rule. The charter requesting this analysis is shown in appendix 1. Our analysis focuses on northern spotted owls and their habitat on the Olympic Peninsula in Washington. The Olympic Peninsula has been consistently noted as an area of concern because the owl population on the peninsula probably has very little interaction with owls in the remainder of the range (Thomas and others 1990; USDA 1988, 1992; USDI 1992). The specific purposes of the analysis were to assess:

- Likely patterns of distribution and persistence of owls on the Olympic Peninsula under the provisions of the Northwest Forest Plan.

Table 1-Land allocations under the Federal Forest Plan on the Olympic Peninsula

Land allocation	Hectares
Congressionally reserved	400 364
Late-successional reserves	167 503
Adaptive management areas	50 384
Administrative withdrawals	121
Riparian reserves	405
Matrix	405
Total	619 183

Source: USDA and others 1994.

- Possible effects on the owl population of habitat loss due to large-scale natural disturbances.
- Benefits to the owl population of various levels of habitat contribution from non-Federal lands.
- Possible effects of establishing habitat connections between the Olympic Peninsula and other parts of the northern spotted owl's range.

Information about northern spotted owl habitat, population status, and demographic rates on the Olympic Peninsula was updated for this analysis from information used in the SETS (USDA and others 1994). Much of the analysis focused on simulations of northern spotted owl populations under various habitat scenarios. These simulations used a spatially explicit model of spotted owl populations developed by McKelvey and others (1992). Our simulations are refined for conditions on the peninsula from range-wide simulations done by Raphael and others (1994) for the SEIS. The analytical work provided useful insights into current and possible future trends of the owl population, as well as insights into the structure and function of the analytical tools. The final conclusions represent a synthesis of those insights.

Terminology

Throughout this report, the terms "owl" and "spotted owl" are used as synonyms for the northern spotted owl. Also, the term "suitable habitat" is used to mean nesting, roosting, and foraging habitat and is distinguished from dispersal habitat. The term "spotted owl activity center" indicates an area of concentrated activity of either a pair of spotted owls or a single owl. For some portions of the analysis, we subdivided the Olympic Peninsula Province into western and eastern subprovinces based on topography and major river drainages.

General Information

We report here on field estimates of population size and demographic rates of spotted owls on the Olympic Peninsula. Home range characteristics of spotted owls and the range expansion of the barred owl (*Strix varia*) also are discussed. This information, in conjunction with the results of population simulation models, provides the background for an informed professional judgment about the security of the owl population under different management scenarios.

Studies of spotted owls on the Olympic Peninsula began in the early 1980s, when calling surveys and home range studies were initiated by the Washington Department of Fish and Wildlife (WDFW). Additional studies of home range and habitat use were conducted by the USDA Forest Service in 1987-89,¹ by the National Park Service in 1988-89 (Mills and others 1993), and by North (1993). Beginning in 1987, the USDA Forest Service Pacific Northwest Research Station began a long-term demographic study of spotted owls on the peninsula. The National Park Service joined in this effort in 1989. The primary objectives of the demographic study have been to estimate survival rates and reproductive rates and to determine population trends. Survival rates have been estimated by using mark-recapture techniques (Burnham and others 1987). Owls were marked with unique color bands and FWS bands. Each study area was searched each year to document previously marked owls, to band any replacements, and to count numbers of young produced by each female. The majority of resident adults and their offspring have been banded on National Forest and Washington Department of Natural Resources (WDNR) lands. The sample of banded owls also includes about 40 pairs monitored within Olympic National Park.

Known Owl Sites

We used professional judgment in assessing the numbers and status of known owl sites; for example, some sites that had not been occupied by owls for several years were dropped from the tally. Our intent was to estimate as accurately as possible the number of known sites occupied by spotted owls in 1993 or 1994. We also included data from 1994 surveys on National Forest and National Park lands, whereas previous summaries included only 1993 data. For these reasons, there are minor differences between our estimates of known owls and those of previous reviews.

In the following summary, "pair" refers to any male and female found nesting or roosting together or heard calling together in the same area on at least two occasions. Surveys across all ownerships on the peninsula between 1989 and 1994 confirmed about 155 sites occupied by pairs of owls and 79 sites occupied by single owls or multiple owls of undetermined pair status (table 2). Further surveys will likely reveal pairs at some of the latter sites; however, some sites where pairs or single owls were found early in the survey period appeared to have been abandoned by 1993-94.

On National Forest lands, there were 79 confirmed pair sites and 16 confirmed sites occupied by one or more owls of undetermined pair status in 1993 and 1994 (table 2). This count excluded six sites where pairs were observed before 1992 but that were not occupied in 1993 or 1994. Some sites where single or multiple owls of undetermined pair status were observed could represent pair sites, but recent surveys have not confirmed this.

Surveys on lands administered by the WDNR in 1993-94 documented 11 sites occupied by pairs and 17 sites occupied by single owls or multiple owls of undetermined status² (table 2). Some of these have been inconsistently occupied in recent years,

¹ E.D. Forsman. Unpublished data. On file with: Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

² Personal communication. 1994. A. Potter, Washington Department of Fish and Wildlife, 600 N. Capitol Way, Olympia, WA 98501.

Table 2-Numbers of known spotted owl sites and estimates of total numbers of spotted owl sites on the Olympic Peninsula, by agency or landowner, based on surveys conducted from 1989 to 1994

Landowners	Known owl sites		Estimate of ownership surveyed	Estimated number of sites with territorial pairs ^b	
	Pairs	Other ^a		Low	High
Percent					
USDA Forest Service:					
Soleduck District	18	5	85	21	27
Quinalt District	20	7	90	22	30
Quilcene District	25	2	75	33	36
Hood Canal District	16	2	75	21	24
WDNR ^c	11	17	90	12	31
Olympic N.P. ^d	63	44	NA	173	173 ^e
Private lands	1	1	NA	-	-
Tribal lands	1	1	NA	-	-
Totals	155	79		282	321

— = survey data not available.

^a Sites where 1 to 2 owls were located but pair status could not be confirmed.

^b Low estimate assumes that sites where pairs were not documented were not occupied by pairs. High estimate assumes that all sites where 1 or more owls were located were occupied by pairs of owls.

^c WDNR = Washington Department of Natural Resources.

^d Olympic N.P. = Olympic National Park.

^e Population estimate for Park lands was based on extrapolation from random survey plots within Olympic National Park (described in the text).

which suggests that they may be relatively marginal habitat.³ Most owls located on WDNR lands were clustered in the northwest corner of the peninsula, which reflects the distribution of habitat on lands administered by the WDNR.

Surveys in Olympic National Park confirmed 63 sites occupied by pairs of owls and 44 sites occupied either by a single owl or by two owls with unknown pair status (table 2). Because of difficult access, survey efforts in the Park have been limited compared to efforts on adjacent National Forest and WDNR lands.

We know of only two sites occupied by owls on tribal lands and two sites occupied by owls on private lands in 1992-94 (table 2). The low number of owls on these ownerships may reflect low population numbers, but survey efforts on these ownerships have been limited. Although numbers of known owls with activity centers on private lands are low, many activity centers on National Forest and National Park lands were adjacent to private lands. Owls in those situations may use private lands for foraging.

³ Personal communication. 1994. S. Horton, Washington Department of Natural Resources, 1111 Washington St. SE, Olympia, WA 98504.

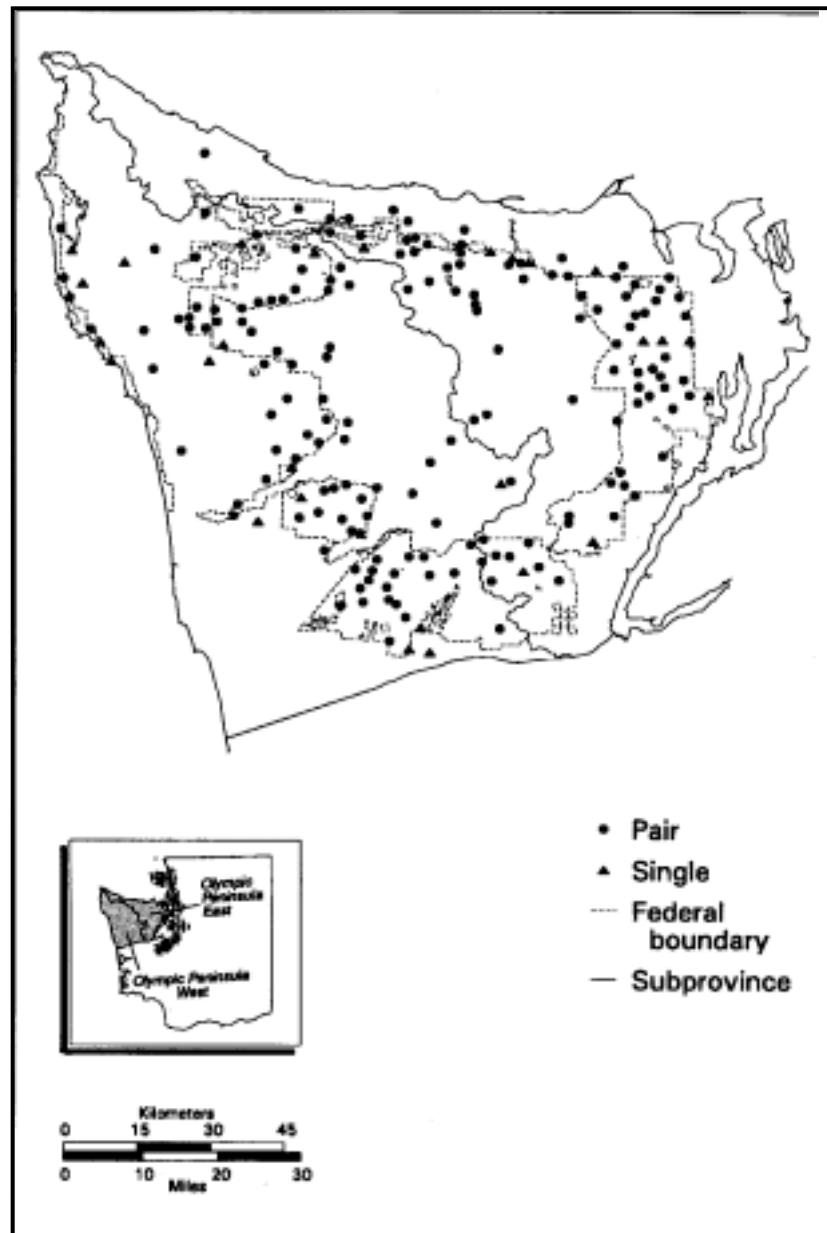


Figure 2-Sites where pairs and territorial (single) spotted owls were located ($n = 191$) on the Olympic Peninsula between 1989 and 1993. Map based on data maintained by WDFW.

The distribution of known owl locations indicates that the range of the owl includes the entire peninsula (fig. 2), but most known owls are concentrated on Federal lands or lands administered by the WDNR. To some extent the uneven distribution of owls may represent survey and reporting effort. It seems, however, that the primary reason for the unequal distribution of owls is that almost all late-successional forests on private lands and tribal lands were clearcut between 1940 and 1990.

Table 3-Elevation of northern spotted owl activity centers (n = 195) and nest sites on the Olympic Peninsula

Elevation band	Activity centers by subprovince ^{a b}		Nest locations by subprovince ^{c d}	
	West	East	West	East
<i>Meters</i>	<i>----- Number -----</i>			
0-152	17	0	11	3
153-305	27	6	28	5
306-457	22	14	37	18
458-610	19	23	34	36
611-762	10	16	17	30
766-914	4	13	0	36
915-1067	5	10	0	19
1068-1219	0	7	0	7
1220-1372	0	1	0	0
1373-1524	0	0	0	0
>1524	0	1	0	0

^a Based on data maintained by the Washington Department of Fish and Wildlife, 600 N. Capitol Way, Olympia, WA 98501.

^b Elevations of activity centers were based on intersecting their locations (fig. 2) with a digital elevation model.

^c Forsman, E.D.; Seaman, D.E. Unpublished data. On file with: Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

^d Nest elevations are from 281 nest records. Values are the number of owls, or nest records, located in each elevation band.

The elevations of owl nest sites and activity centers indicated that owl distribution is limited by elevation and that the upper limit is higher in the eastern than in the western subprovince. Elevations of nests in the eastern subprovince ranged from 114 to 1189 meters (375 to 3,900 feet), with 90 percent of 154 nest records at elevations below 1006 meters (3,300 feet) and 95 percent below 1067 meters (3,500 feet) (table 3). Elevations of nest sites in the western subprovince ranged from 85 to 732 meters (280 to 2,400 feet), with 90 percent of 127 nest records at elevations below 622 meters (2,040 feet) and 95 percent below 652 meters (2,140 feet) (table 3).

The differences in upper elevational limits and elevational distribution of nest sites between the eastern and western subprovinces were probably a function of habitat differences (Henderson and others 1989:38-43). In the western subprovince, forests below about 550 meters (1,800 feet) are typically dominated by western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). At elevations above about 550 meters, forests are increasingly dominated by Pacific silver fir (*Abies amabilis* Dougl. ex Forbes). In comparison, the transition to Pacific silver fir forests in the eastern subprovince occurs at much higher elevations, typically between 850 and

1030 meters (2,800 to 3,400 feet). The relative infrequency of nesting in high-elevation forests on the peninsula indicates that those forests are marginal or unsuitable habitat for spotted owls. It is reasonable to assume, however, that owls nesting in the transition zone between western hemlock/Douglas-fir forests and true fir forests do forage and roost in true fir stands if those stands occur within 2 to 3 kilometers (1 to 2 miles) of the nest (Mills and others 1993). For that reason, any assessment of the amount of habitat available to spotted owls on the peninsula should assume some contribution from true fir stands located above the elevations at which nests occur. Our analysis of potential habitat on the peninsula made such an assumption (see "Development of a Habitat Map").

Population Estimates

Numbers of territorial pairs on the peninsula were estimated with two different approaches. On lands administered by the Forest Service and WDNR, where surveys covered much of the land base and usually were repeated in multiple years, we estimated the proportion of the area that was surveyed in two or more years and extrapolated from the number of confirmed owl sites to the entire ownership. This was done by dividing the number of known owl sites by the estimated proportion of the area that was surveyed. Two estimates were made for each National Forest Ranger District and for lands administered by the WDNR. One estimate assumed that pairs were present at all sites where either pairs or single owls were documented. The other estimate was more conservative; we assumed that pairs were present only at confirmed pair sites. Estimates of owl numbers on National Forest lands were subdivided by Ranger District because estimates of the survey coverage differed with District. The combined population estimate for all National Forest lands was either 97 or 117 pairs, depending on which assumption was made about occupancy of sites where single owls were located (table 2). Comparable population estimates for lands administered by the WDNR were 12 or 31 pairs (table 2).

On National Park lands, the population was estimated by extrapolating densities from randomly selected sample areas to the entire Park (Seaman and others 1992). Population estimates from private lands and tribal lands were not possible because detailed survey data were not available for those areas.

The Olympic National Park survey has been conducted over three years, with an additional year scheduled for 1995. We report preliminary results here. Because the area of potential owl habitat was too large and remote to be surveyed completely, 26 census plots in three survey strata were chosen randomly and surveyed. The density of owls in the census plots was extrapolated to the total area of potential owl habitat in the Park to produce a population estimate.

For the census, potential owl habitat was defined as all forested habitat in the Park, excluding the Pacific coastal strip and the Queets River corridor. This definition allowed sampling of higher elevation forests to determine the upper limit of owl distribution but did not include alpine habitats (rock, ice, meadows) or large lakes. The coastal strip and Queets corridor were excluded because they are very different landscapes than those in the core of the Park, with narrow segments of habitat bounded by extensive clearcuts.

The Park was divided into three survey strata: two low-elevation strata separated along a line running northwest to southeast, and a high-elevation stratum that included all potential habitat above 910 meters (3,000 feet) elevation in the western subprovince and above 1219 meters (4,000 feet) elevation in the eastern subprovince.

Each random plot was sampled in only one year. Plots averaged about 800 hectares (1,977 acres) in area, and the total area of the 22 sampled plots represented roughly 10 percent of the forested land in the Park, excluding the coastal strip and Queets corridor. Calling stations were placed every 400 meters (1,312 feet) along transects spaced 400 meters apart to cover the entire plot. When spotted owls were detected, they were captured if possible and individually banded.

Each census plot was surveyed during the nesting season (15 March to 15 June). Closed population mark-recapture statistics (Otis and others 1978) were used to estimate the proportion of owls missed by this survey scheme, and the observed densities were adjusted accordingly.

Owl pairs were considered residents of a plot and were counted in its density estimate only if their nest or habitual roost sites were within the plot (defined as all area within 200 meters [656 feet] of a calling station). We used nest or habitual roost sites so that density would not be overestimated by including nonresident owls that entered the plot.

Of 43 sites where one or more owls were located within survey plots, 22 did not meet the criteria for pair status and, therefore, were excluded from the pair density estimate. Of the 21 sites with confirmed pairs, one was excluded from the pair density estimate because the nest was outside the plot; 20 sites were included in the pair density estimate of which five had nest locations in a plot, five had young juveniles in a plot (before 9 June in all cases), and 10 had no nest or juveniles found, but survey evidence (habitual roosts) indicated that they were plot residents.

Analysis of the density data for Olympic National Park has not been completed. Preliminary calculations estimate a population of 173 pairs in the Park study area; confidence limits have not yet been developed for this estimate. Because the estimate is an extrapolation from a small sample, variance in the survey plot densities may translate into considerable uncertainty in the Park-wide estimate, and the resulting confidence limits may be quite wide. Again, the study area includes only the forested interior of the Park, not the coastal strip and the Queets corridor, which both contain small numbers of territorial spotted owls.

In summary, surveys in 1992-94 confirmed a minimum of 155 pairs, and extrapolations from the survey data suggest a total population of either 282 or 321 pairs of spotted owls on the peninsula, depending on assumptions about the status of sites occupied by single owls (table 2). These numbers represent two separate point estimates using different assumptions; they do not indicate anything about the variability of the population estimate. These estimates assume few pairs with activity centers on private lands or tribal lands, simply because there are no data to indicate otherwise.

Demographic Studies

In December 1993, data from the Olympic demographic study were analyzed at a workshop in Fort Collins, Colorado, and presented in a report to the Secretary of the Interior (Burnham and others 1994). This report subsequently was included as an appendix to the SEIS (USDA and others 1994) produced for the Northwest Forest Plan. The analysis for the Olympic Peninsula population indicated no significant changes over time in birth or death rates but suggested that the population of territorial owls was declining at about 5.3 percent per year during the period of study. A range-wide meta-analysis that examined 12 study areas, including the Olympic Peninsula, suggested an overall decline in adult female survival rates over the years of study. An overall estimate of population growth based on the survival estimates from the meta-analysis and fecundity estimates from 11 study areas indicated an average annual rate of population decline of 4.5 percent (Burnham and others 1994). The analysis also indicated that the rate of population decline was accelerating (Burnham and others 1994). Burnham and others (1994) state that their analysis applied only to the territorial population.

The results of the Fort Collins workshop generated considerable disagreement within the scientific community over interpretation of the data (see for example, Bart, in press b; Lande and others 1994; USDA and others 1994). One of the primary concerns regarding banding studies of spotted owls is that emigration of juvenile owls might cause an underestimation of juvenile survival rates, which in turn could result in an underestimate of the population growth rate (Bart, in press b; Burnham and others 1994). In their combined analysis of 12 study areas, Burnham and others (1994) attempted to compensate for this potential bias by adjusting the average juvenile survival estimate upward based on estimates of juvenile emigration from two radio-telemetry studies (Forsman and others, in prep.). This increased the estimate of the population rate of change (λ) from 0.9253 to 0.9548, but did not alter the conclusion of a significant population decline. Bart (in press b) concluded that the population growth rates reported by Burnham and others (1994) were underestimates because they considered only one source of bias (juvenile emigration out of the study area) and did not take into account a number of other potential biases, such as adult emigration and juvenile emigration into unmonitored portions of study areas.

Forsman and others (in prep.) used emigration data from a radio-telemetry study in Washington to adjust the juvenile survival estimate presented in Burnham and others (1994) for the Olympic Peninsula. The juvenile survival estimate from the banding study reported in Burnham and others (1994) was 0.245 with a standard error of 0.064. The estimated emigration rate from the radio-telemetry study was 0.600 with a standard error of 0.083, where emigration was defined as any instance when an owl dispersed into an area not regularly searched for owls, survived at least to age 1, and went undetected by conventional calling techniques. After adjustment for emigration, the estimate of juvenile survival was 0.612 with a standard error of 0.204. When this value was substituted in the population growth rate equation, the resulting estimate of population rate of change (λ) for the peninsula was 1.058 with a standard error of 0.065, which was not significantly different from 1.0. Although this result appears to contradict the conclusion of a declining population from the earlier analysis, Forsman and others (in prep.) urged caution in this interpretation for several reasons: only 35 owls were used to estimate emigration rates, emigration estimates were based on only two years of data, and rates of immigration were unknown. All these factors could affect the outcome of the analysis.

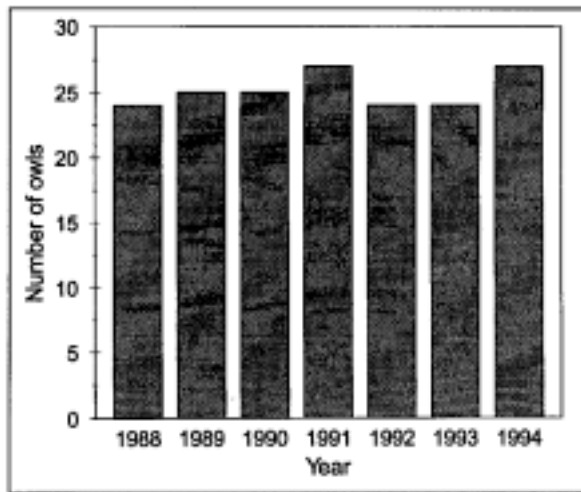


Figure 3-Number of territorial spotted owls located each year on the 355-square-kilometer (137-square-mile) Quinault density study area on the Olympic Peninsula, 1988-94.

It also could be argued that the above analysis underestimates the effect of emigration on the estimated survival rate because the analysis did not consider "internal" emigration. Internal emigration refers to owls that stay within the boundaries of the study area, but settle in areas not regularly surveyed. Such owls would appear to have died when they actually survived, thereby causing survival to be underestimated. The analysis performed by Forsman and others (in prep.) compensated for internal emigration to some extent. In that analysis, radio-marked juveniles dispersing into unsurveyed portions of the Olympic National Park were labeled as emigrants, even though the general study area included the entire Park plus surrounding National Forest and WDNR lands. Thus, much of the internal emigration was accounted for, and the estimation of juvenile survival rates should not be greatly underestimated.

Density Studies

Field studies of changes in the number of territorial owls on the peninsula have been used to evaluate population trends (Forsman and others, in prep.) (fig. 3). The results have been inconclusive, primarily because changes in the number of territorial owls may not reflect the trend in the total population, which also includes floaters (owls without territories), and regression analyses of trends based on small samples cannot detect small annual changes in population size (Taylor and Gerrodette 1993).

Home Range and Habitat Use Studies

Data on home range areas and habitat use of spotted owls on the Olympic Peninsula are available from two as-yet unpublished studies, one conducted by the WDFW from 1984 to 1986,⁴ and another conducted by the Forest Service from 1987 to 1989 (Forsman and others, in prep.). These studies indicate that annual home range areas (estimated by the minimum convex polygon [MCP] method) on the Olympic Peninsula are relatively large and typically encompass large amounts of late-successional forest. Annual home ranges of 10 pairs indicated a median home range of 5775 hectares (14,271 acres; range = 1820 to 11 052 hectares, or 4,497 to 27,309 acres). The median amount of old-growth and mature forest in the annual ranges of seven pairs

⁴ D.W. Hays. Unpublished data. On file with: Washington Department of Fish and Wildlife, 600 N. Capitol Way, Olympia, WA 98501.

was 1853 hectares (4,579 acres) (range = 1128 to 3419 hectares, or 2,787 to 8,448 acres). Based on habitat classifications used in our analysis, home range size tended to decrease with increasing proportion of late-successional forest in the home range ($r = -0.73$, $P = 0.10$). Although other home range estimation techniques produce differing estimates of home range size, the estimated amount of late-successional forest used by owls will be unaffected by the estimator if all the late-successional forest within the MCP home range is used.

Barred Owls

Barred owls have invaded much of the range of the northern spotted owl during the last 50 years (Dunbar and others 1991, Thomas and others 1993). Numbers of barred owl sightings on the Olympic Peninsula have increased steadily since spotted owl surveys began on the peninsula. Most records of barred owls have been from the western subprovince in western hemlock and spruce forests.⁵ Because barred owls have displaced spotted owls and hybridized with spotted owls, the range expansion of the barred owl may represent a threat to the spotted owl population (see for example, Hamer and others 1994, Thomas and others 1993).

There have been two records of barred owl-spotted owl hybrids on the peninsula. One of these was banded as a juvenile in the Gifford Pinchot National Forest in 1984 and subsequently dispersed 190 kilometers (118 miles) to the northwest corner of the peninsula (Hamer and others 1994). The other was first documented as a breeding adult along the Bogachiel River in 1994.⁶

We anticipate that the numbers of barred owls will continue to increase on the peninsula, but there is no way to predict with certainty how the barred owl range expansion will affect the long-term persistence of the spotted owl (Thomas and others 1993). It is unclear whether the range expansion of the barred owl is due to human influences on habitat.

Habitat Dynamics

Spotted owls have evolved with natural disturbance as an important process within their habitat; however, humans have altered disturbance regimes and reduced the availability of suitable habitat in most areas (USDI 1992). The potential exists for natural disturbance to further reduce the amount of suitable spotted owl habitat on the Olympic Peninsula and elsewhere.

Fire and wind are the most significant sources of natural disturbance in peninsula forests. Insects are usually secondary agents of disturbance, but no devastating outbreaks have been documented (Henderson and others 1989). Forest diseases are a greater source of disturbance than insects but do not generally cause substantial negative impacts on spotted owl habitat (Agee and Edmonds 1992).

Wind is the most important source of disturbance along the coast but is less important in interior areas (fig. 4). Near the coast, return intervals for major wind disturbances are about 30 years, with fire return intervals exceeding 1,100 years (Agee 1993). In interior portions of the peninsula, fire is relatively more significant than wind but still relatively infrequent, with fire return intervals of 400 to 750 years (Agee 1993, Henderson and others 1989).

⁵ E.D. Forsman and D.E. Seaman. Unpublished data. On file with: Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

⁶ D.E. Seaman. Unpublished data. On file with: National Biological Service, Olympic National Park Field Station, 600 E. Park Ave., Port Angeles, WA 98362.

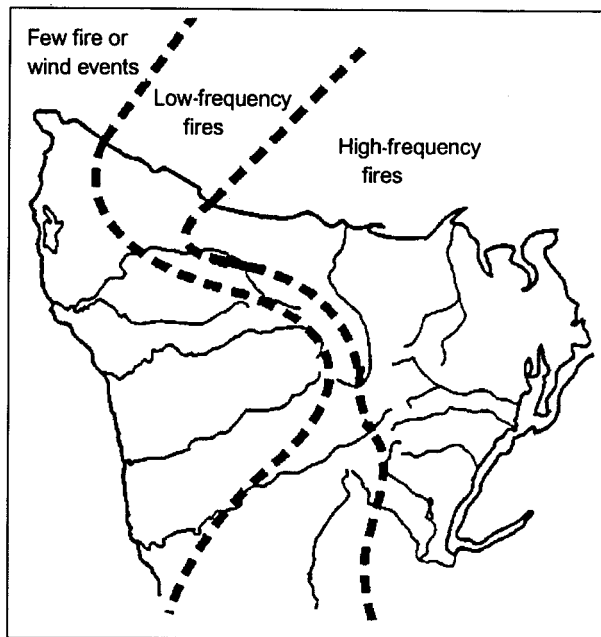


Figure 4-Relative frequency of fire and wind disturbance events on the Olympic Peninsula (from Agee and Edmonds 1992, Henderson and others 1989).

Fire may be more frequent in some areas as a result of local wind patterns or topography. For example, east winds are funneled through a valley near Lake Crescent, in the northwest portion of the peninsula, resulting in an increased likelihood of high-severity fires (Agee 1993) during the next 100 to 200 years⁷ (fig. 5). In 1951, the Forks fire burned more than 13 360 hectares (33,000 acres) in this area. Fires burning when east wind conditions occur in this area are likely to be difficult to control (Agee 1991a).

The Olympic Mountains cast a rain shadow to the east and northeast, where the climate is drier and fire is more frequent (Agee and Edmonds 1992, Henderson and others 1989). Much of the area has burned several times during the last 700 years. Fire is an important element of these ecosystems, and stand-replacing fires are likely during the next 100 to 200 years, especially along the northeastern boundary of Olympic National Park (Ages 1991a) (fig. 5). Because of the steep and deeply dissected terrain, fire control efforts are likely to be severely constrained (Agee 1991a). In this portion of the peninsula, there is a high likelihood that significant areas of suitable spotted owl habitat will burn in the future.

Wind and fire affect spotted owl habitat differently. Wind tends to thin stands by toppling codominant and intermediate crown class trees, leaving some windfirm dominants. Understory trees become the dominants in the succeeding stand. In some cases, such as the blowdown associated with a severe storm on the peninsula in 1921, spotted owls may reoccupy disturbed areas in less than 70 years (North 1993). Although wind may cause short-term habitat loss, in the long term it

⁷ Personal communication. 1994. J.K. Agee, College of Forest Resources, University of Washington, Seattle, WA 98195.

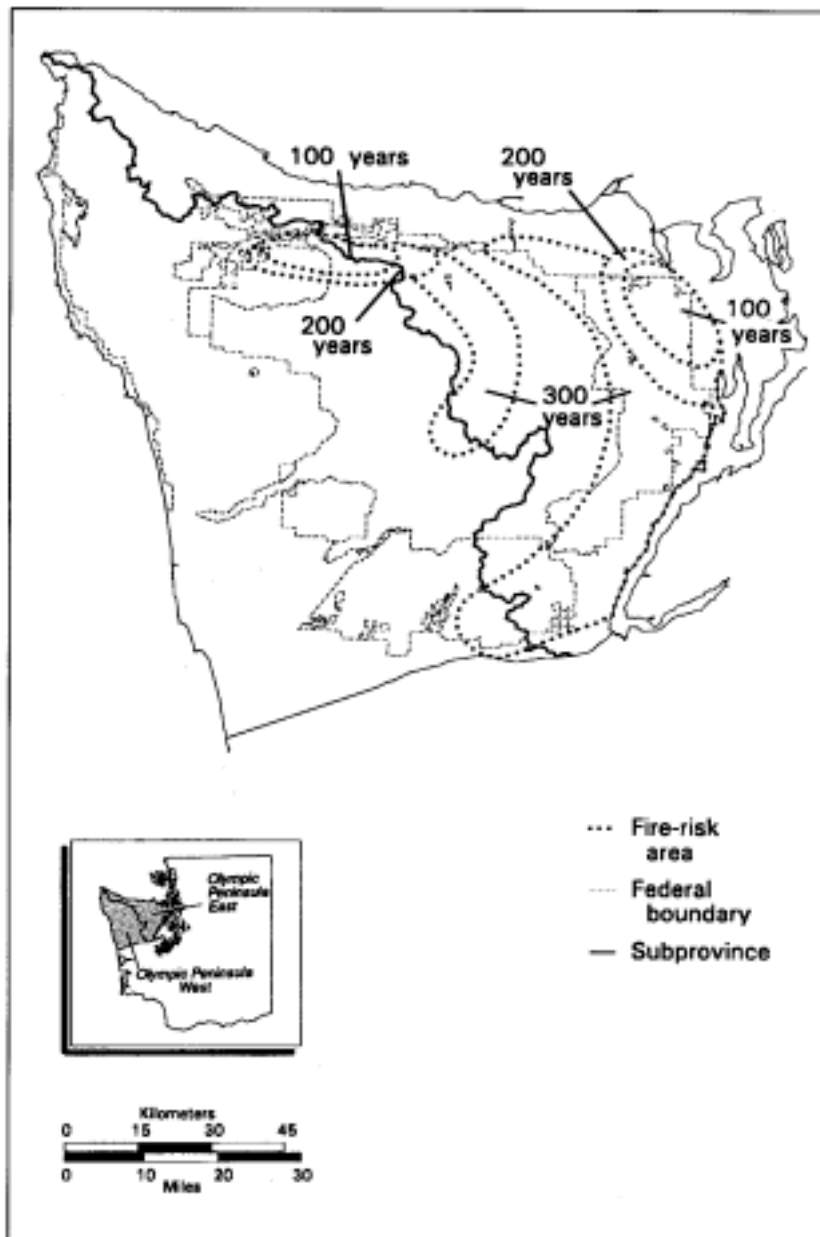


Figure 5-Areas with relatively high likelihood of fire on the Olympic Peninsula. Estimated fire return intervals are also shown (see footnote 7). Simulated worst case analyses included all areas with return intervals less than or equal to 300 years. The solid line bisecting the peninsula from northwest to southeast in this and subsequent figures is a subprovincial boundary following topographic relief that splits the peninsula into east and west subprovinces.

may also contribute to the development of key attributes of spotted owl habitat, such as a multilayered canopy. Mills and others (1993) found that vertical canopy layering was an important predictor of owl presence on the Olympic Peninsula.

Fires on the Olympic Peninsula are generally stand-replacing events (Agee 1991 a), resulting in the loss of suitable spotted owl habitat for a significant period. Following fire on the peninsula, new seedlings may continue to establish for as long as 60 years (Huff 1984). This extended regeneration period may be responsible for some of the structural diversity associated with suitable spotted owl habitat (for example, diverse age and size distribution of trees, multilayered canopies). In the long term, fire has probably been beneficial for spotted owls. But until additional suitable habitat has been regrown, short-term loss of habitat to fire could increase the risk of extirpation within some areas of the peninsula.

An intensive fire suppression strategy is likely to be successful in restricting most fires in the western and interior Olympic Peninsula to a relatively small size (Agee 1991a). From 1950 to 1980, the average size of larger fires on the peninsula was less than 364 hectares (900 acres), and it is unlikely that most fires in the foreseeable future will exceed this average size (Agee 1991a). In especially vulnerable areas in the northeastern portion of the peninsula and near Lake Crescent (areas with 100-year fire return intervals; see fig. 5), there is a risk of relatively large fires resulting in broad gaps in suitable habitat (Agee 1991a). Under worst case conditions (dry easterly winds, extended summer drought), these fires could include most of the Elwha Valley and much of the eastern portion of the peninsula (fig. 5) and not be extinguished until the arrival of seasonal precipitation (Agee 1991b).

Federal and Non-Federal Plans for the Olympic Peninsula

Under the Northwest Forest Plan, a large percentage of the Federal lands on the Olympic Peninsula is either in congressionally reserved status or allocated as late-successional reserves (table 1). Nearly all the suitable nesting, roosting, and foraging habitat for spotted owls is in allocations where it likely will be maintained over time. Only 3400 hectares (8,400 acres) of nesting, roosting, and foraging habitat are in either an adaptive management area or matrix and are potentially available for scheduled timber harvest. Plans at the Olympic National Forest do not call for clearcutting any of this habitat in the foreseeable future⁸. In late-successional reserves, efforts may be undertaken to accelerate the development of characteristics associated with nesting, roosting, and foraging habitat in currently young forest. Firm schedules for such treatments have not been developed.

The WDNR administers about 164 000 hectares (405,250 acres) of state lands on the Olympic Peninsula (table 4). It has voluntarily followed the FWS guidance for determining when the risk of take may occur on lands that it administers. That guidance included (1) retaining 28 hectares (70 acres) of suitable habitat around a spotted owl activity center; (2) retaining about 200 hectares (500 acres) of suitable spotted owl habitat within 1.1 kilometers (0.7 mile) of an activity center; and (3) retaining suitable habitat on 40 percent of the landscape within a circle around an activity center 4.3 kilometers (2.7 miles) in radius. This guidance was used in our analysis to represent the situation that would exist on non-Federal lands if take prohibitions remain in effect.

⁸ Personal communication. 1994. W. Hoffman, Olympic National Forest, 1835 Black Lake Blvd. SW, Olympia, WA 98512.

Table 4-Amount of nesting, roosting, and foraging (NRF) habitat for northern spotted owls in relation to total land area and land ownership, Olympic Peninsula

Landowner	Total area	Total NRF habitat	Land area classified as NRF habitat
	----- Hectares ^a -----		Percent
National Forest	254 300	97 600	38
National Park	364 800	168 300	46
Other Federal	700	100	11
Total Federal	619 800	266 000	43
Tribal	95 600	6 800	7
State	164 000	33 500	20
Other non-Federal	347 200	24 400	7
Total non-Federal	606 800	64 600	11
Total, all lands	1 226 600	330 600	27

^a All values rounded to nearest 100 hectares prior to summing.

Source: Habitat derived from FEMAT (1993) and unpublished data on file with: Washington Department of Natural Resources, 111 Washington St. SE, Olympia, WA 98504.

Methods

Evaluation of relationships between spotted owls and habitat on the Olympic Peninsula requires an accurate map of current habitat conditions and prediction of future conditions, including both forest growth and disturbance. In addition, rules must be developed relating habitat conditions to owl behavior and demographic performance. Such an evaluation is greatly assisted by standardized, repeatable, and biologically reasonable methods to compare potential future scenarios in terms of spotted owl population dynamics.

We created maps of suitable owl habitat given various non-Federal contributions to total habitat on the peninsula (scenarios), ran computer models to simulate population trends and population distributions under each scenario, and investigated the sensitivity of our simulations to alternative assumptions about demographic rates. Effects of change in habitat condition due to fire and regrowth of habitat were also investigated through simulations.

Development of a Habitat Map

Current conditions-

Federal lands-A digital map of suitable spotted owl habitat on National Forest lands throughout the range of the owl was first developed as part of the 1992 final EIS (USDA 1992). The Northern Spotted Owl Recovery Team expanded this map to include lands managed by the U.S. Bureau of Land Management (BLM) and National Park Service. This map of spotted owl habitat on Federal lands was enhanced and resampled on a 16-hectare (40-acre) grid during the FEMAT process (FEMAT 1993) and subsequent SEIS (USDA and others 1994); we used this enhanced map as the best information about currently suitable owl habitat on Federal lands on the Olympic Peninsula for our original report to the FWS (Holthausen and others 1994).

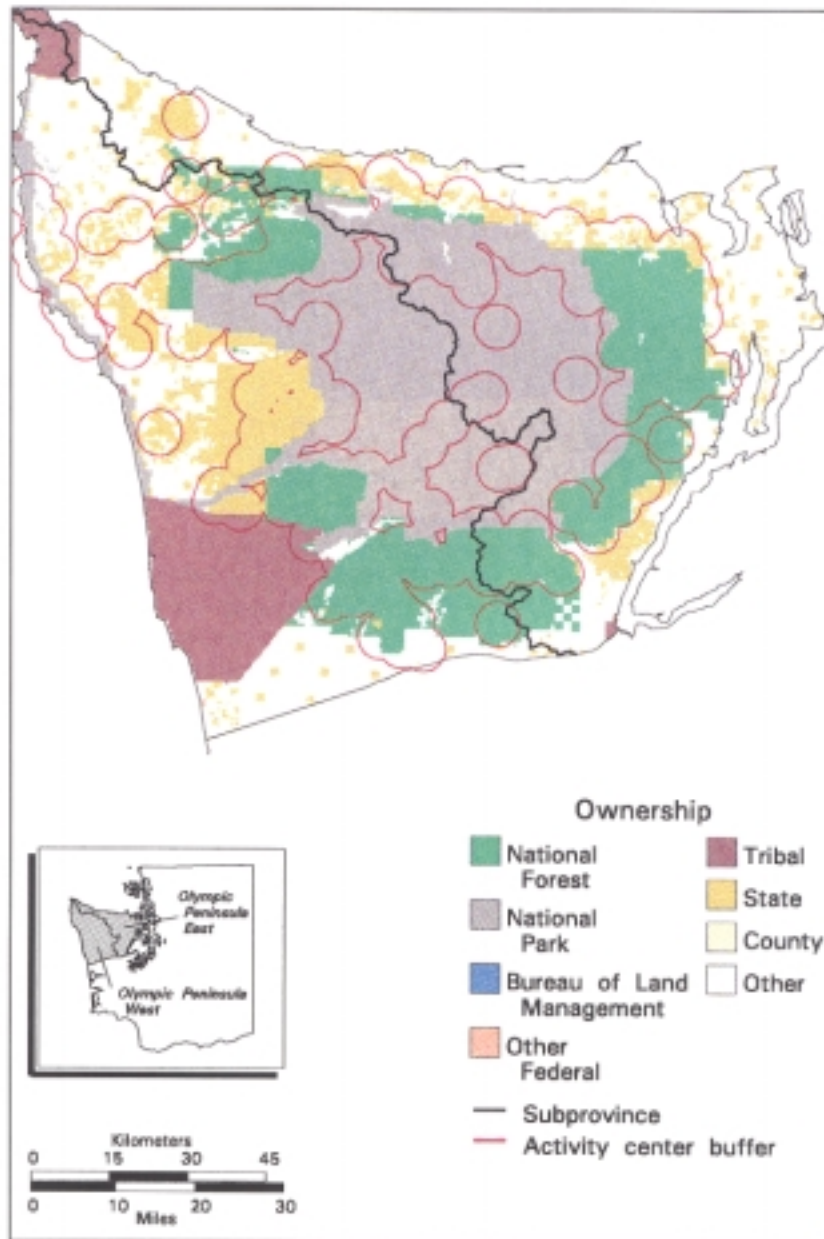


Figure 6-Map of the Olympic Peninsula showing ownership patterns and 4.3-kilometer (2.7-mile) radius buffers surrounding owl activity centers.

As noted by Holthausen and others (1994), this map seemed to underestimate the amount of nesting, roosting, and foraging habitat on National Park lands, especially in the eastern subprovince. For this analysis, we obtained a 1988 Landsat classification with 1991 updates (Green and others 1993) and used the "late-seral" class to represent the nesting, roosting, and foraging habitat in the National Park. We evaluated the new map by examining the distribution of habitat in relation to its overlap with the distribution of spotted owl activity centers, and we concluded that the new map produced a better fit than did the original map.

We further refined the habitat definition for Federal lands by applying an upper elevation limit to exclude areas above the elevations where spotted owls are known to successfully reproduce. To determine this upper limit, we first subdivided the Olympic Peninsula Province into western and eastern subprovinces based on topography and major river drainage patterns (figs. 1 and 6). The dividing line runs diagonally from the northwestern tip of the peninsula to the southeast. For each subprovince, we tallied locations of each spotted owl activity center ($n = 195$, 1992 data) in relation to 152-meter (500-foot) elevation bands (table 3). We then determined the amount of total mapped habitat that fell within the elevation limits of the 90th, 95th, and 100th percentiles of the distribution of these owls (after dropping two outliers from the eastern subprovince). After examining these maps and data about the distribution of known nest sites of spotted owls on the peninsula in relation to elevation (table 3), we concluded that upper elevation limits of 914 meters (3,000 feet) in the western subprovince and 1219 meters (4,000 feet) in the eastern subprovince were reasonable. We used a U.S. Geological Survey 1:250,000-scale digital elevation model (DEM; U.S. Geological Survey 1990) coded into 152-meter (500-foot) elevation zones to identify and screen out any potential habitat that occurred above the upper elevation limits in each subprovince.

Non-Federal lands-No widely reviewed maps of habitat were available for the non-Federal lands on the peninsula; however, we evaluated two draft maps identifying suitable habitat on these lands. The first, "WDNR mosaic," is a product of the WDNR (map version of 31 October 1994) and is being developed in support of that department's proposed habitat conservation plan (HCP). The second, "FWS mosaic," is a product of the FWS's 4(d) rule team. Our evaluation of these two maps was based on a visual review of the maps, tallies of the total amount and distribution of habitat throughout the peninsula, tallies of the distribution of habitat within circles 4.3 kilometers (2.7 miles) in radius centered on owl activity centers, and review by WDFW biologists who are familiar with the area. We concluded that the "WDNR mosaic" was the best choice for our analysis. First, its derivation was easily understood, having been assembled from ground-verified data whenever possible. In contrast, attributes on the "FWS mosaic" map were derived attributes; that is, they were themselves derived from other attributes. For example, much of the map begins with a late-successional stage classification. From a given late-successional stage, an average diameter at breast height (d.b.h.) was assumed, and from that d.b.h. an age was assumed. Thus, the final attributes were somewhat removed from the source data, with the potential to propagate errors. Second, the "WDNR mosaic" was based on a well-documented series of rules for inclusion of data. It was clear to us how and where each data source was used. Third, the WDFW biologists stated that the "WDNR mosaic" provided the best overall fit with what is known about the on-the-ground distribution of owl habitat on the peninsula.

The "WDNR mosaic" (fig. 7, table 4) is an assemblage of the best available information from a variety of different sources, including the FEMAT (1993) habitat classification for National Forest lands and data from the WDFW for some lands administered by the WDNR. For remaining State lands, the WDNR used inventoried stands (land use and land cover database) that met habitat definitions proffered by the Washington Spotted Owl Science Advisory Group. For all other lands, the WDNR used a satellite-derived forest cover classification (Green and others 1993) and

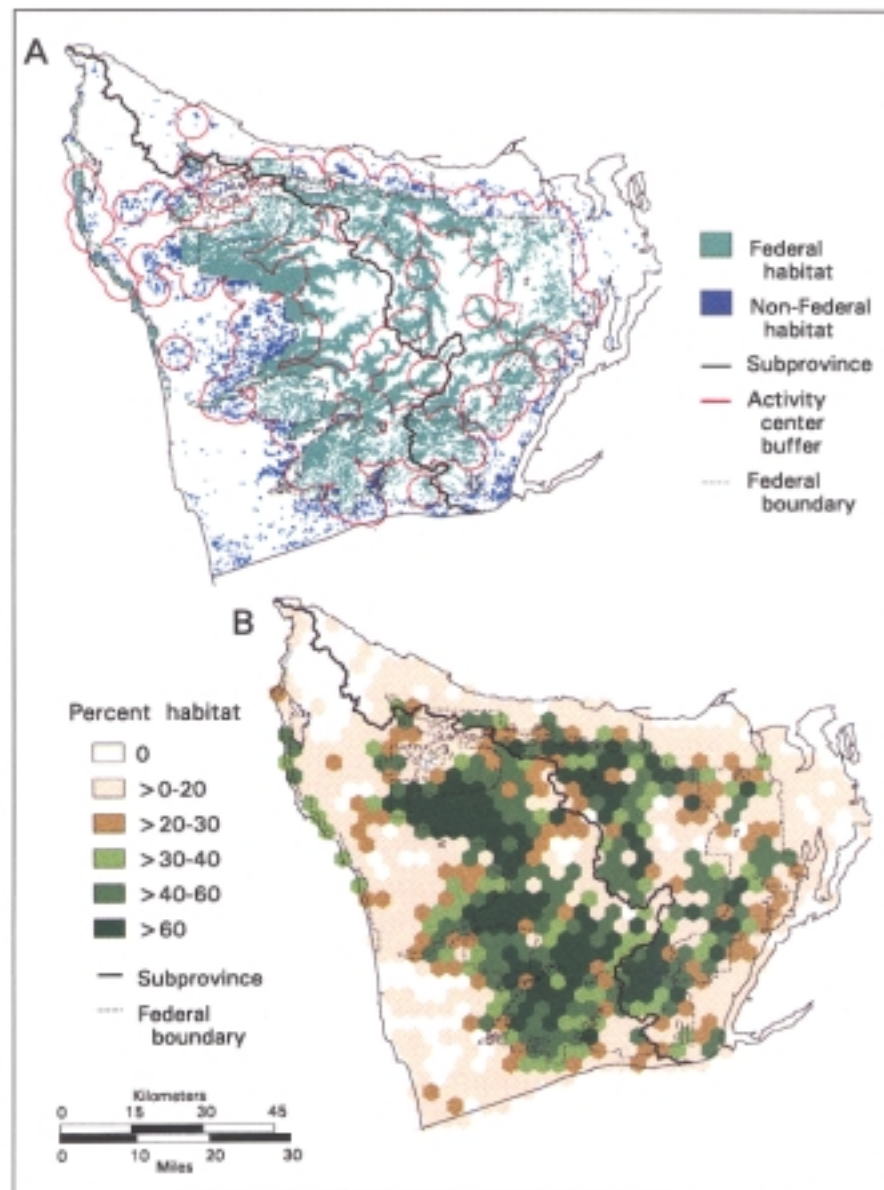


Figure 7-Current habitat on the Olympic Peninsula based on the "WDNR mosaic" and FEMAT databases. Buffers around owl activity centers and the boundary between Federal and non-Federal lands also are shown. A: Base Federal and non-Federal habitat layers; B: the derived 1500-hectare (3,707-acre) hexagonal cells used in simulation runs.

selected as habitat either the late-seral] (generally stands with more than 10 percent cover by trees greater than 53 centimeters [21 inches] d.b.h.) or a combination of the late-seral and mid-seral (less than 10 percent cover by 53-centimeter trees) categories, whichever had the best fit to classified owl habitat within a particular planning unit. The late-seral category is the same as the category selected to represent habitat in the National Park, as discussed above.

Map processing-Our habitat maps were binary maps depicting presence or absence of nesting, roosting, and foraging habitat for northern spotted owls. They were originally digitized in a vector (line) format but were generalized into a raster (grid) format for our analysis. The minimum resolution (cell size) of the gridded maps was about 16 hectares (40 acres). This data resolution is equal to the spatial unified database used in the FEMAT (1993) effort. A comparison of the original line maps to their gridded equivalents showed an overall difference of less than 0.3 percent in amount of habitat (Raphael and others 1994). Each cell on the resulting grid map was coded as suitable habitat if at least half of the underlying map was suitable habitat, and as unsuitable habitat otherwise. All map operations were conducted by using the ARC/INFO geographic information system (GIS).⁹

Projecting habitat through time-Portraying habitat change over time requires (1) a base map displaying stand ages or relative stages of structural development for areas not currently suitable as owl habitat but that may become owl habitat, (2) a model of how those stands change over time, and (3) a determination of the characteristics required for a stand to function as nesting, roosting, and foraging habitat.

Base map-The base map was the successional-stage map of Federal lands developed for FEMAT (1993). This map was derived from Landsat classification. The Landsat imagery and classification covered both National Forest and National Park lands on the west side of the Cascade Range crest in Washington and Oregon. Date of the imagery was 1988. The map created for FEMAT grouped 34 classified vegetation types into 13 vegetation types (table 5) and six structural stages (table 6).

Change in vegetation over time-A preliminary successional model was created for successional vegetation stages as part of the FEMAT analysis (1993:IV.54-IV.55). For coastal areas, including the Oregon Coast Ranges and the Olympic Peninsula, ages and duration associated with each of the conifer stages were estimated by FEMAT (1993). For the current analysis, we refined this model based on consultation with forest ecologists familiar with the peninsula. Separate ages were assigned to the stages for the eastern and western subprovinces of the Olympic Peninsula based on differences in average site indices for those areas (table 7). Average 50-year site indices of 115 and 100 were used to estimate rates of succession for the western and eastern subprovinces, respectively.

Characteristics of spotted owl habitat-It is likely that all four larger successional stages (table 8) contain some stands that have characteristics making them suitable spotted owl habitat. To determine which stages best represented owl habitat, we overlaid the map of structural stages on the map of current spotted owl habitat in the Olympic National Forest and tallied the hectares classified as suitable or not by each successional stage (table 8). Based on this simple comparison, the three oldest stages (medium multistory conifer and large single-story and multistory conifer) contain the largest ratio of suitable habitat to unsuitable habitat and thus seemed to best represent owl habitat.

⁹ ARC/INFO is a product of Environmental Systems Research Institute, Redlands, CA. The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 5-Vegetation types classified in the available seral-stage base map

Conifer	Hardwood
Grass/shrub	Grass/shrub
Seed sap pole	Small hardwood
Low-density conifer	Medium hardwood
Small conifer	Large hardwood
Medium single-story conifer	
Large single-story conifer	
Medium multistory conifer	
Large multistory conifer	
Naturally sparse	

Source: Teply, J. Unpublished data. On file with: Pacific Northwest Region, USDA Forest Service, P.O. Box 3623, Portland, OR 97208.

Table 6-Structural classifications from the available seral-stage base map

Structural class	D.b.h.
	<i>Inches^a</i>
Seedling	<0.9
Sapling	1.0 - 4.9
Pole	5.0 - 8.9
Small	9.0 - 20.9
Medium	21.0 - 31.9
Large	>31.9

^a Multiply inches by 2.54 to find centimeters.

Source: Teply, J. Unpublished data. On file with: Pacific Northwest Region, USDA Forest Service, P.O. Box 3623, Portland, OR 97208.

Application of the model to the Olympic Peninsula-Growth of habitat was modeled only for Olympic National Forest lands. The Olympic National Park, which has been essentially undisturbed by logging, was assumed to be in a state of dynamic equilibrium, where development of young stands is balanced by natural disturbance of older stands. Non-Federal lands were represented in a series of scenarios in the analysis, none of which assumed that additional nesting, roosting, and foraging habitat would be allowed to grow on those lands. The late-successional reserves in the National Forests, which have been harvested in the past, are the lands where regrowth of habitat is likely to occur through time.

Table 7-Duration of each structure stage used to project vegetation through time in the western and eastern subprovinces of the Olympic Peninsula

Structural stage	Subprovince	
	West	East
---- Years---		
Grass shrub	0-5	0-5
Seedling, sapling, pole	5-45	5-50
Small conifer	45-130	50-150
Medium single-story conifer	130-180	150-210
Medium multistory conifer	180-235	210-275
Large conifer	235+	275+

Table 8-Comparison of land classifications for the Olympic National Forest developed bar overlaying the base seral-stage map over the suitable owl habitat map^a

Seral stage	FEMAT classification		Ratio of suitable habitat to unsuitable habitat
	Suitable	Not suitable	
---- Hectares---			
Grass shrub	4288	18 048	0.24
Seedling, sapling, pole	9472	42 304	.22
Small conifer	23 488	52 512	.45
Medium single-story conifer	15 744	14 896	1.06
Large single-story conifer	304	112	2.71
Medium multistory conifer	7472	5104	1.46
Large multistory conifer	35 120	13 104	2.68

^a Nonforested and hardwood-dominated lands were not included.

Source: FEMAT (1993); modified to mask high-elevation habitat.

All stands currently classified as suitable in the spotted owl habitat map ("WDNR mosaic," fig. 7) were considered suitable regardless of their successional -stage designation. Stands not currently classified as suitable became suitable habitat when sufficient time elapsed for them to develop into medium multistory conifer (table 7). Stands already classified in that or later stages, but not currently classified as suitable habitat, did not immediately become suitable. Instead, they were treated as if they were medium single-story conifer at the current time; they were grown from that point and allowed to become suitable habitat when they reached the appropriate age during the simulation. Within each successional stage, we assumed stand age to be uniformly distributed for purposes of the projection.

Spotted Owl Population Simulation

The extent of future precommercial or commercial thinning that will occur in the reserves is unknown. The Northwest Forest Plan encourages thinning to accelerate development of owl habitat in plantations, and significant funding is being projected for forest restoration work. Because no operational plans exist for thinning of currently unsuitable stands to produce suitable owl habitat, none was assumed in the model. To the extent that thinning actually occurs, our simulations could underestimate regrowth of owl habitat for later decades.

To evaluate the relative likelihood of persistence and the pattern of distribution of the northern spotted owl in the Olympic Peninsula Province under various land management alternatives, we used OWL (version 2.01), a single organism, spatially explicit life-history simulator developed by McKelvey and others (1992), and used methods similar to those of Raphael and others (1994). This model is based mainly on models developed by Lande (1987, 1988) and Lamberson (Lamberson and others 1992, 1994; Thomas and others 1990: app. M). It is similar to Pulliam's BACHMAP model (Pulliam and others 1991). The model is sensitive to the shape and location of high-quality habitat. We view this model as a tool for landscape design that creates a logical framework for assessing the effects of qualitative differences in various land management plans on population dynamics of the northern spotted owl.

Parameterizing the model—

Hexagonal cell size--The population simulator uses a hexagonal grid of cells as the fundamental unit of spatial analysis. Habitat quality is coded for each cell, and all life-history functions occur at the hexagonal cell level. The total number of cells in the simulated landscape sets an upper limit for carrying capacity of owl pairs on that landscape. Thus, it is important to set an appropriate cell size. We tried to select a cell size that would result in a total population of pairs within the range of likely estimates for owls on the peninsula. As shown above (table 2), we made our own point estimates of the size of the Olympic Peninsula population of owls. We considered the range of realistic population size to be between the 155 known pairs and the 321 estimated pairs. Thus, we sought to set a cell size that would produce an estimate of carrying capacity within this range.

To investigate cell size, we developed a table showing the expected number of territorial pairs for a range of cell sizes and a range of assumptions about the percentage of habitat within the cell that would support occupancy by a pair (table 9). If the models began with pairs occupying any cell with more than 30 percent habitat (Lehmkuhl and Raphael 1993, Thomas and others 1990), either the 1500-hectare (3,707-acre) or 1250-hectare (3,089-acre) cells would produce reasonable numbers of pairs (table 9).

To choose between the 1500-hectare (3,707-acre) cell or the 1250-hectare (3,089-acre) cell, we examined available information on the mean area per pair of owls, calculated as the inverse of density. Several density estimates were available and were used to estimate average total land area per pair of owls (table 10). These estimates ranged from 714 to 3100 hectares (1,764 to 7,660 acres) per pair, with highest estimated densities in the Park (recognizing that Park estimates were preliminary). The 1250-hectare (3,089-acre) cell resulted in a closer fit with the estimated population size on the peninsula, but 1250 hectares per pair was at the low end of the range of estimates from the density data (table 10); only the estimates from the Park were lower but all others were higher. Given all the above, we selected 1500-hectare (3,707-acre) cells.

Table 9-Expected numbers of pairs of northern spotted owls on the Olympic Peninsula based on different assumptions about territory size and about the percentage of currently suitable habitat assumed necessary to support a pair of owls

Territory	Suitable habitat (percent)				
	>0	>20	>30	>40	>60
<i>Hectares</i>	<i>- - - Number of pairs - - -</i>				
3500	360	182	128	99	34
2500	476	248	204	133	53
1500	736	402	302	229	108
1250	857	468	365	271	137

Table 10-Estimates of density of pairs of northern spotted owls on the Olympic Peninsula

Source	Density	Hectare/pair
	<i>Pairs/km²</i>	<i>Hectares</i>
South Quinault District	0.037	2731
North Quinault District	.042	2400
West Soleduck District	.032	3100
Olympic National Park, west	.087	1149
Olympic National Park, east	.140	714

Source: Forsman, E.D.; Seaman, D.E. Unpublished data. On file with: Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

Vital rates in relation to habitat quality--To link the population of spotted owls to the landscape as portrayed by our GIS maps of habitat, relationships were developed between the amount and distribution of habitat and the survival and reproductive performance of the owl. The model allows for input of parameter estimates relating these vital rates to six classes of habitat. Our analysis was meant to compare the relative effects of different habitat configurations, not to predict the precise number of owls over time. Because there are great uncertainties in such comparisons, we compared results under various sets of assumptions. For this analysis, we developed four "rule sets"; that is, four different sets of vital rates based on different assumptions concerning the effects of the proportion of habitat in each hexagonal cell. The rule sets were modified from those used by Raphael and others (1994), which were developed to apply across the entire range of the owl. For the current analysis, we modified these values to better fit conditions on the Olympic Peninsula. Mean estimates of

vital rates in these rule sets could be taken directly from demographic analysis reported in Burnham and others (1994). To model effects of differing habitat management scenarios, however, the owl's vital rates need to be appropriately varied depending on the amount of suitable habitat in owl home ranges. Burnham and others (1994) do not address the range in vital rates that might be expected in habitats of differing quality.

Several studies have shown that sites occupied by northern spotted owls are located in areas with greater amounts of suitable habitat than are random sites or unoccupied sites (Lehmkuhl and Raphael 1993, Meyer and others 1992, Ripple and others 1991, Thomas and others 1990, USDI 1992). We are aware of only two analyses that relate the amount of suitable habitat to specific demographic performance of spotted owls: Bart and Forsman (1992) report relationships of the amount of habitat available in sites to the density of owls per site, the number of fledglings per site, and the number of fledglings per pair. Bart and Earnst (in: USDI 1992: app. B) report the relationship of adult turnover on sites to the amount of habitat available on those sites. They suggest that turnover is likely to be strongly related to survival but acknowledge that more study is needed to establish the relationship. Even so, this information is the best available to relate habitat to survival and fecundity.

Information from both sources was used by Bart (in press c) to develop regressions of fecundity and survival (as estimated from persistence on sites) to the amount of suitable habitat in those sites. Those regressions were:

$$f = 0.32 + 0.54p$$

and

$$s_a = 0.63 + 0.39p,$$

where f is fecundity, s_a is adult survival, and p is the proportion of the area surrounding an owl activity center that is composed of suitable habitat. Bart reported that slopes of both regressions were significantly different from 0.0 at significance levels less than 0.001.

We used these regressions to establish rule sets relating percentage of suitable habitat in owl territories to demographic parameters. By applying the regression to the categories of suitable habitat, as used in Raphael and others (1994), the resulting rule set is:

Parameter	Suitable habitat (percent)				
	0-20	>20-30	>30-40	>40-60	>60
Adult survival	0.67	0.73	0.77	0.82	0.94
Fecundity	.37	.46	.51	.59	.75

Consistency is poor between this rule set and the demographic data reported by Forsman and others (in prep.) for the Olympic Peninsula. For National Forest lands on the Olympic Peninsula where most of the demographic data were obtained, the average percentage of suitable habitat is 38 percent (table 4). From 1987 to 1993, the rates of adult survival in the Olympic demographic study area are estimated to have been 0.86 (Burnham and others 1994). The estimate of fecundity was 0.38 over the same period (Forsman and others, in prep.). To better match the average parameters with estimates from the Olympic studies, we retained the slope of the regression reported above, but adjusted the intercept to match the Olympic results. In addition, to avoid implausibly high rates, we truncated the survival and fecundity parameters in the highest quality cells. The resulting parameters were:

Parameter	Suitable habitat (percent)				
	0-20	>20-30	>30-40	>40-60	>60
Adult survival	0.76	0.82	0.86	0.92	0.92
Fecundity	.24	.33	.38	.46	.46

These parameters, and the others listed in table 11 and appendix 2, were used as input to the simulation model and were labeled "rule set B." In this rule set, we used an estimate of juvenile survival of 0.29, an estimate that had been used in previous model simulations (Raphael and others 1994) and that was the median from the values in Burnham and others (1994) for 11 study areas. This estimate is slightly higher than that reported by Forsman and others (in prep.) for juvenile survival unadjusted for emigration on the Olympic Peninsula. Rule set A was identical except that the parameters were shifted to the right (into the next highest habitat category); the parameters of rule set C were shifted to the left (into the lower habitat category). A fourth rule set, rule set D, was identical to rule set B except that juvenile survival was increased to 0.38, the estimate from Burnham and others (1994) that was adjusted for emigration of juveniles out of study areas.

These rule sets can be compared based on the estimates of the rate of population change for each habitat percentage class that result from the survival and fecundity rates associated with each habitat class under each rule set (table 12). For the 30- to 40-percent habitat class, which includes the average of 38 percent nesting, roosting, and foraging habitat for National Forest lands, predicted rate of population change (λ) ranges from 0.907 under rule set A to 1.038 under rule set C. The estimated λ from rule set A is lower than Forsman and others' (in prep.) unadjusted λ ; λ s from rule sets B, C, and D are within the range defined by Forsman and others' (in prep.) unadjusted and adjusted λ s (0.947 to 1.058).

Table 11-Summary of parameters under 4 sets of rules used to simulate population dynamics of the northern spotted owl on the Olympic Peninsula

Rule set and parameter	Suitable habitat (percent)				
	0-20	>20-30	>30-40	>40-60	>60
Rule set A:					
Mean survival probabilities ^a --					
Stage 0 (juvenile)	0.20	0.29	0.29	0.29	0.29
Stage 1 (subadult)	.72	.76	.82	.86	.92
Stage 2 (adult)	.72	.76	.82	.86	.92
Rule sets B, D:					
Mean survival probabilities ^a --					
Stage 0 (juvenile) ^b	.29, .38	.29, .38	.29, .38	.29, .38	.29, .38
Stage 1 (subadult)	.76	.82	.86	.92	.92
Stage 2 (adult)	.76	.82	.86	.92	.92
Rule set C:					
Mean survival probabilities ^a --					
Stage 0 (juvenile)	.29	.29	.29	.29	.29
Stage 1 (subadult)	.82	.86	.92	.92	.92
Stage 2 (adult)	.82	.86	.92	.92	.92
Rule sets A, B, C, D:					
Mean fledge probabilities					
Rule set A	.19	.24	.33	.38	.46
Rule sets B, D	.24	.33	.38	.46	.46
Rule set C	.33	.38	.46	.46	.46
Fledge number = 2 ^c					
Male probability of fledging = 0.50 ^c					
Movement ^c					
Nesting OK	.40	.55	.83	1.00	1.00
Aversion	.50	.70	.90	1.00	1.00
Probability female finds male = 0.50					
Male territorial aversion = 0.50					
Directional weighting = 2.00					
Wanderlust	0	.50	.50	.50	.50
Boundary condition ^c					
Total number of runs = 50					
Total run length = 100 Years					
Delta-t = 20					

^a Variance of survival probabilities is 0 for all rule sets and stages.

^b Juvenile survival was 0.29 in rule set B, 0.38 in rule set D (adjustment for emigration from Burnham and others [1994]).

^c See McKelvey and others (1992) and appendix 2 for explanation of these factors.

Table 12-Rates of population change (λ) associated with the various habitat classes and rule sets^a

Rule set	Suitable habitat within a cell (percent)				
	0-20	>20-30	>30-40	>40-60	>60
	λ^a				
A	0.756	0.824	0.907	0.959	1.038
B	.824	.907	.959	1.038	1.038
C	.907	.959	1.038	1.038	1.038
D	.842	.931	.986	1.070	1.070

^a λ values are generated by inserting the associated birth and death rates into a stage matrix and computing the dominant eigenvalue (see Thomas and others 1990: app. L). λ values greater than 1.0 indicate that sites occupied by pairs will be producing young at rates greater than the replacement rate. Sites with associated λ s less than 1.0 will require immigration to maintain occupancy.

Initial population-To start the model, an initial population level must be set. One option was to manually place owls across the simulated landscape. We considered using the locations of all known owl activity centers, but this would have left gaps where owls have not been fully surveyed. Instead, we decided to assume an owl occurs in every cell with more than some specified proportion of habitat and to start the model with a population size within our range of estimates (table 2). We examined the distribution of habitat around known activity centers (fig. 8) and found most sites had more than 40 percent habitat, so we considered 40 percent habitat or greater to start the owl population. This level resulted in initial number of pairs (229 pairs, table 9) lower than the estimated number of pairs on the peninsula. Starting the model with a pair at every cell that exceeded 30 percent habitat resulted in an initial population size (302 pairs) that was within our estimated range, so we used the 30-percent rule to begin our model runs. Because the initial number of pairs strongly influences simulation results over the first years of a simulation run, model results for the first decade or two are not as useful as those from later years.

Simulation runs-Each simulation began with an appropriate habitat map. The map was converted into hexagonal cells, and each cell was coded into a habitat quality class (fig. 7). Each simulation was for 100 years and consisted of 50 replicated runs for each rule set and habitat scenario. For simulations where habitat was changed, either to simulate catastrophic events or habitat growth (discussed below), the run began with the current habitat map (under a particular habitat scenario), and a new map was inserted into the run at the prescribed time(s).

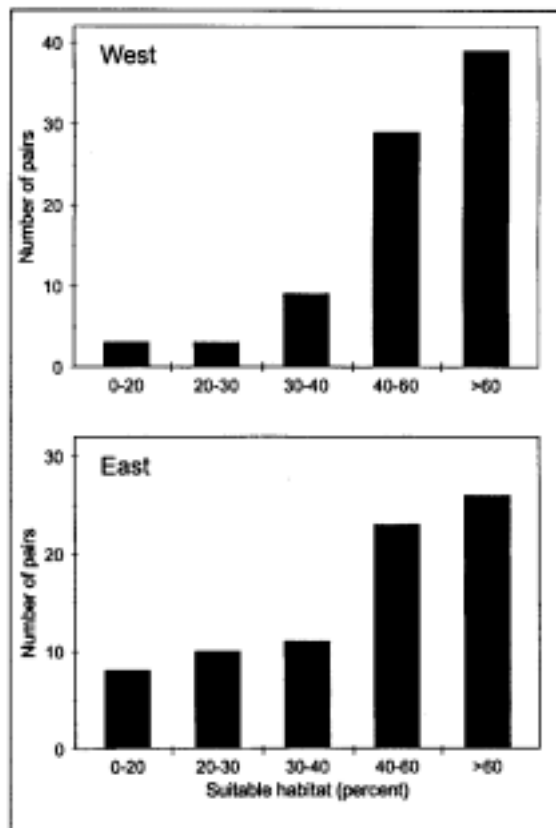


Figure 8-Number of known pairs (see fig. 2) by habitat class. Habitat classifications are based on the percentage of 1500-hectare (3,707-acre) circles surrounding known pair locations (fig. 2).

We summarized several results from each simulation. We calculated the mean number of pairs at each year (averaged over the 50 runs) and an associated 95-percent confidence interval about the mean. Mean occupancy of each cell by pairs of owls over 100 years was calculated and mapped. For each run, a cell was scored as "occupied" if a pair was present in the cell at the end of a year. Mean occupancy was the total occupied cell-years divided by the product of years multiplied by replications. We also calculated the finite rate of population change (λ) for each simulation by using the average change in mean population size for each year from year 60 through year 100. This period was chosen because it eliminated the initial adjustment in the model to startup conditions.

Land Management Scenarios

Current conditions-For our first series of simulations, we assumed that habitat conditions were static; that is, whatever habitat existed at the start of a run would persist to the end of the 100-year run. We examined five land management scenarios, each with different amounts of habitat retained on non-Federal lands (table 13).

Table 13-Total area of suitable spotted owl habitat under each management scenario, Olympic Peninsula^a

Scenario	Total habitat	Non-Federal habitat
----- Hectares-----		
1. Federal habitat only ^b	265 900	0
2. Federal and non-Federal	330 600	64 600
3. Current take guidelines	297 900	32 000
4. Special emphasis areas:		
North	271 200	5200
West	287 100	21 100
Both	292 300	26 300
5. Selective removal: ^c		
Rule B		
10%	295 700	29 700
20%	288 600	22 600
40%	280 600	14 600
60%	271 500	5500
Rule D		
10%	306 200	40 300
20%	298 900	32 900
40%	290 100	24 100
60%	283 800	17 800
Catastrophic fire ^d	189 000	0
Habitat growth: ^e		
Federal habitat only	303 200	0
Federal and non-Federal	367 900	64 600
Current take guidelines	335 200	32 000

^a All values rounded to the nearest 100 hectares.

^b Includes National Forest and National Park only (does not include minor contributions of other Federal land (see table 4).

^c Selective removal of habitat cells based on successively higher mean occupancy (see text for details).

^d Effect of fire as modeled from risk zones depicted in figure 5.

^e Habitat growth was modeled only for National Forest land. Totals reflect cumulative habitat 80 years in the future.

Scenario 1, Federal habitat only-This scenario modeled the lowest level of habitat protection envisioned. For this scenario, we assumed there was no habitat but Federal lands. Any habitat falling outside administrative boundaries of Federal lands was eliminated. Existing Federal habitat was tallied within the 1500-hectare (3,707-acre) hexagonal cells and used as input for model runs.

Scenario 2, Federal and Non-Federal habitat-This scenario modeled the highest level of habitat protection envisioned. It included all existing habitat ("WDNR mosaic"), whether Federal or non-Federal, with no regrowth or harvest.

Scenario 3, current take guidelines-- This scenario modeled an intermediate level of habitat protection that would result from implementing current regulations. We plotted the locations of all known owl activity centers (n = 191, data through 1993 as provided by WDFW), each surrounded by a circular buffer 4.3 kilometers (2.7 miles) in radius following legal take guidelines (figs. 6 and 7A). First, we eliminated all non-Federal habitat outside the circular buffers. Then, if the remaining buffer area contained more than 40 percent habitat (the amount specified in the take guidelines), we eliminated any non-Federal habitat in excess of 40 percent, as long as that removal did not reduce the amount of habitat below 40 percent for any overlapping buffer.

Scenario 4, special emphasis areas-- This scenario for special emphasis areas (SEAs) focused on areas being considered as alternatives under the 4(d) rule process. We obtained maps of proposed SEAs in the northern and western portions of the peninsula and plotted 4.3-kilometer (2.7-mile) buffers for all owl activity centers that overlapped these boundaries. We created a new boundary that followed the outside edge of all such circles. Within this boundary, we retained non-Federal habitat based on the take guidelines described for scenario 3 and eliminated all non-Federal habitat outside the SEAs. We also ran separate simulations on the northern SEA alone and on the western SEA alone.

Scenario 5, selective removal of low-occupancy habitat-- This scenario modeled an intermediate level of habitat protection that would result from relaxing current regulations and using a hypothetical optimal process for selecting areas to protect. For this series of simulations, we selectively removed non-Federal habitat from the "WDNR mosaic" (all habitat) map (scenario 2) based on rates of occupancy by pairs from simulation runs using rule sets B and D under scenario 2. In this series of runs, we first eliminated any non-Federal habitat within hexagonal cells where mean occupancy by pairs of owls was less than or equal to 10 percent, and then ran the simulation based on this new map. Next, we eliminated any habitat from cells that had less than or equal to 20 percent habitat and repeated the run, then repeated all steps removing habitat at the 40-percent occupancy rate, and finally at the 60-percent occupancy rate.

Catastrophic fire--To simulate the effect of catastrophic fire, we defined a fire-risk zone (see footnote 7) covering about 270 000 hectares (666,400 acres) (fig. 5) and, as a worst case analysis, assumed that all habitat was eliminated throughout this zone. We simulated the fire at year 2. This simulation was based on scenario 1 (Federal habitat only).

Habitat growth--Scenarios 1, 2, and 3 were repeated but included an assumption of growth of new habitat within the Olympic National Forest. For these simulations, new maps in which habitat had been grown on National Forest lands were created for years 20, 40, 60, and 80 and inserted into the simulation run at those years.

Connecting corridor--The relative isolation of the spotted owl population on the Olympic Peninsula has been of concern. There have been proposals to improve the interaction of the population on the peninsula with other populations by maintenance of dispersal habitat, as well as by developing small subpopulations that would link to populations along the west side of the Cascades. The northern spotted owl recovery plan (USDI 1992: 109) suggests creating a series of reserves large enough to support 20 pairs of owls and spaced at about 19.3-kilometer (12-mile) edge-to-edge intervals connecting the southern Washington Cascades with the Olympic Peninsula.

To analyze this proposal, we combined the map of current habitat on the Olympic Peninsula (fig. 7) with a hypothetical source population representing the Cascades. We created a series of intermediate reserves similar to those proposed in the final draft recovery plan (USDI 1992) and ran simulations with and without these intermediate reserves. Habitat in the source population (which had a carrying capacity of about 800 pairs of owls) and the intermediate reserves were assumed to be of high quality (more than 60 percent habitat).

We ran 10 different scenarios using rule sets B and D with habitat maps for the Olympic Peninsula representing all habitat and Federal habitat only (table 11), either with intermediate reserves or without them. In addition, we generated two scenarios in which the spotted owl population of the Olympic Peninsula was reduced by 80 percent at the outset.

The population reduction runs were slightly different from all other simulations reported in this paper. In all other runs, all cells containing more than 30 percent habitat began with a pair. In these runs, we randomly removed 80 percent of the population on the peninsula while following normal initialization for the "source" habitat and the connecting corridor. This led to a starting point with an extremely diffuse population and therefore a higher likelihood of local extirpation. In addition, these simulations were run for 200 years to allow for recolonizing or extinction.

Results
Amount and Distribution
of Current Habitat

Suitable habitat of the northern spotted owl (as determined from our databases) is concentrated in the western subprovince, primarily on National Park and National Forest lands (figs. 7 and 9). Of the 330 600 hectares (817,000 acres) of habitat on all ownerships, 197 700 hectares (488,400 acres; 60 percent) occur on the western subprovince and 266 000 hectares (657,300 acres; 80 percent) occur on Federal land in both subprovinces (fig. 7 and table 13). As shown in figures 7 and 9, habitat that occurs on non-Federal lands is distributed in smaller, less contiguous patches than that on Federal lands. Habitat represents an average of 43 percent of the landscape on Federal lands versus 11 percent on non-Federal lands (table 4).

Habitat Projection

Our habitat growth model resulted in the following increases in amount of habitat on National Forest lands (fig. 10):

Years	Habitat growth
0-20	9 400 hectares (23,200 acres)
21-40	8 800 hectares (21,600 acres)
41-60	8 800 hectares (21,700 acres)
61-80	10 400 hectares (25,700 acres)
Total	37 400 hectares (92,200 acres)

The growth rate was approximately linear and constant during the period we simulated, with an average of 466 hectares (1,152 acres) per year (fig. 10B). Much of the habitat grown during the 80-year period was concentrated in the northwestern

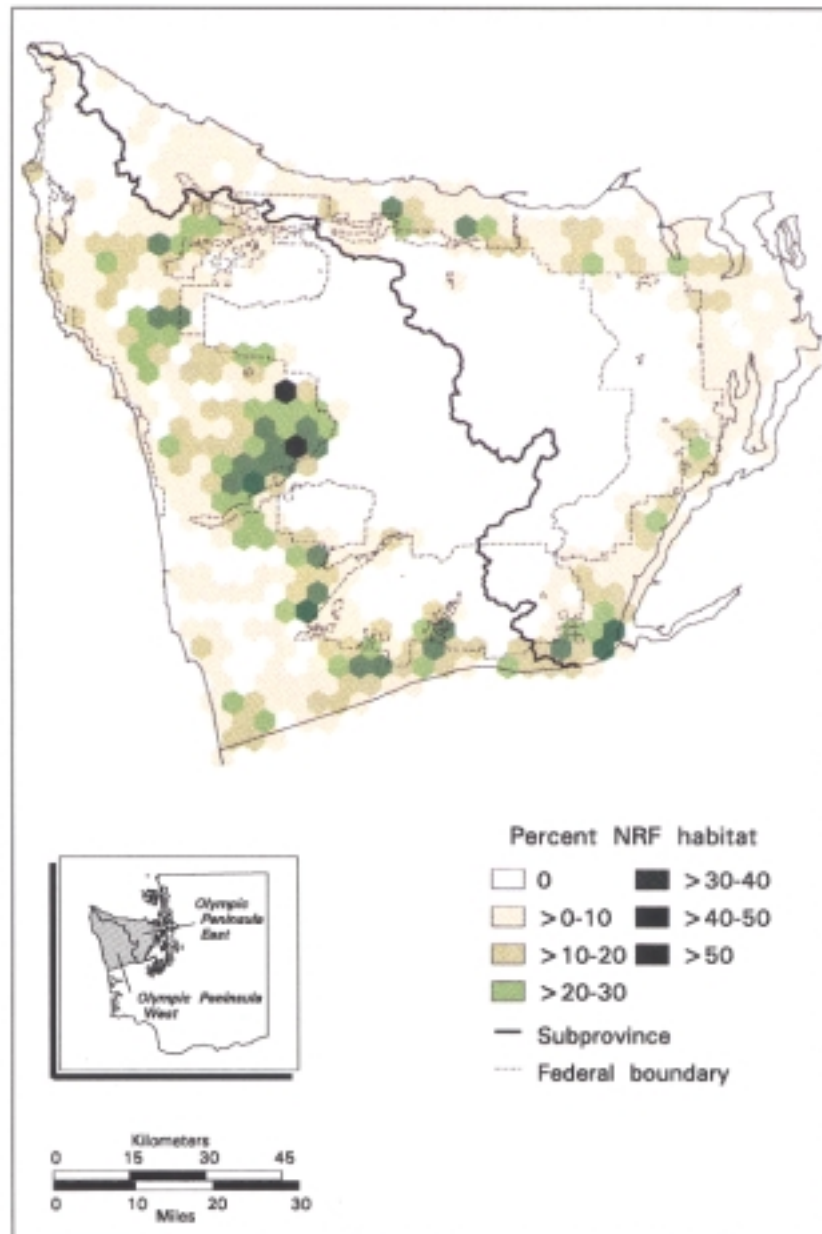


Figure 9-Distribution of nesting, roosting, and foraging habitat on non-Federal lands on the Olympic Peninsula. Map is summarized into 1500-hectare (3,707-acre) hexagonal cells, and the non-Federal contribution of habitat to each cell is presented as the percentage of each cell composed of suitable habitat.

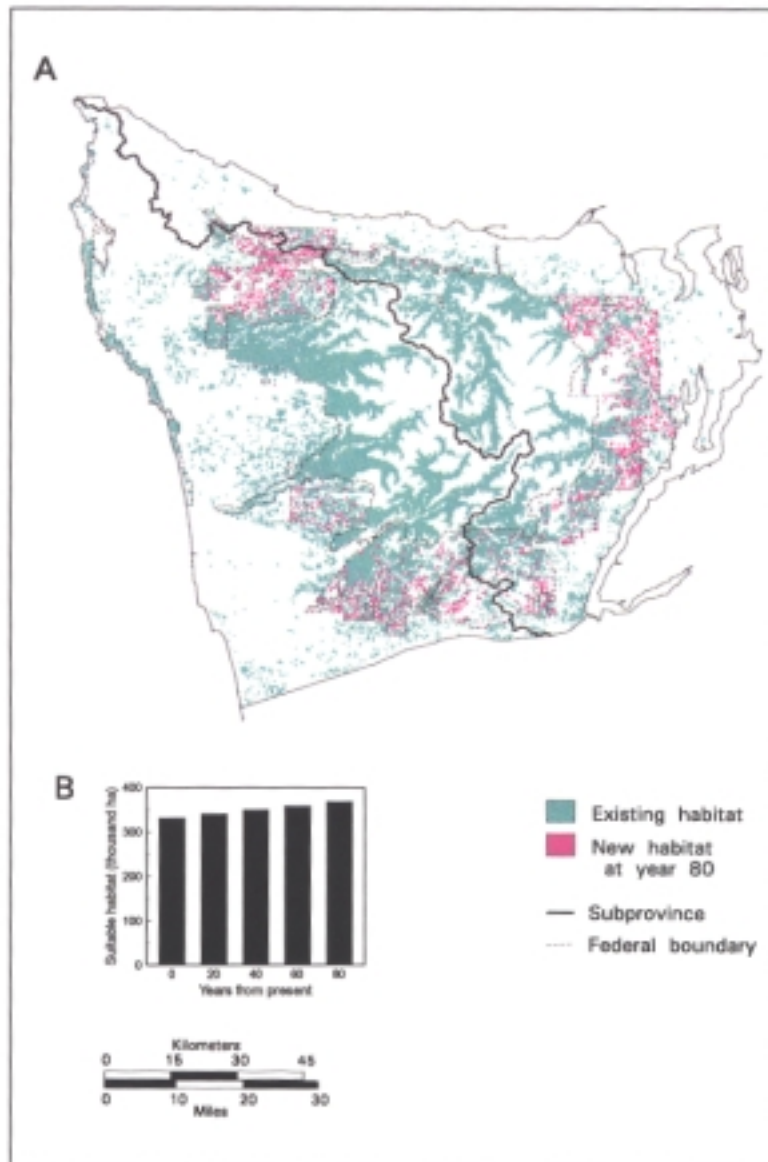


Figure 10-Projected growth of suitable owl habitat on the Olympic Peninsula over the next 80 years. No habitat was grown above 914 meters (3,000 feet) elevation in the western subprovince or 1219 meters (4,000 feet) in the east. Habitat growth was projected for National Forest lands only. **A**: Areas in which habitat grew (magenta) in relation to existing habitat (green); **B**: overall increase in habitat over 80 years.

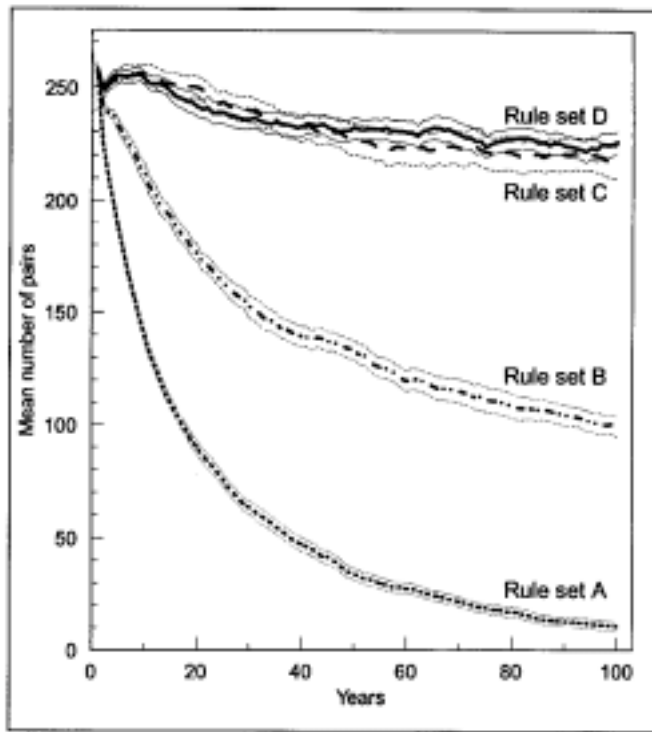


Figure 11-Population trajectories associated with various rule sets and simulated on maps containing current levels of habitat for Federal lands only. The heavy lines are average trajectories based on 50 simulation runs. The thinner lines are 95-percent confidence intervals.

Simulated Owl Population Trends

Scenario 1, Federal habitat only, without regrowth-The results of the population simulations based on the 265 900 hectares (657,100 acres) of Federal habitat (table 13) remapped into suitability classes within hexagonal cells differed greatly depending on the rule set used (fig. 11). Rule set C, which had high rates of fecundity and survival when habitat exceeded 30 percent of a cell, resulted in a slight rate of decline in mean numbers of pairs. Trends under rule set B, where high rates of fecundity and survival required habitat in excess of 40 percent of a cell, declined at a faster rate than under rule set C. Trends under rule set A, where habitat had to exceed 60 percent to support high fecundity and survival, declined even more steeply over the 100 years (fig. 11). Trends under rule set D, which was identical to rule set B except for use of a higher rate of juvenile survival, were nearly identical to those of rule set C (fig. 11). The mean numbers of pairs calculated over the 100 years of each simulation were 56, 143, 232, and 234 for rule sets A, B, C, and D, respectively. Under rule set B, which was designed to best fit the adult survival and fecundity parameters estimated for the peninsula (without a correction for juvenile emigration), the finite rate of population change (λ) was 0.9954 for years 60 through 100 (table 14). Under rule set D, the simulated population declined more slowly ($\lambda = 0.9996$).

Graphs of mean occupancy showed that occupancy was higher in the western subprovince than in the eastern subprovince under any rule set, thereby reflecting the greater concentration of habitat in the west (fig. 12). Plots of mean occupancy

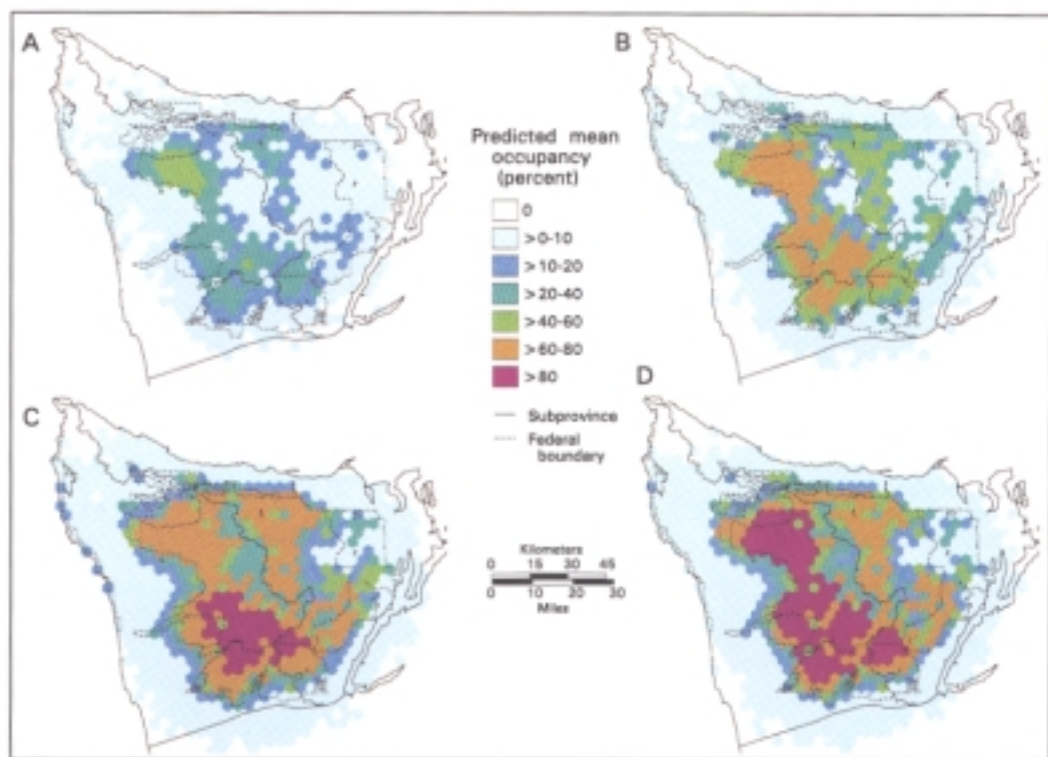


Figure 12-Patterns of mean occupancy by reproductive pairs for simulations using rule sets A through D. All simulations were by run using scenario 1 (Federal habitat only) without regrowth. Occupancy rates are the proportion of years, averaged over all years and simulations, that a particular site was occupied by a reproductive pair. **A:** Rule set A; **B:** rule set B; **C:** rule set C; **D:** rule set D.

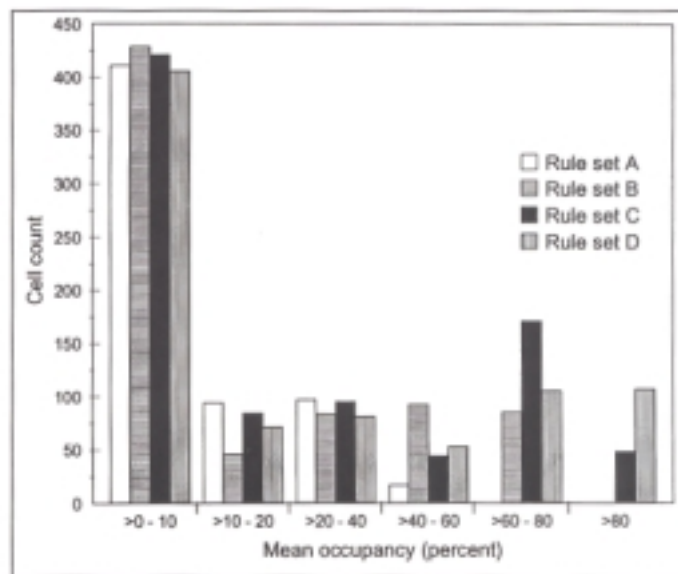


Figure 13-Counts of cells in each of six mean occupancy classes (from fig. 12) of spotted owl pairs as simulated under the four rule sets for scenario 1 (Federal habitat only) without regrowth. Note that only rule sets C and D produce cells with occupancy rates greater than 80 percent.

also revealed obvious differences among outcomes from the four rule sets. Rule set A did not result in any cells with more than 60-percent occupancy at the end of the 100-year simulation period; more cells had higher occupancy under rules B, C, and D; and only rules C and D had cells with more than 80-percent occupancy (fig. 13).

Table 14-Summary of simulation results under various management scenarios using rule sets A, B, C, and D and assuming no regrowth of habitat, Olympic Peninsula

Criterion	Scenarios						
	1 (Federal only)		2 (All	3 (Take	4 (Take guidelines in SEA) ^a		
	Without fire	With fire	habitat)	guidelines)	Both	West	North
Rule set A:							
Amount of habitat (ha x 1000)	266	189 ^b	331	298	292	287	271
Number of cells >60-80% mean occupancy	0	0	0	0	0	0	0
Number of cells >80% mean occupancy	0	0	0	0	0	0	0
Total of cells >60% mean occupancy	0	0	0	0	0	0	0
Mean number of pairs	56	43	66	63	62	61	58
Pairs at year 60	27	21	33	29	32	32	27
Pairs at year 100	10	6	12	11	12	11	9
λ evaluated for year 60-100	0.9762	0.9698	0.9760	0.9769	0.976	0.9749	0.9719
Rule set B:							
Amount of habitat (ha x 1000)	266	189 ^b	331	298	292	287	271
Number of cells >60-80% mean occupancy	85	62	124	108	102	97	92
Number of cells >80% mean occupancy	0	0	0	0	0	0	0
Total of cells >60% mean occupancy	85	62	124	108	102	97	92
Mean number of pairs	143	100	177	162	155	152	146
Pairs at year 60	120	80	153	138	132	132	124
Pairs at year 100	99	68	132	122	110	107	103
λ evaluated for year 60-100	0.9954	0.9961	0.9963	0.9969	0.9954	0.9948	0.9955
Rule set C:							
Amount of habitat (ha x 1000)	266	189 ^b	331	298	292	287	271
Number of cells >60-80% mean occupancy	171	107	132	151	153	146	161
Number of cells >80% mean occupancy	48	29	132	91	83	87	60
Total of cells >60% mean occupancy	219	136	264	242	236	233	221
Mean number of pairs	232	159	293	263	258	252	240
Pairs at year 60	223	142	289	258	250	248	235
Pairs at year 100	217	136	283	254	250	237	225
λ evaluated for year 60-100	0.9993	0.9989	0.9995	0.9996	1.0000	0.9989	0.9989
Rule set D:							
Amount of habitat (ha x 1000)	266	189 ^b	331	298	292	287	271
Number of cells >60-80% mean occupancy	105	50	115	103	106	110	102
Number of cells >80% mean occupancy	107	88	140	131	119	116	112
Total of cells >60% mean occupancy	212	138	255	234	225	226	214
Mean number of pairs	234	160	285	263	252	250	239
Pairs at year 60	230	148	282	260	242	246	233
Pairs at year 100	226	149	276	253	244	242	231
λ evaluated for year 60-100	0.9996	1.0001	0.9995	0.9994	1.0003	0.9996	0.9998

^a SEAs are special emphasis areas being considered as alternatives under the 4(d) rule process (see fig. 15).

^b Year 2.

Scenario 2, Federal and non-Federal habitat-The simulated population in the scenario representing all suitable habitat (330 600 hectares [817,000 acres]) but with no regrowth (table 14), was larger than that of scenario 1 for each rule set. Under rule set B, for example, the average number of pairs over the 100-year simulation was 177 for scenario 2 versus 143 pairs under scenario 1; the rate of decline of the population was lower as well (table 14). Mean occupancy was also greater under scenario 2 than under scenario 1, with 124 cells having occupancy rates exceeding 60 percent for scenario 2 versus 85 such cells for scenario 1 at the end of the 100-year simulation period. This is readily apparent in figure 14A, which shows a large, contiguous area of high-occupancy cells, an area we interpret as representing source habitat where the estimated rate of population change exceeds 1.0. For this scenario, we replicated the entire simulation (fifty 100-year runs) to assess variation in occupancy rates due to stochastic variation within the model. Rule sets B and D were used for these simulations (table 15).

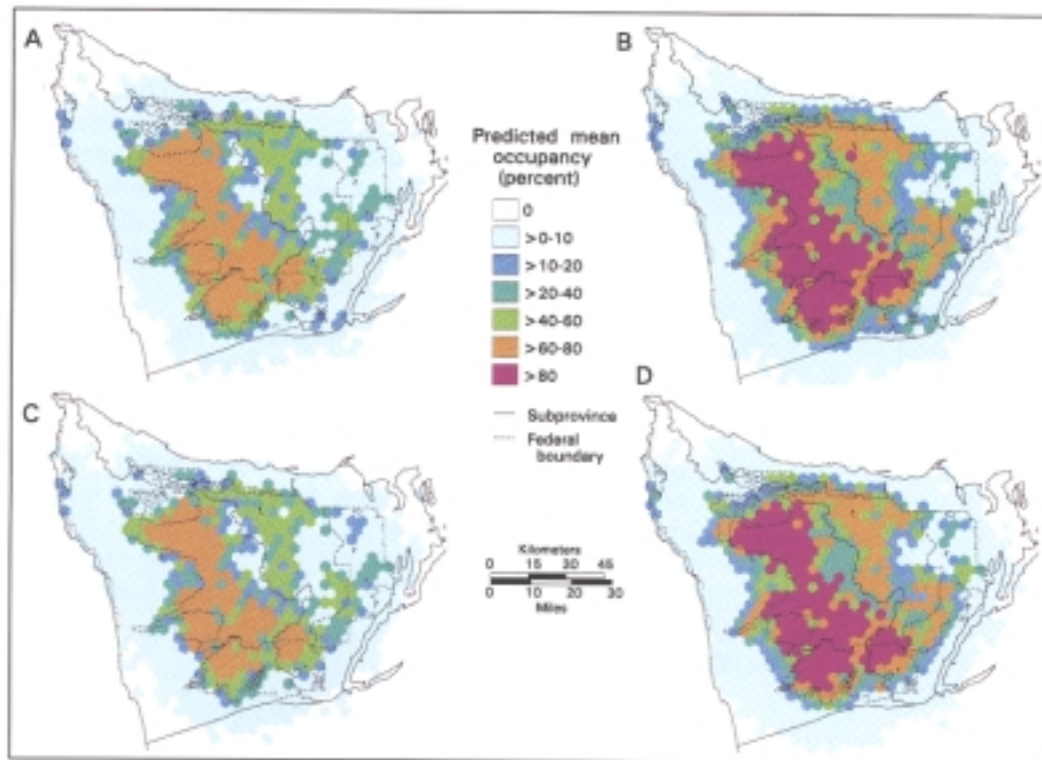


Figure 14-Mean occupancy of spotted owl pairs simulated by using rule sets B and D. **A and B:** Based on current habitat conditions for all lands on the Olympic Peninsula (scenario 2), using rule sets B and D, respectively. **C and D:** Based on current habitat conditions for habitat on Federal lands and including habitat within the buffer areas surrounding owl activity centers on non-Federal lands following current take guidelines (scenario 3) using rule sets B and D, respectively. In scenario 3, non-Federal habitat was removed from owl buffers if the combined contribution from Federal and non-Federal lands exceeded 40 percent.

Table 15-A comparison of occupancy patterns associated with simulating owl population dynamics using rule sets B and D under scenario 2, Federal and non-Federal habitat, Olympic Peninsula

Mean occupancy	Range of cells by cell count ^a	
	Rule B	Rule D
<i>Percent</i>		
0	871-893 (22)	797-815 (18)
>0-10	424-446 (22)	372-395 (23)
>10-20	62-72 (10)	72-84 (12)
>20-40	84-92 (8)	87-97 (10)
>40-60	88-99 (11)	59-68 (9)
>60-80	120-125 (5)	109-121 (12)
>80	0	138-144 (6)

^a Ranges are the extreme values generated from 10 separate simulation runs for each rule set (each run consisted of 50 separate simulations). Simulations assumed that current vegetation patterns were static (no regrowth), and all habitat currently on the Olympic Peninsula was retained. Values in parentheses are ranges.

Scenario 3, current take guidelines-Under current take guidelines, we estimated the retention of a total of 297 900 hectares (736,200 acres) of suitable habitat (assuming no regrowth), a reduction of 32 700 hectares (80,800 acres) from scenario 2 (table 13). Under this habitat scenario, the size of the simulated owl population and rates of occupancy (figs. 14C and D) were intermediate to those of scenarios 1 and 2 (figs. 12B and 14A). Compared to scenario 2 (fig. 14A), the pattern of high-occupancy cells (those greater than 60 percent) was more fragmented and constricted at the end of the 100-year simulation period.

Scenario 4, special emphasis areas-The respective amounts of non-Federal habitat retained under the three SEA options (without regrowth) were 5200 hectares (12,800 acres) with the north SEA retained, 21 100 hectares (52,100 acres) with the west SEA retained, and 26 300 hectares (65,000 acres) with the two SEAs retained (table 13). The simulated owl population trend and size reflected the relative amount of habitat in the three options, but the west SEA made a greater contribution to owl numbers and occupancy rates than did the north SEA under each of the four rule sets (figs. 15 and 16; table 14). Mean number of pairs over the 100-year simulation was nearly as large with the western SEA alone as with both SEAs (table 14).

Scenario 5, selective removal of low-occupancy habitat-Selective removal of habitat (table 13) from cells supporting lower occupancy rates, as determined from our earlier simulation of scenario 2 (all habitat, no regrowth), suggested that it is possible to design alternative non-Federal habitat retention strategies that might be more efficient (require less area of habitat for a given number of owls) than the current take guidelines. Using the approach of successively removing all non-Federal habitat at cells where occupancy was lowest (less than or equal to 10 percent) and then moving to higher levels (more than 10 to 20 percent, more than 20 to 40 percent, more than 40 to 60 percent) showed that removal at the lowest levels had little effect on mean number of pairs (fig. 17). Only after removing habitat where occupancy was up to 60 percent did populations fall below the level resulting from scenario 3 under rule set B; populations were always greater under rule set D.

Effect of catastrophic fire-Simulations of scenario 1 (Federal habitat only) where all Federal habitat within the fire-risk zone was removed (76 900 hectares [190,000 acres], fig. 5) showed a decline in mean numbers of pairs over the 100-year run from 143 to 100 pairs under rule set B, a change of 30 percent compared to the simulations of scenario 1 without fire (fig. 18). The magnitude of this population reduction was proportional to the size of the affected area, about 33 percent of the Federal land. Simulated population trends (that is, the rates of change in population size over time) were similar between the burned and unburned scenarios under each of the four rule sets (table 14). Rates and patterns of mean occupancy on the peninsula before and after the burn (figs. 12 and 19) also differed very little, except for the expected lower rate of occupancy within the burn zone itself. Burning in the eastern subprovince had little impact on occupancy patterns by owls in the western subprovince (fig. 19).

Effect of habitat regrowth-Simulated populations were larger and more widely distributed (figs. 20 and 21) when currently unsuitable habitat on the National Forest was grown as described earlier (fig. 10). Populations declined at a slower rate than without habitat growth under rule sets A and B (table 16). Under rule sets C and D, the estimated rate of population change exceeded 1.0 under each of scenarios 1, 2, and 3 (table 16, fig. 20).

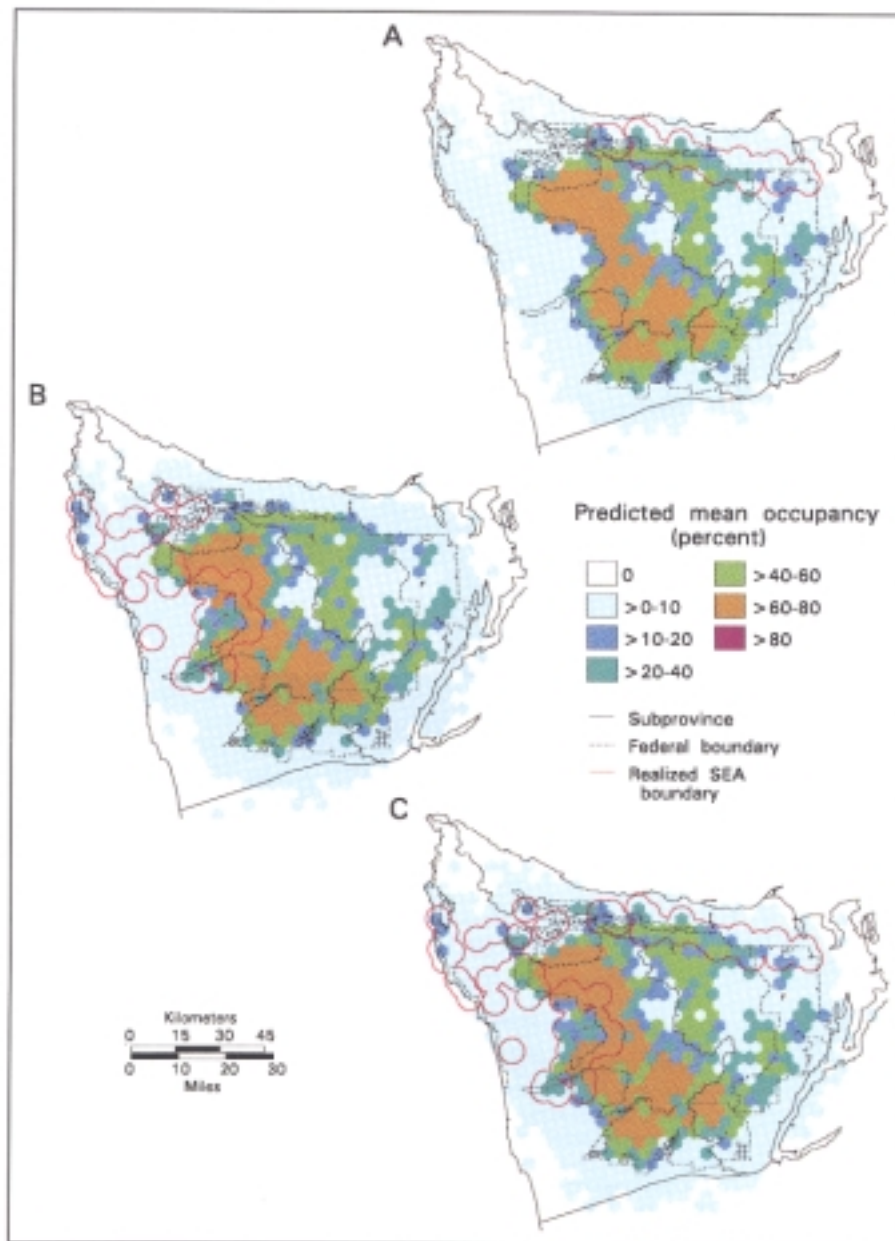


Figure 15-Mean occupancy of spotted owl pairs based on current habitat conditions on Federal lands plus habitat on non-Federal lands that occurred within a 4.3-kilometer (2.7-mile) radius of owl activity centers and that fell within defined special emphasis areas (SEA). **A:** Northern SEA; **B:** western SEA; **C:** both. Simulations were run by using rule set B.

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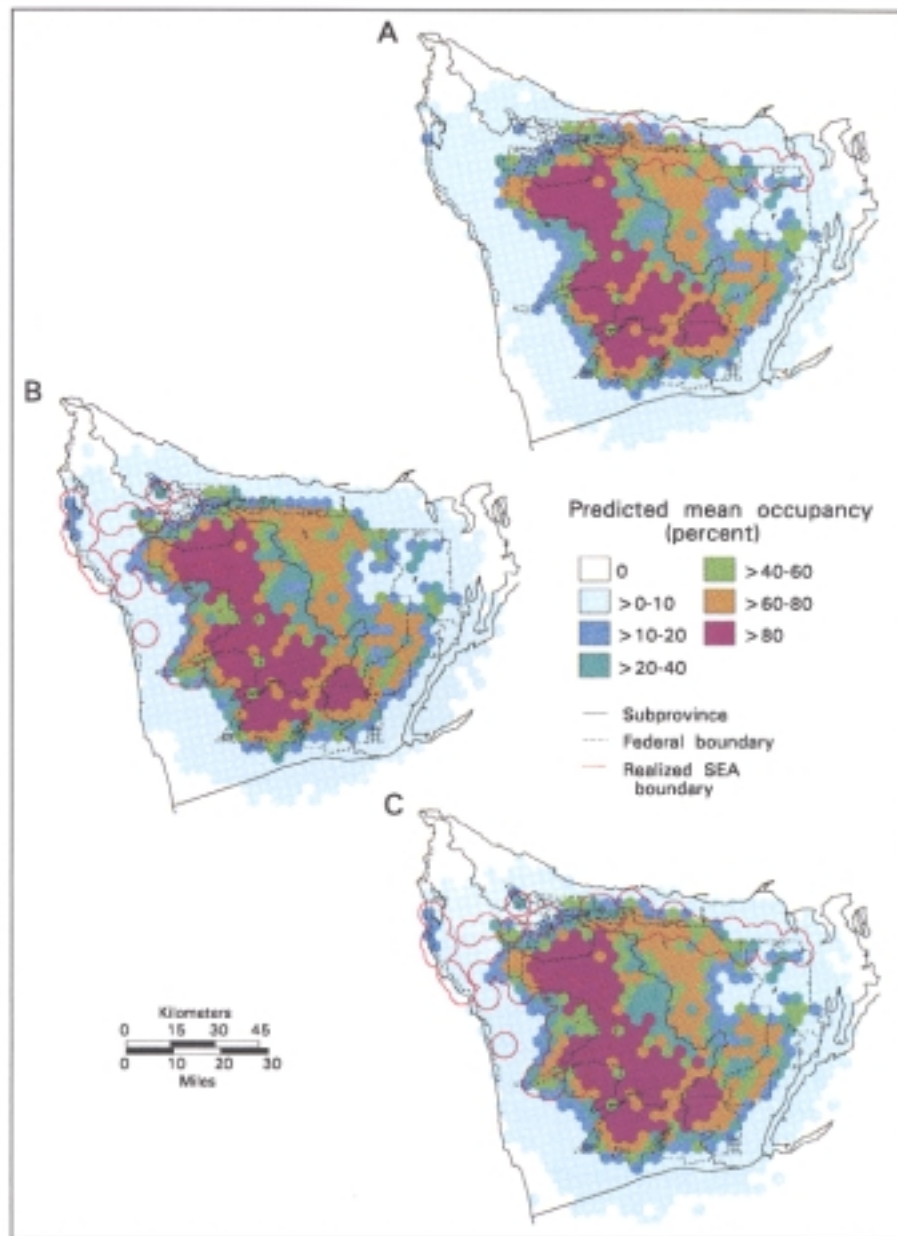


Figure 16-Mean occupancy of spotted owl pairs based on current habitat conditions on Federal lands plus habitat on non-Federal lands that occurred within a 4.3-kilometer (2.7-mile) radius of owl activity centers and that fell within defined special emphasis areas (SEA). **A:** Northern SEA; **B:** western SEA; **C:** both. Simulations were run by using rule set D.

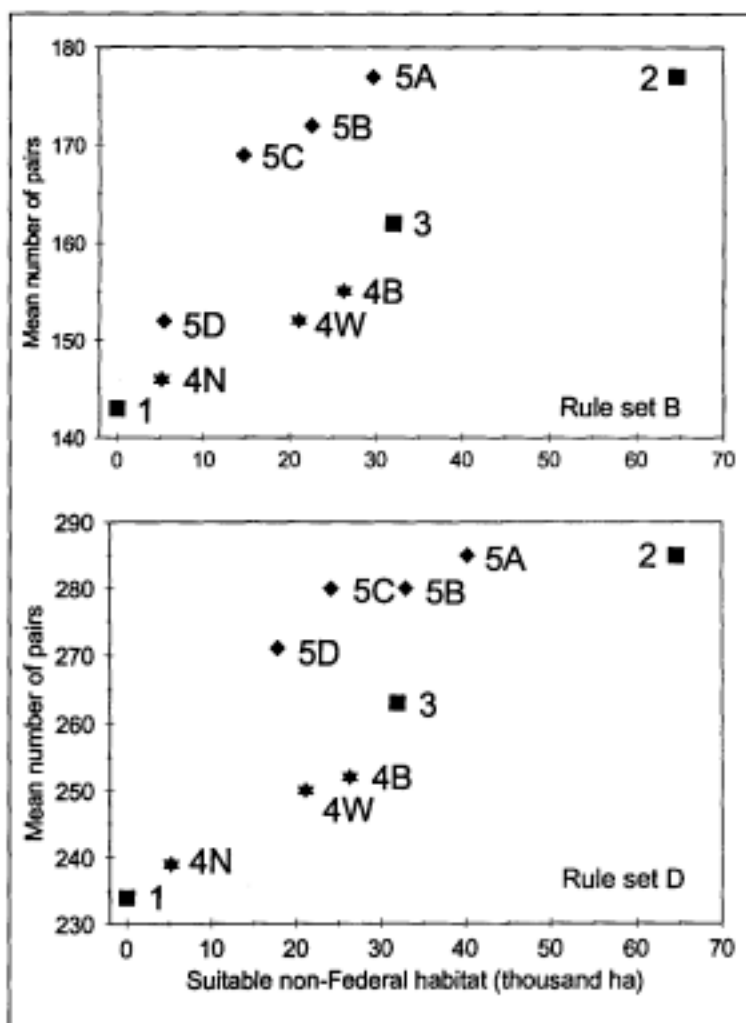


Figure 17-Relationship between non-Federal habitat added with each scenario and the expected average number of pairs. Scenario 1 models Federal habitat only without regrowth. Scenario 2 includes all existing Federal and non-Federal habitat without regrowth or harvest. Scenario 3 retains habitat following the current take guidelines. Scenario 4N protects habitat in the northern special emphasis area (SEA), 4W the western SEA, and 4B both. Scenario 5 saves habitat based on its simulated contribution to population size; 5A results from removal of habitat with occupancy less than or equal to 10 percent, 5B from cells less than or equal to 20 percent, 5C from cells less than or equal to 40 percent, and 5D from cells less than or equal to 60 percent. Occupancy patterns were based on simulations using rule sets B and D (fig. 14).

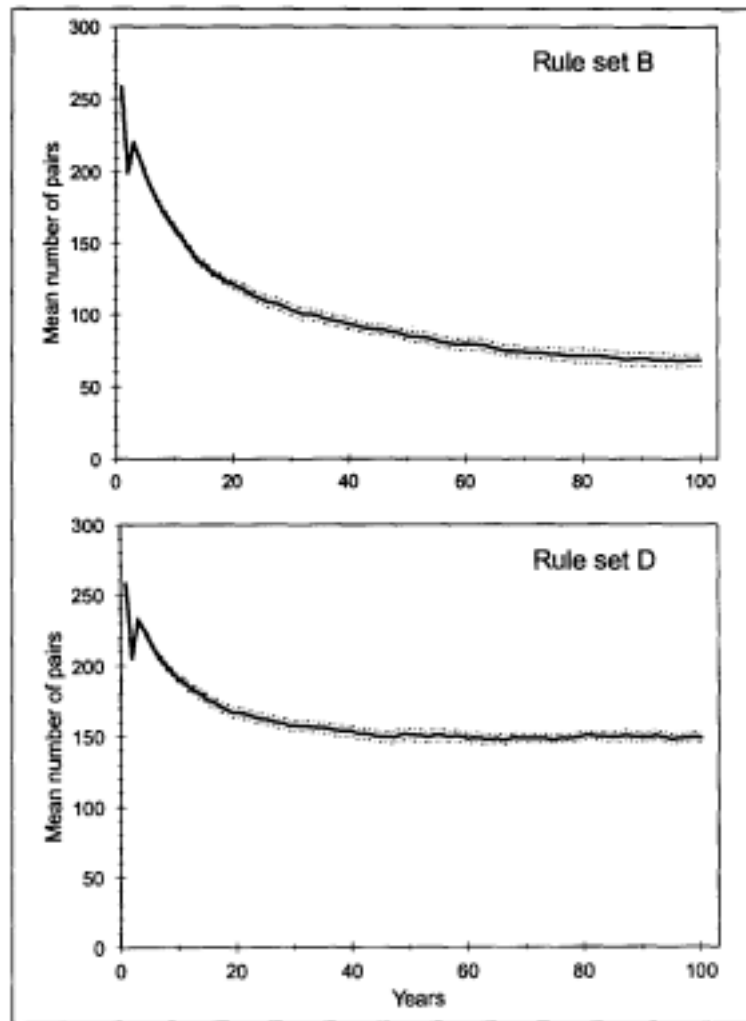


Figure 18-Simulated trends in spotted owl populations over 100 years assuming a catastrophic burn at year 2 (see fig. 5 for map of fire-risk zone). Habitat was limited to Federal lands only (scenario 1).

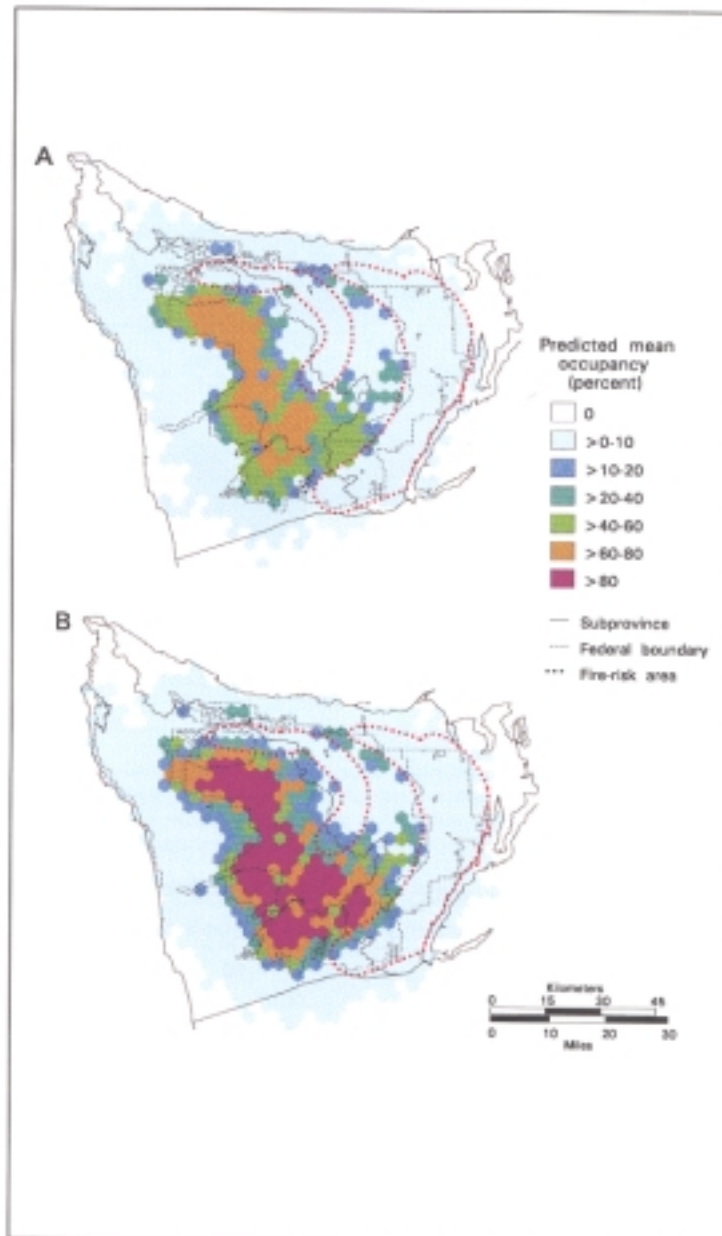


Figure 19-Mean occupancy for simulations with catastrophic burns. Rule sets B and D were used for simulations, and habitat was limited to current conditions and to only Federal lands with no regrowth (scenario 1). **A:** Rule set B; **B:** rule set D.

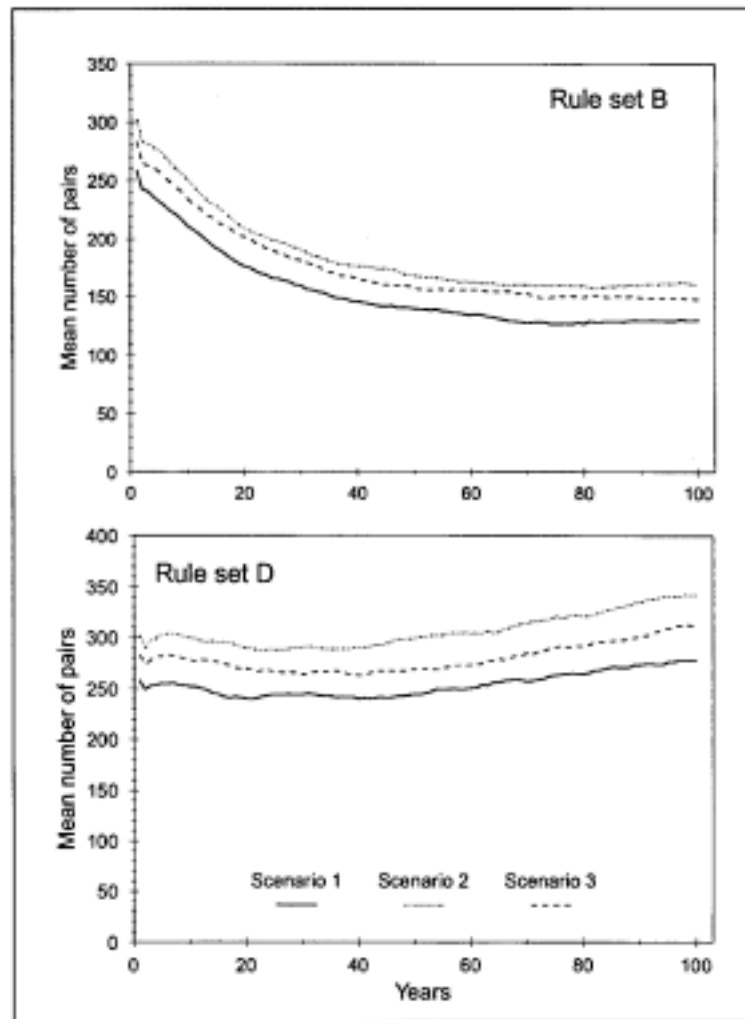


Figure 20-Simulated population trends for spotted owls on maps that included regrowth. Growth was limited to National Forest lands. In scenario 1, only Federal habitat was included, scenario 2 included all habitat, and scenario 3 implemented current take guidelines.

Demographic support from a distant population

Effect of Cascades Range source-We compared the simulations performed for the Olympic Peninsula with those including the Cascade Range source population but not including intermediate reserves to estimate the impact of a large distant source population. For this comparison, we were limited to an analysis of the levels of occupancy. The model is not designed to track the population dynamics for individual subpopulations, so population numbers for the peninsula could not be separated from the source population in these simulations. An evaluation of the occupancy classes shows that the presence of a distant source population had no

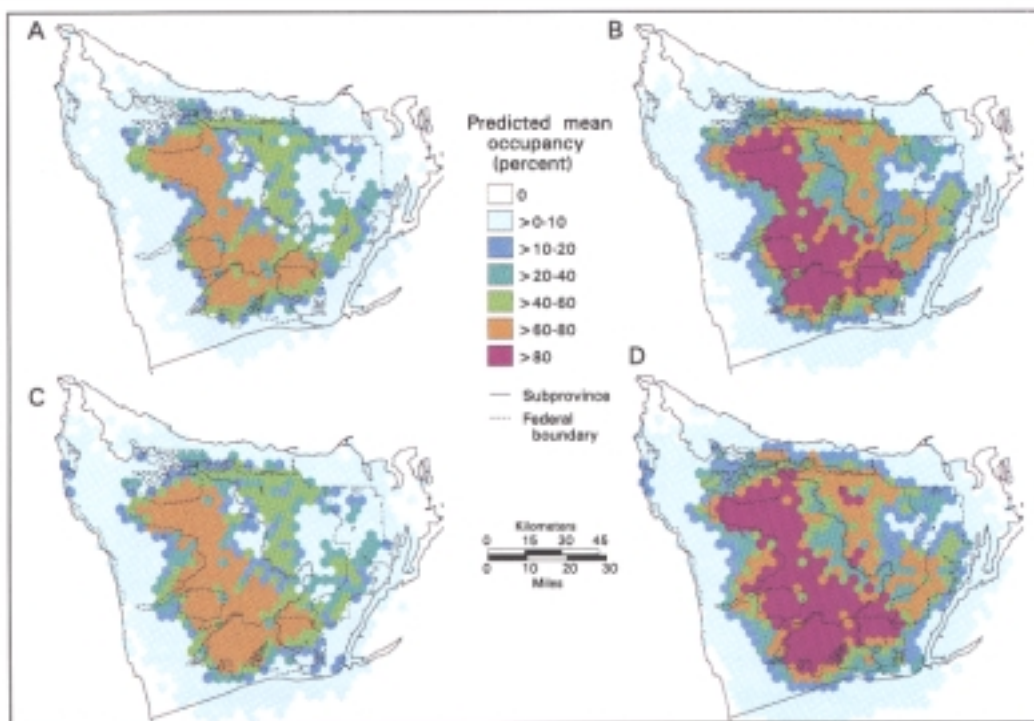


Figure 21-Average occupancy levels associated with simulations of scenario 1 (Federal habitat only) and scenario 2 (Federal and non-Federal habitat) with regrowth only on National Forest lands and maintaining all non-Federal habitat in its current condition. **A:** Scenario 1, rule set B; **B:** scenario 1, rule set D; **C:** scenario 2, rule set B; **D:** scenario 2, rule set D.

significant impact on the mean occupancy. For instance, given rule set B and limiting the habitat to Federal lands, the number of cells in each occupancy class were:

Map	Occupancy class (percent)					
	0	>0-10	>10-20	>20-40	>40-60	>60-80
	<i>Number of cells</i>					
Olympic Peninsula only	205	426	46	79	94	87
Olympic + source	192	441	51	73	89	91

These differences are all well within the anticipated range of variability associated with 50 simulations (table 15).

Table 16-Summary of simulation results under various management scenarios with habitat regrowth using rule sets A, B, C, and D, Olympia Peninsula^a

Criterion	1 (Federal only)	2 (All habitat)	3 (Take guideline)
Rule set A:			
Amount of habitat ^a (ha x 1000)	303	368	335
Number of cells >60-80%mean occupancy	0	0	0
Number of cells >80%mean occupancy	0	0	0
Total of cells >60% mean occupancy	0	00	0
Mean number of pairs	59	69	64
Pairs at year 60	30	35	34
Pairs at year 100	10	16	15
λ , evaluated for year 60-100	0.9730	0.9799	0.9803
Rule set B:			
Amount of habitat ^a (ha x 1000)	303	368	335
Number of cells >60-80% mean occupancy	110	137	131
Number of cells >80% mean occupancy	0	0	0
Total of cells >60% mean occupancy	110	137	131
Mean number of pairs	154	186	175
Pairs at year 60	134	163	156
Pairs at year 100	130	160	148
λ evaluated for year 60-100	0.9993	0.9996	0.9988
Rule set C:			
Amount of habitat ^a (ha x 1000)	303	368	335
Number of cells >60-80% mean occupancy	156	142	148
Number of cells >80% mean occupancy	71	137	106
Total of cells >60% mean occupancy	227	279	254
Mean number of pairs	250	313	283
Pairs at year 60	240	310	278
Pairs at year 100	271	339	305
λ evaluated for year 60-100	1.0030	1.0022	1.0023
Rule set D:			
Amount of habitat (ha x 1000)	303	368	335
Number of cells 60-80% mean occupancy	100	112	106
Number of cells >80% mean occupancy	124	161	142
Total of cells >60% mean occupancy	224	273	248
Mean number of pairs	254	307	280
Pairs at year 60	251	304	274
Pairs at year 100	278	342	313
λ , evaluated for year 60-100	1.0026	1.0030	1.0033

^a Habitat regrowth was modeled only on National Forest land. Amount of habitat reflects cumulative habitat 80 years in the future.

Intermediate reserves as a connecting corridor-Runs with intermediate reserves and a distant source population consistently resulted in occupancies of up to 10 percent in cells that had 0-percent occupancy without these reserves (fig. 22). Cells that had occupancy levels greater than 10 percent were not significantly bolstered by the presence of the connecting reserves. Even in the reduced population runs, which were expected to be more sensitive to the effects of a connecting corridor, the intermediate reserves had little impact on recolonization and expected stability. Runs both with and without intermediate reserves showed lower occupancy rates than any of the previous runs, as would be expected given the low starting populations. Simulations that included a connecting corridor provided an additional 50 cells in the 0- to 10-percent occupancy class (figs. 22 and 23) but virtually no increases in the higher occupancy classes. The increase in the 1- to 10-percent occupancy class indicated that recolonization occurs, but it appears to result only occasionally in the creation of successful populations.

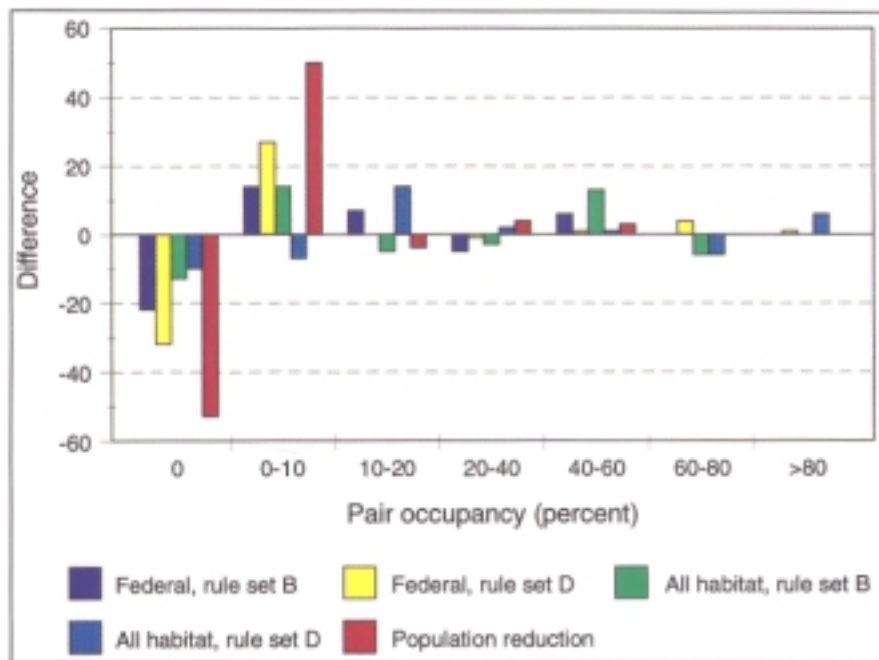


Figure 22-Differences in occupancy levels associated with various combinations of rule sets and the presence or absence of a line of intermediate reserves connecting the Olympic Peninsula population to populations in the southern Washington Cascade Range. Values are the difference in occupancy patterns as evaluated cell by cell. Occupancy classes with negative values had fewer cells in those classes when intermediate reserves were added.

Discussion Condition of the Population

Population estimate (and comparison to previously published numbers)-There are 155 known pairs of northern spotted owls on the Olympic Peninsula, and projections of the total population using two different sets of assumptions resulted in point estimates of 282 and 321 pairs. This was greater than other recently published figures, such as those in the SETS (USDA and others 1994). The SEIS figures were, however, simply the numbers of owls detected in a 5-year period, not a population estimate. A more appropriate comparison would be to the 185 owl pairs estimated to occur in the designated conservation areas on the Olympic Peninsula under the final draft recovery plan (USDI 1992). Were the estimated density of owls in these designated conservation areas projected to all Federal lands that could support spotted owls on the peninsula, the resulting estimate would be about 225 pairs. There could be about 30 additional pairs on non-Federal lands (table 2), thereby bringing the extrapolated estimate from the final draft recovery plan to 255 pairs. Thus, the estimates presented here are substantially higher than earlier numbers such as those reported by Thomas and others (1990), and the lower estimate presented here is about 15 percent higher than the estimate made by the Northern Spotted Owl Recovery Team (USDI 1992) in developing its recommendations for the Olympic Peninsula. As noted in the final draft recovery plan (USDI 1992), the number of spotted owls is less important than the trend in the population. The population estimates made for this paper were considered in establishing the territory size and initial population size used in model projections. This resulted in smaller territory size and higher carrying capacity than in model formulations used previously (Raphael and others 1994).

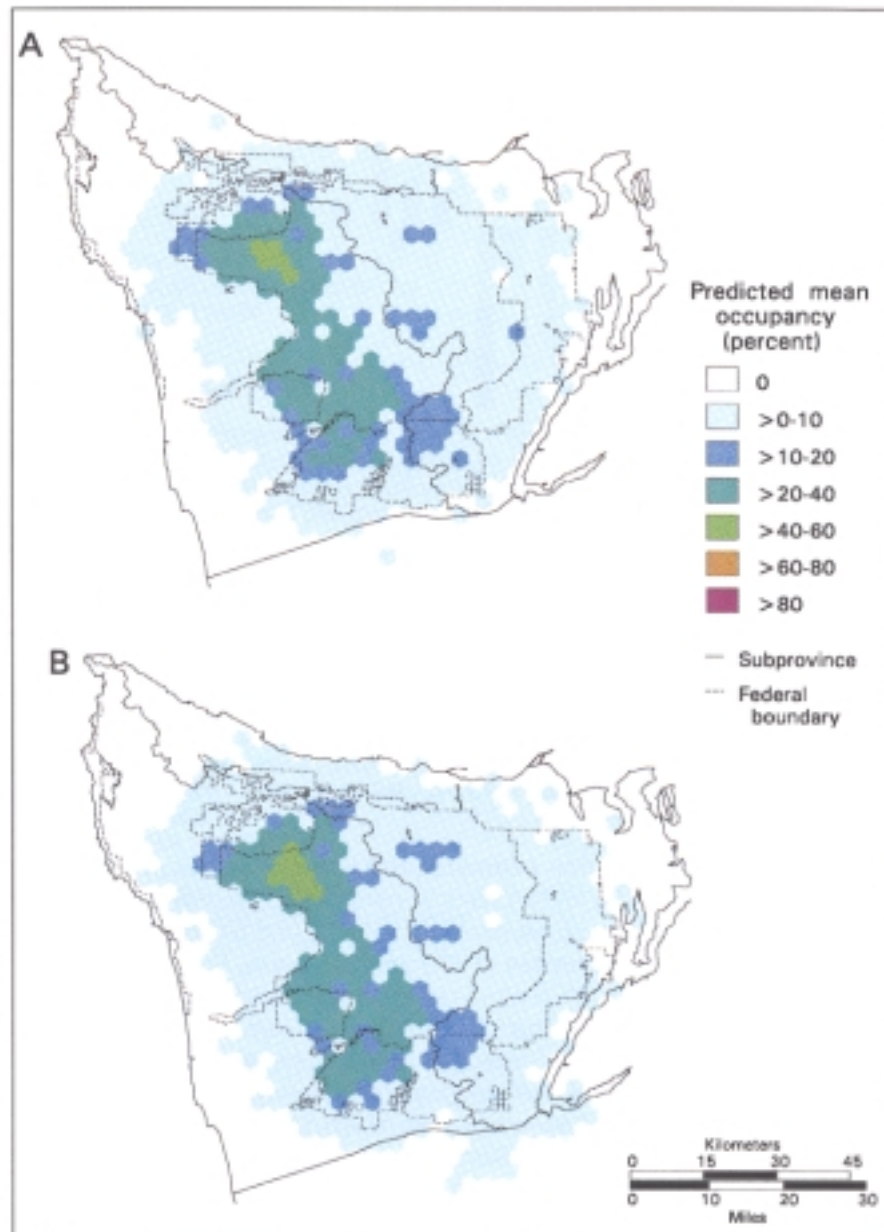


Figure 23-Maps of occupancy patterns with and without a string of intermediate reserves connecting the Olympic Peninsula population to populations in the southern Washington Cascade Range. For these simulations, the model began with a scattered population 20 percent the size of the Olympic Peninsula population of owls that was used to begin all other simulations. Rule set B was used. **A**: Without the intermediate reserves; **B**: with the intermediate reserves.

Table 17-Comparison of demographic values estimated for the Olympic Peninsula and for 12 demographic study areas within the range of the northern spotted owl

Parameter	Olympic study area ^a		Rangewide studies ^b	
	Mean	Standard error	Mean	Standard error
Adult survival	0.862	0.017	0.844	0.005
Adult fecundity	.380	.036	.339	.010
Subadult fecundity	.206	.106	.205	.034
Juvenile survival	.245	.064	.258	.036
Juvenile emigration	.600	.083	.3158	.053
Adjusted juvenile survival	.611	.204	.3769	.060
Lambda unadjusted	.9472	.0255	.9253	.0148
Lambda adjusted	1.0582	.0648	.9548	.0173

^a Forsman and others, in prep.

^b Burnham and others 1994.

Population status—

Demographic studies—Demographic values reported by Forsman and others (in prep.) for the Olympic Peninsula are generally comparable to the combined results reported by Burnham and others (1994) for 12 demographic studies in the range of the spotted owl (table 17), but they differ in two ways. First, the analysis of adult survival on the peninsula does not show a statistical trend over time as is seen in the analysis for all study areas combined (Burnham and others 1994). This declining trend in adult survival was identified as a cause for concern in the analysis of demographic studies (Burnham and others 1994; USDA and USDI 1994). Second, the rate of population change calculated from the Olympic Peninsula study is not significantly different from 1.0 when an adjustment is made for juvenile emigration.

Burnham and others (1994) caution that inferences from individual study areas are weaker than the inferences drawn from analysis of all study areas combined. Standard errors for all parameter estimates are predictably higher for the single study on the Olympic Peninsula than they are for the combined study areas (table 17). The standard error is particularly high for juvenile survival rate adjusted for emigration, because the sample sizes used to estimate emigration were small. Even with a larger sample size, the correction for emigration would remain uncertain because it requires an assumption that emigrating juveniles survive at the same rate as nonemigrants. The lack of a statistical trend over time in adult survival also may be due to smaller sample sizes and lower statistical power in the individual study than was available in the analysis of 12 study areas.

Even with these cautions, the demographic rates observed for the Olympic Peninsula owl population could be viewed as relatively positive. The estimate of juvenile emigration is substantially higher than the value of 0.41, which Burnham and others (1994) calculate would result in a rate of population change of 1.0 when combined with other demographic values calculated for the peninsula study. Also, subsequent to the publication of Burnham and others (1994), Bart (in press, b) has completed simulations indicating that the methods used by Burnham and others (1994) underestimate the true rates of population change by values from 0.03 to 0.13. Given the confidence intervals surrounding the estimates of demographic rates on the peninsula, and the sources of bias discussed by Bart (in press, b), the results of the demographic analysis could be consistent with a nondeclining population, or with a population declining at a rate no greater than the rate of habitat loss (1.1 percent per year estimated for the peninsula for 1982-92 [Raphael and others, in prep.]). A decline in population caused by habitat loss and at about the same rate as the rate of habitat loss would not be surprising and does not suggest that the population would continue to decline if habitat stabilized.

Genetic risk-Isolation of small populations can result in loss of genetic variation and increased risks of inbreeding depression and genetic drift (Frankel and Soule 1981). Some early analyses of risks to northern spotted owls suggested that the population on the Olympic Peninsula might be so small and isolated as to be affected by loss of genetic variation (USDA 1988). Further analysis has suggested that the population of owls on the peninsula is sufficiently large to avoid any short- to mid-term loss of genetic variation, and that the major problems facing spotted owls are short-term habitat loss and population performance (USDA 1988). Inbreeding depression was not explicitly considered, however, and could affect future persistence of the population, especially if it occurred in combination with environmental or demographic events that reduced population size or growth rate (Mills and Smouse 1994). Genetic variability of spotted owls on the peninsula therefore should be monitored. Losses of variability likely could be mitigated by transplanting owls or eggs from other portions of the range.

Projected Future

Factors that could adversely affect spotted owl populations are summarized by the Northern Spotted Owl Recovery Team (USDI 1992) and include systematic habitat loss, habitat fragmentation, demographic variation, environmental variation, population decline to critically small size (Allee effect), loss of genetic variation, catastrophic events, and species interactions. Ideally, all these factors would receive some consideration in an evaluation of potential stability of a population or, conversely, potential risks to a population. The risk factors are interrelated, and the interactions of risk factors can increase overall risks.

In this analysis, a spatially explicit life-history simulator for northern spotted owls was used to assess the effects on owl population dynamics of several of these factors including systematic habitat loss, habitat fragmentation, demographic variation, catastrophic events, and population decline. Several recent spotted owl management plans and analyses have discussed the value of simulation analysis in trying to compare the future population status of owls under different management scenarios (FEMAT 1993, Thomas and others 1993, USDI 1992). These discussions have noted that simulation analysis may be useful in risk assessment, but that the

limitations of simulation models must be clearly understood. Simulation results are entirely dependent on the structure of the models, the assumptions incorporated in them, and the input data supplied to them. Some factors that could significantly influence outcomes, such as the interaction with barred owls, are not currently represented in the models used for this analysis. The results of the models should not be viewed as reality, but rather as a repeatable projection of the modelers understanding of the system. Considerations pertinent to the use and interpretation of models have been summarized by Bart (in press, a). His recommendations include the projection of a variety of scenarios, including best and worst cases, rather than the use of single predictions. Model use in this analysis was consistent with these recommendations. Parameter values were altered to provide both pessimistic and optimistic projections, and various scenarios of habitat growth and disturbance were projected.

Because the relationship between any model run and reality is not known, the relative differences between land management scenarios under a particular rule set are of most interest in the interpretation of model results. Comparisons between rule sets then can show how sensitive those relative relationships are to change in biological understandings. Simulations of scenario 2, for instance, resulted in mean numbers of pairs 18 percent greater than those in scenario 1 under rule set A, 24 percent greater than under rule set B, 26 percent greater than under rule set C, and 22 percent greater than under rule set D (table 14). We inferred from this relationship the probable magnitude of potential contribution from non-Federal lands. The absolute number of pairs projected in the scenarios was of less interest and was given less weight in interpretations of the results. Thus, in interpreting the model results, we generally placed more weight on relative occupancy values, relative number of pairs, and the rate of population change than we did on the absolute number of pairs. Interpretation of the rate of population change should focus on later years in the simulation because the results projected in the early decades of each simulation largely reflected a transition from the starting conditions of the simulation to the projected trends of that simulation. The distribution of the population also was of interest and has a strong effect on stability--the ability of the population to persist over time. Stability may be strongly influenced by population size when populations are small, but it is increasingly dependent on population distribution as population size increases.

Effects of alternative rule sets for demographic parameters—As explained in "Methods," the rule sets for demographic parameters were based on birth and survival rates as estimated in the demographic analyses of Burnham and others (1994) and Forsman and others (in prep.). Regressions from Bart (in press, c) were then used to develop relationships among birth and survival rates and habitat quality in owl territories. Rule sets A, B, and C were formulated by adjusting the relationship of habitat quality to demographic performance. In rule set A, the actual values estimated from the demographic studies were applied to cells in the 40- to 60-percent suitable habitat class (table 11). In rule set B, they were assigned to cells in the 30- to 40-percent suitable habitat class. In rule set C, they were applied to cells in the 20- to 30-percent suitable habitat class. In all three rule sets, the regression

from Bart (in press, c) was used to develop values for cells with greater and lesser amounts of suitable habitat. Rule sets A, B, and C used a juvenile survival rate uncorrected for juvenile emigration. Rule set D was developed from rule set B by replacing the uncorrected juvenile survival rate with the rate of 0.38 that was corrected for emigration in the analysis of Burnham and others (1994).

Overall implications of the four different rule sets are displayed in the population trajectories of figure 11 and the calculated rates of population change in table 14. When simulations using all existing habitat (scenario 2) were run, rates of population change ranged from 0.9760 under rule set A to 0.9995 under rule sets C and D. Although these rates do not represent the full range of lambdas shown in table 17 (0.9253 to 1.0582), they do produce a broad range of simulation results. Under all habitat scenarios (table 14), rule set A resulted in steep population declines and few pairs of owls at the end of 100 years. These results are similar to those that would be obtained by simply projecting into the future the demographic rates reported by Burnham and others (1994).

At the other end of the range, rule sets C and D generally resulted in relatively stable populations, although at levels lower than the starting population size. Rule set B generally led to a slow decline from initial numbers, and the rate of decline was very slow in later years of the simulations (table 14). Because projected model populations approached but did not reach a rate of population growth of 1.0 under most scenarios with this rule set, it provided a relatively sensitive basis for comparison of different habitat scenarios.

The relationship between habitat quality and demographic performance is central to all the rule sets, and few data are available to determine this relationship. As a result, any of the rule sets may be optimistic or pessimistic to an unknown degree. Thus, the simulation results should be viewed in a relative rather than an absolute sense. Results obtained by using different rule sets should be considered as a sensitivity analysis rather than being viewed as a range of real outcomes.

Effects of large-scale disturbances-The possible effects of a catastrophic burn were simulated by projecting a 100-percent burn across the entire area mapped as having high risk of large-scale fire (fig. 5). This was more extreme than the actual "worst case" predicted for this area by Agee (1991a), who foresaw a possible burn of 25 percent across this high-risk zone in a single event and the possibility of three such events per century. No regrowth of habitat was projected after the burn. Under the 100-percent burn scenario and using rule set B, the owl population was essentially eliminated from the eastern subprovince of the peninsula, but there were only small changes in the distribution or occupancy rate of owl pairs in the western subprovince (fig. 19). The size and distribution of the most stable "core" area on the west side changed little. This result strongly suggests that the total area of Federal land that will be managed to maintain spotted owl habitat on the peninsula is large enough to be relatively robust against large-scale disturbance, and that a large-scale fire in the eastern subprovince of the peninsula would not destabilize an otherwise stable population. This finding is illustrated by graphs comparing population trends with and without the assumption of a catastrophic fire (fig. 18). A fire could, however, have the effect of removing the population from a large portion of the eastern subprovince. Owls might slowly resume their original distribution after such a fire, but the process of habitat regrowth and recolonization would take many decades.

Effects of large-scale wind events were not modeled, partially because effects of wind on spotted owl habitat are difficult to quantify. Even large, intense wind storms, like the one that occurred on the peninsula in 1921, do not uniformly remove the forest overstory from extensive areas. Wind events also can leave legacies of large snags and a diversity of tree heights and sizes, which are key elements of suitable spotted owl habitat on the Olympic Peninsula (Mills and others 1993, North 1993). Nonetheless, coastal areas have a return interval of about 30 years for major wind disturbances (Agee and Edmonds 1992), and the potential exists for loss of spotted owl habitat. If an unusually intense, large-scale wind event occurred in one or more of the major drainages of the western peninsula (for example, Quinault, Queets, or Hoh River watershed), spotted owl populations could be reduced significantly. If such a loss occurred in combination with a worst case fire in the eastern subprovince, effects on the spotted owl population peninsula wide could be significantly greater than those projected for a worst-case fire alone. The likelihood of a truly damaging wind event is small, however, and the chance of it occurring in combination with a significant fire is smaller.

Effects of habitat regrowth-The history of forest harvest and natural disturbance has left fragmented forest conditions throughout virtually the entire range of the northern spotted owl. The Olympic Peninsula, outside of Olympic National Park, is no exception. Less than half the late-successional reserve proposed for the Olympic National Forest on the peninsula currently supports suitable habitat for owls. Much of the vegetation not currently of suitable habitat is composed of young stands that resulted from either human or natural disturbance. Young stands in appropriate ecological sites should generally begin to develop characteristics associated with suitable habitat as they age. Over time, such stands could make a significant contribution to landscape-scale habitat quality for spotted owls.

Estimates of habitat regrowth used in this analysis were based on a series of assumptions. Stands not currently of suitable habitat had to grow to a medium, multi-storied structural stage before being classified as suitable habitat. We projected that this would take 180 years from the time of stand initiation in the western subprovince of the peninsula and 210 years in the eastern subprovince. Appropriate management likely could accelerate this development, but none was assumed for this analysis because programs of thinning have not been scheduled. Also, development of young stands into suitable habitat conditions was projected only for National Forest lands and not for National Park lands. Olympic National Park was assumed to be in a state of dynamic equilibrium where development of young stands would be balanced by natural disturbance of older stands. No regrowth of habitat was assumed on non-Federal land because there is no regulatory requirement to develop new habitat on those lands, and normal commercial timber production would be unlikely to result in significant new acreage of suitable habitat. Development of new habitat on non-Federal land might occur under an HCP adopted under section 10 of the ESA, but we had no specific information to base such a projection on. As noted in the section, "Federal and Non-Federal Plans for the Olympic Peninsula," we assumed no loss of habitat due to cutting on Federal lands given current planning direction.

With these assumptions, we projected an increase of about 37 300 hectares (92,200 acres) of nesting, roosting, and foraging habitat over 80 years in the National Forest (fig. 10). This development of additional habitat had a noticeable effect on model projections under all rule sets and all non-Federal habitat scenarios it was applied to (tables 14 and 16). Projected populations stabilized under more scenarios and rule sets with habitat regrowth than without it. Under rule sets C and D, a rate of population change of 1.0 was projected under all habitat scenarios when regrowth was assumed (table 16, fig. 20). The influence of habitat regrowth can be explained by its tendency to fill in the currently fragmented habitat pattern on National Forest lands. Within the assumptions of the model, this results in larger amounts of habitat in individual territory cells and improves demographic performance of owls in those cells. Because there is empirical evidence that increasing amounts of habitat in home ranges improves demographic performance (Bart and Forsman 1992, USDI 1992), it is likely that a beneficial effect from habitat regrowth will be observed in the population.

Relative contributions of non-Federal lands—All the possible contributions of non-Federal habitat (scenarios 2 to 5, see "Methods") resulted in improvements in the status of projected owl populations (table 14, fig. 17). Differences were most obvious in two parameters: the number of cells in which at least 60-percent occupancy was maintained over 100 years, and the mean number of pairs present on the landscape averaged over the 100-year simulation. Relative differences among the scenarios were generally predictable, with greater contributions in habitat leading to greater improvement in simulated population status (fig. 17). The greatest differences were between scenarios 1 and 2 (table 14). Under rule set B, the number of territories with more than 60-percent occupancy was nearly 50 percent greater under scenario 2 than scenario 1, and there were clear differences in mean number of pairs over 100 years and the number of pairs at the end of 100 years (table 14). The rate of population change, however, was not substantially different between scenarios 1 and 2. As with all the model results presented here, it is well to remember that these are projections and not observations. We believe, however, that the projected differences represent biologically significant increases in the stability of the owl population on the peninsula. It should be noted that greater improvements in population status would likely have been projected if our scenarios had included habitat restoration on non-Federal land in addition to retention of existing habitat. Such scenarios were not considered because they are outside the scope of the 4(d) process. Thus, the potential contributions of non-Federal lands in this analysis were limited by the current condition of those lands, which have been strongly modified by past timber harvest.

The projected improvement in population performance associated with non-Federal habitats was generally proportional to the amount of non-Federal habitat included in each of the scenarios (fig. 17). Scenario 2 (all habitat) showed the greatest change from scenario 1, followed in decreasing order by scenario's 3 and 4. Scenario 5 deviated somewhat from this pattern and is discussed below. Within scenario 4, the west SEA made a greater contribution to population performance than did the north SEA (table 14). The north SEA, when analyzed by itself, resulted in little noticeable improvement (table 14 and fig. 15) because this SEA contains only a limited amount of suitable habitat on non-Federal land (fig. 9 and table 13).

We developed scenario 5 with the objective of determining if non-Federal contributions of habitat could be made in a more efficient way than by following the current take guidelines. For scenario 5, we started with the map of territory occupancy rates projected for scenario 2 and then progressively removed non-Federal habitat that contributed less to occupancy by pairs. We first removed non-Federal habitats that supported occupancy of 0 to 10 percent, then removed habitats supporting occupancy of more than 10 and up to 20 percent, and so forth, up to the final cut that removed habitats supporting occupancy rates up to 60 percent. The future of the population was simulated under rule sets B and D with each of these habitat removals. Results are shown in figure 17 where they are compared to scenarios 1, 2, 3, and 4. Scenario 5 resulted in a much more efficient contribution of non-Federal habitat to the performance of the population, with a larger increase in mean pairs of owls per hectare of habitat than was seen in other scenarios. We believe this demonstrates that contributions of non-Federal habitat can be more efficient if they are made in appropriate locations rather than scattered across the landscape. We view the actual results of this scenario with caution, however. Using the results of the model to improve the performance of the model produces projections at least two steps removed from reality. Whereas the concepts of scenario 5 may suggest that there are more effective ways to design non-Federal contributions, the actual results require additional analysis before they can be used to design a more efficient strategy.

It is interesting to compare the effects of regrowing habitat on the National Forest with the effects of retaining non-Federal habitat without an assumption of regrowth of new habitat on Federal land. The amount of non-Federal habitat retained under scenario 3 (32 000 hectares [79,000 acres], table 13) is similar to the amount projected to regrow on Federal land over 80 years (37 300 hectares [92,000 acres], fig. 10). Projected effects of these two habitat scenarios (scenario 3 in table 14 and scenario 1 in table 16) are quite similar. The small differences projected between these two scenarios likely reflect the different locations of the suitable habitat under each, and the fact that non-Federal habitat is available from the beginning of the projections while habitat regrowing on Federal land develops incrementally over the first 80 years of the projection.

One significant caution must be applied to the interpretation of all the non-Federal habitat scenarios. These analyses are strongly dependent on the reliability of the habitat map that was used. The non-Federal map used for this analysis was developed by the WDNR Habitat Conservation Planning Team and data for the map came from several sources. For clusters of watersheds being used as planning units by WDNR, alternative source maps were compared to ground-verified maps of spotted owl habitat that had been completed for some portion of the planning unit. The source map that performed best in this comparison was then applied across the entire watershed. The reliability of the resulting map is not known. If it is significantly in error, then the results of these projections could be biased.

Effects of the connecting corridor-The connecting corridor tested in this analysis followed the design criteria established by the Northern Spotted Owl Recovery Team (USDI 1992). This corridor consisted of a single chain of small reserves connecting the owl population on the peninsula to the population in the Washington Cascade Range. When both source populations began with a reasonable number of owl pairs, this chain of connecting reserves had little effect on the stability of the population on the peninsula. There were several probable reasons for this. One is that most of the high-occupancy cells predicted by the model were in the western subprovince and therefore were further from the connecting reserves. In addition, population size relationships must be taken into account. The Olympic Peninsula simulation began with about 200 pairs. The connecting reserves were each of a size that could support 20 pairs. The internal rates of dispersal in the comparatively large population on the Olympic Peninsula will generally swamp the modest number of dispersers produced by the small connecting reserves. This relationship can be quantified by using some simple calculations in conjunction with published dispersal data. Fecundity rates for spotted owls differ greatly from year to year but on average are about 0.3 (Burnham and others 1994). If we assume that fecundity rate, a cluster containing 20 reproductive pairs will produce an average of six females per year. Of this number, some will die before dispersal and the rest will disperse. Of the dispersers, some will settle within the natal cluster. For this exercise, we assumed that all six females lived to disperse and that those that moved less than 16 kilometers (10 miles) settled within the natal cluster. Based on data from Thomas and others (1990:app. P, table P1), about 25 percent of dispersing females nest within 16 kilometers (10 miles) of their natal site. This leaves 4.5 dispersers that might emigrate to the Olympic Peninsula population each year from the hypothetical system of connecting reserves. Of course, not all will travel in the right direction. Assuming that 0.25 travel in the right direction, then we have on average 1.1 female juveniles entering the Olympic Peninsula population each year. Not all will live to reproduce. If we apply the juvenile survival rate of 0.38 (Burnham and others 1994:20), then about 0.41 female per year will enter the Olympic Peninsula population as potential subadult breeders from the connecting reserve system. If the population is close to carrying capacity, then these owls may be forced to "float" for an indefinite period.

Conclusions

Several recent spotted owl analyses have suggested that human judgment must ultimately be used to assess the efficacy of options for spotted owl management (FEMAT 1993, Thomas and others 1993, USDI 1992). Analytical tools can be extremely helpful but do not take the place of professional judgment. In particular, the results of models should not be viewed as reality but rather as repeatable projections of a set of assumptions. In this effort, we reviewed all the pertinent analytical information and then summarized our conclusions through response to the following questions.

1. Given the design suggested by the Northern Spotted Owl Recovery Team (USDI 1992), is there significant potential for a habitat connection across southwestern Washington to provide demographic rescue for the owl population on the Olympic Peninsula?

Our conclusions on this question rested largely on the results of simulation analyses described under "Methods" and "Results." Those analyses suggested that a habitat connection across southwestern Washington would have little effect on the status of the owl population on the peninsula if that population was stable or nearly stable.

Whereas the habitat connection seemed to provide little demographic benefit, it likely would provide for significant interchange between owl populations on the Olympic Peninsula and in the Washington Cascades. This would increase genetic mixing, which could have a beneficial effect on the population. Loss of genetic variation is not currently considered a major risk to the owl population on the peninsula (Barrowclough and Coats 1985), but it cannot be entirely discounted as a future threat (Mills and Smouse 1994). Genetic variation can, however, be maintained by only a few immigrants per generation. Such rates of interchange may occur without significant development of new habitat across southwestern Washington, or a similar result likely could be achieved by transplanting a small number of owl eggs from another portion of the range. However, development of new habitat would help assure that immigration would take place.

The habitat connection described by the Northern Spotted Owl Recovery Team (USDI 1992) was constrained by feasibility and the high cost of developing habitat in this heavily harvested landscape. Other more ambitious designs likely would have significantly greater effect on the status of the Olympic Peninsula population, but they would be increasingly unrealistic. Also, the connecting corridor clearly would have significant effects on the likelihood of maintaining owls in southwestern Washington, but those effects were outside the scope of this paper.

We conclude that the stability of the owl population on the Olympic Peninsula will primarily depend on local habitat conditions. Modest alterations in land use patterns in southwestern Washington probably will not result in meaningful impacts on the owl population on the peninsula. Even the generation of connecting reserves, which required the development of 150 000 hectares (370,700 acres) of high-quality habitat, had little impact.

This discussion was limited to the role of corridors connecting reserves separated by large distances. The results do not imply that dispersal habitat in the intervening areas between more closely spaced reserves is unimportant.

2. What is the likelihood of maintaining a stable, well-distributed population of spotted owls on Federal lands on the Olympic Peninsula, for at least 100 years, with no non-Federal habitat contribution?

We concluded that it is likely, but not assured, that a stable population would be maintained on portions of the Olympic National Forest and the core area of the National Park in the absence of any non-Federal contribution of habitat. The lack of non-Federal habitat would make it unlikely that an owl population would be maintained on the western coastal strip of the National Park, and this could result in fewer high-occupancy or core areas on the remaining Federal land.

Despite generally positive results observed in this analysis, there is significant uncertainty in interpreting demographic results; in variability observed in simulations under different assumptions; and in the effect of eliminating up to 64 600 hectares (159,700 acres) of suitable habitat on non-Federal land. There also is uncertainty associated with the increase in the barred owl population and resulting competition and hybridization with spotted owls. Our confidence in maintaining a stable population on the peninsula would improve if the uncertainties in knowledge were resolved and indicated a favorable outcome, or the conditions on the peninsula became significantly more robust given these uncertainties.

This conclusion was predicated on standards and guidelines for spotted owl habitat management contained in the Northwest Forest Plan (USDA and USDI 1994). We agreed on the following points in reaching this conclusion:

- Assuming that other demographic values estimated on the peninsula do not contain significant bias, a juvenile survival rate of 0.422 would yield a stable population with a rate of population change of 1.0. The survival rate of 0.422 falls within the range of estimates (0.24 to 0.61) calculated for the population on the peninsula.
- Habitat on Federal lands is relatively stable and no significant harvest of habitat is expected.
- Even a worst-case fire is projected to have little long-term effect on population stability.
- Regrowth of habitat on the Olympic National Forest will likely provide significant benefit to the spotted owl population through time.
- The increase in the barred owl population could have potentially serious effects on the spotted owl population, and such effects are not represented in modeling efforts.

3. To what extent would the contribution of non-Federal habitat change the likelihood of maintaining a well-distributed and stable population on the Olympic Peninsula?

We concluded that the retention of non-Federal habitat could result in a biologically significant contribution to the maintenance of a stable population of spotted owls distributed across currently occupied portions of the Olympic Peninsula. Our conclusion was based mainly on the results of simulations. The simulations consistently showed increases in the numbers of pairs of owls maintained over time and the rate of occupancy of owl territories on Federal lands when non-Federal habitat was retained. When all possible non-Federal habitat was retained in addition to the Federal habitat, the number of pairs maintained over 100 years increased about 24 percent. When only habitat associated with the take guideline was added, the increase was close to 14 percent. Retention of non-Federal habitat in the west SEA would be particularly significant as this area contains the greatest concentration of habitat remaining on non-Federal land. The retention of this habitat likely would increase the chances of maintaining a population on the coastal strip of the Olympic National Park. Such an effect was not, however, observable in the model runs. Non-Federal lands may provide the majority of low-elevation habitat, which is poorly represented on Federal lands and might be of superior quality compared to higher elevation habitat.

Although we concluded that retention of non-Federal habitat would significantly improve the projected status of the population, we do not believe that it would fully resolve the uncertainties associated with the future of spotted owls on the Olympic Peninsula. Although the retention of non-Federal habitat could be significant, we did not conclude that it would alter the basic uncertainties enough to assure the maintenance of a population distributed across the portions of the peninsula currently occupied by owls.

We caution that these conclusions should not be extrapolated to other portions of the range of the northern spotted owl. Each portion of the range represents a different situation and different relationship between Federal and non-Federal lands. The Olympic Peninsula is unique because of the large block of relatively unfragmented habitat in the Olympic National Park, the relative isolation of the Olympic population from owls in the rest of the range, and significant areas of non-Federal habitat occurring adjacent to the Federal late-successional reserve. Thus, the insights gained from this analysis are specific to the peninsula. We also emphasize that this assessment focused only on spotted owls and their habitat; it does not address effects on other species for which there are legal, social, or biological concerns.

Recommendations

We believe that, in the interaction between science and policy, the appropriate role for scientists is to provide analyses that can be used to formulate policy. Therefore, we do not offer recommendations concerning the difficult issue of non-Federal roles under the ESA. We do offer the following recommendations for strengthening the scientific base that can be used in formulating policy for spotted owl management.

First, we recommend that the techniques used in this analysis be applied more broadly throughout the owl's range as plans for owls continue to be implemented and refined. Although the results are not definitive, they help clarify the relative roles that could be played by Federal and non-Federal lands in maintaining spotted owl populations. The simulations done for this analysis provided a way to consistently test hypotheses about owl populations and their relationship to habitat management. The results of these simulations should not be accepted without critical evaluation, but they improve our ability to objectively analyze questions about the value of habitat connections between the Olympic Peninsula and other portions of the owl's range.

One of the prerequisites for such analyses is the availability of reliable habitat information for both Federal and non-Federal lands. Data currently are unavailable for large portions of non-Federal lands, and the quality of data available for Federal lands could be improved. For example, we found that the current designation of nesting, roosting, and foraging habitat on the Olympic National Park underrepresents such habitat, especially in the eastern subprovince. This designation, which was originally developed by the Northern Spotted Owl Recovery Team, should be reassessed in light of our findings. One significant step toward the improvement of habitat data would be acceleration of efforts to understand the influence of different stand characteristics on the use of those stands by owls. Such research has long been recognized as a high priority (USDA 1988), but the amount of information available is still meager.

A second step that would improve habitat data is the development of better databases for both habitat and owl locations for non-Federal land. We were fortunate in this analysis to have a habitat database developed by the WDFW and WDNR, but such data are not available for the entire range of the owl. Additional cooperative efforts between the states and the Federal government could help generate this information. Participation by private landowners in such efforts would greatly improve the reliability of the results.

This analysis also emphasized the need to continue monitoring owl populations, including their genetic variability, and to continue demographic studies as part of that monitoring. Uncertainty still exists concerning trends in owl populations and the influence of immigration and emigration, among other factors, on demographic estimates. Understanding of these issues can be improved only with additional years of data and with additional radio-tracking of owls in those studies.

This analysis has reinforced the need to better understand how owls use their home ranges and the influence of both stand and home range characteristics on their reproduction and survival. The relationship between home range estimates and density estimates for owls on the peninsula is not straightforward, and additional collection of home range data from areas where densities are being estimated is needed. Better understanding of the relationships among habitat quality in home ranges, size of home ranges, and demographic performance is critical to improve our ability to manage habitats for owls.

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Appendix 1: Reanalysis Team Charter

Background

Purpose: To determine the extent to which non-Federal lands contribute to and may be necessary for the conservation of the northern spotted owl on the Olympic Peninsula.

The Reanalysis Team (Team) has been established to provide an analysis of the potential for and pattern of long-term persistence of the northern spotted owl on the Olympic Peninsula with varying levels of habitat contributions from non-Federal lands. Federal lands under the preferred alternative (Alternative 9) in the Final Supplemental Environmental Impact Statement on Management of Habitat for Late-Successional and Old-Growth Forest Related Species within the Range of the Northern Spotted Owl (FSEIS) and the non-Federal lands for which firm Habitat Conservation Plan (HCP) commitments have been made (for example, the Washington State Experimental Forest) will be included as the principal baseline for analysis.

This assessment will provide additional information to support the development of regulations and policies affecting non-Federal forest management for the Olympic Peninsula, under section 4(d) and section 10 of the Endangered Species Act. Beyond this effort, we do not anticipate further involvement of the Team in the 4(d) effort. If a need arises for any additional efforts, however, they will be negotiated with individual members of the Team.

At the time the President announced Alternative 9 as the basis for the then proposed Forest Plan, he also announced that the Administration would seek to ease the burden on non-Federal landowners through a 4(d) rule. The content and schedule for a 4(d) rule are receiving higher priority now that the President's Forest Plan for Federal lands has been completed and the injunctions have been dissolved. It remains Federal policy to rely primarily on contributions from Federal lands for the conservation of the northern spotted owl, and to rely on non-Federal lands only to the extent that they are believed to be necessary to supplement Federal contributions in order to achieve conservation goals.

The unpublished Final Draft Recovery Plan for the Northern Spotted Owl (Final Draft Recovery Plan) provides recent guidance on the contributions needed from non-Federal lands; however, several developments have occurred since its completion that could change the contribution needed from non-Federal lands. One such development is the adoption of a new Federal lands late-successional, old-growth forest ecosystem management strategy. The new Federal strategy establishes reserves and management guidelines for Federal lands on the Olympic Peninsula that will provide nesting, roosting, and foraging habitat for the owl and meet the habitat requirements of numerous other species. The overall change in Federal management strategy on the Olympic Peninsula between the Final Draft Recovery Plan and Alternative 9 in the FSEIS is the increased Federal protection for the owl. In particular, the strength of the Federal land reserve system and the Adaptive Management Area, and the associated management guidelines in Alternative 9, may have important implications for the role of non-Federal landowners.

Recent modeling work, carried out principally by Martin Raphael and Kevin McKelvey (Raphael and others 1994) served as one mechanism to compare Alternatives 1, 7, and 9 in the FSEIS-given a variety of assumptions. The model provides a good tool to address and simulate critical population size, but only in a relative sense. One cannot estimate absolute risk by using the model, but the model can be used to estimate the relative contribution from specific areas to the overall efficacy of management across ownership boundaries. The model, therefore, can provide a logical framework to evaluate the potential contributions associated with spotted owl habitat on non-Federal lands on the Olympic Peninsula.

Tasks To Be Performed

The Team should perform the following tasks:

Task 1. Review the Forest Plan, FSEIS, and Record of Decision to develop an understanding of the habitat conditions that exist and are expected to develop on Federal lands. For purposes of this analysis, Alternative 9 is assumed to be the Federal contribution to recovery.

Task 2. Review existing data and existing and new model output to assess the likelihood and pattern of persistence of the owl population on the Olympic Peninsula, given Alternative 9, including appropriate non-Federal lands as part of the principal baseline as discussed above. Assess how that persistence and its pattern would be changed by varying levels of contribution from non-Federal land, recognizing the limitations of current statutory authority regarding take prohibitions and the voluntary nature of HCPs. Where practicable, the following issues should be investigated and discussed:

- a. Ranges and effects of regrowth of habitat.
- b. Possible ranges and effects of catastrophic events.
- c. Ranges and effects of elevational gradients in suitability of habitat.
- d. Benefits derived from various levels of contributions from non-Federal land.
- e. Possible ranges and effects of birth and survival rates keying off those values used in previous published model runs to the extent possible.
- f. Possible ranges and effects of dispersal rates.
- g. Possible ranges and effects of connectivity to other provinces on persistence of owls on the Olympic Peninsula. Where gaps in owl distribution between the Olympic Peninsula population and other populations occur now, or are anticipated in the future, the significance of the gap should be addressed relative to the persistence of the owl on either side of the gap.
- h. Possible ranges and effects of genetic issues, including hybridization with the barred owl.
- i. Possible ranges and effects of time periods.

Task 3. Prepare a draft report documenting the Team's review, indicating the degree of consensus of the Team regarding the conservation value from non-Federal lands and noting any significant dissent within the Team from that consensus.

Task 4. Work with appropriate staff in the Region 1 Regional Office [USDI Fish and Wildlife Service] to execute peer review.

Task 5. Revise the Team Report as appropriate to reflect peer review comments and submit it to the Regional Director by October 17, 1994. Meeting this deadline is contingent upon no major new analyses arising from the peer review process.

Appendix 2: Additional Model Parameters

For simulating owl dynamics on the peninsula, the rule sets that we constructed differed primarily in the assumed response of the population to changes in habitat quality. The relationships between vital rates and habitat quality were of primary concern because the potential land management rules (scenarios) that we postulated were defined by the retention and growth of suitable owl habitat. Here we describe varied other parameters listed in table 11 that are necessary to drive the model but that we did not change across runs. Additional discussion of these parameters can be found in McKelvey and others (1992) and McKelvey and others (in rev.).

Fledge number, male probability of fledging-These two parameters determine the number of birds born and the sex ratio of those birds. The values used in these simulations cause the young to be born in groups of two and with a 1:1 sex ratio.

Nesting OK-This parameter controls nest-site selectivity. When a dispersing male searches an unoccupied site it must make a decision to either become territorial or continue searching. The parameter values are the probability that a site of a given quality will be chosen. The parameters used in these simulations were developed to match observed relationships between density and habitat¹ (Bart and Forsman 1992).

Aversion--This parameter controls the probability that a dispersing bird enters an adjacent cell of a given quality. It is assumed that owls will preferentially choose to enter high-quality habitat and the parameters used cause dispersers to be twice as likely to enter high-quality habitat as low-quality habitat.

Probability that a female finds a male-If a nonterritorial female enters a site occupied by a territorial male, she obligately becomes territorial. This parameter sets the likelihood that she locates a territorial male in an adjacent cell before entering it. If she locates a male, she obligately moves to that site and pairs with the male.

Male territorial aversion-It is assumed that a dispersing male will preferentially choose to enter unoccupied rather than occupied habitat if the quality is similar. Given the value presented, a dispersing male is twice as likely to move into unoccupied habitat.

Directional weighting-Large values for this parameter cause an organism to move in a consistent direction. A value of 1.0 produces a random walk. The value we used causes a dispersing owl to move forward with twice the probability of moving in an alternate direction.

Wanderlust At each move, an owl can either move in one of six possible directions or remain stationary. The values we used cause owls to never remain stationary in the poorest quality habitat.

¹ Personal communication. 1994. J. Bart. Cooperative Wildlife Research Unit, Ohio State University, 1735 Neil Ave., Columbus, OH 43210.

Boundary condition-Three global boundary conditions can be specified: absorbing, reflecting, and wrap-around. In addition, internal boundaries can be created by declaring cell types that have no chance of survival (and thus "absorb" the owl) or create total aversion (and thus "reflect" the owl). For modeling landscapes, combinations of these global and internal boundaries can be used to create reasonable boundary conditions. In the maps presented in this document, the southern map boundary was absorbing, and boundaries that represented the ocean were reflecting. Because dispersers can be expected to continue south beyond the map boundary, and because few owls from southwest Washington will be entering the map area due to the low numbers in this area, an absorbing boundary is the most reasonable choice for the southern boundary.

Delta-t-This value is the number of habitat cells that an organism can search in a year. Sensitivity analyses (McKelvey and others, in rev.) and analytical models (Carroll and Lamberson 1993; Noon and McKelvey, in prep.) show that for organisms displaying the life history attributes of spotted owls, very little is gained in search effectiveness by searching more than 20 cells per year.

Holthausen, Richard S.; Raphael, Martin G.; McKelvey, Kevin S.; Forsman, Eric D.; Starkey, Edward E.; Seaman, D. Erran. 1995. The contribution of Federal and non-Federal habitat to persistence of the northern spotted owl on the Olympic Peninsula, Washington: report of the Reanalysis Team. Gen. Tech. Rep. PNW-GTR-352. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 68 p.

This report describes likely patterns of distribution and persistence of owls on the Olympic Peninsula under the provisions of the Federal Forest Plan, benefits to the owl population of varying levels of habitat contribution from non-Federal lands, and possible effects of establishing habitat connections between the Olympic Peninsula and other parts of the owl's range. Updated information about spotted owl habitat, population status, and birth and survival rates for the Olympic Peninsula were summarized, and much of the analysis focused on simulations of spotted owl populations under alternative scenarios.

Keywords: Northern spotted owl, spatial model habitat, simulation model, land management, conservation.

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