A1 **APPENDIX A - DNR'S FOREST MANAGEMENT**

A1 **Federal Grant Lands**

A1 **Forest Board Lands**

A2 **Community College Forest Reserve Lands**

A2 **Natural Area Preserves and Natural Resource Conservation Areas**

A2 **Summary of Forest Resource Plan Policies**

- General Management Policies
- Harvest Regulation Policies
- Financial Policies
- Special Lands Policies
- Landscape Planning Policies
- SEPA Policy
- Aquatic Systems Policies
- Wildlife Policy
- Endangered, Threatened and Sensitive Species Policy
- Historic and Archaeological Sites Policy
- Public Access and Rights of Way Policies
- Forest Recreation Policy
- Silviculture Policies

Appendix A - DNR's Forest Management

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Appendix A

DNR's Forest Management

Federal Grant Lands

On November 11, 1889, President Benjamin Harrison signed the proclamation that made Washington the 42nd state. As part of the preparation for statehood, the Omnibus Enabling Act of 1889, passed by Congress a few months earlier, set aside 2 square miles of every 36 to produce financial support for the common schools. In addition, the act granted additional lands to other public institutions. These lands are known as federal grant lands and consist of eight specific trusts:

1. Common school lands, which support the construction of public schools.
2. Agricultural school lands, which support Washington State University in Pullman.
3. Charitable, educational, penal and reformatory institutions lands, which support those public institutions.
4. University original lands, which were used to support the University of Washington in Seattle. Only a small amount of that acreage remains.
5. University transfer lands, which were originally part of the charitable trust but were transferred by the state legislature to provide additional support to the University of Washington.
6. Normal school lands, which currently support three universities (Western Washington University in Bellingham, Central Washington University in Ellensburg and Eastern Washington University in Cheney).
7. Scientific school lands, which support Washington State University.
8. Capitol building lands, which support the construction of state office buildings on the capitol campus in Olympia.

Forest Board Lands

The Forest Board was established in 1923 to manage logged and abandoned properties formerly owned by individuals and corporations. The land reverted to the counties when the original owners failed to pay property taxes. These properties were subsequently transferred to the state, and the Forest Board was established to regenerate trees on the lands, which are now managed for timber production in perpetuity. Revenues produced from Forest Board Transfer lands support the county and junior taxing districts (such as schools, road, and cemetery districts) in which they are located. The department manages these properties as trustee. Forest Board Purchase lands were acquired by gift or

purchase. Revenues go to the county and junior taxing districts in which they are located and the state general fund for the benefit of public schools.

Community College Forest Reserve Lands

In addition to federal grant and Forest Board lands, the department also manages a small amount of forest lands for community colleges. The Community College Forest Reserve was established by the state legislature in 1990; monies for the department to purchase the properties were appropriated that year. Additional land will be purchased if funds are allocated. These lands, located near urban areas, form a buffer between working forests and suburban uses. The properties are managed for sustainable timber production, but special consideration is given to aesthetics, watershed protection, and wildlife habitat. Revenues go in a special fund for building and capital improvements on community college campuses.

Natural Area Preserves and Natural Resource Conservation Areas

In recognition of the need for the state to own special lands, the legislature created programs to identify and purchase Natural Area Preserves (NAP) and Natural Resource Conservation Areas (NRCA). For each NAP and NRCA, DNR is preparing a management plan that outlines protection, enhancement, restoration, and allowable uses. These vary widely with the current condition and conservation objectives of each site. NAPs provide the highest level of protection for the excellent examples of unique or typical natural features of Washington State. NAPs are valued particularly by land managers and scientists because they provide (1) a genetic resource for native plants and animals, especially endangered, threatened, or rare species; (2) environmental reference points; and, (3) outdoor laboratories for scientific research and education.

NRCAs are established to protect outstanding examples of native ecosystems, habitat for endangered, threatened and sensitive plants and animals, and scenic landscapes. Some NRCAs provide opportunities for outdoor environmental education as well as opportunities for low-impact public use consistent with resource protection.

Summary of Forest Resource Plan Policies

General Management Policies

Federal Grant Land Base

The department will maintain a diversified base of federal grant lands, including nonforest properties. In deciding whether to sell, exchange, or acquire lands, the department will balance current economic returns and trust benefits with future economic returns and trust benefits.

Forest Board Land Base

The department will perpetuate a productive forest base of Forest Board lands. In deciding whether to exchange lands, the department will assess whether timber harvesting

is impractical on these properties and, if so, will attempt to replace them with productive forest lands.

Land Classifications

The department intends to designate those lands and timber resources that are unavailable for harvest as "off-base." All deferrals will be included in this category.

Harvest Regulation Policies

Sustainable, Even-Flow Timber Harvest

The department will manage state forest lands to produce a sustainable, even-flow harvest of timber, subject to economic, environmental, and regulatory considerations.

Harvest Levels Based on Volume

The department's harvest calculations will be based on volume rather than acreage or other considerations.

Western Washington Ownership Groups

The department will establish a sustained, even-flow harvest level within specified ownership groups in western Washington, as follows:

1. Forest Board Transfer lands, where the harvest will be calculated by individual counties.
2. Federal grant lands and Forest Board Purchase lands, where the harvest will be calculated by department administrative regions.
3. The Capitol State Forest, which will be considered a separate ownership group.
4. The Olympic Experimental State Forest, which will also be considered a separate ownership group.

Eastern Washington Ownership Groups

The department will establish sustained, even-flow harvest levels within specified ownership groups in eastern Washington, as follows:

1. Yakima River.
2. Klickitat.
3. Highlands and South Okanogan.
4. Arcadia.
5. North Columbia.

Special Forest Products

The department will encourage and promote the sale of special forest products where appropriate and will market them in a manner consistent with the overall policies of this plan.

Forest Health Trust Asset Protection Policies

The department will incorporate forest health practices into the management of state forest land to bring about a net benefit through the reduction or prevention of significant forest resource losses from insects, diseases, animals, and other similar threats to trust assets.

Fire Protection

The department will supplement the state's fire protection program to bring about a net benefit through the reduction of significant resource losses from wildfire on department-managed land.

Financial Policies

Managing "On-Base" Lands

The department will manage "on-base" forest lands at different levels of intensity depending on biological productivity and economic potential. Investment decisions will be made according to expected returns.

Annual Review of Financial Assumptions

The department will review and adjust annually its financial assumptions used in management decisions.

Special Lands Policies

Special Ecological Features

The department will identify state forest lands with special ecological features that fill critical gaps in ecosystem diversity, and it will seek legislation and funding to remove these lands from trust ownership.

Old Growth Research Area Deferrals

During this planning period, the department will continue to defer from harvest certain old growth research stands in western Washington to maintain the ability to acquire information on ecological relationships which may affect intensive timber management.

The Genetic Resource

The department will protect and enhance a diverse gene pool of native trees on state forest lands to ensure well-adapted, future, commercial forests.

Landscape Planning Policies

Landscape Planning
The department will develop plans by setting management objectives for specified landscapes consistent with the Forest Resource Plan.

Soliciting Information
The department will solicit comments from interested parties, including local neighborhoods, tribes, and government agencies when preparing landscape-level objectives.

SEPA Policy

SEPA Review
The department will conduct a SEPA review when subsequent plans and activities constitute a non-exempt agency action under the act.

Aquatic Systems Policies

Watershed Analysis
The department will analyze by watershed the effects of past, present, and reasonably foreseeable future activities on water quality and quantity, and it will modify operations to control risks to public resources and trust interests.

Riparian Management Zones
The department will establish riparian management zones along Type 1-4 Waters and when necessary along Type 5 Waters. The department will focus its efforts on protecting key nontimber resources, such as water quality, fish, wildlife habitat, and sensitive plant species.

Wetlands
The department will allow no overall net loss of naturally occurring wetland acreage and function.

Wildlife Policy

Wildlife Habitat
The department will provide wildlife habitat conditions which have the capacity to sustain native wildlife populations or communities. The department will develop wildlife habitat objectives based upon habitat availability and function, species status and vulnerability, and trust obligations. When there are apparent conflicts between meeting the wildlife habitat and trust management objectives, the department will seek balanced solutions and policies.

Endangered, Threatened, and Sensitive Species Policy

Endangered Species

The department will meet the requirements of federal and state laws and other legal requirements that protect endangered, threatened, and sensitive species and their habitats. The department will actively participate in efforts to recover and restore endangered and threatened species to the extent that such participation is consistent with trust obligations.

Historic and Archaeological Sites Policy

Identifying Historic Sites

The department will establish a program to identify and inventory historic and archaeological sites and protect them at a level which, at a minimum, meets regulatory requirements.

Public Access and Rights-of-Way Policies

Providing Public Access

The department will provide public access for multiple uses on state forest lands. In certain circumstances the department will control vehicular or other access, but only where necessary to accomplish specific management objectives. Public access may be closed, restricted, or limited to protect public safety; to prevent theft, vandalism, and garbage dumping; to protect soils, water quality, plants, and animals; or to meet other objectives identified in the plan.

Granting Public Rights-of-Way

The department will grant rights-of-way to private individuals or entities when there is an opportunity for enhancing trust assets and when any detriments are offset.

Acquiring Rights-of-Way

The department will acquire right-of-way across private or other public lands to department-managed forest land when this access is needed to increase the value of trust assets or for management purposes. The department will acquire these rights-of-ways by gift, purchase, exchange, condemnation, or road use agreement. Permanent, public access rights are preferred.

Developing and Maintaining Roads

The department will develop and maintain a road system which integrates management needs and controls effects on the forest environment.

Forest Recreation Policy

Recreation on State Forest Lands

The department will allow recreation on state forest land when compatible with the objectives of the Forest Resource Plan. As part of its efforts, the department will continue to comply with the Statewide Comprehensive Outdoor Recreation Plan.

Silviculture Policies

Silviculture Activities

The department will plan and implement silvicultural activities to meet trust responsibilities. In cases warranting special attention, the department will accept a reduction in current income or return on investment when the department determines that it is necessary to provide extra protection for soil, water, wildlife, fish habitat, and other public resources.

Harvest and Reforestation Methods

The department will select the harvest method which produces the best mix of current and long-term income, achieves reforestation objectives, and integrates nontimber resource objectives identified in the Forest Resource Plan. Reforestation objectives must ensure adequate restocking, produce acceptable benefits to the trusts, and protect public resources.

Green-up of Harvest Units

The department will reduce the impacts of clearcutting and certain even-aged silvicultural systems by generally limiting the size of harvest areas to a maximum of 100 acres, requiring "green-up" of adjacent areas before harvesting timber, and employing other techniques to blend harvested areas into the landscape.

Control of Competing Vegetation

To prevent domination of crop trees by other vegetation, the department will select from the following methods for controlling competing vegetation:

1. No treatment.
2. Nonherbicide.
3. Ground-applied herbicide.
4. Aerial-applied herbicide.

The department will consider the no treatment method first and then move sequentially down the list. The department will select the first method on the list which is both effective and produces an acceptable return on investment. A method lower on the list may be used only if it substantially outperforms other methods.

Fertilizing, Thinning, and Pruning

The department will use fertilization, thinning, and pruning on stands which will respond and produce an acceptable rate of return on investment.

B1 APPENDIX B - GEOLOGY/SOILS/ VEGETATION

B1 Geology

- Five West-Side Units
- Olympic Peninsula
- Three East-Side Units

B2 Soils

- West-Side Planning Units
- OESF
- East-Side Planning Units

B6 Vegetative / Forest Zones

- Vegetative Zones
- Sitka Spruce Zone
- Western Hemlock Zone
- Pacific Silver Fir Zone
- Subalpine Fir/ Mountain Hemlock Zone
- Alpine Zone
- Grand Fir Zone
- Douglas-fir Zone
- Ponderosa Pine Zone
- Current Resource Management Practices and Policies
- Forest Habitat Characteristics of Three Seral Stages

Appendix B

Geology/Soils/Vegetation

Geology

Five West-Side Units

Puget Sound is a partially submerged glaciated area with moderate relief (change in elevation). The coastal section, including the Willapa Hills, is made of unconsolidated deposits of alluvial, glacial, and volcanic materials. Glaciers have carved deep, steep-sided valleys along the western slopes of the Cascade Range. Tributary channels flow at high angles into rivers that, in turn, flow through broad valleys, such as the Skagit River valley. Steep slopes are subject to debris flows from the heads of stream channels (USDA and USDI 1994a p. 3&4-8).

Olympic Peninsula

The Olympic Peninsula Province is made up of a central core of the rugged Olympic Mountains surrounded by almost level lowlands. The lowland strips are narrow on the east and north, but wider on the west and south sides of the peninsula. Most ridges in the Olympic Mountains are 4,000-5,000 feet in elevation with some higher peaks attaining elevations to 7,965 feet. Glaciation has strongly influenced landforms. All main river valleys are broad and U-shaped, and all major peaks are ringed with cirques, many containing active glaciers (Franklin and Dyrness 1973 p. 9).

Geologically, the mountainous portion of the Olympic Peninsula is made up of volcanic and sedimentary rocks. The sedimentary rocks make up the center and western part of the peninsula while the volcanic form the northern, eastern and southern fringe. Unconsolidated sediments from glacial outwash, till, and alluvium dominate the low elevation areas west of mountains (Henderson et al. 1989).

Three East-Side Units

The three east-side planning units are referred to as the Klickitat, Yakima, and Chelan. The Klickitat unit ranges in topography from 12,276 at the peak of Mount Adams to about 72 feet on the Columbia River pool behind Bonneville Dam. The southern and southeastern part of the unit is underlain by Columbia River basalt cut by northwest-trending faults. Elevations rise toward the westernmost part of the unit, near Mount Adams. The bedrock in this part of the unit is an older (Miocene to Oligocene) sequence of tuffs and volcanic sandstones overlain by Quaternary andesite and basalt flows. Many cinder cones aligned on extensions of the older faults to the southeast are present on the Quaternary lava flows. Patchy deposits of alpine glacial drift are found above elevations

of about 1,800-2,000 feet. In the northeast part of the unit, Columbia River basalts are folded into anticlinal ridges separated by synclines that are filled with Pliocene through Recent alluvium.

The Yakima unit extends from the Cascade crest from Mount Adams to Snoqualmie Pass and eastward to the Columbia Basin. Accreted Mesozoic metamorphic and altered sedimentary rocks are found in the vicinity of White and Snoqualmie Passes. The rest of the area in the higher elevations is comprised of tertiary lava flows and volcaniclastic rocks patchily covered with alpine glacial drift. The lower elevations to the east consist of
anticlinal ridges of Columbia River basalt separated by synclinal basins filled with upper Miocene through recent alluvial sediments and distal alpine glacial outwash deposits.

The Chelan unit extends from Stevens Pass to the Canadian border along the Cascade crest on the west to the Columbia Basin on the southeast and the Okanogan Highlands on the east and northeast. The rugged, mountainous core along the western and central parts of the unit are underlain by the crystalline core of the North Cascades--thoroughly metamorphosed gneisses and granitic stocks and batholiths ranging in age from pre-Cambrian through Eocene. In the eastern and southern parts of the unit are two northwest-trending structural basins filled with Cretaceous and Eocene sedimentary and volcanic rocks respectively. All but the highest peaks in the area have been heavily glaciated and the valleys all have relatively flat bottoms and steep walls. Glacial scour has been extremely deep, gouging out basins reaching depths of nearly 2,000 feet in Lake Chelan.

Soils

Soil can be defined as the material at the earth's surface which is capable of supporting plants. It is the ecosystem element located at the interface of the climatic, geologic, water, and biologic ecosystem elements. It is a dynamic, natural, three-dimensional body composed of weathered mineral and organic material that provides plants with air, water, root anchorage, and nutrients. Soil characteristics and soil behavior are a product of the interaction of five soil-forming factors: (1) parent material (the material from which the soil has formed); (2) climate; (3) organisms; (4) topography; and, (5) time. The soil characteristics and soil behavior which occur across HCP planning units will be discussed in terms of these soil forming factors. This discussion is based on soil maps and detailed information including soil characteristics, soil behavior, and forest soil management interpretations from the Soil Layer of DNR's Geographic Information System and soil survey reports published by the U.S. Soil Conservation Service (now the U.S. Natural Resources Conservation Service).

West-Side Planning Units

North Puget Sound, South Puget Sound, and Straits Planning Units

Soil characteristics and soil behavior on most forested state trust lands in the North Puget Sound, South Puget Sound, and Straits planning units, as well as other glaciated terrain in Washington State, are strongly influenced by glacial activity during the Fraser Glaciation.

In the Fraser Glaciation, which occurred approximately 25,000 to 10,000 years B.P., alpine glacial activity in the Cascade and Olympic ranges and continental glacial activity on terrain covered by the Puget and Juan de Fuca glacial lobes shaped topography and deposited soil parent materials throughout this area.

The relatively short time period since deglaciation is a factor which has limited the degree of soil formation in the parent materials on this glaciated terrain. The glacial deposits and other surface parent materials remaining after deglaciation have not experienced the higher level of physical and chemical alteration and related soil horizon development generally found in unglaciated areas of Washington State. These glaciated terrain soils tend to have much lower levels of organic matter accumulation in their surface horizons and less horizon development in general than the older, more heavily weathered, better-developed soils in other parts of Washington State.

Parent material is a major factor influencing soil characteristics and soil behavior on this glaciated terrain. Major types of glacial parent materials, in order of their relative coverage, are glacial till, glacial outwash, and glacial lake sediments.

Glacial till is an unsorted, nonstratified mixture of clay, silt, sand, and rock fragments deposited directly by glacial ice. Glacial till soils are commonly found on broad, moderately sloping till plains, but can also be found capping the bedrock on steeper mountainous terrain. Glacial till soils are generally found with hard, impermeable lodgement till at an average depth of 24-36 inches, covered by loose, permeable ablation till. Restricted soil drainage caused by the impermeable lodgement till at shallow depths can be a management concern on glacial till soils. The deeper, better drained, more heavily weathered glacial till soils such as the Tokul Gravelly Loam found in the higher precipitation areas along the foothills of the Cascades tend to be among the most productive forest soils in the Puget Sound lowland.

Glacial outwash is the gravel, sand, and silt, usually stratified, deposited by glacial meltwater. Glacial outwash soils are commonly found on broad outwash plains or on the higher terraces in the larger valleys. Most soils on the lower terraces in these valleys have formed on recent stream alluvium and tend to have younger, less well-developed soil profiles.

Restricted drainage is rarely a problem on glacial outwash soils because they tend to be deep and relatively coarse textured. These coarse textured soils also tend to have lower compaction potentials than the finer textured glacial till or glacial lake sediment soils. The coarse textures of glacial outwash soils such as the Everett Very Gravelly Sandy Loam tends to limit their capacity to retain and supply nutrients and water and, therefore, limits their potential productivity. The soils formed on glacial outwash, as well as the soils formed on other glacial parent materials, tend to be less productive in the lower precipitation areas in the rain shadow of the Olympics.

Glacial lake sediments consist primarily of silt and clay materials which were deposited in lakes dammed by glacial ice. Most glacial lake sediments are bedded, interbedded or laminated. Glacial lake sediment soils are commonly found in mountain valleys which

were dammed by glacial ice. The drainage in glacial lake sediment soils tends to be restricted by their fine textures and their bedding or laminations, when present. Although they tend to have high potential productivity, soils, such as the Pastik Silt Loam, have a higher mass-wasting potential on steep topography than soils formed on glacial till or glacial outwash because they tend to have higher pore-water pressures and lower soil strengths. Glacial lake sediment soils also tend to have higher compaction potentials because of their finer textures and higher moisture contents, particularly during the wet season.

Soils formed from mixtures of colluvial bedrock materials, glacial drift deposits, and volcanic ash are often found at medium to high elevations in glaciated portions of the Cascade and Olympic ranges. These soils tend to be deeper, finer textured, better developed, and more productive on gentle slopes and on toeslopes or other terrain features where soil parent materials tend to accumulate and be retained. Soils in these areas, however, tend to be thinner, have less soil profile development, and are less productive on the steeper, less stable topography where high levels of surface erosion and mass-wasting activity tend to minimize soil retention. The potential for surface erosion and mass-wasting activity tends to be greater on soils in the rain-on-snow elevation zones in the Cascades and Olympics because the potential for surface flow is greater.

Volcanic ash has been deposited on most soil surfaces throughout the Cascades, the Puget Sound lowlands and the Olympics. Variations in volcanic ash content are influenced primarily by topography and geographic location. As indicated above, gentle topography has tended to favor thicker volcanic ash accumulations. Most volcanic ash from the Cascade volcanoes was deposited to the north and east of the Cascade crest and the soils of the Puget Sound lowlands and the Olympics tend to have less volcanic ash influence than soils in and along the Cascades. Increases in weathered volcanic ash content tend to increase the nutrient status, water-holding capacity and potential productivity of soils. Deep, heavily weathered volcanic ash soils such as the Cinebar Silt Loam are among the most productive soils at moderate elevations in the Cascades.

South Coast and Columbia Planning Units

The South Coast and Columbia planning units, in comparison with the North Puget, South Puget, and Straits planning units described above, have had relatively small portions of their forested state trust lands influenced by glacial activity. Some soils on older, more heavily weathered glacial deposits from the Olympics are found in northern portions of the South Coast Planning Unit and some soils on younger, less heavily weathered glacial deposits are found in the Cascades in the Columbia Planning Unit.

The soils on forested state trust lands in the South Coast and Columbia planning units tend to be older, deeper, finer-textured, and have higher nutrient status than those on the more widely glaciated planning units to the north. Because of these soil characteristics and the generally favorable climatic conditions, the average potential productivity of the forested state trust lands in the South Coast and Columbia planning units tends to be higher than in other planning units.

Most forested state trust land soils on terrain features above the alluvial valley bottoms in the South Coast and Columbia planning units have formed on parent materials derived from the underlying bedrock. Topography has played a major role influencing the characteristics and behavior of these soils. Primarily because of the increased potential for surface erosion and mass wasting, the soils on the steeper terrain tend to be shallower, have higher gravel content and lower potential productivities than the soils formed on gentle terrain.

Major soils on basalt bedrock in the Willapa Hills, for example, include the moderately deep Katula Very Cobbly Loam on ridgetops and very steep sideslopes; the deep Bunker Silt Loam on moderate to steep sideslopes; and the very deep Boistfort Silt Loam on gentle to moderate sideslopes and toeslopes. Similar relationships between topography and soil characteristics and behavior are found on sedimentary bedrock types and other parent materials.

Parent materials play a major role in determining the mass-wasting potential of soils in the South Coast and Columbia planning units. The high mass-wasting potential of the St. Martin Gravelly Silty Clay Loam and similar soils in Skamania County is determined by the unstable character of the old landslide deposits on which they have formed. Soils formed over sedimentary bedrock or weathered or brecciated igneous bedrock tend to have higher mass-wasting potential than soils formed over unweathered or unbrecciated igneous bedrock.

OESF

The range in soil characteristics and behavior on forested state trust lands in the Olympic Experimental State Forest is very large because of the wide range in each of the soil forming factors. As in other west-side planning units, those soils with the highest potential productivity and lowest mass-wasting potential tend to be found on gentle to moderate slopes and low to moderate elevations and those soils with the lowest productivity and highest mass-wasting potential tend to be found on the steepest terrain at the highest elevations.

The Ilwaco Silt Loam and the Klone Very Gravelly Loam soils are two of the most productive and easily managed soils on forested state trust lands in this planning unit. The Ilwaco soils are very deep, well-drained, and formed in highly weathered sandstone residuum on moderately sloping foothill topography. The Klone soils are very deep, well- drained, and formed on glacial outwash terrace deposits. Well-drained soil conditions favor high commercial forest productivity levels, but many areas, primarily on glacial drift plains and alluvial bottoms at lower elevations in the Olympic Experimental State Forest Planning Unit, have limited commercial forest productivity potential because of poor drainage conditions and high water tables.

Limited commercial forest productivity potential is also found on higher elevation soils in the Olympics due primarily to shallower soil depths in combination with shorter growing seasons. The Sollecks Very Gravelly Loam, Frigid, 60-90 percent Slopes is a major soil type on state trust lands at higher elevations in the Olympics. The Sollecks is formed

from colluvial sandstone and conglomerate parent materials on ridgetops and very steep sideslopes. The depth of this soil ranges from shallow to moderately deep, varying with percentage slope and slope position. This high elevation terrain where the Sollecks and similar soils are found has a high mass-wasting potential because it is very steep and because of the frequent heavy rainfall storms and rain-on-snow events.

East-Side Planning Units

Climatic differences have resulted in significant differences between the soils in the west-side planning units described above and the east-side planning units. The east-side planning units occur in the rain shadow of the Cascade Range and their lower precipitation levels have tended to limit their potential forest productivity levels and soil profile development.

The forested state trust lands closer to the eastern edges of the east-side planning units are those which tend to have the lowest potential forest productivity and lowest levels of soil profile development because they have the lowest mean annual precipitation levels. The forested state trust lands closer to the western edges of the east-side planning units will tend to have higher potential forest productivity and more soil profile development because of their higher mean annual precipitation levels. Potential forest productivity, however, is restricted on the higher elevation areas with shorter growing seasons. Forested state trust lands in east-side planning units tend to have fewer problems with mass-wasting activity than those in west-side units because of their lower frequency of heavy rainfall storms and rain-on-snow events.

Vegetation / Forest Zones

Vegetative Zones

Vegetative zones are broad areas that have similar types of vegetation. The HCP area includes land in the zones described below. These brief descriptions are followed by Table 1 that lists selected plant species found in each zone. This table, compiled from "Natural Vegetation of Oregon and Washington" (Franklin and Dyrness 1973), is meant to illustrate the variety of tree, shrub, and other vegetation found in Washington, and is not intended to be a complete list.

Sitka Spruce Zone

Along the Pacific coast and extending inland up river valleys is a narrow band of vegetation where Sitka spruce is considered climax. This is the Sitka spruce zone. In most places it is usually only a few miles wide and occurs where summer fog and drip precipitation are common. The climate in this zone is the mildest of any Washington forest zones. Winter rains are heavy and snow is infrequent. Trees are tall and stands are dense. Productivity and biomass are high, and there are relatively few hardwoods. Rain forests of the Olympic National Park are a special type within the Sitka spruce zone.

Western Hemlock Zone

The western hemlock zone extends from sea level to 2,000 feet throughout most of Washington. The inland boundary of this zone coincides roughly with the western boundary of the national forests in the Cascade mountains. The climax trees are western hemlock, with western redcedar in moister areas and Douglas-fir in drier areas. The forest canopy is dense, tall conifers. This forest zone is the largest in the state and contains some of the most productive and most intensively managed forest lands. Most state forest land in western Washington is in this zone. However, because of its extent and accessibility, most of the western hemlock zone has been disturbed, logged, or burned at least once in the past 200 years. As a result, large portions are now dominated by Douglas-fir in seral stands or contain mixtures of hardwoods. Even before settlement by Europeans, there were extensive Douglas-fir stands, probably the result of old fires. Remnants of these original stands are commonly referred to as old growth. Red alder is a common pioneer species throughout the zone.

Climate of the western hemlock zone is mild, wet, and maritime. Snow is common but not persistent. The Puget Sound lowlands are considered a special type; forest composition is modified by the rain shadow of the Olympic Mountains and gravelly glacial soils.

A version of the western hemlock zone occurs east of the Cascade Range. Extensive stands of western hemlock and western redcedar occur in moist pockets and along streams and rivers throughout northeastern Washington, as well as farther east. The trees, understory vegetation, and high precipitation give these inland stands their distinct maritime flavor.

Pacific Silver Fir Zone

The Pacific silver fir zone extends from about 2,000 to 4,000 feet in elevation in Washington. On the west side of the Cascades, it abuts the western hemlock zone at lower elevations and extends upward to subalpine forests in the Olympic and Cascade mountains. Pacific silver fir community types are also found east of the Cascades.

Throughout the zone the climate is cool and wet, with a short growing season. It is common in this zone for up to half of the annual precipitation to fall as snow and persist as winter snowpacks for 3-7 months. Dense forests consist of tall conifers and patches of shrubby undergrowth. Huckleberry species are common. Douglas-fir is also a major component of this zone.

Subalpine Fir/Mountain Hemlock Zone

Subalpine fir/mountain hemlock forests make up the highest forest zone in the Olympics and on both sides of the Cascade mountains, extending from about 4,000 feet to the timberline. Mountain hemlock predominates at the lower elevations and is replaced with subalpine fir at higher elevations. The zone ends at the high altitudes mosaic of tree groups, glades, and meadows.

East of the Cascades and in the Okanogan Highlands, subalpine fir is found associated with Engelmann spruce.

Scattered pockets of Engelmann spruce are found on the east side of the Olympics and west of the Cascades in the Mt. Baker-Ross Lake area. This zone is Washington's coolest and wettest forest environment. Forests here are dense and contain short to medium-tall conifers, often with an understory mixture of shrub and herbaceous vegetation.

Alpine Zone

Alpine meadows and high-altitude barrens are found in the Olympics and Cascades above timberlines. This zone lacks timber production potential. Vegetation consists of complex mixtures of forbs, grasses, sedges, and low shrubs. Several types of plant communities on Washington alpine lands are linked to local microclimatic variations of moisture, snowpack duration, and substrate. Winters are cold and long, and summers are brief. Growth, except for spectacular floral displays, is slow.

Grand Fir Zone

An extensive grand fir zone occurs below the subalpine forest in eastern Washington. From a management point of view, the grand fir zone and Douglas-fir zone, with which it merges, are usually considered together. However, in an ecological sense, they should be considered separately. The zone is cooler and moister than the lower Douglas-fir zone, but warmer and with less snow accumulation than subalpine forests.

Douglas-fir Zone

The Douglas-fir zone in eastern Washington is particularly prominent in the northern portion of the state. Douglas-fir in Washington is commonly bordered at lower and drier elevations by a band of ponderosa pine that separates it from shrub steppe and grass communities of the Columbia Basin.

Subtle limitations of temperature and moisture are probably important in separating the Douglas-fir zone from the moister grand fir zone and the drier ponderosa pine zone. Forests in both the grand fir and Douglas-fir zones consist of dense medium and tall conifers. Where overstory density permits, understory vegetation may be of extensive brush or grass, depending on soil moisture content.

Ponderosa Pine Zone

The ponderosa pine zone, lowest of the forest zones in eastern Washington, occurs between 2,000 and 4,000 feet elevation. The ponderosa pine zone typically borders the shrub-grassland zone but in south-central Washington, a community of Oregon white oak is located between the two.

This zone is the driest of the Washington forest zones. Precipitation is low, especially in summer. Winter precipitation commonly falls as snow which accumulates as a result of low temperatures. Summer days are hot and summer nights cool. The effective growing season is short and probably moisture-limited. Soil moisture regulates the distribution of understory vegetation, which ranges from brush to grass. The forest consists of dense to open stands of tall trees.

Table 1: Vegetative zones of area covered by the HCP

(Source - compiled from Franklin and Dyrness 1973)

Vegetative Zone	Elevation range (feet)	Average precipitation (inches)	Major tree species	Common shrubs	Herbaceous plants
Sitka spruce	0 - 500'	80 - 120"	Sitka spruce, western hemlock, western redcedar, Douglas-fir, grand fir, Pacific silver fir, red alder	red huckleberry, devilsclub, salmonberry	sword fern, Oregon oxalis, false lily-of-the-valley, evergreen violet, wood violet, Smith's fairybells
western hemlock	0 - 3,000'	60 - 120"	Douglas-fir, western hemlock, western redcedar, red alder, bigleaf maple	vine maple, Pacific rhododendron, creambush oceanspray, California hazel, western yew, Pacific dogwood, red huckleberry, Oregongrape, salal, trailing blackberry	deerfoot vanillaleaf, evergreen violet, white trillium, sword fern, twinflower, Pacific peavine, common tarweed, white hawkweed, snow-queen, common beargrass, Oregon iris, western fescue, western coolwort, Hooker's fairybells, wild ginger, ladyfern, deerfern, Oregon oxalis

Vegetative Zone	Elevation range (feet)	Average precipitation (inches)	Major tree species	Common shrubs	Herbaceous plants
Pacific silver fir	2,000 - 4,250'	80 - 120"	Pacific silver fir, western hemlock, noble fir, Douglas-fir, western redcedar	vine maple, salal, Oregongrape, red huckleberry, big huckleberry, Alaska huckleberry, ovalleaf huckleberry, devilsclub	beargrass, twinflower, bunchberry dogwood, deerfoot vanillaleaf, queencup beadlily, dwarf blackberry, western coolwort, white trillium, ladyfern
mountain hemlock and subalpine fir	4,000 - 6,000'	65 - 110"	mountain hemlock, subalpine fir, lodgepole pine, Alaska-cedar	big huckleberry, ovalleaf huckleberry, Cascade azalea, blueleaf huckleberry, rustyleaf	beargrass, one-sided wintergreen, dwarf blackberry, Sitka valerian, evergreen violet, avalanche fawnlily
alpine	4,000+	60-120		western cassiope, blueleaf huckleberry, red mountainheath, luetkea	Alaskan clubmoss, mountain hairgrass, American bistort, Sitka valerian, showy sedge, feathery mitrewort, American false hellebore, arctic lupine, fireweed, black alpine sedge, alpine willowweed, slender hawkweed, fanleaf cinquefoil, smallflower paintbrush, western pasqueflower

Vegetative Zone	Elevation range (feet)	Average precipitation (inches)	Major tree species	Common shrubs	Herbaceous plants
grand fir	3,500 - 6,500'	25 - 50"	grand fir, ponderosa pine, lodgepole pine, western larch, Douglas-fir	common snowberry, shinyleaf spirea, woods rose, Nootka rose, mallow ninebark, creambush oceanspray	pinegrass, northwestern sedge, elk sedge, broadleaf arnica, kinnikinnick
Douglas-fir	2,000 - 4,500'		Douglas-fir, ponderosa pine, lodgepole pine, western larch	baldhip rose, Oregon boxwood, prickly currant, big huckleberry	Columbia brome, sweetscented bedstraw, starry solomonplume, western meadow-rue, heartleaf arnica, sideflower mitrewort, bigleaf sandwort, white hawkweed, twinflower, trail plant, Piper anemone, Lyall anemone, wood violet, white trillium, queencup beadlily, wild ginger, broadleaf lupine, dwarf blackberry

Vegetative Zone	Elevation range (feet)	Average precipitation (inches)	Major tree species	Common shrubs	Herbaceous plants
ponderosa pine	2,000 - 4,000'	15 - 30"	ponderosa pine, western juniper, quaking aspen, Oregon white oak	Saskatoon serviceberry, chokecherry, black hawthorn, creambush oceanspray, common snowberry, woods rose, Nootka rose, mallow ninebark, shinyleaf spirea, creeping western barberry, Wyeth buckwheat, snow eriogonum, yellow leafless mistletoe	bluebunch wheatgrass, Idaho fescue, Sandberg's bluegrass, western yarrow, western gromwell, yellow salsify, large-flowered brodiaea, beauty cinquefoil, purple-eyed grass, spreading dogbane, arrowleaf balsamroot, sagebrush buttercup, low pussytoes, slender fringecup, littleflower collinsia, miner's lettuce, Japanese brome, cheatgrass brome, narrow-leaved montia, smallflower forgetmenot, vernal draba, autumn willowweed, Nuttall's fescue, little tarweed, pink annual phlox, shining chickweed

Current Resource Management Practices and Policies

DNR Forest Management

In addition to following statutory regulations, management guidance is provided to the department through policies established by the Board of Natural Resources and the Commissioner of Public Lands. The Forest Resource Plan (DNR 1992b) is the major policy document providing direction for management of forested trust lands. The Forest Resource Plan was developed and written by the Department of Natural Resources to guide it in managing 2.1 million acres of state forest land through 2002. The plan does not identify management activities on specific tracts of land (for example, individual timber sales). Rather, it describes the department's general policies and priorities.

The Forest Resource Plan reaffirms the department's commitment to act as a prudent land manager. The department will continue to generate income from state forest land to support schools and other beneficiaries. The policies of the plan also require the department to analyze and, if necessary, modify the impact of its activities on watersheds, wildlife habitat, special ecological features, wetlands, and other natural resources. The plan focuses the department's attention on these resources so that it can make better decisions that accommodate the public's need for school revenue, wood, and healthy forests.

DNR divisions and regions are responsible for carrying out these policies. Many of the policies are translated into operational guidelines for implementation. Regions accomplish planning for, and on-the-ground management of, forest lands in a manner consistent with policy. See Appendix A, p. A2 for summary of Forest Resource Plan policies.

Forest Habitat Characteristics of Three Seral Stages

Seral Stages Defined

Ecological succession can be thought of as a series of progressive changes that a plant community goes through, that culminate in a relatively stable condition. Seral stages are the communities and environmental conditions that replace each other as succession progresses. A seral stage is characterized by a particular range of environmental attributes including plants, moisture, and nutrient regimes, soil conditions, physical structure, and habitat features.

Succession occurs in different ways on different sites. Variations in moisture, temperature and nutrients can result in profound differences in species, structure, and rates of change. In describing an individual seral stage, it's helpful to remember that ecological parameters exist on a continuum, so that a description of a particular seral stage is a generalized snapshot, not a model that will apply in all cases. The duration of each seral stage depends in large part on the longevity of the dominant species, which is able to maintain dominance until senescence (the end of the life cycle).

Different terminologies are used to describe successional change. The systems used by Oliver (1981) and Brown (1985) are roughly parallel to seral stages in that they are tree-growth related, but use artificial systems based on tree diameter as opposed to an ecologically based approach. The seral stages described by Spies and Franklin (1991) are based on major ecosystem processes (such as nutrient cycling, rate of growth, types of vegetation, and soil character) that change as a forest matures.

Table 2 describes a general progression of seral stages for forests in western Washington. Eastern Washington forests are more difficult to describe, due to a more complex history of human intervention including fire suppression, and such human-induced disturbances as grazing, slash burning, and partial cutting, which has had a powerful impact on succession. In addition, succession on the east slope of the Cascades is likely to proceed at a slower rate than that described in the Table 3, due to generally drier and colder growing conditions.

The first, early seral stage begins after a disturbance such as logging or fire.[1] The vegetation that initially invades a site is generally shade-intolerant, nutrient demanding and often relatively short-lived. The canopy structure generally consists of a single tree layer (which may include several species), and an understory of deciduous shrubs and herbs. After some time, the canopy will close to the extent that the light-demanding understory species are shaded out and excluded from the stand. This stage is also known as the "stem exclusion stage" because the stand density inhibits the establishment of new stems, and trees with a competitive advantage will suppress or kill off their less competitive neighbors. (Oliver and Larson 1990). The mid-seral (or understory reinitiation) stage begins when shade tolerant trees and understory species start to establish in the understory. This is the stage that silviculturists recognize as mature forest, where mean annual increment is culminated. The structure of such forests is likely to still consist of one major canopy layer through most of the stage, until gradually gaps form in the canopy and some of the trees in the understory begin to achieve some height. The late seral stage is characterized by multiple canopy layers, large diameter live trees, large snags, and down logs. Trees of all ages exist in the stand, and canopy gaps supply light for a variety of understory species. This stage encompasses most definitions of old growth. It is important to note that old-growth forests are not synonymous with climax forests; a climax forest is dominated by the most shade tolerant tree species that can reproduce on the site, while old-growth forests are defined by structure and are frequently dominated by late seral species.

The Old Growth Definition Task Group (1986) has a definition of old growth that applies to forests in western Washington, and includes the following minimum requirements:

> **Live trees:** Two or more species, with a wide range of age and size. More than eight Douglas-fir trees per acre, either greater than 32 inches dbh or greater than 200 years old.

[1] Brown et al. 1985 state that a temperate stand that has been clearcut and broadcast burned will remain in an "open sapling, pole" stage for 10 to 20 years, in a "closed sapling, pole" stage for 40 to 100 years, in a "large saw-timber" stage for 10 to 120 years, and an "old growth" stage for up to 700 years.

Canopy: Deep and multi-layered.
Snags: Greater than 4 conifer snags per acre, greater than 20 inches dbh and greater than 15 feet tall.
Logs: Greater than 15 tons of logs per acre, including 10 pieces per acre that are greater than 23 inches in diameter and greater than 49 feet long.

Habitat Characteristics

Wildlife species depend on a variety of structural features in the forest for foraging, breeding, shelter, and resting. Some species require all the conditions described by a particular seral stage or stand condition[2] for some or all of their life cycle. Others require only one or two key habitat features (such as nest cavities or deciduous forage), without regard for the type of stand where such features occur. Each species also has its own degree of flexibility as to what type of stand conditions it can utilize; some species are obligate denizens of old-growth or early seral-stand conditions, and others may use several stand conditions throughout their lives.

It is the particular structural features of a stand that make it good or poor habitat for a given wildlife species. Table 3 outlines some of the key habitat features that are generally associated with different seral stages.

Table 2: Comparison of classification systems

Classification system	EARLY herb and shrub	EARLY seral	MID seral	LATE seral
Brown 1985	Grass-forb, shrub, and open sapling-pole conditions	Closed sapling-pole, sawtimber condition	Large sawtimber condition	Old growth
Spies and Franklin 1991	---	Young	Mature	Old growth
Oliver 1981	Stand initiation stage	Stand initiation stage, stem exclusion stage	Understory re-initiation stage	Old growth

[2] Brown (1985) describes several stand conditions that are roughly equivalent to the seral stages described above; Early = open pole-sapling and closed pole-sapling conditions, Mid = large sawtimber condition, Late = old-growth condition.

Table 3: Comparison of Seral Stage Structure and Vegetation

Seral stage	EARLY herb and shrub stage	EARLY seral	MID seral	LATE seral
Age of dominant trees[3]	0 to 30 years	30 to 80 years	80 to 195 years	> 195 years
Characteristic structure	Initially dominated by light and nutrient-demanding herb and shrub species and tree seedlings. Eventually an "open" pole stand condition evolves, with shade-intolerant tree species dominating.	Single-layer canopy, often of shade-intolerant species, usually including hardwoods as well as conifers, deciduous shrubs and forbs in understory. Eventually may develop closed canopy with little understory; some mortality in canopy.	Single-layer canopy with an understory of small shade-tolerant seedlings, saplings and evergreen shrubs. Snags and down logs mostly pre-date current stand. Where stand may appear multi-layered, understory trees are of one age, but achieve different sizes through competition.	Multi-layer canopy of mixed species and mixed ages, including some smaller diameter, shade-tolerant tree species. Understory may include shade-tolerant evergreen shrubs as well as deciduous shrubs and forbs in canopy gaps. Large live trees, large snags, large diameter down logs and canopy gaps are characteristic.

[3] Spies and Franklin 1991

Seral stage	EARLY herb and shrub stage	EARLY seral	MID seral	LATE seral
Habitat features[4]	A mix of coniferous trees and deciduous trees and shrubs provides songbird nesting and foraging areas, and browse for ungulate species. Voles and shrews utilize understories of forbs and grasses for food and shelter. Coyotes and raptors hunt burrowing rodents.	A mix of coniferous trees and deciduous trees and shrubs provide songbird nesting and foraging areas, and browse for ungulate species. Voles and shrews utilize understories of forbs and grasses for food and shelter. Rabbits, mountain beavers and grouse shelter and forage in the understory, and bobcats shelter and feed on rabbits.	Canopy provides thermal cover for many wildlife species, and nesting and foraging areas for some songbirds. Trees provide cones and shelter for squirrels; raptors nest and feed on rodents. Down wood provides habitat for rodents, amphibians, martens, and other species.	Large dead trees provide nesting and denning cavities, and food sources for woodpeckers. Large live trees provide broad nesting platforms; closed portions of stand provide thermal cover; and canopy gaps provide deciduous forage. Down logs provide habitat for amphibians, rodents and other animals, which in turn provide food for forest carnivores such as weasel, marten and fisher.
Plant species characteristic of moist forests[5]	red alder, Douglas-fir, salmonberry, trailing blackberry, fireweed, brackenfern	Douglas-fir, big leaf maple, red alder, salmonberry, brackenfern, trailing blackberry, thimbleberry	western hemlock, Sitka spruce, western redcedar, Douglas-fir, Pacific silver fir, salal, swordfern, Alaska huckleberry, western white anemone	western hemlock, pacific silver fir, Sitka spruce, Douglas-fir, pacific yew, vanilla leaf, three-leaved foamflower, Oregon oxalis, Smith's fairybells

[4] Brown 1985

[5] Bigley and Hull in prep.; Lesher and Henderson, 1989; Franklin and Dyrness, 1973

Seral stage	EARLY herb and shrub stage	EARLY seral	MID seral	LATE seral
Plant species characteristic of dry forests	California hazel, serviceberry, oceanspray, creeping snowberry, kinnickinnick, white hairy hawkweed, bigleaf sandwort, Scouler's hairbell, broadleaf starflower, common mullein, Idaho fescue	Douglas-fir, western hemlock, lodgepole pine, Pacific madrone, prickly currant, oceanspray, baldhip rose, creeping snowberry, trailplant, California hazel, vanillaleaf	Douglas-fir, western hemlock, lodgepole pine, Oregongrape, red huckleberry, salal, bigleaf sandwort	northern twinflower, thin-leaved huckleberry, prince's pine

C1 **APPENDIX C - CALCULATING JUVENILE SURVIVAL RATES AND THE FINITE RATE OF CHANGE OF THE SPOTTED OWL POPULATION ON THE OLYMPIC PENINSULA**

C. Appendix C - Calculating Juvenile Survival Rates and the Finite Rate of Change of the Spotted Owl Population on the Olympic Peninsula

Appendix C

Calculating Juvenile Survival Rates and the Finite Rate of Change of the Spotted Owl Population on the Olympic Peninsula.

Burnham et al. (1994) reported "apparent" survival rates (ϕ) as 0.245 (s.e. = 0.064) for juvenile spotted owls on the Olympic Peninsula, which made it possible to calculate the 95 percent confidence interval around ϕ as 0.116 to 0.374. This was calculated by first solving for the sample size (n) used in estimating ϕ, assuming the standard error was calculated for a binomial population (in which individuals survive or die) as:

$$\text{s.e.} = \sqrt{\phi(1-\phi)/n}$$

to give n = 45, then using tables of t-values to calculate confidence intervals using 2-tailed values for p = 0.05, 44 DF. Burnham et al. (1994) also describe how to correct ϕ for emigration: the "true" survival probability (S) results from adjusting ϕ for the rate at which juveniles emigrate and survive 1 year (E), or

$$S = \phi / (1 - E).$$

They estimated $E = 0.3158$, with a 95 percent confidence interval of 0.2113 to 0.4203, based on 76 juvenile owls that were monitored with radio telemetry and survived 1 year. From these data, then a range of estimates of S can be derived. Substituting the point estimates, low and high values from the 95 percent confidence intervals for ϕ and E into the equation above provides an estimate of $S = 0.3581$, ranging from 0.1471 to 0.6451. That range can then be compared to the value needed to result in a stable Olympic Peninsula sub-population ($S = 0.413$, Burnham et al. 1994 Table 9) for an empirical test of their hypothesis that the Olympic Peninsula sub-population is declining.

The finite rate of population change can be calculated by constructing Leslie matrices using adult and subadult survivorship and fecundities from Burnham et al. (1994) and the estimate and range of S presented above, then solving each for its dominant eigenvalue (Caswell 1989).

D1 **APPENDIX D - METHODS FOR THE EVALUATION OF CONSERVATION ALTERNATIVES FOR SPOTTED OWL ON THE OESF**

D1 **Methods for a General Evaluation of Habitat Capability**

D3 **Methods for Conducting Computer Simulations of Spotted Owl Life Histories**

- Introduction
- Model Description
- Habitat Analysis Module
- Movement Module
- Demographic Module
- Parameterizing the Model
- GIS Data
- Habitat Parameters
- Dispersal Barriers
- Movement Parameters
- Demographic Parameters
- Population Initial Conditions
- Analysis of Alternatives

D13 **Methods for Estimating Incidental Take of Spotted Owls**

Appendix D - Methods for the Evaluation of Conservation Alternatives for Spotted Owl on the OESF

D.

Appendix D

Methods for the Evaluation of Conservation Alternatives for Spotted Owl on the OESF

Three techniques were used to evaluate the alternatives: (1) a general evaluation of the habitat capability of the OESF area that will result, in the near- and long-term, from each alternative and how each can address the threats described in Section 4.2.3.3.1a; (2) computer simulations of spotted owl life histories in response to landscape conditions that are expected to result from each alternative; and, (3) the degree to which each alternative either avoids or allows incidental take (Frederick 1994) of currently known owl sites.

Methods for a General Evaluation of Habitat Capability

Both stand- and landscape-level characteristics of forests are important to their capability as habitat for spotted owls (see Horton in press for a review). Forest stands with a particular structure and composition have been defined as either young- or old-forest spotted owl habitat in western Washington (Hanson et al. 1993). Stands with these characteristics have been otherwise variously classified as small sawtimber, large sawtimber, and old growth (Brown 1985) or young, mature, and old growth (Spies and Franklin 1991). An estimate of the current amount and distribution of forest stands of these types, in the OESF area, has been derived from analysis of Landsat Thematic Mapper satellite imagery (WDFW 1994b, see Map 26 and Table 4). Projections of future amounts and distributions of these stand-types under the alternatives can be based on: (1) the relationships among stand age, structure, and composition; and, (2) succession and harvest patterns under the alternatives, and other assumptions about land use. These estimates of current and likely future landscape conditions can then be used to evaluate the capability of current and likely future landscapes as habitat for spotted owls.

Spotted owls respond to landscape characteristics at the scale of home ranges of pairs, and expand the areas they traverse to encompass sufficient habitat to meet their resource needs (Carey et al. 1992). Holthausen et al. (1994) reported the median home range area from a study of 10 radio-tagged owl pairs on the western Olympic Peninsula as 14,721 acres, and that those ranges encompassed a median area of old-growth and mature forests of 4,579 acres (32 percent of the median range). To assess the capability of current and likely future landscape conditions around the OESF, the density of potential owl habitat (including young- and old-forest habitat, Hanson et al. 1994) at the scale of pair range-sized circles (2.7 miles radius) was calculated using a series of assumptions (described below) about the outcomes of current, proposed, and likely future policies and rules, action alternatives, and natural processes, as well as about the ages at which forest stands take on the characteristics of owl habitat. A threshold density of at least 40 percent

young- and old-forest habitat was used for these analyses because: (1) a broader range of young-forest types were classified as habitat (after Hanson et al. 1993) than have been reported in other studies (e.g., Bart and Forsman 1992; Holthausen et al. 1994) in which lower proportions of landscapes that supported owls were classified as habitat; and, (2) the U.S. Fish and Wildlife Service considers 40 percent habitat (including young-forest types) as the threshold below which incidental take occurs (Frederick 1994). The total area of all ownerships within the OESF that meet or exceed 40 percent potential habitat at the scale of 2.7-mile radius circles is assumed to reflect the capability of the OESF area to support owl pairs, a good basis for comparison among the alternatives.

In order to estimate habitat density, habitat was considered as a binary variable; that is, stands were either potential habitat or they were not. Stands that were classified as small sawtimber, large sawtimber, or old growth by WDFW (1994b) were assumed to be current potential habitat. Habitat capability was also projected 100 years into the future for each of the three alternatives. For projections of habitat capability, stands that were developed under OESF action alternatives (presumably with silvicultural techniques that promoted habitat development) and were older than 50 years were assumed to be habitat. Otherwise young stands were assumed to be managed such that they did not become habitat. It was assumed that landscape-wide habitat proportions for different categories of land ownership, 100 years in the future, would be: (1) 90 percent of the landscape of Olympic National Park and Olympic National Forest, Late-Successional Reserves (USDA and USDI 1994b); (2) 55 percent of the landscape in all (for Alternative 3) or parts (for Alternative 2) of DNR-managed lands in the OESF; (3) 55 percent of the landscape in Olympic National Forest, Adaptive Management Areas (USDA and USDI 1994b); (4) 25 percent of all (for the No Action alternative) or parts (for the Zoned Forest alternative) of DNR-managed lands in the OESF; and, (5) 10 percent of all other lands.

Simple, conservative assumptions were developed, based on the following reasoning, for the proportions of habitat for each distinct combination of land ownership and alternative:

(1) Physical and biotic factors prevent all land area from becoming potential habitat, thus 90 percent was assumed for Olympic National Park and Olympic National Forest Late-Successional Reserves.

(2) Several independent, spatially-explicit projections of potential management scenarios under the Zoned Forest and Unzoned Forest alternatives suggest that potential owl habitat will comprise greater than 55 percent of some (Alternative 2) or all (Alternative 3) DNR-managed landscapes in the OESF (Traub 1995; Martin 1995). Thus, the conservative assumption (less habitat than may actually result) of 55 percent is used.

(3) The mission of the OESF is to learn how to integrate commodity production and ecosystem support, similar to that of the Adaptive Management Areas (USDA and USDI 1994b), thus landscape conditions that are hypothesized to serve this mission in the OESF are assumed for the Olympic National Forest Adaptive Management Areas.

(4) Over the course of 100 years under Alternative 1 (the No Action alternative), potential habitat in current owl circles on DNR-managed lands is assumed to be lost due to natural

disturbances, harvest following shifting or "decertified" owl circles, and other events. It is assumed that management practices will permit no habitat development except as needed to follow current policy for protection of riparian ecosystems. Habitat in these areas is projected to comprise 25 percent of DNR-managed lands in 100 years (approximately the same as the current abundance of potential owl habitat on DNR-managed lands, see Table 4). Areas outside of owl zones under Alternative 2 are assumed to be similarly-managed, thus habitat is projected to comprise 25 percent of them as well.

(5) Owl habitat is projected to comprise 10 percent of other lands in 100 years, approximately the same as their current composition (Table 4).

Four digital maps describing current or projected conditions were constructed with a grid-based GIS (ESRI 1995). The maps of land ownership (DNR 1995d) or land cover (WDFW 1994b) were resampled to 10-acre pixel size (660 feet square). For simplicity, habitat proportions were assumed to be constant within combinations of ownership and alternative. Thus, all pixels within each of those combinations were assigned the habitat proportions described under numbers 1-5 above as their value. A GIS function that accumulated the values of neighboring cells was conducted over a radius of approximately 2.7-miles (22 cells) for each cell in the digital maps. Subsequent calculations assigned each cell a value that was the proportion of the 2.7-mile circle around that cell that was potential habitat. Areas of all ownerships within the OESF that had at least 40 percent potential habitat at the scale of 2.7-mile radius circles were then measured and mapped. This allowed the projected long-term outcomes of all alternatives to be directly compared both against current conditions and against each other.

Methods for Conducting Computer Simulations of Spotted Owl Life Histories

Introduction

Mathematical models and computer simulations have played a significant role in the conservation of the northern spotted owl (Thomas et al. 1990; USDI 1992b, Raphael et al. 1994). In general, the structure and complexity of models are determined by: (1) modeling objectives; (2) knowledge and understanding of the system; and (3) available technology. Over the past 5 years the complexity of spotted owl population models has increased with changes in each of these factors. The intent of early spotted owl population models (Marcot and Holthausen 1987; USDA 1988; Lande 1988; Noon and Biles 1990, Burnham et al. 1994) was to estimate λ, the finite rate of population change. Estimates of λ provided better understanding of population dynamics, and were implicit predictions about the future state of the population. These models examined population dynamics in one dimension -- time. They did not consider other the effects of variables that are best described in spatial dimensions, namely landscape composition and pattern. Evolving conservation objectives, increased understanding, and improved technology have propelled the development of more complex spotted owl models that consider spatially-dependent variables.

Well-constructed models can be valuable tools for developing decisions on conservation plans. They allow knowledge, assumptions, and objectives to be organized and integrated in a logical framework such that their outcomes can be objectively evaluated. For example, a good spotted owl model would predict outcomes based on knowledge of owl ecology, population biology, forest succession, and land cover; assumed relationships between habitat quality and population biology; and assumed changes in landscape characteristics based on objectives for land use.

Alternatives for management of the OESF were analyzed with a recently developed computer model that incorporated both spatial and temporal effects on the spotted owl population. Comparisons among alternatives were based on model predictions of their long-term effects on the size, stability, and distribution of the spotted owl population on the Olympic Peninsula. The outcomes predicted under each alternative were quantified in two ways. Habitat analyses estimated the amount, quality, and distribution of potential habitat. These analyses indicated the relative differences among alternatives in their ability to provide habitat capable of supporting owl pairs, and the geographic distribution of that habitat. The model also predicted the abundance and distribution of paired and unpaired owls over time. These predictions allowed comparisons of the relative effects of each alternative on population size, trends, and distribution. However, it must be emphasized that the strengths of these predictions is in the relative differences among predicted outcomes rather than in the absolute numbers and locations of owls predicted by the model.

Model Description

Schumaker (1995) provides a detailed description of the simulation model. It was written in the C programing language and runs on a SUN Microsystems Workstation™. The simulation model is designed to be used with raster GIS data that represent land cover, and consists of three separate modules that conduct habitat analysis, movement simulation, and demographic simulation. All modules are accessed through windows-style user interfaces and the movement and demographic modules have a fully animated graphical output. Viewing these processes while simulations are ongoing can be useful to the modeler. The habitat analysis module is used to generate a data file that specifies the locations and qualities of hexagon-shaped units of land cover. The resulting data are used in both the movement and demographic modules.

Habitat Analysis Module

GIS data representing the spatial distribution of land cover may contain millions of pixels. Each pixel corresponds to a small patch of earth, and is assigned a category that represents the cover-type which predominates on that patch. To simplify the habitat model, a regular grid of hexagons is intersected with the raster GIS data to obtain a map of hexagonal "sites" that are classified as either suitable or unsuitable. A suitable site is one that has sufficient quality and quantity of habitat to support a resident single or breeding pair, and is also referred to as a "territory."

The construction of the hexagonal habitat map is controlled by the following parameters: the numeric habitat value of each GIS category, a hexagon size, an "expansion"

parameter, and the threshold for territories. The habitat module calculates a score for each site that equals the average habitat value of all pixels contained within it. Hexagons having scores above the threshold are classified as suitable sites. In addition, suitable sites can result when sub-threshold sites "expand" to use habitat from adjacent supra- or sub-threshold sites. However, each unit of habitat may be used by only one site. The expansion parameter may be assigned any real value from 0-6. At its lower limit, no habitat from adjacent sites is used, while at the upper limit a site may include all the habitat available within its six immediate neighbors. Hexagon boundaries and scores do not change as a result of expansion. Expansion simply allows sub-threshold sites with sufficient, nearby, available habitat to be classified as suitable.

Movement Module

The movement module is individual-based, and simulates the dispersal of fledglings and the seasonal wandering of floaters. Movements across the landscape consist of a series of steps taken from one hexagon to one of six neighboring hexagons. The movements of juveniles, floaters, and unpaired territorial individuals are simulated once each year. All juveniles and floaters move from their present site, but unpaired territorial owls make a decision to move based on the habitat quality of their present site. In the simulator, males search for empty suitable sites and females search for single territorial males. Movement decisions are not affected by the presence of other individuals. Owls can move through an occupied territory or reside in an occupied territory as a floater. Owls stop moving when they (1) have found the object of their search; (2) have taken the maximum number of allowable steps; or (3) a decision to stop has been made. No mortality occurs during movement.

The length of a single step is the center-to-center distance between neighboring hexagons, and the path length is the sum of steps. The model is parameterized with a mean path length which is then converted to a stopping probability. Before each step the stopping probability is used to decide whether to stop or to take another step. In addition, the movement model requires specification of the minimum and maximum number of steps allowed. The minimum movement distance is adhered to by juveniles, but is ignored by floaters.

Direction of movement is controlled by interactions among two parameters, "Bias to Quality" and "Autocorrelation." The degree to which owl movements are guided by habitat quality is specified by the "Bias to Quality" parameter. This parameter determines the frequency with which owls move to the neighboring site with the highest habitat quality. If Bias to Quality equals 1, then owls always move to the neighboring site with the highest habitat score, but if this parameter equals zero, then owls never consider the habitat quality of neighboring sites when moving. If bias to quality equals 0.5, then, on average, owls consider the habitat quality of neighboring sites on half of their steps.
If owls do not move to the neighboring hexagon with the highest habitat quality, then the "Autocorrelation" parameter determines the direction of the next step. This parameter determines the linearity of the movement path. When Autocorrelation equals 1, the next step will be in the same direction as the previous step, i.e., straight ahead. When Autocorrelation equals zero, there is an equal probability of moving to any of the neighboring six hexagons. When this parameter equals 0.5 the next step has a higher

probability of veering right or left than moving straight ahead. A true random walk can be obtained by setting both Bias to Quality and Autocorrelation to zero. Increasing Autocorrelation produces a directed random walk, and increasing Bias to Quality has the effect of concentrating the searching effort in areas of superior habitat quality.

Unpaired territorial owls make a decision to leave their present site based on the habitat quality of their present site. A nonlinear function describes the relationship between site fidelity, i.e., the probability of moving, and habitat quality (Figure 1a). Minimum site fidelity occurs on the poorest quality suitable site, and maximum site fidelity occurs on suitable sites that are above a high quality habitat threshold. The shape of this function implies that over some range of high quality habitat, spotted owls are insensitive to differences in habitat quality.

The edges of the habitat map may be made to function as absorbing, reflecting or wrapping boundaries. Individual sites can be made to function as reflecting boundaries in order to prevent movement across large bodies of water, mountain ranges, etc.

Demographic Module

Population demographics were simulated using an individual-based, two-sex, three stage-class model. A key feature of the demography module is its ability to link certain life history parameters -- survivorship, fecundity, and site fidelity -- to habitat quality. An owl surrounded by high quality habitat is less likely to disperse, more likely to survive, and more likely to produce a large brood. The model uses an annual time step with each year broken up into four phases: the movement of floaters and territorial singles, reproduction, movement of juveniles, and survival (Figure 2). The module records a variety of demographic information including the number of owls in each stage class (adults, subadults, and juveniles), the number of pairs, single territorial birds, and floaters. In addition, the model generates an "occupancy map" that can be used to investigate the spatial distribution and frequency of occupancy of sites over time. A built-in time series function allows the model to read new territory maps on a yearly basis, and thus, to simulate landscape change through time.

The simulation model is initialized with only pairs of adult owls being present; other stage classes, floaters, and single territorial birds are generated during the simulation. The model allows the initial owl pairs to be located in a flexible manner. Pairs can be located randomly on suitable sites, on the best suitable sites, or can be placed manually on specific suitable sites. If the initialization is strictly random, then it becomes necessary to determine if these locations should remain fixed across model runs, or whether new initial locations should be picked at the start of each run.

The model is stochastic. Individual-based models are demographically stochastic since the fate of each individual is determined independently. To simplify the interpretation of results, environmental stochasticity of parameters was not incorporated into the simulations.

Survivorship was simulated as a stochastic variable and as a function of site habitat quality. The relationship between survivorship and habitat quality has a linear portion

with survivorship increasing with habitat quality up to a threshold value above which there was no change in survivorship (Figure 1b). For each stage-class, there are minimum and maximum survivorship parameters which, with the survivorship threshold parameter, define a function that relates survival probability to site score. The minimum survivorship occurs in the site with the lowest score. The maximum survivorship occurs in all sites with scores greater than the high quality habitat threshold.

Fecundity was also simulated as a stochastic variable and as a function of site habitat quality. For each stage-class, there are minimum and maximum values for the probability of failing to produce fledglings. These values were used to define a nonlinear function that indirectly relates fecundity to site score (Figure 1c). The maximum probability of a site failing to produce fledglings occurs on the suitable site with the lowest score. The minimum probability or nesting failure occurs on suitable sites that are above a high quality habitat threshold. This function and the observed frequency of brood sizes (Forsman et al. 1984) determine the probability of an owl pair producing zero, one, two, or three fledglings.

Three constants, b_1, b_2, b_3, are the frequency of broods with one, two, and three fledglings respectively, observed for reproductively successful spotted owl pairs. Let $P_{NF}(ss)$ be the nonlinear function that relates nesting failure to site score. Then, the probability of producing a brood of size zero equals $P_{NF}(ss)$, and the probability of producing a brood of size i, P_i, equals $[1-P_{NF}(ss)]\bullet b_i$, where i = 1, 2, or 3. The sum of $P_{NF}(ss)$, P_1, P_2, and P_3 equals one.

Parameterizing the Model

Values for demographic parameters have been estimated for the Olympic Peninsula's spotted owl population (Burnham et al. 1994). The data used to calculate the values were collected across the entire peninsula over a wide range of spotted owl habitat quality, but those values are not expressed as functions of habitat quality. A major difficulty in implementing a model with habitat-dependent parameters is establishing the link between the demographic parameters and the habitat model.

The functions relating survival and fecundity to habitat quality were developed through "parameter tuning." Parameter tuning was also used to develop movement parameters. The population simulator accommodates this process by generating statistics on realized survival rates, fecundity and movement distances. To tune parameters, 100 replicate trials of 50 years using a territory map derived from the reclassified 1990 and 1991 GIS data (as discussed below) were run. This method of parameterization is an iterative process which may be summarized as: (1) select an initial value; (2) run the population simulator; (3) examine the statistics of interest; (4) adjust the parameter value; and (5) repeat the steps (1) through (4) until the desired realized value is obtained. Parameter values are summarized in Table 5.

GIS Data

Habitat maps were constructed from GIS data. GIS data for the northwest portion of the Olympic Peninsula, which includes the entire OESF, were based on 1991 Landsat Thematic Mapper (LTM) imagery (WDFW 1994b). Pixel resolution was 30 meters (98

feet) resampled to 25 meters (82 feet). Supervised classification of the LTM imagery resulted in GIS data with nine categories: old growth, large saw, small saw, pole, sapling, open canopy/mixed conifer, open/nonforested, water, and cloud/cloud shadow (Table 6). GIS data for the remainder of the peninsula were based on 1990 LTM imagery (Green et al. 1993). This GIS data had a different classification scheme. Pixels were classified as late-successional, mid-successional, or early-successional forests, nonforested, water, or clouds. Using aerial photography and historical patterns of timber harvest, those data were reclassified to correspond with the nine categories of the 1991 LTM image. Some forest stands on the eastern and southern peninsula did not match the classification criteria for any of the other categories. For these, a new classification, "mid-seral," was created.

GIS data covering different portions of the peninsula were merged, and an elevation model based on the environmental zones described in Henderson et al. (1989) was used to develop a new category, high elevation forest. Forests above 3,000 feet in the western and southern Olympic Mountains, above 4,000 feet near the middle of the range, and above 4,500 feet in the northeastern portion of the mountain range were reclassified as such. In the model, this forest type has no value as nesting habitat, but can function as dispersal habitat. The complete reclassified GIS data appear in Map 30. The GIS data were assumed to represent the current land cover on the Olympic Peninsula.

Habitat Parameters

The size of hexagons in the model corresponds to the minimum home range of an owl pair. The density of owl pairs in the low-elevation old-growth forests of Olympic National Park is estimated to be 0.32/1,000 acres (Seaman et al. 1994). This density is equivalent to an exclusive home range of 3,088 acres/pair. The Olympic National Park has the highest density of good owl habitat on the Olympic Peninsula. Spotted owl range sizes vary inversely with the density of high quality habitat (Carey et al. 1992). Thus, 3,088 acres/pair was considered to be the minimum home range. The resolution of pixels in the GIS grid restricts the set of hexagon sizes that can be generated by the model. Since the hexagon size closest to 3,088 acres was 3,134 acres, this was used in the model.

The expansion parameter is used to better model the response of owls to landscape composition and pattern. This parameter represents two aspects of owl behavior. As the density of good habitat decreases, owls expand the size of their home ranges and increase the degree of overlap with the ranges of their neighbors (Carey et al. 1992). The expansion parameter represents the maximum amount of neighboring hexagons that may be included in a home range. For 20 owl home ranges studied on the western Olympic Peninsula (Forsman in prep. cited by Holthausen et al. 1994) the median size of home ranges was 14,296 acres. The maximum home range size was 27,308 acres. With a hexagon size of 3,134, the maximum home range that can be modeled is 21,938 acres (a hexagon plus its six neighboring hexagons). In the habitat model, the maximum value was assigned to the expansion parameter value.

Spotted owls demonstrate a marked selection for old-growth stands but their habitat selection becomes increasingly general from nesting to roosting to foraging (reviewed by

Horton in press). Large and small sawtimber stands are sometimes selected and frequently used in proportion to their availability, but other stand types are generally avoided (reviewed by Horton in press). Thus, old growth, large saw, and small saw were assigned values as habitat for the model. In order to define weighted values for those stand types, a habitat utilization index (HUI) was calculated for each. HUI estimates the value of each stand type based on observed ratios of use of stand types, and is defined as:

$$HUI = \frac{\text{mean \% of radio telemetry relocations in habitat type X}}{\text{mean \% of home range in habitat type X}}$$

Using preliminary data from 20 radio-tagged owls from the western Olympic Peninsula (E. D. Forsman, USFS, Corvallis, OR, unpubl. data, 1990), HUI was highest for old growth, lower for small sawtimber, and intermediate for large sawtimber. The ratio of HUIs for two different stand types is a measure of the differential response of owls to those types, and reflects their comparative habitat quality. Those ratios were, $HUI_{OG}/HUI_{LS} = 1.50$ and $HUI_{OG}/ HUI_{SS} = 2.19$. For modeling, old growth was assigned the highest possible habitat value (9) to increase the level of discrimination among site quality (Table 7). Based on the ratios, habitat values of 6 and 4 were assigned to large and small sawtimber respectively (Table 7). No radio-telemetry data were available from owls in the mid-seral stand type from the eastern and southern Olympic Peninsula. It was assigned a weight of 1 (Table 7) based on its structure, composition, and the distribution and abundance of owls in those areas.

The habitat threshold for suitable sites was calculated with the following equation:

$$T = HV_{OG}\, A_{OG} + HV_{LS}\, A_{LS} + HV_{SS}\, A_{SS}$$

where A is the mean proportion of area covered by each stand type within home ranges (E. D. Forsman, USFS, Corvallis, OR, unpubl. data, 1990), and HV is the habitat value of each stand type. This equation uses the mean composition of home ranges and the relative
values of habitat quality for each stand type to derive a threshold habitat value for suitable sites. Using the values in Table 8, T was found to be 5.

Dispersal Barriers

Owls on the Olympic Peninsula were modeled as a closed population. The ocean and inland waterways form natural barriers to the west, north, and east. Poor habitat acts as an effective barrier to the south. In reality, there may be some movement of owls to and from the peninsula, but it is believed to have an insignificant impact on population demographics (e.g., Holthausen et al. 1994). Barriers to dispersal were modeled as reflecting boundaries. Reflecting barriers were also placed in high elevation sites that were more than 75 percent nonforested.

Movement Parameters

The mean number of movement steps was adjusted so that the model reported a mean net dispersal distance as close as possible to 24.2 km, the value observed by Eric Forsman for dispersing juvenile spotted owls on the Olympic Peninsula (E. D. Forsman, USFS, Corvallis, OR, pers. comm., 1995). Forsman's data also specifies minimum and maximum observed net dispersal distances of 8.7 and 58.2 km, respectively. Using β to represent the value assigned to the mean number of dispersal steps, the model parameters specifying the minimum and maximum number of movement steps were set to $8.7/24.2 \bullet \beta$ and $58.2/24.2 \bullet \beta$, respectively. The Auto precorrelation and Bias to Quality parameters were adjusted to obtain the desired mean dispersal distance (24.2 km) (15 miles) while at the same time obtaining a ratio of total to net dispersal distances that fell within the range observed in the field. Forsman (E. D. Forsman, USFS, Corvallis, OR, pers. commun., 1995) suggests the ratio of total to net dispersal distance for the Olympic Peninsula population could be as high as 4. Data cited in Thomas et al. (1990 p. 305) give an estimate of total to net dispersal distance of 1.9. The final values for Autocorrelation and Bias to Quality gave a ratio of total to net dispersal distance of 2.4. Tuning resulted in Bias to Quality of 0.21 and Autocorrelation of 1.0. In effect, as owls move across the landscape they move into the best available habitat on 1 out of every 5 steps, and when not guided by habitat quality owls move in a straight line.

There are no published data from which to directly derive parameters to describe site fidelity. An assumption that related the probability of an unpaired owl dispersing and habitat quality was developed arbitrarily. The relationship has a linear portion over which dispersal probability decreases from 50 percent at the suitable site with the lowest quality habitat up to a threshold site quality value above which unpaired owls did not disperse (Figure 1a).

Demographic Parameters

The parameters for minimum and maximum adult survivorship were chosen to yield a realized adult survivorship approximately equal to that of Burnham et al. (1994) for the Olympic Peninsula -- 0.862 (Table 5). The maximum value of adult survivorship was set to 0.92, the same maximum value used by Holthausen et al. (1994), and the minimum value was adjusted to yield the desired realized value. Subadult survivorship is thought to be lower than adult survivorship, but Burnham et al. (1994) did not detect a statistically significant difference between them. Thus, the minimum and maximum subadult survivorship were set equal to that of adults.

Selecting a value for juvenile survivorship was more problematic because current understanding of juvenile survival rates on the Olympic Peninsula is incomplete. For example, Burnham et al. (1994) estimated a survival rate, uncorrected for emigration, of 0.245 while Holthausen et al. (1994) estimated a 0.612 survival rate, corrected for emigration. But Holthausen et al. (1994) used values of 0.29 and 0.38 in their simulations of the Olympic Peninsula population. Given the range of uncertainty surrounding estimates of juvenile survivorship on the Olympic Peninsula, we chose to simplify this part of the model. Juvenile survivorship was implemented as a constant, i.e., this parameter was not a function of habitat quality, and simulations were run with a wide range of plausible values -- from 0.38 to 0.53.

We assumed a fledgling sex ratio of 50:50 (Noon and Biles 1990; Thomas et al. 1990). The parameters b_1, b_2, b_3 were estimated from the data in Forsman et al. (1984 p. 33-34) and set to 0.36, 0.56, and 0.08, respectively. Juveniles were assumed to be nonreproductive (fecundity = 0). The parameters for minimum and maximum probability of nesting failure, $P_{NF}(ss)$ (Table 5), were chosen to yield a realized fecundity approximately equal to that of Burnham et al. (1994). For the Olympic Peninsula these values were 0.760 and 0.412 fledglings/female for adults and subadults, respectively. The minimum value of adult $P_{NF}(ss)$ was set to 0.465, which is equivalent to a maximum fecundity of 0.92 fledglings per female, the same maximum value used by Holthausen et al. (1994). Again, there were no published estimates of fecundity in high quality habitat, but 0.92 was considered plausible as it represents a pair producing nearly two fledglings every other year. The maximum value of adult $P_{NF}(ss)$ was adjusted to yield the desired realized fecundity. The maximum for subadult $P_{NF}(ss)$ was chosen so that the ratio between the maximum adult and maximum subadult fecundities equaled the ratio between the Burnham et al. (1994) estimates for adult and subadult fecundities.

The nonlinear functions for site fidelity, survivorship, and fecundity (i.e., nesting failure) all reflect thresholds to habitat quality. Above these thresholds, site fidelity, survivorship, and fecundity are constant values. Similar functions were used in other spotted owl population analyses (Raphael et al. 1994; Holthausen et al. 1994). There are no published data which directly describe thresholds to habitat quality, so plausible values were derived for these parameters. The results of Bart and Forsman (1992) indicate that the threshold is greater than 60 percent older forest within 1,000 acres of the nest site, but how much greater is unknown. On the Olympic Peninsula, 2,000-acre circles around locations of paired spotted owls contained 61 percent suitable habitat (Lehmkuhl and Raphael 1993). This value is an average for 59 call-survey locations, and therefore, the "high quality" circles probably contained a proportion of suitable habitat much greater than 61 percent. With these results in mind, we set the high quality habitat threshold equal to 7. This value is equivalent to a site that is approximately three-quarters old-growth forest, or one-third old growth/two-thirds large saw, or any combination of old growth, large saw, and small saw that yields an average value equal to 7. This value may be too high, but choosing a high value was intentional because it provides a conservative estimate of the response of demographic parameters to habitat quality.

Population Initial Conditions

The model allows the user to specify the initial number of breeding pairs and their spatial distribution. The current number of nesting pairs on the Olympic Peninsula is estimated to be between 280 and 320 (Holthausen et al. 1994). The locations of many owl nest sites are known exactly, and reasonable estimates for the spatial distribution of other owl nest sites could be derived, but the complexity of this task was beyond the scope of this analysis. Nesting pairs could have been distributed on randomly selected suitable sites across the peninsula, or assigned to the best 300 suitable sites, but these initial conditions seemed unrealistic.

No reliable estimates for the number of resident single and floater owls are currently available. The inability to specify the initial conditions for these stages presents two problems. First, model results are not useful until the simulated population approaches a

stable distribution of all stages. This stable distribution may not be approached for several decades, and therefore no valid results would be available with which to evaluate conditions in the near future. Second, the model is sensitive to initial conditions, particularly the initial density of individuals. The presence of resident single owls increases the likelihood that a dispersing bird will find a mate, and this affects the population's average fecundity. Also, a population without a pool of adult floaters to replace dead breeders will decline more rapidly than one with such a pool. Under this unrealistic scenario, the simulated population is more likely to become extinct.

To overcome the problems associated with specifying locations of nesting pairs and the initial abundances and distribution of unpaired adults, the initial conditions were established as follows. First, at the beginning of each replicate trial, the Olympic Peninsula was saturated with nesting pairs. That is, an owl pair was assigned to every suitable site (435 sites for the 1994 hexagonal habitat map). Second, 50 replicate trials were run with the parameters in Table 5 and with the hexagonal habitat map held constant. Third, the average trajectory of owl pair abundance was examined to determine the time step, or year, at which the number of pairs was closest to 300. This time step was defined to be 1994. This process was repeated for each value of juvenile survivorship used in the analysis. For example, when juvenile survivorship equaled 0.44, the number of owl pairs declined from 435-300 in 11 years. Year 11 was set to 1994, and all other time dependent parameters or simulator functions (e.g., simulation duration, the landscape time series) were modified accordingly. Using this method to set the initial conditions for unpaired owls in 1994, the average number of floaters ranged from 50-60 and the average number of resident single owls ranged from 25-30.

Analysis of Alternatives

Alternatives 1, 2, and 3 were analyzed. Each alternative was represented by a series of six GIS images of the Olympic Peninsula: the present, and then 20, 40, 60, 80, and 100 years hence. A fourth scenario, a static landscape, in which current land cover remained constant for 100 years was also analyzed for purposes of comparison.

There are four major land ownership groups on the Olympic Peninsula: tribal, private, federal, and DNR. It was assumed that tribal and private lands would continue to be intensively managed for timber production and would remain, on average, in the same condition as present. Thus, for the sake of simplicity, habitat conditions those lands were held constant for analysis of all alternatives. Federal lands consist of three different management designations: Olympic National Park, and the Late-Successional Reserves and Adaptive Management Areas of the Olympic National Forest. Again, for simplicity's sake, the park and Adaptive Management Areas were assumed to remain constant over time for each alternative. It was assumed that the Late-Successional Reserves would develop toward old-growth forest. Changes in the Late-Successional Reserves were projected using a simple model of forest succession (Table 9), and were used for analysis of each alternative.

It was recognized that changes to the distribution, but probably not the abundance of potential habitat would occur over time on DNR-managed lands under the No Action

alternative. However, for the sake of simplicity, habitat conditions on DNR-managed lands were held constant over time for analysis of the No Action alternative.

Schedules of potential forest succession and harvest were developed as the basis for representing each of the OESF action alternatives (Traub 1995). Desired future landscape conditions, representing the constraints or thresholds of each OESF action alternative, were entered into SNAP (Scheduling and Network Analysis Program) (Sessions and Sessions 1994). SNAP applies a heuristic algorithm to identify efficient plans to attain timber harvest targets while heeding all constraints and landscape-level thresholds (Sessions 1994). Two basic pathways were modeled: one employed two commercial thinnings followed by a regeneration harvest at 100 years, this was the basic prescription for upland areas; the other employed 50 percent-volume harvests at 100-year intervals, this prescription was applied in sensitive areas that allowed some harvest (Traub 1995). These pathways were chosen to represent simplistic, modal management regimes envisioned for the OESF and are similar both in concept and intended objectives to the "biodiversity pathway" regimes developed and analyzed by the Washington Landscape Management Project (Carey et al. in press).

SNAP projected changes in forest stand conditions as harvest and succession proceeded over 100-year simulations. Those changes were reported as areas within 10-year interval age classes and within each of the owl management zones or landscape planning units for the Zoned and Unzoned Forest alternative, respectively. Age classes were then converted to land cover categories (Table 9) for modeling owl populations. For all alternatives, stand conditions were modeled separately for the interior-core and exterior riparian buffers, such that it was assumed that the interior-core developed into old-growth and the exterior buffer developed into large sawtimber.

The changes on DNR-managed lands were modeled for each of the approximately 11,000 forest stands identified in DNR's GIS database. For simplicity's sake, those changes were modeled stochastically rather than deterministically. That is, harvests were assigned to stands at random rather than following an actual, predetermined schedule for each stand. Stands were assigned a random integer between 1 and 1,000. Then using the random numbers, stands were assigned cover-types according to the proportion of the total OESF occupied by that type. For example, if SNAP projected that outside of riparian buffers 16.7 percent of the OESF would be small sawtimber, and 20.2 percent would be large sawtimber, then stands with random numbers between 1 and 167 were reclassified as small saw, and stands with random numbers between 168 and 369 were reclassifed as large saw.

Methods for Estimating Incidental Take of Spotted Owls

It is anticipated that during the life of the HCP, some spotted owls may be displaced, and habitat conditions for some individual owls or owl pairs may be degraded by DNR activities in the OESF such that their ranges are temporarily incapable of supporting them. These activities will constitute incidental take of spotted owls as defined by the ESA. The degree to which each alternative either avoids or allows incidental take is another method for comparing those alternatives. The evaluation criteria of the U.S. Fish

and Wildlife Service to estimate the risk of incidental take (Frederick 1994) were used for these analyses. Their criteria are based on maintaining a threshold proportion of habitat in home range-sized circles around known owl sites as defined by WDFW.

Sites where spotted owls have been observed are assigned a status by WDFW staff based on the nature of the observations recorded: pair - observations of two owls behaving as a pair; two birds - observations of two birds not behaving as a pair; single - repeated observations of a single owl suggesting territorial status; unknown - isolated observations that do not suggest territorial status. These sites are the basis for estimates of the potential of the conservation strategy for the OESF to result in incidental take of spotted owls. The simplest estimate is based on the advice of the U.S. Fish and Wildlife Service regarding incidental take (Frederick 1994), i.e., harvest of potential owl habitat within 2.7- mile radius circles around owl site centers in which habitat comprises 40 percent or less land cover. There are two types of situations where this could occur: DNR harvests within 2.7-miles of sites with less than 40 percent habitat, or DNR harvests that reduce sites from 40 percent or more to less than 40 percent habitat.

However, simple estimates of take as described above are likely to overestimate impacts to the persistence and productivity of owls at known sites in and near the OESF because habitat conditions at several of these sites make it unlikely that owls will reside there. Additional data that can be used to refine the simple estimate of take are the habitat conditions around sites and the recent history of observations at sites. These data allow inferences about the likelihood that sites can actually support resident owls and the recent occupancy of sites, and thus, refined estimates of the risk of actually taking owls. Sites that are surrounded by less than 20 percent habitat are significantly less likely to support occupancy than those surrounded by more habitat (Bart and Forsman 1992). Based on the quality and results of owl surveys, additional inferences about occupancy at such sites can be made to arrive at a refined estimate of the number of sites that appear to have the potential to support resident owls, and/or may currently support resident owls, and that should be considered to be at risk for take under the several alternatives. However, after sites have been screened based on these additional data, take would occur as described above.

The locations and status of owl sites are from the WDFW Interagency spotted owl database (July 1995). Additional information on survey locations, timing, and results are from DNR surveys in the OESF between 1987 and 1995 (DNR, Olympic Region, Forks, WA, unpubl. data) and personal communications with biologists from federal agencies (E. D. Forsman, USFS, Corvallis, OR, pers. commun., 1987-1995; D.E. Seaman, National Biological Survey, Olympic National Park, pers. commun, 1987-1995) and private industry (D. Varland, Rayonier, Hoquiam, WA, pers. commun, 1987-1995; W. Buck, Beak Consultants, Kirkland, WA, pers. commun., 1987-1995). An estimate of habitat and land ownership around owl sites was developed using satellite imagery (WDFW 1994b) and digital maps of public land ownership (DNR 1995d). This information was used to classify owl sites for simple and refined estimates of the potential for incidental take under the action alternatives for the OESF.

Table 4: Estimates of forest cover on lands of different ownership in the Olympic Experimental Forest area, July 1991[1]

Landowner	Cover-type	Total Area (ac)	Percent of Area[7]	Percent of Cover-type[8]
Olympic National Park	late seral[2]	216,137	16.5	59.1
	other[4]	16,298	1.2	18.7
	mid-seral[3]	143,857	11.0	16.8
Olympic National Forest	late-seral	66,325	5.0	18.1
	mid-seral	15,434	1.2	17.7
	other	93,294	7.1	10.9
DNR-managed, OESF[5]	late-seral	52,150	4.0	14.3
	mid-seral	20,990	1.6	24.1
	other	197,974	15.1	23.1
Other[6]	late-seral	30,983	2.4	8.4
	mid-seral	34,293	2.6	39.4
	other	421,558	32.1	49.2
Total		1,312,758	100	

[1] Land cover estimated by supervised classification of Landsat Thematic Mapper scenes taken July 1991, (WDFW 1994b). Land ownership estimated from DNR's digital public lands map (DNR 1995d).
[2] Late seral forests = old growth and large-saw cover
[3] Mid-seral forests = small-saw cover
[4] other land cover = pole, sapling, open-canopy/mixed conifer, open areas (clearcuts, high-elevation barrens, towns, etc.), water, cloud/shadow cover
[5] DNR-managed lands proposed as the Olympic Experimental State Forest (OESF)
[6] Other lands include all private ownerships, tribal lands, DNR-managed lands outside the OESF
[7] The area within the cover-type within the ownership class, divided by the total area described
[8] The area within the cover-type within the ownership class, divided by the total area within the cover-type

Table 5: Complete list of model parameters and control variables used in spotted owl simulations

Movement Parameters:	
Minimum Steps	11
Mean Steps	31
Maximum Steps	75
Autocorrelation	1.0
Bias To Site Quality	0.21
Site Fidelity Probability: Min. and Max.	50 100
Demographic Parameters:	
Sex Ratio	50:50
Maximum Brood Size	3 fledglings
Probabilities of Each Brood Size	1=0.36; 2=0.56; 3=0.08
Juvenile Survivorship	0.38, 0.41, 0.44, 0.47, 0.50, 0.53
Subadult Survivorship: Min. and Max.	0.700 0.920
Adult Survivorship: Min. and Max.	0.700 0.920
Juvenile Probability of Nesting Failure: Max. and Min.	1.00 1.00
Subadult Probability of Nesting Failure: Max. and Min.	0.858 0.710
Adult Probability of Nesting Failure: Max. and Min.	0.840 0.465
High Quality Habitat Threshold	7.0
Fit To Site Quality (Linear / Logistic)	Linear
Program Control Variables:	
Number of Runs	50
Number of Years in a Run	variable
Initial Number of Pairs	435
Year to Begin Tracking Occupancy	year 20
Display (On / Off)	Off
Sampling Function (On / Off)	Off
Initialization Method (Random / Weighted / Custom)	Weighted
Initialization Protocol if Random (Re-Randomize / Fixed)	N/A
Boundary Condition (Absorbing / Reflecting / Wrapping)	Reflecting

Table 6: Forest classifications used in GIS data (WDFW 1994b)

Old growth: dominant dbh 30" or greater; usually more than 8 dominant trees/acre; three or more canopy layers with less than complete canopy closure; several snags/acre 20" dbh or greater; several down logs /acre 24" dbh or greater

Large saw: dominant dbh 20-30"; more than 10 dominant trees/acre of this size; codominant trees are 14" dbh or greater; two or three canopy layers more closed than old growth; small snags present with sparse or no large snags; few large down logs

Small saw: dominant dbh 14-20"; one or two canopy layers; small snags or none present; small down dead wood or none present

Pole: dominant dbh 10-14"; one canopy layer; little or no down dead woody debris

Sapling: approximately 2-5" dbh

Open canopy/ mixed conifer: canopy closure less than 60%, any mixture of at least 90% conifers

Open/ nonforested: clearcuts, open sapling stands, pasture, human settlement

Table 7: Landscape parameters and values

Parameter	Value
min. home range size	1,269 ha[1]
home range expansion	6.0
suitable habitat threshold	5.0
Habitat Values:	
old growth	9
large saw	6
small saw	4
mid-seral	1
all other types	0

[1] 3,134 acres

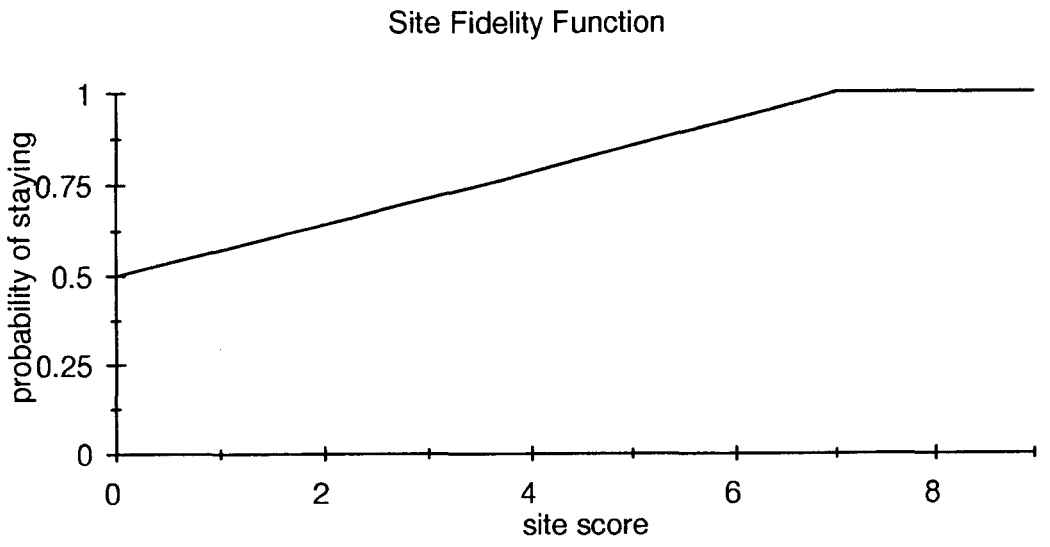
Table 8: Values used in calculation of suitable spotted owl habitat threshold: Habitat Utilization Indices (HUI) rounded to the nearest integer, and the mean proportion of each stand type in Olympic Peninsula home ranges (E. D. Forsman, USFS, Corvallis, OR, unpubl. data, 1990).

Stand Type	Proportion of HUI	Home Range
old growth	9	0.47
large saw	6	0.4
small saw	4	0.13
all others	0	0.36

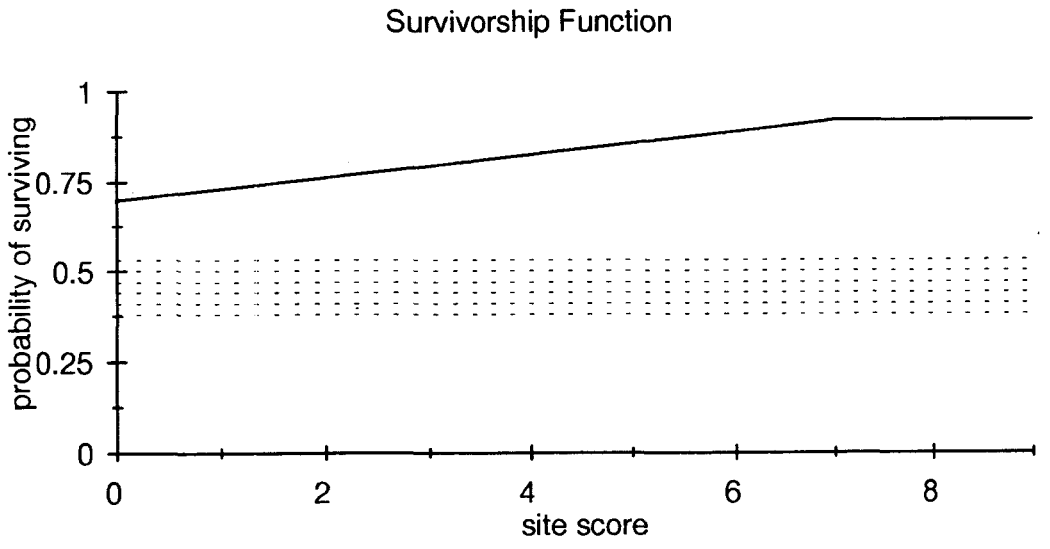
Table 9: Forest growth model used for projecting changes in National Forest Late-Successional Reserves. OG=old growth, LS=large saw, SS=small saw, PO=pole, SP=sapling, CC= clearcut (nonforested).

Stand Age in 1994	Forest Growth Through Time					
	1994	2014	2034	2054	2074	2094
≥200	OG	OG	OG	OG	OG	OG
100-199	LS	LS	LS	OG	OG	OG
50-99	SS	SS	LS	LS	LS	LS
25-49	PO	SS	SS	SS	LS	LS
13-24	SP	PO	SS	SS	SS	LS
≤12	CC	PO	PO	SS	SS	LS

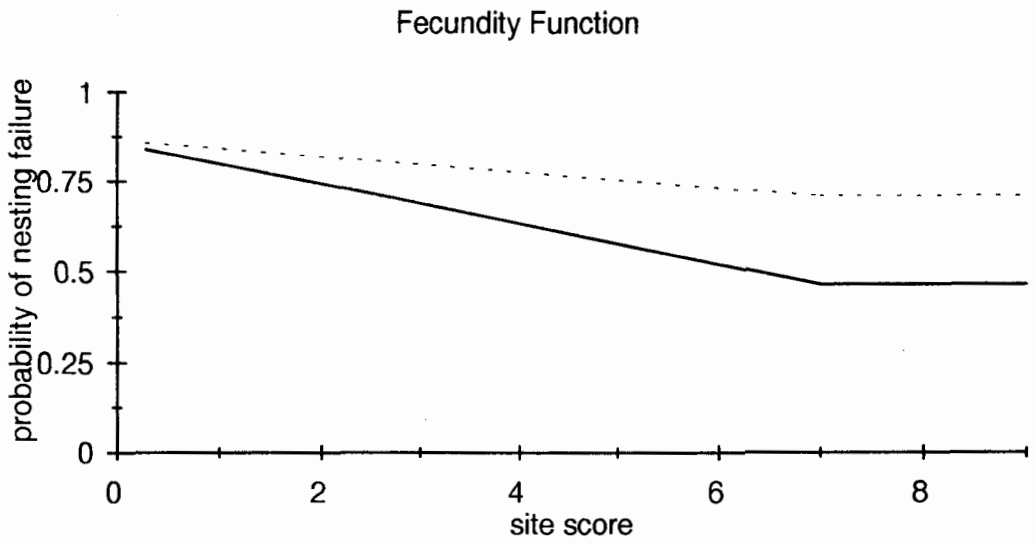
Figures 1a-c: **Nonlinear functions describing the relationship between spotted owl site score (habitat quality) and certain parameters. The breakpoint in the function corresponds to the high quality habitat threshold. For this analysis, a value of 7 was assigned to the high quality habitat threshold.**



1a. Site Fidelity -- expressed as the probability of leaving a suitable site.



1b. Survivorship -- nonlinear function was the same for adults and subadults. Horizontal dashed lines represent the different values of juvenile survivorship used in the analysis.



1c. Fecundity -- expressed as probability of nesting failure. solid line = adult function; dashed line = subadult function. Juvenile fecundity was set to zero, i.e., probability of nesting failure equals one.

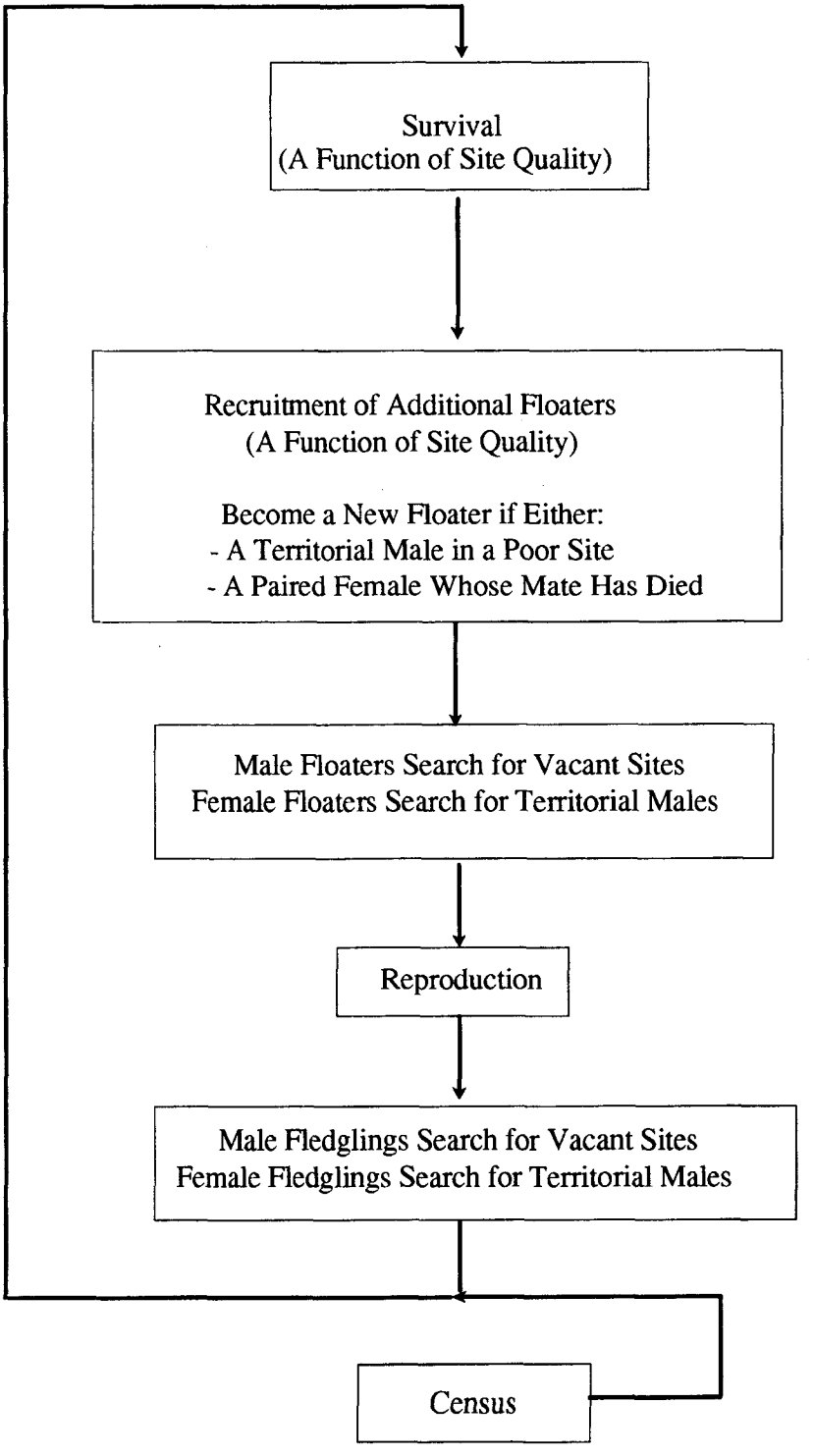



Figure 2: Flow chart showing one yearly cycle through the spotted owl population simulator. Survival, reproduction, and census blocks are parts of the demographic module. Reproduction is also a function of site habitat quality. Other blocks are parts of the movement module.