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Evaluation of Landscape Alternatives for Managing Oak at Tenalquot Prairie, Washington

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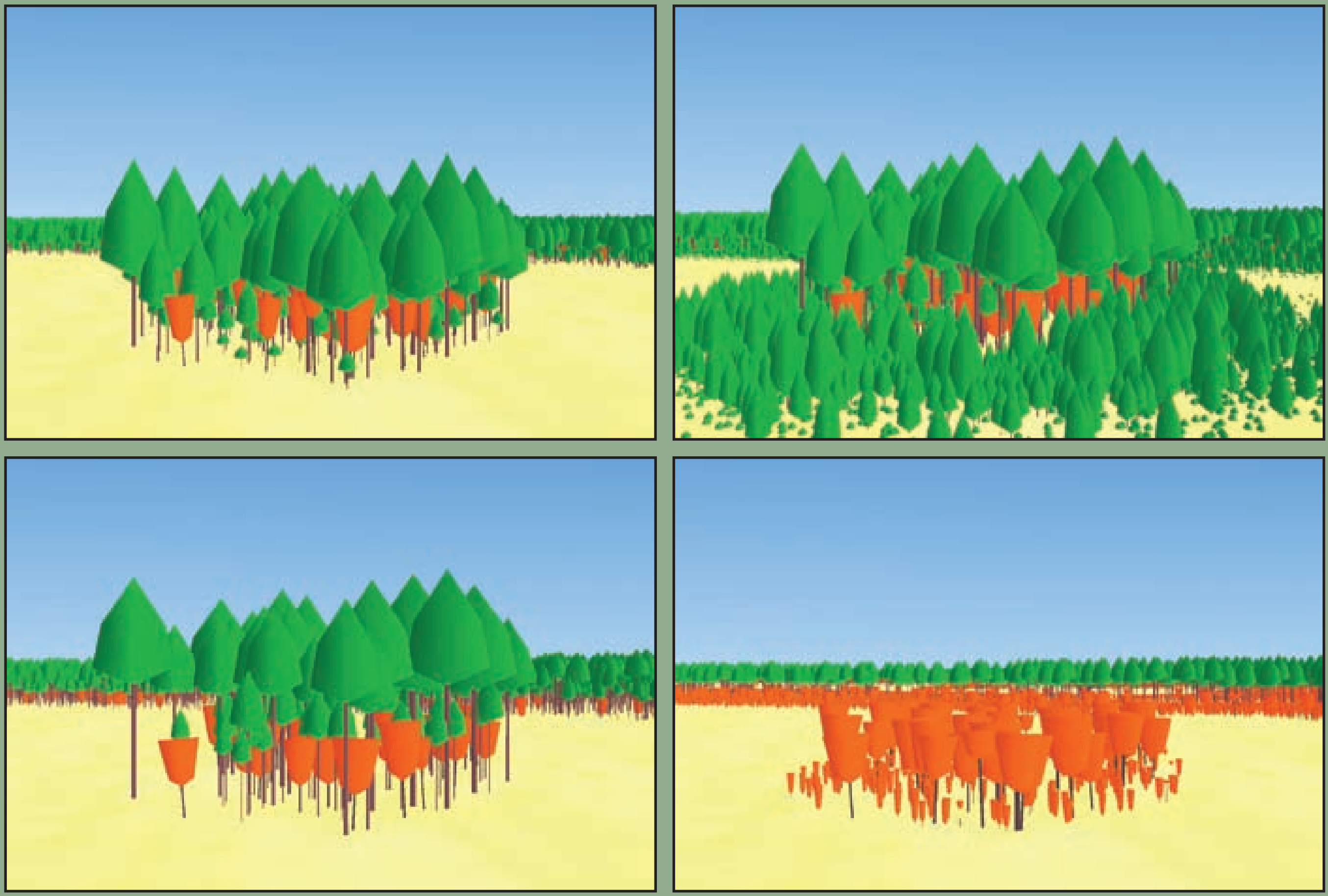

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Abstract

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In recent years, interest has increased in restoring Oregon white oak (*Quercus garryana* Dougl. ex Hook.) and prairie landscapes in the Pacific Northwest, especially where elements of historical plant communities are intact. We evaluated the effect of alternative management scenarios on the extent and condition of Oregon white oak, the extent of prairie, and the harvest and standing volumes of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) within a 2934-ha portion of Fort Lewis, Washington (named the Tenalquot Planning Area for the purpose of the project). A landscape-level analysis of the scenarios was completed using a geographic information system, a forest growth model (ORGANON), and landscape visualization software (EnVision). The scenarios ranged from no active management to restoration of the historical extent of oak and prairies within the planning area. The results indicate that the window of opportunity for restoring oak and prairie landscapes in the Puget Sound lowlands and other regions is small, and aggressive management is needed to maintain or enhance these landscapes. The project demonstrates the value of landscape-level analyses and the use of new technologies for conveying the results of alternative management scenarios.

Keywords: *Quercus garryana,* forest growth models, Puget Sound, Douglas-fir, restoration.

Summary

Landscapes containing Oregon white oak (*Quercus garryana* Dougl. ex Hook.) woodlands, savannas, and associated prairies historically covered a sizeable part of the Pacific Northwest, west of the Cascade Range. However, oak and prairie landscapes are rare today due to urban and agricultural development and succession to conifer forests in the absence of frequent fire. In this study, we evaluated the effect of alternative management scenarios on the extent and condition of the oak resource, the extent of prairie, and the harvest and standing volumes of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) within a 2934-ha portion of Fort Lewis, Washington (named the Tenalquot Planning Area for the purpose of the project). The scenarios were (1) no management activity, (2) management for conifer production, (3) management for conifer production plus oak management in five areas, (4) management for both conifer production and oak restoration, and (5) restoration of the historical extent of prairie and stand densities typical of 1853. A landscape-level analysis of the scenarios was completed using a geographic information system that incorporated inventory data and stand delineation maps, a forest growth model (ORGANON) that was used to project stand and prairie development over a 50-yr period under each scenario, and landscape visualization software (EnVision) that was used to visually compare the scenarios. Without management to prevent Douglas-fir encroachment, 67 percent of the initial prairie was projected to succeed to forest (scenario 1) and pure oak stands were expected to begin to rapidly shift to conifer-oak stands by the end of the projection period (scenarios 1 and 2). The oak resource was improved most by removing conifers from conifer-oak stands to expand the area of pure oak forest and woodlands. Without conifer removal or thinning (scenario 1), 68 percent of oaks in conifer-oak stands were projected to die. Thinning without wholesale conifer removal reduced mortality somewhat to 58 percent (scenario 2). Our results indicate that the window of opportunity for restoring oak and prairie landscapes in the Puget Sound lowlands and other regions is narrow, and more aggressive management is needed within the next several decades. The project demonstrates the value of landscape-level analyses and the use of new technologies for conveying the results of alternative management scenarios on landscape mosaics.

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Introduction

Oak and Prairie Landscapes

Conifer forests dominate much of the natural landscape of the Pacific Northwest west of the Cascade Range. However, Oregon white oak (*Quercus garryana* Dougl. ex Hook.) woodlands, savannas, and associated prairie communities historically covered a sizeable part of the regional landscape, especially in the Willamette Valley of Oregon (Habeck 1962, Sprague and Hansen 1946, Thilenius 1968), the Puget Lowlands of Washington (Crawford and Hall 1997, Foster and Shaff 2003, Thysell and Carey 2001), and eastern Vancouver Island, British Columbia (Gedalof et al. 2006). Oak and prairie landscapes were favored by early Euro-American settlers for raising livestock and farming. Settlements were often centered in these landscapes, and, over time, agricultural conversion and urban development have covered a large part of what had been woodlands, savannas, and prairies. A frequent low-intensity fire regime maintained by Native Americans was a critical factor in sustaining these landscapes (Thilenius 1968). Most sites that supported oaks and prairies can also support Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and other conifers. Frequent fires largely exclude conifers, but allow some oak to become established and persist, in part owing to the ability of oak to sprout following injury (Regan and Agee 2004). In the absence of fire, most of the remaining oak and prairie landscapes are in the process of succeeding to conifer forests. Once established, conifers reduce the diversity and productivity of understory communities (Thysell and Carey 2001). Oregon white oak is shade intolerant and typically attains a maximum height of less than 30 m (Stein 1990). Oaks are frequently overtopped by conifers, resulting in reduced vigor (Devine and Harrington 2006) and death.

The remaining oak and prairie landscapes are important to the biodiversity of the Pacific Northwest. The western grey squirrel (*Sciurus griseus*), which is listed as a state-threatened species by the Washington Department of Fish and Wildlife, is closely associated with Oregon white oak (Bayrakci et al. 2001, Ryan and Carey 1995b), and its decline is linked to the loss of oak habitat. The Mazama pocket gopher (*Thomomys mazama*), streaked horned lark (*Eremophila alpestris strigata*), and the Taylor checkerspot butterfly (*Euphydryas editha taylori*) are prairie-associated species that are being considered for listing as state-threatened species in Washington (Stinson 2005). Plant communities found in oak understories and associated prairies are more diverse than those found under conifers and contain species that cannot persist in the closed-canopy forests that dominate the region (Chappell and Crawford 1997, Thysell and Carey 2001). Oak and prairie landscapes

Plant communities found in oak understories and associated prairies are more diverse than those found under conifers and contain species that cannot persist in the closed-canopy forests that dominate the region.

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are also cultural legacies of Native American land use practices and provide an important link to the presettlement history of the region. In contemporary landscapes, open oak woodlands are far less prone to crown fires than conifer forests and can play an important role in reducing the severity of wildfires, particularly in the wildland-urban interface.

In recent years, there has been increasing interest in restoring some oak and prairie landscapes, especially where elements of the original communities still persist. The Fort Lewis Military Reservation near Tacoma, Washington, has the greatest area of oak stands and prairies in western Washington. These areas have not been greatly influenced by changes in land allocation but have been impacted by plant succession, nonnative species, forest management decisions, and military activities. We selected a 2934-ha portion of Fort Lewis for a theoretical planning exercise to determine the effects that alternative management scenarios would have on the extent of different vegetation communities and, for the oak stands, also determined the effects on tree growth and mortality. We designated the study area the Tenalquot Planning Area, as it encompasses the Tenalquot Prairie, which was a major landscape feature in the area prior to 1850. The study area was selected because it contained a mosaic of prairies, oak woodlands, conifer-oak stands, and pure conifer stands that reflected the range of conditions found in contemporary oak and prairie landscapes. Our analysis of alternative scenarios was done using a landscape approach rather than the traditional approach of modeling the effects of management in one or only a few stands. The landscape approach was more complex and data intensive than an approach focusing on individual stands but allowed us to (1) evaluate actions in a large number of stands with different initial conditions in a spatial context, (2) project the cumulative effect of actions across a large area, and (3) compare the extent of current plant community types with the extent of those types in the past. We brought together several tools to do the landscape analysis: a geographic information system (GIS), a stand-level growth model (ORGANON), and a landscape visualization system (EnVision).

Description of Scenarios

The five scenarios used in this planning exercise were selected to represent general categories of management intent and associated activities to implement that intent. None of them are intended to represent what Fort Lewis will do in the future. The conifer thinning prescription was based on Fort Lewis's current management of conifer stands, and scenario 3 (manage for conifer production and manage for oak in some areas) most closely resembles the overall current management on the fort installation.

Scenario 1: no active management—
This scenario projected landscape development without any type of active management. The purpose of the scenario was to provide a basis from which we can judge the effects of the other scenarios. Under this scenario:

- All existing stands were projected without thinning.
- Douglas-fir was projected to encroach into the prairies in the absence of management to prevent it.
- Douglas-fir was projected to encroach into the pure oak stands.

Scenario 2: management for conifer production (oak not cut)—
The purpose of the scenario was primarily to estimate the benefit of repeated conifer thinning on oak within conifer-oak stands. Under this scenario:

- Pure conifer stands were thinned in yrs 0, 10, 20, 30, and 40 and growth was projected. About 15 percent of the Douglas-fir basal area in trees with d.b.h. (diameter at breast height; 1.37 m above the ground) > 20 cm was thinned in each entry.
- Conifer-oak stands were thinned in the same manner as pure conifer stands. Oaks were not cut during thinning. The only loss of oak was the mortality projected by ORGANON due to competition with conifers and other factors.
- Douglas-fir encroachment into pure oak stands was simulated in the same manner as in scenario 1.
- Mixed-hardwood stands were projected without thinning.
- Prairies were maintained by prescribed burning or other practices.

Scenario 3: manage for conifer production and manage for oak in five areas—
Scenario 3 was a minor modification of the conifer production management regime (scenario 2). The purpose of this scenario was to estimate how relatively small changes in the management regime would impact the oak resource across the planning area. Under this scenario:

- Pure conifer and conifer-oak stands were thinned as in scenario 2.
- Conifers were removed in yr 0 from portions of conifer-oak stands in five areas, which more than doubled the extent of pure oak stands. Oak ingrowth was added to simulate natural regeneration or supplemental planting.
- Pure oak stands were projected without ingrowth. We assumed prescribed fire or some other method would be used to maintain existing oak stands.
- Mixed-hardwood stands were projected without thinning.
- Prairies were maintained by prescribed burning or other practices.

Scenario 4: manage for both conifer production and oak restoration—
The purpose of this scenario was to estimate the degree to which the expanded use of current practices (removal of conifers as part of timber sales, planting) within the current delineation of stands can be used to restore oak. Oak restoration became a management objective equal in importance to conifer production. Under this scenario:

- Pure conifer stands were thinned as in scenario 2.
- Conifers were removed in yr 0 from all conifer-oak stands. Natural regeneration or supplemental planning was simulated as in scenario 3.
- Pure oak stands were projected without ingrowth as in scenario 3.
- Some prairies were converted into oak savannas in yr 0 to connect existing oak and conifer-oak areas. To establish savannas, 25 seedlings/ha were added in yr 0 to simulate planting in prairies.
- Mixed-hardwood stands were projected without thinning.
- Prairies were maintained by prescribed burning or other practices.

Scenario 5: restoration of historical extent of prairie and stand densities typical of 1853—
Scenario 5 represented a major departure from the current management of the planning area in favor of restoring the oak and prairie landscape that existed in the area at the time of Euro-American settlement. This changed the relative importance of various management objectives (e.g., conifer production for timber and other values became much less important) and redrew most stand boundaries to correspond with ecological targets rather than existing stand conditions and management histories. This scenario served as a useful reference for evaluating the magnitude of change in the planning area and the restoration potential of the other scenarios. Under this scenario:

- Pure conifer stands that occur where prairies or savannas existed in 1853 were thinned to 10 trees/ha in yr 0 to restore the savanna. Oak ingrowth (25 stems/ha) was added in some stands to convert them to oak-conifer savannas that connected existing pure oak and conifer-oak stands. We assumed periodic burning or other methods would be used to prevent conifer ingrowth.
- Pure conifer stands that occur where conifer woodlands existed in 1853 were thinned to 25 trees/ha in yr 0. No ingrowth occurred to simulate the effects of periodic burning.
- Conifers were removed in yr 0 from conifer-oak stands to create pure oak stands, oak woodlands, and savannas.

- The remaining pure conifer stands were thinned as in scenario 2.
- Mixed-hardwood stands were projected without thinning.
- Prairies were maintained by prescribed burning or other practices.

Background and Simplifying Assumptions

The Forestry Program at Fort Lewis manages the forested lands on the installation for several objectives, but the primary objective is to support military training. Forest management is also done to provide funds from the timber sale program to support forest management activities at Fort Lewis and other military bases, to support the Fort's strong prescribed burning and fire control organization, to maintain biodiversity, and to participate in the natural resource community in the region. As part of the Department of Defense, Fort Lewis is not subject to state regulations but is restricted by its own internal rules and regulations and also by those that apply to all lands; for example, it consults with the U.S. Fish and Wildlife Service to ensure that planned activities are in compliance with the Endangered Species Act. The Northwest Forest Plan in 1992 designated Fort Lewis as critical habitat to provide connectivity between northern spotted owl (*Strix occidentalis caurina)* populations in the Cascade Range and the Olympic Peninsula (Regan and Agee 2004, USFWS 1992). Fort Lewis manages coniferous forests to promote the development of old-forest structure that would increase dispersal habitat for the northern spotted owl. Fort Lewis has been certified under the Forest Stewardship Council program, and some activities proposed under the scenarios may not be consistent with the certification contract. For the purposes of the scenarios, however, we assumed that the proposed activities could be implemented regardless of whether they would be likely to occur under various constraints. Other practical considerations, such as how large of an area could be manipulated in a given year, were not considered in formulating the scenario, but would likely impact their implementation. Additional simplifying assumptions were:

1. ORGANON accurately projected the growth of trees in all stand types (conifer and oak, natural or planted), and edge effects (which ORGANON does not consider, as it is a stand-level model) did not impact adjacent stands.
2. Douglas-fir would rapidly encroach into pure oak stands without management to prevent it. Douglas-fir encroachment was simulated by a surge of ingrowth in yr 5 (100 seedlings/ha) and yr 10 (657 seedlings/ha). We assumed that very little regeneration would be greater than 1.37 m (the minimum tree height in ORGANON) in yr 5, and much more regeneration would reach that height by yr 10.

3. Abundant natural oak regeneration would establish following conifer removal in conifer-oak stands or oak would be planted if natural regeneration failed. Oak ingrowth, which grows more slowly than Douglas-fir, was added in the former conifer-oak stands in yr 10 (150 seedlings/ha) and yr 15 (300 seedlings/ha).
4. Douglas-fir would encroach into the contemporary prairies without active management such as prescribed fires. We assumed future encroachment rates would be similar to those in the past century. The calculation of encroachment rates is described in the methods section.
5. Timber sales would continue to be an option for the Fort Lewis Forestry Program and it would be economically feasible to cut all trees that our scenarios called for.
6. Prescribed burning would continue to be an option (or some other method of reducing or eliminating regeneration of woody plants in prairies would be available). We assumed that prescribed burning could be used in all locations desired; in reality, however, there would be areas close to the boundary of the installation, other sensitive areas, and public roads that cross the installation that would not be treated.
7. There are some in-holdings (land owned by others) within the Tenalquot Planning Area. We ignored the ownership of these lands and treated them as though they were managed by Fort Lewis.

Methods

Study Area

The Tenalquot Planning Area covers 2934 ha in the southwestern part of the Fort Lewis military reservation (fig. 1). Fort Lewis falls within the Puget Trough, a lowland region surrounding Puget Sound that is characterized by sandy and gravely soils that were deposited as glacial drift and alluvium (Kruckeberg 1995, Stinson 2005, USDA NRCS 2006). Fort Lewis is in the northern portion of the range of Oregon white oak, which is the only oak native to Washington. The dominant soils in the planning area are Spanaway gravelly sandy loam (51 percent of the area) and Everett gravelly sandy loam (32 percent of the area) (USDA NRCS 2006). Although oaks and prairies were maintained by Native Americans burning vegetation on several different soil types, the gravelly, well-drained soils in the planning area are typical of those that supported widespread prairies, savannas, and oak woodlands as these droughty soils were already less favorable for the establishment of conifers (Kruckeberg 1995). The entire area was primarily a mosaic of prairies and

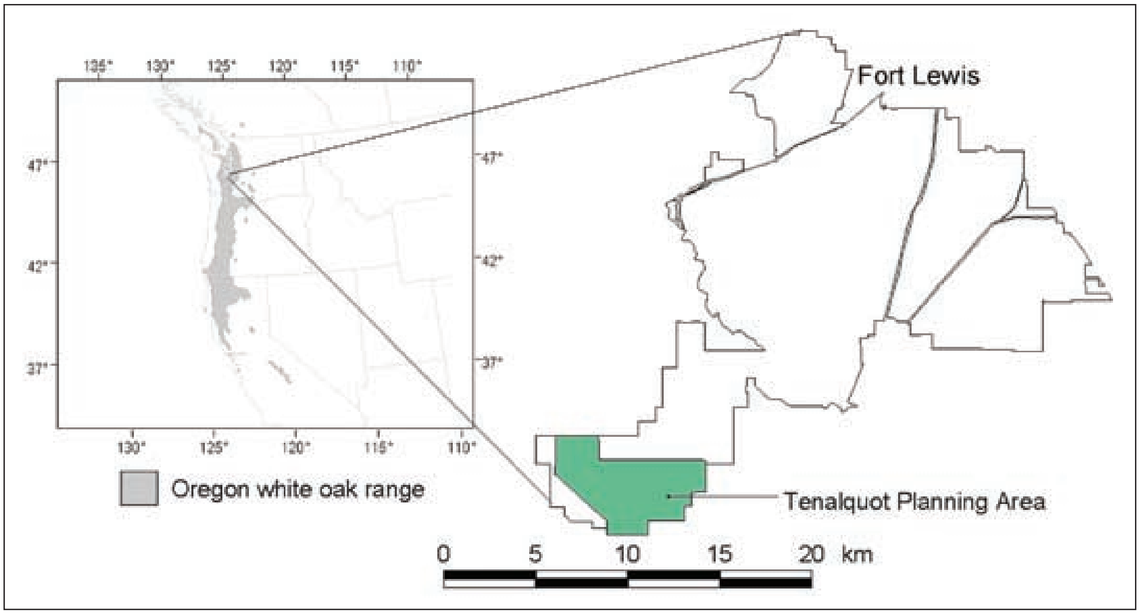

Figure 1—The location of Fort Lewis within the range of Oregon white oak (left) and the location of the Tenalquot Planning Area within Fort Lewis (right).

savannas at the time of Euro-American settlement. U.S. Geological Survey maps labeled the area the Tenalquot Prairie; "Tenalquot" is reportedly an Anglicization of the Nisqually name for the area that means "best yet" (Palmer and Stevenson 1992). Three large fragments of the original Tenalquot Prairie are presently known as Upper and Lower Weir Prairies in the southeast corner of the planning area, and Johnson Prairie near the center. Two unnamed prairie areas in the northwest portion of the planning area were named the Pipeline and North Spurgeon Prairies for the purpose of this project.

Stand Delineation and Typing

Fort Lewis has developed land classification maps that delineate areas of water, wetlands, prairies, forests, and other land types. Forest areas are subdivided into stands, which are areas that are similar in tree age, site quality, and species composition. Stand boundary maps developed by the Fort Lewis Forestry Program were modified prior to modeling to better reflect the actual occurrence of oak on the landscape. A current Fort Lewis stand boundary GIS layer (which did not contain any stands designated as oak or conifer-oak) was used as a starting point for delineating new stand boundaries. A regional map of oak woodlands developed by the Washington Department of Natural Resources Natural Heritage Program (Chappell et al. 2003) was used to identify major areas of oak occurrence. Field reconnaissance was then undertaken to refine oak stand boundaries, determine the compositions of stands containing oak, and identify and map oak stands that had not been mapped previously. Pure oak and conifer-oak stands were then added to the Fort Lewis stand boundary GIS layer by partitioning and combining portions of existing stands. The original Fort Lewis stand boundary map had 71 forested stands (excluding prairies, wetlands, and other nonforested areas). The new GIS layer that we created to better represent initial conditions in the planning area had 192 forested stands. The new stand boundary map included 106 oak-conifer stands and 15 pure oak stands.

Stand boundaries were further modified for the various scenarios. For example, new stands were created when existing oak or conifer-oak stands were expanded into neighboring stands or prairie areas under scenarios 3, 4, and 5. The greatest change in stand boundaries occurred under scenario 5, where much of the planning area was converted into oak and conifer savannas. Fort Lewis provided a digitized map of the extent of prairies and savannas created from surveyors' notes from 1853. The map was used to delineate savanna areas with the additional objective of preserving and linking existing oak stands in a prairie-savanna-woodland mosaic.

The rate of conifer encroachment under no active management (scenario 1) was estimated using some simplifying assumptions. We assumed that the rate of encroachment over the projection period would be similar to the encroachment rate over the last century. The best historical estimate of the area of prairie in the planning area is the 1853 map. Approximately 1151 ha of prairie occurred in the planning area when it was surveyed in 1853. In 2000, there was approximately 430 ha of prairie within the 1853 prairie extent (a loss of more than 60 percent). We assumed that encroachment was minimal prior to 1900 based on the ages of trees within stands that now occupy former prairies (most are < 100 yr old) (Foster and Shaff 2003). This delay in colonization may have been due to livestock grazing or burning by early settlers. An encroachment rate of 7.2 ha/yr (based on the loss of 721 ha over the past 100 yr) was used for the 50-yr projection period. We assumed that future Douglas-fir encroachment would occur along the prairie margins; in reality, encroachment is patchy and more complex. In the first and second decades of the projection, a rate of encroachments of 20 m per decade was used to model the loss of about 72 ha of prairie per decade. In the third, fourth, and fifth decades, the encroachment rate was increased to 40 m per decade to compensate for the shrinking perimeters of the prairies. Encroachment was modeled in two phases, with 100 Douglas-fir seedlings/ha added at the beginning of the decade and 675 seedling/ha added at the end of the decade.

Stand Data

Information on the initial condition of the individual stands within the planning area was needed for the landscape-level projections. Data from Fort Lewis's continuous forest inventory (CFI) and data collected by the Olympia Forestry Sciences Laboratory (OFSL) were used to construct tree lists that represented the initial condition of each stand. Tree lists are summaries of stand densities and compositions and include the following information: species, d.b.h., crown ratio (the proportion of the stem length with live foliage), tree height, and expansion factor (the trees per hectare represented by each observed tree). Data from Fort Lewis CFI plots were used to develop tree lists for conifer and mixed-hardwood stands. However, information on oak was not available from the CFI plots. Although oak is the predominant tree species in some areas, it is relatively uncommon across Fort Lewis as a whole, and the network of CFI plots was not dense enough to reliably sample rare species. More detailed data were collected by the OFSL to develop tree lists for oak and conifer-oak stands. Plots were measured in the pure oak and conifer-oak stands that were identified in the stand delineation process. Information from one oak-conifer stand in the southeast part of the planning areas was previously collected as part of a study examining experimental oak release from conifer competition (Devine and Harrington 2006). Additional plots were measured on the edges of prairies, roads, and oak kettles (geological depressions that contain or are ringed by oaks) to more accurately characterize these areas.

Stand ages for non-oak stands were assigned using a GIS stand layer supplied by Fort Lewis. Age estimates ranged from < 5 yr to 104 yr. Site index (a measure of site productivity) was estimated from digitized soil survey maps (USDA NRCS 2006). Site-index estimates ranged from 32 to 40 m at 50 yr; these estimates were generally consistent with, or somewhat lower than, the site-index values supplied by Fort Lewis for some stands. Estimates of site index from the soil survey were used for all stands because they provided a more complete and consistent coverage of the planning area.

Stand Projections

ORGANON, a forest-growth model, was used to project the stands that made up the planning area under each scenario for a 50-yr period. ORGANON projects the growth and mortality of most major northwestern tree species in 5-yr steps (Hann 2006). The model requires the following information on each stand to start a projection: site index, stand age, and a tree list. The output from the model is a new tree list. Differences between the input and output tree lists reflect tree growth and mortality. ORGANON projects the growth of stands individually; the stands that make up the planning area landscape were each projected separately and then the results for a scenario were combined across stands. Stand treatments such as thinnings and conifer removal were simulated using ORGANON's stand treatment menu. Regeneration is not directly modeled in ORGANON, but users may add ingrowth to simulate natural regeneration or planting. The ORGANON equations to project the development of Oregon white oak were recently revised using a large data set that included trees from Fort Lewis (Gould et al. 2008). Initial stand conditions and ORGANON projections were summarized using three metrics: mean d.b.h. (cm), number of stems (trees/ha), and mean basal area (m^2/ha). Basal area is a measure of stand density that takes both tree size and number of stems into account. It is calculated by converting diameter to cross-section area at breast height (imagine cutting a thin wood "cookie" at breast height and measuring its area on one side) and summing the cross-section areas for an average hectare. Detailed summaries of the projections are shown in the appendix.

Landscape Visualizations

EnVision, a landscape visualization program developed by the Pacific Northwest Research Station (Wilson and McGaughey 2000), was used to create images of the planning area landscape under each scenario. EnVision displays trees on a three-dimensional landscape that is created using a digital elevation model. We used a LiDAR[1]-derived digital elevation model of the planning area (Puget Sound Lidar Consortium 2007) that was simplified by resampling on a 4- by 4-m grid. Surface textures for prairies and wetlands were developed using samples from aerial photos. EnVision displays images as they would be seen from user-defined viewpoints. Viewpoints are specified by the three-dimensional location and focus direction of the virtual camera that captures the image. In this case, viewpoint locations were selected to highlight changes in oak areas over time and between scenarios. Oaks were displayed with orange crowns to increase the contrast between vegetation types; orange was selected as being somewhat similar to the fall foliage of oak.

Tree lists and GIS polygons representing the modified stands were used to populate stands for EnVision. As a default, EnVision randomly assigns tree locations whenever a new landscape is visualized. We chose to create user-defined tree coordinates for the initial landscape so that tree locations could be maintained between scenarios and over the projection period. Tree dimensions (d.b.h., height, live-crown ratio) were updated based on ORGANON projections, and trees were

[1] LiDAR (light detection and ranging) is a remote sensing technology that has been used to map terrain and vegetation (Reutebuch et al. 2005).

eliminated according to projected mortality or stand treatments (e.g., conifer removal). New tree locations were added for ingrowth and then maintained for the duration of the projections. Some oaks were clumped and others were located individually to simulate their natural distribution within the stands.

Results

Initial Landscape and Treatments

In the initial landscape, pure oak and conifer-oak stands occurred mostly along the prairie margins (fig. 2). The size range of pure oak stands was from 0.1 to 11.1 ha and the range of conifer-oak stands was from 0.1 to 65.7 ha. The largest pure oak stand occurred in the southeast quadrant of the planning area between Upper and Lower Weir Prairies. Additional pure oak and conifer-oak stands with large oak components occurred nearby along the southeast border of the planning area. A second group of pure oak and conifer-oak stands occurred near the center of the

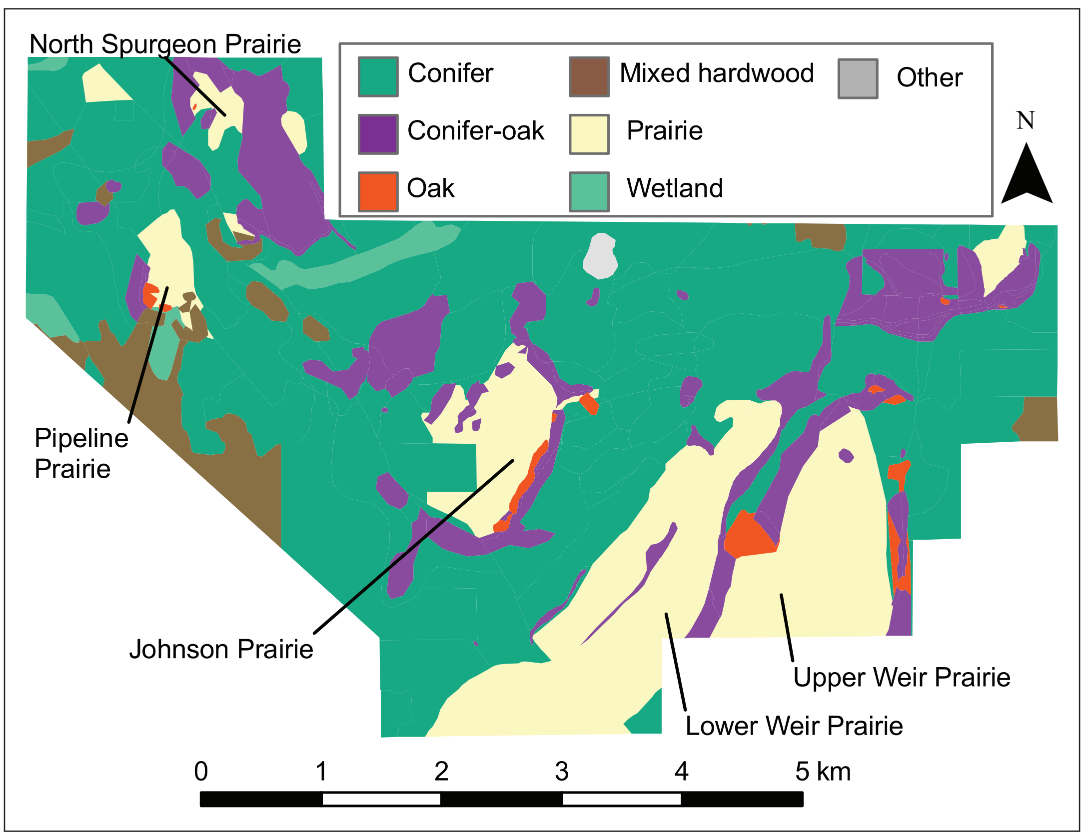

Figure 2—Forest types and prairie extent in the Tenalquot Planning Area at the beginning of the projection period. Forest types remained unchanged in scenarios 1 and 2; however, some prairie areas were invaded by conifers in scenario 1. The rectangular area extending into the west side of Johnson Prairie is the boundary of an area that is not currently owned by Fort Lewis.

planning area along the margins of Johnson Prairie. Several conifer-oak stands with small oak components occurred in the northeast and northwest portions of the planning area. Smaller conifer-oak kettles (0.1 to 0.3 ha) were embedded within the predominant pure conifer forest type. The size range of pure conifer stands was from 0.4 to 118.4 ha. The initial forest types were unchanged in scenarios 1 and 2, but some stands were converted between forest types in the other scenarios.

The initial stand compositions differed greatly between forest types (table 1). Pure oak stands included primarily Oregon white oak with a small component of Pacific madrone (*Arbutus menziesii* Pursh). Oregon white oak was, on average, a relatively minor component of conifer-oak stands, but the mean diameter of oak was about equal in both stand types. Douglas-fir was the dominant species in both the conifer and conifer-oak types by a large margin. Red alder (*Alnus rubra* Bong.) was the dominant species in the mixed-hardwood stands. Bigleaf maple (*Acer macrophyllum* Pursh.) was the second-most-important species in the conifer-oak, conifer, and mixed-hardwood stands.

Under scenario 1, all of the initially forested area within the planning area was projected as under no management (table 2). All growth projections were carried out without any harvests. Conifer thinning was carried out over most of the forested area (excluding pure oak and mixed-hardwoods stands) under scenario 2. Under scenario 3, 2.4 percent of the forest area was converted from conifer-oak to pure oak stands through conifer removal. The release of oak in conifer-oak stands more than doubled the area of pure oak stands. Under scenario 4, conifer removal was conducted in all conifer-oak stands and was extended in some cases into pure conifer stands to connect oak stands with prairies. The forested area was also increased by 0.5 percent by planting oaks in prairies. Conifer thinning was still the dominant management approach under scenario 4. The most complex management approach was simulated in scenario 5 to restore the prairie-savanna landscape. About one-half of the initial forested area was converted into oak, conifer, and oak-conifer woodlands and savannas. The remaining forested area (42.8 percent) remained under conifer thinning.

Existing pure oak stands were expanded in five areas in scenario 3 by removing conifers in adjacent conifer-oak stands (fig. 3). Three of the conifer-removal treatment areas were located along Upper and Lower Weir Prairies in the southeast quadrant of the planning area. The net effect of these treatments was to greatly increase the area of pure oak stands adjacent to the prairies. Similarly, conifer removal in conifer-oak and pure conifer stands on the eastern margin of Johnson Prairie expanded the area of pure oak and increased the connectivity between the

Table 1—Initial stand compositions by forest type

Type	Species	Basal area	Density	Mean diameter at breast height
		m²/ha	*Trees/ha*	*cm*
Pure oak	Oregon white oak	19.8	472.3	20.9
	Pacific madrone	0.1	1.3	23.8
	All	19.9	473.6	20.9
Conifer-oak	Douglas-fir	27.3	175.7	37.0
	Bigleaf maple	3.1	19.8	38.1
	Oregon white oak	2.0	36.6	22.0
	Red alder	0.3	3.5	31.0
	Quaking aspen	< 0.1	< 1.1	14.8
	Ponderosa pine	< 0.1	< 0.1	104.0
	Western redcedar	< 0.1	< 0.1	83.3
	All	32.7	236.6	35.0
Conifer	Douglas-fir	28.2	244.9	29.0
	Bigleaf maple	3.4	32.2	34.5
	Red alder	0.7	10.3	28.4
	Western hemlock	0.3	3.7	33.0
	Ponderosa pine	0.2	1.3	38.4
	Western redcedar	< 0.1	0.6	19.8
	Quaking aspen	< 0.1	0.6	16.3
	Bitter cherry	< 0.1	0.2	22.6
	All	32.9	293.8	29.6
Mixed hardwood	Red alder	38.7	303.6	39.2
	Bigleaf maple	4.8	33.9	39.1
	Quaking aspen	0.8	10.6	27.8
	Douglas-fir	0.7	10.9	23.6
	All	45.0	358.9	38.4

Table 2—Management activities and their extent under the five scenarios

Management	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	Percentage of initially forested area				
Conifer thinning	0	92.1	89.7	73.4	42.8
Convert conifer-oak to oak woodland or savanna (conifer removal)	0	0	2.4	17.4	17.4
Maintain pure oak	0	0	1.4	1.4	1.4
Convert pure conifer to oak-conifer woodland/savanna or oak savanna (conifer removal + oak planting)	0	0	0	0.8	20.0
Convert pure conifer to conifer woodland/savanna (conifer removal)	0	0	0	0	11.7
Convert prairie to oak savanna (oak planting)	0	0	0	0.5	0
No management	100.0	7.9	6.5	6.5	6.5

oak stands and prairie. A small pure oak stand was also enlarged on the margin of Pipeline Prairie.

Extensive conversion of conifer-oak to pure oak stands in scenario 4 greatly increased the area of pure oak stands bordering the major prairie areas (fig. 4). Conifer removal and oak planting were done in stands in the northeast planning area that were classified as conifer-oak stands but also had very low initial oak densities. Oak plantings were conducted to create an oak savanna to link two pure oak stands, which were created by removing conifers from conifer-oak stands, on the southwest margin of Johnson Prairie. Oak plantings were also done in south Lower Weir prairie to establish a new oak savanna and in east Johnson Prairie to link two oak release stands with a pure oak stand.

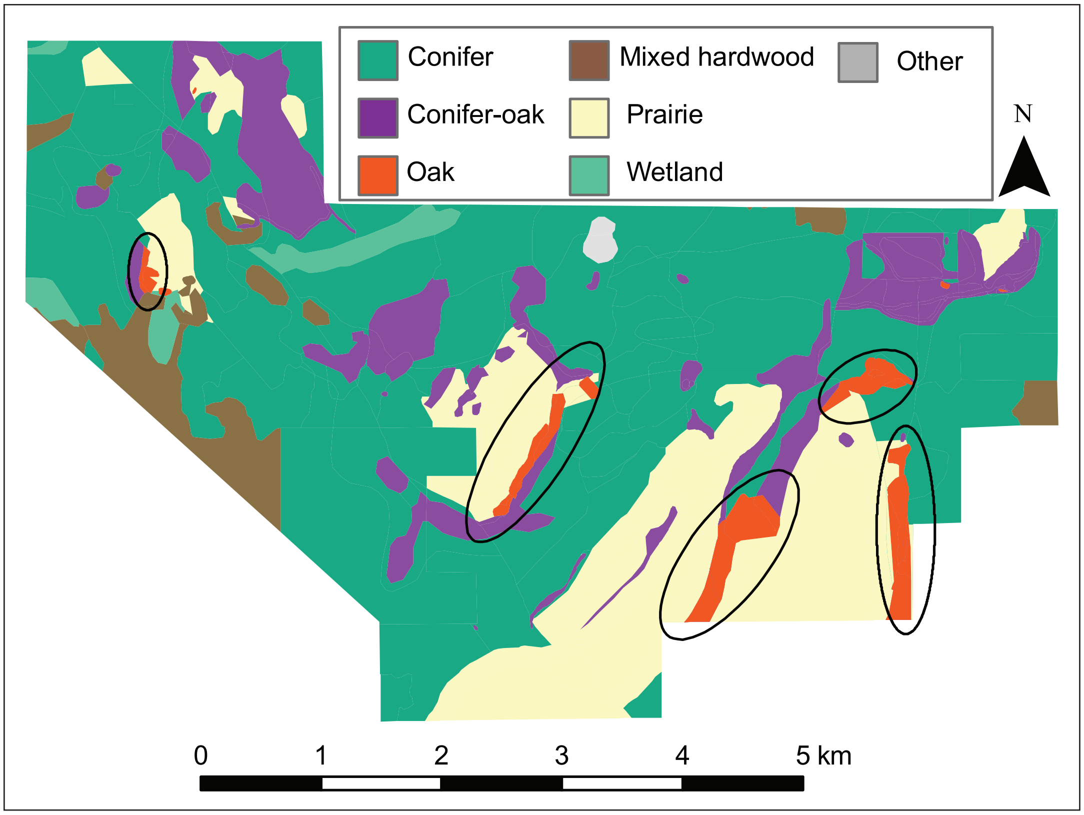

Figure 3—Tenalquot Planning Area showing five areas managed for oak under scenario 3 (black circles). Conifer removal in conifer-oak stands resulted in expanded pure oak stands.

Treated areas under scenario 5 generally followed the extent of the 1853 Tenalquot Prairie, but boundaries were modified or shifted to take advantage of existing conditions (fig. 5). For example, the 1853 Tenalquot Prairie was discontinuous between Johnson and Pipeline Prairies, but the prairies were connected by a narrow oak savanna under scenario 5. A large continuous area of conifer-oak savanna was created by conifer removal and oak planting in pure conifer stands, conifer removal in conifer-oak stands, and the maintenance of existing pure oak stands. As a result, the major extant prairie areas were connected by savannas and oak stands to create a continuous area with little or no forest canopy across much of the planning area. An oak woodland island was created north of Lower Weir Prairie by removing conifers and planting oak in an area that was historically a forested patch within the prairie.

Projections in Pure Oak and Conifer-Oak Stands

ORGANON was used to project how the individual stands of the Tenlaquot Planning Area would develop under each of the five scenarios. Detailed results of the ORGANON projections are given in the appendix. This study was most concerned

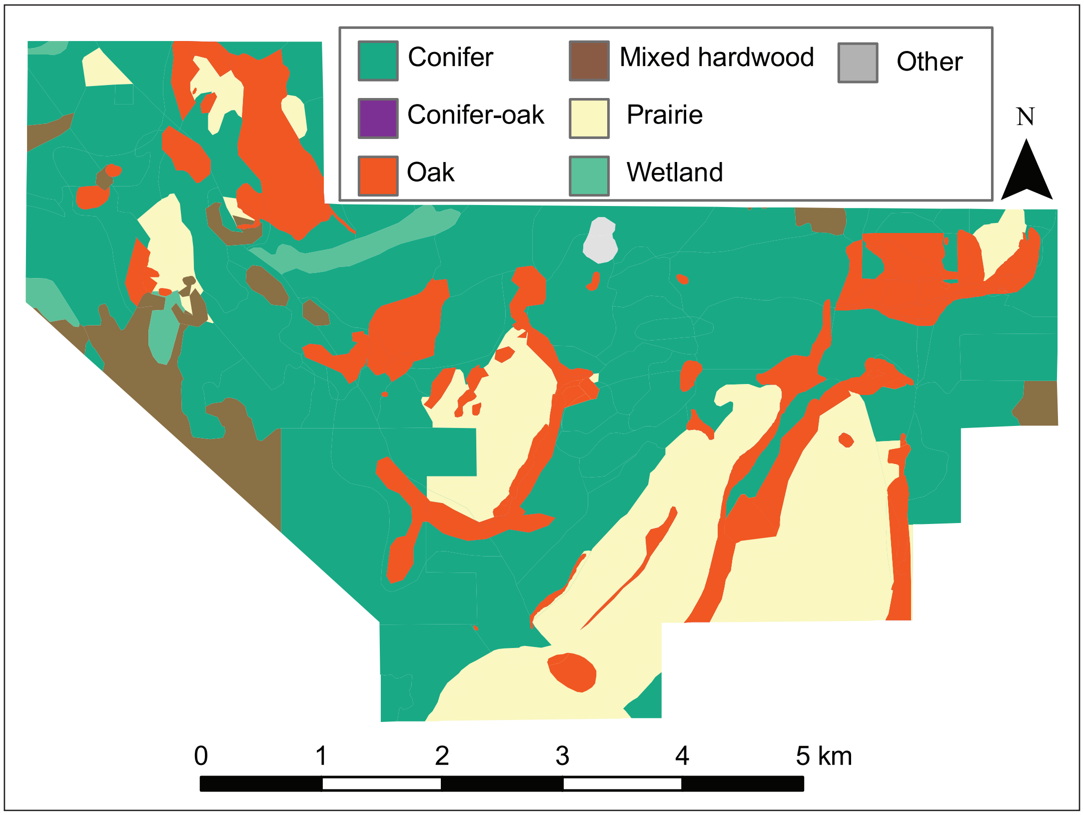

Figure 4—Tenalquot Planning Area under scenario 4. All conifer-oak stands were converted into pure oak stands (orange) through conifer removal.

with the development of pure oak and conifer-oak stands because the condition of these stands determines the condition of the oak resources across the landscape. Two management alternatives were projected for pure-oak stands: (1) no management with conifer encroachment (scenarios 1 and 2) and (2) management such as prescribed burning to prevent conifer encroachment (scenarios 3, 4, and 5) (fig. 6). Encroaching Douglas-fir were added in yr 5 and yr 10 but were projected to remain considerably smaller than the oak by yr 20; however, by the end of the projection period (yr 50), the Douglas-fir were approximately as tall as the oak. The effect of Douglas-fir encroachment on the growth and survival of oak was minor owing to its slow early growth. The growth of oak averaged across all pure oak stands was only slightly higher without Douglas-fir encroachment than with encroachment. However, in the final period of the projection (yr 40 to yr 50), the basal area of encroaching Douglas-fir increased by about 70 percent, and the oaks began to grow more slowly with encroachment than without. Thus, Douglas-fir encroachment had little effect on oak growth and survival over the projection period, but it greatly changed the appearance and future growth trajectory of pure oak stands. Conditions were created where Douglas-fir would soon overtop oak and become

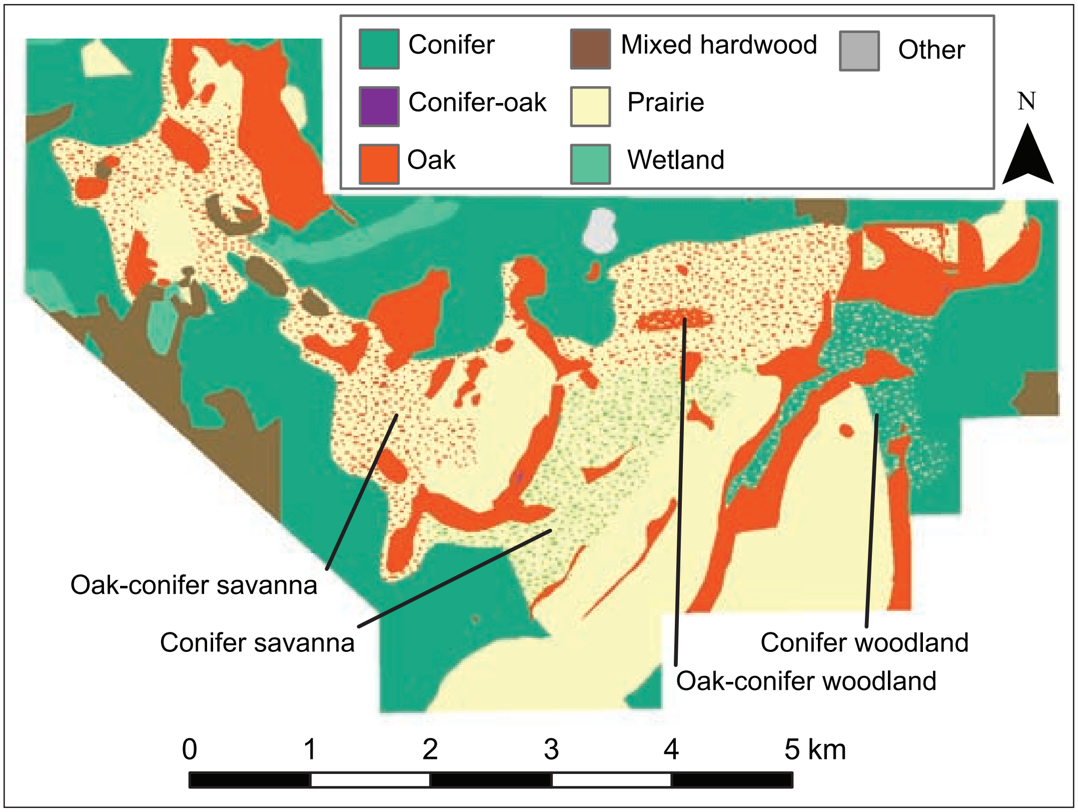

Figure 5—Tenalquot Planning Area with the implementation of scenario 5, which restored the extent of prairies and oak and conifer savannas present in 1853.

the dominant species. Pure oak stands would then resemble those that were initially classified as conifer-oak stands.

Three management alternatives were projected in conifer-oak stands: (1) no management, (2) periodic thinning of conifers and (3) complete conifer removal (fig. 7). The effect of the different management alternatives depended, in part, on the initial condition of each stand. Without any management, oak mortality was generally predicted to be very high. About two-thirds of the oak within all conifer-oak stands were projected to die over the 50-yr projection period, and individual stands were projected to lose between 20 and 100 percent of their oak. Oak mortality was also projected to be high with periodic conifer thinning (58 percent mortality in all stands, range of individual stands = 18 to 90 percent). Surviving oaks were projected to grow slowly with or without conifer thinning. The basal area of oak in all conifer-oak stands was projected to decrease by 33 percent without conifer thinning (range of individual stands = 100 percent decrease to 22 percent decrease) and it was projected to decrease by 8 percent with thinning (range of individual stands = 61 percent decrease to 58 percent increase). Under complete

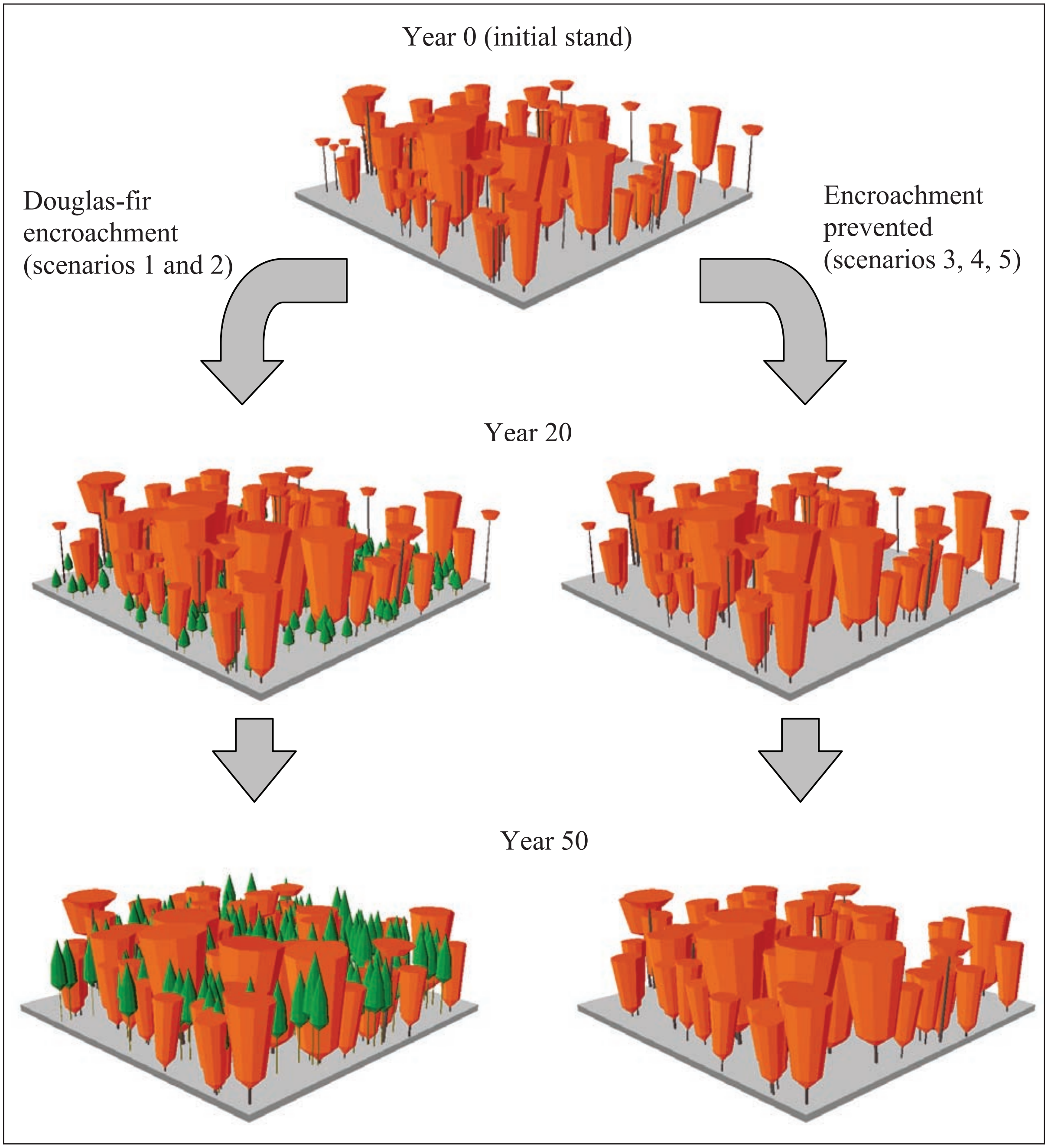

Figure 6—Projections of management alternatives in pure oak stands. The images show a 0.4-ha area from a representative stand within the Tenalquot Planning Area. Pure oak stands were projected with Douglas-fir encroachment (left) and with management to prevent encroachment (right). Douglas-fir encroachment had little effect on oak growth and survival over the 50-yr projection period; however, it created conditions where Douglas-fir would become dominant in later decades.

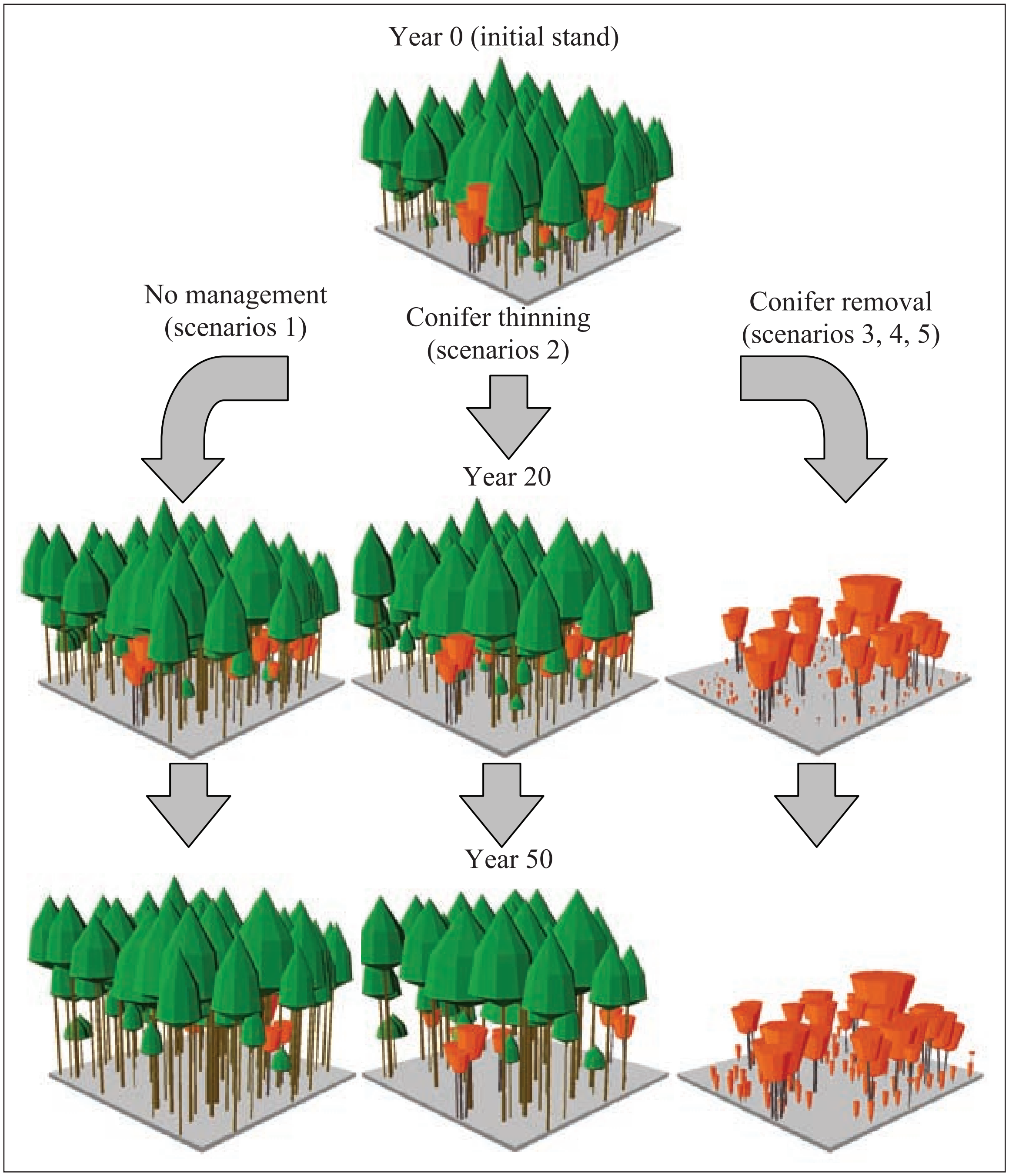

Figure 7—Projections of management alternatives in oak-conifer stands. The images show a 0.4-ha area from a representative stand within the Tenalquot Planning Area. Stands were projected without any management (left), with periodic conifer thinning (center), and complete conifer removal (right). Oak mortality was high under no management and periodic conifer thinning. Conifer removal reduced mortality and increased growth considerably.

conifer removal, the mortality of existing oak in all stands was reduced to only 20 percent over the 50-yr projection period (range of individual stands = 3 to 71 percent). Oak basal area increased by more than 100 percent (range of individual stands = 2 percent decrease to 200 percent increase) and the mean diameter of oak increased nearly 80 percent (range of individual stands = 27 to 160 percent increase). Oak regeneration was added following conifer removal and most of the regeneration was projected to survive. The density of oak (including regeneration) following conifer removal in all conifer-oak stands was projected to increase from 37 trees/ha at the beginning of the projection period to about 340 trees/ha.

Landscape Projections

The ORGANON projections for individual stands were combined to create landscape-level projections and visualizations for each of the management scenarios. There was little difference between scenarios in the growth and survival of oak in pure oak stands; therefore, the condition of the oak resource was largely determined by the management of conifer-oak stands and, for scenario 5, the conversion of pure conifer stands to oak-conifer savannas. Under scenario 1, where conifer-oak stands were not thinned, the basal area of oak across the landscape declined by about 6 percent and the number of stems declined by nearly 60 percent. Thinning conifer-oak stands under scenario 2 reduced mortality slightly and allowed surviving oaks to grow enough to produce a slight increase in oak basal area (8 percent) across the landscape. Under scenario 3, about 13 percent of the area in conifer-oak forest was converted to pure oak through conifer removal. Oak basal area increased by about 25 percent across the landscape. Mortality of established oaks remained high (about 50 percent), but oak regeneration in the former conifer-oak stands was nearly equal to oak mortality across the landscape.

Conifer removal occurred in all conifer-oak stands under scenarios 4 and 5, and a sizeable area of pure conifer forest was converted to oak-conifer savanna under scenario 5. Oak basal area increased by about 110 percent across the landscape under scenario 4 and 130 percent under scenario 5. The mortality of existing oak was reduced to about 33 percent across the landscape, and oak regeneration and planting in former pure conifer stands resulted in a fourfold increase in the number of oaks under both scenarios.

The area of forest with at least 4 m^2/ha of oak basal area was calculated over projection period for the five scenarios. This threshold was used to distinguish stands that were projected to have a relatively large oak component and meet the minimum oak basal area suggested by Ryan and Carey (1995a) for suitable western grey squirrel habitat. Under scenario 1, the area with high oak basal area decreased by about 65 percent from 143 to 50 ha. Smaller decreases were projected under scenarios 2 and 3 (22 and 9 percent, respectively). Conifer removal under scenario 3 allowed oak in some stands to grow enough to reach the threshold for high oak basal area, whereas other stands that did not have conifer removal fell below the threshold because of oak mortality. Widespread conifer removal under scenarios 4 and 5 prevented stands that were initially above the threshold from falling below it. The growth of released oak under these scenarios also shifted some stands above the threshold, resulting in an 80-percent increase in the number of hectares with high oak basal area.

The standing and cumulative harvest volumes of Douglas-fir were summarized to evaluate the relative effects of the scenarios on the extent of Douglas-fir and the potential timber production in the planning area. A net increase in the standing volume of Douglas-fir was projected under all scenarios except scenario 5. Without management (scenario 1), the volume of Douglas-fir was expected to increase by about 150 percent, partially owing to the encroachment of Douglas-fir into the prairies. Approximately two-thirds of the initial area of prairie was projected to be occupied by Douglas-fir under scenario 1. The conversion of some conifer-oak stands to pure oak (scenario 3) had a very small impact on standing volume compared to conifer thinning only (scenario 2). Despite the widespread conifer removal in scenario 4, the standing volume of Douglas-fir increased by about 5 percent over the projection period owing to growth in pure conifer stands. The standing volume of Douglas-fir decreased by about 30 percent under scenario 5 owing to the conversion of both conifer-oak and pure conifer stands to savannas and woodlands. Although a much greater volume of Douglas-fir was harvested in scenario 5 over the first decade of the projection, total harvest volumes over the 50-yr period were remarkably similar (0.65 to 0.69 million m^3) in the four scenarios where timber was harvested.

Visualizations of Alternative Landscapes

The landscape visualizations integrated the spatial information from the revised stand map and the ORGANON projections of individual stands to illustrate the condition of the planning area under each scenario. Six viewpoints were selected to highlight areas that were managed differently under the scenarios. The viewpoints show (1) pure oak and oak-conifer stands on the margins of Upper Weir Prairie (fig. 8), (2) the forested area within the historical Tenalquot Prairie between Lower Weir and Johnson Prairies (fig. 9), (3) the eastern margin of Johnson Prairie (fig. 10), (4) a landscape view of the northeast potion of the planning area (fig. 11), (5) a similar view of the northwest portion of the planning area (fig. 12), and (6) a closer view

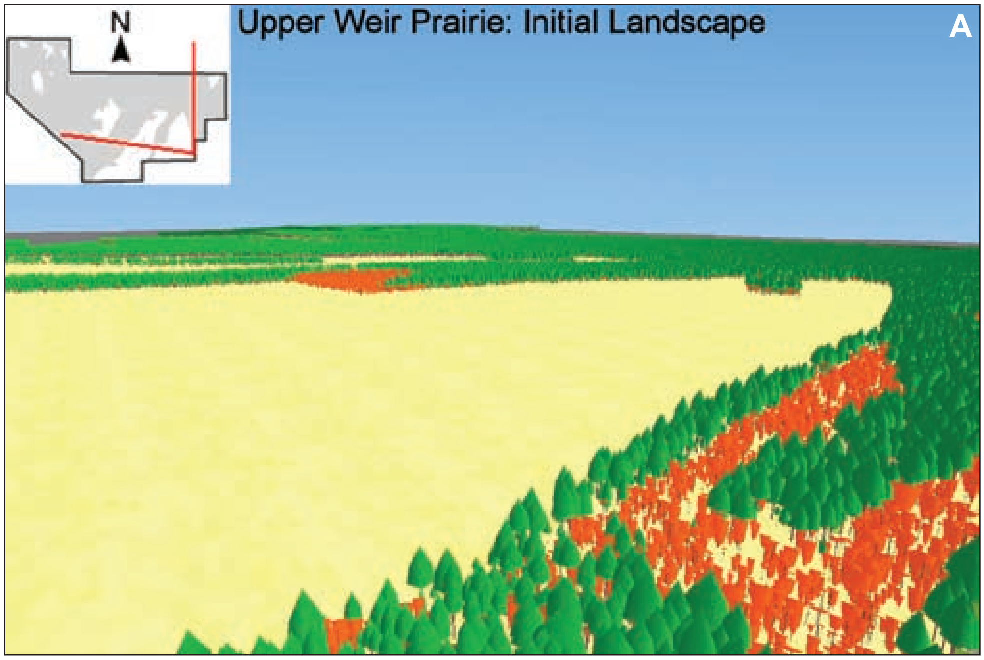

Figure 8A—Initial landscape as seen from Upper Weir Prairie looking northwest (see inset map). Upper and Lower Weir Prairies were the largest remnants of the original Tenalquot Prairie. Multiple pure oak and conifer-oak stands occupied the prairie margins in the initial landscape. The two prairies were divided by a narrow band of forest containing small pure oak, conifer-oak, and pure conifer stands located on a slope that descends from Upper Weir Prairie to Lower Weir Prairie (background).

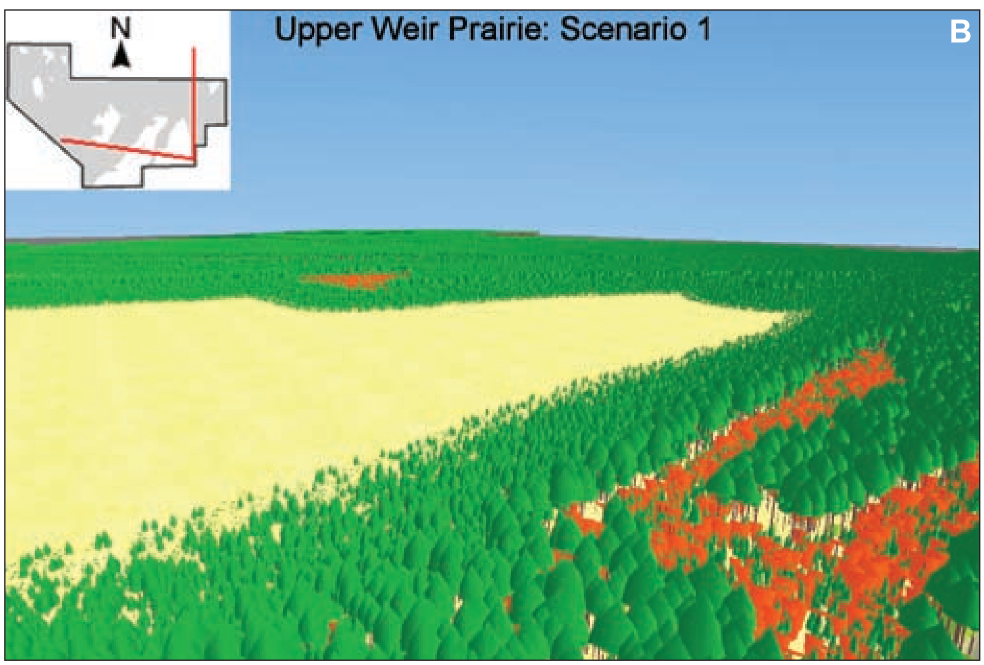

Figure 8B—Viewpoint from Upper Weir Prairie under scenario 1. Without active management to maintain the existing prairie, Douglas-fir was projected to encroach into the prairies and significantly reduce their extent. In all, 67 percent of the landscape that was initially classified as prairie became occupied by Douglas-fir under scenario 1. The pure oak stands that had been located at or near the prairie margins were surrounded by conifers, which reduced the continuity between the oaks and prairie and likely increased conifer competition on the edges of the oak stands. The thin strip of forest that separated Upper and Lower Weir Prairies was greatly expanded, and the northern portion of Lower Weir Prairie became completely forested. Douglas-fir encroachment within the pure oak stands (e.g., right foreground) changed their appearance and created conditions where Douglas-fir would soon become the dominant species in these stands.

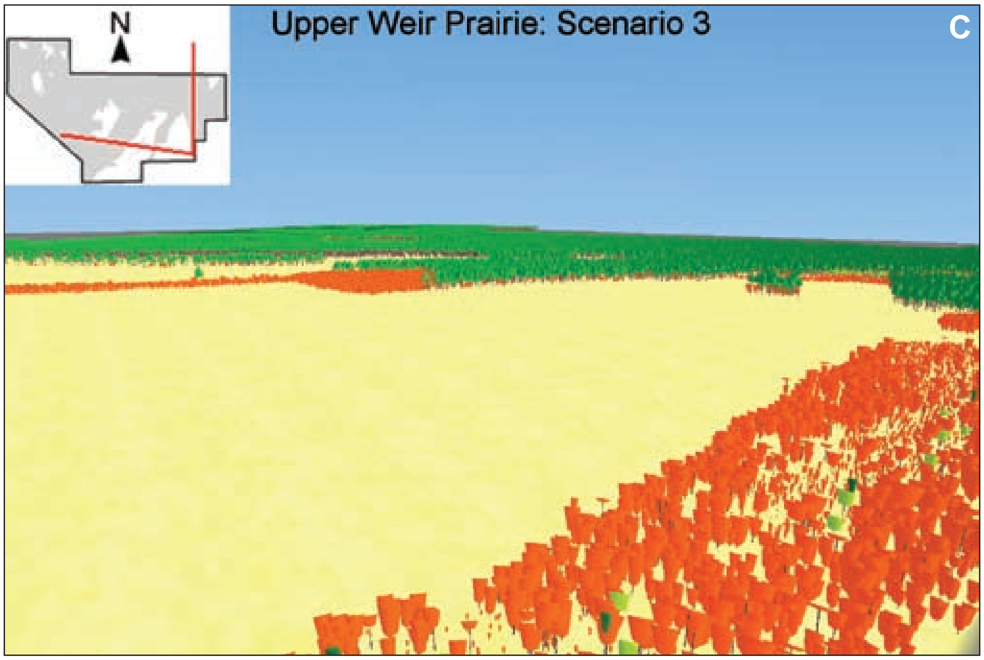

Figure 8C—Viewpoint from Upper Weir Prairie under scenario 3. The conifer-oak stands that surrounded Upper Weir Prairie provided many opportunities for oak restoration. Three of the five conifer-oak stands that were selected for conifer removal under scenario 3 occurred along the margins of Upper Weir Prairie. Existing pure oak stands on the west (background) and east (foreground) margins of the prairie were expanded by conifer removal. Conifer removal was followed by the establishment of a new cohort of oak to produce relatively dense oak stands. The removal of large conifers in the forested strip between Upper and Lower Weir Prairies increased the visibility between the prairie areas. The increased continuity between the oak stands and prairies suggests that prescribed fire or other methods could be used to maintain these areas as a single management unit.

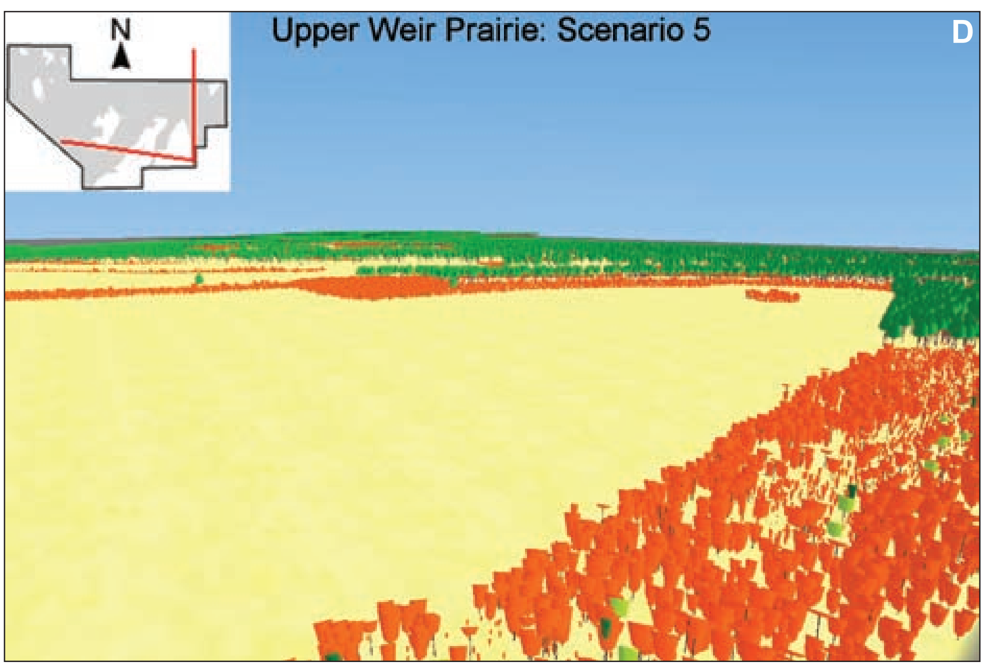

Figure 8D—Viewpoint from Upper Weir Prairie under scenario 5. All conifers were removed from conifer-oak stands under scenarios 4 and 5; therefore, the landscape from this viewpoint was nearly identical under both scenarios. The potential for oak restoration near Upper Weir Prairie was fully realized under these scenarios. The extensive conifer-oak stands and existing pure oak stands provided the opportunity to make oak the most prominent tree species in the area. The only remaining conifers on the prairie margin occupy a small area to the northeast (center right). Upper and Lower Weir Prairies were joined by a narrow pure oak stand, and additional oak stands are visible in Lower Weir Prairie.

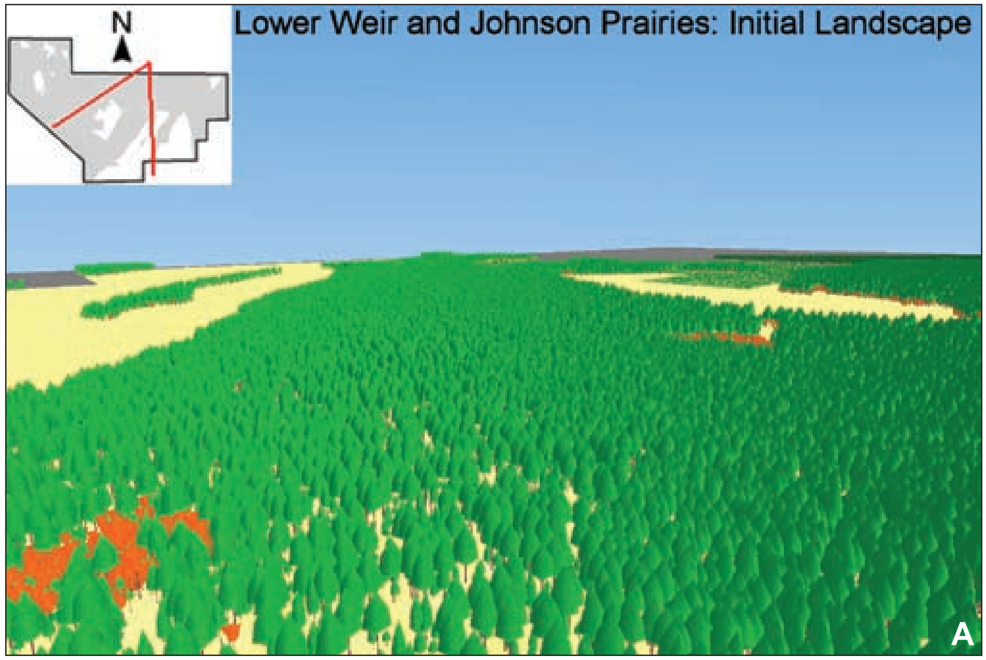

Figure 9A—Initial landscape view between Lower Weir (left) and Johnson Prairies (right) (see inset map). The two prairie areas were part of the historical Tenalquot Prairie but were separated by encroaching conifers following the cessation of the historical fire regime. A small conifer-oak stand was located between the prairies (lower left), and pure oak and conifer-oak stands were located on the prairie margins.

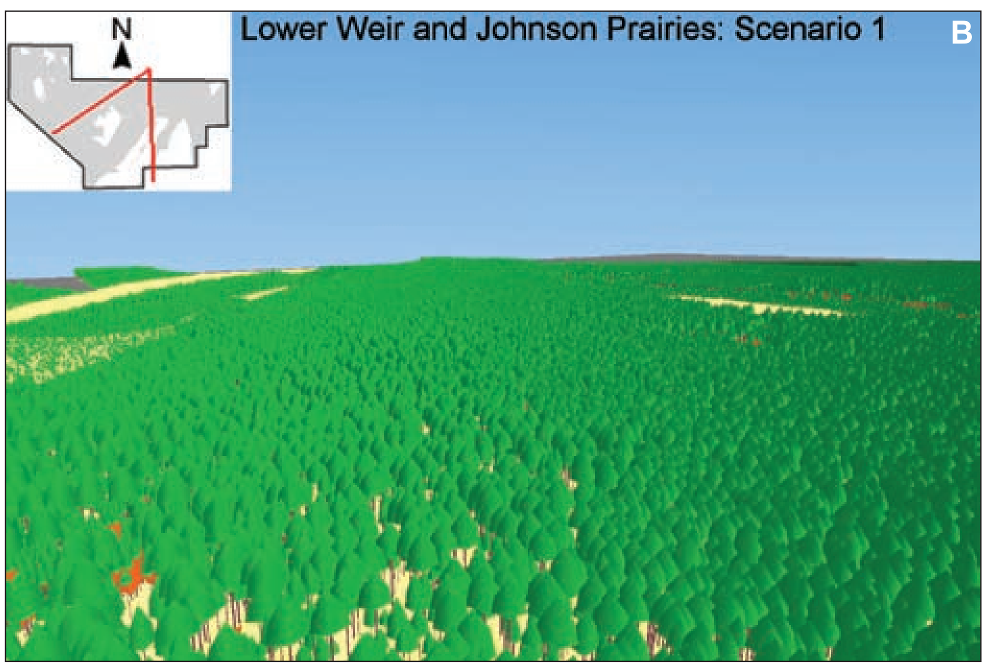

Figure 9B—Viewpoint between Lower Weir and Johnson Prairies under scenario 1. Douglas-fir encroachment was projected to continue to reduce the remnants of the Tenalquot Prairie without management such as prescribed fire to maintain existing prairie areas. Conifers in the conifer-oak stands and surrounding pure conifer stands reduced the visibility of oak on the landscape and reduced their growth and survival.

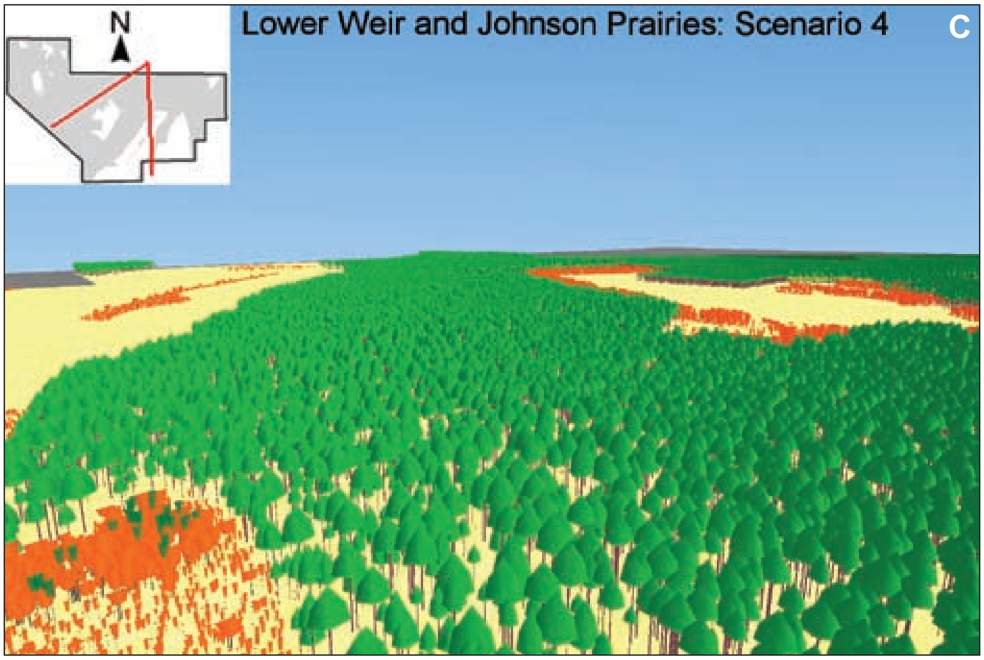

Figure 9C—Viewpoint between Lower Weir and Johnson Prairies under scenario 4. Oak became a much more prominent part of the landscape following conifer removal in all conifer-oak stands. Pure oak stands occupied most of the margin of Johnson Prairie under scenario 4 and some of the margin of Lower Weir Prairie. However, a large area of pure conifer forest remained between the prairies.

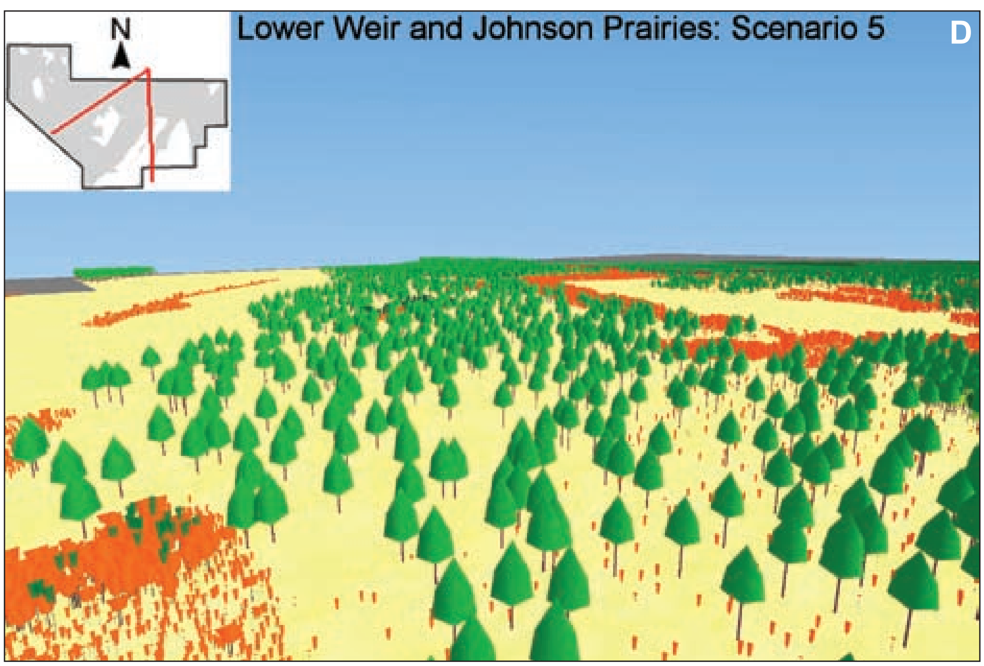

Figure 9D—Viewpoint between Lower Weir and Johnson Prairies under scenario 5. Treatments were expanded into pure conifer stands to re-create historical tree densities and species compositions within the former Tenalquot Prairie. Pure conifer stands were heavily thinned to create a savanna connecting the two prairie remnants. Oak were planted in some former pure conifer stands to create oak-conifer savannas (right foreground). The resulting landscape could provide opportunities to maintain large continuous areas in an open condition using prescribed fire or other tools.

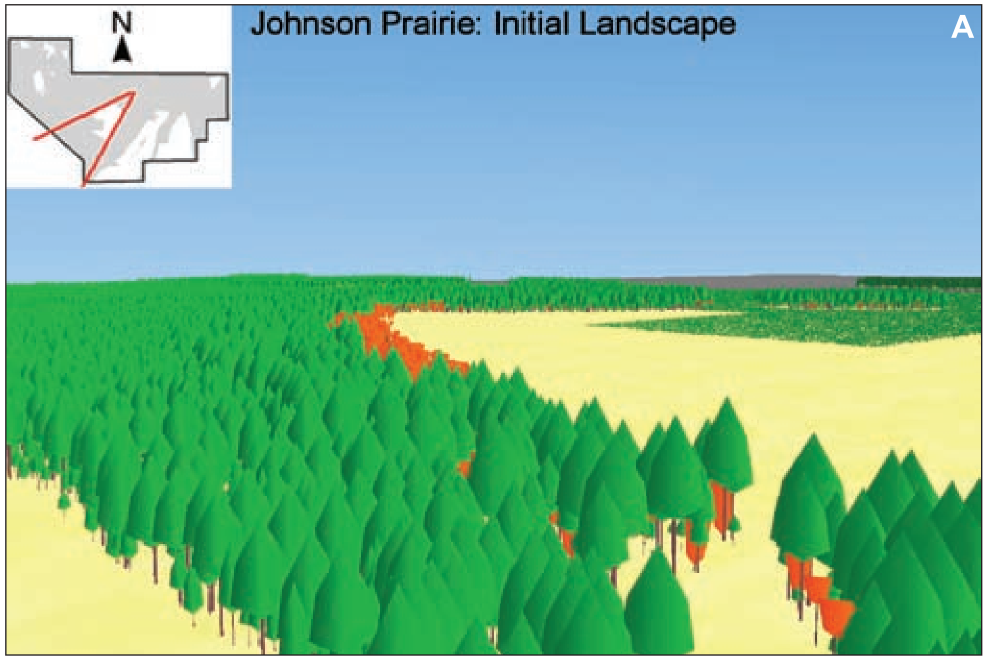

Figure 10A—Initial landscape view from the eastern margin of Johnson Prairie. Johnson Prairie had conifer-oak stands along its eastern margin and a narrow pure oak stand directly adjacent to the prairie (see inset map). A small patch of prairie extended into the surrounding forest and divided two oak-conifer stands. A recently regenerated pure conifer stand was a prominent part of the prairie's western margin.

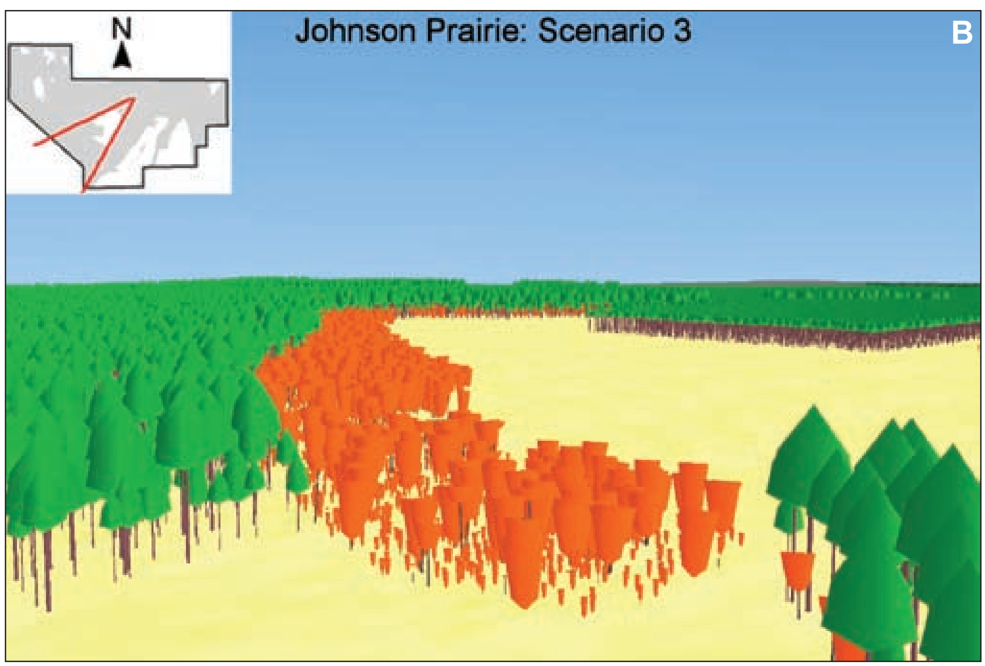

Figure 10B—Johnson Prairie viewpoint under scenario 3. One of the five areas targeted for oak management is shown. Conifers were removed to expand the narrow pure oak stand into the adjacent conifer-oak stand. Conifers were removed from an additional area to expand the prairie and reduce conifer competition at the edge of the pure oak stand. A conifer-oak stand continued to occupy the southeastern margin of the prairie (center) and a dense pure conifer stand developed on the western margin (center right).

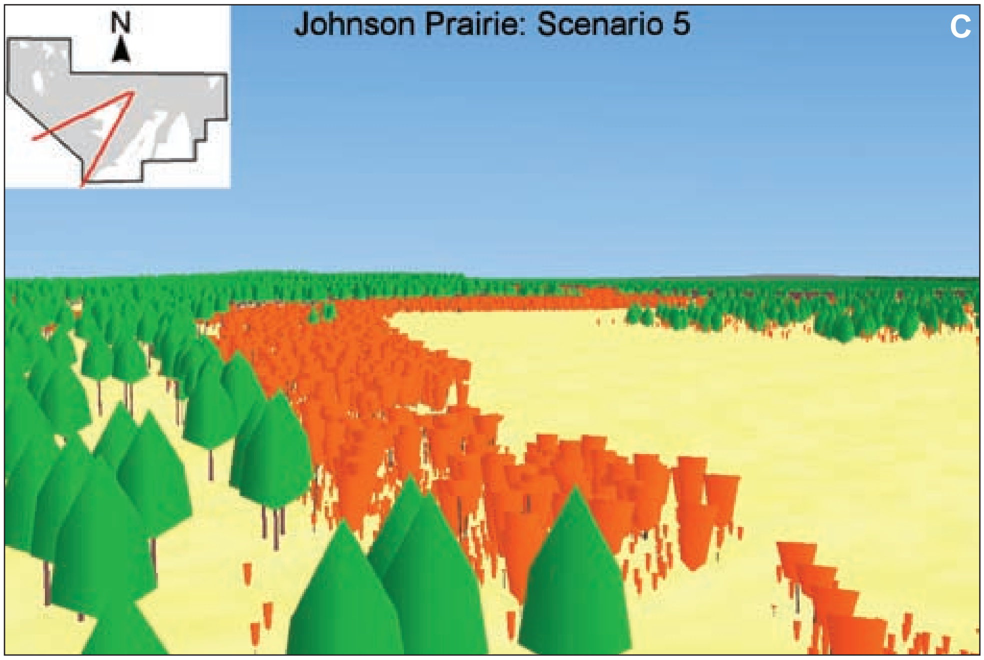

Figure 10C—Johnson Prairie viewpoint under scenario 5. Conifers were removed from all conifer-oak stands under scenarios 4 and 5, producing landscapes that were nearly identical from this viewpoint; however, pure conifer stands were heavily thinned in scenario 5 only, producing the conifer savanna visible to the east (left) and the oak-conifer savanna to the west (center right). The entire prairie was surrounded by pure oak stands and oak-conifer savannas under scenario 5.

of an oak area near Pipeline Prairie (fig. 13). The first image in each set shows the initial landscape condition, and it is followed by a series of images from the same viewpoint to show the appearance of the landscape at the end of the planning period under contrasting scenarios. Images are not included for scenario 2 because the initial landscape conditions were generally unchanged under this scenario.

Project Summary

The five scenarios explored a range of management approaches from no action to alternatives that increasingly improved the long-term condition and extent of the oak resource within the Tenalquot Planning Area. Management for conifer production (scenario 2) provided only a marginal improvement in the condition of oak over no management (scenario 1); thus, repeated thinning is not sufficient to forestall oak mortality or significantly increase oak growth rates in thinned stands. Managing a small area of conifer-oak forest for oak (scenario 3) improved the condition of oak in those five stands and was sufficient to produce a net gain in oak basal area across the landscape. Increasing the growth of oak in these stands also helped to maintain the number of hectares with high oak basal area over the projection period. The small area of expanded pure oak stands created under scenario 3 could potentially

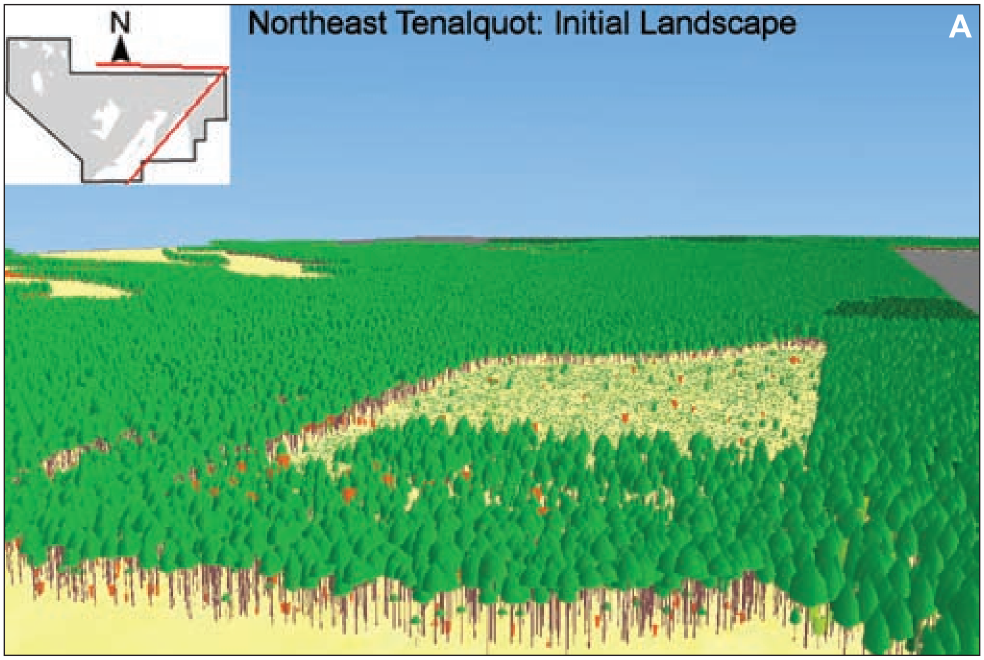

Figure 11A—Initial landscape view of the northeast Tenalquot Planning Area. The northeast portion of the planning area lacked pure oak stands but had a high percentage of area in conifer-oak stands (see inset map). One conifer-oak stand included scattered larger trees and abundant conifer regeneration (center). Oak within this stand were initially taller than the conifer regeneration and grew in a relatively open environment.

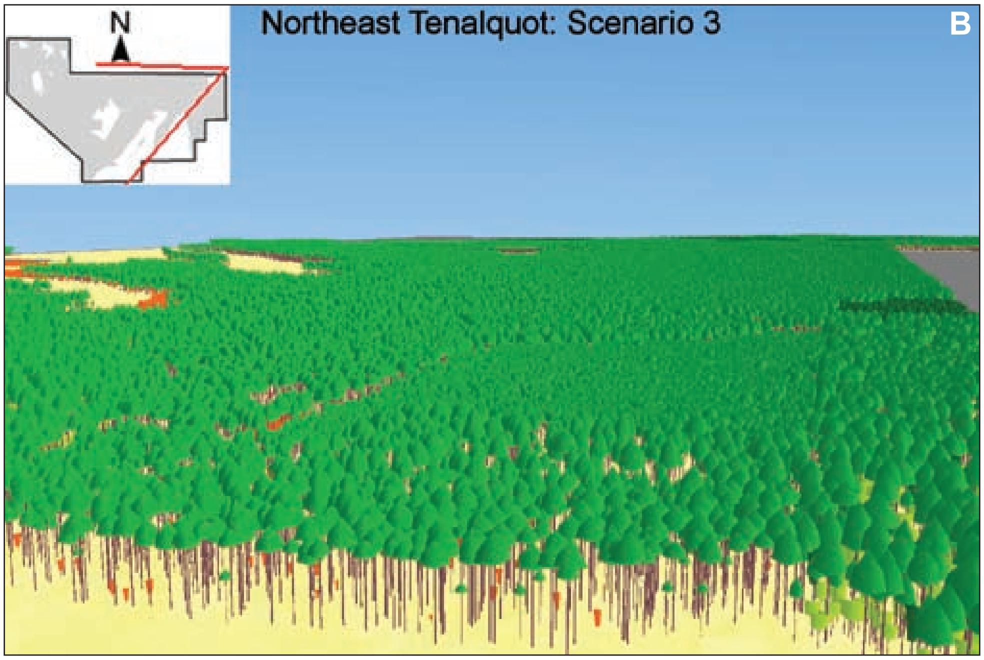

Figure 11B—Northeast view under scenario 3. The northeast portion of the planning area did not contain significant pure oak stands; therefore, conifer removal was not done in the area under scenario 3. Although the prairie areas were maintained under this scenario, conifers became a more dominant part of the landscape. Conifer regeneration overtopped the oak in the center stand and created a continuous canopy of conifers. The difference in height between Douglas-fir and oak in the older conifer-oak stands increased and the density of oak was reduced by competition.

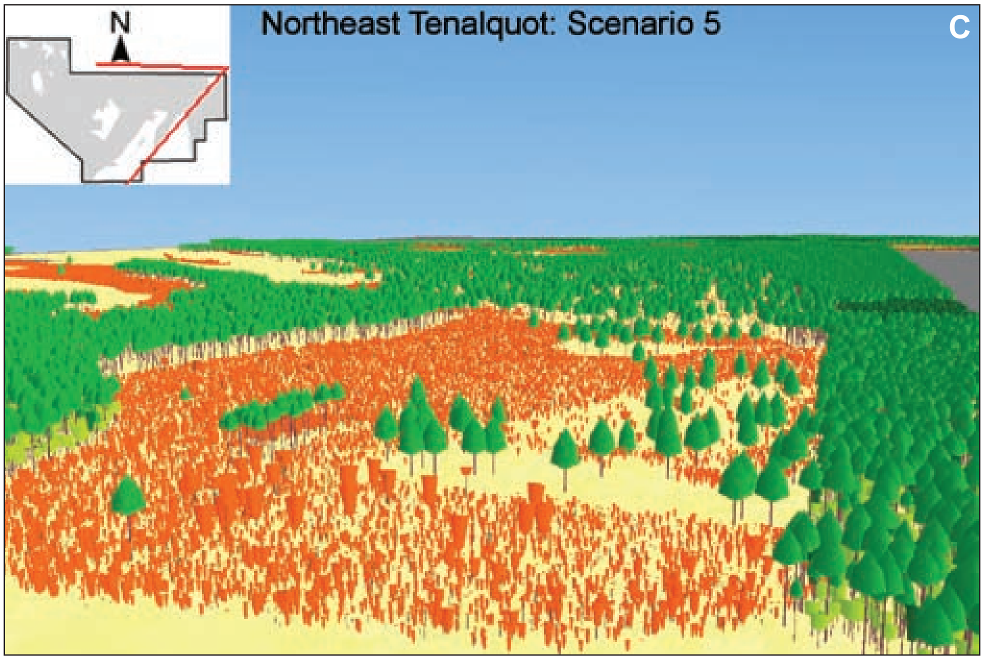

Figure 11C—Northeast view under scenario 5. The conifer-oak stands in the northeast portion of the planning area provided an opportunity to create substantial pure oak stands where none had been previously. The appearance of the landscape from this viewpoint was similar under scenario 4 where conifers were also removed in all conifer-oak stands. The oak-conifer savanna created under scenario 5 to link the area with the larger prairies to the south is visible (center right). The oak-conifer savanna approximately follows the 1853 extent of the Tenalquot Prairie.

be useful to wildlife, although its impact on the overall oak resource in the planning area was small. A much greater portion of the planning area was managed for oak in scenarios 4 and 5; these scenarios substantially shifted the planning area back toward an oak and prairie landscape.

Existing pure oak stands were not strongly affected by Douglas-fir encroachment over the projection period. The pure oak stands were initially dense, and understory Douglas-fir was projected to grow slowly. However, the trend in Douglas-fir growth and the visualizations show that the pure oak stands were approaching a threshold by the end of the projection period after which Douglas-fir would begin to overtop oaks. It is likely that the conifer-oak stands that are presently found within the planning area went through a similar transition. Understory plant communities also have likely changed, and will continue to do so without management, as species common to conifer forests replace those that are common to oak understories (Chappell and Crawford 1997, Thysell and Carey 2001). Maintaining pure oak stands through prescribed fire or other means is critical to preserving the small, but important, part of the landscape that is dominated by oak.

Management in conifer-oak stands has the greatest potential to affect the oak resource across the planning area. Conifer-oak stands initially covered a much

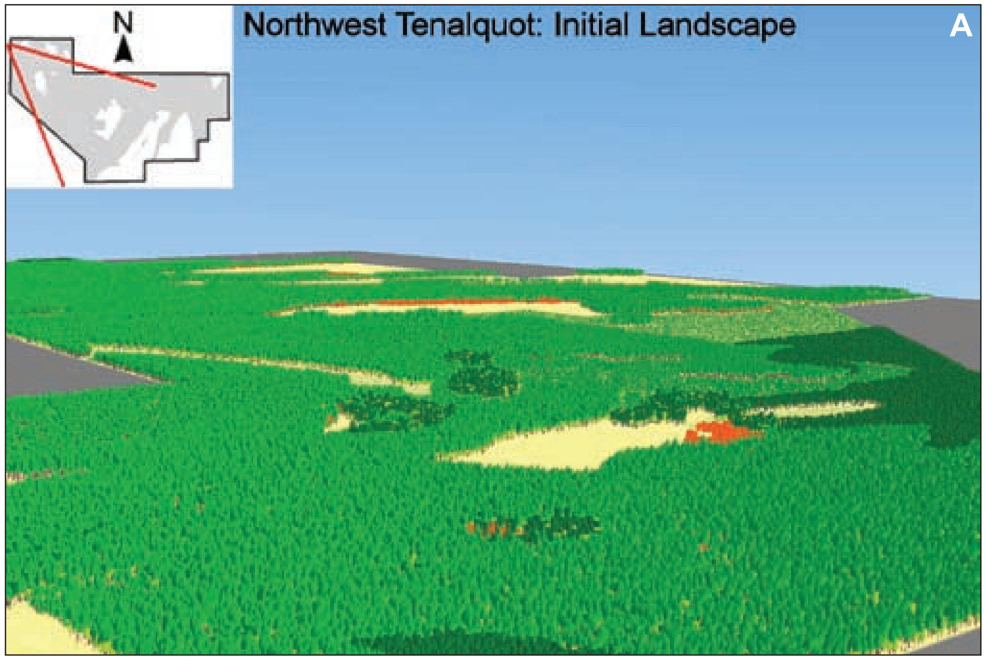

Figure 12A—Initial landscape view of the northwest Tenalquot Planning Area (see inset map). The northwest portion of the planning area contained fewer oak and prairie areas than the southeast and more area was occupied by pure conifer stands. Pipeline Prairie (center) had a small pure oak stand on its southwest margin. Mixed-hardwood stands (dark green) and wetlands (light green; center left and to the right of the prairie area) were also prominent parts of the landscape.

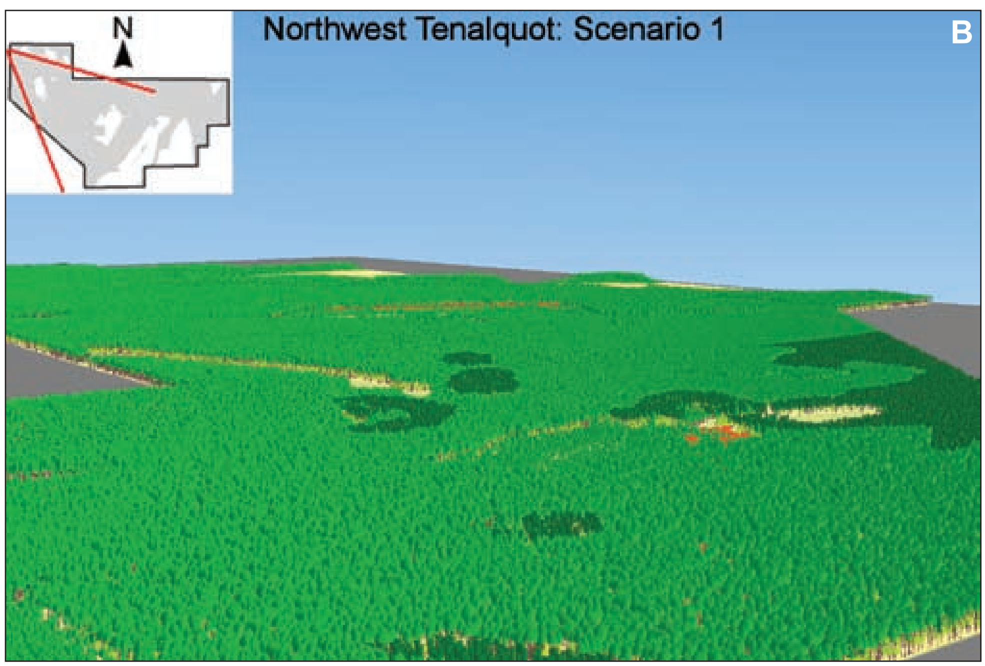

Figure 12B—Northwest viewpoint under scenario 1. Conifer forests became more dominant on the landscape under this scenario. The small prairies in the area were projected to be quickly filled by conifers in the absence of management to prevent conifer encroachment. Wetlands were not projected with conifer encroachment and remained open. Few oaks remained visible.

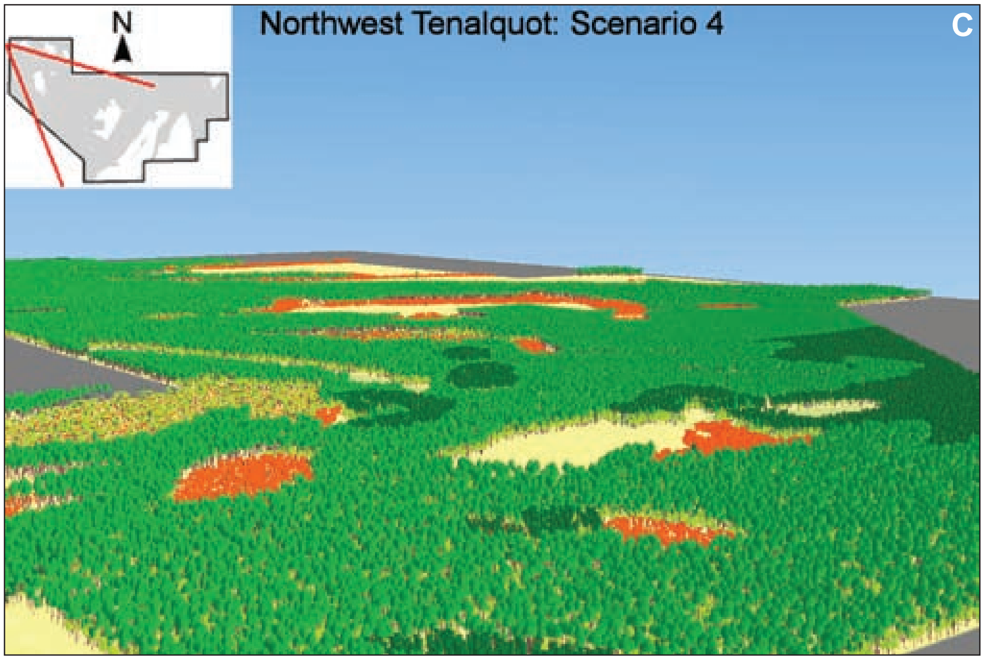

Figure 12C—Northwest viewpoint under scenario 4. Several pure oak stands were created by conifer removal; however, these stands were dispersed and generally surrounded by pure conifer stands. An exception was the pure oak stand along the Pipeline Prairie which was expanded by conifer removal in an adjacent conifer-oak stand. An oak-bigleaf maple stand (center left) was created by conifer removal in a stand that had a large component of oak and bigleaf maple before treatment.

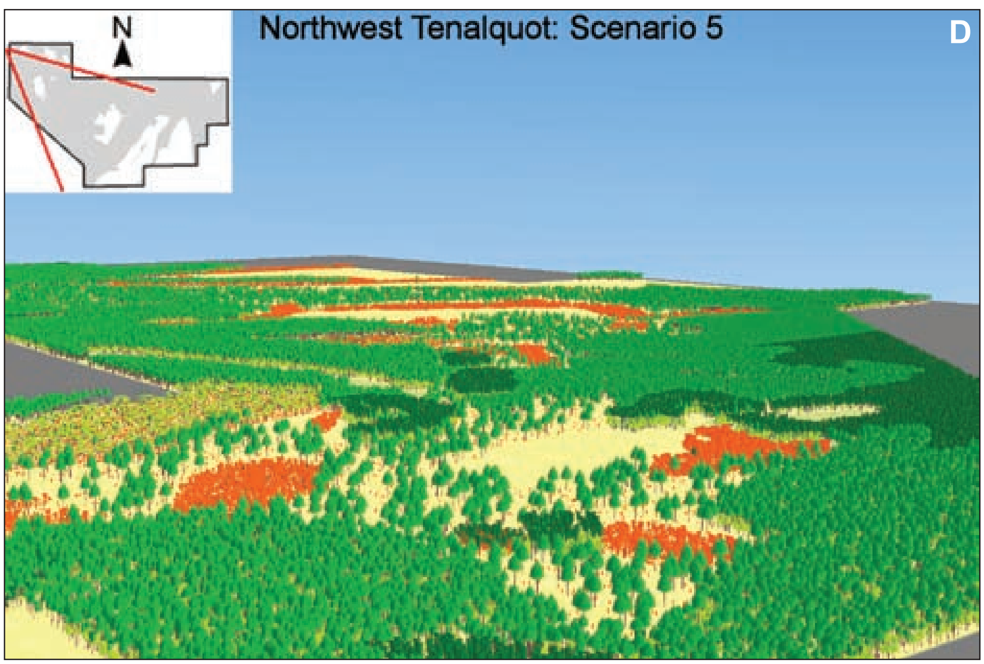

Figure 12D—Northwest viewpoint under scenario 5. An oak-conifer savanna was created by heavily thinning conifers and planting oak to connect the dispersed oak stands that were created by conifer removal in conifer-oak stands. The Pipeline Prairie (center) was the remnant of a larger prairie area that was separated from the Tenalquot Prairie in the 1853 survey. Under scenario 5, this area was connected to the restored Tenalquot Prairie by a narrow strip of oak-conifer savanna. The result was a continuous area of prairie and savanna that transverses the planning area.

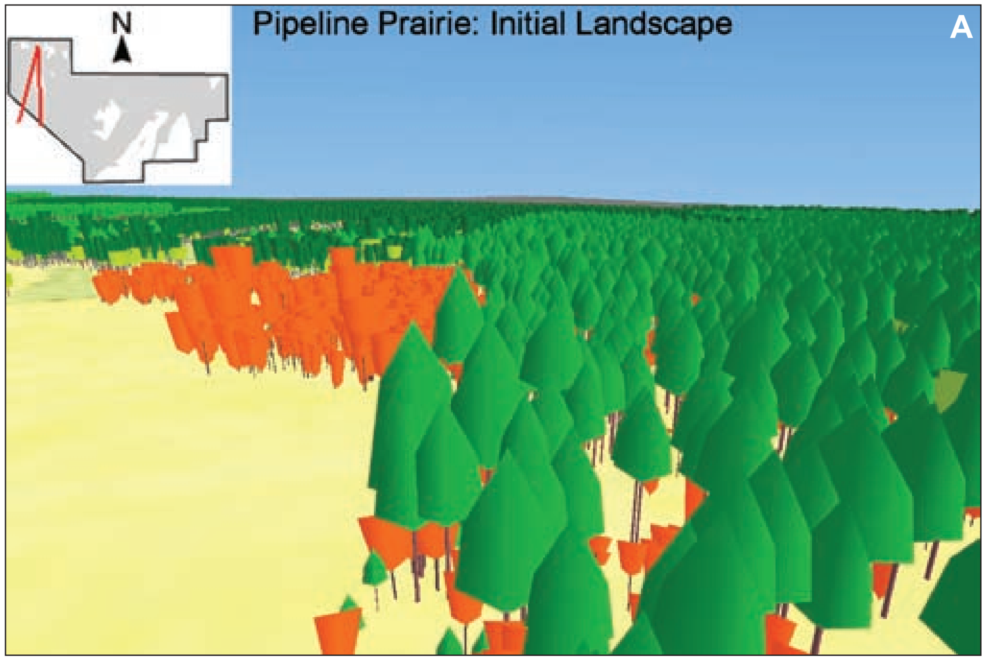

Figure 13A—Initial landscape view at Pipeline Prairie. The only pure oak stands in the northwest section of the Tenalquot Planning were on the margin of Pipeline Prairie (see inset map). An adjacent conifer-oak stand provided an opportunity to expand the pure oak stand through conifer removal.

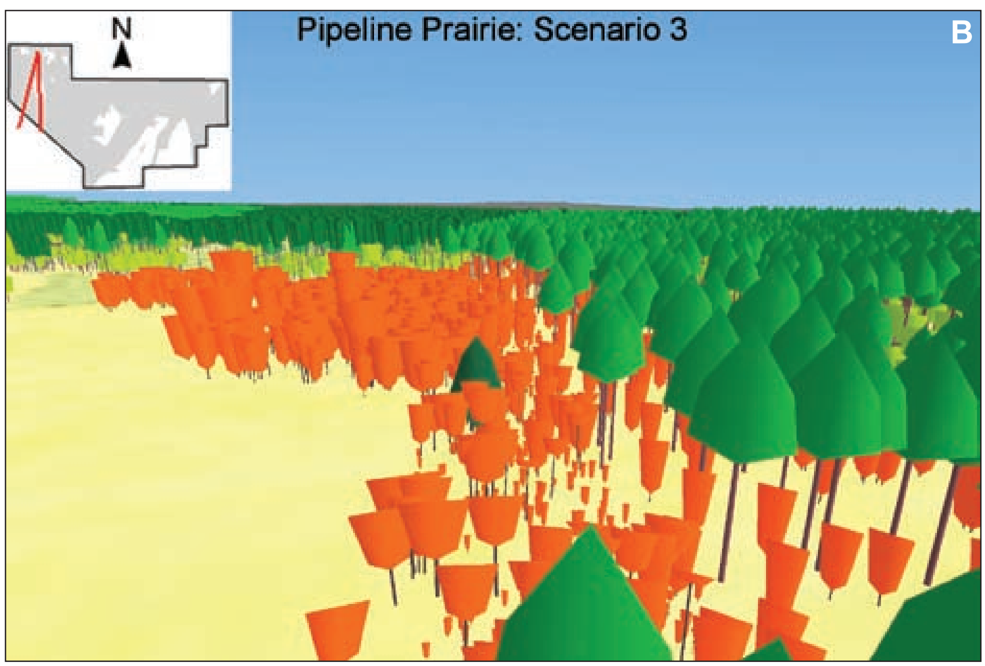

Figure 13B—Pipeline Prairie viewpoint under scenario 3. The area of the pure oak stand was nearly doubled by removing conifers in part of the adjacent conifer-oak stand; however, the area treated (1.4 ha) represented a very small fraction of the landscape. The released oak (center foreground) were projected to remain smaller in height and diameter than the oak in the pure oak stand (center background), but were larger than those that continued to grow under conifer competition (right). A western redcedar, which is an uncommon species on Fort Lewis, was retained.

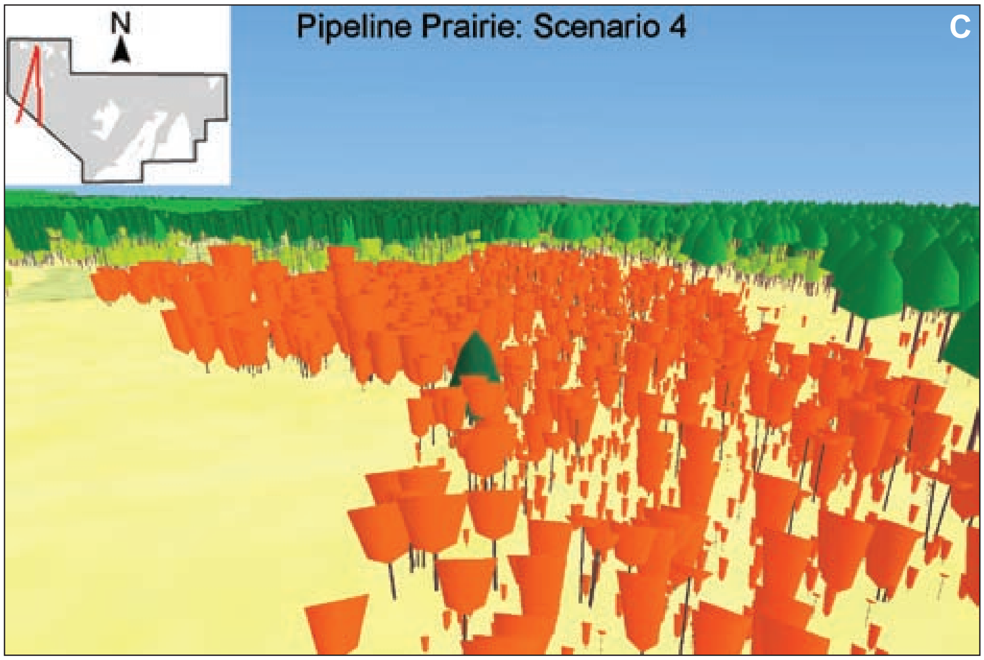

Figure 13C—Pipeline Prairie viewpoint under scenario 4. Conifers were removed from the entire conifer-oak stand to greatly expand the existing pure oak stand.

greater percentage of the planning area (17 percent of forest) than pure oak stands (< 2 percent). The same condition is undoubtedly common in many former oak and prairie landscapes; pure oak stands that have evaded conifer encroachment are relatively rare, and those that are in some stage of transition to conifer stands are much more common. On Fort Lewis, conifer encroachment into prairies and oak savannas has been underway for at least 100 yr (Foster and Shaff 2003). The next 50-yr period appears to be critical for oak currently in conifer-oak stands. Without management, a large percentage of established oaks in conifer-oak stands would be expected to die. Conifer thinning reduces mortality somewhat, and established oaks can be preserved through conifer removal. The established oaks in these stands are a resource that cannot easily be replaced. In six conifer-oak stands on Fort Lewis, the mean age of overtopped midstory oaks ranged from 94 to 130 yrs (Devine and Harrington 2006). The continued loss of oak in conifer-oak stands will severely reduce the potential for oak restoration within the planning area over the next five decades. Replacing century-old trees would require a great deal of time and effort.

The general long-term condition of the oak resource in the planning area was clearly improved in scenarios 4 and 5 where conifers were removed in all conifer-oak stands. Projected mortality of established oak was reduced to about 20 percent. The basal area of established oak was projected to double and the mean diameter was projected to increase substantially. The low stand densities that resulted from conifer removal allowed a large proportion of the simulated oak regeneration to survive after it was established. There was a large difference between scenarios in the areas covered by oaks after treatment. Pure oak or released oak stands covered about 19 percent of the initially forested area at the end of the projection period in scenario 4. Pure oak, released oak, and conifer-oak savannas and woodlands covered about 35 percent of the area in scenario 5. The differences in area covered and variability in the types of tree-growth conditions created in the two scenarios result in the potential for even greater differences between these two scenarios in oak densities and basal areas beyond the 50-yr projection period as the planted oaks and natural regeneration mature. The restoration of oak stand conditions typical of 1853 will take longer than the 50-yr projection period. For example, the mean diameter of established oak was about 39 cm (range = 4.0 to 50.0 cm) in yr 50 under scenario 5. Surveyor records from 1853 indicate that the mean tree diameter in oak woodlands was 57 cm (GBA Forestry 2002). The 1853 mean diameter suggests that oak woodlands contained larger, and probably older, trees in the past. Thinning in pure oak stands, which was not included as part of scenario 5, also may help to accelerate the growth of oak and restore open conditions in dense oak stands.

The scenarios illustrate tradeoffs between several of the current management objectives for Fort Lewis. Some of the objectives are clearly incompatible and must be met in different areas. For example, the development of old-conifer-forest structure to provide habitat for the northern spotted owl cannot occur in the same areas that are managed for oak and prairies and the species that are associated with them. Most or all conifers need to be removed to restore oak areas. Prescribed fire or other treatments are necessary to maintain prairies and oak, but fire is generally detrimental to old-forest conditions and conifer production in west-side forests. Intermingling oak and prairie areas with conifer stands may increase the risk of fire escape; thus, it may be advantageous to combine oak and prairie areas into large blocks rather than spreading them out across the landscape. The present distribution of prairies, pure oak, and conifer-oak stands in the planning area is favorable for creating relatively large blocks that can be managed as a unit. Many of the pure oak stands were located along the prairie margins and were adjacent to conifer-oak stands. The adjacent stands provide good opportunities for expanding pure oak stands to create larger units that can be managed as oak and prairie areas. Managers may allow prescribed fires to burn under some conditions from the prairies into oak stands to reduce conifer encroachment. Undoubtedly, past fires of this kind played an important role in maintaining the pure oak stands present on the initial landscape. Although tradeoffs between management objectives are unavoidable, the maintenance and restoration of oak and prairie areas should be considered a high priority. These areas contribute disproportionately to regional biodiversity, and sites with good restoration potential are rare. Much of Fort Lewis and the surrounding forested areas could be managed for old-forest characteristics or conifer production, but areas suitable for oak management are rare. The Tenalquot Planning Area has an exceptionally high potential for restoration. Much of this restoration potential within the Tenalquot Planning Area can be realized by removing conifers from less than 20 percent of the forested area and consolidating areas to manage for oak and prairie.

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The accuracy of the growth and mortality projections depends largely on how well ORGANON predicts oak growth and survival and on some important assumptions. The ORGANON equations for Oregon white oak were developed, in part, from data collected on Fort Lewis. Consequently, they reflect environmental conditions similar to those in the Tenalquot Planning Area. However, edge effects, which are not accounted for in ORGANON, may have a strong impact on the growth and survival of oak. Many pure oak stands were small and were surrounded by conifers. Competition with conifers on the edges of these stands may reduce the growth and survival of oak relative to the ORGANON projections. The accuracy of the mortality model is particularly important because of its role in projecting future densities. The model predicts mortality as a constant process that is largely a function of competition. True mortality can be highly episodic owing to more variable factors such as climate fluctuations. Under scenarios 1, 2, and 3, many of the established oak remained overtopped in conifer-oak stands. These trees are typically of poor vigor and would be particularly vulnerable to additional stress, which might lead to high mortality in some years. The initial data used to populate the stands also affected the model projections. The data are representative of the stands within the planning area, but more detailed data would help to refine the projections.

Several assumptions also affected the projections. The regeneration of oak after conifer removal in conifer-oak stands requires that sufficient seedlings become established and then survive the prescribed fires or other treatments needed to prevent conifers from reestablishing. Success of natural regeneration would be critical to maintaining or increasing posttreatment oak densities in conifer-oak stands; planting would be necessary if it fails. Measures to protect oak seedlings during prescribed fires may also be needed. It is also possible that natural oak regeneration may be more successful than assumed in some of the scenarios. In scenario 1, for example, only conifers were assumed to encroach into prairies, but oaks may also establish and eventually increase the area of pure oak or conifer-oak forest. Some natural regeneration may also occur in low-density pure oak stands. The assumed rate of conifer encroachment strongly affected the appearance of scenario 1, but it did not affect projected oak growth and mortality as encroachment produced pure conifer stands only.

Although the scenarios presented in this study were applied to the specific conditions within the Tenalquot Planning Area, a similar approach may be useful in other situations where oak restoration is a goal. Oak are often found in changing landscapes that include areas that are in different stages of transitions. The landscape-level analysis used in this study provides a good platform for evaluating management alternatives in areas that include a wide range of initial conditions. Evaluating alternatives on a landscape can also be useful for efficiently allocating areas to different land uses, such as conservation of oak and prairies, development of old-forest conditions, and timber production. Landscape visualizations created with EnVision can be used to create a better understanding of how management decisions for individual stands can shape the larger landscape. Landscape visualizations are especially useful for explaining management alternatives to nontechnical audiences (Roth and Finley 2007, Roth et al. 2006). The management environment will be different in other cases, and scenarios should be developed that make sense for a given set of initial conditions, management objectives, and constraints. In addition, managers may consider a wider range of approaches than was evaluated in this study. For example, conifers could be heavily thinned instead of completely removed in conifer-oak stands to improve the growth and survival of oak. The targeted removal of conifers around individual oaks is another option that has been shown to increase oak growth and vigor (Devine and Harrington 2006, Harrington and Devine 2006). Fort Lewis has adopted a targeted removal approach in some conifer-oak stands to create oak-dominated stands that provide high-quality habitat for western grey squirrel. Pure oak stands may also be thinned to create and maintain vigorous trees with large crowns and restore more open savannas. The response of oak to stand treatments is less understood than that of common conifers in the region. There is a need for forest managers to experiment with different approaches and share their results with others.

The response of oak to stand treatments is less understood than that of common conifers in the region.

Conclusions

Our intent in this project was to demonstrate the effects of various management alternatives at both the landscape and stand levels; however, none of the scenarios fully represent current management or what is likely to occur on this or similar landscapes where a mosaic of oak, conifer, conifer-oak stands, and prairies occur.

Nonetheless, the projections suggest that conifer thinning alone (as in scenario 2) is inadequate for maintaining oak in transitional landscapes. Managing a few areas for oak (as in scenario 3) would have a relatively small effect on the oak resource at a landscape level, as established oaks in other stands would remain under conifer competition and many would be expected to die. However, this approach would have a very strong impact on the oaks within the stands that were treated, and it might be easy to incorporate oak release projects into larger timber sales. To have a greater effect at the landscape level would require a management approach that treats a significant percentage of the landscape as in scenario 4 or 5, both of which included widespread conifer removal. Our hope is that the results from these projections will foster discussion about the future management of oak and prairie landscapes and highlight some opportunities for improving them.

Acknowledgments

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English Equivalents

When you know:	**Multiply by:**	**To find:**
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Hectares (ha)	2.47	Acres
Trees per hectare	0.405	Trees per acre
Square meters per hectare (m^2/ha)	4.37	Square feet per acre
Cubic meters (m^3)	35.3	Cubic feet

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Appendix: Summaries of ORGANON Projections

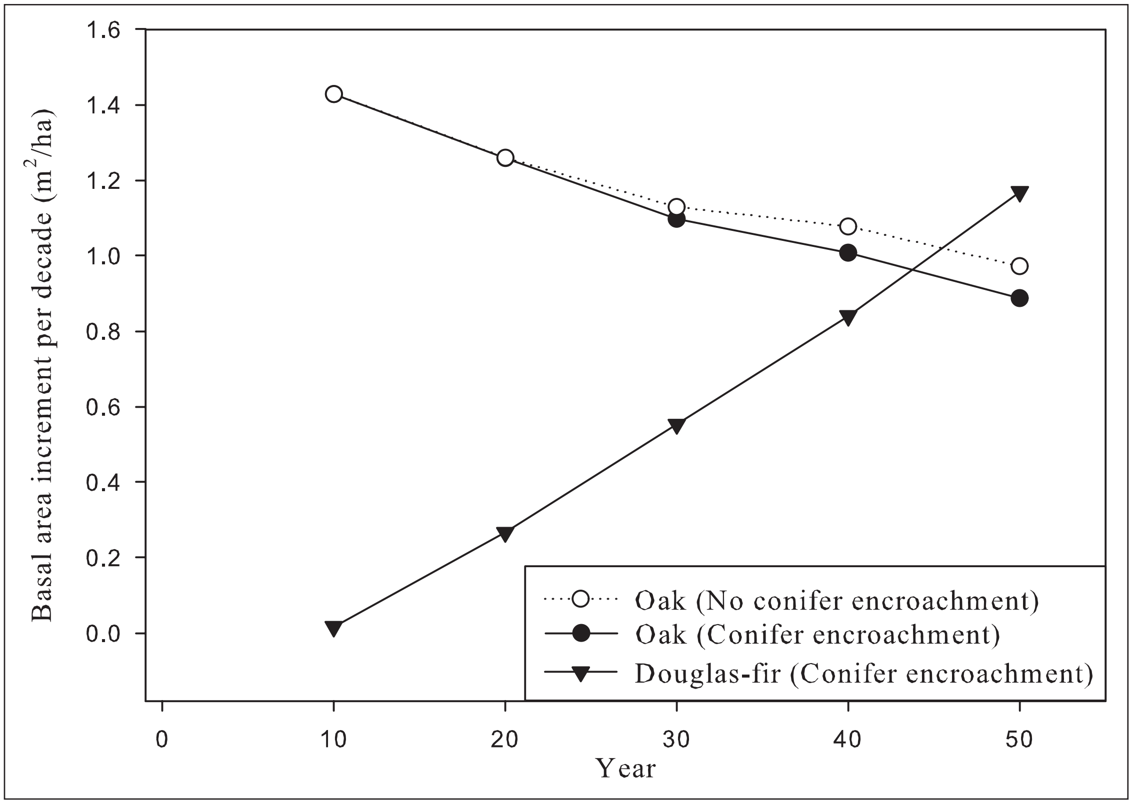

Figure 14—The projected rate of basal area growth of encroaching Douglas-fir and established oak in pure oak stands (secnarios 3, 4, and 5) and oak without conifer encroachment (scenarios 1 and 2). There was little difference between scenarios in the total growth and survival of oak over the projection period; however, the growth rate of Douglas-fir accelerated and the growth rate of oak declined near the end of the projection, foretelling a shift between the species in future dominance.

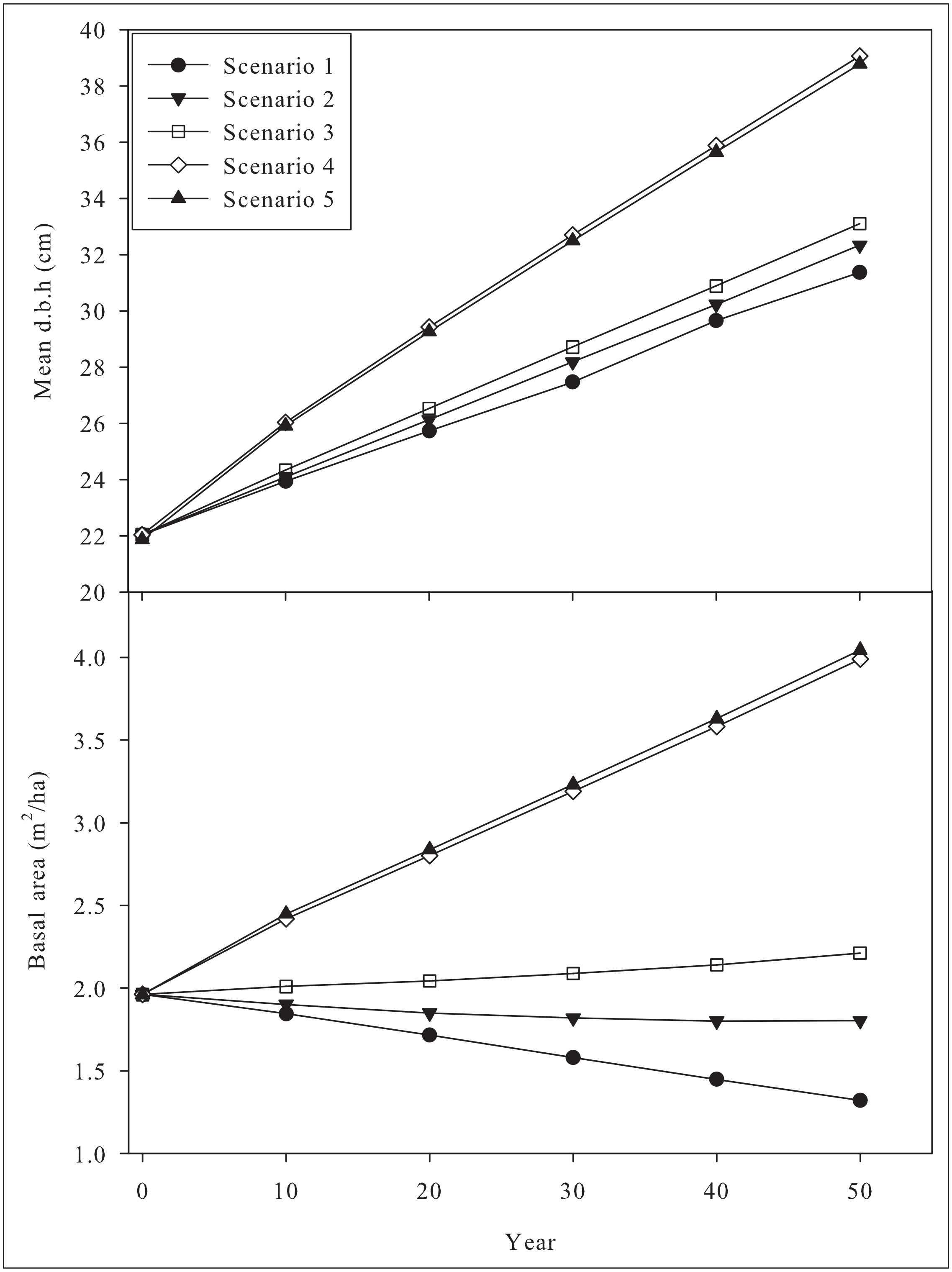

Figure 15—Projected mean diameter at breast height (d.b.h.) and basal area of established Oregon white oak (excluding regeneration) in conifer-oak stands. Regeneration that occurred over the projection period greatly reduced the mean d.b.h., but added little to basal area.

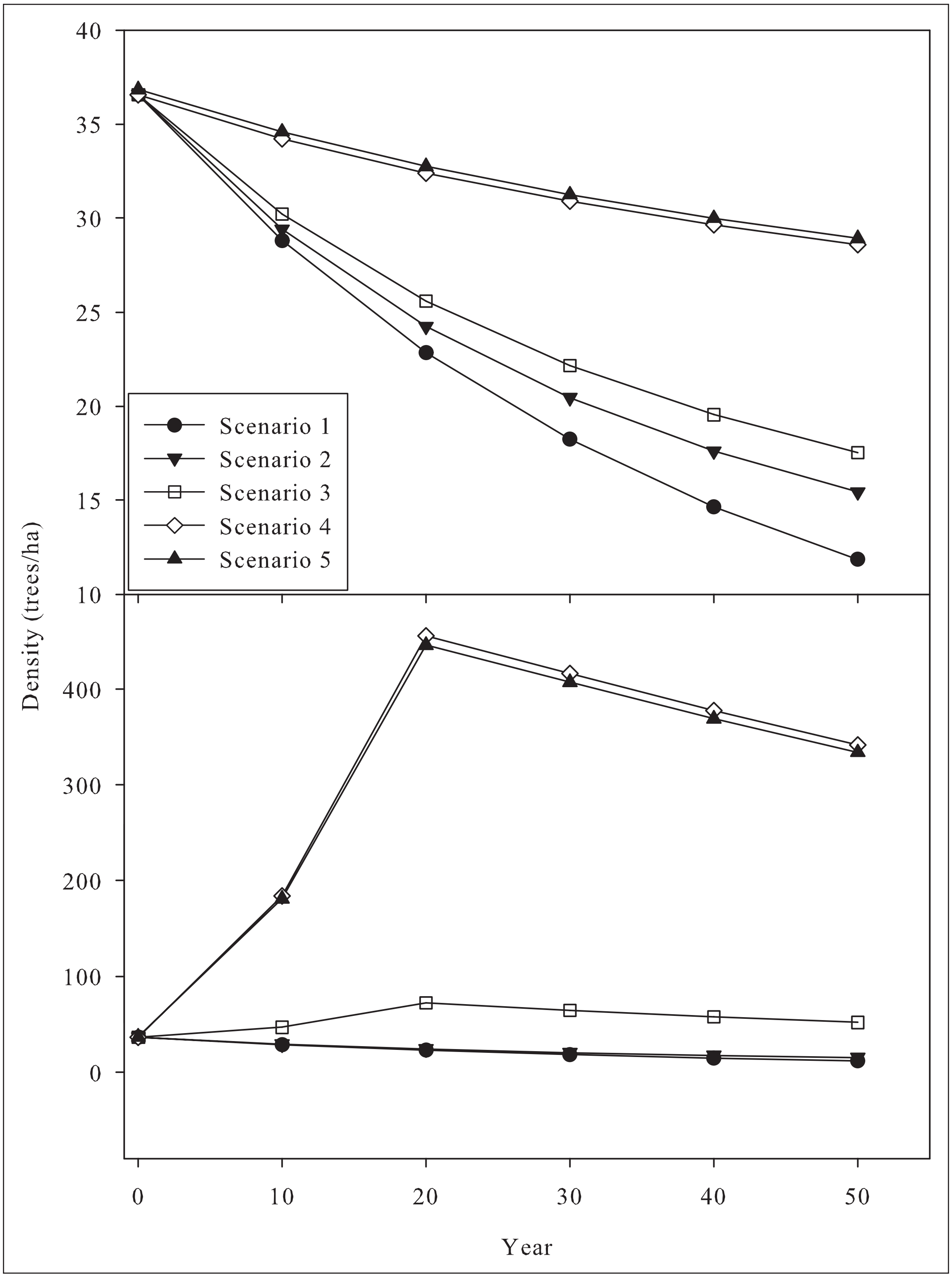

Figure 16—Projected densities of Oregon white oak in conifer-oak stands without regeneration (top) and with regeneration (bottom).

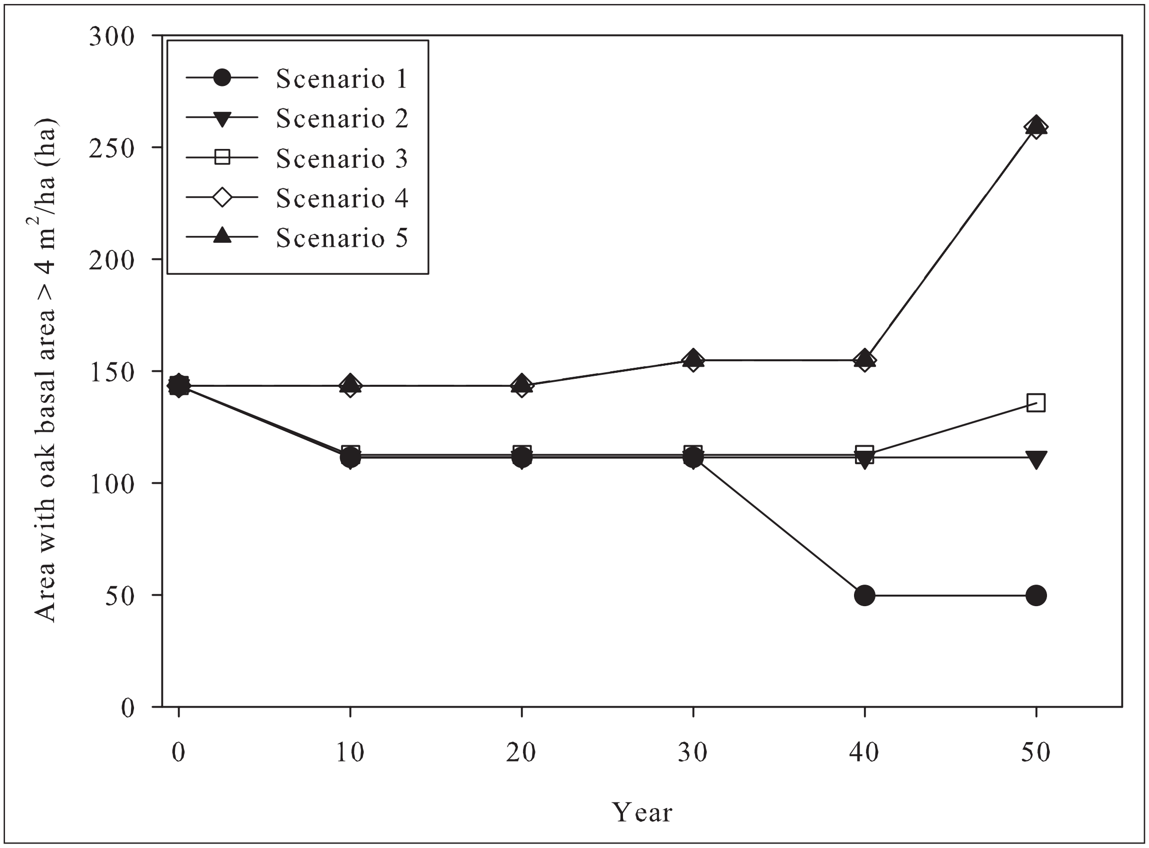

Figure 17—The number of hectares within the Tenalquot Planning Area projected to have high Oregon white oak basal area (at least 4 m^2/ha) under the five scenarios. The basal area threshold represents a proposed lower limit for western grey squirrel habitat. Projections were identical for scenarios 4 and 5.

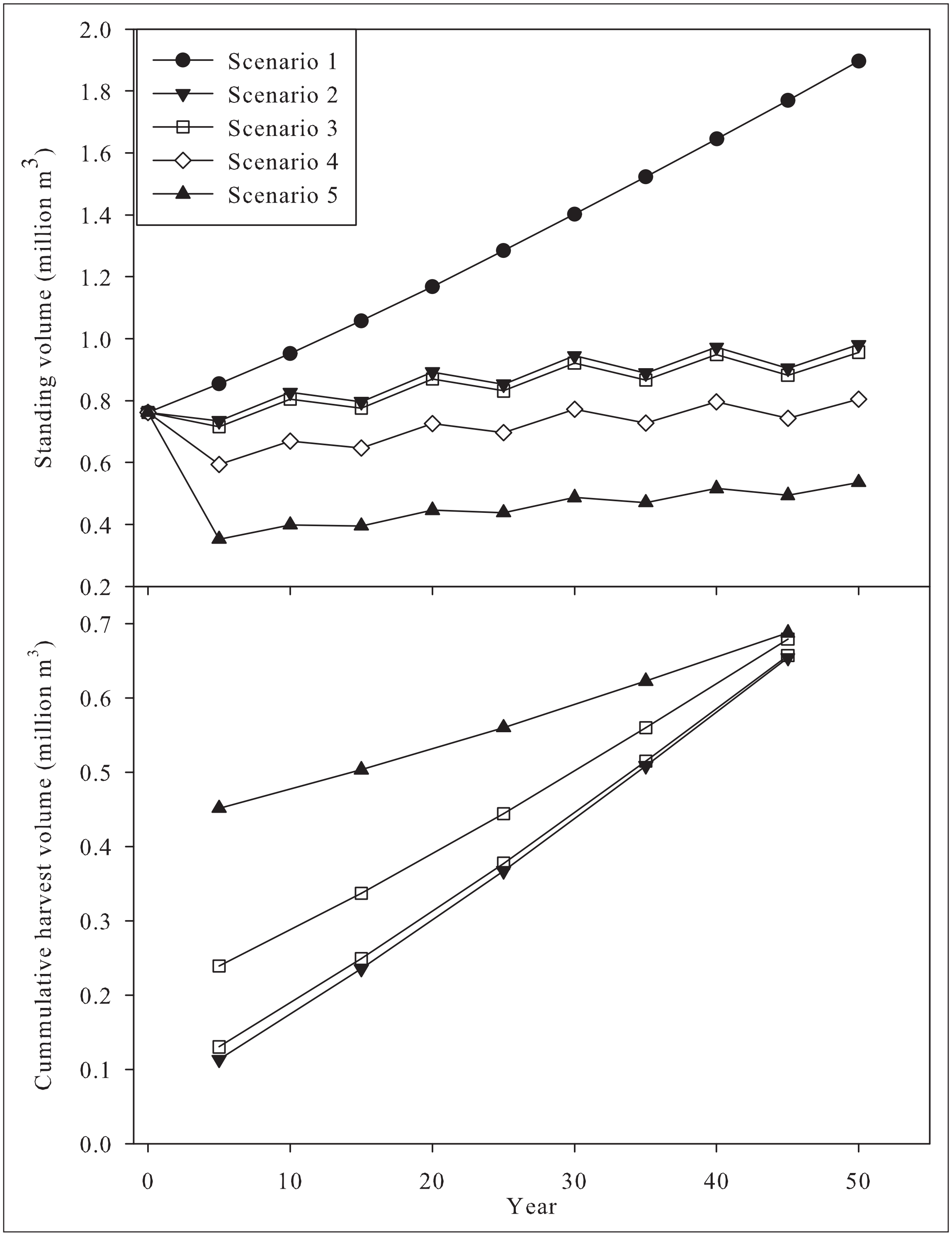

Figure 18—Projected standing volume (top) and cumulative harvest volume (bottom) of Douglas-fir under the five scenarios summed across the entire Tenalquot Planning Area. Cumulative harvest volumes were nearly identical for all five scenarios.

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