GROWTH RATES AND THE DEFINITION OF OLD-GROWTH IN FORESTED WETLANDS OF THE PUGET SOUND REGION

by

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ABSTRACT

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As part of a program to protect rare habitats in Washington State, state agencies have adopted definitions of mature and old-growth forest, with minimum size and age criteria for the largest trees. State wetland rating and functional assessment guidelines use these criteria to identify mature and old-growth forested wetlands; however, these forest definitions are based on the characteristics of Douglas-fir forests in upland habitats, and are not applicable to forested wetlands. In this study, data from forested wetlands in the Puget Lowlands were analyzed with linear regression to estimate growth rates for five tree species: western red cedar, Sitka spruce, western hemlock, red alder and coast pine. For these species, estimated diameter is significantly smaller than the mature and old-growth size criteria. Estimated average diameter for mature forest is 18 inches (46 cm), and for old-growth 27 inches (69 cm). Trees in some wetland types average significantly smaller than these mean values. The estimated average diameter for mature forest in the Snohomish River estuary is 15 inches (38 cm). Coast pine and other trees in sphagnum bogs are typically smaller than even this low estimate, and require a separate criterion if they are to be identified as mature or old-growth based on size. Analysis of height data indicates that trees in forested wetlands are in a low to moderate range of productivity and size. Ecological characteristics such as plant associations and forest succession are also different in forested wetlands, compared to upland forests.

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TABLE OF CONTENTS

TABLES

FIGURES

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Growth Rates and the Definition of Old-growth in Forested Wetlands of the Puget Sound Region

1 Introduction

In National Forests of the Pacific Northwest, logging of large old trees came to a halt in 1991, when challenged under the provisions of the Endangered Species Act. The controversy centered on the habitat needs of northern spotted owls (*Strix occidentalis caurina*), which are dependent upon old-growth forests. Researchers with the U.S. Forest Service (Forest Service) developed definitions of mature and old-growth forest in the Pacific Northwest, and these definitions were used by the Forest Service and other agencies to inventory federal land for spotted owl habitat, as part of the Northwest Forest Plan (FEMAT 1993). Today, the value of old-growth forests as rare and biologically diverse ecosystems is widely recognized, and regulations at both the federal and state level have been designed to protect remaining old-growth forest stands.

Wetland old-growth forests are even more rare than upland old-growth. Wetlands are only a small portion of the landscape, and many wetlands are not forested. In western Washington, wetlands with mature forest stands are extremely rare, because most forested areas have been logged at least once in the last century. Washington State regulations provide a high level of protection for mature forested wetlands, and the Washington State Department of Ecology (WDOE) provides guidelines for identifying them in its *Washington State wetland rating system for western Washington* (Hruby 2004).

Under the WDOE system, wetlands are placed in one of four categories. Conservation measures are often based on these categories, with Category I wetlands receiving the highest level of protection. For example, mitigation ratios are higher for Category I wetlands, and buffer size may be larger (Granger et al. 2005). Since the rating system assigns mature and old-growth forested wetlands to Category I, these wetlands may receive more protection than wetlands with younger stands of trees.

Definitions of mature and old-growth forest used by WDOE are based on the *List of Priority Habitats* published by the Washington State Department of Fish and Wildlife (WDFW 1999). The WDFW definitions are based on those published by the Forest Service for inventories of spotted owl habitat. The WDOE mature and old-growth definitions for forested wetland ratings in western Washington are as follows:

- Old-growth forests: (west of Cascade crest) Stands of at least two tree species, forming a multi-layered canopy with occasional small openings; with at least 8 trees/acre (20 trees/hectare) that are at least 200 years of age **or** have a diameter at breast height (dbh) of 32 inches (81 cm) or more.
- Mature forests: (west of the Cascade Crest) Stands where the largest trees are 80-200 years old **or** have average diameters (dbh) exceeding 21 inches (53cm); canopy cover may be less than 100%; decay, decadence, numbers of snags, and quantity of large downed material is generally less than that found in old-growth. (Hruby 2004)

The wetland rating system adds a note to these descriptions, explaining that the size criteria are "based on measurements for upland forests," and that "trees in wetlands will often have a smaller dbh because their growth rates are often slower." Therefore, age is important, because the size guidelines may not accurately reflect the characteristics of wetland trees (Hruby 2004). These size criteria were originally developed to apply throughout western Washington and Oregon for upland forests dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). When WDOE needed a definition of old-growth for forested wetlands, data were not available to create more specific criteria based on wetland trees. Therefore, the standard definition used throughout the region was applied to wetlands.

This study examines the size and age characteristics of forested wetland trees, and compares these characteristics to the guidelines for identifying mature and old-growth forested wetlands in western Washington. The statistical analysis tests the hypothesis that 80-year-old and 200-year-old trees in forested wetlands in the Puget Lowlands are significantly smaller on average than the size criteria in the WDOE definitions of mature and old-growth forested wetlands. Data are from a study of growth rates in forested wetlands initiated in 1993 by Sarah S. Cooke. Between 1993 and 2006, Cooke Scientific staff and volunteers collected age, size, and habitat information for trees in forested wetlands in the Puget Sound region. I collected additional data, and analyzed the data to estimate growth rates for five wetland tree species – western red cedar (*Thuja plicata* Donn ex D. Don), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), red alder (*Alnus rubra* Bong.), and coast pine (*Pinus contorta* Dougl. ex Loud var. *contorta*). Some other wetland tree species were examined qualitatively. Results indicate that the accepted size criteria – 21 inches (53 cm) in diameter for mature forest and 32 inches (81 cm) for old-growth forest – are too large when applied to wetlands. Results tables and graphs are presented in Appendices A, B and C, and Data Tables in Appendix D.

2 Forests, Wetlands, and Old-growth Definitions

2.1 The Puget Lowlands Region

This study focuses on forested wetlands in a region of western Washington called the Puget Lowlands. According to the Washington State Department of Natural Resources (WDNR), "The Puget Lowland physiographic province consists of a broad, low-lying region situated between the Cascade Range to the east and the Olympic Mountains and Willapa Hills to the west. In the north, the beautiful San Juan Islands form the division between the Puget Lowlands and the Strait of Georgia in British Columbia" (WDNR 2001b). The Puget Lowlands region is the area within these boundaries below about 2000 feet (600 meters) above sea level in elevation (Figure 1). This region is also called the Northern Puget Trough Lowlands Ecoregion by the Washington Natural Heritage Program and The Nature Conservancy (Kunze 1994).

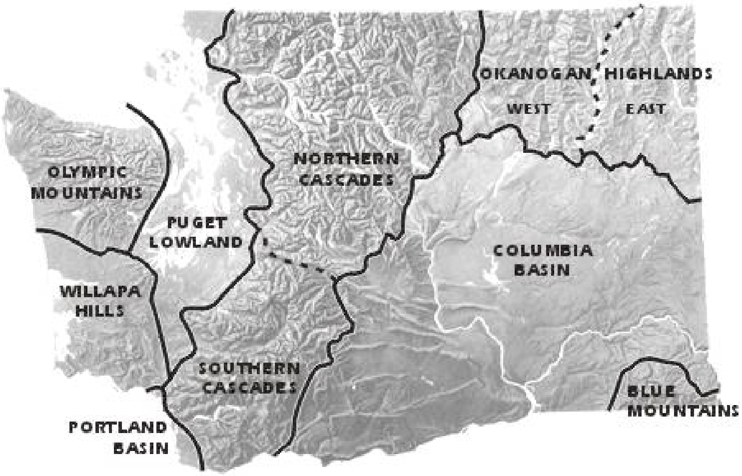

Figure 1. Washington State Physiographic Regions (WDNR 2001a)

The climate in the Puget Lowlands is temperate, with mild, wet winters, dry summers, and a long growing season. Trees grow quickly compared to trees at higher elevations, and can become very large, but not as large as those of the wetter western slope of the Olympic Mountains. Few large trees remain today because of extensive logging and development.

According to Franklin and Dyrness (1973), annual precipitation in the Puget Lowlands is typically 31 to 35 inches (80 to 90 cm). The area is in the rain shadow of the Olympic Mountains, and so receives less precipitation than some surrounding areas, but these figures are too low, particularly for the southern part of the region. The National Climatic Data Center reports averages of 37 inches (94 cm) for Seattle, 36 inches (91 cm) for Bellingham, 39 inches (99 cm) for Tacoma, 51 inches (130 cm) for Olympia, and 66 inches (168 cm) for Shelton (NCDC 2002). Precipitation in the region falls mostly in the winter months.

Most soils in the region were deposited by glaciers, and are usually coarse-grained and poor in nutrients. Poorly drained sites with swamps or bogs were once common, but now many have been drained or filled. Soils in these wetlands may be organic, composed of the remains of plants (Franklin and Dyrness 1973).

The Puget Lowlands region has some plant species rarely found elsewhere in western Washington or northwestern Oregon, such as quaking aspen (*Populus tremuloides* Michx.) and paper birch (*Betula papyrifera* Marsh.). These tree species are found mostly in the northern part of the region. The southern part of the region has some unique prairie and oak woodland plant communities. The plant communities of the Puget Lowlands have much in common with those of southwestern British Columbia and the Willamette Valley in northwestern Oregon (Franklin and Dyrness 1973).

2.2 Wetland Types and Plant Associations

Forests are commonly described in terms of their climax vegetation; that is, the species that will eventually dominate if the forest is undisturbed. In the Puget Lowlands, the dominant climax forest species is western hemlock; therefore, this region is within the western hemlock zone, which includes most of western Washington and Oregon, excluding the Pacific Coast. Western red cedar is a common subdominant species in this zone. Douglas-fir is considered a subclimax species (Franklin and Dyrness 1973; Topik et al. 1986).

Douglas-fir currently dominates most of the forests in the western hemlock zone, because the climax forest has been removed by logging, development, or fire. If undisturbed, this forest will eventually transition to a mixed-species forest dominated by western hemlock, a process that can take 400 years or more (Franklin and Dyrness 1973). Forested wetlands have a different pattern of succession and different plant communities. Douglas-fir is rare in wetlands. Forested wetlands in the western hemlock zone commonly have a mixed forest of western hemlock, western red cedar, Sitka spruce, and red alder. Oregon ash (*Fraxinus latifolia* Benth.) is also common in wetlands in the southern part of the region. The understory is typically dominated by salmonberry (*Rubus spectabilis* Pursh), vine maple (*Acer circinatum* Pursh) and other shrubs. Skunk cabbage (*Lysichiton americanus* Hultén & St. John) is frequently the dominant herbaceous species; lady fern (*Athyrium filix-femina* (L.) Roth.), slough sedge (*Carex obnupta*

Bailey), and false lily-of-the-valley (*Maianthemum dilatatum* (Wood) Nels. & Macbr.) are also common in wetlands (Franklin and Dyrness 1973; Topik et al. 1986). Bigleaf maple (*Acer macrophyllum* Pursh) and black cottonwood (*Populus balsamifera* L. ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw) are common in riparian areas, but bigleaf maple is not normally found in places with prolonged saturation of the rooting zone.

Franklin and Dyrness (1973) described skunk cabbage as the indicator of the wettest forested sites. They identified western hemlock/skunk cabbage and western red cedar/skunk cabbage as typical swamp plant associations. Sites that are moist, but not as wet as swamps with skunk cabbage, are typified by sword fern (*Polystichum munitum* (Kaulf.) Presl) in the understory. Sword fern is not a dominant species in wetlands, except on elevated hummocks, so this plant association is not indicative of saturated soil conditions.

The western hemlock/skunk cabbage vegetation association and other wetland plant associations of western Washington are also described in *Preliminary Classification of Native, Low Elevation, Freshwater Wetland Vegetation in Western Washington*, by Kunze (1994). Kunze classified wetlands according to plant community types (the equivalent of "plant associations" in Topik et al. (1986) and Henderson et al. (1989)), and divided wetland plant communities in the Puget Lowlands broadly into two groups: minerotrophic wetlands and sphagnum bogs.

Sphagnum bogs receive much or all of their water from direct precipitation, rather than groundwater. Bogs have acidic, nutrient-poor soils, with plants adapted to these conditions. The cool northern climate and high water table result in slow plant growth and very slow decomposition, producing an accumulation of dead plant material called peat.

Minerotrophic wetlands are fed by groundwater containing dissolved minerals, and are usually less acidic than bogs, resulting in a different plant community. Some minerotrophic wetlands may still accumulate partially decomposed plant material as peat or muck in permanently saturated areas (Kunze 1994). The distinction between these two types of wetlands is not always clear, and some wetlands may have portions in both categories (Kulzer et al. 2001).

Kunze lumped together two plant communities described separately by Franklin and Dyrness, *Thuja plicata/Lysichiton americanus* and *Tsuga heterophylla/Lysichiton americanus*. Since *Thuja plicata* and *Tsuga heterophylla* frequently occur together in wetlands, it is reasonable to combine these two plant communities into one, called *Thuja plicata-Tsuga heterophylla/Lysichiton americanus*. Most of the samples of western red cedar and western hemlock in the data for this study are from sites with this wetland plant community type, with Sitka spruce as a subdominant species. Examples are Hylebos Wetland and Lilliwaup Swamp, discussed in more detail below in this section.

The *Alnus rubra* communities described by Kunze are similar to the "cedar and alder swamps" described by Franklin and Dyrness (1973), who comment, "it is in some of these swamp communities that *A. rubra* appears to be a climax species." Two of these are the *Alnus rubra/Lysichiton americanus*, and *Alnus rubra/Rubus spectabilis* plant communities. Kunze adds that these *Alnus rubra* plant community types are probably progressing toward the *Thuja plicata-Tsuga heterophylla/Lysichiton americanus* type.

Most of the sampling sites in this study had one of these three plant communities as described by Kunze (1994). An exception is the Sitka spruce dominated wetland of the Snohomish River freshwater estuary. This wetland plant community is similar to Sitka spruce tidal swamps that were mentioned by Franklin and Dyrness (1973) as part of the coastal *Picea sitchensis* or Sitka spruce zone. Kunze also described a *Picea sitchensis-Alnus rubra/Rubus spectabilis/Carex obnupta* (Sitka spruce-red alder/salmonberry/slough sedge) community type, occurring on surge plain terraces and along major river and slough channels in coastal areas. Like Franklin & Dyrness, Kunze placed this plant community in the coastal Sitka spruce zone, not the western hemlock zone. Soils described by Kunze for this wetland type are a mixture of clay, silt, and organic matter, including large woody debris. This matches the soil description for sites sampled in the Snohomish estuary, and these wetlands are overall very similar to the Sitka spruce surge plain wetlands described by Kunze.

The National Wetlands Working Group of Canada (1988) described wetlands in coastal areas of British Columbia, some of which are similar to forested wetlands in western Washington. Certain riparian wetlands, or "stream swamps," have a mix of conifers and red alder in which "western red cedar is usually the dominant species." These stream swamps are contrasted with floodplain swamps, where "Sitka spruce has greater dominance and much better growth than in stream swamps." These floodplain swamps are similar to the wetland plant community of the Snohomish River freshwater estuary.

Little Egypt wetland in Mason County, one of the sites sampled in this study, can be described as a mixed conifer *Thuja plicata-Tsuga heterophylla/Lysichiton americanus* community type. It is better described, however, by Kunze's *Picea sitchensis-Alnus rubra/Lysichiton americanus* community type, which occurs primarily in the western Olympic Peninsula (Kunze 1994). Sitka spruce is frequently a strong component of a mixed forest in wetlands of the Puget Sound region, and sometimes it is the dominant species. Such wetlands may be in transition toward a forest dominated by western hemlock and western red cedar.

Another common forested wetland type found in the Puget Lowlands is dominated by Oregon ash, with an understory of Douglas spirea (*Spiraea douglasii* Hook.) and slough sedge (Kunze 1994). Insufficient data were collected from such sites to make any conclusions about growth rates of Oregon ash in these wetlands.

The National Wetlands Working Group (1988) also described "Pacific coast swamps," similar to the *Thuja plicata-Tsuga heterophylla/Lysichiton americanus* plant community described by Kunze (1994). Skunk cabbage in these swamps is an indicator of the nutrient status of the swamp. Vigorous growth of skunk cabbage indicates a rich, mucky soil; stunted skunk cabbage indicates nutrient-poor conditions.

Tree size is an indicator of nutrient availability, although productivity may also be restricted by a high water table and poor soil aeration. "The best stands are dominated by spruce or cedar of moderate size, whereas the nutrient-poor swamps are dominated by stunted hemlock. Over time, productive cedar-spruce skunk cabbage swamps gradually fill in with decayed wood and other organic matter until they support poor-quality hemlock/blueberry/moss associations elevated above the water table." Similarly, in riparian wetlands, "Tree growth is relatively poor, but red cedar, spruce, and grand fir tolerate the semi-stagnant conditions and grow much better than hemlock. Hemlock occurs mostly on raised, organic hummocks" (National Wetlands Working Group 1988).

Different tree species respond differently to both depth and rate of flow of groundwater. Minore and Smith (1971) found western hemlock to be intolerant of water tables higher than 15 cm below the soil surface, but both western red cedar and Sitka spruce grew well in these conditions. Western red cedar and Sitka spruce fared differently, however, in response to the amount of underground flow. Western red cedar was more tolerant of stagnant water tables than Sitka spruce, but less common than spruce where groundwater was flowing; Sitka spruce grew faster with flowing groundwater.

Wetlands dominated by coast pine (*Pinus contorta* var. *contorta*) or western white pine (*Pinus monticola* Dougl. ex D. Don) in the Puget Lowlands are usually sphagnum bogs (Kunze 1994). Coast pine are typically smaller at maturity than other conifers of this region, and may be stunted when growing in a bog. Plants associated with coast pine sampled in this study indicate that most, if not all, of the sampled sites were sphagnum bogs.

Much of the literature about forested wetlands in western North America has focused on sphagnum bogs. Fitzgerald (1977) described the vegetation communities of Kings Lake Bog, near Seattle; this study is illuminating for its discussion of microenvironments and bog succession. The National Wetlands Working Group of Canada (1988) was mostly concerned with the sphagnum bogs that cover much of arboreal Canada. Kunze (1994) described four forested sphagnum bog plant communities in the Puget Lowlands, all with stunted trees. For example, western hemlock only13 inches (33 cm) in diameter may be over 300 years old (Kunze 1994).

The foundational work of Franklin and Dyrness (1973), Kunze (1994), and others who described and classified the forested wetlands of western Washington, is summarized in *The Pacific Northwest Forested Wetland Literature Survey Synthesis Paper*, published by WDNR in 2005 (CSS 2005). This comprehensive review and the accompanying annotated bibliography provide a wide range of information pertaining to the climate, ecology, wildlife, and management of forested wetlands in Washington State.

2.3 Upland Plants in Wetlands

Western hemlock is a dominant climax species for many forested wetlands in the Puget Lowlands. This fact can be confusing when attempting to identify wetlands, because western hemlock has a facultative wetland rating of FACU-, meaning it is much more likely to occur in uplands than in wetlands (see Appendix E, Table E-1 for an explanation of wetland indicator categories). By contrast, other common wetland species such as red alder, Sitka spruce, and western red cedar have a facultative rating of FAC, meaning they are as likely to occur in wetlands as in uplands (Reed 1988; Tiner 1999).

The U.S. Army Corps Of Engineers (USACE) discussed these western hemlock wetlands in a delineation guidance document for Oregon and Washington (USACE 2005). In this guidance, "hemlock swamps" are cited as an example of a situation in which a FACU plant may be used as a wetland indicator species, on the basis of observation. In these western hemlock dominated wetlands, salal (*Gaultheria shallon* Pursh) may be the dominant shrub (Franklin and Dyrness 1973). Salal is also an upland plant, with a facultative wetland rating of FACU. Ralph Tiner discussed this and other

FACU wetland plant associations in *Wetland Indicators* (Tiner 1999), and concluded, "The individuals growing in wetlands are clearly adapted in some way for life in periodically anaerobic soils and are considered hydrophytes." This agrees with the guidance from the Army Corps Of Engineers that western hemlock can be considered a wetland indicator plant, because it is observed as a dominant species in wetlands.

Western hemlock and other tree species have shallow roots when growing in wetlands, a form of hydrophytic adaptation. Topik et al. (1986) found the rooting depth in the western hemlock/skunk cabbage plant association to be 37 cm, very shallow; most upland plant associations had rooting depths in the range of 80 to 100 cm.

Trees in wetlands are often widely spaced, and depend on nurse logs, stumps, and hummocks formed by other trees to provide elevated rooting opportunities. This is especially true for western hemlock, a species usually found in upland conditions. A large old-growth tree can build a large mound of detritus around its roots, providing a place for other trees, shrubs, and herbs to grow above the water table, including upland species. The result is a diverse and complex plant community.

2.4 Wetland Forest Succession

Since wetland trees are affected by a high water table, the old-growth succession model of upland forests may not apply to wetland forests. A recent study in Mount Rainier National Park concluded that "old-growth forest on the coldest and *wettest* sites in the Park had low similarity to the published definition of Douglas-fir old-growth forest ...suggesting that the existing definition may not apply at these environmental extremes" (Acker et al. 2006; emphasis added). Moist sites in the Park did not have typical old-growth structure, so "it may be that the typical pattern of development and resulting old-growth structure are fundamentally different in the cold and wet extremes." The stresses experienced by trees on a wet site result in a forest structure different from that of typical old-growth stands.

One important difference is the virtual absence of Douglas-fir in wetlands. Pioneer species are typically red alder, Sitka spruce, western red cedar, and Oregon ash, with western hemlock on raised hummocks and nurse logs. The plant community may be diverse, with both wetland and upland species.

There are also differences in the density and development of a wetland forest stand. Stress caused by a high water table limits the density of the forest, and causes dependence on nurse logs and hummocks. As fallen logs and root mounds proliferate, seedlings find more niches in which to grow, and the density of the forest increases. This is opposite to the typical trend in upland forests, which often start out dense and become less dense with age, leaving large amounts of dead wood and standing snags.

Because of these differences, wetland stands may take longer than upland stands to develop some of the classic ecological characteristics normally associated with old-growth, such as the abundance of large trees and accumulation of dead wood and snags. Species diversity, however, may be relatively high in a forested wetland. Because of the stratification of moisture regimes between the soil surface (wet) and raised logs and hummocks (drier), forested wetlands may have many niche habitats.

Mature forested wetlands are not simply slow-growing forests; they have their own unique ecology. It is appropriate to use definitions of old-growth and mature forest to identify older forested wetlands, but the concepts of forest succession and stand development on which these definitions are based do not accurately reflect the ecology of wetland forests.

2.5 Old-growth and Mature Forest Definitions

No single old-growth forest definition is adequate, because of differences between ecosystems (Franklin and Spies 1991; Moeur et al. 2005). The definition used by WDOE is based on guidelines intended for Douglas-fir dominated forests of western Washington and Oregon. It is a simplified version of the definition used by the Northwest Forest Plan to identify habitat for the northern spotted owl. For example, the plan's Forest Ecosystem Management Team described an old-growth stand as: "A forest stand usually at least 180-220 years old with moderate to high canopy closure; a multilayered, multispecies canopy dominated by large overstory trees; high incidence of large trees, some with broken tops and other indications of old and decaying wood (decadence); numerous large snags; and heavy accumulations of wood, including large logs on the ground" (FEMAT 1993). Size criteria were based on the findings of the Old-Growth Definition Task Group (1986).

This definition, with the size criteria, was called the "interim" old-growth definition (Old-Growth Definition Task Group 1986). The term "interim" reflects the understanding that more refinement of the definition was needed. It was painted with a very broad brush, to apply to upland Douglas-fir forests in the Pacific Northwest. Wetland ecology is different, and growth rates of some tree species are slower in wetlands than in suitable upland habitats. Two of the authors of the interim definition wrote in 1991: "Further development of old-growth definitions should probably be directed toward developing more site-specific definitions, such as for specific habitat types, geographic locales, or both" (Franklin and Spies 1991). One purpose of this study is to refine the definition of old-growth for the specific habitat type of wetlands, and for the specific geographic locale of the Puget Lowlands.

Old-growth definitions have generally specified 200 years as the age at which a stand becomes old-growth, based on a typical range of 180-220 years required to develop old-growth ecological characteristics; however, old-growth characteristics begin to appear well before 200 years, as growth slows, and trees are said to be "mature." Mature stands have some relatively large live and dead trees. In Douglas-fir forests of western Washington and Oregon, this mature stage begins at about 80 to 120 years of age, depending on site conditions and history. For this reason, 80 years has been chosen as the minimum age for mature forest stands (FEMAT 1993; Old-Growth Definition Task Group 1986). In the Northwest Forest Plan, forests older than 80 years were called "late-successional," including both mature and old-growth forests in this one category.

Another factor that is usually considered in connection with old-growth forest definitions is overall stand area. The Old-Growth Definition Task Group recommended a minimum stand size of 80 acres (32 hectares) or more, reasoning that the ecological characteristics of old-growth forest are characteristics of the interior of a forest, so a stand must be large enough to create these interior conditions. Smaller stands are affected by proximity to the stand edge, resulting in different ecological characteristics.

The WDOE wetland rating system does not include stand area as part of the definition of old-growth, but in order to receive a Category I rating, a stand of mature or old-growth trees must be at least one acre (0.4 hectare) in size (Hruby 2004). This small stand size is a departure from the reasoning of the Old-Growth Definition Task Group, but it is appropriate for the purpose of identifying the few remaining bits of old-growth forested wetland in western Washington. This small size threshold may still be too large, considering the scarcity and ecological value of mature forested wetlands. Even very small pockets of old forest enhance biological diversity and provide support for rare plant and animal species. A large, old tree can be a haven for fungi, insects, and other species that are part of the old-growth forest ecosystem. Such trees preserve some of the species associated with old-growth, and shorten the time needed for diverse old-growth habitat to develop (Carey 2003; Franklin et al. 2000). The discrepancy in stand size between WDOE and the Old-Growth Definition Task Group illustrates the different purposes served by old-growth definitions, and the need to adapt to fit the intended purpose.

In recognition of the fact that wetland trees may be stunted, the WDOE wetland rating system emphasizes the importance of age, rather than size. The emphasis on age is consistent with the purpose of the rating system, which is intended to identify rare and functionally valuable wetlands, and wetlands that are very difficult or impossible to replace. The age emphasis is also consistent with the intent of the interim old-growth definition: "The age alternative to size is to accommodate low-quality sites where Douglas-firs are unable to attain large diameters even in three or four centuries" (Old-Growth Definition Task Group 1986). In practice, however, it is difficult to determine the age of a tree, particularly a large tree, so most people will rely on size rather than age when classifying a forested wetland.

It is important to note that the size guidelines in the interim old-growth definition were intended as minimum standards, not averages. The intent was to include less productive old-growth sites (sites where trees grow slowly) by setting a low minimum size standard that would encompass “nearly all the old-growth stands for which we have data” (Old-Growth Definition Task Group 1986).

To determine size criteria for the interim old-growth definition, researchers first identified certain stands of trees as old-growth, based on ecological characteristics. The size and age characteristics of dominant trees in these stands were measured, and the mean size and age calculated for each stand. Using these means as a reference, the minimum size for old-growth was set in the “low to very low range." The Old-growth Definition Task Group apparently did this by a judgment call: "These criteria for identifying old-growth forests are based on limited sampling and minimal values; that is, the lowest values generally encountered" (Old-Growth Definition Task Group 1986).

Later studies published by the Forest Service in 1993 sampled a large number of stands, and set the minimum size criterion one standard deviation below the mean of the means of the sampled stands. In these later studies, all trees larger than 5 inches dbh (12.7 cm) were included in the stand statistics. The mean dbh in this case was the quadratic mean, which is a little larger than the arithmetic mean. The quadratic mean compensates to some degree for the inclusion of small trees in the sample. This quadratic mean dbh was plotted against stand age, which was "based on the oldest cohort of trees where there were at least 10 per acre" (USDA Forest Service 1993).

According to the interim old-growth definition, western red cedar, Sitka spruce, or western hemlock can be substituted for Douglas-fir when applying the definition to stands not dominated by Douglas-fir (Franklin and Spies 1991; Old-Growth Definition

Task Group 1986). In an effort to be more specific, the later old-growth definitions published by the Forest Service in 1993 contained a series of criteria for different forest types and site classes (low or high productivity). The western hemlock series report (USDA Forest Service 1993) recommended a minimum size criterion of 21 inches (53 cm) for *old-growth* western hemlock on low-productivity sites, much smaller than the 32 inches (81 cm) of the interim definition. On the most productive sites, such as the west slope of the Olympic range, the dbh size criterion could be as large as 42 inches (107 cm). With these criteria, older, slow-growing trees on less productive sites are counted as old-growth, even if their average dbh is relatively small. This is consistent with the intent of the interim old-growth definition. Unlike the interim definition, however, trees that attain a large size at a relatively young age are not counted as old-growth.

In 1995, the Northwest Forest Plan monitoring program adopted standards for vegetation mapping based on a report by a study group called the "The Vegetation Strike Team" (Hemstrom et al. 1998). This report set thresholds of 20 inches (51 cm) dbh for mature, and 30 inches (76 cm) dbh for old-growth forest, smaller than the criteria of the interim definition. These categories have been used to map forest types in forest inventories, based on the quadratic mean diameter of dominant and codominant trees. Since the quadratic mean is slightly larger than the arithmetic mean, the resulting criteria are lower than they would be if the arithmetic mean were used (Hemstrom et al. 1998; Moeur et al. 2005).

Old-growth definitions have continued to evolve. One approach is to use a more graduated old-growth index, to define "various degrees of old-growthiness" (Franklin and Spies 1991). An example is a system for inventories of old-growth forests on Washington state lands, published by the Washington Department of Natural Resources (Franklin et al. 2005). This method assigns an old-growth index to a stand based on attributes measured in forest inventories. It does not substantially change old-growth definition parameters, and does not address the special case of forested wetlands. Unlike the 1993 definitions from the Forest Service, this method emphasizes tree size rather than age. The result is that relatively young stands with large size are counted as old-growth. The emphasis on tree size works against the inclusion of slow-growing trees as old-growth, with the logic that slower-growing stands take longer to develop old-growth characteristics. With this method, age matters less than the presence of certain old-growth characteristics.

With some approaches to the definition of old-growth, an argument could be made to increase the minimum age criterion for sites with slow growth, such as forested wetlands, because these sites take longer to develop the classic old-growth characteristics. Wetland forests are different, however, from upland forests, so these old-growth characteristics are not directly applicable to wetlands. Age criteria in the WDOE definitions of mature and old-growth forest are based on general patterns of growth for these tree species, and there is no clear reason to revise them without further study of wetland forest characteristics. Therefore, in this study, the age criteria for mature and old-growth forested wetlands are accepted as given, and used as the basis for evaluating the size criteria.

3 Methods

The methods used to derive these old-growth forest definitions required sampling a number of old-growth stands, to find the mean age and diameter. The ages of large trees were measured by cutting them down, or by comparing them to nearby stumps of similar size. If enough old-growth stands are sampled, a picture of the normal distribution of stand characteristics emerges. There are not enough old-growth wetland stands available to use these methods for forested wetlands, because mature and old-growth forested wetlands in the Puget Lowlands are extremely rare. Instead, in this study, data for dominant and codominant trees from a number of wetlands are combined using linear regression, with a natural logarithmic transformation. This growth curve is then used to estimate the average size of trees 80 years or 200 years old.

Some sampling sites had mature forest stands. Comparing the criteria of the mature and old-growth definitions to summary statistics for these mature wetland stands provides an additional assessment of the usefulness of these criteria.

3.1 Sampling and Data Groups

Trees in this analysis were growing in forested wetlands in the Puget Lowlands ecoregion. Data collected include location, tree species, diameter at breast height (dbh), height, age at breast height (abh), soil type, soil moisture, and plant associates. Diameter was measured with a dbh tape, using standard protocols (Daniel et al. 1979; Forest Club UBC 1971). Height was measured using a clinometer and a measuring tape (or optical rangefinder). Soil was sampled to a depth of at least 18 inches (45 cm), and classified broadly as organic or mineral (defined below). All trees sampled were growing in jurisdictional wetland, as determined by standard wetland indicators – wetland hydrology, hydric soil, and hydrophytic vegetation, as defined by the *Washington State Wetlands Identification and Delineation Manual* (WDOE 1997).

Age was determined by extracting a core with an increment borer. The core was mounted, sanded, and the rings counted under a dissecting microscope. If the center rings were not present in the core, the number of missing rings was estimated. This was done only when the rings present in the core provided confidence in estimating the position and width of missing rings. Most age extrapolations were less than four years. Larger estimates, up to 11 years, were used for some older trees, but in all cases the estimate was a small percentage of the total age of the tree. Cores that were not close enough to the center to allow a reasonable estimate of the total age of the tree were discarded.

The age determined by tree coring is called "age at breast height" (abh) because it is the number of rings at the height at which the core was taken. This age does not include the years it took the tree to grow to breast height (defined as 4.5 feet or 1.4 m). To estimate the total age of a tree, it is necessary to add a correction factor for the years required to reach breast height. Age correction factors used in this analysis are from *Forestry Handbook for British Columbia* (Forest Club UBC 1971), for sites in coastal British Columbia with medium productivity. These factors are listed under the heading "Abh adj." in Appendix A, Table A-1. The tree age criteria in old-growth definitions refer to total age, not age at breast height.

It can be difficult to measure the age of a large tree. The longest increment borer available for this study was 24 inches long. This allows coring of trees up to about 40 inches (100 cm) in diameter. The largest tree successfully sampled in the study was 34 inches (89 cm) in diameter. Larger trees were attempted, but the core was incomplete, not reaching the center. Other borers used by volunteers were shorter. Therefore, large trees may not have been sampled simply because the borer was not long enough.

Even when the borer is long enough, coring a large tree can be extremely difficult and time-consuming. Simply screwing the borer into the tree is much more difficult than with a small tree, and it is harder to find the center on a large tree. Many large trees have heart rot, which makes coring useless. If the center of the tree is soft, the borer may lose traction and become stuck, requiring extreme effort to remove. It is not unusual to spend a large amount of time coring a large tree, without extracting a usable core.

For these reasons, large trees are under-represented in the sample, even when present on the sampling site. Heart rot, which is also present in some smaller trees, has an additional effect on the data of removing all trees with soft centers from the sample. It is possible that trees with heart rot grow at a different rate from trees without rot. If trees with heart rot grow more slowly, then the dataset may be skewed toward faster-growing trees.

Sampling sites were divided into two groups on the basis of soil composition – organic or mineral. Organic soils, also called Histosols, are composed of the remains of plants, and are usually classified as "very poorly drained." Sandy soils with more than 20 percent organic material by weight in the upper 16 inches (41 cm), or clayey soils with more than 30 percent organic material in the upper 16 inches, are considered organic soils. All other soils are classed as mineral (Tiner 1999). The identification of a soil as organic or mineral was done in the field, so exact percentages by weight were not calculated; however, the distinction was clear in most cases. Many organic soils in wetlands in western Washington are composed almost entirely of accumulated plant material. For example, Hylebos Wetland is mapped as Seattle Muck soil, a deep organic soil with layers of peat and mucky peat formed from sedges and wood (Snyder et al. 1973).

Sphagnum bogs have organic soils, but trees in sphagnum bogs are often severely stunted, so these bogs are grouped separately from minerotrophic wetlands in the data analysis. If sphagnum bogs were included in the data with other sites, the range of variation would be too great to draw useful conclusions. The distinction is in some cases unclear, but it is useful for the purpose of focusing the analysis on a particular range of variation.

There is another reason for considering sphagnum bogs separately. Under the WDOE rating system, forested sphagnum bogs are rated Category I, regardless of the age of the forest. Wetlands that are not sphagnum bogs must have one acre (0.4 hectare) or more of mature or old-growth forest to be rated Category I; therefore the mature forest size criterion is more consequential for minerotrophic forested wetlands than it is for sphagnum bogs.

It is not always clear whether or not a particular forested wetland should be classed as a sphagnum bog. In this study, the distinction is made according to the guidelines in the WDOE wetland rating system (Hruby 2004). Bogs have organic (peat or muck) soils, but other wetlands also may have organic soils. If a wetland is forested, has organic soil, and has any bog indicator plant species or combination of species (from the WDOE bog plant list) with greater than 30 percent cover, it qualifies as a bog. On this basis, if a sampling site had a significant amount of a bog indicator species, and had organic soil, it was classified as a bog for the data analysis.

For example, one of the sampling sites was a forested wetland called Lilliwaup Swamp, adjacent to Lilliwaup Creek in Mason County. The dominant trees in this swamp were western red cedar and Sitka spruce, and the entire wetland had deep mucky peat soil. One area had significant amounts of Labrador tea (*Ledum groenlandicum* Oeder*)*, a plant on the list of bog indicator species. Therefore, data from this section of the wetland (Lilliwaup areas A and D) are analyzed separately from the rest of the site. Trees in this area were much smaller than trees in other parts of the site, but relatively old, so the distinction served the purpose of distinguishing a site with very stunted trees from the rest of the data.

Another part of Lilliwaup Swamp (designated area F) had some sedges (*Carex* spp.) and live sphagnum (*Sphagnum* spp.), but the cover from these bog indicator species was less than 30 percent, so the area was not classified as a bog by these rules. Trees were somewhat stunted, but were generally larger than trees in areas A and D.

Hylebos Wetland, in Federal Way, probably developed as a sphagnum bog, but is now in a late stage of bog succession. A plant list published by the Friends of the Hylebos Wetlands (2001) indicates that some bog species were found there, and the soil is a deep peat with mosses, but an examination of the sampling site and surrounding area found only one small individual of Labrador tea and no live sphagnum moss. Therefore, even though this wetland had some characteristics of a bog, it did not meet the criteria for a bog under the WDOE definition. Hylebos Wetland has significant flow in and through the wetland, hydrology that is consistent with its minerotrophic classification. This is at times a fuzzy distinction, and Hylebos Wetland is a good example of the difficulty of applying strict categories to natural systems.

One grove of western hemlock trees sampled in Hylebos Wetland (designated area A) formed a slightly elevated mound of interlocking roots. The trees were small for their age compared to hemlocks in the rest of Hylebos Wetland. Although this grove had some mossy peat in the soil, no live sphagnum was found. It appeared to be a raised peat bog, where the peat extends above the surrounding ground level. The vegetation in this small area was similar to the *Tsuga heterophylla/Sphagnum* spp. plant community described by Kunze (1994), except for the virtual absence of sphagnum, Labrador tea, or other bog species. Skunk cabbage grew around the edges of this grove, and overall the site matched the *Tsuga heterophylla-Thuja plicata/Lysichiton americanus* plant community. It may be that this grove was more ombrotrophic and more deficient in nutrients than the surrounding wetland; however, it had few bog indicator plants and no live sphagnum, so it did not qualify as a bog by the rules of the rating system.

Table 1 displays the number of trees and sites sampled for four tree species. These data are a subset of data collected by Cooke Scientific, and do not include sites that qualified as sphagnum bogs under the WDOE wetland rating system. Summary statistics for age and diameter are presented in Appendix B, and for height in Appendix C. For complete data tables see Appendix D.

Table 1. Sample Sites and Counts	western red cedar *Thuja plicata*	Sitka spruce *Picea sitchensis*	western hemlock *Tsuga heterophylla*	red alder *Alnus rubra*	Totals
Trees Sampled	43	60	45	105	**253**
Number of Sites	10	10	9	26	**33**

3.2 *Analysis methods*

The first part of the analysis is an estimation of site indexes for some of the study sites. This provides a rough estimate of growth rates relative to other sites. The second part is a comparison of sampled stand characteristics to existing standards. Next, linear regression is used to estimate the average diameter of wetland forest stands 80 or 200 years old. These size estimates are compared to accepted size criteria for mature and old-growth forests.

3.2.1 Site index

Site index is a measure of forest productivity, and productivity is related to growth rate. Site index can be defined as the average height of dominant or codominant trees at a specified age, usually 50 or 100 years. The average height, and therefore the site index, is higher on more productive sites (where trees grow quickly), and lower on less productive sites (where trees grow slowly). Sites may be characterized as high, medium, low, or poor productivity, based on site index. The height of dominant trees is less affected by crowding than is their diameter, so height is a better way to gauge the productivity of a site, particularly for young trees.

In this analysis, standard site index equations (Henderson et al. 1989) were used to calculate site indexes for some of the sites in the dataset, and to estimate an average index for each species (see Appendix C, following Table C-2, for equations used). The tree species analyzed in this study are commercially harvested, and much information has been published on their growth rates in the form of site index tables, graphs, and equations. Coast pine is the exception; available site indexes for *Pinus contorta* are for the inland variety, and do not apply to the coastal variety.

Site index equations are usually intended for single-species stands of uniform age and density. In forested wetlands, tree distribution is patchy, species are mixed, and there may be a wide range of ages. Also, the increased importance of small-scale habitat factors in wetlands makes site index a less useful measure in wetlands than it is in upland sites, because wetland trees are responding to factors other than the general quality of the site. Nevertheless, site index can be informative as a rough indication of how the average growth rate of trees on a site compares to other sites. In this study, this productivity assessment was made by comparing calculated site indexes to graphs found in *Forested Plant Associations of the Olympic National Forest* (Henderson et al. 1989) and the *Forestry Handbook for British Columbia* (Forest Club UBC 1971). These reference site index equations and graphs are for forests in low-elevation coastal areas of the Pacific Northwest and British Columbia.

In the Snohomish Estuary samples, there is such wide variation in the data that it seems these samples must include trees with damaged or atypical tops. Since site index should be based on typical large, dominant, undamaged trees, some of the shortest trees were excluded from the site index calculations. For other sites as well, some shorter trees were excluded if they were much shorter or younger than other trees in the group.

After trees mature, at about 80 to 120 years of age for conifers in the Pacific Northwest, their height increases much more slowly, and many older trees have broken or damaged tops. Therefore, height is of little use for estimating the ages of mature trees. Diameter, even though it is highly variable, is a better way to estimate the ages of older trees, and is the measurement used for size criteria in old-growth definitions.

3.2.2 Dbh Estimates

Analysis of the diameter/age relationship in this study has three parts:

1) Evaluate specific wetland stands using the WDOE mature and old-growth forest criteria.
2) Estimate expected size of wetland trees at 80 and 200 years of age, based on a linear regression of size and age data.
3) Compare expected values based on linear regression to the size criteria for mature and old-growth forested wetlands, and to the statistics of sampled stands.

For the linear regression analysis, data from different wetlands were grouped by species, then by soil type. Most of the trees sampled in the study were growing in organic soils (peat, muck, or mucky-peat). Red alder and Sitka spruce are well represented with data from both organic and mineral soils, so these species were analyzed for both soil types. For western hemlock and western red cedar, only those trees growing in organic soils were included in the analysis. There are very few samples of these species from mineral soils. Because of the small sample size, these data were not used, although they fit in well with the data from organic soils.

The size/age relationship for trees is an S-shaped, logistic function. The growth curve begins with a concave portion in which early growth increases exponentially, followed by a middle portion at first linear and then convex as growth slows, and finally a linear, nearly horizontal portion as growth becomes very slow in old age (Figure 2).

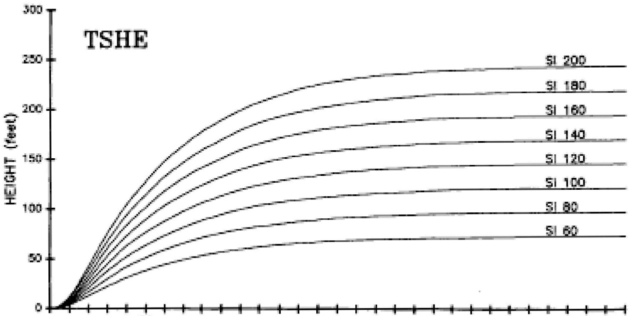

Figure 2. Site index curves for western hemlock, illustrating the S-shaped growth function. (Henderson et al. 1989)

Exponential functions are used to model growth. The data for this study, however, are located in the middle portion of the growth curve, and can be modeled with simpler functions. The convex portion of the curve can be closely approximated with a logarithmic function of the form: Size = a(Ln(Age)) + b, where a and b are coefficients, and Ln is the natural logarithm. It can also be modeled with a reciprocal function of the form: Size = a(1/Age) + b. To determine the best model for the data, both of these approximations of the growth curve were used to generate estimates of diameter for a given age.

In both cases, the correlation coefficient is much higher than with untransformed data. The reciprocal transformation produces estimates that are slightly different from the logarithmic transformation. At 80 years of age, some species have a larger estimated diameter with the reciprocal transformation, and others smaller. At 200 years, all size estimates are lower with the reciprocal correlation, because the reciprocal curve flattens more at high age values.

The differences between the reciprocal model and the logarithm model are small, but the logarithm model has some advantages. The correlation coefficient is slightly higher with the logarithmic transformation in all but one case, and the slightly larger estimates of diameter for old trees appear graphically to be a better fit with the data. Using these larger size estimates also results in less difference from existing standards.

For these reasons, conclusions in this study are based on a linear regression with a natural logarithmic transformation of the age variable. Results of regression modeling are compared to the accepted definitions for mature and old-growth forests, to evaluate the usefulness of these definitions when applied to forested wetlands.

A 90 percent confidence interval is used to determine the significance of the difference between the expected diameter of trees 80 or 200 years old and the size criteria. This interval was calculated using a standard linear regression equation for the interval estimator of the mean of the dependent variable (Keller 2001). Results were checked using Microsoft Excel with the Data Analysis Plus add-in (Keller 2001). Graphs, statistics, and linear regression results were generated with Microsoft Excel version X for Macintosh.

3.2.3 Variation and Correlation

Estimating the size/age relationship for a given site is best done in an even-aged stand of uniform density, with only one tree species, and with all trees growing in essentially the same conditions. For upland sites, differences in growth are due in large part to differences in available moisture, sunlight, and nutrients. In wetlands, water is readily available, and too much water becomes one of the limiting factors. Trees take advantage of small hummocks and nurse logs to root above the saturated soil, and small differences in situation can result in large differences in growth. Individual trees respond to these small-scale habitat differences, resulting in wide variation in growth rates of wetland trees, even within the same site.

The inherent variability in tree growth rates has some consequences for this study of forested wetlands. First, a large sample size is needed in order to make useful statistical observations. Second, the coefficient of determination, or R^2, for a best-fit regression curve is likely to be low, even with a large number of samples. No correlation curve will explain all of the variation in tree size as a function of age, because other factors are involved. On the other hand, this study is much more focused and limited in scope than was the original research that created the mature and old-growth forest criteria. The purpose of this study is to refine these definitions for forested wetlands in western Washington, and the factors included in the analysis are appropriate for this purpose.

There are other difficulties with the use of linear regression to analyze tree growth rates. One of the required conditions for use of linear regression is that y has constant variability for all x; that is, for all tree ages, diameter should be normally distributed with the same standard deviation. This condition is violated, because differences in growth rates will necessarily result in greater divergence in size as trees get older. Therefore, variability in size is not constant, but increases with stand age. This is a problem, but the change in variability is not large within the range of the data under consideration.

Residual plots can be used to analyze variability. Residuals are the differences between the actual and expected values in a linear regression. If variability is constant, the residuals will be randomly distributed with no overall pattern. Residuals can also reveal trends in the data that are not accounted for by the linear regression relationship. With the exception of the western hemlock analysis, residual plots from the regression analyses in this study show no clear pattern, supporting the conclusion that variability is constant enough to satisfy required conditions (see data plots and residual plots, Appendix A, Figures A-1 through A-7). Data for western hemlock increase in variability as age increases, so the condition of constant variability may not be satisfied in this case. See the analysis of western hemlock, section 4.3.4, for further discussion of this issue.

The focus on sampling older, dominant trees, combined with the scarcity of very old trees, resulted in an accumulation of data around the middle of the age range, 60 to 120 years of age. The low number of older trees in the dataset reduces the statistical significance of the correlation. The clustering of data gives a good idea of the average size in the middle of the age range, but the slope of the regression line as it extends to older ages is determined by a small number of points at the old age extreme. Therefore, estimates of the average diameter of old-growth trees are limited by a lack of data.

In addition to variability between individual trees in a wetland, there are, of course, differences between wetlands. To limit variability in the data, sphagnum bogs were analyzed separately, as discussed above. With trees grouped by species, and the extreme case of bogs grouped separately, the differences between trees in an individual wetland are generally greater than or similar to the differences between trees in different wetlands. The data from different sites fit together well, reinforcing rather than obscuring the central tendencies of the data.

An exception is the data from the Snohomish River freshwater estuary. These Sitka spruce trees show wide individual variation, but are on average significantly smaller than Sitka spruce trees from other sampled sites. The division of data into two groups based on soil type separates the Snohomish estuary from the rest of the sites, but the difference in growth rate may be due to the estuarine conditions rather than the soil type. The small number of Sitka spruce sampled in mineral soils from other sites are more similar to trees sampled in organic soils than they are to trees in the Snohomish estuary.

It is important to note that the estimates and confidence intervals resulting from this regression analysis are not estimates of the likely size of individual trees. They are estimates of the *average* size of trees of a given age. Variation among individual trees is so large that it is not possible to reliably estimate the size of an individual tree from its age, or vice-versa, with a reasonable degree of precision. For example, the regression model predicts with 90 percent confidence that an *individual* western hemlock 200 years old (in a forested wetland that is not a sphagnum bog) will have a diameter at breast height between 17 and 34 inches (43 to 86 cm), a very wide estimate range.

3.2.4 Outliers

A small number of sampled trees had growth/age characteristics so far from the norm that they were deemed likely to be errors. If possible, these data points were checked against the original field records, or by actually revisiting the site. In most cases, it was not possible to revisit the site or to identify the individual tree to check the data, so some data points remained questionable and were not used.

Some extreme values may be due to violation of the parameters of this study. These data are part of a more general effort to measure growth characteristics in forested wetlands, so some data may have been collected with a less restricted understanding of the sampling criteria. These could include samples from sites that were sphagnum bogs according to WDOE guidelines, but not clearly identified as such.

All sampled trees were supposed to be dominant or codominant, but it is possible that not everyone had the same understanding of what this means, or that some smaller trees were sampled with the idea that they would grow into dominant trees. Small trees may actually be suppressed, or otherwise stunted, and not representative of the growth rate of dominant trees on the site. Suppressed or subdominant trees would be unusually small for their age, but this may not be obvious in the field. A small number of outliers were removed from the dataset for this reason.

One possible source of error is in the identification of a wetland. All trees sampled in the study are supposed to be growing in a wetland, according to standard wetland identification protocols. It is possible that some trees were sampled at the edge of a wetland, outside the wetland boundary. Large trees at the edge of a wetland may appear to be rooted in the wetland, but frequently have roots extending to drier soil nearby. In these conditions there is plenty of moisture, but stress from the high water table is relieved, and trees may grow very quickly. Within the wetland, saturation of the soil slows the growth of trees. The distance between stunted trees in the wetland and large trees at the edge of the wetland may be very small, and the wetland boundary may be unclear. Because of this ambiguity, some trees that were actually rooted outside a wetland may have been included in the dataset. These trees could skew the data toward larger size for a given age.

Even within a wetland, environmental factors cause wide differences in the sizes of trees. For example, in forested wetlands stand density is often low compared to typical upland stands, with many canopy gaps. Sampling of forest stands normally would avoid trees that are at the edge of a stand, or in the open with little competition. In wetlands, these distinctions are difficult to maintain. Trees may be in scattered, open groves, or in stands with wide age and size variation.

Disturbance may also be a factor in variability. For example, in Lilliwaup Swamp there was a gravel roadbed about 50 cm higher than the surrounding wetland. Along this road were some of the largest Sitka spruce trees in the wetland, some exceeding 30 inches (76 cm) in diameter, but one that was sampled was only about 70 years old. In this nutrient-poor wetland, these trees may have been fertilized by soil brought in for the road, and their roots extended into this elevated soil.

Forest sampling ideally focuses on trees that are unaffected by individual microhabitat differences. The idea is to typify the stand by measuring trees that reflect the climate and soil conditions. Dominant and codominant trees on good sites have a relatively constant growth rate, gradually slowing with age, providing an indication of the growth potential of trees on the site. In wetlands, such "normal" trees are the exception rather than the rule. Wetland trees are stressed, and many individual trees have wide fluctuations in growth rate from year to year, reflecting changes in the height of the water table and other environmental conditions. A wetland tree may be flooded by a small increase in the height of the water table, suppressing its growth for that year; nearby upland trees may be unaffected by this small change. In another year, a small drop in the water table that does not have much affect on the growth of upland trees may allow the wetland tree to "breathe," resulting in increased growth. This fluctuation in growth rates can result in higher variability in wetlands than in uplands. Occasionally, a wetland tree finds the right combination of conditions to grow quickly and unimpeded for its entire life. These trees may be outliers, very large for their age. The occasional large tree may be an indication of site potential, but it is not indicative of conditions experienced by most of the trees on the site.

In summary, it is likely that some low size values represent suppressed or subdominant trees, and should be removed from the dataset. It is also likely that some large size values are from trees that were at the wetland edge, but some are simply trees that grew faster than their peers.

Outliers create two difficulties. If an outlier is a very old tree, but unusually large or small for its age, it can pull the best-fit line away from the true average value for the population. Older trees have a big influence on the slope of the line, since there are few samples in the upper part of the age range.

If the outlier is a middle-aged tree, the range where most of the data are clustered, the effect is to obscure the linear relationship. Outliers extend the range of variability of the dependent variable (size). The average or best-fit value may be about the same with or without the outlier, but the correlation coefficient and significance of the correlation are improved if the outlier is removed.

Therefore, in most cases the one or two highest and lowest outliers have been removed from the data analysis. This has little effect on the predicted size values for middle-aged trees. Also, if an old tree had a dramatically large or small size, it was removed from the analysis, since the value may not be representative, and each individual point in the higher age range has a strong influence on the slope of the linear regression model. More specific information on outliers is included in the discussion of results for each species.

4 Results and Discussion

4.1 Estimates of Site Index

Site indexes can provide a rough idea of the forest productivity of a site, relative to other sites. A site that produces larger, faster-growing trees has a higher site index than a site with a slower growth rate. Estimated site indexes are presented in Appendix C, and site index equations at the end of Appendix C.

In general, estimated site indexes indicate that the stands sampled in this study are in a low to moderate range of productivity; therefore, trees in forested wetlands are small on average, compared to trees of the same species on other sites. Site indexes are below the middle of the range in all cases, indicating they are on the low side of the range of productivity, but not extremely so (see the end of Appendix C for standard site index ranges). This finding is consistent with the description in Topik, et al. (1986) of the western hemlock/skunk cabbage plant association as "low to moderate" in productivity.

Some calculated site indexes are very low – Sitka spruce in Lilliwaup Swamp, Sitka spruce in the Snohomish estuary, and western red cedar in a more ombrotrophic portion of Lilliwaup Swamp (areas A and D). Site indexes for western hemlock are a little lower in two sphagnum bogs than in other sites.

Site indexes calculated for red alder are very close to values cited in the *Snohomish County Soil Survey* for wetland soil types (Debose and Klungland 1983). The estimated values, about 80 feet at 50 years of age, are on the low side of the reference site index range of 40 to 140 feet.

This rough estimation and comparison of site indexes shows that forested wetlands in the Puget Lowlands are generally in a low to moderate range of productivity, and some are very low. The wetlands with the lowest productivity were in the Snohomish estuary, and or in areas with bog indicator species. The site index equations used in these calculations were not intended for mixed-species stands, so these results are a rough approximation.

4.2 Old-growth and Mature Forest Criteria

Part of the analysis of diameter is an evaluation of sampled stands according to accepted criteria for mature and old-growth forests. This evaluation is possible for sites that were sampled more extensively: Hylebos Wetland, Lilliwaup Swamp, Little Egypt Swamp, and Snohomish estuary. Summary statistics for these sites may be compared to the criteria in the definitions. It is also useful to consider some of these sites in smaller sections. Some large sites had distinct areas that were identified separately in sampling, and were large enough and distinct enough to be analyzed as separate stands, with cohorts of trees similar in age.

Ages of trees discussed in this section are total age, unless otherwise indicated. Total age is an estimation of the actual age of the tree, derived by adding a correction factor to the age at breast height. Summary statistics in this section use a correction factor of 8 years. This correction factor is appropriate for these species on sites with medium productivity. Therefore, it is likely that trees on low-productivity sites were actually a few years older than estimated in these calculations.

4.2.1 Old-growth Evaluation

The WDOE old-growth criteria require "at least 8 trees/acre (20 trees/hectare) that are at least 200 years of age **or** have a diameter at breast height (dbh) of 32 inches (81 cm) or more" (Hruby 2004). Most sampling sites did not have any trees this old or this large, because of logging within the last 100 years. Many sites had large stumps, but few large trees. In some cases, large trees were present, but not sampled. Many large trees have soft centers (which prevents successful coring), and some are too large to core, so large trees are under-represented in the data even when they were present on the site.

Little Egypt Swamp area B had some large trees, and qualified as old-growth based on the number of trees larger than 32 inches (81 cm) in diameter. These included Sitka spruce and western red cedar too large for coring. One western red cedar was 45 inches (115 cm) in diameter. The core was incomplete, but contained 228 rings, so this tree was well over 200 years old. Another 202-year-old red cedar was only 22 inches (57 cm) in diameter. The site qualified as old-growth because there were enough large trees, but some of the large trees were much older than 200 years, and some 200-year-old trees were smaller than the size threshold. None of the younger trees sampled were large enough to be counted as old-growth. Some large Sitka spruce trees may have been younger than 200 years old, but these were not sampled (the ones that were attempted had soft centers).

In Hylebos Wetland, one western red cedar was 206 years old, with a diameter of 32 inches (82 cm), just passing both the age and the size criteria. A Sitka spruce 174 years old had a diameter of 35 inches (89 cm); another Sitka spruce only 121 years old exceeded the old-growth size threshold, with a diameter of 33 inches (84 cm). Hylebos Wetland also had a few Douglas-fir trees, some relatively large. One Douglas-fir 33 inches (83 cm) in diameter was only about 95 years old; another 31 inches (78 cm) in diameter was about 106 years old. At the other end of the size range, a western red cedar 161 years old was only 22 inches (56 cm) in diameter, and a Sitka spruce 184 years old had a diameter of 25 inches (63 cm), well below the minimum. Hylebos Wetland had one very large Sitka spruce, 55 inches (139 cm) in diameter, and a large Douglas-fir snag 48 inches (123 cm) in diameter, both too large for coring. These large trees perhaps indicate the potential for dominant trees on this site. In general, there were not enough old or large trees for Hylebos Wetland to qualify as old-growth. The older trees were distributed both above and below the minimum size criterion for old-growth.

Lilliwaup Swamp area F was an old-growth stand, based on the number of large and old trees. Of seven trees sampled, all were older than 175 years, and three were 200 years or older. Only one of these trees was larger than the minimum size criterion, a 193-year-old western red cedar with a diameter of 32 inches (82 cm). There were larger trees with too much rot to sample, but they appeared to be much older. There were also some very large stumps. It seemed that the dominant trees were removed from this stand when the area was logged, probably in the 1920s, and the trees that remained were the ones considered not worth the trouble. Therefore, it is questionable to call these the dominant trees. Nevertheless, these are the dominant trees on the site now. In general, most of the old trees in this old-growth stand were not large enough to pass the minimum size criteria, except for some that were probably much older than 200 years. This area had some bog indicator species, and the plant community was different from that found in other portions of Lilliwaup Swamp, with sedges and a small amount of live sphagnum, but it did not meet the WDOE bog criteria.

Most trees sampled in other parts of Lilliwaup Swamp did not exceed the old-growth size threshold, but some younger Sitka spruce came close. One large spruce was only 72 years old, but 32 inches (81 cm) in diameter, meeting the size criteria for old-growth trees. This tree was larger than most in the vicinity, but younger than many of the other trees.

In summary, Little Egypt and Lilliwaup Swamp each contained an old-growth stand, when assessed with the existing criteria. This result is appropriate, since they do contain large, old trees; however, most old trees were below the 32-inch (81 cm) minimum. The mean age of trees sampled in Lilliwaup area F was about 202 years, but the mean diameter was only 25 inches (63 cm). In Lilliwaup, Little Egypt and Hylebos, some trees reached sizes exceeding the old-growth minimum size criterion before 200 years of age, but most did not.

4.2.2 Mature Forest Evaluation

The mature forest criteria are stated in a different way from the old-growth criteria: "the largest trees are 80-200 years old **or** have average diameters (dbh) exceeding 21 inches (53 cm)" (Hruby 2004). Like the old-growth criteria, the mature forest age criterion is stated in terms of "the largest trees"; however, the size criterion refers to the *average* diameter (presumably of the largest trees). The size criterion would be met more easily if it also referred to "the largest trees," rather than the average size, since average size is a more specific requirement. Therefore, the criterion for age is more lenient than the criterion for size, since it is less specific about the composition of the stand.

Little Egypt Swamp was sampled in two sections that are not contiguous, so they are examined separately. Area B was identified (above) as an old growth stand because of the presence of large trees. Area A did not have enough old or large trees to qualify as old-growth.

The samples from Little Egypt area A include two trees that are substantially older and larger than the others. Leaving out these two trees provides a relatively even-aged cohort of dominant trees. The sample of six trees had an average total age of 93 years, and average diameter of 21 inches (54 cm). Even without the older, larger trees, this stand passed both the age and the size criteria, but at an age 13 years older than the 80-year minimum. Since the trees averaged 21 inches (54 cm) in diameter at 93 years, the average growth rate was about 0.23 inches (0.58 cm) per year. Mature trees grow more slowly, so they likely had been growing at a rate somewhat slower than this overall average; even with a reduced rate of growth, however, it is likely that the trees grew more than 0.5 inch (1 cm) in 13 years. So, the average diameter of this cohort of trees was smaller than 21 inches (53 cm) when the average age was 80 years, and on this site the stand of trees has to be older than 80 years to have an average dbh larger than 21 inches. The size criterion is too large, but not by a large amount.

Hylebos Wetland exceeded the minimum criteria for both age and size for mature forested wetlands. Total age averaged 107 years, with average diameter of 23 inches (57 cm). As at Little Egypt Swamp, it is likely that the average diameter was smaller than 21 inches dbh (53 cm) when the average age was 80 years, but the difference was probably small. The stand probably passed the minimum size criterion sometime between 80 and 100 years of age.

One section of Hylebos Wetland, area A, had a cohort of trees similar in age, and these trees were smaller for their age than the trees in the surrounding area. This stand, (also discussed in section 3.1) was composed almost entirely of western hemlock, with an understory of salal. Four trees sampled in this cohort had an average age of 108 years, and an average diameter of 18 inches (46 cm). This stand of trees did not pass the minimum size criterion for mature forest, even at an average total age of 108 years.

Lilliwaup Swamp Area F was described above as an old-growth stand. Other areas of Lilliwaup Swamp did not qualify as old-growth, but they met the mature forest criterion for age. Grouping the trees from one section of the site – areas B, B2, and C – provides a relatively even-aged cohort, with 15 trees sampled. Average total age was 76 years, with 18.7 inches (48 cm) average diameter. This stand was close to 80 years of age on average, and had enough older trees to pass the age standard, but the average diameter was smaller than the minimum criterion for mature forest by more than 2 inches (5 cm).

Another part of Lilliwaup Swamp – areas A and D – had significant amounts of Labrador tea (*Ledum groenlandicum*), a bog indicator species. The areal cover from this bog species was near 30 percent, enough to qualify this portion of the wetland as a bog, so these areas are separated from the rest of the site for the analysis. Seven trees sampled in these areas averaged 131 years total age, with only 15 inches (39 cm) average diameter. These trees were much older than the minimum age for mature forest, but much smaller than the minimum size criterion, and more stunted than trees in other parts of the site.

Forested wetland stands in the Snohomish River freshwater estuary were smaller on average than stands of similar age in other wetlands. On Otter Island, 17 dominant Sitka spruce trees averaged 95 years total age, but only 17 inches (42 cm) in diameter. This stand was 15 years older on average than the minimum age for mature forest, but much smaller than the minimum size. Trees sampled on Spencer Island had a similar average age, 96 years, but the average size was 19 inches (49 cm). These trees were larger than those on Otter Island, but still smaller than the mature forest size criterion.

Otter Island is the most pristine, undisturbed site in the estuary. Unlike Spencer Island, it has not been diked or logged, and so is more representative of natural conditions in the estuary. Nearby Ebey Island contains some spruce trees larger than those on Otter Island, which may indicate that diking relieves the trees of flooding stress, allowing them to grow larger (Brennick 1999; Moore 1999). Perhaps this is the reason that trees on Spencer Island averaged a little larger than trees on Otter Island.

Otter Island had the oldest tree sampled in the study, but it was not particularly large – a Sitka spruce about 455 years old, but only 22 inches (57 cm) in diameter. This tree was left out of the stand average, since it is clearly from a different cohort, and it is an outlier. It was one of the largest trees on the site, but it took a very long time to grow to that size.

Silver Lake bog had a mature stand of coast pine and western hemlock. Taking both together, and averaging the largest trees of both species (N=10), the stand had an average diameter of 15 inches (37 cm), and average age of about 83 years. The largest trees were the four hemlocks; averaging them alone results in an average diameter of 19 inches (48 cm), and 81 years average age.

These examples show that even when a forested wetland stand is older on average than the minimum age criterion for mature or old-growth forest, the trees are likely to be smaller on average than the minimum size criterion. To obtain a more specific prediction of the likely average size of trees of a given age, I combined data from similar sites in a linear regression analysis. These results are presented in the next section.

4.3 Growth Rate Analysis and Expected Values

In this analysis, the middle portion of the growth curve is modeled using linear regression with a natural logarithm transformation of the age variable. Results and graphs of the linear regression are presented in Appendix A.

Ages of trees discussed in this section are total age, unless otherwise indicated. Total age is derived by adding a correction factor to the age at breast height. Correction factors vary according to species and site quality. These correction factors are for sites with medium productivity, from the *Forestry Handbook for British Columbia* (Forest Club UBC 1971). Since these sites are generally in a low to medium range of productivity, as discussed above in the analysis of site index, it is likely that the total tree ages used in this analysis of diameter are underestimated by a few years.

4.3.1 Western Red Cedar (*Thuja plicata*)

Forty western red cedar trees from ten wetland sites were analyzed to derive an estimate of diameter at breast height for 80 and 200 years of age. All were growing in organic peat or muck soils (Histosols). These results are summarized in Appendix A, Table A-1. Scatter plots, best-fit and confidence interval lines, and residual plots are shown in Appendix A, Figure A-1. Total age of western red cedar trees is estimated by adding 9 years to the age at breast height.

Predicted average diameter for western red cedar 80 years old is 18.2 inches (46 cm), with a 90 percent confidence interval of 16.7 to 19.7 inches (42 to 50 cm). This estimate is smaller than the mature forest criterion of 21 inches (53 cm) by almost 3 inches (7 cm), and the upper end of the confidence interval is 1.3 inches (3 cm) smaller.

Data for western red cedar include seven trees older than 160 years, the oldest 261 years old, providing some basis for an estimate of size at 200 years, the minimum age for old-growth. The confidence interval is wider at older ages, because of the small number of old trees in the sample. Estimated average diameter for western red cedar 200 years old is 28.0 inches (71 cm), with a 90 percent confidence interval of 25.9 to 30.1 inches (66 to 77 cm). Therefore, the size estimate for 200 years total age is significantly smaller than the old-growth criterion of 32 inches (81 cm).

The coefficient of determination (R^2) for this regression is 0.52, and the p-value is 0.00, indicating a significant correlation. The inherent variation in tree growth rates, and the importance of microhabitat factors in wetlands means the coefficient of determination will always be relatively low. For example, the diameter of individual trees near 80 years of age varies by a factor of two or more, even in the same wetland site. Visual inspection of the scatter plot indicates a good fit of the line to the data. The residual plot shows no overall pattern, indicating that variability is constant in the range of the data, satisfying a necessary condition for linear regression.

Many western red cedars of various sizes were not sampled because they had soft centers (heart rot), which precludes measuring age by tree coring. The prevalence of heart rot may introduce a bias in the data, since only those trees without heart rot were included in the sample. If the absence of heart rot correlates with faster growth, the resulting size estimate may be skewed upward, producing a larger size estimate than would be obtained if all dominant trees could be sampled. On the other hand, if some of the trees that were too large or too soft to sample were relatively young for their size, including them in the sample could shift the results toward a larger estimate of size at 200 years of age.

As discussed above in the mature forest evaluation, Lilliwaup Swamp areas A and D had some bog indicator species, and were not included in the regression analysis. Trees in these areas were severely stunted. For example, the oldest and largest tree (a western red cedar) was about 250 years old, but only 23 inches (58 cm) in diameter. Three trees about 100 years old were all less than 15 inches (22 cm) in diameter.

These data show that mature western red cedar trees in forested wetlands in the Puget Lowlands are, on average, significantly smaller than the size criteria in the definitions of mature and old-growth forested wetlands in western Washington. These size estimates are consistent with the results based on stand averages, discussed above in section 4.2.

4.3.2 Sitka Spruce (*Picea sitchensis*), in Organic Soils

Sixty Sitka spruce trees were included in the analysis of growth rates, but they were divided into two groups by soil type. Thirty-five Sitka spruce from six wetland sites were growing in organic peat or muck soils (Histosols). Twenty-five Sitka spruce were growing in mineral soils, discussed below in section 4.3.3. Results for Sitka spruce in organic soils are summarized in Appendix A, Table A-1 and Figure A-2. Total age of Sitka spruce trees is estimated by adding 8 years to the age at breast height.

For Sitka spruce growing in organic soils, estimated average diameter at 80 years of age is 18.8 inches (48 cm), with a 90 percent confidence interval of 17.2 to 20.3 inches (44 to 52 cm). The midpoint of the estimate is smaller than the 21-inch (53 cm) criterion by 2 inches (5 cm), and the upper end of the confidence interval is smaller by .7 inch (1 cm). This estimate is significantly smaller than the mature forest criterion of 21 inches (53 cm), and is similar to the size estimate for western red cedar.

The data include four trees older than 160 years, the oldest 198 years old. Because of the small number of old trees in the sample, the confidence interval for the size estimate at 200 years is wider than it is for western red cedar. The estimated average diameter for Sitka spruce 200 years old is 29.7 inches (76 cm), with a 90 percent confidence interval of 26.7 to 32.8 inches (68 to 83 cm). Therefore, the data suggest that the estimated size of Sitka spruce at 200 years is 2 inches (5 cm) smaller than required by the old-growth criterion, but upper end of the 90 percent confidence interval includes this 32-inch (81 cm) criterion.

The coefficient of determination (R^2) for this regression is 0.42, with a p-value of 0.00, a statistically significant relationship. As with western red cedar, the variation in size at a given age is very wide, and trees near 80 years of age vary in diameter by a factor of two or more. Visual inspection of the scatter plot indicates a good fit of the line to the data. The residual plot shows no overall pattern, indicating constant variability in the range of the data.

One Sitka spruce 226 years old, but only 23 inches (58 cm) in diameter, was excluded from the analysis as an outlier. Another at the other end of the size/age range was 72 years old, and 32 inches (81 cm) in diameter; this tree was also excluded. These trees are circled on the scatter plot in Appendix A, Figure A-2, but not included in calculations.

The very wide variation in size for a given age means that a larger sample size would be helpful, but the data are sufficient to provide a good estimate of average size at 80 years of age. As with most other species in the study, there are not enough old trees in the data to confidently estimate the average size of 200-year-old trees.

These data show that mature Sitka spruce trees in forested wetlands in the Puget Lowlands are, on average, significantly smaller than the size criterion for mature forested wetlands in western Washington. The data suggest that the same holds true for the old-growth size criterion, but the data are insufficient to determine this with confidence.

4.3.3 Sitka Spruce (*Picea sitchensis*), in Mineral Soils (Snohomish Estuary)

Analysis of Sitka spruce in mineral soils included twenty-five trees from five wetland sites. Soils were composed of a mix of silt, sand, and organic material. All were in the Snohomish River freshwater estuary. Sitka spruce trees growing in organic soils (Histosols) were grouped and analyzed separately (section 4.3.2). Results and graphs are presented in Appendix A, Table A-1 and Figure A-3. Total age of Sitka spruce trees is estimated by adding 8 years to the age at breast height.

For Sitka spruce growing in the Snohomish estuary, estimated average diameter at 80 years of age is 15.4 inches (39 cm), with a 90 percent confidence interval of 13.6 to 17.1 inches (34 to 44 cm). This estimate is significantly smaller than the mature forest criterion of 21 inches (53 cm), and also significantly smaller than the estimated size for Sitka spruce in organic soils. The midpoint of the estimate is smaller than the mature forest size criterion by almost 6 inches (14 cm), a very large difference, and the upper end of the confidence interval is smaller by almost 4 inches (9 cm).

Data analyzed for the Snohomish estuary include only one tree older than 120 years. This tree was 159 years old, and 19 inches (48 cm) in diameter. Most trees in the sample were between about 70 and 115 years of age. This lack of data in the older age range results in a very wide confidence interval at 200 years, and suggests that the extrapolated estimate is unreliable. The estimated average diameter for Sitka spruce 200 years old is 24.3 inches (62 cm), with a 90 percent confidence interval of 18.8 to 29.8 inches (48 to 76 cm). The estimated size at 200 years is smaller than the old-growth criterion of 32 inches (81 cm) by a difference of almost 8 inches (19 cm), and the upper end of the confidence interval is 2 inches (5 cm) smaller. Therefore, the data indicate that the estimated size is significantly smaller than required by the old-growth criterion, with 90 percent confidence; however, at this age the model is extended beyond the range of the data, and therefore may be inaccurate.

The oldest tree growing on Otter Island was about 455 years old, and only 22 inches (37 cm) in diameter. This tree was excluded from the analysis because it is an extreme outlier. There were no other older trees in the dataset, so this unusually slow-growing tree would have a large effect on the slope of the regression line if it were included. A second outlier, growing on Spencer Island, was much larger than all the other trees sampled in the estuary, 30 inches (76 cm) in diameter. This tree was not included in the growth rate analysis.

The coefficient of determination (R^2) for this regression is 0.21, and the p-value is 0.00, indicating a significant correlation. As in other cases, the wide variation in growth rates of individual trees precludes a high coefficient of determination. Another factor is the clustering of the data in a narrow age range. This clustering probably provides an accurate estimate of the average size at 80 years, since that is near the middle of the data cluster, but the linear relationship would be stronger if the data were more spread out in age. The residual plot shows no overall pattern, indicating constant variability in the range of the data, as required for linear regression.

These results indicate that mature Sitka spruce trees in forested wetlands in the Snohomish River freshwater estuary are much smaller on average than the size criterion in the mature forested wetland definition. The same is probably true of the old-growth size criterion. These size estimates are consistent with results based on stand averages, discussed above in section 4.2.

For other tree species in this study, data from mineral soils do not appear to be significantly different from data for the same species in organic soils, but the sample sizes are small, and no statistical test was done to compare the soil groups. There are a few western hemlocks and western red cedars in the dataset that were growing in mineral soils, and they fit well with the data from organic soils for the same species, but they were not used in the analysis. Results for red alder, presented below, are also very similar for both soil types. This suggests that the difference observed with Sitka spruce may be due to the influence of the estuary, or some other factor, rather than the difference in soil type.

4.3.4 Western Hemlock (*Tsuga heterophylla*)

The western hemlock growth rate analysis included 38 trees, from 9 wetland sites; all were growing in organic soils (Histosols). Results and graphs are presented in Appendix A, Table A-1 and Figure A-4. Total age of western hemlock trees is estimated by adding 9 years to the age at breast height.

Estimated average diameter for western hemlock 80 years old is 19.3 inches (49 cm), with a 90 percent confidence interval of 18.1 to 20.5 inches (46 to 52 cm). The midpoint of the estimate is smaller than the mature forest criterion by 1.5 inches (3 cm), but the upper end of the confidence interval is only 0.5 inch (1 cm) smaller. This estimated value is a little larger than the estimate for western red cedar and Sitka spruce, but still significantly smaller than the mature forest size criterion.

The oldest tree in the dataset was 180 years old, but this is the only one older than 131 years. Most were between 50 and 100 years of age. As with other species, the small number of old trees results in a wide confidence interval at the high end of the age range. The estimated average diameter for western hemlock 200 years old is 26.7 inches (68 cm), with a 90 percent confidence interval of 24.0 to 29.4 inches (61 to 75 cm). The estimated size at 200 years is significantly smaller than the old-growth criterion of 32 inches (81 cm), even with the wide confidence interval. The results suggest that the estimated size of western hemlock at 200 years is smaller than the old-growth size criterion, but the estimate extends beyond the range of the data, and therefore may be inaccurate.

The coefficient of determination (R^2) for this regression is 0.48 and the p-value is 0.00, indicating a significant correlation. Variability is high – trees near the middle of the age range vary in diameter by a factor of two or more. Visual inspection of the scatter plot indicates a good fit of the line to the data, and the R^2 value shows a high degree of correlation.

The slope of the best-fit line is in part determined by a cluster of points in the low age range, 25 to 30 years old. These trees are similar in size, so the variability is much smaller at this end of the age range. This change in variability is reflected in the residual plot. The line is a good fit to the data, but the condition of constant variance across the range of the data may be violated in this case.

The analysis could be done without these young trees, but they increase the linearity of the data by extending the age range. Since size varies so much in the middle of the range, it is difficult to determine the slope of the best-fit line without the full range of data. Analysis without these young trees results in a very low coefficient of determination (R^2), but the estimated size at 80 years is about the same whether they are included or not.

Western hemlock trees sampled in sphagnum bogs were not included in the regression analysis. Most of these were young trees, but three were older than 80 years, and they were the largest trees sampled at the Silver Lake bog site. Average age for these three trees was 92 years, and average diameter was 18 inches (46 cm).

These results indicate that mature western hemlocks in forested wetlands in the Puget Lowlands are, on average, significantly smaller than the size criterion for mature forested wetlands in western Washington. The results suggest that the same holds true for the old-growth size criterion, but additional data are needed to make such a projection with confidence.

4.3.5 Red Alder (*Alnus rubra*), in Organic Soils

Red alder data were divided into two groups according to soil type. Analysis of growth rate in organic soils was based on 36 trees, from 12 sites. In most sites only a few red alder trees were sampled; the largest number sampled on one site was 13. Red alder is not part of mature or old-growth forest in the standard definitions such as the interim old-growth definition, except as a member of the understory. It is an early seral species, and so by definition is not dominant in a mature forest. For example, red alder may dominate early seral stages in the western hemlock/skunk cabbage plant association, but is usually much reduced by about 80 years, leaving a mixed stand of conifers with some alders in the understory (Henderson et al. 1989; Newton and Cole 1994).

The WDOE definition of mature forest is not specific about which tree species may be counted, and red alder can live to be over 100 years old, so it could play a role in some cases. Red alder trees 80 years old or older could tip the balance in the rating of a forested wetland. They are generally smaller, however, than the coniferous species with which they share the forest. Red alder in mature stands on good sites typically have diameters of 18 to 20 inches (45 to 50 cm). On wetland sites, they would probably be smaller than this typical size (Newton and Cole 1994).

In this regression analysis, the estimated average size of red alder 80 years old (using a correction factor of 5 years) is 15.2 inches (39 cm), with a 90 percent confidence interval of 14.2 to 16.2 inches (36 to 41 cm). This result is smaller than the mature forest size criterion by almost 6 inches (14 cm), and the upper end of the confidence interval is almost 5 inches (12 cm) smaller. Results and graphs are presented in Appendix A, Table A-1 and Figure A-5.

The regression line has a coefficient of determination (R^2) of 0.51, and a p-value of 0.00, indicating a significant correlation. Visual inspection confirms that the regression line is a good fit, and the residual plot shows no overall pattern.

Red alder rarely live to 200 years of age, and are typically in senescence by about 100 years of age (Newton and Cole 1994). For this reason, red alders would not be part of an old-growth rating as dominant trees, although they are important as part of the understory and the species diversity. The data for this analysis include one tree 120 years old; the rest are all less than 100 years old.

These results show that mature red alder in forested wetlands with organic soils are on average significantly smaller than the mature forest criteria, and the difference is relatively large. For red alder 80 to 100 years of age, only two out of eight trees were larger than 21 inches (53 cm) in diameter, and the best-fit line projected to 120 years of age does not exceed 18 inches (45 cm) in diameter.

4.3.6 Red Alder (*Alnus rubra*), in Mineral Soils

Regression analysis of red alder in mineral soils included 68 trees from 14 sites. Soils included sandy, gravelly, and silty loam soil types. Results are summarized in Appendix A, Table A-1 and Figure A-6. As with red alder in organic soils, the correction factor for total age was 5 years added to the age at breast height.

For red alder in mineral soils, the estimated average diameter at 80 years old is 15.1 inches, (38 cm) with a 90 percent confidence interval of 13.9 to 16.2 inches (35 to

41 cm). This result is smaller than the minimum size for mature forest by almost 6 inches (15 cm), and the upper end of the confidence interval is almost 5 inches (12 cm) smaller. These results are almost exactly the same as the results for red alder in organic soils.

The regression line has a coefficient of determination (R^2) of 0.34, and the p-value is 0.00, indicating a significant correlation. Variability is high, but the large number of data points allows confidence in the resulting model. The residual plot shows no overall pattern. Size variability increases near the middle of the age range, but decreases at the upper end of the age range, so there is no overall trend of variability. As with other species examined in this study, the variability between different sites is no larger than the variability within a site.

The data analysis confirms that, as expected, mature red alder are much smaller on average than the mature forest size criteria. The results for both organic and mineral soils are nearly the same. Even on good sites, mature red alder are generally smaller than the mature forest criterion; on these less-productive wetland sites they are much smaller than the criterion, and it is unlikely they would come into play in support of a mature forest rating based on size.

4.3.7 Coast pine (*Pinus contorta* var. *contorta*)

Coast pine is a coastal variety of the well-known lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm. ex S. Wats.) of the interior. Coast pine trees are typically more shrubby and gnarled than the straight and upright inland variety. In the Puget Lowlands, wetlands dominated by coast pine are usually sphagnum bogs. Trees in these bogs may be very stunted, and even on productive sites coast pine are generally smaller than other conifer species of the Pacific Northwest. Mature trees typically range from 6 to 20 inches (15 to 50 cm) in diameter (Burns and Honkala 1990). Because of this small size, and because most of the coast pine trees in the dataset were from sphagnum bogs, this species is considered separately in the assessment of mature and old-growth criteria.

Fifteen trees were sampled, from 4 wetland sites. Twelve of these trees came from two sites that were clearly identified as sphagnum bogs. Of the remaining 3 trees, two were growing in soil identified as silty loam, which means the site was not a sphagnum bog. These two trees are included in the analysis, because they appear to fit in well with the rest of the group, and because the overall sample size is small. They are the two oldest trees in the data, so removing them would make the linear regression much less significant.

The data include six trees older than 80 years (with an age correction factor of 10 years). The two oldest were about 150 years old. These two trees were 14 and 18 inches (35 and 45 cm) in diameter. The six oldest trees averaged 116 years total age, but only 13 inches (34 cm) in diameter. Trees from Silver Lake averaged a little smaller than trees from the other sites – six trees averaged 84 years total age, but only 11 inches (27 cm) in diameter.

Linear regression of the combined data for coast pine yields an estimated diameter of 12.0 inches (31 cm) at 80 years of age, with a 90 percent confidence interval of 11.2 to 12.8 inches (29 to 33 cm). Although the correlation is statistically significant ($R^2 = .67$, and $p = 0.00$) more data are needed to account for variation between sites. Results are presented in Appendix A, Table A-1 and Figure A-7.

Coast pine may live to 400 years or more, and may be the climax species in a coastal forested wetland (Despain 1983; Kunze 1994). Therefore, coast pine trees may be the dominant trees in an old-growth forest in a sphagnum bog, but will be much smaller than the old-growth size criterion. It is likely that old-growth (200 year-old) coast pine would be smaller than even the *mature* forest criterion of 21 inches (53 cm). This species and this ecosystem were not part of the original scope of the interim old-growth definition on which these criteria are based. The *Pinus contorta* bogs of the Pacific Northwest cannot be lumped with other coniferous climax forests of the region; they require a separate definition of the meaning of old-growth. Other conifers also may be severely stunted when growing in sphagnum bogs, and hence outside the scope of the old-growth definition.

4.4 Other Wetland Tree Species

Some other tree species that commonly occur in wetlands in the Puget Lowlands include Oregon ash (*Fraxinus latifolia*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), and Pacific willow (*Salix lucida* Muhl. ssp. *lasiandra* (Benth.) E. Murr.). Douglas-fir are also found in wetlands, but not as a dominant species. All of these species were sampled in the Cooke Scientific data collection.

Like red alder, all of these species except Douglas-fir are relatively short-lived, compared to the time-scale of a coniferous old-growth forest. They are early seral species, and may also be present as part of the species mix in later stages. These tree species were not considered candidates for dominant trees in old-growth forest in the context of the interim old-growth definition. Since the WDOE old-growth definition is open to include any tree species, large or old trees of these species could come into play in the rating of a forested wetland.

Douglas-fir are rare in wetlands, but Hylebos Wetland contains a few scattered individuals. Even in this relatively low-nutrient environment, Douglas-fir were not severely stunted. One large tree 33 inches (83 cm) in diameter was only about 95 years old; another 31 inches (78 cm) in diameter was about 106 years old. A large Douglas-fir snag 48 inches (123 cm) in diameter was too large to core for age determination. Therefore, Douglas-fir in some wetlands are not severely stunted, and may exceed the old-growth criteria at an age younger than 200 years.

Oregon ash and black cottonwood are commonly found in riparian and seasonally flooded habitats. Soils are usually mineral, or mineral with a thin organic veneer (Burns and Honkala 1990; Kunze 1994). Field observations suggest that the largest individuals grow at the edges of wetlands, or in areas of seasonal flooding, not in areas of prolonged inundation.

Oregon ash may live 250 years, and can become quite large. Mature trees over 100 years old are about 16 to 30 inches (40 to 75 cm) in diameter on good sites, although some individuals may be twice this size (Burns and Honkala 1990). Therefore, some individuals could live to be old enough, and become large enough, to be counted as old-growth trees, but they would be exceptional.

Data for this study include five Oregon ash from the White River in King County. The age range is small, 61 to 76 years abh, but the diameter range is wide, 9 to 21 inches (23 to 53 cm). Average age was 67 years abh (probably about 72 years total), and average diameter was 14.9 inches (38 cm). Since growth had begun to slow by this age, it seems unlikely that these trees would average 21 inches (53 cm) in diameter after another 8 years of growth. The largest individuals, however, will meet the minimum size criterion for mature forest, and so could contribute to a mature forest rating based on size.

Black cottonwood is "the largest hardwood tree in western North America... the most productive sites are the bottom lands of major streams and rivers west of the Cascade Range in the Pacific Northwest. Pure stands may form on alluvial soils" (Burns and Honkala 1990). Black cottonwood can grow very quickly, and can live for more than 200 years. It may attain a diameter of 8 inches (20 cm) or more by the age of 10 on good sites. Exceptional trees may be 72 to 120 inches (180 to 300 cm) in diameter. Black cottonwood trees are very intolerant of shade, but their rapid growth helps them stay above the competition (Burns and Honkala 1990).

Data for this study include 23 black cottonwood trees from 6 wetlands (plus some that were removed as outliers or suspect data points). The oldest trees were only 50 years abh, so it is impossible from these data to estimate diameter at 80 years of age. However, 10 of these trees had a diameter larger than 21 inches (53 cm), some as young as 22 years abh. Two trees younger than 40 years abh were larger than 34 inches (87 cm) in diameter. The overall average age at breast height was 28 years, and the average diameter was 20 inches (52 cm). It seems clear that these trees would average well over the mature forest size criterion when the average age is 80 years. Some were already larger than the *old-growth* size criterion at 40 years of age.

Pacific willow is more often discussed as a shrub rather than a tree, but in the right conditions it can have the form of a tree, and can become large. Usually, the tree form occurs in upland conditions, or at the edge of a wetland. In a wetland, it is more likely to have a shrubby, multi-trunk morphology. The *Oregon Register of Big Trees* lists a Pacific willow 27 inches (68 cm) in diameter as the Oregon state champion (Oregon Department of Forestry 2002).

Data for this study include 35 Pacific willow trees from 16 wetlands; however, all but 4 were less than 40 years old, and most were less than 14 inches (35 cm) in diameter. The 4 oldest trees were from a single site, Jenkins Creek in King County. They formed a cohort 71 to 110 years abh. Average age of these 4 trees was 89 years abh, with average dbh of 16 inches (41 cm). These were old for willows, and it is unlikely that they would grow to exceed the mature forest criterion of 21 inches (53 cm). The fact that the Oregon State Champion is only 27 inches (68 cm) in diameter supports the conclusion that only a very exceptional Pacific willow would exceed 21 inches in diameter.

In summary, black cottonwood trees frequently attain a size that exceeds the mature forest criterion, and may exceed even the old-growth criterion well before 80 years of age. Some relatively large Oregon ash trees may exceed the mature forest criterion by 80 to 100 years of age, and an exceptional individual may live 200 years and may exceed the old-growth criterion. A Pacific willow tree larger than the mature forest criteria is rare. These tree species are more likely to attain these large sizes at the edges of a wetland, or in conditions of seasonal flooding, rather than in a wetland with prolonged surface saturation. Douglas-fir, although rare in wetlands, is not necessarily severely stunted in wetland conditions, and may exceed the old-growth size criterion at a relatively young age.

5 Conclusion

Analysis of the diameter/age relationship reveals that the accepted mature and old-growth size criteria are significantly larger than the average size of trees in forested wetlands at 80 and 200 years of age. Analysis of height data indicates that forested wetland sites in the Puget Lowland region are in a low to moderate range of productivity for the four species examined: western hemlock, Sitka spruce, western red cedar, and red alder. The Puget Lowland is a highly productive region in general, but growth of trees is suppressed in wetlands, due to the high water table and low availability of nutrients. Sphagnum bogs are an extreme example of these stressful conditions, and trees in these bogs are sometimes very stunted.

The concepts behind the standard old-growth definition are not directly applicable to forested wetlands. Sites where trees grow slowly, such as wetlands, take longer to develop the ecological characteristics typically associated with old-growth (Franklin and Spies 1991; USDA Forest Service 1993). Old-growth inventory methods differ in how they deal with this fact. Some emphasize size, so that slow-growing stands must be older than fast-growing stands to count as old-growth. Others maintain the same age criterion, but allow a smaller size for less-productive sites. This is the approach used by the WDOE old-growth definition; it serves the purpose of protecting old wetland forests, regardless of how well they match up with standard descriptions of old-growth. Nevertheless, the size criteria are important, because it is much more difficult to determine the age of a wetland tree than it is to measure its diameter, and because size criteria are a feature of accepted old-growth definitions.

Succession and stand development are different in forested wetlands than in upland stands. One of the basic characteristics of upland forest succession in the Pacific Northwest lowlands is the early dominance of Douglas-fir, shifting to mixed stands of more shade-tolerant species (Franklin and Spies 1991). Forested wetlands, by contrast, have very little Douglas-fir at any stage, and usually have a mixed species composition at all stages, although western hemlock typically becomes more dominant as the wetland fills in with dead wood.

Because a wetland is a stressful environment for trees, small changes in topography and substrate can make big differences in the growth rates of trees. Seedlings grow primarily on nurse logs and root hummocks. As a stand matures, there is an increase in the number and variety of these habitat niches, resulting in increased plant diversity, stand density, and canopy layering. Therefore, wetland forest stands may be less dense, but more diverse, than the surrounding upland forest, and stand density may increase with age. This is different from the normal succession in upland stands, which frequently begin very dense, and become less dense with age. Wetland and upland forests have some characteristics in common, such as an increase in the amount of dead wood and snags as a stand ages, but specific requirements for canopy closure and forest density in the standard old-growth definition are not directly applicable to wetlands.

The purpose of the old-growth definition is different for forested wetlands than it is for upland forests. Definitions such as the one used by WDOE were devised to distinguish a certain type of forest habitat, important for the recovery of the northern spotted owl, and encompassing a range of features typical of old Douglas-fir forests. In the case of forested wetlands, the goal is to identify a different rare habitat type – wetlands with old forests. These old wetland stands have a different ecology from the classic Douglas-fir old-growth, which makes them ecologically and scientifically valuable in their own right.

Age and diameter measurements show that mature western red cedar (*Thuja plicata*), Sitka spruce (*Picea sitchensis*), and western hemlock (*Tsuga heterophylla*) in wetlands are significantly smaller on average than the size criterion in the mature forest definition, with 90 percent confidence. Similarly, the size estimate for 200-year-old wetland trees is significantly smaller than the size criterion in the old-growth definition, although in most cases the projection is beyond the range of the data (for Sitka spruce in organic soils, the difference in size at 200 years does not reach the 90 percent confidence level of significance). These results indicate that most of the time the average size of trees in forested wetlands is below the minimum mature or old-growth size criterion, even after they have passed the age criterion.

Red alder (*Alnus rubra*) is an early seral species, and old-growth definitions were not intended to apply to this species. It is frequently present in forested wetlands, however, and may come into play as one of the dominant species in a mature forest stand. The WDOE forested wetland ratings do not limit the species that can be used to meet the criteria, so red alder could be counted when making a mature forest determination. Results of this study show that some mature forested wetlands contain red alder older than 80 years, but they rarely reach 21 inches (53 cm) in diameter, and so would not normally be counted as mature based on size.

Other forested wetland trees that could be part of a mature stand include Pacific willow, Oregon ash, black cottonwood, and Douglas-fir. Pacific willow is unlikely to exceed 21 inches (53 cm) in diameter. Oregon ash is smaller than the mature and old-growth size criteria on average, but some individuals could exceed the criteria. Black cottonwood is a large, fast-growing tree species, and could easily surpass the old-growth size criterion, even at a relatively young age. Douglas-fir trees are rarely found in wetlands, but when present they can attain large size, in some cases exceeding the old-growth criteria well before 200 years of age.

Coast pine is a special case. Even very old coast pine are unlikely to reach 21 inches in size, and wetlands dominated by coast pine are usually sphagnum bogs. Other tree species in sphagnum bogs frequently do not meet size criteria for mature or old-growth forest, even when they meet the age criteria, because they are often very stunted. In the WDOE system, sphagnum bogs are recognized as priority habitats even without forest, so the size of trees does not affect their rating. From the standpoint of science, a separate ecological definition of old-growth is necessary if the concept of old-growth is to be applied to forested sphagnum bogs.

The Puget Lowlands region is a highly productive area, yet even here accepted mature and old-growth forest size criteria are too large when applied to forested wetlands. This finding has implications for wetlands in other parts of the Pacific Northwest. At higher elevations, the shorter growing season results in smaller wetland trees, so the size criteria would be even less appropriate than in the Puget Lowlands.

5.1 Recommendations

Size criteria in the accepted definitions of mature and old-growth forests do not reflect the actual characteristics of forested wetlands, and should be revised downward. Recent upland old-growth inventories have adopted revised criteria of 20 inches (51 cm) dbh for mature forest, and 30 inches (76 cm) dbh for old-growth (Moeur et al. 2005). These revised criteria are still larger than the size estimates produced by this analysis, the results of which are presented in Appendix A, Table A-1.

Creating a minimum size standard for mature and old-growth forest requires a decision about how inclusive the standard will be. If the predicted averages are used as criteria, the expectation is that half of the sampled stands that are old enough will be too small; therefore, this may be considered a value that is conservative in terms of what it includes. Many mature wetland stands would still be smaller on average than this middle value, and so would not be identified as mature on the basis of average size.

One way to derive an average value is to average the results for the dominant wetland species. Averaging the size estimates at 80 years for western red cedar, Sitka spruce, and western hemlock, including both organic and mineral soils, yields a value of 18 inches (46 cm) for the minimum average diameter of mature trees (80 years of age). The old-growth criterion by this approach would be 27 inches (69 cm). These average values are very close to the results for western red cedar and Sitka spruce in organic soils.

These estimates are probably a good indication of what to expect in the western red cedar-western hemlock/skunk cabbage plant association, a common forested wetland type in the Puget Lowlands. These average values, however, would not identify mature forest stands in some other less-productive wetlands until they are much older than 80 years. Otter Island in the Snohomish River estuary is an example of a mature forested wetland that would not pass an 18-inch (46 cm) average size criterion. Also, wetlands that are slightly more acidic and lower in nutrients may have stands that are on average smaller than these estimates.

The intent of the original interim old-growth definition was to set a standard low enough to include “nearly all the old-growth stands for which we have data” (Old-Growth Definition Task Group 1986). The estimated size at 80 years for trees in the Snohomish River estuary is about 15 inches (38 cm). Therefore, a minimum average size of 15 inches for mature forest would be needed to ensure that wetlands such as these are properly evaluated based on size. This is small enough to include most of the mature forested wetlands likely to be found in the Puget Lowlands, except those in sphagnum bogs, or those dominated by red alder or coast pine. If this smaller minimum size criterion is used, it is more likely that some stands will be counted as mature before 80 years of age, but more mature stands will be identified and protected; if the larger size is used, more stands that are old enough to be counted as mature will be too small to pass the size criterion.

A size criterion for trees 200 years old is more difficult to judge, because of the scarcity of large, old trees. A criterion of 24 inches (61 cm) would include "nearly all the old-growth stands for which we have data," except for those in sphagnum bogs. This is the average size estimate for old-growth in the Snohomish River estuary, but there were no 200-year-old trees in those data, so there is little basis for making such a projection.

This value of 24 inches is low for 200-year-old trees, but the Forest Service published a size criterion of 21 inches (53 cm) for old-growth western hemlock on low-productivity sites, even lower than this estimate of 24 inches (USDA Forest Service 1993).

The wording of the mature forest age and size criteria is not entirely consistent in the WDOE definition. A stand would be more likely to pass the size criterion if it, like the age criterion, required only that "the largest trees" exceed the minimum standard, rather than requiring that the average exceed the minimum standard. This difference means the age criterion is easier to pass than the size criterion. Changing "average" to "the largest," in regard to size, similar to the way it is worded in the old-growth definition, would have the effect of lowering the bar, making it easier for a stand to qualify as mature on the basis of size.

The largest trees in a stand are not always the oldest. The oldest tree sampled in this study was about 455 years old, and only 22 inches (57 cm) in diameter; another Sitka spruce in the same general area and wetland type (the Snohomish estuary) was 30 inches (76 cm) in diameter, but only 84 years old. Both trees were unusual, but they serve to illustrate the point that growth rates are highly variable, even in the same wetland.

As the ecology of forested wetlands becomes better known, more refined descriptions of growth and succession in these ecosystems will be possible. This is a scientific endeavor, but it is linked to policy. Society has an interest in identifying and protecting these sensitive, valuable, and rare ecosystems. One possible way to support protection of forested wetlands in Washington would be to increase the value given to coniferous forested wetlands in the WDOE wetland rating system. All forested wetlands dominated by coniferous trees could be given a Category I rating, the same as mature forested wetlands. This would remove the question of growth rates for some wetlands (those most likely to be mature) from the arena of policy, since they would be treated the same regardless of age. Wetlands with deciduous trees could still be rated based on age or size, or they too could receive a Category I rating. The growth rates of wetland trees would still be of scientific interest, but would be less consequential in the protection of these rare forest environments.

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Acronyms

FEMAT	Forest Ecosystem Management Team
Forest Club UBC	The Forest Club of the University of British Columbia
NCDC	National Climate Data Center
USACE	United States Army Corps of Engineers
USDA	Unites States Department of Agriculture
WDFW	Washington State Department of Fish and Wildlife
WDNR	Washington State Department of Natural Resources
WDOE	Washington State Department of Ecology

Appendix A: Expected Diameter and Regression Results

Table A-1. Linear Regression Results

y=dbh, x=abh; y=a*Ln(x)+b

Expected dbh at 80 yrs total age

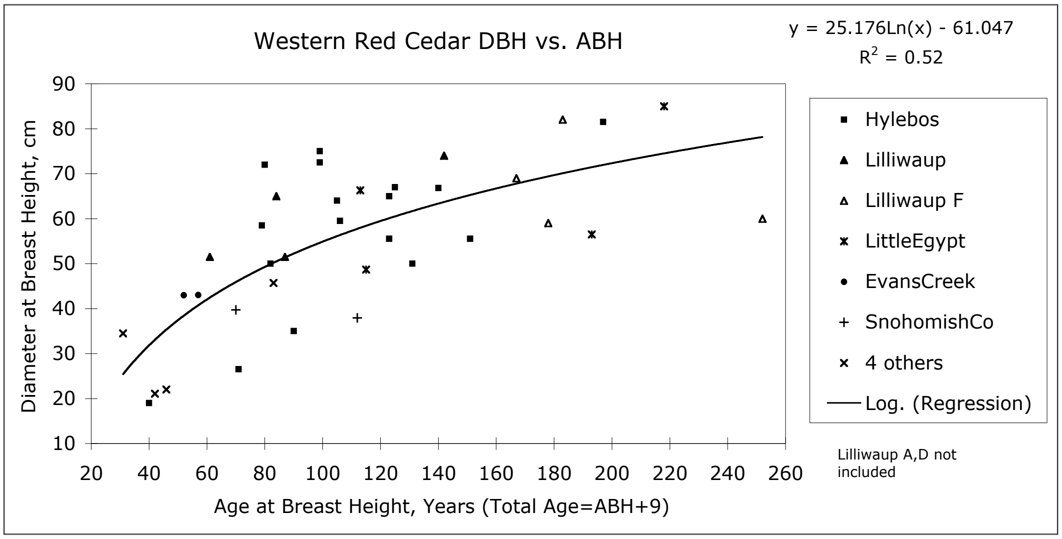
Species	**Soil type**	**ABH adj.**	**Count**	**Expected**	**90% CI**	**R^2 p-value**
western red cedar *Thuja plicata*	organic	9	40	**18.2 in** **46 cm**	16.7-19.7 in 42-50 cm	0.52 p=0.00
Sitka spruce *Picea sitchensis*	organic	8	36	**18.8 in** **48 cm**	17.2-20.3 in 44-52 cm	0.42 p=0.00
Sitka spruce *Picea sitchensis*	mineral	8	25	**15.4 in** **39 cm**	13.6-17.1 in 34-44 cm	0.21 p=0.00
western hemlock *Tsuga heterophylla*	organic	9	38	**19.3 in** **49 cm**	18.1-20.5 in 46-52 cm	0.48 p=0.00
red alder *Alnus rubra*	organic	5	35	**15.2 in** **39 cm**	14.2-16.2 in 36-41 cm	0.51 p=0.00
red alder *Alnus rubra*	mineral	5	68	**15.1 in** **38 cm**	13.9-16.2 in 35-41 cm	0.34 p=0.00
coast pine *Pinus contorta*	organic+ mineral	10	15	**12.0 in** **31 cm**	11.2-12.8 in 29-33 cm	0.67 p=0.00
Mature forest definition				**21 in (53 cm)**		

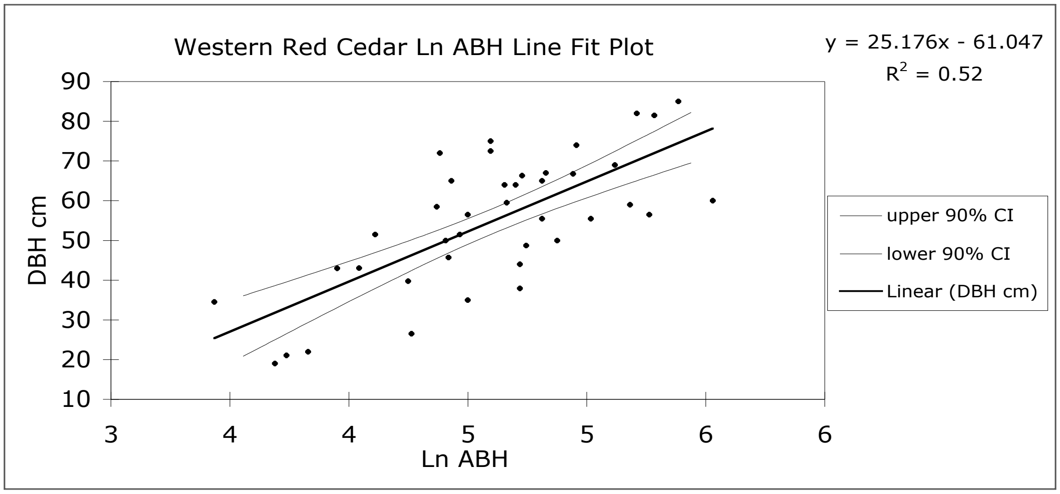
Expected dbh at 200 yrs total age (R^2 and p-values as above)

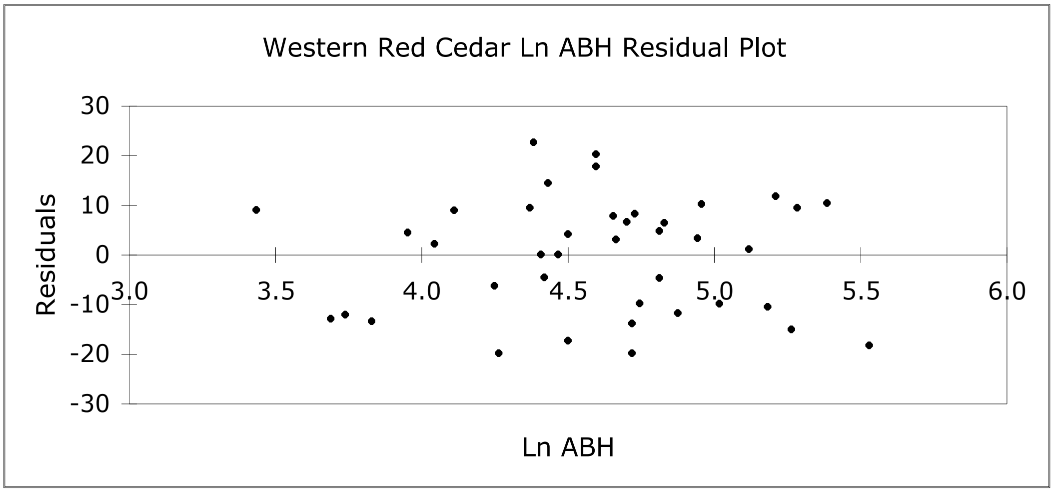
Species	**Soil type**	**ABH adj.**	**Count**	**Expected**	**90% CI**	**Max age in data**
western red cedar *Thuja plicata*	organic	9	40	**28.0 in** **71 cm**	25.9-30.1 in 66-77 cm	261
Sitka spruce *Picea sitchensis*	organic	8	35	**29.7 in** **76 cm**	26.7-32.8 in 68-83 cm	198
Sitka spruce *Picea sitchensis*	mineral	8	25	**24.3 in** **62 cm**	18.8-29.8 in 48-76 cm	159
western hemlock *Tsuga heterophylla*	organic	9	38	**26.7 in** **68 cm**	24.0-29.4 in 61-75 cm	180
coast pine *Pinus contorta*	organic+ mineral	10	15	**15.7 in** **40 cm**	14.0-17.4 in 36-44 cm	150
Old-Growth definition				**32 in (81 cm)**		

Appendix A: Expected Diameter and Regression Results

Figure A-1. Western Red Cedar (*Thuja plicata*) Regression Plots

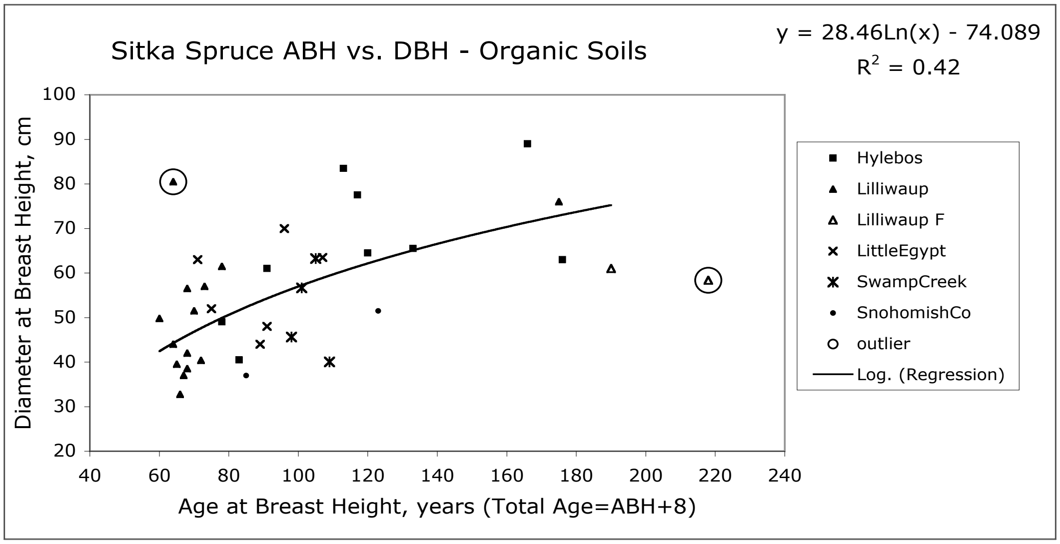


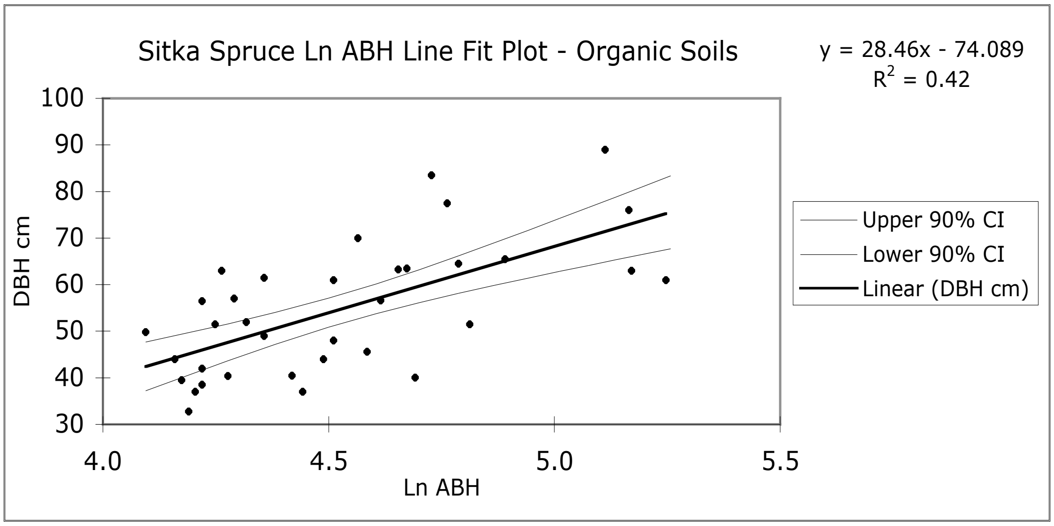


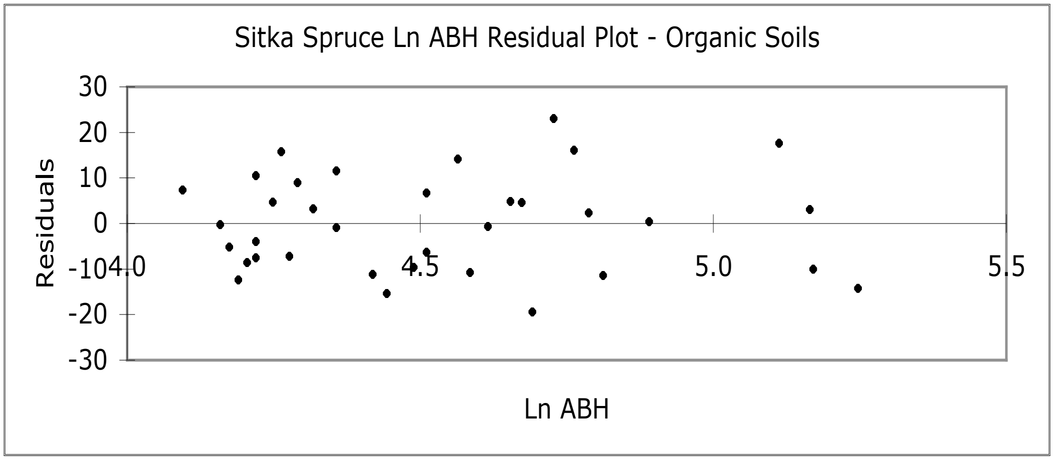


Appendix A: Expected Diameter and Regression Results

Figure A-2. Sitka Spruce (*Picea sitchensis*) Regression Plots for Organic Soils

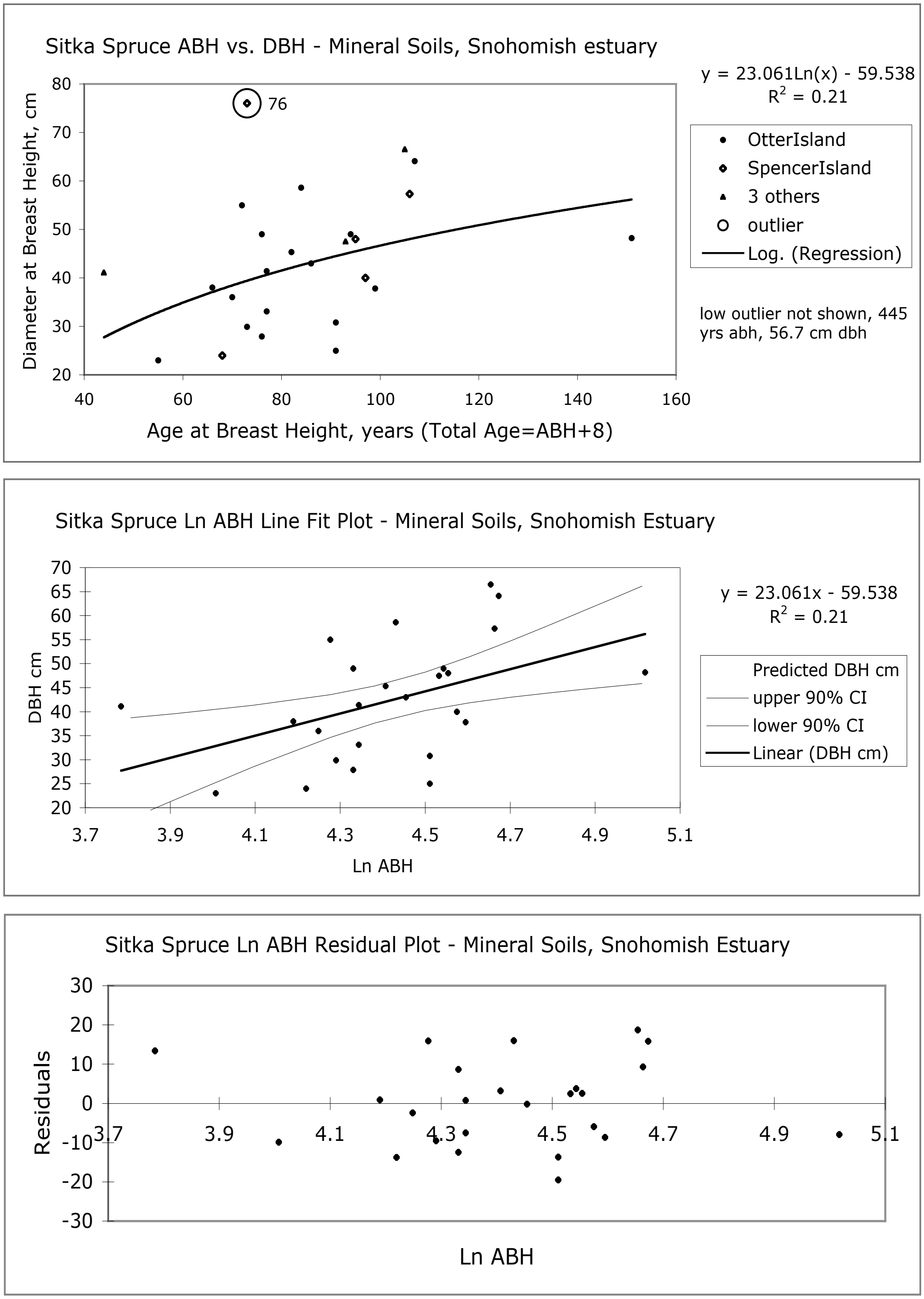






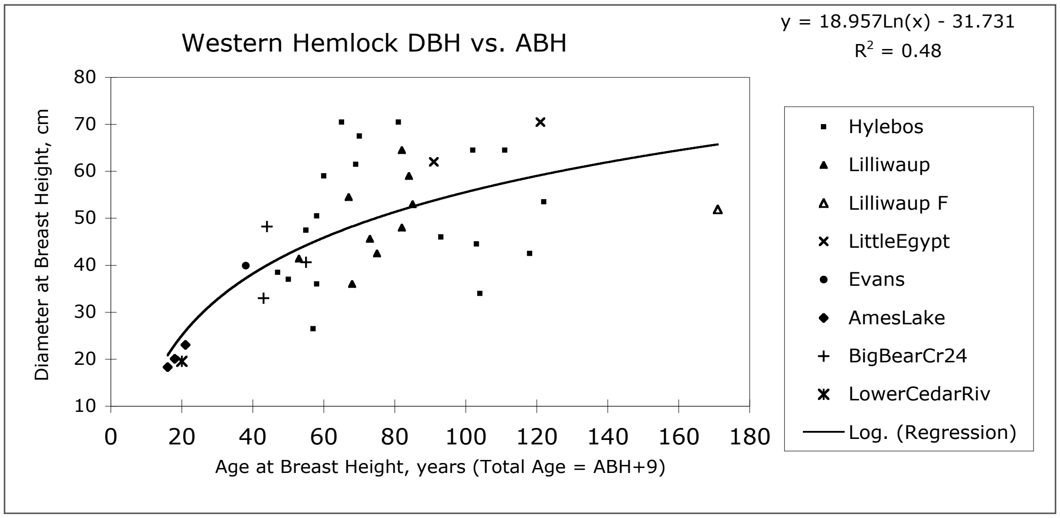
Appendix A: Expected Diameter and Regression Results

Figure A-3. Sitka Spruce (*Picea sitchensis*) Regression Plots for Mineral Soils, Snohomish Estuary

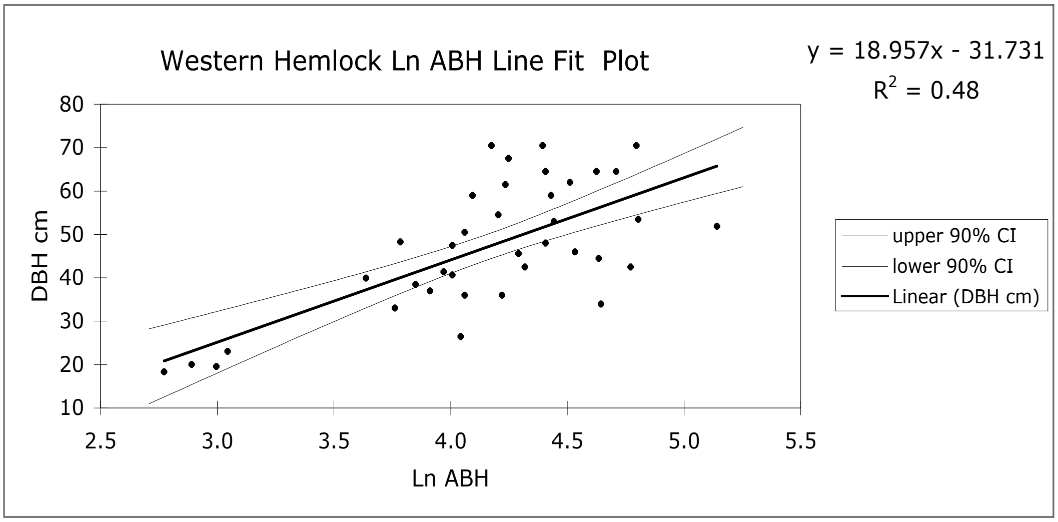


Appendix A: Expected Diameter and Regression Results

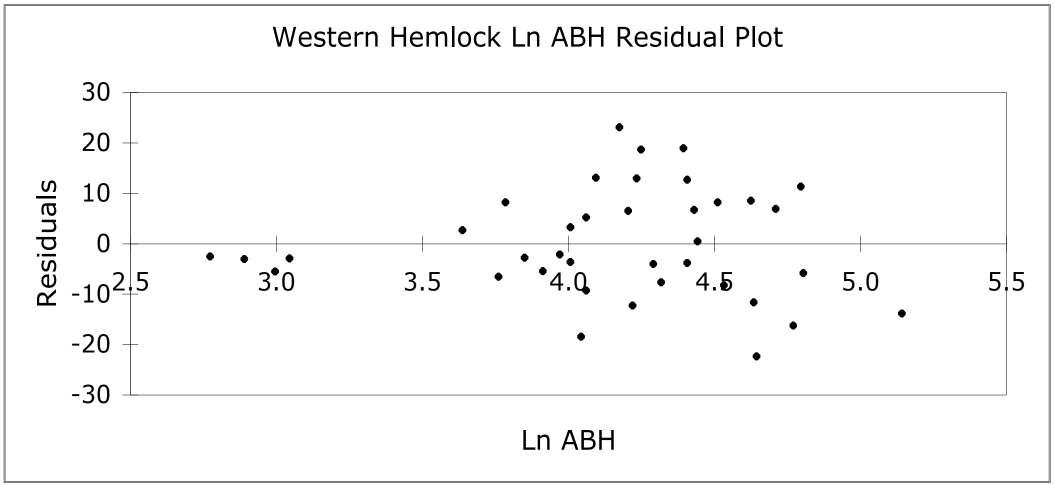
Figure A-4. Western Hemlock (*Tsuga heterophylla*) Regression Plots



Western Hemlock DBH vs. ABH



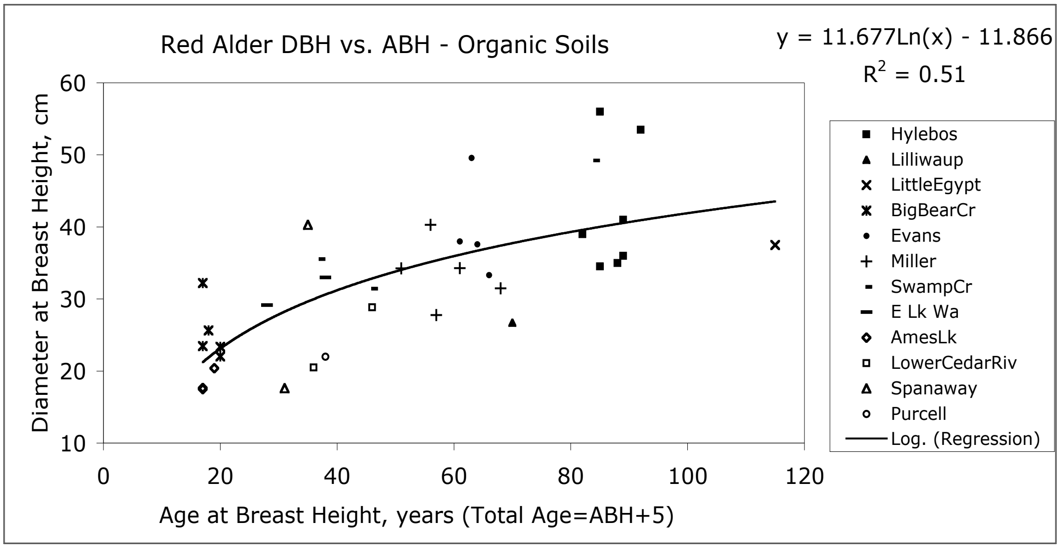
Western Hemlock Ln ABH Line Fit Plot

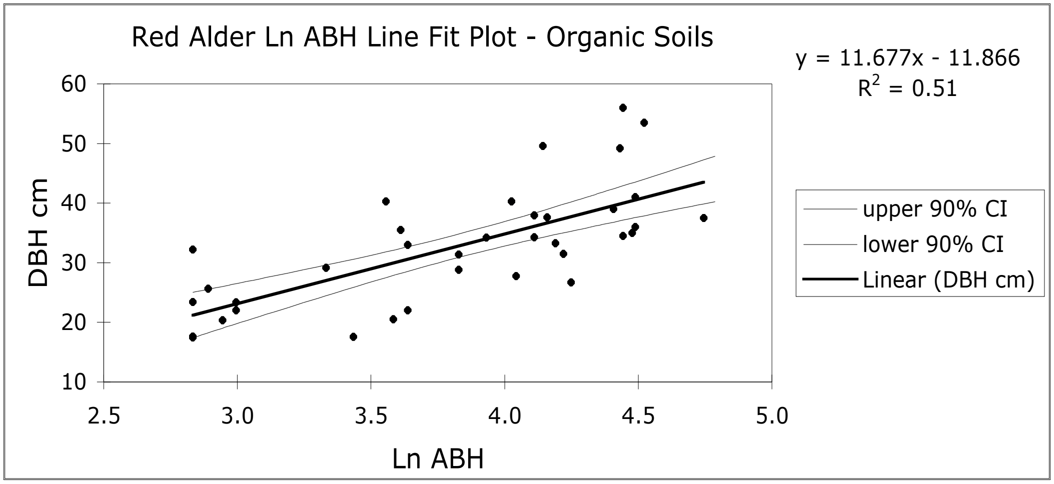


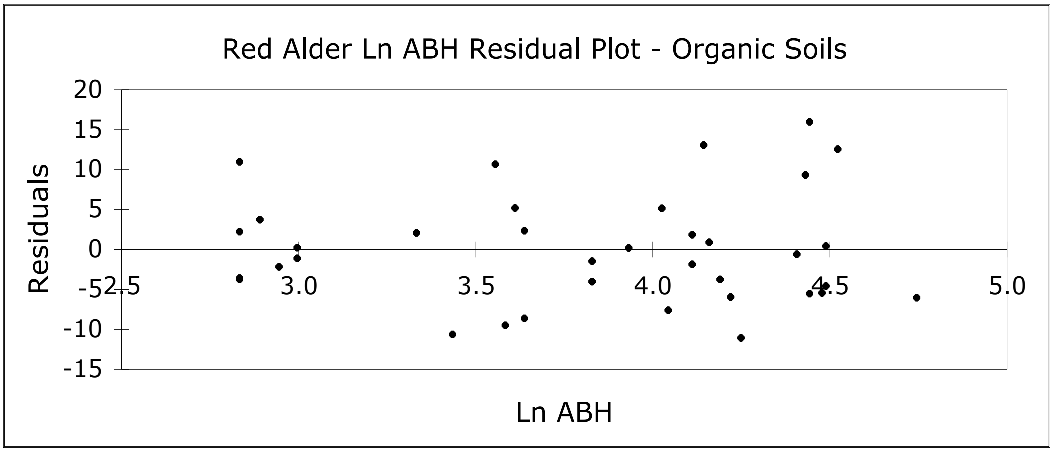
Western Hemlock Ln ABH Residual Plot

Appendix A: Expected Diameter and Regression Results

Figure A-5. Red Alder (*Alnus rubra*) Regression Plots for Organic Soils







Appendix A: Expected Diameter and Regression Results

Figure A-6. Red Alder (*Alnus rubra*) Regression Plots for Mineral Soils

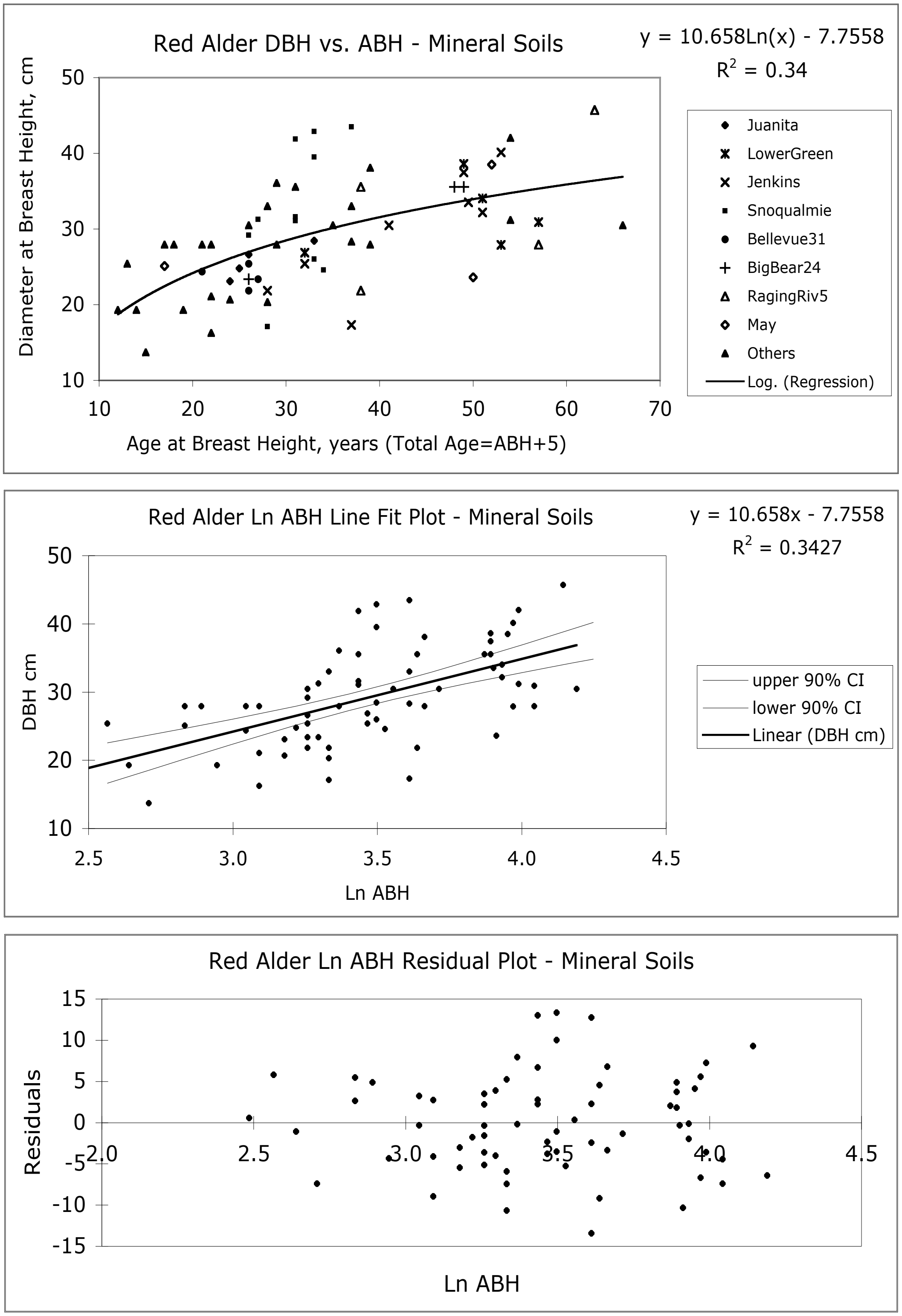
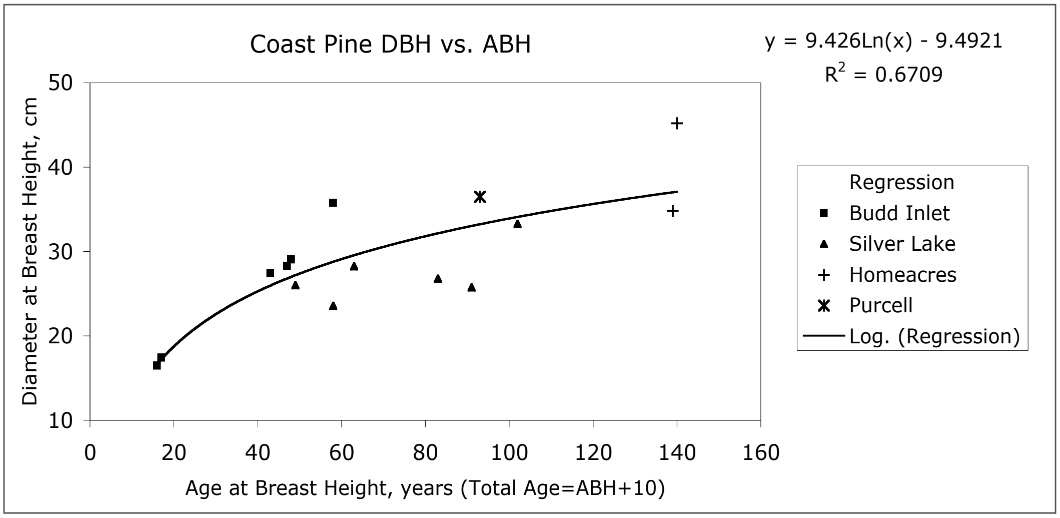
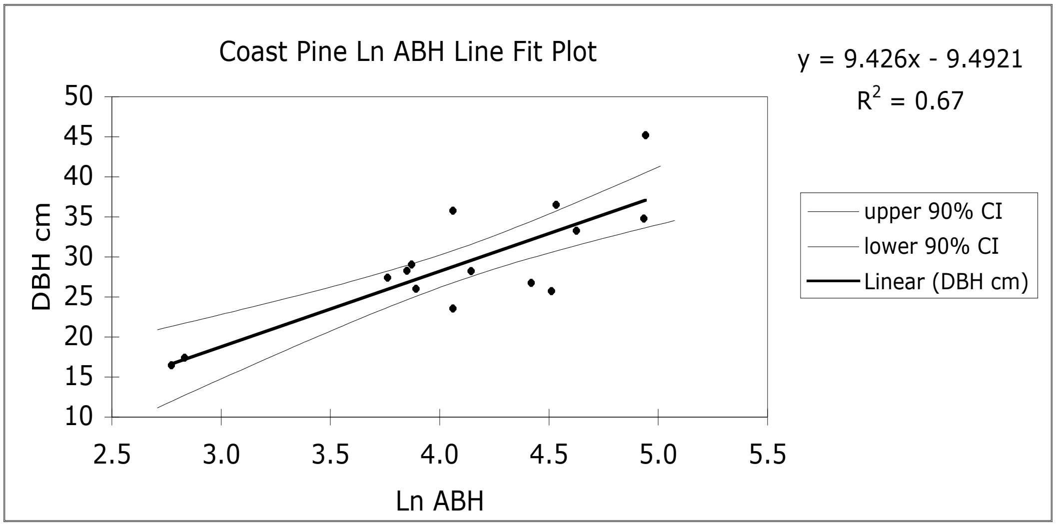
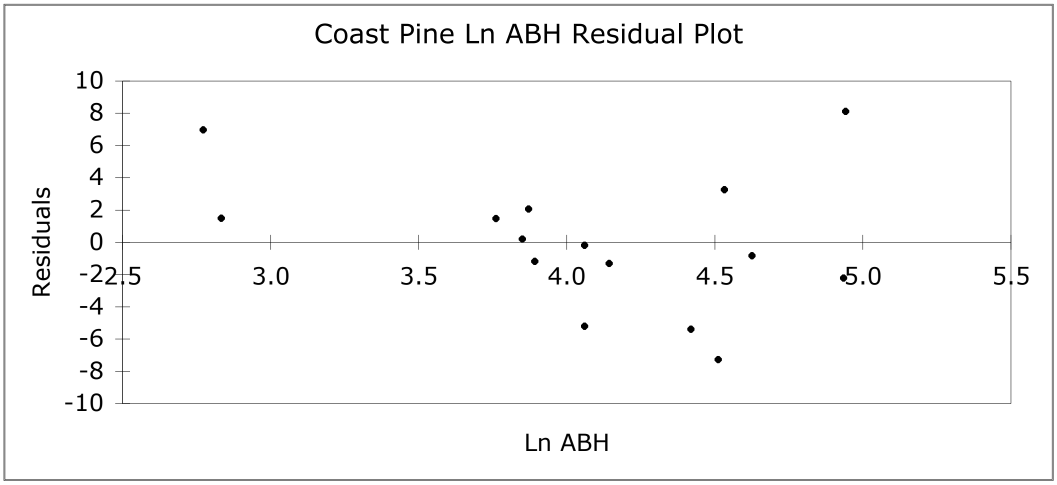


Figure A-7. Coast pine (*Pinus contorta*) Regression Plots







Appendix B: Mean Diameter, Age, and Summary Statistics for Wetland Stands

Appendix B: Mean Diameter, Age, and Summary Statistics for Wetland Stands

THPL = *Thuja plicata*; TSHE = *Tsuga heterophylla;* PISI = *Picea sitchensis*;
ALRU = *Alnus rubra*; PICO = *Pinus contorta*; PSME = *Psuedotsuga menziesii*
ABH = age at breast height, years; DBH = diameter at breast height
Total age = ABH + 8

Table B-1. Mean Diameter, Age, and Summary Statistics

Little Egypt All (without ALRU) -- THPL, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	112.8	59.6	23.5	121
median	107	62	24.4	115
stdev	40.6	11.3	4.4	
min	71	44	17.3	79
max	218	85	33.5	226
count	15	15	15	15

Little Egypt Area A -- THPL, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	105.8	60.1	23.7	113.75
median	90.5	59.3	23.3	98.5
stdev	47.7	13.2	5.2	
min	71	44	17.3	79
max	218	85	33.5	226
count	8	8	8	8

Little Egypt Area A without oldest -- THPL, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	84.5	54.3	21.4	93
median	89.5	54.3	21.4	97.5
stdev	9.0	7.6	3.0	
min	71.0	44.0	17.3	79
max	91.0	63.0	24.8	99
count	6	6	6	6

Little Egypt Area B (without ALRU) -- THPL, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	120.9	59.0	23.2	129
median	112.0	63.5	25.0	120
stdev	32.4	9.6	3.8	
min	96	44	17.3	104
max	193	70	27.6	201
count	7	7	7	7

Appendix B: Mean Diameter, Age, and Summary Statistics for Wetland Stands

Table B-1 (cont.)

Hylebos All -- THPL, TSHE, PISI, ALRU, PSME				
	ABH	DBH cm	DBH in	
mean	98.7	57.0	22.5	107
median	92.0	58.5	23.0	100
stdev	31.6	15.0	5.9	
min	47	34	13.4	55
max	197	89	35.0	205
count	51	51	51	51

Hylebos All (without PSME) -- THPL, TSHE, PISI, ALRU				
	ABH	DBH cm	DBH in	Total age
mean	99.6	56.3	22.2	108
median	92.5	57.3	22.5	101
stdev	32.2	14.5	5.7	
min	47	34	13	55
max	197	89	35	205
count	48	48	48	

Hylebos All (without ALRU or PSME) -- THPL, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	101.8	58.8	23.1	110
median	102.0	61.0	24.0	110
stdev	34.4	14.0	5.5	
min	47.0	34.0	13.4	55
max	197.0	89.0	35.0	205
count	41	41	41	41

Hylebos All without ALRU -- THPL, TSHE, PISI, PSME				
	ABH	DBH cm	DBH in	
mean	100.6	59.4	23.4	109
median	99.0	61.3	24.1	107
stdev	33.6	14.4	5.7	
min	47	34	13.4	55
max	197	89	35.0	205
count	44	44	44	44

Hylebos middle ages (without ALRU, PSME) -- THPL, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	89.2	56.8	22.4	97
median	90.0	58.5	23.0	98
stdev	9.3	13.5	5.3	
min	78	35	13.8	86
max	103	75	29.5	111
count	13	13	13	13

Appendix B: Mean Diameter, Age, and Summary Statistics for Wetland Stands

Table B-1 (cont.)

Hylebos Area A,A2,B -- TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	78.4	54.3	21.4	86
median	70.0	50.5	19.9	78
stdev	24.3	14.3	5.6	
min	47	36	14.2	55
max	122	83.5	32.9	130
count	17	17	17	17

Hylebos Area A -- TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	93.5	51.2	20.1	102
median	92.0	49.8	19.6	100
stdev	18.0	8.9	3.5	
min	69	40.5	15.9	77
max	122	61.5	24.2	130
count	6	6	6	6

Hylebos Area A, A2 -- TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	76.2	52.1	20.5	84
median	67.0	49.0	19.3	75
stdev	24.5	13.8	5.4	
min	47	36.0	14.2	55
max	122	83.5	32.9	130
count	14	14	14	14

Hylebos Area A interior -- TSHE				
	ABH	DBH cm	DBH in	
mean	100.3	46.1	18.2	108
median	98.0	45.3	17.8	106
stdev	16.6	5.4	2.1	
min	83	40.5	15.9	91
max	122	53.5	21.1	130
count	4	4	4	4

Appendix B: Mean Diameter, Age, and Summary Statistics for Wetland Stands

Table B-1 (cont.)

Lilliwaup All except D and A -- THPL, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	79.1	45.6	20.6	87
median	78.2	50.8	21.8	86
stdev	54.2	24.6	11.6	
min	6	6	3.0	14
max	218	89	51	226
count	54	54	54	54

Lilliwaup Area D and A (bog) -- THPL, TSHE				
	ABH	DBH cm	DBH in	Total age
mean	78.9	42.4	16.7	87
median	92.0	49.8	19.6	100
stdev	38.9	20.1	7.9	
min	18.0	8.9	3.5	26
max	122.0	61.5	24.2	130
count	5	5	5	5

Lilliwaup E -- THPL, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	83.1	47.9	22.7	91
median	83.6	53.7	22.8	92
stdev	57.8	24.5	12.9	
min	7	7	5.3	15
max	197	89	51	205
count	32	32	32	32

Lilliwaup F transitional bog -- THPL, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	59.8	42.6	18.5	68
median	58.5	43.3	18.4	67
stdev	38.9	26.0	9.0	
min	17	14.3	5.6	25
max	122	83.5	32.9	130
count	6	6	6	6

Lilliwaup B, B2, and C -- TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	78.3	42.2	17.1	86
median	87.0	49.1	19.3	95
stdev	53.0	25.2	9.2	
min	6	6	3.0	14
max	218	85	33.5	226
count	16	16	16	16

Appendix B: Mean Diameter, Age, and Summary Statistics for Wetland Stands

Table B-1 (cont.)

Sno Estuary All -- PISI				
	ABH	DBH cm	DBH in	Total age
mean	85.0	43.4	17.1	93
median	82.0	41.4	16.3	90
stdev	20.4	13.0	5.1	
min	44	24	9.4	52
max	151	76	29.9	159
count	23	23	23	23

Sno Estuary Otter Island -- PISI				
	ABH	DBH cm	DBH in	Total age
mean	86.6	41.9	16.5	95
median	82.0	41.4	16.3	90
stdev	19.9	11.2	4.4	
min	66	25	9.8	74
max	151	64.1	25.2	159
count	17	17	17	17

Sno Estuary Spencer Island South -- PISI				
	ABH	DBH cm	DBH in	Total age
mean	87.8	49.1	19.3	96
median	95.0	48.0	18.9	103
stdev	16.4	19.4	7.6	
min	68	24	9.4	76
max	106	76	29.9	114
count	5	5	5	5

Sno Estuary All above 41 cm -- PISI				
	ABH	DBH cm	DBH in	Total age
mean	89.2	49.8	19.6	97
median	84.0	48.2	19.0	92
stdev	21.5	10.9	4.3	
min	66	36	14.2	74
max	151	76	29.9	159
count	15	15	15	15

Appendix B: Mean Diameter, Age, and Summary Statistics for Wetland Stands

Table B-1 (cont.)

Silver Lake (bog) largest trees, all species – PICO, TSHE, PISI				
	ABH	DBH cm	DBH in	Total age
mean	72.6	36.8	14.5	83
median	78.5	34.7	13.7	89
stdev	21.4	12.2	4.8	
min	42	26	10	52
max	102	63	25	112
count	10	10	10	10

Silver Lake (bog) -- PICO				
	ABH	DBH cm	DBH in	(ABH+10)
mean	77.6	28.0	11.0	88
median	83.0	26.8	10.5	93
stdev	21.4	3.1	1.2	
min	49	26	10	59
max	102	33	13	112
count	5	5	5	5

Silver Lake (bog) -- TSHE				
	ABH	DBH cm	DBH in	Total age
mean	73.0	47.7	18.8	81
median	78.5	45.9	18.1	87
stdev	22.0	12.0	4.7	
min	42	36.2	14.3	50
max	93	62.7	24.7	101
count	4	4	4	4

Appendix C: Stand Height and Site Index

Table C-1. Stand Height and Site Index

ABH=age at breast height, years; Ht=height; SI=Site Index;
Base age = 50 or 100 total years

***Thuja plicata* (THPL) Site Indexes**	ABH	Ht m	Ht ft	Total age	SI 100
THPL Hylebos all areas -- mean	108.3	27.4	89.8	118	86
stdev	36.1	7.2	23.8		
count	17	17	17		
THPL Little Egypt all areas -- mean	144.0	29.7	97.5	154	89
stdev	62.7	7.3	24.1		
count	7	7	7		
THPL Hylebos and Little Egypt mean SI					**87**

***Thuja plicata* (THPL) Site Indexes -- bog**	ABH	Ht m	Ht ft	Total age	SI 100
THPL Lilliwaup A and D -- mean	131.2	23.0	75.6	141	**70**
stdev	62.9	0.9	3.0		
count	5	5	5		

***Picea sitchensis* (PISI) Site Indexes**	ABH	Ht m	Ht ft	Total age	SI 100
PISI Lilliwaup all areas except A and D -- mean	67.8	21.1	69.2	76	**74**
stdev	5.2	4.4	14.6		
count	9	9	9		

***Picea sitchensis* (PISI) Site Indexes**	ABH	Ht m	Ht ft	Total age	SI 100
PISI Hylebos all areas -- mean	119.7	29.9	97.9	128	95
stdev	34.4	4.2	13.6		
count	9	9	9		
PISI Little Egypt all -- mean	88.2	29.1	95.4	96	96
stdev	13.4	3.1	10.2		
count	6	6	6		
PISI Swamp Creek -- mean	103.3	29.3	96.1	111	95
stdev	4.8	4.0	13.1		
count	4	4	4		
PISI Hylebos, Little Egypt, and Swamp Creek mean SI					**95**

***Picea sitchensis* (PISI) Site Indexes**	ABH	Ht m	Ht ft	Total age	SI 100
PISI Snohomish Estuary Otter Island --mean	88.0	22.5	73.8	96	**74**
stdev	22.9	2.2	7.3		
count	12	12	12		

Table C-1 (cont.)

Tsuga heterophylla **(TSHE) Site Indexes**	ABH	Ht m	Ht ft	Total age	SI 100
TSHE Hylebos -- mean	81.7	32.1	105.2	91	110
stdev	25.9	4.8	15.9		
count	18	18	18		
TSHE Lilliwaup without Areas A and D -- mean	82.0	32.3	106.0	91	111
stdev	0.0	3.5	11.5		
count	2	2	2		
TSHE Little Egypt -- mean	106.0	35.4	116.3	115	111
stdev	21.2	2.4	7.9		
count	2	2	2		
TSHE Hylebos, Lilliwaup, Little Egypt mean SI					**111**

Tsuga heterophylla **(TSHE) Site Indexes -- bogs**	ABH	Ht m	Ht ft	Total age	SI 100
TSHE Budd Inlet -- mean	35.2	18.2	59.6	44	103
stdev	9.4	2.1	6.9		
count	5	5	5		
TSHE Silver Lake -- mean	78.5	28.5	93.5	88	100
stdev	4.9	0.6	2.1		
count	2	2	2		
TSHE Budd Inlet and Silver Lake mean SI					**101**

Alnus rubra **(ALRU) Site Indexes -- histosols**	ABH	Ht m	Ht ft	Total age	SI 100
ALRU Hylebos -- mean	88.0	26.8	88.0	93	79
stdev	2.7	2.6	8.5		
count	6	6	6		
ALRU Evans Creek -- mean	63.7	27.4	89.9	69	83
stdev	2.5	4.7	15.4		
count	3	3	3		
ALRU Miller Creek -- mean	58.6	28.1	92.0	64	86
stdev	6.3	2.3	7.6		
count	5	5	5		
ALRU histosol -- mean SI					**82**

Appendix C: Stand Height and Site Index

Table C-1 (cont.)

***Alnus rubra* (ALRU) Site Indexes -- nonhistosol**	ABH	Ht m	Ht ft	Total age	SI 100
ALRU Lower Green River -- mean	48.4	22.8	74.7	53	72
stdev	9.6	1.6	5.3		
count	5	5	5		
ALRU Jenkins Creek -- mean	50.6	24.4	80.0	56	76
stdev	1.8	2.8	9.2		
count	4	4	4		
ALRU Snohomish River -- mean	31.3	22.1	72.6	36	78
stdev	3.3	4.9	16.0		
count	11	11	11		
ALRU Juanita Creek -- mean	27.0	21.6	70.9	32	80
stdev	4.1	2.0	6.5		
count	4	4	4		
ALRU nonhistosol -- mean SI					**76**

Mixed Coniferous Species Site Indexes	ABH	Ht m	Ht ft	Total age	SI 100[1]
Hylebos – mean	100.6	30.8	100.9	109	95
stdev	34	5	16		
count	40	40	40		
Little Egypt Area A -- mean	105.8	31.4	103.1	114	95
stdev	47.7	4.6	15.0		
count	8	8	8		
Little Egypt Area B -- mean	107.8	29.0	95.0	116	90
stdev	8.5	3.1	10.2		
count	4	4	4		
Lilliwaup B, B2, and C – mean	67.1	23.6	77.6	75	90
stdev	7.3	6.1	20.0		
count	14	14	14		
Mixed Species -- mean SI					**93**
Lilliwaup Areas A and D (bog) – mean	123.4	22.4	73.4	131	**65**
stdev	54.4	2.8	9.1		
count	7	7	7		

[1] Based on mixed-species site index in Forest Club (1971)

Appendix C: Stand Height and Site Index

Table C-2. Reference Site Indexes

Species	SI Range (ft)	Midpoint (ft)	Source
western red cedar *Thuja plicata*	60-200	130	Henderson et al. 1989 Heygi et al. 1979
Sitka spruce *Picea sitchensis*	80-220	150	Henderson et al. 1989 Heygi et al. 1979
western hemlock *Tsuga heterophylla*	60-200	130	Henderson et al. 1989 Barnes 1962
red alder *Alnus rubra*	40-140	90	Henderson et al. 1989 Heygi et al. 1979

Site Index Equations

Site indexes were estimated using the equations listed below, as cited in Henderson et al. (1989). Age is total age (TAge) in years; height (Ht) is in feet:

Thuja plicata, western red cedar: base age = 100 years total age (Hegyi et al. 1979):

$$SI = Ht/(1.1243\ [1-e^{(-0.0263TAge)}]^{1.5662})$$

Picea sitchensis, Sitka spruce: base age = 100 years total age (Hegyi et al. 1979):

$$SI = Ht/(1.0458\ [1-e^{(-0.0380TAge)}]^{1.9804})$$

Tsuga heterophylla, western hemlock: base age = 100 years total age, for ages 30-400 (Barnes 1962):

$$SI = Ht(07.409 + 12.96258/TAge + 1348.904/TAge^2)$$

Alnus rubra, red alder: base age = 50 years total age (Hegyi et al. 1979):

$$SI = Ht/(1.1302\ [1-e^{(-0.0421TAge)}]^{0.9422})$$

Appendix D: Data Tables

Table D-1: Forested Wetland Data

Wetland Site Name	County	Species	Rings Actual	ABH Final	DBH cm	DBH inch	Height feet	Soil Type	Comment
Ames Lake	King	ALRU	16	17	17.7	7.0	45	Histosol w/ clay at 20"	
Ames Lake	King	ALRU	18	19	20.4	8.0	57	Histosol w/ clay at 20"	
Ames Lake	King	ALRU	15	17	17.5	6.9	54	Histosol w/ clay at 20"	
Ames Lake	King	ALRU	53	54	31.2	12.3	77	sandy loam	
Ames Lake	King	ALRU	49	54	42.0	16.6	90	sandy loam	
Ames Lake	King	SALA	17	19	32.7	12.9	63	Histosol w/ clay at 20"	
Ames Lake	King	TSHE	18	18	20.1	7.9	54	Histosol w/ clay at 20"	
Ames Lake	King	TSHE	16	16	18.3	7.2	32	Histosol w/ clay at 20"	
Ames Lake	King	TSHE	19	21	23.1	9.1	38	Histosol w/ clay at 20"	
Bellevue 3I	King	ALRU	26	26	25.4	10.0		sandy silt loam	
Bellevue 3I	King	ALRU	19	21	24.4	9.6		sandy silt loam	
Bellevue 3I	King	ALRU	27	27	23.4	9.2		sandy silt loam	
Bellevue 3I	King	ALRU	26	26	21.8	8.6		sandy silt loam	
Bellevue 3I	King	POBA	25	28	40.6	16.0		fine silt	
Bellevue 3I	King	POBA	30	33	63.5	25.0		fine silt	
Bellevue 3I	King	SALA		20	30.5	12.0		Histosol	
Big Bear Creek 10	King	ALRU	16	17	23.4	9.2	68	Histosol	
Big Bear Creek 10	King	ALRU	20	20	22.0	8.7	49	Histosol	
Big Bear Creek 10	King	ALRU	20	20	23.4	9.2	49	Histosol	
Big Bear Creek 10	King	ALRU	15	17	32.2	12.7	55	Histosol	
Big Bear Creek 10	King	ALRU	15	18	25.6	10.1	44	Histosol	
Big Bear Creek 10	King	POBA	24	26	61.8	24.4	104	Histosol	
Big Bear Creek 10	King	POBA	19	21	45.4	17.9	74	Histosol	
Big Bear Creek 10	King	POBA	13	15	38.1	15.0	99	Histosol	

Appendix D: Data Tables

Table D-1 cont.

Big Bear Creek 10	King	POBA	14	15	34.3	13.5	95	Histosol	
Big Bear Creek 10	King	SALA	15	17	33.6	13.2	52	Histosol	
Big Bear Creek 10	King	SALA	15	16	22.5	8.9	59	Histosol	
Big Bear Creek 10	King	SALA	16	17	27.4	10.8	59	Histosol	
Big Bear Creek 24	King	ALRU	22	26	23.4	9.2		silty gravelly loam	
Big Bear Creek 24	King	ALRU	45	48	35.6	14.0		silty gravelly loam	
Big Bear Creek 24	King	ALRU	44	49	35.6	14.0		silty gravelly loam	
Big Bear Creek 24	King	TSHE	52	55	40.6	16.0		Histosol	
Big Bear Creek 24	King	TSHE	43	43	33.0	13.0		Histosol	
Big Bear Creek 24	King	TSHE	41	44	48.3	19.0		Histosol	
Big Bear Creek 30	King	POBA	46	48	66.1	26.0	131	gravelly loam	
Big Bear Creek 30	King	POBA	37	37	52.5	20.7	128	gravelly loam	
Big Bear Creek 30	King	POBA	24	30	22.2	8.8	68	gravelly loam	
Budd Inlet	*Thurston*	*PICO*	*17*	*17*	*17.4*	*6.9*	*33*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*PICO*	*14*	*16*	*16.5*	*6.5*	*31*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*PICO*	*45*	*47*	*28.3*	*11.1*	*54*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*PICO*	*57*	*58*	*35.8*	*14.1*	*52*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*PICO*	*48*	*48*	*29.1*	*11.4*	*53*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*PICO*	*43*	*43*	*27.4*	*10.8*	*54*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*TSHE*	*26*	*30*	*22.0*	*8.7*	*69*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*TSHE*	*31*	*34*	*27.8*	*11.0*	*57*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*TSHE*	*38*	*44*	*37.7*	*14.8*	*62*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*TSHE*	*45*	*45*	*29.9*	*11.8*	*50*	*Histosol*	*bog*[1]
Budd Inlet	*Thurston*	*TSHE*	*22*	*23*	*31.8*	*12.5*	*60*	*Histosol*	*bog*[1]
East lake sammamish 61	King	ALRU	23	26	30.5	12.0		silty sandy loam	
East lake sammamish 61	King	ALRU	25	28	33.0	13.0		silty sandy loam	
East lake sammamish 61	King	ALRU	29	29	27.9	11.0		silty sandy loam	

Appendix D: Data Tables

Table D-1 cont.

East lake sammamish 61	*King*	*TSHE*	*63*	*65*	*33.0*	*13.0*		*Alderwood*	*nonhistosol*[1]
East Lake Washington 1	King	ALRU	35	37	33.0	13.0		Fine Silt	
East Lake Washington 1	King	ALRU	35	35	30.5	12.0		Fine Silt	
East Lake Washington 1	King	SALA	27	35	27.9	11.0		Sandy	
East Lake Washington 1	King	SALA	40	40	40.6	16.0		Sandy	
East Lake Washington 1	King	SALA	17	19	19.3	7.6		Sandy	
East Lake Washington 2	King	ALRU	36	38	33.0	13.0	47	Histosol	
East Lake Washington 2	King	ALRU	27	28	29.1	11.5	57	Histosol	
East Lake Washington 2	King	SALA	22	22	24.2	9.5	37	Histosol	
Evans Creek	King	ALRU	66	66	33.3	13.1	86	Histosol	
Evans Creek	King	ALRU	61	63	49.6	19.5		Histosol	
Evans Creek	King	ALRU	61	64	37.6	14.8	77	Histosol	
Evans Creek	King	ALRU	60	61	38.0	15.0	107	Histosol	
Evans Creek	King	THPL	52	52	43.0	16.9	71	Histosol	
Evans Creek	King	THPL	56	57	43.0	16.9	99	Histosol	
Evans Creek	King	TSHE	38	38	39.9	15.7	69	Histosol	
Homeacres	Snohomish	PICO	135	139	34.8	13.7	64	silty loam	
Homeacres	Snohomish	PICO	127	140	45.2	17.8	69	silty loam	
Homeacres	Snohomish	PISI	103	105	66.5	26.2	95	silty loam	
Homeacres	Snohomish	THPL	27	31	34.5	13.6	49	Histosol	
Jenkins Creek	King	ALRU	28	28	21.8	8.6		sandy loam	
Jenkins Creek	King	ALRU	27	32	25.4	10.0		sandy loam	
Jenkins Creek	King	ALRU	41	41	30.5	12.0		sandy loam	
Jenkins Creek	King	ALRU	36	37	17.3	6.8	44	sandy loam	
Jenkins Creek	King	ALRU	49	49	37.5	14.8	72	sandy loam	
Jenkins Creek	King	ALRU	48	51	32.2	12.7	80	sandy loam	
Jenkins Creek	King	ALRU	51	53	40.1	15.8	93	sandy loam	
Jenkins Creek	King	ALRU	46	49.5	33.5	13.2	75	sandy loam	

Appendix D: Data Tables

Table D-1 cont.

Jenkins Creek	King	SALA	23	26	13.7	5.4		silty loam	
Jenkins Creek	King	SALA	30	30	27.9	11.0		silty loam	
Jenkins Creek	King	SALA	71	78	46.2	18.2	77	sandy loam	
Jenkins Creek	King	SALA	74	79	34.3	13.5	69	sandy loam	
Jenkins Creek	King	SALA	87	87	41.1	16.2	85	sandy loam	
Jenkins Creek	King	SALA	110	110	43.6	17.2	72	sandy loam	
Jenkins Creek	King	SALA	28	38	24.5	9.7	67	sandy loam	
Jenkins Creek	King	THPL	81	83	45.7	18.0		Histosol	
Juanita Creek	King	ALRU	25	25	24.8	9.8	73	sandy	
Juanita Creek	King	ALRU	22	24	23.1	9.1	62	sandy	
Juanita Creek	King	ALRU	24	26	26.6	10.5	71	sandy	
Juanita Creek	King	ALRU	33	33	28.4	11.2	77	sandy	
Juanita Creek	King	POBA	21	22	60.0	23.6	133	sandy	
Juanita Creek	King	POBA	22	27	49.4	19.5	94	sandy loam	
Juanita Creek	King	SALA	24	26	28.4	11.2	68	sandy	
Juanita Creek	King	SALA	17	18	26.3	10.3	58	sandy loam	
Lilliwaup Swamp A	*Mason*	*THPL*	*75*	*75*	*24.8*	*9.8*	*48*	*Histosol*	*bog - Lab. tea*[1]
Lilliwaup Swamp A	*Mason*	*THPL*	*129*	*131*	*43.0*	*16.9*	*75*	*Histosol*	*bog - Lab. tea*[1]
Lilliwaup Swamp A	*Mason*	*THPL*	*94*	*95*	*30.0*	*11.8*	*75*	*Histosol*	*bog - Lab. tea*[1]
Lilliwaup Swamp A	*Mason*	*TSHE*	*81*	*83*	*38.5*	*15.2*	*82*	*Histosol*	*bog - Lab. tea*[1]
Lilliwaup Swamp A	*Mason*	*TSHE*	*125*	*125*	*30.2*	*11.9*	*54*	*Histosol*	*bog - Lab. tea*[1]
Lilliwaup Swamp B2	Mason	PISI	66	68	38.5	15.2	77	Histosol	
Lilliwaup Swamp B	Mason	PISI	63	66	32.8	12.9	59	Histosol	
Lilliwaup Swamp B	Mason	PISI	63	65	39.5	15.6	63	Histosol	
Lilliwaup Swamp B	Mason	PISI	69	70	51.5	20.3	84	Histosol	
Lilliwaup Swamp B	Mason	PISI	56	60	49.8	19.6	58	Histosol	
Lilliwaup Swamp B	Mason	PISI	76	78	61.5	24.2	98	Histosol	
Lilliwaup Swamp B2	*Mason*	PISI	*61*	*64*	*80.5*	*31.7*	102	*Histosol*	*outlier*[1]

Appendix D: Data Tables

Table D-1 cont.

Lilliwaup Swamp B2	Mason	THPL	55	61	51.5	20.3	97	Histosol	
Lilliwaup Swamp B2	Mason	TSHE	79	82	64.5	25.4	114	Histosol	
Lilliwaup Swamp B2	Mason	TSHE	83	85	53.0	20.9		Histosol	
Lilliwaup Swamp C	Mason	ALRU	69	70	26.7	10.5	58	Histosol	
Lilliwaup Swamp C	Mason	PISI	62	64	44.0	17.3	56	Histosol	
Lilliwaup Swamp C	Mason	PISI	65	67	37.0	14.6	57	Histosol	
Lilliwaup Swamp C	Mason	PISI	71	72	40.4	15.9	71	Histosol	
Lilliwaup Swamp C	Mason	TSHE	50	53	41.4	16.3	92	Histosol	
Lilliwaup Swamp D	*Mason*	*THPL*	*99*	*99*	*35.3*	*13.9*	*79*	*Histosol*	*bog - Lab. tea*[1]
Lilliwaup Swamp D	*Mason*	*THPL*	*87*	*91*	*37.8*	*14.9*	*71*	*Histosol*	*bog - Lab. tea*[1]
Lilliwaup Swamp D	*Mason*	*THPL*	*235*	*240*	*58.3*	*23.0*	*78*	*Histosol*	*bog - Lab. tea*[1]
Lilliwaup Swamp E	Mason	PISI	65	68	42.0	16.5		Histosol	
Lilliwaup Swamp E	Mason	PISI	173	175	76.0	29.9		Histosol	
Lilliwaup Swamp E	Mason	PISI	67	73	57.0	22.4		Histosol	
Lilliwaup Swamp E	Mason	PISI	63	68	56.5	22.2		Histosol	
Lilliwaup Swamp E	Mason	THPL	142	142	74.0	29.1	110	Histosol	
Lilliwaup Swamp E	Mason	THPL	87	87	51.5	20.3		Histosol	
Lilliwaup Swamp E	Mason	THPL	84	84	65.0	25.6	110	Histosol	
Lilliwaup Swamp E	Mason	TSHE	83	84	59.0	23.2		Histosol	
Lilliwaup Swamp E	Mason	TSHE	82	82	48.0	18.9	98	Histosol	
Lilliwaup Swamp E	Mason	TSHE	71	75	42.5	16.7		Histosol	
Lilliwaup Swamp E	Mason	TSHE	69	73	45.6	18.0		Histosol	
Lilliwaup Swamp E	Mason	TSHE	68	68	36.0	14.2		Histosol	
Lilliwaup Swamp E	Mason	TSHE	67	67	54.5	21.5		Histosol	
Lilliwaup Swamp F	Mason	PISI	185	190	61.0	24.0		Histosol	
Lilliwaup Swamp F	*Mason*	PISI	*211*	*218*	*58.4*	*23.0*		*Histosol*	*outlier*[1]
Lilliwaup Swamp F	Mason	THPL	175	178	59.0	23.2		Histosol	
Lilliwaup Swamp F	Mason	THPL	161	167	69.0	27.2		Histosol	

Appendix D: Data Tables

Table D-1 cont.

Lilliwaup Swamp F	Mason	THPL	245	252	60.0	23.6		Histosol	
Lilliwaup Swamp F	Mason	THPL	177	183	82.0	32.3		Histosol	
Lilliwaup Swamp F	Mason	TSHE	161	171	51.9	20.4		Histosol	
Lilliwaup Swamp F	*Mason*	*TSHE*	*170*	*175*	*38.0*	*15.0*		*Histosol*	*dbh estimated*[1]
Lilliwaup Swamp C	*Mason*	*PISI*	*65*	*66*	*80.1*	*31.5*	83	*Histosol*	*outlier; by roadbed*[1]
Little Egypt A	Mason	PISI	88	89	44.0	17.3	88	Histosol	
Little Egypt A	Mason	PISI	74	75	52.0	20.5	79	Histosol	
Little Egypt A	Mason	PISI	70	71	63.0	24.8	103	Histosol	
Little Egypt A	Mason	PISI	91	91	48.0	18.9	95	Histosol	
Little Egypt A	Mason	THPL	89	90	56.5	22.2	109	Histosol	top split[2]
Little Egypt A	Mason	THPL	218	218	85.0	33.5	119	Histosol	top split[2]
Little Egypt A	Mason	TSHE	121	121	70.5	27.8	122	Histosol	
Little Egypt A	Mason	TSHE	91	91	62.0	24.4	111	Histosol	
Little Egypt A	*Mason*	*TSHE*	*63*	*63*	*25.0*	*9.8*	51	*Histosol*	*suppressed*[1]
Little Egypt B	Mason	ALRU	115	115	37.5			Histosol	
Little Egypt B	Mason	PISI	95	96	70.0	27.6	103	Histosol	
Little Egypt B	Mason	PISI	105	107	63.5	25.0	104	Histosol	
Little Egypt B	Mason	THPL	112	112	44.0	17.3	67	Histosol	top broken[2]
Little Egypt B	Mason	THPL	108	110	64.0	25.2	81	Histosol	top damage[2]
Little Egypt B	Mason	THPL	110	113	66.3	26.1	88	Histosol	
Little Egypt B	Mason	THPL	190	193	56.5	22.2	69	Histosol	top split[2]
Little Egypt B	Mason	THPL	115	115	48.7	19.2	85	Histosol	
Little Egypt B	*Mason*	*THPL*	*228*	*270*	*115.0*	*45.3*	*135*	*Histosol*	*age estimated*[1]
Lower Cedar River	King	ALRU	34	39	38.1	15.0		silty gravel	
Lower Cedar River	King	ALRU	62	66	30.5	12.0		silty gravel	
Lower Cedar River	King	ALRU	43	46	28.8	11.4	57	Histosol	
Lower Cedar River	King	ALRU	35	36	20.5	8.1	84	Histosol	
Lower Cedar River	King	THPL	42	42	21.1	8.3		Histosol	

Appendix D: Data Tables

Table D-1 cont.

Lower Cedar River	King	TSHE	17	20	19.6	7.7	48	Histosol	
Lower Green River	King	ALRU	47	49	38.6	15.2	79	sandy	
Lower Green River	King	ALRU	54	57	30.9	12.2	70	sandy	
Lower Green River	King	ALRU	53	53	27.9	11.0	70	sandy	
Lower Green River	King	ALRU	50	51	34.0	13.4	74	sandy	
Lower Green River	King	ALRU	32	32	26.9	10.6	81	sandy	
Lower Green River	King	POBA	48	51	72.5	28.5	150	sandy	
Lower Puget Sound	King	ALRU	15	15	13.7	5.4		org. silty loam	
Lower Puget Sound	King	ALRU	17	19	19.3	7.6		org. silty loam	
Lower Puget Sound	King	ALRU	22	22	16.3	6.4		org. silty loam	
Lower Puget Sound	King	ALRU	28	28	20.3	8.0		org. silty loam	
Lower Puget Sound	King	ALRU	14	17	27.9	11.0		org. silty loam	
May Creek	King	ALRU	16	17	25.1	9.9	53	fine sand loam	
May Creek	King	ALRU	49	52	38.5	15.2	64	fine sand loam	
May Creek	King	ALRU	41	50	23.6	9.3	66	fine sand loam	
May Creek	*King*	*THPL*	*130*	*140*	*44.1*	*17.4*	*71*	*silty loam*	*nonhistosol*[1]
May Creek	*King*	*THPL*	*91*	*91*	*56.4*	*22.2*	*93*	*silty loam*	*nonhistosol*[1]
McAleer Creek	King	ALRU	23	24	20.7	8.1	81	sandy	
McAleer Creek	King	SALA	19	22	19.3	7.6	70	sandy	
McAleer Creek	King	SALA	24	27	32.3	12.7	63	sandy	
McAleer Creek	King	SALA	19	20	20.3	8.0	70	sandy	
Middle Green River	King	ALRU	12	14	19.3	7.6		org. silty loam	
Middle Green River	King	ALRU	15	18	27.9	11.0		org. silty loam	
Middle Green River	King	ALRU	10	12	19.3	7.6		org. silty loam	
Middle Green River	King	POBA	16	17	33.0	13.0		sandy gravelly loam	
Middle Green River	King	POBA	17	18	48.3	19.0		sandy gravelly loam	
Middle Green River	King	POBA	11	14	24.4	9.6		sandy gravelly loam	
Middle Green River	King	SALA	15	15	15.5	6.1		org. silty loam	

Appendix D: Data Tables

Table D-1 cont.

Miller Creek	King	ALRU	51	51	34.2	13.5	84	Histosol	
Miller Creek	King	ALRU	55	56	40.3	15.9	86	Histosol	
Miller Creek	King	ALRU	65	68	31.5	12.4	94	Histosol	
Miller Creek	King	ALRU	60	61	34.3	13.5	103	Histosol	
Miller Creek	King	ALRU	56	57	27.8	10.9	94	Histosol	
Patterson Creek	King	ALRU	20	22	21.1	8.3		org. silty sandy loam	
PC12	King	ALRU	21	21	27.9	11.0		org. silty sandy loam	
PC12	King	ALRU	38	39	27.9	11.0		org. silty sandy loam	
PC12	King	ALRU	28	31	35.6	14.0		org. silty sandy loam	
Posell		PISI	89	93	47.5	18.7	92	min/organic	
Purcell	Snohomish	ALRU	38	38	22.0		67	organic	
Purcell	Snohomish	PICO	87	93	36.5	14.4		Histosol	
Purcell	Snohomish	THPL	43	46	22.0	8.7		Histosol	
Raging River	King	ALRU	34	38	35.6	14.0		silty sandy loam	
Raging River	King	ALRU	33	38	21.8	8.6		silty sandy loam	
Raging River	King	ALRU	49	57	27.9	11.0		silty sandy loam	
Raging River	King	ALRU	57	63	45.7	18.0		silty sandy loam	
Raging River	*King*	*TSHE*	*21*	*25*	*22.6*	*8.9*		*silty sandy loam*	*nonhistosol*[1]
Raging River	*King*	*TSHE*	*37*	*41*	*30.5*	*12.0*		*silty sandy loam*	*nonhistosol*[1]
Silver Lake	*King*	*PICO*	*100*	*102*	*33.3*	*13.1*	*39*	*Histosol*	*bog*[1]
Silver Lake	*King*	*PICO*	*86*	*91*	*25.8*	*10.1*	*43*	*Histosol*	*bog*[1]
Silver Lake	*King*	*PICO*	*58*	*58*	*23.6*	*9.3*	*28*	*Histosol*	*bog*[1]
Silver Lake	*King*	*PICO*	*60*	*63*	*28.2*	*11.1*	*61*	*Histosol*	*bog*[1]
Silver Lake	*King*	*PICO*	*49*	*49*	*26.0*	*10.2*	*59*	*Histosol*	*bog*[1]
Silver Lake	*King*	*PICO*	*83*	*83*	*26.8*	*10.5*	*45*	*Histosol*	*bog*[1]
Silver Lake	*King*	*PISI*	*24*	*26*	*26.7*	*10.5*	*30*	*Histosol*	*bog*[1]
Silver Lake	*King*	*PISI*	*44*	*46*	*37.0*	*14.6*	*54*	*Histosol*	*bog*[1]

Appendix D: Data Tables

Table D-1 cont.

Silver Lake	*King*	*PSME*	*72*	*72*	*57.8*	*22.8*	*117*	*Histosol*	*bog*[1]
Silver Lake	*King*	*PSME*	*56*	*57*	*47.2*	*18.6*	*99*	*Histosol*	*bog*[1]
Silver Lake	*King*	*TSHE*	*33*	*35*	*28.5*	*11.2*	*48*	*Histosol*	*bog*[1]
Silver Lake	*King*	*TSHE*	*91*	*93*	*40.1*	*15.8*	*67*	*Histosol*	*bog*[1]
Silver Lake	*King*	*TSHE*	*80*	*82*	*36.2*	*14.3*	*92*	*Histosol*	*bog*[1]
Silver Lake	*King*	*TSHE*	*71*	*75*	*62.7*	*24.7*	*95*	*Histosol*	*bog*[1]
Silver Lake	*King*	*TSHE*			*31.0*	*12.2*	*67*	*Histosol*	*bog*[1]
Silver Lake	*King*	*TSHE*	*41*	*42*	*51.7*	*20.4*	*31*	*Histosol*	*bog*[1]
Sno Estuary-Otter Is.	Snohomish	PISI	91	94	49.0	19.3	79	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	83	86	43.0	16.9	71	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	96	99	37.8	14.9	50	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	90	91	25.0	9.8	49	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	150	151	48.2	19.0	77	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	104	107	64.1	25.2	82	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	55	55	23.0	9.1	38	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	61	66	38.0	15.0	64	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	79	82	45.3	17.8	64	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	74	77	41.4	16.3	79	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	67	72	55.0	21.7	81	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	80	84	58.6	23.1	72	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	72	77	33.1	13.0	31	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	71	76	27.9	11.0	38	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	90	91	30.8	12.1	63	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	72	73	29.9	11.8	47	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	74	76	49.0	19.3	73	silty	
Sno Estuary-Otter Is.	Snohomish	PISI	66	70	36.0	14.2	82	silty	
Sno Estuary-Otter Is.	*Snohomish*	*PISI*	*438*	*445*	*56.7*	*22.3*	*78*	*silty*	*outlier*[1]
Sno Estuary-Rhodes	Snohomish	PISI	42	44	41.1	16.2	79	mineral	

Appendix D: Data Tables

Table D-1 cont.

Sno Est.-Spencer Is. South	Snohomish	PISI	94	97	40.0	15.7	79	silty	
Sno Est.-Spencer Is. South	Snohomish	PISI	91	95	48.0	18.9	87	silty	
Sno Est.-Spencer Is. South	Snohomish	PISI	65	68	24.0	9.4	52	silty	
Sno Est.-Spencer Is. South	Snohomish	PISI	104	106	57.3	22.6	53	silty	
Sno Est.-Spencer Is. South	*Snohomish*	*PISI*	*71*	*73*	*76.0*	*29.9*	*72*	*silty*	*outlier*[1]
Snohomish Co Wet	Snohomish	PISI	80	85	37.0	14.6	55	Histosol	
Snohomish Co Wet	Snohomish	PISI	121	123	51.5	20.3	111	Histosol	
Snohomish Co Wet	Snohomish	THPL	112	112	37.9	14.9	51	Histosol	
Snohomish Co Wet	Snohomish	THPL	70	70	39.7	15.6	58	Histosol	
Snohomish Estuary Rhodes	Snohomish	PSME	36	39	25.2			mineral	
Snoqualmie River 25	King	ALRU	25	26	29.2	11.5	52	fine sandy loam	
Snoqualmie River 25	King	ALRU	37	37	43.5	17.1	80	fine sandy loam	
Snoqualmie River 25	King	ALRU	29	33	42.9	16.9	81	fine sandy loam	
Snoqualmie River 25	King	ALRU	33	34	24.6	9.7	53	fine sandy loam	
Snoqualmie River 25	King	ALRU	30	31	41.9	16.5	73	fine sandy loam	
Snoqualmie River 25	King	POBA	31	31	25.5	10.0	98	fine sandy loam	
Snoqualmie River 25	King	POBA	26	27	33.3	13.1	99	fine sandy loam	
Snoqualmie River 25	King	POBA	35	35	43.5	17.1	118	fine sandy loam	
Snoqualmie River 25	King	SALA	28	29	32.9	13.0	59	loam	
Snoqualmie River 25	King	SALA	36	37	42.7	16.8	68	loam	
Snoqualmie River 25	King	SALA	38	38	41.4	16.3	65	loam	
Snoqualmie River 25	King	SALA	33	34	30.1	11.9	55	loam	
Snoqualmie River 34	King	ALRU	26	27	31.3	12.3	99	sandy loam	
Snoqualmie River 34	King	ALRU	30	31	31.1	12.2	84	sandy loam	
Snoqualmie River 34	King	ALRU	29	31	31.6	12.5	84	sandy loam	
Snoqualmie River 34	King	ALRU	32	33	26.0	10.2	70	sandy loam	
Snoqualmie River 34	King	ALRU	28	28	17.1	6.7	47	sandy loam	
Snoqualmie River 34	King	ALRU	32	33	39.5	15.6	77	sandy loam	

Appendix D: Data Tables

Table D-1 cont.

Snoqualmie River 34	King	SALA	30	31	23.5	9.2	71	sandy loam	
Snoqualmie River 34	King	SALA	26	26	19.4	7.6	73	sandy loam	
Snoqualmie River 34	King	SALA	30	32	29.8	11.8	74	sandy loam	
Snoqualmie River 34	King	SALA	34	35	29.8	11.7	90	sandy loam	
Snoqualmie River 34	King	SALA	23	24	20.5	8.1	86	sandy loam	
Snoqualmie River 34	King	SALA	25	26	25.3	10.0	70	sandy loam	
Soos Creek	King	ALRU	10	13	25.4	10.0		organic silty loam	
Soos Creek	King	ALRU	19	22	27.9	11.0		organic silty loam	
Soos Creek	King	SALA		16	35.6	14.0		organic silty loam	
Spanaway Park		ALRU	34	35	40.3		106	organic	
Spanaway Park		ALRU	28	31	17.6		78	organic	
Spanaway Park		FRLA	34	35	14.6			organic	
State Reform Farm	Snohomish	SALA	26	29	40.9	16.1	77	clay loam	
State Reform Farm	Snohomish	SALA	23	24	21.0	8.3	50	clay loam	
Swamp Creek	Snohomish	ALRU	32	37	35.5	14.0	65	Histosol	
Swamp Creek	Snohomish	ALRU	44	46	31.4	12.4	72	Histosol	
Swamp Creek	Snohomish	ALRU	84	84	49.2	19.4	85	Histosol	
Swamp Creek	Snohomish	ALRU	26	29	36.1	14.2	73	loam	
Swamp Creek	Snohomish	ALRU	37	37	28.3	11.2	71	loam	
Swamp Creek	Snohomish	PISI	97	98	45.6	18.0	82	Histosol	
Swamp Creek	Snohomish	PISI	109	109	40.1	15.8	111	Histosol	
Swamp Creek	Snohomish	PISI	94	105	63.2	24.9	103	Histosol	
Swamp Creek	Snohomish	PISI	101	101	56.6	22.3	89	Histosol	
Swamp Creek	King	POBA	27	27	59.9	23.6	135	sandy loam	
Swamp Creek	King	POBA	25	27	63.4	25.0	129	sandy loam	
Swamp Creek	King	POBA	28	36	87.7	34.5	127	sandy loam	
Swamp Creek	King	POBA	24	33	94.5	37.2	124	sandy loam	
Swamp Creek	King	POBA	36	36	65.4	25.7	146	sandy loam	

Appendix D: Data Tables

Table D-1 cont.

West Hylebos A	King	PISI	90	91	61.0	24.0	90	Histosol	
West Hylebos A	King	PISI	82	83	40.5	15.9	89	Histosol	
West Hylebos A	King	TSHE	101	103	44.5	17.5	123	Histosol	
West Hylebos A	King	TSHE	67	69	61.5	24.2	106	Histosol	
West Hylebos A	King	TSHE	92	93	46.0	18.1	111	Histosol	
West Hylebos A	King	TSHE	122	122	53.5	21.1	125	Histosol	
West Hylebos A	*King*	*TSHE*	*110*	*110*	*29.5*	*11.6*	95	*Histosol*	*intermediate*[1]
West Hylebos A2	King	PISI	112	113	83.5	32.9	87	Histosol	
West Hylebos A2	King	THPL	40	40	19.0	7.5	38	Histosol	
West Hylebos A2	King	TSHE	49	50	37.0	14.6	88	Histosol	
West Hylebos A2	King	TSHE	46	47	38.5	15.2	87	Histosol	
West Hylebos A2	King	TSHE	55	58	50.5	19.9	87	Histosol	
West Hylebos A2	King	TSHE	58	58	36.0	14.2	91	Histosol	
West Hylebos A2	King	TSHE	57	57	26.5	10.4	89	Histosol	
West Hylebos A2	King	TSHE	55	55	47.5	18.7	101	Histosol	
West Hylebos A2	King	TSHE	60	60	59.0	23.2	90	Histosol	
West Hylebos A2	King	TSHE	61	65	70.5	27.8	116	Histosol	
West Hylebos A3	King	ALRU	92	92	53.5	21.1	81	Histosol	
West Hylebos A3	King	ALRU	86	89	36.0	14.2	92	Histosol	
West Hylebos A3	King	PISI	118	120	64.5	25.4	103	Histosol	
West Hylebos A3	King	THPL	103	106	59.5	23.4	92	Histosol	
West Hylebos B	King	PISI	77	78	49.0	19.3	74	Histosol	
West Hylebos B	King	PISI	116	117	77.5	30.5	104	Histosol	
West Hylebos B	King	TSHE	70	70	67.5	26.6	101	Histosol	top dead[2]
West Hylebos C	King	ALRU	89	89	41.0	16.1	88	Histosol	
West Hylebos C	King	ALRU	87	88	35.0	13.8	96	Histosol	
West Hylebos C	King	ALRU	85	85	34.5	13.6	95	Histosol	
West Hylebos C	King	THPL	82	82	50.0	19.7	92	Histosol	

Appendix D: Data Tables

Table D-1 cont.

West Hylebos C	King	THPL	79	79	58.5	23.0	92	Histosol	
West Hylebos C	King	THPL	94	99	72.5	28.5	104	Histosol	
West Hylebos C3	King	THPL	77	80	72.0	28.3	91	Histosol	
West Hylebos D	King	PISI	164	166	89.0	35.0	107	Histosol	split top[2]
West Hylebos D	King	PISI	133	133	65.5	25.8	118	Histosol	
West Hylebos D	King	THPL	149	151	55.5	21.9	71	Histosol	split top[2]
West Hylebos D	King	THPL	123	131	50.0	19.7	89	Histosol	
West Hylebos D	King	THPL	98	105	64.0	25.2	117	Histosol	
West Hylebos D	King	THPL	88	90	35.0	13.8	60	Histosol	
West Hylebos D	King	TSHE	101	102	64.5	25.4	106	Histosol	
West Hylebos D2	King	ALRU	81	82	39.0			Histosol	top broken[2]
West Hylebos D2	King	THPL	139	140	66.8	26.3	128	Histosol	
West Hylebos D2	King	THPL	195	197	81.5	32.1	122	Histosol	
West Hylebos D2	King	TSHE	115	118	42.5	16.7	125	Histosol	
West Hylebos D2	King	TSHE	77	81	70.5	27.8	128	Histosol	
West Hylebos D2	King	TSHE	108	111	64.5	25.4	129	Histosol	
West Hylebos E	King	ALRU	84	85	56.0	22.0	75	Histosol	
West Hylebos E	King	PSME	87	87	82.5	32.5		Histosol	
West Hylebos E	King	PSME	98	98	78.0	30.7		Histosol	
West Hylebos E	King	PSME	67	68	43.5	17.1		Histosol	
West Hylebos F	King	PISI	174	176	63.0	24.8	104	Histosol	
West Hylebos F	King	THPL	121	123	65.0	25.6	82	Histosol	
West Hylebos F	King	THPL	122	123	55.5	21.9	81	Histosol	
West Hylebos F	King	THPL	123	125	67.0	26.4	110	Histosol	
West Hylebos F	King	THPL	68	71	26.5	10.4	59	Histosol	
West Hylebos F	King	THPL	94	99	75.0	29.5	100	Histosol	
West Hylebos F	King	TSHE	103	104	34.0	13.4	86	Histosol	
West Hylebos F	*King*	*TSHE*	*80*	*83*	*32.5*	*12.8*		*Histosol*	*suppressed[1]*

Appendix D: Data Tables

Table D-1 cont.

White River	King	FRLA	60	61	45.2	17.8	67	loam	
White River	King	FRLA	73	76	53.0	20.9	74	loam	
White River	King	FRLA	60	62	23.1	9.1	76	loam	
White River	King	FRLA	58	63	35.9	14.2	65	loam	
White River	King	FRLA	71	72	32.0	12.6	69	loam	
Willapa Bay	*Pacific*	*ALRU*	*18*	*20*	*15.9*	*6.3*	*42*	*Histosol*	*out of area*[1]
Willapa Bay	*Pacific*	*ALRU*	*15*	*16*	*19.0*	*7.5*	*53*	*Histosol*	*out of area*[1]
Willapa Bay	*Pacific*	*PISI*	*37*	*39*	*25.9*	*10.2*	*50*	*clay loam*	*out of area*[1]
Willapa Bay	*Pacific*	*PISI*	*45*	*50*	*57.2*	*22.5*	*58*	*clay loam*	*out of area*[1]
Willapa Bay	*Pacific*	*PISI*	*36*	*37*	*23.7*	*9.4*	*34*	*clay loam*	*out of area*[1]
Willapa Bay	*Pacific*	*PISI*	*37*	*39*	*17.1*	*6.7*	*44*	*clay loam*	*out of area*[1]
Willapa Bay	*Pacific*	*PISI*	*63*	*66*	*47.0*	*18.5*	*77*	*clay loam*	*out of area*[1]
Willapa Bay	*Pacific*	*TSHE*	*31*	*34*	*33.8*	*13.3*	*68*	*Histosol*	*out of area*[1]
Willapa Bay	*Pacific*	*TSHE*	*43*	*43*	*28.5*	*11.2*	*62*	*clay loam*	*out of area*[1]
Willapa Bay	*Pacific*	*TSHE*	*43*	*43*	*24.8*	*9.8*	*68*	*clay loam*	*out of area*[1]
Willapa Bay	*Pacific*	*TSHE*	*44*	*44*	*17.1*	*6.7*	*44*	*clay loam*	*out of area*[1]
Wetland Site Name	County	Species	Rings Actual	ABH Final	DBH cm	DBH inch	Height feet	Soil Type	Comment

[1] Rows in italics were not included in dbh growth rate analysis

[2] Trees with damaged or split tops were not included in site index calculations

Appendix E: Wetland Indicator Categories

Table E-1. Interpreting Wetland Indicator Categories		
Wetland Indicator Code	**Wetland Indicator Category**	**Estimated Probability of Occurrence Under Natural Conditions**
OBL	Obligate wetland	Occurs almost always (estimated probability 99%) in wetlands
FACW	Facultative wetland	Usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands
FAC	Facultative	Equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%)
FACU	Facultative upland	Usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%)
UPL	Upland	Occurs almost always (estimated probability 99%) non-wetlands
A positive (+) or negative (-) sign may be used with the Facultative Indicator categories to more specifically define the frequency of occurrence in wetlands. A positive sign indicates a frequency toward the higher end of the category (more frequently found in wetlands), and a negative sign indicates a frequency toward the lower end of the category (less frequently found in wetlands).		
Source: NRCS (National Resource Conservation Service). (undated). Interpreting Wetland Indicator Status. USDA website, accessed February 24, 2007. http://plants.usda.gov/wetinfo.html#categories		