Hood Canal riparian landscapes:
early historical condition and ecological changes

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Executive Summary

Though limited in spatial extent, riparian forests are among the most dynamic and diverse environments in the Pacific Northwest. At the interface between terrestrial and aquatic ecosystems, riparian environments host an array of critical plant and animal species, enrich the region's aesthetic landscape, and support an array of crucial ecological services like nutrient processing/transformation, water quality protection, and flood hazard reduction. Our knowledge of riparian forest ecology has expanded rapidly over the last 30 years. However, there is little information on historical changes to riparian forests and this knowledge gap hinders effective ecosystem management.

In this study, we combined archival land survey records and contemporary field surveys to reconstruct historical riparian forest conditions and chart ecosystem change in Hood Canal, Washington. Historical General Land Office (GLO) surveys (c. 1870) for Hood Canal and adjacent areas were integrated with a 1910 timber cruise survey for the 60 km^2 Dewatto watershed in a GIS. Field surveys at 80 riparian sites were used to validate our approach and to chart historical vegetation composition change.

Comparisons among historical land surveys and with a contemporary vegetation inventory revealed potential bias in historical survey records. To account for these biases we limited our analyses and capitalized on the complementary nature of the historical surveys, using the GLO records for forest composition and the 1910 timber cruise for forest age and spatial structure. Archival land survey information was mapped in relation to contemporary GIS map layers of streams, wetlands, and floodplains which were then used to attribute and summarize spatial data.

Our results show striking variation in historical riparian forest composition and structure across different shoreline types, landforms, and landscape position. By number and biomass, conifer species dominated along all shoreline types. Hardwood species were relatively abundant along estuary shorelines and in stream bottomlands but declined progressively in importance at higher positions in the stream network and at greater distances from waterbodies. Older, more structurally diverse forests clustered in stream

ravines, whereas wildfire reduced the age and structural diversity of upland forests. In unlogged portions of the Dewatto watershed stream-riparian fir and cedar dominants measured 2.5 and 4.5 times larger in biomass, respectively as compared to upland areas.

Comparisons of historical and contemporary forest composition at 80 stream-riparian locations across Hood Canal showed significant vegetation change for particular vegetation types at lower elevation sites in/near bottomlands. Over the historical period, 57.9% of cedar-spruce forest type sites transitioned to hardwood/mixed forest, as compared to other forest types which showed ≤35.3% change. Over two-thirds of sites that underwent vegetation change transitioned from conifer-dominance to hardwood/mixed forest, representing 23.2% of all sites.

We used classification and regression tree (CART) statistical models to predict historical vegetation change as a function of forest type and various environmental variables including stream size, stream and bottomland proximity, elevation, landform type, conifer regeneration, and exotic species count. Two separate model runs underscored historical forest type, elevation, and bottomland proximity as important predictors of vegetation change. Historically conifer sites in/near bottomlands were two times more likely to transition to hardwoods/mixed forest vs. remain unchanged. Conversely, mid-to-high elevation hardwood/mixed forest sites tended to succeed to conifer, while upland conifer and lowland hardwood/mixed sites generally experienced no change over the historical period.

Relatively infrequent, low density conifer regeneration and the presence of exotic species at approximately half of all riparian sites indicate that natural recovery of native riparian forests is not occurring even as new species invade these sensitive environments. Our findings suggest new questions pertinent to land management policies, provide important context for contemporary field studies and restoration, and underscore the critical importance of an historical perspective for effective ecosystem management.

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Introduction

A recent review of watershed restoration approaches in the Pacific Northwest stresses the need for ecosystem assessments to provide historical context and focus restoration planning and implementation (Roni et al. 2002). One crucial component of such assessments is a characterization of historical and present-day riparian forest conditions. At the interface between terrestrial and aquatic ecosystems, riparian areas are a pivotal landscape element, supplying organic matter (leaf detritus, large wood), moderating material fluxes (water, sediment, and nutrients), and modifying microclimate (light, temperature, and humidity) along streams, wetlands, and estuaries (Gregory et al. 1991, Mitsch and Gosselink 2000).

Riparian forests occupy the most dynamic portions of the landscape, subject to fire, flood, wind, and landslide disturbances. As a result of varied disturbance processes and diverse soil and topographic conditions, riparian communities exhibit high species and structural diversity. High plant biomass and species richness is matched with high vertebrate and invertebrate species diversity (Gregory et al. 1993, Pollock 1998b). Though riparian areas account for a small fraction of total watershed area, some 14% of all mammal, bird, amphibian, and reptile species found in Washington State require riparian habitats during at least one life history phase, and an additional 21% are more numerous or make heavier use of riparian environments as compared to uplands (Raedeke 1988). Certain animal groups have higher rates of dependency; 34% of Pacific Northwest bird species and 60% of amphibian species require riparian habitats to complete some aspect of their life history (Kelsey and West 1998). Most well known, is the importance of healthy, diverse riparian forests to the creation and maintenance of high quality fish habitat, as sources of large wood, shade, and detritus – the latter serving as the basis for stream and estuary food webs on which salmon depend.

Our knowledge of riparian forest ecological values and functions in the Pacific Northwest has expanded rapidly over the last 30 years (see Naiman et al. 1998 for a review). However, relatively little information exists on the historical condition of Pacific Northwest riparian forests and this information gap hinders effective ecosystem management. The belief that historical forests were perpetually ravaged by wildfire has been used to justify aggressive, extractive timber cutting regimes. Meanwhile, a competing myth posits that historically *all* Pacific Northwest riparian areas were dominated by old-growth conifer forest, before early logging and conversion to alder-dominated stands. What did the historical riparian forest landscape of Hood Canal look like? And how can such information improve our contemporary conservation efforts?

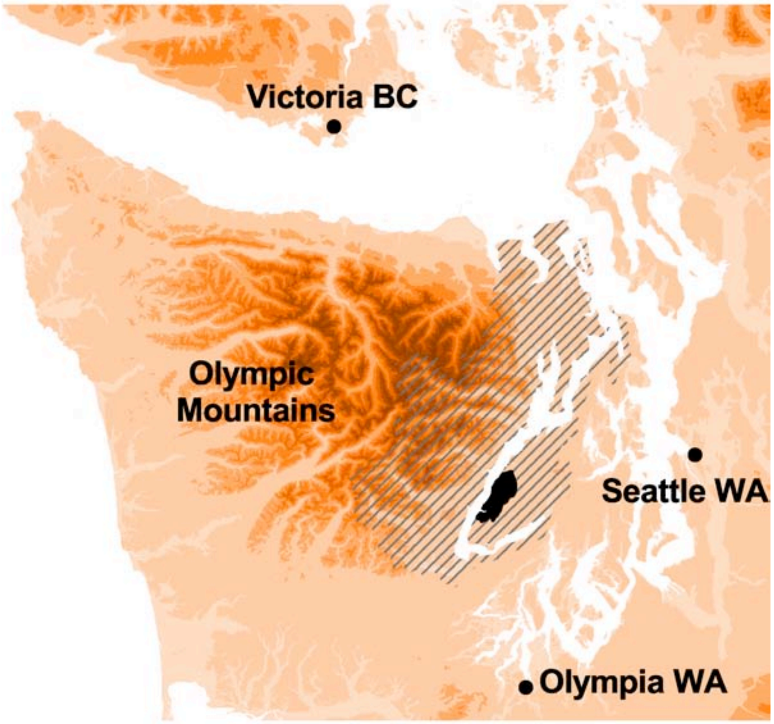
During the last 150 years, Euro-American settlement of the Pacific Northwest has proceeded rapidly, dramatically reducing or modifying native ecosystems and leading to the extinction of certain species and landscape elements. A rich legacy of archival materials offer ecologists a means to understand these lost ecosystem components (Sedell and Luchessa 1982, Egan and Howell 2001). In recent years several historical studies of individual Pacific Northwest watersheds have emerged (Benner 1991, Beechie et al. 1994, Habeck 1994, Coulton et al. 1996, Pess et al. 2000) but until recently few quantitative summaries of historical riparian forest conditions have been available for comparison with contemporary data (Pollock 1998a, Collins et al. 2002, Collins and Montgomery 2002). This relative lack of historical ecology studies is striking as compared to other regions in the eastern U.S. and Europe, where the need for such work is well understood and the concept of ecosystems as historical systems is well established (Decamps et al. 1988, Egan and Howell 2001).

In this study we analyzed archival land survey information for Hood Canal, Washington to reconstruct historical riparian landscape conditions. Information gleaned from General Land Office surveys and an historical timber cruise of one watershed were combined to characterize historical riparian forest composition and structure. Comparison of historical and present-day riparian forest data supported analysis of ecosystem change over the last 150 years. Riparian forest data, as well as miscellaneous notes on the incidence and extent of marshes, swamps, beaver, fire, and other landscape features were entered into a GIS to facilitate integration with contemporary map layers.

Study Area

The 3121 km^2 Hood Canal basin lies at the western edge of the Puget lowland ecoregion on the eastside of the Olympic Mountains, in Washington State USA (Figure 1). The landscape consists of flat glacial till plains rising 100-200 meters over central and eastern portions of the basin, and steep terrain of the Olympics Mountains to the west. Select tributary watersheds include the Skokomish (642 km^2), Dosewallips (316 km^2), Hamma Hamma (220 km^2), Duckabush (194 km^2), Big Quilcene (176 km^2), and Tahuya (117 km^2) rivers, as well as numerous independent small streams (all <100 km^2).

Figure 1. Map of study areas showing Hood Canal and adjacent Strait of Juan de Fuca area in grey hatching (GLO survey) and Dewatto watershed in black (1910 timber cruise).



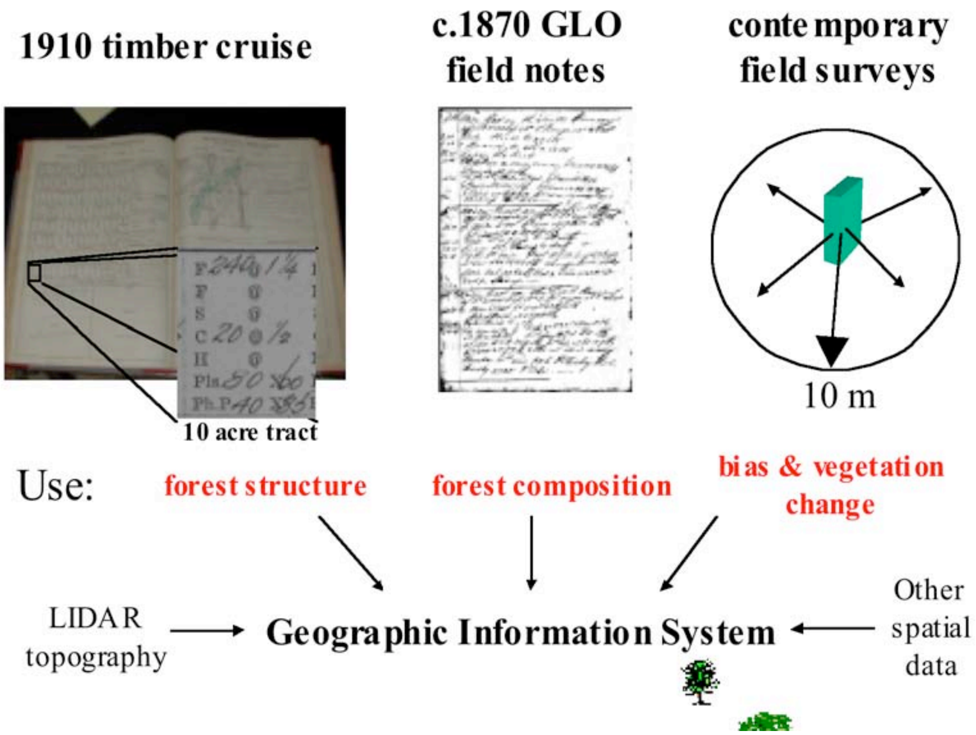
Lying at the boundary of two physiographic regions, Hood Canal harbors diverse geology, landforms, and rainfall regimes. Across lowland areas, glacial till plains are dissected by numerous ravine-bound low-gradient streams with a winter-rain/summer-drought hydrology, moderated by large groundwater reserves and headwater wetlands. In contrast, higher-gradient Olympic Mountain watersheds have streams with both winter-rain and spring-snowmelt high flow periods. The Olympic Mountains create a pronounced rainshadow effect over northern lowland portions of the basin. Average annual rainfall ranges from 255 cm at Cushman Dam (near Potlatch) to 75.7 cm at Chimacum.

Natural vegetation consists of mixed deciduous and conifer forests typical of the lowland Douglas-fir/western hemlock plant association (Franklin and Dyrness 1973). The study area covers portions of Jefferson, Kitsap, and Mason counties, including mostly private rural residential and managed commercial forestlands, as well as state and federal public forestlands. Agricultural development is limited and concentrated in select areas such as the Skokomish, Quilcene, and Chimacum watersheds. The area includes the eastern portion of the usual and accustomed area for the Port Gamble S'Klallam, Jamestown S'Klallam, Lower Elwha Klallam, and Skokomish tribes. For the present analysis, we compiled General Land Office (GLO) survey records for all of the Hood Canal basin, as well as adjacent areas in Discovery Bay and Quimper Peninsula in northeast Jefferson County.

Methods

We integrated historical land surveys and a contemporary forest inventory in GIS to characterize historical forest conditions and chart ecological changes over time (Figure 2). These methods parallel an approach developed by Collins et al. (2002), but include supplemental data from historical timber cruise surveys and an analysis of vegetation change across the riparian landscape. Before outlining methods, we provide a brief overview of historical sources, as well as biases and limitations in their use.

Figure 2. Archival sources, their use, and integration with contemporary field surveys to characterize historical forest conditions and change.



Historical land survey sources – Archival land survey records have been repeatedly used by ecologists to provide information on the historical location and character of vegetation, wetlands, and other natural features (Whitney and DeCant 2001). Understanding the intent and methods of early land surveys is key to the responsible use of these sources to interpret the historical forest landscape. The General Land Office (GLO) rectangular surveys of public land in the United States are one, frequently-used source. Early timber cruise records are another, less well-known source.

The GLO surveys were initiated in 1785 to facilitate the rapid and orderly disposal and settlement of public lands through establishment of a permanent, monumented land division grid. Though methods evolved during early years of the public lands survey, basic land division and data recording techniques were largely standardized by 1854 when the Washington State surveys began (Bourdo 1955, White 1983, Galatowitsch 1990). Townships of thirty-six square miles were referenced to principal north-south and east-west meridians and subdivided into one-mile-square sections. Surveyors walked township and section line boundaries, measuring distances in chains and links (1 chain=100 links=66 feet, 1 mile=80 chains) to stream/wetland crossings, section and quarter-section corners, as well as other prominent natural features. Where survey lines intercepted large, navigable waterways a "meander corner" was established. At quarter-section, section, and meander corners, surveyors set a post from which the distance to, bearing, diameter, and species of 2-4 "bearing trees" were recorded.

Along township and section lines, GLO surveyors recorded the location and character of natural features intercepted, including large "line" trees (noting species and diameter); streams and wetlands (noting width, bearing, and occasionally water depth); and miscellaneous features such as topography, roads, settlements, and burnt or logged over areas (Bourdo 1955, White 1983). Along mile-long survey lines, surveyors noted general timber and soil qualities, as well as dominant tree and undergrowth species. At the completion of a township survey, a map was drawn depicting general topography, stream and wetland locations, and other prominent features.

Early timber cruise records are another, less frequently-used information source on historical forest landscapes. In response to widespread landowner complaints about arbitrary timber land tax assessments, many western U.S. states established tax commissions and required systematic timber cruise surveys to assess timber values during the early 20th century. In 1906 the Washington State legislature required that local counties conduct a full timber cruise of all private and state lands in their jurisdiction as a basis for timber tax assessment. These early timber cruise surveys – completed during 1907-1910 – are available for portions of some western Washington counties (Cowlitz, Grays Harbor, Lewis, Mason, Pacific, Skamania, Thurston, Wahkiakum, and Whatcom) through the State Archives. The surveys pre-date much of the early logging and provide detailed age-structure and spatial-distribution data for then commercially-valuable species like Douglas-fir (*Pseudotsuga menziesii*) and western redcedar (*Thuja plicata*).

These historical timber cruise records consist of timber volume estimates (by species) in ten-acre tracts; total section-level estimates of merchantable timber; general notes on the character of timber, land, logging, and soil conditions; and detailed section-level maps depicting streams, wetlands, roads, and logged-over or burnt areas. Timber volume estimates for each tract are provided as counts and average board feet/species for saw logs, as counts and average lengths for fir piles and cedar phone poles, and as counts of cedar shingle bolts and railroad ties. In a few cases, average fir pile and cedar phone pole lengths are only provided for a section, and/or timber volume is reported for forty-acre tracts.

Though detailed instructions have not been located, the survey records themselves provide some information on methods used. Lewis J. Wade, chief timber cruiser for Mason County, instructed surveyors to:

> ..copy all details from their field books and give full information under each heading in the report, keeping in mind that TOO MUCH INFORMATION cannot be given with reference to the character of each variety of timber, logging conditions, availability, percentage of clear timber on section, percentage of Nos. 1, 2, and 3 logs, value of stumpage, and in fact any and all information pertaining to the value of the timber, character and topography of the ground, undergrowth, and the nature and composition of the soil. [emphasis in the original, Wade 1910]

Timber cruisers of the period typically conducted strip surveys, which enabled 2-3 person crews to survey one square mile (64 10-acre tracts) in 4-5 days, as reported in the cruise records. In a strip cruise, surveyors walked a series of one or two chain-wide (20-40 m) strips counting and measuring every tree in the strip, moving across a tract. Surveyors then used the strip counts to estimate a total count and average volume per species for a tract. By modern standards, a strip cruise is considered inferior because it requires a two-person crew, the survey area can be difficult to estimate, tree heights are more difficult to accurately measure, and statistical data summary is problematic (Bell and Dilworth 1998).

Bias and limitations of historical data – The use of historical land surveys for ecological reconstructions carries with it the responsibility for understanding potential biases and errors, and avoiding particular uses. Bourdo (1955), Galatowitch (1990), and Almendinger (1997) provide a thorough treatment of bias, limitations, and errors associated with GLO survey data and its uses. Surveyors frequently avoided small, or very large thick-barked bearing trees that were difficult to blaze and scribe, and may not have selected the closest trees to section and quarter-section posts. As a result of this bias, tree diameter and distance measures cannot be reliably compared with modern forest tree size or density distributions (Bourdo 1955). Other limitations include: pre-survey land use impacts (e.g. white settler-laid fires), inconsistent survey description detail, difficulties interpreting surveyor handwriting, and transcription errors.

Similar constraints limit the use of archival timber cruise records to reconstruct historical forest conditions and standing volumes. Many accessible areas had been cleared or selectively logged by the time of these early cruises. The cutting and removal of individual trees from stream-side forests where logs could be "driven" downstream during high flow periods was common and widespread by 1910. Moreover, timber cruisers only surveyed merchantable timber species and tree sizes, ignoring small trees or species with no commercial value at the time of the survey. For example, Karlwolfgang (1998) compared 1908-9 and 1920-21 cruise records for Cowlitz County, Washington and noted a 143% increase in timber volume estimates, due in part to a decrease in the minimum size of tree considered merchantable over this twelve-year period. Lastly, timber volume estimates likely represent not gross but net volume, the *average* amount of wood merchantable from trees after accounting for breakage, rot, defect, or other deficiencies. Thus, raw average tree volume estimates cannot reliably be used to reconstruct absolute standing timber volumes.

However, many of these errors and limitations are alleviated by the careful cross-examination of historical surveys in relation to one another and contemporary maps, and by the selection of large study areas for landscape-level characterizations. Bias in the selection of certain tree species or sizes can be evaluated and can inform the appropriate application and use of historical surveys. For example, species bias in GLO bearing tree selection can be evaluated, and their application limited to analysis of forest composition changes across different landforms or environments (Almendinger 1997, Radeloff et al. 1999, Collins and Montgomery 2002).

Historical data acquisition and GIS integration – Historical survey data was integrated and spatially referenced in ArcView GIS 3.2a, using head-up digitizing over contemporary 1:24,000-scale map layers of streams, wetlands, floodplains, and cadastral land survey subdivisions (Table 1). Complete GLO survey notes for portions of 38 townships covering a 2734 km^2 area were examined on microfiche, and pertinent stream, wetland, and riparian vegetation data extracted and translated into GIS layers.

Table 1. Spatial data layers used to geo-reference and analyze historical survey data.

GIS Coverage	*Features*	*Scale*
WA DNR hydrography	streams and wetlands	1:24,000
US FWS National Wetland Inventory	wetlands	1:24,000
FEMA Q3 floodplain	floodplains	1:24,000
WA DNR cadastral land survey	township & section boundaries	1:24,000

In ArcView, moveable 80 chain-long graphic rulers (incremented at one-chain intervals) were used with reported GLO survey distances to precisely locate features along a survey line. All section, quarter-section, and meander corners within 90 m of streams, wetlands, lakes, floodplains, and marine shorelines were mapped and data on bearing tree species, diameter, and distance from the post were recorded. In addition, line trees, stream/wetland crossings, and miscellaneous riparian vegetation notes were mapped. Line trees species and diameter were recorded, as well as the width and bearing of stream/wetland crossings. Notes on general conditions along a surveyed section line (fire, logging, dominant trees, and understory vegetation) were recorded for each mile-long section line across all east Hood Canal drainages (Kitsap and Tahuya peninsulas) and select riparian areas for the remainder of the study area. Table 2 defines species equivalencies for the GLO survey bearing trees.

Table 2. Species equivalents for Hood Canal, Washington.

GLO Vegetation Name	*Common Name (Genus species)*	*Species Code*
Maple ≤8 in dia, or vinemaple	Vine maple (*Acer circinatum*)	ACCI
Maple >8 in dia	Bigleaf maple (*Acer macrophyllum*)	ACMA
Alder	Red alder (*Alnus rubra*)	ALRU
Laurel	Pacific madrone (*Arbutus menziesii*)	ARME
Hazel	Western beaked hazelnut (*Corylus cornuta v. californica*)	COCO
Dogwood	Pacific dogwood (*Cornus nuttallii*)	CONU
Ash	Oregon ash (*Fraxinus latifolia*)	FRLA
Fir	Douglas fir (*Pseudotsuga menziesii*), or Grand fir (*Abies grandis*)	FIR
Crabapple	Pacific crabapple (*Malus fusca*)	MAFU
Pine, scots pine, or white pine	Western white pine (*Pinus monticola*), or lodgepole pine (*Pinus contorta*)	PINE
Spruce	Sitka spruce (*Picea sitchensis*)	PISI
Cottonwood, or balm-of-Gilead	Black cottonwood (*Populus balsamifera, v. trichocarpa*)	POBAT
Cherry	Bitter cherry (*Prunus emarginata v. mollis*)	PREM
Chittamwood, shittemwood, or bearberry	Cascara (*Rhamnus purshiana*)	RHPU
Willow	*Salix* species	SALIX
Yew, or ironwood	Pacific yew (*Taxus brevifolia*)	TABR
Cedar	Western redcedar (*Thuja plicata*)	THPL
Hemlock	Western hemlock (*Tsuga heterophylla*)	TSHE

The approximate location of unmapped streams and wetlands (those not on contemporary maps but reported in GLO surveys) were also mapped, as well as any adjacent corner posts. In a few cases, minor location adjustments (generally <1-2 chains) were made to align point features with contemporary map layers. Distances from mapped stream and wetland crossings proved particularly helpful in spatially referencing GLO survey features. However, the accuracy of mapped GLO features was limited in certain cases by errors in the location and extent of streams, wetlands, and floodplains in contemporary maps.

Early Mason County, Washington timber cruise records (Wade 1910) were obtained from Washington State Archives (Southwest Regional Branch, Olympia, WA) for portions of townships 22 N range 3 W, 23 N range 2 W, and 23 N range 3 W. This area encompasses most of the 60-km^2 Dewatto River watershed and adjacent portions of the Hood Canal shoreline. Timber cruise data were compiled in a MS Access database then spatially referenced in ArcView GIS using the cadastral land survey coverage for sections, systematically cut into ten- or forty-acre parcels to match the original cruise resolution.

For each survey tract, we recorded: number and average volume of live fir, spruce, cedar, hemlock, and pine; number, average length and top diameter of fir piles and cedar telephone poles; number of railroad ties and cedar bolts; as well as number and average volume of dead timber (merchantable, standing or down fir and cedar); presence of logging in the tract; and tract size (ten or forty acres). Where two separate tree count and average volume estimates for a species were provided, both were recorded.

For missing pile and pole lengths and diameters, section-level average values were used. Knouf's rule (Bell and Dilworth 1998, p. 14) was used approximate tree volumes for fir pile and cedar poles: $V=[(D^2-3D)/(10)](L/2)$, where V is Scribner board foot (BF) volume; D is top diameter in inches; and L is log length in feet. Cedar cords were converted to an approximate Scribner board foot (BF) measure equivalent using an empirical relationship derived from the original survey records: total cedar BF was divided by the total number of cords in a section where both were reported, resulting in an estimate of 360 BF/cord which compared favorably with values for other conifers reported in Bell and Dilworth (1998, p. 145 Table 8).

All GLO survey section corners within 60 m of watercourses were coded by shoreline type (estuary, stream, headwater, or wetland/lake) and landform category (bottomland vs. hillslope) using a combination of LIDAR topography, GIS coverages listed in Table 1, and miscellaneous GLO survey notes. Corner locations along mapped and unmapped stream channels $\geq$0.6m and <0.6m wide were coded as "stream" and "headwater" shoreline types, respectively. Riparian bearing tree data were compiled by species count and basal area for different shoreline types and landform categories. For the historical timber cruise, Douglas-fir and redcedar maximum tree volume, and number of timber types (distinct species/size-classes of commercial sawlogs, piles, or poles) were summarized for tracts <30 m, 30-90 m, and >90 m from streams and floodplains.

Contemporary forest surveys – To evaluate species bias in the GLO survey and analyze historical stream-riparian forest change, vegetation was surveyed at 82 riparian section corners during December-February 2002-2005 following methods developed by Collins and Montgomery (2002). For these analyses we limited our focus to section corners (with 3-4 bearing trees each) because the two-tree sample at quarter-section and meander corners was deemed less reliable for describing dominant trees present at a given location (Almendinger 1997).

Using GPS and aerial photos, we navigated to section corners and conducted two, parallel vegetation surveys. First, original GLO survey procedures were replicated: four bearing trees were selected and species, diameter at breast height (dbh), and distance from the corner marker were recorded. Where one or more established bearing trees were not identified, trees were selected following criteria based on the original GLO survey instructions. Selected trees were: (1) >7.5 cm in diameter, (2) in opposite directions from the corner marker, (3) closest to the marker, (4) alive, and (5) <60 m from the section corner marker. At nine sites where no corner markers were found, we established an approximate marker location with GPS and selected four bearing trees following the bearing tree selection criteria.

Second, species and diameter were recorded for all stems ≥2 cm dbh and ≤10 m from section corner markers. Exotic tree or shrub species present ≤30 m from section corners were identified and counted. At sixty sites conifer tree saplings measuring 0.5-2 cm dbh and ≤10 m from section corners were identified to species and counted. Distances to adjacent stream courses and associated bottomland areas from section corner markers were measured using a laser rangefinder. Each site was categorized by adjacent stream size (<5, 5-10, 10-20, >20m bankfull width), landform type (bottomland, transition, or hillslope), and if disturbed by recent (<10 year-old) tree cutting, agriculture, or residential development.

Historical riparian change analysis – We conducted a preliminary analysis of historical changes to forest composition using the 82 stream-riparian section corners. We focused our initial riparian community change analysis on streams, due to their dual role as critical salmon spawning and nursery habitat, and as pathways for nutrient loading and delivery to downstream estuaries. In particular, we were interested in altered large woody debris recruitment in stream riparian corridors, and potential for altered nitrogen loading to Hood Canal resulting from shifts to alder-dominated forest stands.

We classified sites by historical forest type (HFT, Table 3), and paired historical and contemporary riparian tree composition data to code sites into one of four vegetation transition categories (TC, Table 4). To properly code HFT, we utilized supplemental GLO survey vegetation notes where available. In coding the vegetation transition categories, we counted two agricultural sites with no stems >2 cm dbh as contemporary "hardwood/mixed". We considered and rejected a cluster analysis approach to define HFT, due to low sample sizes and the difficulty of systematically incorporating supplemental historical GLO notes on vegetation. Elevation for all sites was calculated in GIS using a digital terrain model.

Table 3. Historical forest types (HFT) and criteria.

Name	*Criteria*
fir-hemlock	>70% BA fir, hemlock, and small cedar
cedar-spruce	>70% BA cedar, spruce, and small fir or hemlock
alder	>70% BA alder
other hardwood/mixed	>70% BA other hardwood species, OR mixed forest

Table 4. Vegetation transition categories (TC) and criteria. The four transition categories are highlighted in grey. Sites in the conifer-to-hardwood/mixed transition category (in bold**) were contrasted with sites the other three transition categories under the two-category vegetation change model.**

		Contemporary Vegetation	
		≥70% conifer BA	hardwood/mixed/pasture
Historical Vegetation	≥70% conifer BA	CON no change	**CON-to-HWM**
	hardwood/mixed	HWM-to-CON	HWM no change

Exploratory data analyses were used to compare HFT and TC distributions to each other and to continuous and categorical environmental variables. Site environmental variables used in this analysis included: distance from stream, distance from bottomland, elevation, number of exotic species, number of conifer saplings, as well as landform, stream size, and disturbance class categories. Descriptive statistics, box-and-whisker plots, and histograms were used to investigate general patterns and determine whether variables followed normal distributions.

Vegetation transition category was modeled as a function of environmental variables and HFT using classification and regression tree (CART) analyses (Biggs et al. 1991) for both a four- and two-category transition model (see Table 4 above). Since we were specifically interested in sites which transitioned from conifer to hardwood/mixed over the historical period, a two-category model was implemented contrasting this transition with sites that experienced no change or underwent apparent succession from hardwood/mixed to conifer.

The CART method repeatedly splits data into two mutually exclusive groups based on a single explanatory variable, continuing with all variables until user-specified stopping criteria are met. This results in subsets of the data that are as homogeneous as possible with respect to a target response variable (e.g. transition vegetation category). The CART method accepts continuous and categorical variables, is easy to understand and interpret, does not require normally-distributed input variables, and avoids problems with unbalanced designs and interaction terms common in linear regression and analysis of variance applications (De'ath and Fabricius 2000). Analyses were conduced using the AnswerTree software package (SPSS Inc., Chicago IL). Cross validation was used to evaluate model performance and optimize tree size (De'ath and Fabricius 2000).

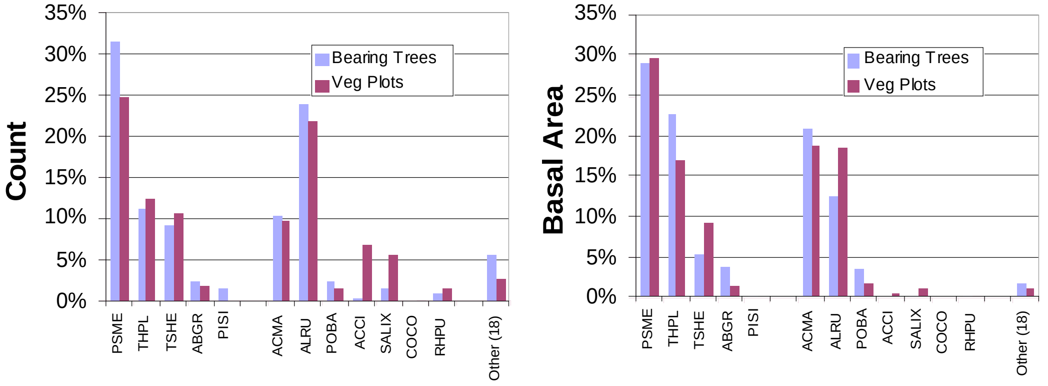
Results

GLO survey notes for portions of 38 separate townships were examined and 1141 riparian corner posts were mapped, including 225 section and 916 quarter-section and meander corners for a total of 2598 bearing trees (Table 5). In addition, 565 line trees, 1650 stream/wetland crossings, and 1119 miscellaneous features were mapped from the Hood Canal GLO notes. Within the Dewatto River watershed and adjacent portions of the Hood Canal shoreline, 1460 individual timber cruise parcels were mapped, of which 97% were approximately 10 ac in size and only 26% were logged as of 1910.

Survey bias and limitations – Pairing historical surveys with one another and with a contemporary vegetation survey revealed important biases in both the GLO and timber cruise surveys, better defining their limitations and appropriate uses. Along stream, headwater, and wetland-lake shorelines 75.1-78.3% of historical bearing trees were ≤10 m from corner locations and 85.8-93.7% were ≤16 m, indicating that corner locations were generally close to and generally representative of most bearing tree locations along these shoreline types. In contrast, only 49.6% of estuary bearing trees were ≤10 m from posts.

A comparison of bearing tree vs. 10-m vegetation plot surveys for all 82 re-occupied riparian section corners indicated that bearing tree data were adequate for gross characterization of relative basal area of riparian forest dominants, but less representative of relative stem counts among all tree species. Numerous small-diameter hardwood tree stems were present at many sites, some of which were often missed by the bearing tree survey. This resulted in a high relative percentage of vinemaple, willow, hazelnut, cascara and other species in stem count distributions. After an examination of the historical bearing tree database revealed only 0.23% of all trees with diameters <7.5 cm, we excluded stems less than this value from our 10-m vegetation plot inventory and re-plotted relative stem counts and basal area. This resulted in improved agreement between bearing trees and vegetation plots (Figure 3). This analysis indicated that though bearing tree data poorly described forest tree species diversity, it adequately characterized relative stem counts and biomass for common overstory riparian tree dominants.

Figure 3. Relative stem counts and basal area by species for 82 re-occupied stream-riparian section corners.



Tree size selection bias was apparent in GLO survey data, limiting its application for reconstruction of forest age structure and spatial distribution. Across the Hood Canal study area, GLO surveyors marked redcedar as large as 305 cm dbh and pine as large as 256 cm dbh, though no Douglas-fir larger than 178 cm dbh in spite of its numerical dominance (comprising 35% of all riparian bearing trees, Table 5). However, historical timber cruise records reveal that large fir >2500 Scribner board feet (BF) were common in riparian areas, suggesting that GLO surveyors may have avoided large fir, perhaps due to their strong commercial value or thick bark, which is difficult to blaze and scribe.

The historical timber cruise – focused on commercial sawtimber – offered little information on species of low or no commercial value in 1910. For example, western hemlock was noted in only 30 of 1445 tracts (2%) in the 1910 timber cruise of the Dewatto watershed though it figured prominently in the GLO survey of the area, represented at 6 of 30 corner posts (20%). The lack of specific information on cruise methods (such as minimum tree size inventoried) limited the computation of common basal area and trees per acre statistics for comparison with contemporary data. To avoid such constraints, we compared the distribution of relative tree volumes and timber types across the watershed to infer patterns of historical forest age structure and spatial distribution.

Historical riparian forest species composition – Estuarine and stream shoreline types exhibited the greatest number of riparian tree species (16 and 15 identified species, respectively), followed by wetland/lake (12), and headwater (11) shoreline types. These totals do not account for two unidentified trees (one each along estuarine and stream shoreline types), as well as multiple indistinguishable “fir” and “pine” species found across all shoreline types. Distinct species composition differences were apparent among shoreline types (Figure 4). Hardwood trees were relatively abundant along estuary shorelines (43% of all bearing trees) but declined progressively in number moving upstream along stream and headwater shoreline types.

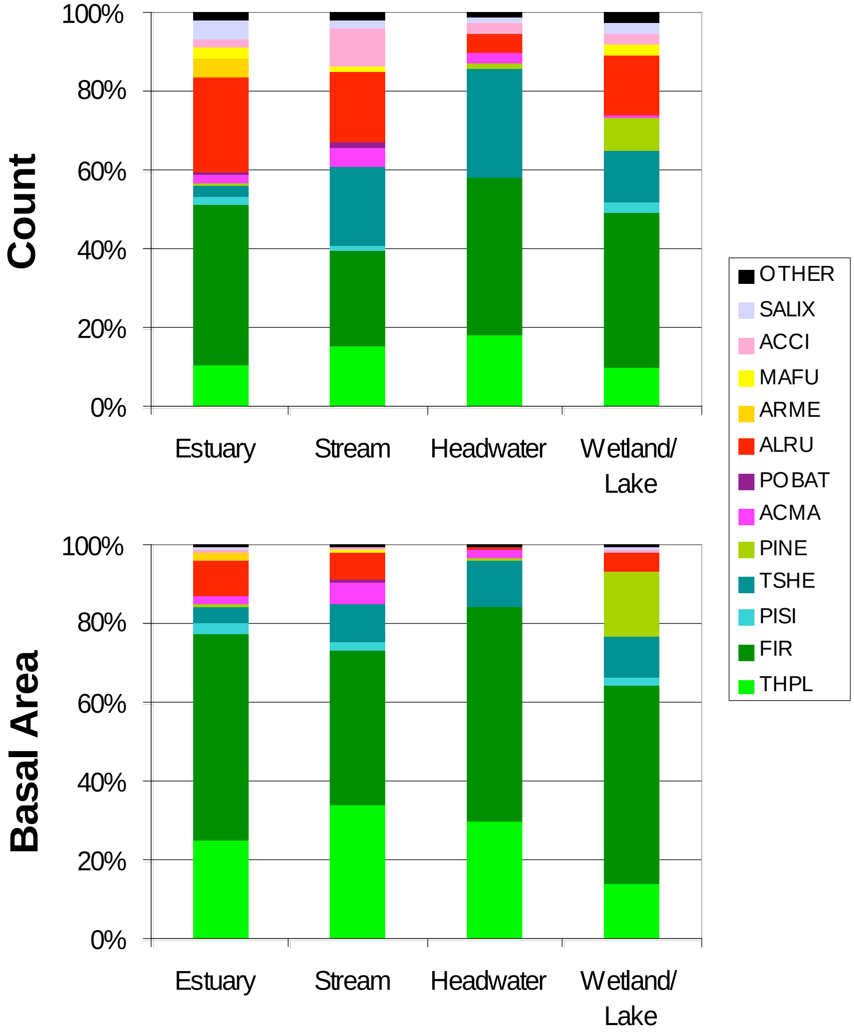
Red alder was the most abundant hardwood species (comprising 51% of all hardwood bearing trees), and was the second and third most numerous species of bearing tree along estuary and stream shoreline types, respectively. Numerically, conifer species dominated in all shoreline types, showing increased dominance higher in stream networks. Fir, hemlock, and redcedar (in decreasing order of abundance) were the most numerous conifer species, though along wetland/lake shorelines pine was also important.

Table 5. Species, number, diameter, and elevation of riparian GLO bearing trees.

	Estuary	*Stream*	*Headwater*	*Wetland/ Lake*	*Total*	*Median diameter (range, cm)*	*Median elevation (range, m)*
Cedar	81	114	143	31	369	45.7 (7.6-304.8)	25 (-1-239)
Fir	319	176	300	126	921	40.6 (7.6-177.8)	29 (-1-296)
Spruce	19	11	1	8	39	35.6 (12.7-101.6)	2 (0-73)
Hemlock	23	145	213	41	422	27.9 (7.6-101.6)	43 (0-296)
Pine	2	3	11	26	42	25.4 (10.2-256.5)	44 (2-318)
Yew	2		2		4	20.3 (15.2-45.7)	3 (0-11)
Total Conifer	**446**	**449**	**670**	**232**	**1797**		
Bigleaf maple	20	34	7	2	74	38.1 (10.2-91.4)	5 (0-127)
Oregon ash	1				1	38.1	1.2
Cottonwood	3	9			14	27.9 (7.6-76.2)	5 (1-74)
Alder	189	132	8	49	405	20.3 (7.6-76.2)	3 (-1-117)
Madrone	36			1	40	20.3 (7.6-61.0)	2 (-1-45)
Crabapple	25	8		7	41	15.2 (7.6-40.6)	2 (0-74)
Dogwood		5	5		12	15.2 (7.6-20.3)	15 (4-82)
Cascara	2	5		7	15	12.7 (5.1-30.5)	47 (1-85)
Vine maple	17	71	3	10	117	12.7 (7.6-30.5)	13 (1-210)
Willow	37	16	5	9	69	12.7 (5.1-71.1)	2 (0-106)
Cherry	7	1			9	10.2 (7.6-20.3)	2 (1-34)
Hazelnut		2			2	10.2	3 (2-4)
Total Broadleaf	**337**	**283**	**94**	**85**	**799**		
Unknown	1	1			2		
Total	**784**	**733**	**764**	**317**	**2598**		

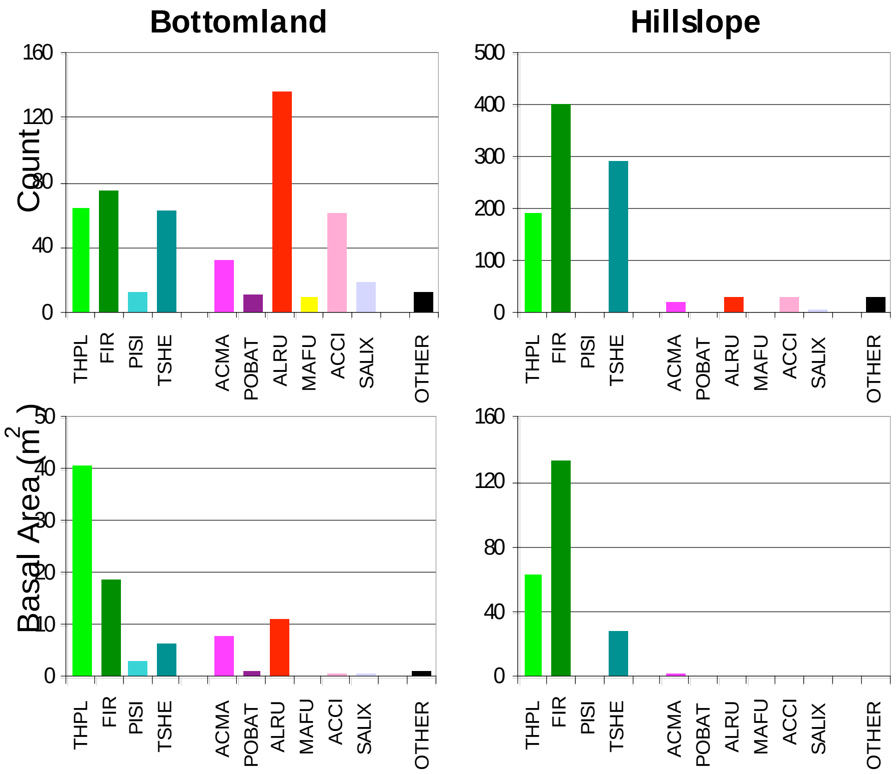
Conifer dominance was more pronounced when bearing tree data were evaluated on a percent basal area basis (Figure 4). Though abundant, alder and hemlock were small-sized and did not account for more than 5% and 8% of total basal area, respectively. Fir and redcedar together accounted for 78%, 73%, and 85% of total riparian tree basal area along estuarine, stream, and headwater shorelines, respectively. Along wetland/lake shorelines, pine replaced redcedar as the second most prominent species, comprising 16% of total basal area – second only to fir (50%) in importance.

Figure 4. Riparian tree species composition by shoreline type.



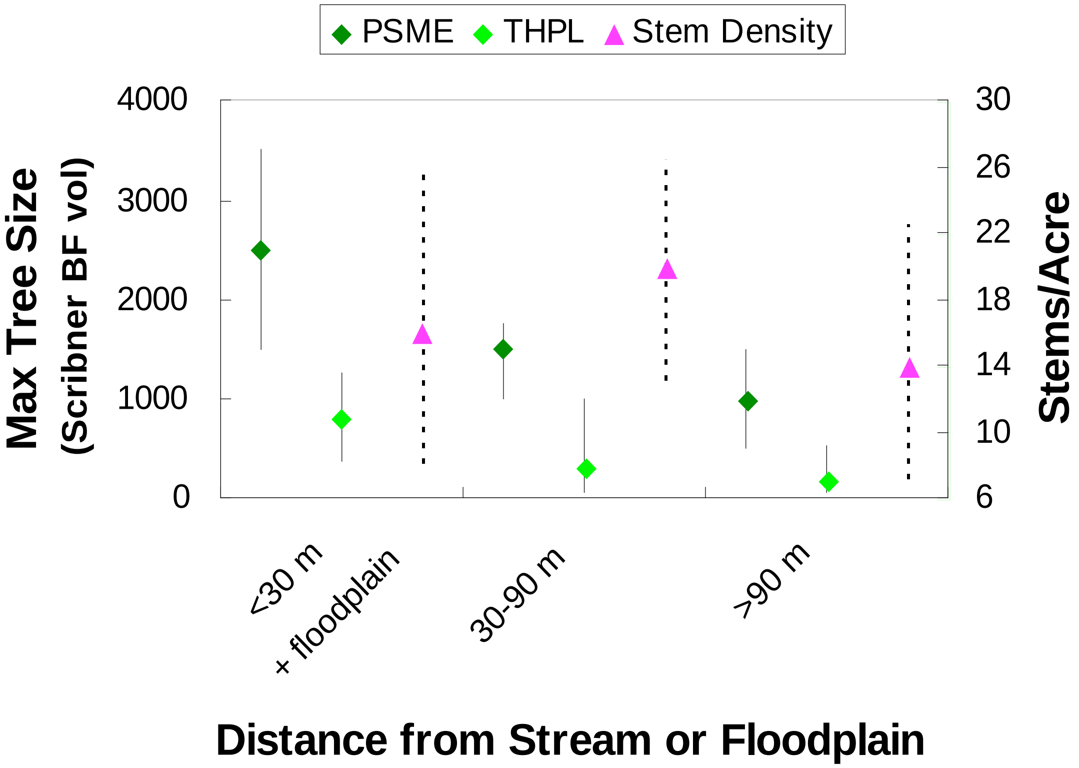
For stream and headwater shoreline types, species composition varied between bottomland and hillslope landform categories (Figure 5). Hardwood species (principally red alder, vine maple, and bigleaf maple) were relatively abundant in bottomland areas, representing 47% and 25% of total bearing trees numbers and basal area, respectively. On hillslopes, conifers dominated by number and biomass, representing 90% and 98% of tree counts and basal area, respectively.

Figure 5. Stream and headwater riparian tree species composition by landform type.



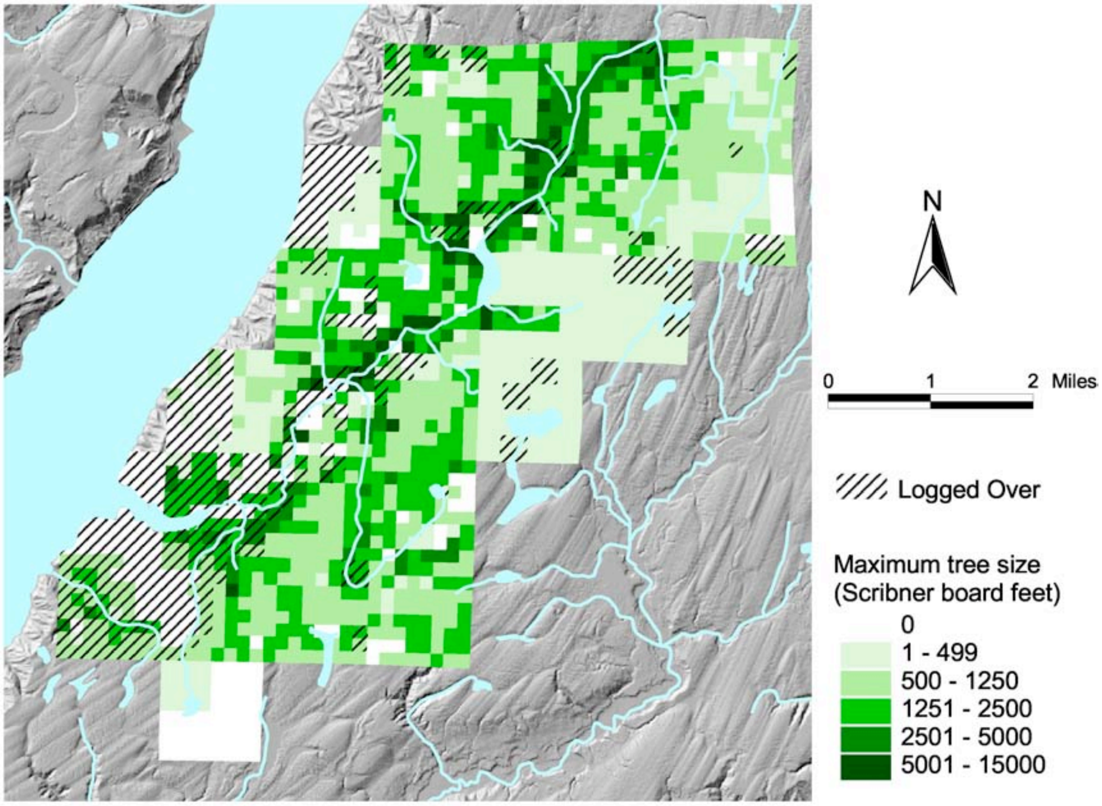
Spatial distribution of historical forests – Historical timber cruise records show large-volume Douglas-fir and redcedar trees clustered in and around stream valley bottoms and lower ravine slopes (Figures 6 & 7). Median tract-maximum fir tree volumes for unlogged riparian areas (<30 m from streams and floodplains) measured 2,500 Scribner board feet (BF) vs. 1000 BF in upland areas (>90 m from streams and floodplains). For redcedar, maximum tree volumes measured 810 vs. 180 BF in riparian and upland unlogged tracts, respectively. For both species, ravine side slopes 30-90 m from streams or floodplains showed intermediate tract-maximum tree volumes (Figure 6).

Figure 6. Median tract-maximum tree size and stem density by landscape position, showing unlogged tracts only from the Dewatto watershed 1910 timber cruise. Error bars show the 25th and 75th percentiles.



The incidence of unlogged survey tracts with three or more species or size-classes of commercial sawlogs, piles, or poles ("timber types", indicating greater forest structural diversity) also differed by landscape position: 48% of riparian tracts <90 m from streams and floodplains harbored three or more timber types as compared to just 17% of upland tracts. Tracts with high numbers of cedar and hemlock sawlogs clustered heavily in stream bottom areas, while burned-over stands with one or two timber types were common in upland areas. Because early timber harvest frequently targeted accessible high-volume stands first, the pattern of logged off lands in the Dewatto 1910 timber cruise also suggests a concentration of big timber in stream bottoms (Figure 7).

Figure 7. Tract-maximum tree size, Dewatto watershed 1910 timber cruise.



Historical riparian change – Of four identified historical forest types (HFT), cedar-spruce showed the highest percentage change, with 11 of 19 sites (57.9%) shifting to hardwood/mixed forest over the historical period (Table 6). The fir-hemlock, alder, and other hardwood/mixed HFT categories all had ≤35.3% change. Of the 11 cedar-spruce sites that underwent change, six sites transitioned to alder dominance (>50% BA), two had lesser amounts of alder (21-28% BA alder), and three were dominated by other hardwoods or pastureland.

Table 6. Summary of transition category classification by historical forest type for the 82 sites surveyed. Bolded **numbers indicate categories where no change in the dominant forest type occurred. CON=conifer and HWM=hardwood/mixed.**

Historical Forest Type		TRANSITION CATEGORY				Total	Percent that changed
		CON no change	HWM no change	HWM-to-CON	CON-to-HWM		
fir-hemlock	Number	**28**	0	0	8	36	22.2%
	Percentage	**77.8%**	0.0%	0.0%	22.2%		
cedar-spruce	Number	**8**	0	0	11	19	57.9%
	Percentage	**42.1%**	0.0%	0.0%	57.9%		
alder	Number	0	**7**	3	0	10	30.0%
	Percentage	0.0%	**70.0%**	30.0%	0.0%		
other hardwood/mixed	Number	0	**11**	6	0	17	35.3%
	Percentage	0.0%	**64.7%**	35.3%	0.0%		

Exploratory data analyses revealed non-normal distributions and low mean precision estimates for environmental variables among different HFTs. Consistent with overall species distribution patterns discussed above, most alder and other hardwood-mixed HFT sites clustered in/near bottomlands, while the majority of sites >20m from bottomlands and on hillslopes were in the fir-hemlock HFT category. The distribution of HFTs also varied by stream size, with 55.6% of fir-hemlock and 63.2% of cedar-spruce sites found along streams <5m BFW, and 50.0% of alder HFT sites found along streams >20m BFW. Sites in the cedar-spruce and alder HFTs were, on average, closer to streams and showed similar, intermediate elevation ranges as compared to other HFT types.

Comparing sites with and without vegetation changes over the historical period revealed that change sites were lower in elevation (t-test, *P*=0.044), in/close to bottomlands (t-test, *P*=0.080), and concentrated at the transition between bottomland and hillslope landforms (Fisher's exact test, *P*=0.055), as compared to sites with no change. Nineteen of 28 (67.8%) sites that underwent vegetation change transitioned from conifer- to hardwood/mixed-dominance, representing 23.2% of all locations.

The four-category vegetation transition CART model produced a tree with six branches and four terminal nodes, one for each vegetation transition category (Figure 8). The cross-validated estimate of classification accuracy of 78.7%, was significantly greater than the classification accuracy expected from a random assignment of sites to transition categories (25%, Table 7). Historical forest type (HFT), elevation, and distance from bottomland were selected as important predictor variables. Fir-hemlock and cedar-spruce HFT sites ≤0.75 m from bottomlands were 2.2 times more likely to transition to hardwood/mixed forest than remain in conifer, while those outside of (>0.75 m from) bottomlands were 6.2 times more likely to remain in conifer. Alder or other hardwood/mixed HFT sites at elevations >39 m tended to succeed to conifer, while all sites at lower elevations remained in hardwood/mixed forest.

A two-category vegetation transition model produced similar results, highlighting historical forest type, elevation, and distance from bottomland as important predictors of sites that converted from conifer- to hardwood/mixed forest-dominance (Figure 9). The CART model produced a six-branched tree with four terminal nodes, and a cross-validated classification accuracy estimate of 80.7% (vs. 50% for a random assignment to categories, Table 8). Sites transitioning from conifer- to hardwood/mixed forest-dominance were all found at elevations <196 m, and nearly all (18 of 19, 94.7%) were ≤32 m from bottomlands.

Figure 8. Four-category CART model of riparian vegetation change. CON=conifer and HWM=hardwood/mixed. Improvement is a relative importance measure for explanatory variables, and here refers to the Gini impurity measure (AnswerTree software, SPSS, Inc.).

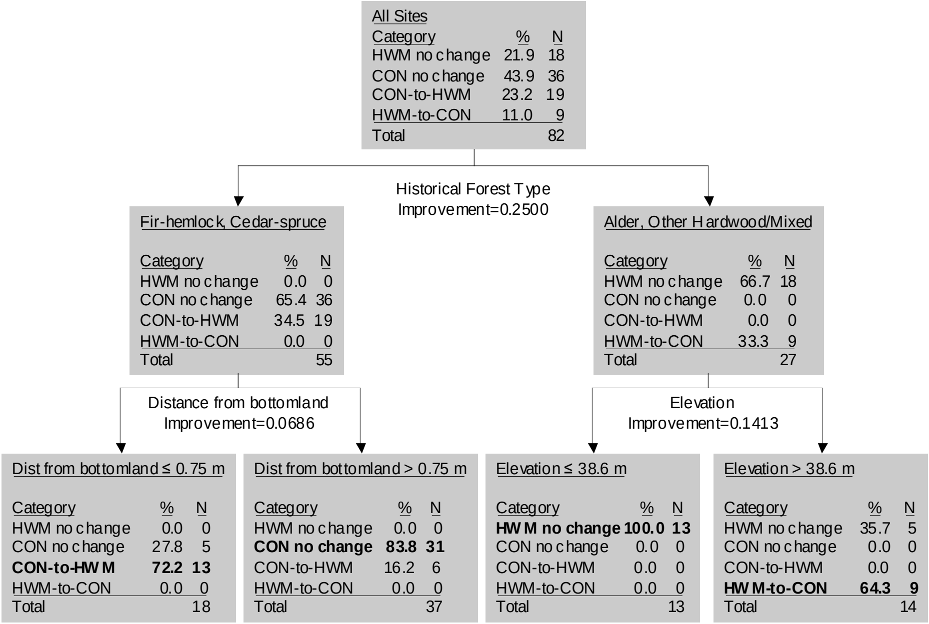


Table 7. Summary of classification results for the four-category vegetation change model. (Bolded **numbers indicate the number correctly classified).**

Predicted Vegetation Change Category	Actual Vegetation Change Category				
	HWM no change	CON no change	CON-to-HWM	HWM-to-CON	Total
HWM no change	**13**	0	0	0	13
CON no change	0	**31**	6	0	37
CON-to-HWM	0	5	**13**	0	18
HWM-to-CON	5	0	0	**9**	14
Total	18	36	19	9	82

	Naïve Risk	Cross-Validated Risk
Risk Estimate (RE)	0.1831	0.2131
Standard Error of RE	0.0402	0.0468
Percent Correct	81.7%	**78.7%**

Figure 9. Two-category CART model of riparian vegetation change. CON=conifer and HWM=hardwood/mixed. Improvement is a relative importance measure for explanatory variables, and here refers to the Gini impurity measure (AnswerTree software, SPSS, Inc.).

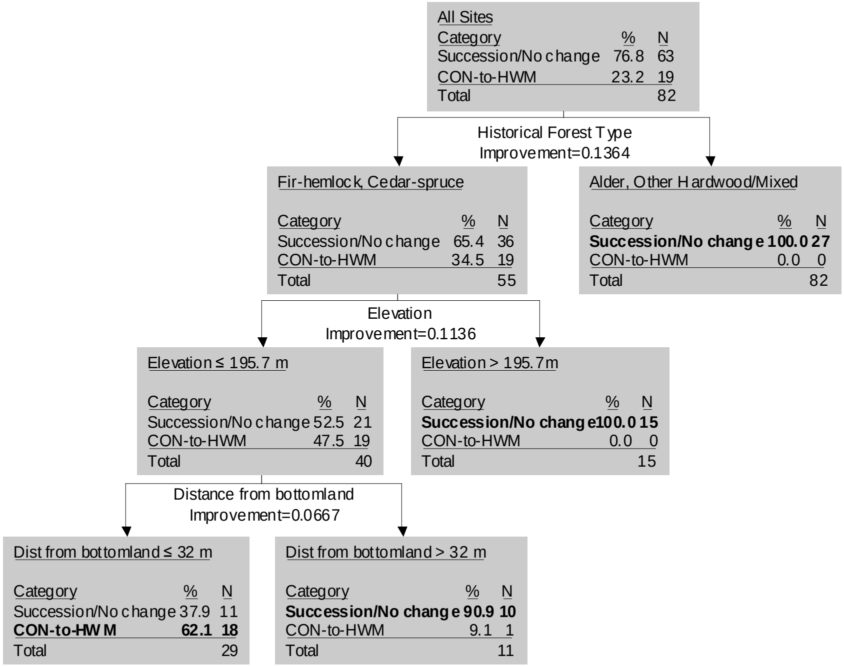


Table 8. Summary of classification results for two-category vegetation change model (Succession/No change vs. CON-to-HWM). (Bolded **numbers indicate the number correctly classified).**

Predicted Vegetation Change Catetory	Actual Vegetation Change Category		
	Succession/No change	CON-to-HWM	Total
Succession/No change	**52**	1	53
CON-to-HWM	11	**18**	29
Total	63	19	82
	Naïve Risk		Cross-Validated Risk
Risk Estimate (RE)	0.1136		0.1926
Standard Error of RE	0.0350		0.0525
Percent Correct	88.6%		**80.7%**

Conifer regeneration at the sixty sampled 10-m vegetation plots was generally low but variable (mean 0.011 tree/m^2, range 0-0.16 tree/m^2) and occurred at less than half (48%) of all sites. At historically conifer-dominated sites (n=36), conifer regeneration was similarly low (mean 0.009 tree/m^2, range 0-0.06 tree/m^2) but slightly more frequent, occurring at 61% of all sites. In either case, there were no statistically significant differences in conifer regeneration densities between sites with vegetation change vs. no change.

One or more exotic shrub or tree species were present at nearly half (49%) of all sites. Most riparian sites with exotic species harbored one or two non-native species, but seven sites had three or four species. Himalayan blackberry (*Rubus discolor*), reed canarygrass (*Phalaris arundinacea*), and European holly (*Ilex aquifolium*) were the three most frequent exotic species present at 29 (36.3%), 11 (13.8%), and 9 (11.3%) of all sites. Other less common species included Scots broom (*Cytisus scoparius*, 7 sites), non-native grasses (7 sites), English ivy (*Hedera helix*, 4 sites), Japanese knotweed (*Fallopia japonica*, 2 sites), evergreen blackberry (*Rubus laciniatus*, 1 site), and bull thistle (*Cirsium vulgare*, 1 site).

Miscellaneous historical landscape features – The GLO and historical timber cruise surveys also contain a wealth of information on the distribution and character of beaver, marshes, swamps, tidal sloughs, early logging, fire, streams, and wetlands. We do not summarize or analyze this supplemental GLO survey data here, but make it available to others as part of the spatial and tabular data distributed with this report.

This supplemental data may be useful for local watershed assessments, as a source of information on landscape change as pioneered by Bahls and Rubin (1996) for Chimacum Creek watershed. Streams mapped in the GLO survey and not present in the contemporary WA-DNR stream hydrography GIS layer may serve as useful starting points for efforts to field-truth regulatory maps (Bahls and Ereth 1994, Washington Trout 2002). Historical stream width and wetland size information can also be used to indicate patterns of aquatic habitat loss or change (Bahls and Rubin 1996, Pess et al. 2000).

A few general patterns in this supplemental data warrant special mention. According to the 1910 Mason County timber cruise survey notes, log drives occurred on the Dewatto and Tahuya rivers, which is surprising given the small size of these rivers. Beaver were relatively scarce in both the GLO and timber cruise surveys, which suggests that early trapping or some other limiting factor may have reduced their numbers across the study area prior to these early surveys.

In upland areas, burned over lands were widespread and common landscape features across Hood Canal during the GLO survey period. The GLO survey and Euro-American settlement period in the Pacific Northwest corresponded with an era of high fire activity (Agee 1993) so it is difficult to draw firm conclusions from this data. Surveyors noted evidence of recent fire activity along 94 of 522 (18%) surveyed section lines across the Kitsap and Tahuya peninsulas. Along an additional 18 lines (3%) "dead timber" was noted, suggesting that during this period approximately 21% of the land area was affected by recent disturbance, whether natural or human-caused. However, it is notable that few stream riparian corridors were noted as burned in both GLO and early timber cruise surveys.

Discussion

Interpreting historical forest conditions – Pairing archival records and contemporary forest surveys, we evaluated bias and demonstrated the utility of using settlement-era land surveys to reconstruct historical riparian forest conditions. Both historical sources showed unique strengths and limitations, which made them natural complements of one another. The GLO survey data showed how vegetation composition varied across different shoreline and landform types, whereas the timber survey illustrated forest size and spatial structure. This information provides a valuable historical perspective on riparian conditions in Hood Canal, prior to widespread Euro-American settlement, land clearing, and logging.

Historically, conifer species were dominant by number and biomass on hillslopes in stream and headwater riparian corridors of Hood Canal (Figure 5). In bottomlands, a mix of hardwood and conifer species predominated, with one conifer – western redcedar – representing 44% of tree biomass. By numbers and biomass, conifers dominated along all shoreline types, and showed increasing prevalence at higher positions in the drainage network (Figure 4). Certain species showed greater affinity for individual shoreline types, such as pine along wetland/lakes and vinemaple along streams (Figure 4 and Table 5).

Historical timber cruise records corroborate patterns observed in GLO surveys, showing older, more structurally-complex fir- and cedar-dominated forests clustered in stream bottoms and on adjacent hillslopes (Figures 6 and 7). On average, fir dominants were 2.5 and cedar 4.5 times larger by volume in riparian vs. upland environments (<30 m vs. >90 m from streams and floodplains). Streamside forests also harbored more species and size-classes of commercial timber, whereas upland areas had more burned-over stands with only one or two timber types.

Comparisons with field studies – Though this historical forest summary analysis blends together different forest stands with varied disturbance histories and site conditions, the results are consistent with contemporary field studies of older, undisturbed riparian forest stands. Past studies of environmental gradients in Pacific Northwest riparian forests show increased conifer basal area with elevation, distance from and elevation above streams, time since disturbance, and stream gradient (Hawk and Zobel 1974, Andrus and Froelich 1988, Minore and Weatherly 1994, Pabst and Spies 1999). Adapted to high soil moisture and flood disturbance frequencies, red alder and other hardwoods are typically prominent in bottomlands and along streams, but may be overshadowed by fewer high-biomass, long-lived conifers such as cedar or spruce (Naiman et al. 1998, Pabst and Spies 1999).

Similarly, our observed spatial pattern of old-growth forests clustering in stream riparian areas with younger, less structurally complex forests dominating upland areas is consistent with forest landscape studies from Cascade and Olympic mountain drainages (Hemstrom and Franklin 1982, McKee et al. 1982). Due to the rarity of severe fire, these riparian stands frequently retain greater tree age distribution and species diversity, a well-developed multi-layer canopy, and more snags and downed wood (Sedell and Swanson 1984).

Our results underscore the importance of an historical context for contemporary riparian field studies. Though contemporary field studies of older forests offer first-hand ecological perspectives, in practice it is often difficult to locate undisturbed stands, confounding results. Due to widespread logging, truly undisturbed riparian stands are often located in steep, higher elevation terrain and do not represent the full range of historical stand conditions. In practice, a more comprehensive ecological understanding of historical riparian forests will come when results from contemporary field studies, historical ecology, and ecosystem modeling are compared and combined.

Historical changes – The cedar-spruce HFT exhibited relatively high rates (57.9%) of vegetation change over the historical period, as compared to all other forest types which experienced ≤35.3% change. Historical cedar-spruce and alder forest types showed similar environmental distributions, tending to be nearer streams and at intermediate elevations as compared to other forest types. However, cedar-spruce and fir-hemlock HFTs were more common along small streams <5 m wide as compared to alder, which was more frequent along large streams >20 m wide. Overall, sites that changed were at lower elevations, clustered in/near stream bottomlands, and tended to be at the transition between bottomland and hillslope landforms. The majority of sites (67.8%) that experienced vegetation change were in the cedar-spruce and fir-hemlock HFTs, representing 23.2% of all sites.

The CART modeling corroborated these patterns, supporting probability analyses of vegetation change as a function of environmental variables and original HFT. Both the two- and four-category CART models highlighted HFT, elevation, and distance from bottomland as important predictors affecting the probability of vegetation change. Fir-hemlock and cedar-spruce HFT sites ≤0.75 m from bottomlands were more than two times more likely to transition from conifer to hardwood/mixed forest vs. remain unchanged. Sites changing from conifer to hardwood-mixed were all <196 m elevation, and nearly all in or close to (≤32 m) stream bottomlands.

Understory conifer regeneration occurred at low densities (~0.01 tree/m^2) at approximately half of all surveyed riparian sites, and varied independently of historical forest type or vegetation change category. Exotic species were present at nearly half of all sites, with most harboring one or two exotic species. These preliminary results indicate little/no natural conifer regeneration and high rates of exotic species colonization in Hood Canal riparian forests.

In a similar study, Collins and Montgomery (2002) detected significant shifts in the proportion of deciduous vs. conifer forest tree species in streamside forests of the Nisqually River as a result of historical logging of large fir and cedar. Available evidence indicates strong shifts in the distribution and frequency of riparian forest types in Hood Canal, with dramatic reductions in the number and extent of cedar-spruce and a corresponding expansion of stands dominated by alder and other hardwoods. Near-stream fir-hemlock stands have also been reduced, but to a lesser extent than the cedar-spruce forest type. With the exception of stream size, there was high overlap in environmental variables between cedar-spruce and alder HFTs, suggesting a pattern of headwater-ward expansion and replacement of cedar-spruce by alder during the historical period. Our preliminary data suggest very limited natural recovery of conifers is occurring in riparian areas, as new unknown impacts emerge from invasion of exotic species.

Landscape modeling and fire disturbance – The lack of documented fire in stream-riparian areas, as well as species abundance and distribution patterns in the historical surveys suggests longer fire return intervals for riparian vs. upland forest stands in Hood Canal. Frequent reburns likely delayed forest growth and succession in upland areas (Agee 1993), but the abundance and size of fire-prone cedar and hemlock species in historical riparian forests indicate that catastrophic, stand-replacement fires were infrequent. Huff (1984) and Agee (1993) describe species response to fire disturbance for a range of wet-to-dry Douglas-fir/western hemlock zone forests. Based on this information and our data, we conclude that stand-replacement fire intervals in Hood Canal stream-riparian corridors ranged 300-500 years or longer.

This study demonstrates dramatic forest composition changes through time and suggests longer fire return intervals prevailed in early settlement-period riparian forests underscoring the critical importance of an historical perspective for ecosystem studies and management. Landscape-level ecosystem modeling is now the preferred tool for providing scientists and policy-makers much-needed ecological context on issues like climate change, wildland fire, and coastal eutrophication. However, without historical ecology studies these landscape models lack realistic inputs, and assumptions often cannot be validated.

For example, recent models of historical forest landscape dynamics in the Pacific Northwest (Cissel et al. 1998, Wimberly et al. 2000) have generated coarse-scale estimates of older forest acreage as a function of fire frequency, size, and severity, but typically ignore finer-scale topographic controls, which may buffer stream-riparian ecosystems from the ravages of upland wildfire. This study found distinct differences between historical riparian and upland forest stand structure and little evidence of catastrophic fire penetration of stream riparian areas suggesting that fire processes differed in riparian vs. upland forest ecosystems.

To be useful, landscape modeling focused on generating ecosystem management goals should incorporate such spatially-explicit data. For this purpose, historical ecology is invaluable, providing a snapshot of early settlement-era landscapes in order to chart long-term change. Historical ecosystem conditions cannot define contemporary land management goals, but this data does aid development of ecosystem indicators, suggest new avenues of investigation, and highlight restoration priorities.

Future work and management applications – This work suggests new questions pertinent to land management policies, provides important historical context for ecosystem studies, and informs our restoration vision for Hood Canal. As Hood Canal ecosystem models are developed, the spatial data developed in this study can be applied to chart historical changes to riparian forests. Additional resources are needed to analyze vegetation change across a larger site network, incorporating GLO survey quarter-section and meander corner locations and sites along estuary and headwater shorelines. Using aerial photos and LIDAR remote sensing to analyze contemporary forest composition, we estimate the sample of vegetation change locations could be increased ten-fold, supporting more refined and spatially-explicit analyses of historical riparian vegetation change.

Terrestrial ecosystem shifts from old-growth conifer to early-mid seral hardwood/mixed riparian forests has strong implications for stream and estuarine ecosystem function and processes. The reduction of older conifer streamside forests implies a corresponding loss of durable large wood debris inputs, critical to the creation and maintenance of in-stream habitat for fish and other aquatic biota (Bilby and Bisson 1998). The headwater-ward expansion of red alder – a smaller, shorter-lived nitrogen-fixing tree with low wood durability – implies a shift in stream nutrient inputs and higher nitrogen loading, potentially affecting the trophic status of downstream estuarine ecosystems (McClain, Bilby, and Triska 1998). Stottlemeyer (1992), Triska et al. (1994), and Volk (2004) found significantly higher stream water nitrate concentrations at red alder vs. old-growth conifer sites, through some combination of nitrogen-enriched groundwater and litterfall.

Riparian forest management regimes based on deterministic stand modeling (e.g. Washington State forest practice rules) need to account for historical ecosystem change and landscape-level variation in forest composition, structure, and processes. Many present-day riparian hardwood stands – particularly those along small streams – were likely conifer-dominated historically. At present many of these stands lack conifer regeneration, nearby seed sources, and downed wood germination sites, which will delay or preclude natural recovery (Hibbs and Giordano 1996, Pabst and Spies 1999). New management strategies are needed to protect stand-adjacent seed trees and encourage underplanting and/or release of preferred conifer species.

Acknowledgements

We are indebted to Brian Collins, whose pioneering work on the historical ecology of Puget Sound large river environments inspired us to delve into the historical record for Hood Canal. Mike Hagen and Mike Cronin provided numerous insights into historical timber cruise methods and forest conditions. Lanny Weaver, Washington State Archives – SW Region, provided assistance with Mason County timber cruise records, and we thank Jim Labbe for first making us aware of this information-rich source. Jim Agee, Brian Collins, Mike Hagen, Jim Labbe, George Pess, and Steve Todd provided helpful comments on an early draft.

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