Appendix A: Approach and Methods Used to Create GIS Map Layers

ABSTRACT

This chapter presents methods used to develop Geographic Information System (GIS) coverages of the riverine environment around the time of early Euro-American settlement. Principal source materials include maps and field notes from the General Land Office (GLO) cadastral survey and US Coast & Geodetic Survey (USC&GS) charts of near-shore areas. We cross-referenced this with information post-dating the earliest settlement by a few decades, including the first US Geological Survey (USGS) topographic maps and the earliest aerial photography, and with modern sources that include published soils and geological mapping, recent topographic mapping, and a high-resolution digital elevation model (DEM). We integrated these materials into a GIS to map the channels, wetlands, forest characteristics, and ponds. Because uncertainty is inherent in working with historical materials, in the GIS coverages we document sources, the logic with which they were used, and relative certainty for each mapped feature, to make assumptions and certainty transparent. We also use GLO bearing tree data to describe riverine forests, and present results of field trials to assess biases in their use. These landscape-scale coverages describe the historical environment and habitats, and how landforms, hydrographic features, and land cover vary through the study area.

INTRODUCTION

Scope

This chapter describes methods used to create Geographic Information System (GIS) coverages of historical channels, wetlands, and riverine forests. The coverages describe conditions at the time of early Euro-American settlement, or about 1870-1890. GIS products include (1) coverage showing channels, water bodies, and wetlands, and (2) coverages that characterize the pre-settlement forest, including the sizes, distributions, and factors influencing locations of tree species.

Historical Landscape Reconstruction

The problem of reconstructing badly degraded landscapes, or landscapes that no longer exist, is at the intersection of archaeology, ecology, landscape ecology, ethnobotany, palynology, and has been recently considered under the umbrella of historical ecology (e.g., Egan and Howell 2001). Environmental history, which includes a focus on understanding the political, social, and cultural forces behind landscape change and how those changes in turn shape society, overlaps with and complements historical ecology (e.g., White 1992; Whitney 1996). Reconstructing the riverine environment of Puget Sound can draw on the methods of these disciplines and also must be grounded in geology and process geomorphology, because the riverine landscape is geologically young and physically dynamic, and its ecosystems closely linked to physical processes.

Our historical reconstruction in the Puget Sound region focuses on conditions that existed in the mid 19^{th} century, the time of early settlement by Euro-Americans, in order to reconstruct the "native" landscape (e.g., Grossinger 2001), or that existing prior to widespread modifications by non-indigenous peoples. We refer to the "historical" landscape rather than the "natural" environment, because people have inhabited the Puget Lowland—and managed its resources (e.g., Deur, 1999; 2002)—at least since the glaciers last retreated. We use "landscape" because what we seek to reconstruct was indeed a landscape, resulting from a fusing of cultural and natural influences that included native land-management practices.

We draw most heavily on sources from the time of first arrival of non-native settlers because for the time prior to the written record we can only make broader, less detailed descriptions using indirect field methods. This snapshot-in-time neglects longer-term (Holocene) landscape and ecosystem evolution. However, doing so does not significantly limit understanding of the native landscape; forest composition in the region probably attained modern characteristics approximately 6,000 ybp (Barnosky 1981; Leopold et al. 1982; Cwynar 1987; Brubaker 1991). Additionally, the interplay of isostatic uplift, river incision and sea level change is slow and causes only minor change over the time frame of a few centuries, and we have recent analogs to draw on for understanding the effects of intermittent, dramatic disturbances to river valleys such as volcanic lahars (such as those from the 1980 eruptions of Mt. St. Helens) and earthquake-associated uplift. Archival and field studies can characterize changes occurring on decadal and more frequent time scales. Moreover, many agents of anthropogenic change over the last ~150 years have been much more rapid than natural processes.

Working with Historical Sources

Knowledge of historical landscapes is inherently uncertain. Historical materials are incomplete, can be inaccurate, and are inherently imprecise compared to modern mapping capabilities. Many historical documents were developed for purposes quite different from the uses we put them to. The spatial and temporal variability of landsapes and landscape processes further complicate efforts to reconstruct historical conditions. For these reasons it is important in reconstructing historical landscapes to reduce uncertainty by using multiple sources and methods having different strengths and scales that overlap and cross reference (Figure A-1).

It is also important to characterize uncertainty associated with individual features, so that users of historical mapping are aware of the relative certainty with which a particular feature can be viewed (e.g., Grossinger 2001). To make uncertainties transparent, we assign each mapped feature with a code that indicates the sources, the logic with which they were used, and the relative certainty with which we view our mapping of the feature. Codes for each type of feature (e.g., large channels, small channels, wetlands, ponds) are summarized later in the report. Table A-1 generalizes the logic behind the relative certainty levels.

Uses and Limitations of Landscape-Scale Mapping

Our mapping characterizes historical landforms, hydrographic features, land cover, and how each varied along and across the valley bottom. It also provides the basis for quantitative estimates of aquatic habitat and its change through time at a landscape scale. It is not at the detailed resolution appropriate for site characterization. Mapped features have inherent inaccuracies and uncertainties, and some features that existed have not been mapped at all, because they "fall between the cracks" of the available sources, or our ability to interpret them.

SOURCES

Land Survey Records

Scanned images of the General Land Office (GLO) cadastral survey maps were georeferenced and "rubber sheeted" to current Washington Department of Natural Resources (WDNR) corner and quarter-corner data. Survey maps and field notes in the Nooksack study area span the years 1859 to 1903 (Table

A-2), in the Skagit-Samish-Sauk study area from 1866 to 1895 (Table A-3), in the Stillaguamish watershed between 1872 and 1892 (Table A-4), in the Snohomish River in 1866-1871, in the Skykomish in 1872 and 1883 and in the Snoqualmie in 1865-1873.

In their field notes, surveyors were instructed to record land and water features they encountered, including major changes to the plant community, streams and marshes, and the width of all "water objects." Springs, lakes and ponds and their depths, the timber and undergrowth, bottomlands, visual signs of seasonal water inundation, and improvements were also to be noted along section lines. While this information is not equally complete in the notebooks of different surveyors, it is important descriptive data, particularly for wetlands. For example, we used the date at which observations of water depth were made by surveyors, and their notes on indicators of seasonal water depths, to characterize summer and winter water depths in wetlands.

We also made use of bearing tree records from reference points at the corners of mile-square sections and half way between corners ("quarter corner" points), where surveyors measured the distance and the compass direction to several nearby trees. (For overviews of previous work using land survey records to reconstruct historical landscapes, see Whitney 1996; Collins & Montgomery 2002; Whitney & DeCant 2001.) Surveyors were instructed to identify four witness trees at section corners and two at quarter-corner boundaries, or on Indian reservations, at 1/16 corners (White 1991). If there were no trees nearby, surveyors built a mound of earth. In their field notes, surveyors recorded the diameter and common name of each witness tree and the distance and bearing to it. We used the distances in conjunction with diameters and species to help map wetland types. In addition to these regularly-spaced points, surveyors also established "meander corner" points where section lines intersected the banks of navigable rivers and sloughs and documented two bearing trees. These meander points allow us to characterize separately streamside trees from other valley-bottom trees; we call these "streamside" to distinguish them from points farther from the river, which we call "valley bottom."

Coast Survey Charts

The US Coast & Geodetic Survey (USC&GS) published charts of estuarine areas of the greater Nooksack delta in 1887 and 1888. We georeferenced USC&GS charts previously registered by Bortleson et al. (1980), as well as paper or digital copies of original T-sheets. Limited tideland diking had occurred by the time charts were made in the Nooksack delta area; in undiked areas, map patterns distinguish saltmarsh and freshwater marsh. The US Coast & Geodetic Survey (USC&GS) charted estuarine areas of the greater Skagit delta between 1886 and 1893. We georeferenced copies of the USC&GS field T-sheets (Table A-5) and supplemented them with versions previously registered by Bortleson et al. (1980). Some tideland diking had occurred by the time charts were made in the Skagit delta area; in undiked areas, map patterns distinguish saltmarsh and freshwater marsh. For the Stillaguamish delta, we georeferenced paper copies of USC&GS charts T-1755 "Port Susan and Stillaguamish River" (1886) and T-2156 "Skagit Bay, Delta, and River—Washington" (1889). We georeferenced a paper copy of the 1:20,000-scale USC&GS chart T-1681 "Snohomish River, Washington Ter., (to head of ordinary steamboat navigation)" (1884-1885).

Army Engineers Records

We made use of early maps drawn by the US Army Corps of Engineers (USACOE) showing Swinomish Slough (USACOE 1892) and the greater Skagit delta area (USACOE 1897). We also drew from the Annual Reports of the Chief of Engineers (U. S. War Department, 1876-1906) for field descriptions and reports of field operations, such as their snagging program, which can give an indication of in-channel wood loads and characteristics (e.g. Collins et al. 2002, Sedell and Frogatt 1984).

Aerial Photographs

In the Nooksack River area, we georeferenced aerial photographs taken Oct. 19 1938 and Oct. 25 1938 (1:12,000 BW) that cover the study area, except for the Middle Fork, for which we georeferenced 1:20,000-scale 1944 Army Corps of Engineers photomosaics, from 1943 photographs. We georeferenced 1937 1:12,000-scale aerial photographs that cover the Skagit-Samish rivers delta and upstream to the confluence with the Sauk River, and 1:20,000-scale 1944 photos covering the remainder of the study area. For the Stillaguamish watershed, we orthorectified 1933 B/W 1:12,000 scale aerial photographs that covered the mainstem and the North Fork to RM 30 and South Fork to RM 33 . We orthorectified 1947 B/W aerial photographs to cover the upper one river mile in the South Fork, and to cover northern and southern portions of the delta that were not covered by the 1933 photos. In the Snohomish River valley, we orthorectified 1933 B/W 1:12,000 scale and 1938 B/W 1:10,000 scale aerial photographs. No comparable photo coverage was available for the French Creek Marsh area. In the Skykomish River area we georeferenced 1938 B/W 1:10,000 scale aerial photographs. For the Snoqualmie River valley, we orthorectified 1936 B/W 1:9,600 scale and 1938 B/W 1:10,000 scale aerial photographs.

Digital Elevation Models

For the Nooksack River area we used a 2.5-m-cell DEM made from elevations from a photogrammetric survey, provided by Whatcom County. For the greater Skagit River delta (the Skagit and Samish river distributaries, downstream of Sedro Woolley) we made a 10-m DEM from elevations surveyed by the US Army Corps of Engineers and provided by Skagit County. In the Snoqualmie valley we made a DEM from LIDAR provided by the Puget Sound Lidar Consortium.

Geologic and Soils Mapping

In the Nooksack River valley we delineated landforms (e.g., floodplains, alluvial fans, terraces, large landslides) using published geologic mapping (e.g. Easterbrook 1976; Dragovich et al. 1997; 1999), and the DEM. We also made use of hydric soils mapping in the National Soil Survey Geographic (SSURGO) online database and peat deposits mapped by Rigg (1958) in our wetland mapping. We delineated landforms in the Skagit study area using published geologic mapping (e.g. Dragovich et al; 1998; 1999; 2000), and the DEM. We also made use of hydric soils mapping from recent soils mapping [Klungland, and McArthur 1989; National Soil Survey Geographic (SSURGO) online database] soils mapping National Soil Survey Geographic (SSURGO) and earlier mapping (Ness and Ritchins 1958). For the Stillaguamish River valley we delineated landforms using published geologic mapping (e.g. Minard 1985a, 1985b, 1985c; Tabor et al. 1988; Booth 1989) and topographic mapping. In the Snohomish and Snoqualmie river valleys we delineated landforms using published geologic mapping (e.g. Minard 1985d, 1985e, 1985f, 1985g; Booth 1990) and topographic mapping. We made use of older (Mangum 1909) and more recent [Debose and Klungland 1983; National Soil Survey Geographic (SSURGO) online database] soils mapping and older forest mapping (Plummer et al. 1902), and in the Snoqualmie valley upstream of RM 5, a DEM from LIDAR data.

Local Histories

Local histories and pioneer accounts consulted include Jeffcott (1949), Judson (1984) and Royer (1982), Eide (1996), Essex (1971), and Interstate Publishing Company (1906).

Status of GIS Layers

The analysis for this report is based on our GIS coverages (all last edited in January 2003)

"NKS_1880_v1p2," "SKG_1880_v1p1," STL_1880_v1p0," "SNH_1880_v1p0," and "SNQ_1870_v1p0." Source codes (see below) have not yet been added to the SNH coverage, and the source codes in the SNQ coverage have not been edited for consistency with those used in the other coverages and as described below in this chapter.

CHANNEL AND LAND COVER MAPPING: METHODS, ASSUMPTIONS, AND CERTAINTY

The mapping approach and assumptions differ for each type of map feature in the channel and land cover layer.

Large channels

We use "large channels" to refer to channels wide enough to be drawn as polygons on original source materials and "small channels" to refer to those drawn as lines. On GLO plat maps, large channels have generally been meandered, their widths have been field-measured, and the actual width is depicted on the maps (see below for discussion of discrepancies between plat maps and field notes). This contrasts with small channels, which have not been meandered, and are accurately located only where they intersect section lines (see below).

We interpret channel widths in the GLO survey to have been measured from bank to bank. Some earlier workers making use of channel widths from GLO notes have concluded that GLO channel widths referred to the channel's wetted width (e.g. Knox 1977). We think the widths refer to bankfull widths in the Puget Sound region for several reasons. Instructions indicate that rivers are to be meandered along "both banks" (White, 1991). Second, widths measured by GLO are generally consistent with the bankfull widths in the photographic and post-GLO map record (approximately over the last 100 years) in areas where the channel is relatively unchanged. The earliest instructions to surveyors, issued early in the 19th century, did not specify that widths be measured from bank to bank, supporting the possibility that earlier surveys, such as those in the Midwestern U.S., could have measured the wetted channel width.

If large channels meandered by the GLO or surveyed by plane table by the USC&GS were topographically plausible, and consistent with evidence on early aerial photographs (except in cases where subsequent channel changes had erased evidence of previous channel locations) we generally mapped them as drawn on the original source materials and considered them to have a relatively high certainty level (Table A-6). Where large channels were not consistent with topography, we locally adjusted their location or shape, trying to maintain the original width or area. This was typically necessary where channels as drawn on GLO maps were inconsistent with the valley boundaries (Table A-6). We also made adjustments to tidal channels mapped on USC&GS charts when early aerial photographs showed these channels as relict channels closed off by sea dikes. Because diking was generally very early (e.g., commonly in the 1870s and early 1880s), we assume that such relict tidal channels are a good indication of their location and shape at the time of interest.

In a few cases, the channel was sketched as a polygon on the GLO notes, but had not been meandered. In these cases we drew the channel between GLO control points at section lines by use of 1930s aerial photographs and topography (Table A-6). In one area (the confluence of the Sauk and Suiattle rivers) channels drawn on GLO maps appeared to be considerably simplified compared to the channels shown on topographic mapping made only a few years later, and we used the topographic mapping (Table A-6). Finally, a few channels not shown on original source materials were drawn from early topographic maps or 1930s photographs.

Surveyors did not always accurately draw the plat maps from the field notes. In north Puget Sound drainages, channels on plat maps were drawn as much as 137% wider and 100% narrower than the values recorded in the field notes (as much as 116% wider and 39% narrower in the Skagit; Figure A-2). Despite the considerable scatter, on average map widths were greater than field-measured widths by only several percent (e.g., Skagit mean = 7.3%; median = 1.5%), and are consistently wider on plat maps than in the notes, on average, for each of the four north Puget Sound basins in Figure A-2. Different surveyors also drew channels on plat maps with varying amounts of accuracy and precision (Figure A-3). A few drew the channels with both precision and accuracy, whereas others lacked both; the drafting error for individual surveyors is shown in Figure A-3 with decreasing accuracy from left to right. This information makes it possible to assess the general accuracy of the depiction of channels in a given township.

Small Channels

Small channels on GLO plat maps were not meandered. Surveyors encountered small channels along section lines, or along the banks of a large channel they were meandering. Surveyors would not generally walk out such a channel, but instead sketch it between these points of intersection. In many cases, these locations are plainly wrong in the context of modern topographic data. Thus, the plat maps cannot be expected to accurately show channel locations except immediately adjacent to section lines or meandered channels. Smaller channels thus generally involve the most interpretation and have a lower level of certainty than larger channels.

In drawing small streams on the ~1880 layer we made use of stream locations along surveyed section lines, but then relied on stream locations shown on the 1938 aerial photos and high-resolution DEMs. We considered the certainty to be relatively high where the two sources were in agreement, or could confidently be reconciled (Table A-7). We considered the certainty level to be intermediate when early photographs showed the location of relict (as opposed to active) channels, because of the uncertainty about when the relict channel was last active, and in some cases its exact location. We also considered the certainty level to be intermediate when the channel was not shown on GLO maps, but was shown as a channel on early topographic maps or on early aerial photos. This was commonly the case for channels that the GLO survey would have missed because they did not cross section lines.

We developed similar rules for assessing the relative certainty of channels charted by the USC&GS (Table A-7). We gave greater weight to relict channels in evaluating channels on USC&GS charts (compared to the weight we gave them in evaluating GLO channels). As indicated above in discussing large channels, this is because tidal channels were diked quite early.

Small channels having a relatively high level of evidence accounted for 29% of the cumulative length of the channel network portrayed. Those having a moderate certainty accounted for 40%. We assigned our mapping of small channels a relatively low certainty in one of three circumstances (Table A-7). These were (1) when channels were not shown on the GLO maps, but were evident as relict channels on the GLO maps (accounting for slightly more than one-quarter the cumulative length of small-channel network); (2) when they were shown on GLO maps but there was no evidence from later sources to substantiate the GLO data; and (3) channel segments that were drawn in to connect upstream channel segments, that had a higher certainty level.

Wetlands

Our wetland classification follows Cowardin et al. (1985), with the exception that we use “riverine-tidal” to refer to freshwater wetlands influenced by tidal backwater effects.

The GLO surveyors, instead of using a modern wetland classification, viewed the landscape through their mandate to identify “swamp and overflowed” lands that were considered “unfit for cultivation.” The 1850 “Swamp Lands Act”,” extended to Oregon in 1860, granted lands “wet and unfit for cultivation” to the states or territories (White, 1991). This placed a large burden on the surveyors, who were charged with recording the points at which they entered such lands, and to document the “distinctive character of the land” including “whether it was a swamp or marsh, or otherwise subject to inundation to an extent that, without artificial means, would render it “unfit for cultivation.” The surveyors were also charged with noting the depth of inundation and its frequency.

The instructions to surveyors for describing their responsibility to document “swamp lands, use the words “marsh,” “swamp,” “marshy areas,” “overflowed lands,” and “bottom,” but define none, nor do their uses appear to be consistent. It is also not clear if surveyors used the terms with consistency in the field. As a result, in describing wetlands as emergent, scrub-shrub, or forested (following Cowardin et al., 1985) we use these descriptors as secondary to the information provided by bearing trees, vegetation descriptions, USC&GS mapping, and modern data (e.g. soils mapping; wetland remnant patches visible on 1937 aerial photos). Table A-8 lists some of the descriptive terms encountered in the GLO notes and the wetland types we interpret from them in association with other data. (Appendix C provides detailed wetland descriptions, including inundated area, and describes the methods we used to estimate inundation.)

We used several certainty ratings for the presence and boundaries of wetlands (Table A-9). Polygons given a high certainty level were mapped by the GLO, USC&GS, or USGS respectively, and are consistent with topography. The GLO wetland mapping often does not extend far from section lines. Some polygons reflect extrapolations within section interiors (i.e., between polygons GLO-mapped along section lines) that are consistent with topography and are shown on early topographic maps, or extrapolate USC&GS polygons into areas adjacent to the limit of USC&GS mapping, and are shown by recent soils mapping as having hydric soils. These are given a “moderate” certainty rating. Some other extrapolations lack confirmation on early topographic maps, but have equivocal evidence on 1938 aerial photographs or are mapped by recent soils mapping as having hydric soils, and are topographically reasonable; these are given a “low” certainty coding.

Our GIS coverages include tidal creeks that were drawn from relict channels visible on 1930s aerial photographs, as described previously. These channels are important clues to the nature and extent of wetlands. Even in cases where relict channel network visible on the photos was discontinuous or fragmentary (e.g., see portions of the Stillaguamish estuary), they were important for delineating wetlands because they indicate the directional source of tidal water, and thus whether the source is fresh or salt.

We used USC&GS charts to delineate the MLLW (mean lower low water), which we took as the outer limit of tideflat. We have not calibrated 1800s tidal datums with modern datums.

Ponds

The GLO surveyors were instructed to meander all ponds greater than 40 acres (99 ha) (White, 1991). Thus some ponds on GLO maps were mapped in detail, and others sketched, based on the information gathered where the section line intersected the pond. We gave pond polygons a “high” certainty if they were mapped by GLO or USC&GS, and we may or may not have had to slightly modify the shape slightly using topography and early maps or photos. Pond polygons mapped by the GLO or USC&GS were given a “moderate” certainty rating if it was necessary to substantially alter their shape to be consistent with topography or early topographic mapping. Ponds not mapped by the GLO (because of their location within section interiors), but which are shown on early topographic maps and are consistent with topography, were also given a “moderate” level of evidence rating (Table A-10).

Forests

The continuous extent of forest cover is assumed based on the continuous forest cover described along section lines in GLO notes. However, this simplification misses non-wetland meadow patches in the valley-bottom forest, either natural or caused by indigenous land management, either within section interiors or along section lines but not noted in field notes.

Using Bearing Tree Records to Characterize the Riverine Environment

Species Equivalents for Trees Identified by GLO Surveyors

Surveyors used common names for vegetation, which can make ambiguous identifying the scientific name (Whitney 1996). Previous workers have created lists of species equivalents for GLO bearing trees (e.g. Shanks 1953; Crankshaw et al. 1965; Grimm 1984; Galatowitsch 1990), but we are aware of none for forest trees in the western United States. Among the most common bearing trees in the study area (Table A-11), only "fir" is potentially ambiguous; we assume it refers to Douglas fir *(Pseudotsuga menziesii),* because surveyors also identify the occasional "white fir," indicating that they differentiate firs, and Douglas fir is expected to be the most common fir in the study area.

Among less common species, we assume that "white fir" is misidentified grand fir *(Abies grandis)* because unlike grand fir white fir does not appear in the area's modern flora. "Juniper" we take to be Rocky Mountain juniper *(Juniperus scopulorum)*, which we have seen growing in the Snohomish River estuary. We assume that the uncommon "barberry" and "bearberry" are used interchangeably to refer to the same plant. The most likely—if much less than certain—reference is to Oregon grape *(Berberis nervosa)* or possibly Bearberry Honeysuckle *(Lonicera involucrate).* Assigning equivalents to other of the less common or incidental species is relatively straightforward (Table A-11).

How Well do Bearing Trees Represent Forest Composition?

Bearing tree records are not necessarily reliable proxies for historical forest conditions because surveyors did not select trees randomly, but instead used instructions having several criteria. While these instructions are not completely clear, we interpret instructions to surveyors current in the early 1870s for the region in context of earlier instructions (White 1991), as giving emphasis to selecting trees that are, in decreasing order of importance: (1) greater than 7.5 cm (3 inches) in diameter; (2) in opposite directions from the survey point at quarter corners and in each quadrant at corners; (3) closest to the point; (4) alive; and (5) within 60.25 m (3 chains) of the survey point. While the instructions indicate a 6 cm (2.5 inch) minimum diameter, we used 7.5 cm (3 inches); in inspecting over 7,000 bearing-tree records from western Washington, we found very few that were less than 7.5 cm, indicating that this was the minimum diameter tree that surveyors selected.

To evaluate how well bearing trees represent forest composition, we followed the Instructions to Surveyors at 1873 GLO survey points in the Nisqually River valley. (We used a differential GPS to reoccupy the original GLO survey points to compare 1873 and 2000 forests; see Collins and Montgomery 2002.) Because the Nisqually River valley was originally platted as the Nisqually Indian Reservation, there are survey points on a regular 1/16-mile grid. We also reoccupied “meander” points, or we established new points where the river had moved from its 1873 location. We selected two bearing trees at meander points and quarter corners, and four at corners, consistent with the instructions to surveyors. At the same locations, we also measured the diameter of all trees > 1 cm diameter within a 10-m radius from the survey point. For “streamside” points we marked out rectilinear plots that extended 10 m from the bank, and followed the bank for 15.7 m upstream and the same distance downstream, to sample an area equal to the 10-m radius plots. We established 26 points, at which we documented 56 bearing trees and 1,275 trees within the 314-m^2 plots.

We used the two sets of data to evaluate the bias caused by bearing trees being greater than 7.5 cm in diameter. Bearing tree records should under-represent smaller-diameter species. We found this most noticeably to be the case for vine maple *(Acer circinatum),* which was by far the most common tree in our plot samples but accounted for only a few percent of bearing trees (Figure A-4A). Consequently, all other species are underrepresented when counted by stem number. However, when counted by basal area, there is less discrepancy between the two samples (Figure A-4B). The difference between the two samples for individual species was as great as 13% but averaged 4% (Figure A-4B). This suggests preliminarily (i.e., in absence of a larger data set) that estimating percent basal area from bearing tree records is a reasonably accurate way to characterize the historical forest.

We also examined the distribution of tree diameters in the two samples, for individual species, to assess whether we had a bias for selecting larger trees for bearing trees (rather than the nearest tree). The distributions of the five species common enough to make meaningful comparisons (Figure A-5A) show that black cottonwood *(Populus trichocarpa)* were significantly smaller in the plot sample than in the bearing tree sample. However, 83 of 104 cottonwoods were measured at a single site, averaging 11.7 cm in diameter. Excluding this site changes the mean diameter for cottonwood from 28.3 cm to 41.7 cm for trees >7.5 cm diameter (23.1 cm to 41.7 cm in diameter for all cottonwoods measured regardless of size). This suggests the discrepancies in diameter distributions between the two types of sample may be due more to sample size being small relative to the species clumping than it is due to bias in tree selection.

Using Bearing Tree Records to Map the Riverine Environment

We use bearing tree records to delineate and characterize land cover types by the 1) distance to bearing trees; 2) diameters of trees; 3) tree species; and 4) geomorphic environment. This information was attributed to the corresponding tree points in the GIS.

Surveyors recorded distances from survey points to the bearing trees. While previous researchers have used this data for several decades to compute forest density (e.g. Cottam and Curtis 1956), most researchers do not believe it is possible to do so accurately (see discussion in Whitney and DeCant 2001). Instead, we use the measured tree distances to index relative tree density, for comparative purposes, to spatially delineate vegetation types. This general approach has been used to delineate savannah from woodland (Nelson 1997) or prairie from forest in river bottoms (Nelson et al. 1998).

We used the distance to trees averaged at each survey point to distinguish cover types, particularly scrub-shrub areas from forested areas; species frequency and abundance (measured by basal area) also showed differences useful in delineating cover types. The bearing trees also indicate the species and diameters of trees that would have fallen into channels, thus providing insight into the character of historical in-channel wood. Information on the geomorphic and geographic characteristics of trees' growth locations also provides guidance to reforestation efforts.

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Table A-1. General criteria for assigning certainty levels to mapped features. "Early map" refers to GLO plat maps, USC&GS charts, and early USGS topographic maps. See Tables 4-8 for detail on individual features (e.g. wetlands, channels, ponds).

RELATIVE CERTAINTY	GENERAL CRITERIA
HIGH	• Appears on early map as a feature known to have continuous field verification, AND consistent with modern data (e.g. topography, soils, hydrography).
MEDIUM	• Appears on early map as a feature known to have only spot field verification AND continuous information appears on 1930s aerials, AND unlikely feature could have been modified in intervening time OR modern data (e.g. topography, soils, hydrography) can reasonably be used to verify (if 1930s photos cannot be expected to show feature). • For features that have been "frozen in time" (e.g. by early diking), appears on 1930s aerials, and very unlikely feature could have been modified in intervening time.
LOW	• Does not appear on early map (but does not contradict mapping) BUT interpretation of 1930s photos or modern data give strong indication of presence as historical feature. • Appears on early map, BUT feature not known to be reliable, AND no information available to substantiate.

Table A-2. General Land Office surveys used for mapping the Nooksack River study area.

STUDY AREA	TOWNSHIPS	YEARS OF SURVEY
Delta	38N1E, 38N2E, 39N1E, 39N2E	1859-1873
Lower Mainstem	40N2E, 40N3E, 40N4E	1872-1874
Upper Mainstem	39N4E, 38N5E, 39N5E	1884-1889
North Fork	39N5E, 40N5E, 40N6E 39N6E	1889-1893 1905
Middle Fork	38N5E, 39N5E	1884-1889
South Fork	38N5E, 37N5E, 36N5E	1884-1890

Table A-3. General Land Office surveys consulted in the Skagit-Samish study area.

STUDY AREA	TOWNSHIPS	YEARS OF SURVEY
Skagit River Delta	T36NR2-3E, T35NR2-4E, T34NR2-4E, T33NR2-4E, T32NR3-4E	1866-1874
Skagit River below Sauk	T35NR5-9E	1877-1884
Sauk River	T35NR9E, T34NR9-10E, T33NR10E, T32NR9-10E	1884-1892
Skagit River above Sauk River	T36NR11E, T35NR9E, T34NR9-10E	1884-1895

Table A-4. General Land Office surveys used for mapping the Stillaguamish River study area.

STUDY AREA	TOWNSHIPS	YEARS OF SURVEY
Mainstem and Camano Island	32N3E, 31N3E, 32N4E, 31N4E, 32NR5E	1872-1875
North Fork	32N5E, 32N6E, 32N7E 32N8E, 32N9E	1890-1892 (32N5E 1875)
South Fork	31NR5E, 31N6E, 30N6E	1874-1881

Table A-5. Coast Survey charts consulted in mapping the Skagit-Samish study area.

CHART TITLE	CHART NUMBER	SCALE	YEARS OF SURVEY
Skagit Bay, Delta and River Washington	T-2156	1 : 20,000	1889
Skagit Bay, Washington	T-2050	1 : 20,000	1890
Padilla Bay, W. T.	T-1815	1 : 20,000	1887
Map of the Harbor of LaConner, Wash. Topography and Hydrography	T-2108	1 : 4,800	1892
Sheet No. 3 Topography of Rosario Strait, W.T., Fidalgo and Padilla Bays	T-1747	1: 10,000	1886
Bellingham Bay, Washington	Chart 6378	1: 40,000	1893

Table A-6. Mapping situations, and relative strength of evidence for each, in delineating large channels in ~1880 GIS coverage.

	MAPPING CRITERIA	CERTAINTY LEVEL
C1A C1B	Meandered by GLO (C1A) or charted by USC&GS (C1B) and consistent with topography (and early aerial photographs, where photo evidence is possible).	H
C2A	Meandered by GLO, but necessary to locally refine boundaries because location is inconsistent with topography (e.g., river goes uphill).	M
C2B	Sketched (not meandered) by GLO; channel location and shape between GLO control points adjusted using topography and more recent aerial photographs.	M
C2C	Mapped on 30' USGS topographic maps. Topographic map, made within only a few years of the GLO maps, shows significantly more detail than GLO map. Applies only to section of Sauk River near confluence with Suiattle.	M
C3A	Channel mapped from early aerial photos or topographic maps.	L
C3B	Sketched (not meandered) by GLO; insufficient information to confidently confirm or adjust channel location.	L

Table A-7. Mapping situations, and relative strength of evidence for each, in delineating small channels in ~1880 GIS coverage. "Percent of total" is the percent of the cumulative length of the small channel comprised by each category.

	MAPPING CRITERIA	CERTAINTY LEVEL
CR1A	Shown on (i) GLO maps AND (ii) on early maps or aerial photos, and no (or minor) adjustments need be made to reconcile with the early maps or photos.	H
CR1B	(i) Shown as channel on GLO map OR as tic mark crossing section line on GLO map AND (ii) as *channel* on earliest topographic maps or early aerial photographs AND (iii) significant adjustments to channel location can be made confidently based on early photo or map information.	H
CR1C	(i) Shown onUSC&GS charts AND (ii) on early maps or aerial photos. Adjustments may be made to reconcile with the early maps or photos.	H
CR2A	(i) Shown as channel on USC&GS charts but (ii) not possible to confirm using supporting information from early aerial photos or topographic maps.	M
CR2B	(i) Shown as channel on GLO map OR as tic mark crossing section line on GLO map AND (ii) as *relict channel* on earliest topographic maps or early aerial photographs AND (iii) adjustments to channel location can be made confidently (e.g. evidence that channel has not been ditched or moved prior to early photos or maps) based on early photo or map information.	M
CR2C	(i) Not shown on GLO or USC&GS but (ii) *channel* shown on earliest topographic maps or early aerial photographs (or in case of tidal channels, *relict channel*), and evidence suggests that channel has not been ditched or moved prior to early photos or maps.	M
CR3A	(i) Not shown on GLO or USC&GS but (ii) *relict channel* shown on earliest early aerial photos, and evidence suggests that channel has not been ditched or moved prior to early photos or maps.	L
CR3B	(i) Shown on GLO and (ii) insufficient information available from early photographs or maps for confirming or adjusting location. Channel shown as on GLO map or locally modified using topography.	L
CR3C	Channel segment that connects confirmed upstream and downstream channels or upstream channel.	L

Table A-8. Typical descriptors used in GLO field notes, and equivalent wetland interpretation. Examples are from Nooksack and Skagit rivers.

WETLAND CLASSIFICATION	TYPICAL NOTATION IN GLO NOTES
Estuarine Emergent	"Tide prairie" or "Prairie" "Low tide prairie covered with grass"
Estuarine Scrub-Shrub	"Tide prairie, covered with tules, flags, grass and scattering timber" "Tide flats and subject to overflow of 1 to 3 ft. Timber, spruce, crabapple, alder and willow, undergrowth same, with hardhack and gooseberry bushes" "Tide prairie with scattering crab apple"
Riverine-tidal	"Subject to inundation by freshets and high tides 1 or 2 ft."
Emergent	"Open marsh"
Scrub-shrub	"Marsh" "Hardhack swamp" "Marsh covered with clumps of willow and hardhack" "Willow and hardhack swamp"
Forested	"Crabapple swamp" "Alder swamp" "Swamp covered with skunk cabbage and very dense thickets of spruce and crabapple"

Table A-9. Mapping situations, and relative strength of evidence for each, in delineating wetlands and ponds on ~1880 GIS coverage.

	MAPPING CRITERIA	CERTAINTY LEVEL
W1A	Appears on USC&GS chart; consistent with GLO field notes.	*H*
W1B	Appears on GLO maps or field notes; near to field-surveyed section line.	H
W1C	Appears on early topographic maps.	H
W2A	Hydric soils on recent soils map; adjacent to wetlands appearing on GLO map; not crossed by section line.	M
W2B	Hydric soils on recent soils map; adjacent to wetlands appearing on GLO map; crossed by section line, with inconclusive indications in GLO notes.	M
W2C	Hydric soils on recent soils map; elevation used to extend tidally-influenced wetlands.	M
W3A	Hydric soils on recent soils mapping; inconclusive evidence in GLO field notes.	L
W3B	Topography used to extend boundary of GLO-mapped wetland.	L

Table A-10. Mapping situations, and relative strength of evidence for each, in delineating ponds on ~1880 GIS coverage.

	MAPPING CRITERIA	CERTAINTY LEVEL
P1A	Appears on GLO map. Shape and boundaries refined using 1930s aerial photos.	H
P1B	Does not appear on GLO map or early 30' topographic map. Appears on 1930s aerial photos, and improbable that feature could have been created in the preceding half century.	H
P2	Appears n GLO map. Does not appear on early topographic maps or on 1930s aerial photos, and therefore is not possible to refine boundaries or confirm size.	M

Table A-11. Trees and shrubs recorded as witness trees in GLO field notes in the study area, and probable common and scientific names. Trees are listed in decreasing frequency of occurrence.

FRE-QUENCY	NAME USED IN GLO NOTES	PROBABLE COMMON NAME	SPECIES
30% of total	Alder	Red alder	*Alnus rubra*
Common (2%-10%)	Hemlock	Western hemlock	*Tsuga heterophylla*
	Willow	Willow spp.	*Salix* spp.
	Maple	Bigleaf maple	*Acer macrophyllum*
	Cedar	Western redcedar	*Thuja plicata*
	Vine maple	Vine maple	*Acer circinatum*
	Spruce	Sitka spruce	*Picea stchensis*
	Fir	Douglas-fir	*Pseudotsuga menziesii*
	Cottonwood	Black cottonwood	*Populus trichocarpa*
	Crabapple	Pacific crabapple	*Malus fusca*
Uncommon (0.5-2%)	Barberry, Bearberry	Oregon grape (?) Bearberry honeysuckle (?)	*Berberis nervosa* *Lonicera involucrata*
	Pine	Shore pine	*Pinus contorta*
	Hazel	California hazel	*Corylus cornuta californica*
	Juniper	Rocky Mountain juniper	*Juniperus scopulorum*
	Birch	Paper birch	*Betula papyrifera*
Incidental (<0.5%)	Yew	Pacific yew	*Taxus brevifolia*
	White fir	Grand fir	*Abies grandis*
	Dogwood	Western flowering dogwood	*Cornus nuttalli*
	Elder	Elderberry	*Sambucus* spp.
	Poplar	Quaking aspen	*Populus tremuloides*
	Chittemwood	Cascara	*Rhamnus purshiana*
	Cherry	Bitter cherry	*Prunus emarginata*

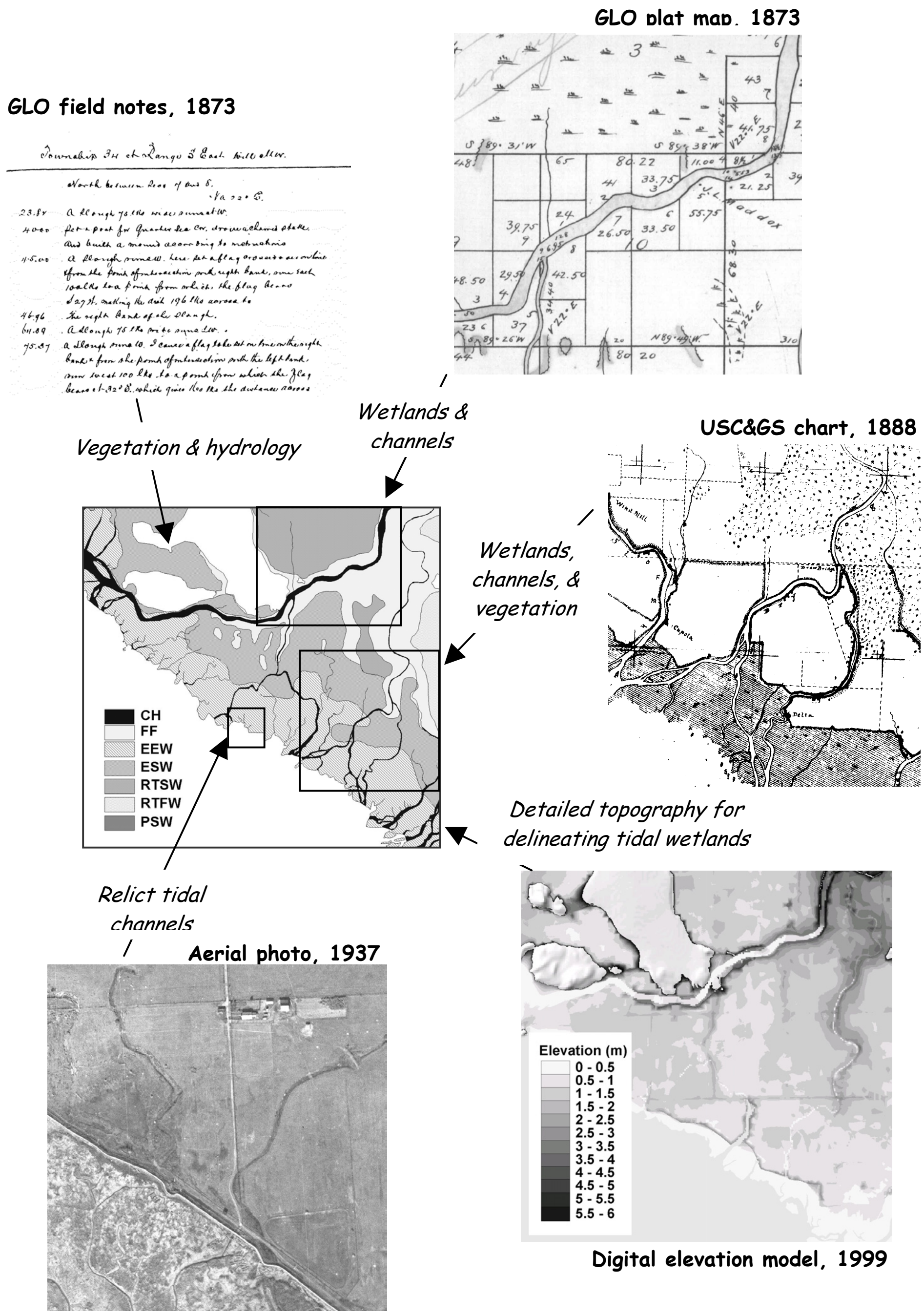

Figure A-1. The use of archival materials, field studies, aerial photographs, and digital elevation models (DEMs) in a GIS to map the historical riverine environment (from Collins et al., 2002). Example shows area of Fir Island in the Skagit River delta.

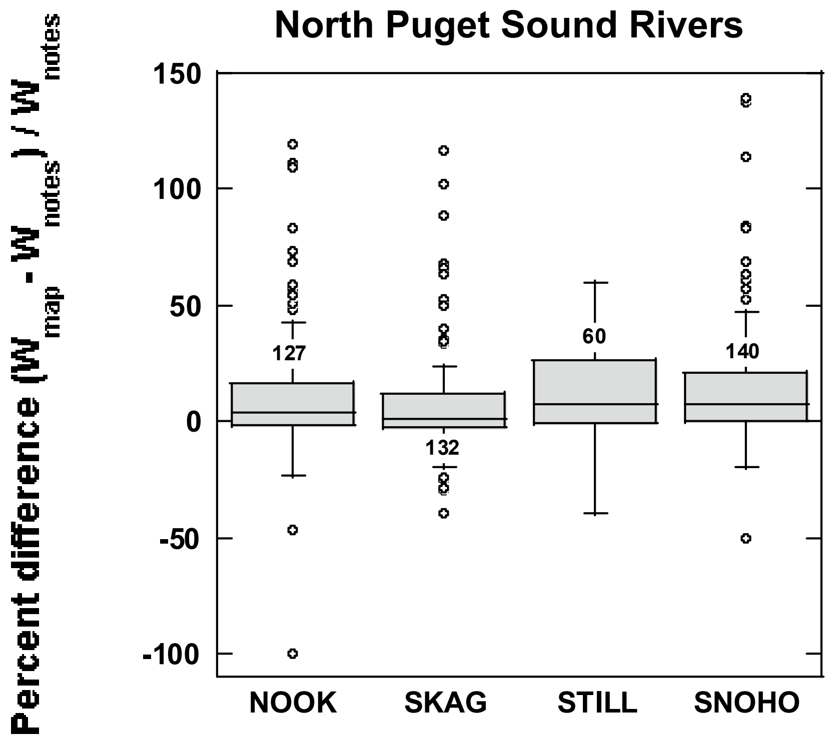

Figure A-2. Percent difference between distance across stream along section line, as field-measured and recorded in GLO survey notes, and the distance recorded on plat maps, in the Skagit River study area. A positive difference means that the map width is greater than the measured width. Nooksack median= 4.1, mean=11.1; Skagit median=1.5, mean=7.3; Stillaguamish median=7.8, mean = 12.3; Snohomish median=7.1, mean=14.1). Each box encloses 50% of the data. Horizontal line within box represents median. The lines extending from the top and bottom of boxes indicate minimum and maximum values, excepting outlier values (circles) greater than the inner quartile plus 1.5 times the inner two quartiles.

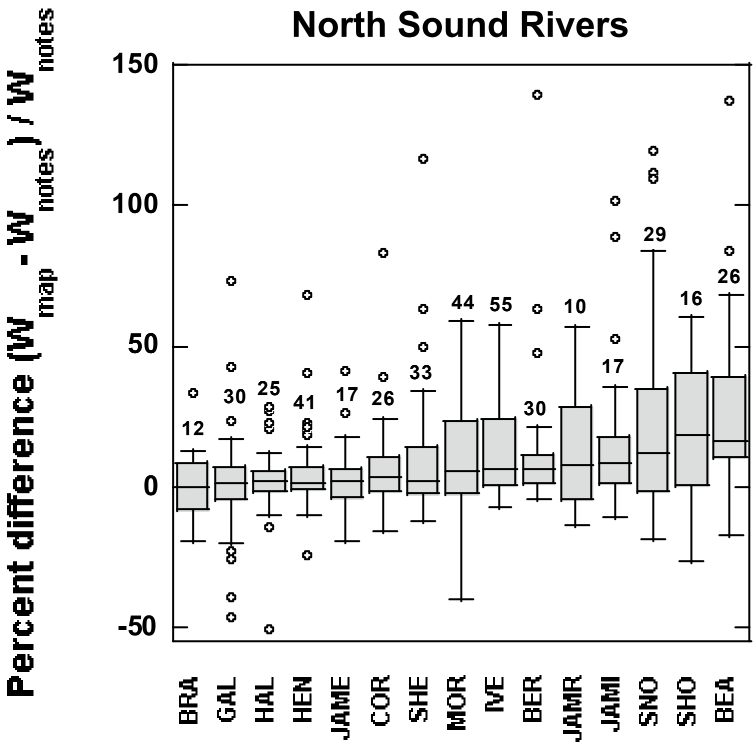

Figure A-3. Percent difference between distance across stream along section line, as field-measured and recorded in GLO survey notes, and the distance recorded on plat maps, in the Nooksack, Skagit, Stillaguamish, and Snohomish watersheds, for individual surveyors. A positive difference means that the map width is greater than the measured width. BRA: Brakins; GAL: Galbraith; HAL: Hall; HEN: Henry; JAM: Jameson; COR: Cornelius; SHE: Sheets; MOR: Morgan; IVE: Iverson; BER: Berry; JAMR: Jamirson; SHO: Shoecraft; SNO: Snow; BEA: Beach. Excluded are surveyors with less than 10 records (Cornelius and Snow; Lemfest, Ober, Oullette, Parsons, Reynolds, Spearin, Richardson). Surveyors most represented in the Skagit River study area, and the number of observations from each included in the above figure, include Henry (41), Sheets (33), and Jamison (17).

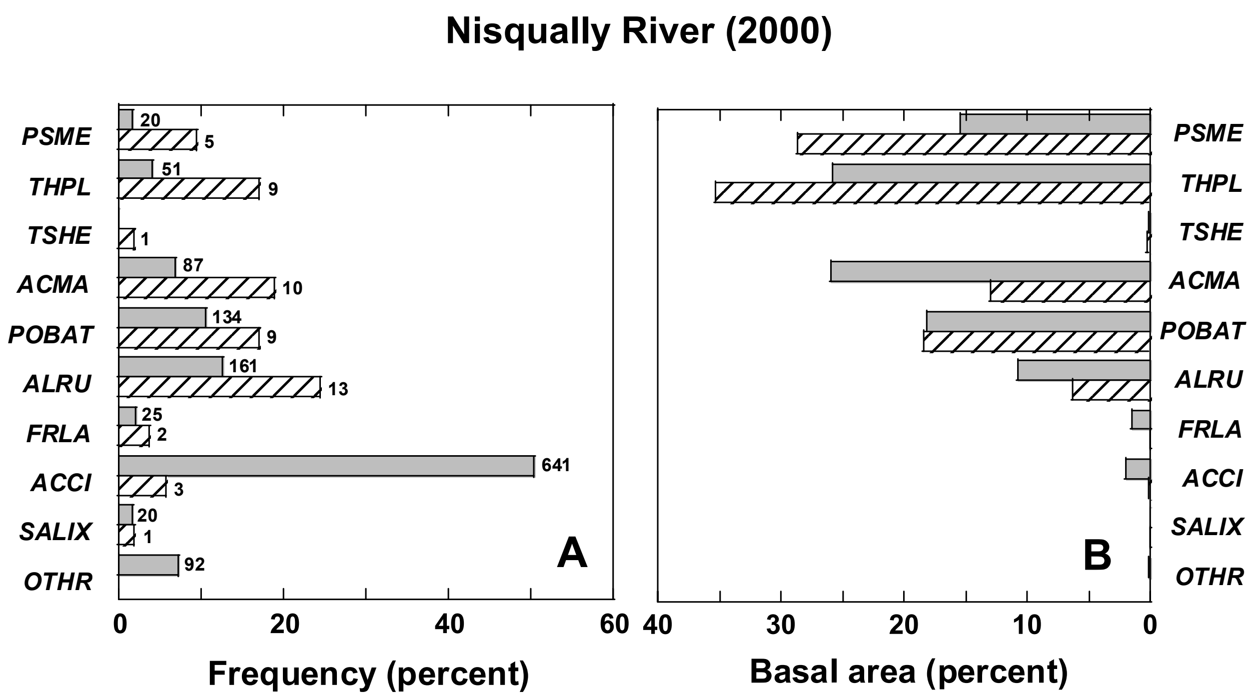

Figure A-4. (A) Frequency and (B) basal area of tree species in the Nisqually study site in 2000. Plot data are shown with a solid bar, and bearing tree with a striped bar. PSME: *Pseudotsuga menziesii*; THPL: *Thuja plicata;* TSHE: *Tsuga heterophylla*; ACMA: *Acer macrophyllum*; ALRU: *Alnus rubra*; POBAT: *Populus trichocarpa*; FRLA: *Fraxinus latifolia*; ACCI: *Acer circinatum; SALIX: Salix* spp. "Other" species include: *Cornus nuttallii* (western flowering dogwood), *Corylus cornuta var. californica* (beaked hazelnut), *Oemleria cerasiformis* (Indian plum), *Rhamnus purshiana* (cascara), *Sambucus racemosa* (red elderberry).

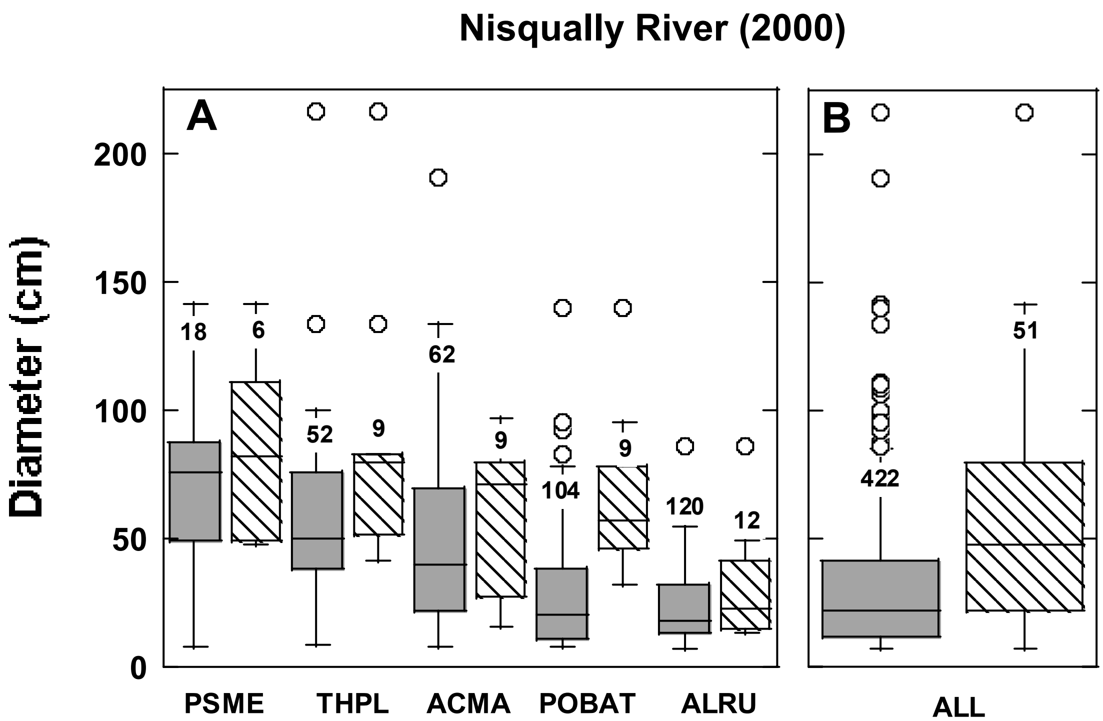

Figure A-5. In the Nisqually River study area diameter distribution for the five most abundant species of trees (A) in plots (solid bar) and bearing tree (striped bar) samples, and (B) all trees. Excluded are trees in plots <7.5 cm in diameter. Numbers are sample size. Horizontal line within box represents median. The lines extending from the top and bottom of boxes indicate minimum and maximum values, excepting outlier values (circles) greater than the inner quartile plus 1.5 times the inner two quartiles.