Historical riverine dynamics and habitats of the Nooksack River

Final Project Report to:

Nooksack Indian Tribe
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SUMMARY

Archival materials, including maps and field notes from the General Land Office (GLO) cadastral survey from 1859-1893, US Coast & Geodetic Survey (USC&GS) charts from 1887 and 1888, topographic and land cover maps from 1906-1918, and aerial photographs from 1938 and 1944, were entered into a GIS (geographic information system). In combination with a DEM (digital elevation model) constructed from 1993 photogrammetry and published geologic mapping, archival materials were used to map the channel, wetland, forest, and oxbow ponds in the Nooksack River valley during early Euro-American settlement, or about 1880. To evaluate subsequent change, conditions were also mapped for (i) the early 20th century (~1910) from USGS topographic maps (1906-1918) and soil and land use mapping (1909), (ii) for 1938, from aerial photographs, and (iii) for 1998, from aerial photographs and National Wetland Inventory. The study area is the Nooksack River from the mouth to RM 56 on the North Fork, to South Fork RM 16, and Middle Fork RM 5.

Each feature in the historical GIS coverages incorporates assumptions and draws on different sources, which are coded, and given an associated relative certainty rating. The landscape-scale mapping is intended to provide best estimates of change to aquatic habitat, and to document how landforms, hydrographic features, and land cover vary along and across the Nooksack valley and through time. It provides a starting point for more detailed site-specific investigations.

Historically the greater Nooksack delta (including the Lummi and Nooksack rivers) included extensive estuarine and riverine-tidal freshwater wetlands, primarily on the Lummi River side, which had been the dominant outlet to saltwater until the mid 1800s. Upstream of the delta, glacial processes created distinctly different valley topography in different parts of the study area, which in turn influenced river morphology and valley landforms. Upstream of the delta, in the lower mainstem (to about Everson), Pleistocene glaciation resulted in a broad, low-gradient valley. Holocene (post-glacial) deposition by the

Nooksack River built up the river and its meander belt typically 3-4 m above the valley bottom. Extensive wetlands (primarily with scrub-shrub vegetation and having numerous beaver dams) occupied low areas marginal to the meander belt. Upstream of Everson, the valley narrows and steepens, and has 3-4 m of relief associated with multiple channels, sloughs, and islands. The channel had a branching or "anastomosing" pattern, with multiple channels and sloughs, and forested islands.

Hardwoods, most commonly red alder *(Alnus rubra),* dominated the pre-Euro-American-settlement forest, according to GLO field notes. Western redcedar *(Thuja plicata),* while only one-fourth as common as alder, was the most common conifer, and also the largest tree. Among conifers, Sitka spruce *(Picea sitchensis*) grew in the lowest elevations, and western hemlock *(Tsuga heterophylla)* the highest. Among hardwoods, Pacific crabapple (*Malus fusca*), willow (*Salix* spp.) and birch *(Betula papyrifera)* grew in lower elevations, black cottonwood *(Populus trichocarpa)* in moderate elevations, and alder at all elevations. In the delta, red alder was the most common-streamside tree, but Sitka spruce the only large-diameter tree and by far the dominant conifer by basal area. Small willow, crabapple, and alder dominated scrub-shrub estuarine wetlands, with Sitka spruce the only large tree; riverine-tidal wetland forests were similar, with addition of western redcedar. Black cottonwood joined Sitka spruce as the most common large-diameter streamside trees immediately adjacent to the lower Nooksack, with western redcedar being the largest tree more distant from the riverbanks. In the upper Nooksack and forks, alder was the most common and cedar the largest streamside tree. Douglas fir *(Pseudotsuga menziesii)* and cedar were the largest trees in the red-alder-dominated forest distant from the river.

Wood jams were historically abundant and had a variety of geomorphic and habitat functions in the Nooksack. The GLO bearing tree data indicate species that would have contributed very large wood that could potentially function as key pieces in jams. Sitka spruce was the sole source on the delta; black cottonwood would have augmented spruce in the lower Nooksack; in the upper Nooksack cedar would have been the most common, and secondarily spruce, fir, and cottonwood. In the forks, primarily cedar and fir and secondarily cottonwood and maple would have commonly provided very large wood.

The Nooksack valley's forests and wetlands were transformed within the first few decades of Euro-American settlement. Most of the native forest had been burned or logged by the beginning of the 20th century, and most wetlands, especially estuarine and riverine-tidal wetlands formerly extensive on the Lummi River delta, and historically extensive palustrine wetlands in the lower mainstem, had been diked and ditched. In the delta and lower mainstem, these burned or logged lands were almost entirely converted to agriculture by 1938, while in the upper mainstem and forks, some of this burned or logged land was converted to agriculture and the remainder returned to forest.

Early in the 20th century, dikes closed off deltaic distributary and blind-tidal channels from water influx, eliminating substantial estuarine channel habitat from the Lummi River delta. In the lower mainstem, meanders were cut off, diminishing the Nooksack River's length, and tributary creeks were ditched. Between ~1880 and the 1930s, the upper mainstem and much of the forks changed from an anastomosing channel to a much wider, braided channel, with extensive gravel bars. The channel in most cases has narrowed since, although remaining wider than in ~1880; in the North Fork and Middle Fork the widening trend has continued throughout the period of record.

Quantitative estimates of summer- and winter-inundation of wetlands made primarily from GLO field notes for ~1880 conditions indicate that winter-inundated freshwater wetland historically exceeded the total freshwater bankfull channel area and summer-inundated area was nearly as great as bankfull channel area. Comparing ~1880.and 1998 mapping indicate that winter inundated freshwater wetland in 1998 was about 5% of that in ~1880, and summer inundated freshwater wetland was about 1% that of the ~1880 estimate. The extent of tidally inundated estuarine wetland in 1998 was about 30% that in 1880; this reflects substantial loss in estuarine wetland on the Lummi River delta from diking, but also substantial increase in wetland area on the Nooksack River delta from deltaic progradation.

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SCOPE

This report and accompanying Geographic Information System (GIS) data describe historical channels, wetlands, and riparian forests associated with the Nooksack River valley from the mouth to RM 56 on the North Fork, to South Fork RM 16, and Middle Fork RM 5 (Figure 1). This description was undertaken to characterize salmonid physical habitat in the river and valley floor at the time of early Euro-American settlement and at subsequent times. The purpose of this assessment is to assist the Nooksack Indian Tribe and its partners in identifying and prioritizing protection and restoration actions.

The study maps and describes channels, water bodies, and wetlands in ~1880, ~1910, 1938, and 1998 and makes inferences about processes in the historical riverine landscape. This provides a broad context for habitat restoration planning and a foundation for more site-specific planning, including to direct efforts to maintain or restore floodplain features and their connection with the river. The study also develops estimates of the areas and lengths of channel and wetland habitat units, useful for quantifying historical changes to aquatic habitat. It also maps and describes the pre-settlement forest, including the sizes, distributions, and factors influencing locations of tree species, information useful for planning riverine forest restoration.

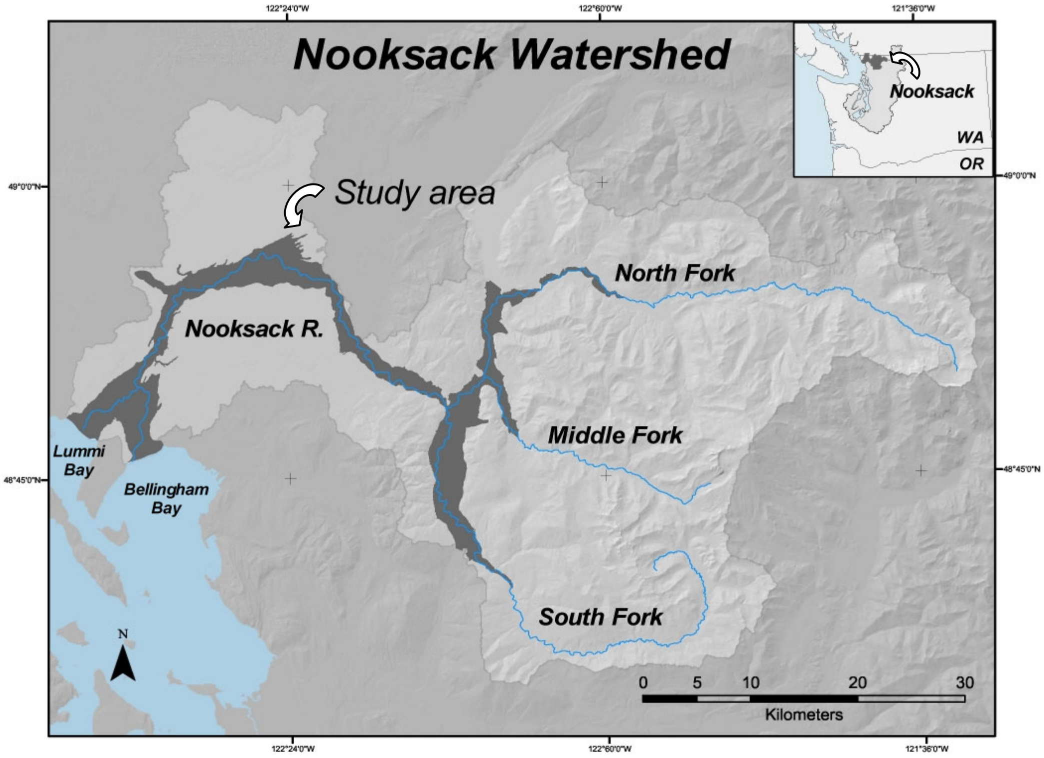


Figure 1. Location of the Nooksack River watershed in northern Puget Sound, Washington. The portion of the Nooksack River valley that comprises the study area is shown by a darker pattern.

GEOLOGIC AND TOPOGRAPHIC INFLUENCES ON THE STUDY AREA

We delineated the valley bottom, and valley bottom landforms (e.g. floodplain, terraces, alluvial fans, and large landslides) using a combination of published geological mapping (Easterbrook 1976; Dragovich et al. 1997; Lapen 2000) and analysis of elevations from a DEM created from Whatcom County Public Works elevation data. For analysis purposes we divided the study area into six segments (Table 1 and Figure 2). The upper limit of mapping in the South Fork and Middle Fork was dictated by the diminished utility of historical materials in narrow, mountainous river valleys. The geological history shapes the river bottom morphology and landforms in these different segments, as described below.

Nooksack Delta (RM 0-RM6). The greater Nooksack River delta includes the historic Lummi River and the Nooksack River. At the time of earliest British and Euro-American exploration and Euro-American settlement, the Lummi River channel was the dominant distributary channel; this is shown on early Boundary Survey maps, and discussed by early U. S. Coast & Geodetic Survey (USC&GS) surveyors (Gilbert 1887) and early investigations by the U. S. Army Engineers (Habersham 1880; Ogden 1894). Over the course of the delta's development, substantial amounts of water and sediment would have flowed to both sides of the delta. The outer limit of tidal marsh on the Nooksack River delta has prograded (built seaward) roughly 2 km between the first detailed (USC&GS) map in 1887 (see Table 2) and 1998. In the early 20th century, the Nooksack avulsed from one distributary to another several times, in some cases assisted by settlers (Deardorff 1992). The Nooksack River has been partially diked beginning in the 1920s (Deardorff 1992). The lower delta (RM 0-RM2) includes the avulsing distributary channels, and the upper delta (RM 2-RM 6, at the I-5 bridge near Ferndale) lacked distributary channels other than the Lummi River.

Lower Nooksack (RM 6-RM 20). The lower Nooksack valley (upstream of Ferndale and downstream of Everson) is broad, ranging in width between 0.7 and 4.5 km (Figure 3), and is inset within gently rolling hills underlain by glacial sediments. This broad, gently sloping valley (Figure 4) presumably resulted from runoff from the lobe of the Cordilleran ice sheet that entered the lower Nooksack through the Sumas River valley (Dragovich et al. 1997). The channel gradient increases from about 0.0005 to 0.001, as part of a gradual increase from the river's mouth to the upper end of the study area in the North Fork (Figure 5). Riverbanks and natural levees are higher than the surrounding floodplain, which drops in elevation with distance from the channel, typically by 3-4 m below the riverbanks (Figure 5a; the profiles in Figure 5 were made by sampling a DEM made from data provided by Whatcom County Public Works, at 2.5-m intervals). Levees were built along the lower Nooksack, beginning primarily in the 1930s. Levees are not widespread elsewhere in the study area outside of the delta or lower Nooksack. The lower part of the Lower Nooksack (RM 6-RM15) is slightly sinuous and historically has migrated very slowly (~1.5 m/yr; Figure 7). An upper part (RM 15-RM 20) migrated slightly more rapidly (~4 m/yr; Figure 7) and had a meander belt several times the channel width (Figure 8a) but only a small fraction of the valley width (Figure 8b).

Upper Nooksack (RM 24-RM 37). Upstream of Everson and downstream of the forks, the valley is steeper and narrower than the lower river (Figure 4), ranging in width between 0.3 and 2.3 km. The cross-valley profile contrasts to that of the lower Nooksack (Figure 6b); elevation differences of 3-4 m on the valley bottom are associated with current or former channels, sloughs, and forested islands. Based on ongoing work in Puget Sound river valleys, we assume the difference between the lower and upper Nooksack reflect their contrasting Holocene aggradational and degradational regimes, respectively. The uppermost four river miles of the Lower Nooksack (RM 20-RM 24) are transitional between the upper and lower river, in channel dynamics (Figure 7) and channel and valley morphologies. The lower part of the Upper Nooksack (RM 24-RM 31) historically has had high migration rates (~13 m/yr; Figure 7) and a wide historic channel occupation zone (Figure 8). The upper part (RM 31-RM 37) has had somewhat lower migration rates and an occupation zone somewhat narrower than the lower segment, but still in sharp contrast in morphology and dynamics with the lower Nooksack.

South Fork Nooksack (SF RM 0-SF RM 16). The South Fork valley is nearly as wide as, but steeper than, the valley of the lower Nooksack River (Figure 4). The large landslide from Slide Mountain, likely late Holocene in age (Dragovich et al. 1997), constricts the width of the South Fork floodplain (i.e., the valley bottom exclusive of terraces, alluvial fans, and landslide deposits) to about 0.5 km immediately above the confluence with the North Fork. Upstream the floodplain widens to about 2.5 km. The floodplain cross-section varies systematically with distance along the valley. In the first few miles above the Slide Mountain landslide deposit, the river channel is higher than the floodplain by about a 1 m at RM 2.7, by about 0.5 m at RM 4.6, and roughly at the same height as the floodplain by RM 6.8 (Figure 6c). It is possible that this reflects the constricting effect of the Slide Mountain landslide, which could have induced deposition along the channel. That the floodplain to the east of the river in this northern part of the South Fork is lower than the riverbanks partially explains the existence of historically extensive wetlands in the Black Slough area. The upper South Fork valley steepens, between about Acme and Saxon Bridge, and the floodplain's cross-section reflects the "corrugated" topography apparent in the upper Nooksack. Above Saxon Bridge the valley narrows to about 400 m and is constrained by valley walls.

North Fork Nooksack (RM 37-RM 58). The valley and channel gradients (Figures 4 and 5, respectively) continue to steadily increase from the upper Nooksack through the North Fork Nooksack. The valleybottom is narrower than the upper Nooksack, on average (Figure 2), but the floodplain width varies considerably along the North Fork (Figure 3). The floodplain is widest (about 1,200 m) in the approximately three-river-mile-long segment downstream of the Middle Fork confluence. Upstream of the Middle Fork confluence, a large Holocene landslide at about RM 44 on the North Fork, similar in size and age to the landslide on the South Fork (see Dragovich et al. 1997), blocked the North Fork valley and now narrows it to only 70 m at the narrowest spot (at approximately RM 43.6). Upstream of this landslide constriction and to about RM 52 the floodplain alluvial and glacio-fluvial terraces narrow the floodplain (Figure 2). Upstream, mountain slopes largely confine the valley. The North Fork channel braids, which presumably reflects the large amounts of coarse sediment the river carries. Similar to the historic transition in the upper Nooksack, the river pattern appears to have changed from a more branching pattern in the earliest map records to its current braided pattern.

E. T. Coleman, in an 1869 report of his expedition to climb Mt. Baker, described the contrast between the North and South forks:

> "The south fork, which emerges from a sequestered leafy nook, looked very tempting. Its waters are gentle and limpid until they mingle with the turbulent main stream, and were suggestive of the peaceful current of youth before entering upon the toils and trials of manhood." (Coleman 1869)

The contrast Coleman noted is probably in part a result of the larger glacial sediment load of the North Fork compared to the South Fork, and probably also because of its steeper gradient (Figure 5). The floodplain profile of the North Fork Nooksack (Figure 6d) reflects the river's braided pattern.

Middle Fork Nooksack (MF RM 0-MF RM 5). The Middle Fork is the steepest and narrowest of the study area's river valleys (Figure 4), the channel gradient is steeper than other channel segments, and the channel gradient undergoes a rapid decline (Figure 5). Low terraces of lahar sediments (Lapen 2000) restrict the floodplain in the lower three river miles (Figure 2). Currently the Middle Fork is substantially wider than shown on earlier map records, and has a primarily braided pattern.

Table 1. Analysis segments used in this study. River miles are continuous along the Nooksack and North Fork Nooksack rivers; separate river mile systems exist on the South Fork and Middle Fork rivers.

RIVER MILE (RM)	SEGMENT	LOCATION
RM0 –RM6	Delta	Mouth to I-5 bridge below Ferndale
RM 0—RM 2	Delta 1 (DL1)	Mouth to Smuggler Slough
RM 2—RM 6	Delta 2 (DL2)	Smuggler Slough to I-5 bridge
RM6 –RM24	Lower Nooksack	Ferndale to Everson
RM 6—RM 15	Lower Nooksack 1 (LN1)	I-5 bridge at Ferndale to Guide Meridian Road bridge
RM 15—RM 20	Lower Nooksack 2 (LN2)	Guide Meridian Road bridge to RM 20.4 (relative to RM marks printed on USGS topographic map)
RM 20—RM 24	Middle Nooksack (MN)	RM 20.4 to Everson (HWY 544 bridge)
RM24 –RM37	Upper Nooksack	Everson to Deming
RM 24—RM 31	Upper Nooksack 1 (UN1)	Everson (HWY 544 bridge) to Nugent’s Corner (HWY 9 bridge)
RM 31—RM 37	Upper Nooksack 2 (UN2)	Nugent’s Corner (HWY 9 bridge) to Confluence
RM37—RM56	North Fork	Confluence to Canyon Creek
RM 31—RM 40	North Fork 1 (NF1)	South Fork confluence to Middle Fork confluence
RM 40—RM 58	North Fork 2 (NF2)	Middle Fork confluence to Glacier
MF RM0—MF RM5	Middle Fork	Confluence to Mosquito Lake Rd. Bridge
SF RM0—SF RM16	Lower South Fork	Confluence to Dyes Canyon
SF RM 0—SF RM 13	South Fork 1 (SF1)	Confluence to near Saxon bridge
SF RM 13—SF RM16	South Fork 2 (SF2)	Saxon Bridge to near County line

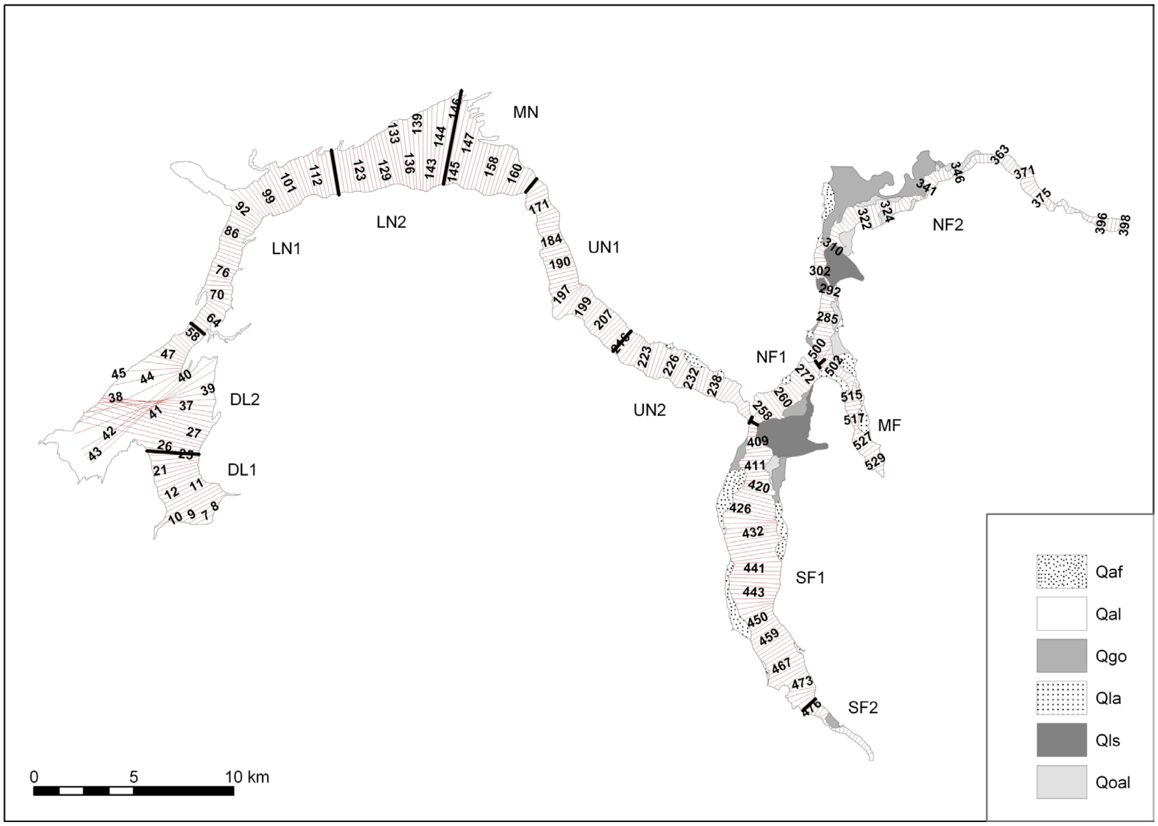


Figure 2. Geology of the study area, location of floodplain transects (numbered), and end points of study segments (Table 1), marked by cross marks. Qal = floodplain; Qaf = alluvial fan; Qgo = glacial outwash terrace (in North and South Forks of the Nooksack); Qla = lahar terrace (in Middle Fork Nooksack River valley); Qls = large Holocene landslide deposits (in North Fork and lower South Fork river valleys); Qoal = Holocene fluvial terraces. Transect numbers are referred to in Figures 3, 7 and 8.

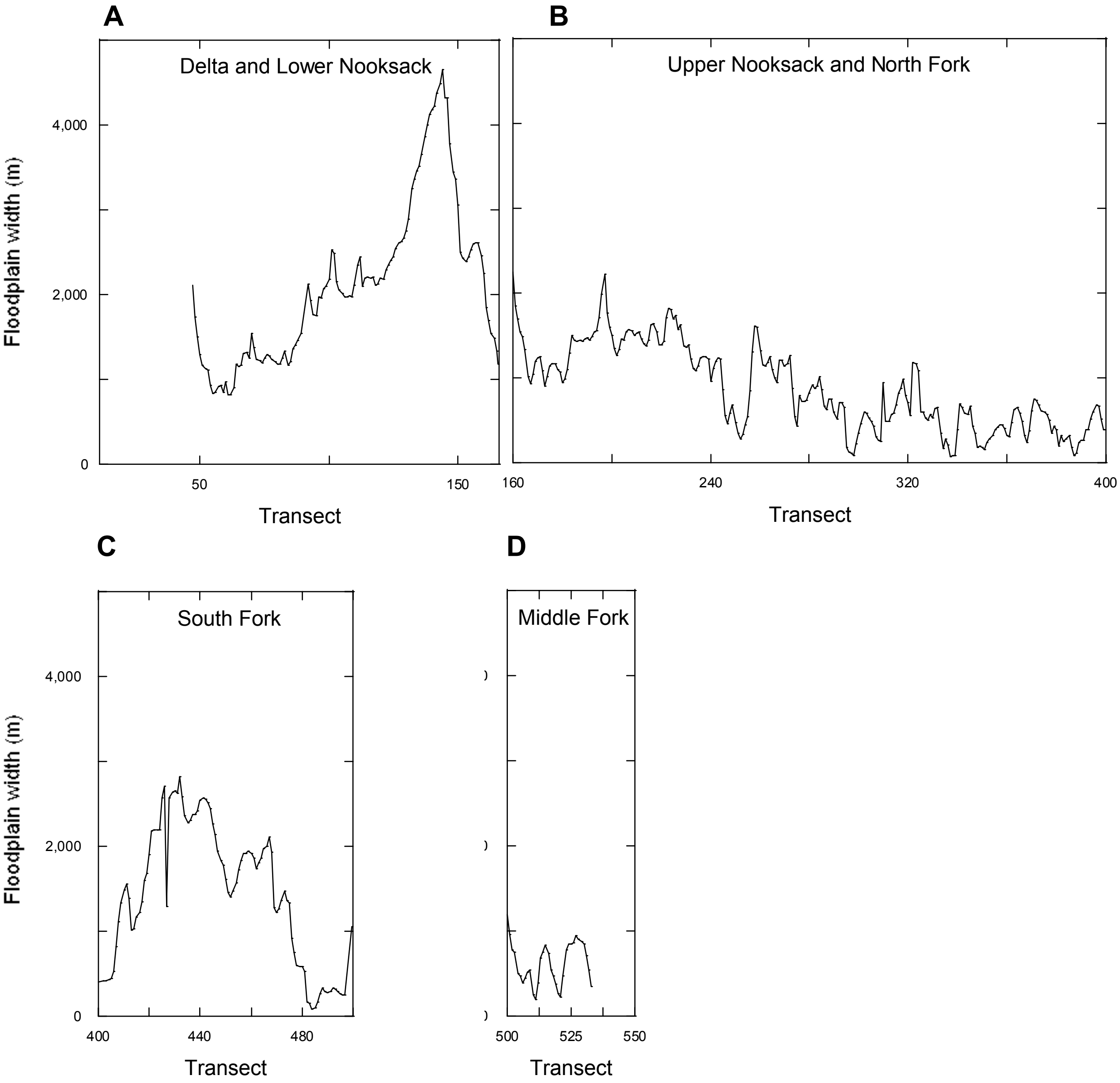


Figure 3. Floodplain width, in meters. Transect numbers refer to Figure 2. Scale of vertical and horizontal axes is the same in each panel. Transects 5-46 on delta (see Figure 2) have been excluded.

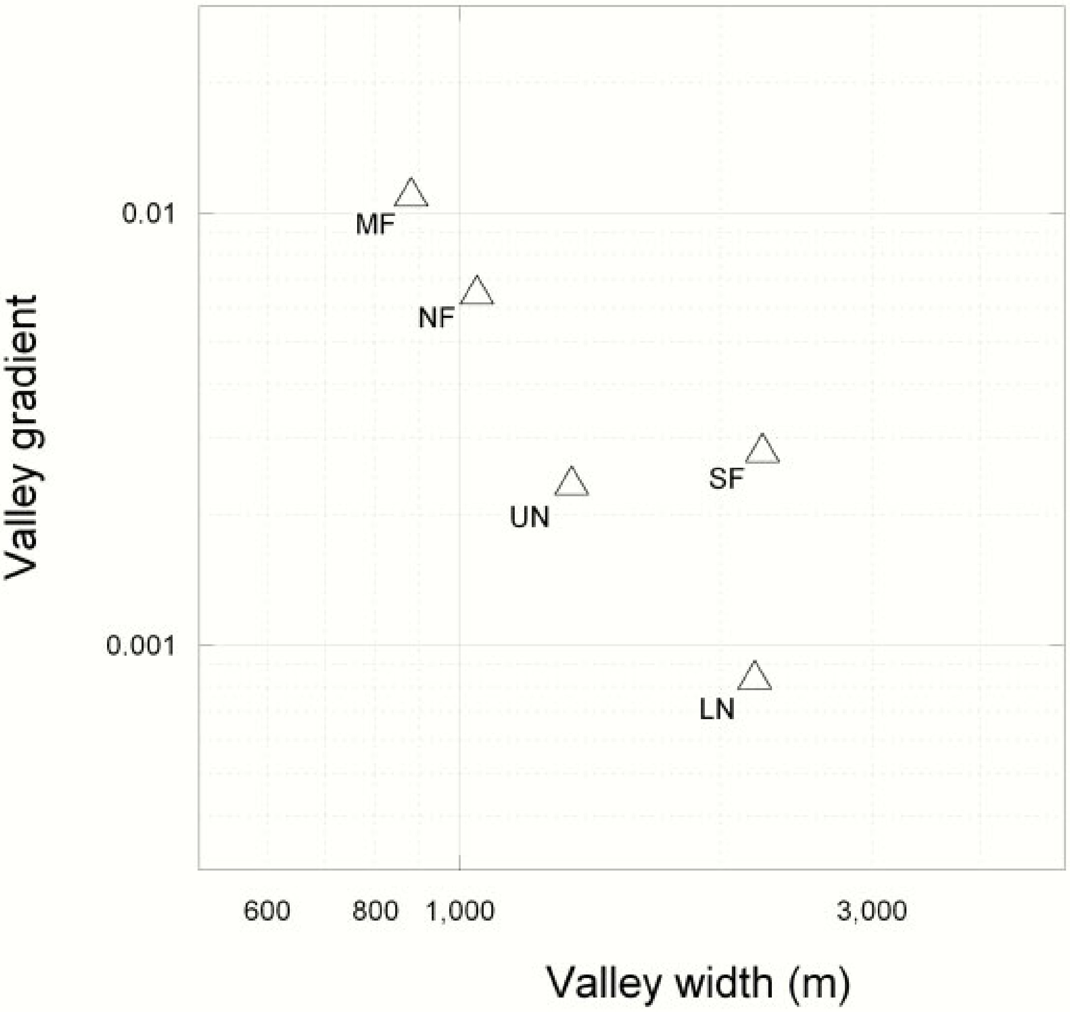


Figure 4. Valley width and valley gradient for the lower Nooksack (NL), Upper Nooksack (UN), South Fork (SF), North Fork (NF), and Middle Fork (MF) valleys. The valley width used in this figure includes the floodplain, terraces, and alluvial fans. Two large Holocene landslides in the North Fork Nooksack (Figure 2) are not included as part of the valley width.

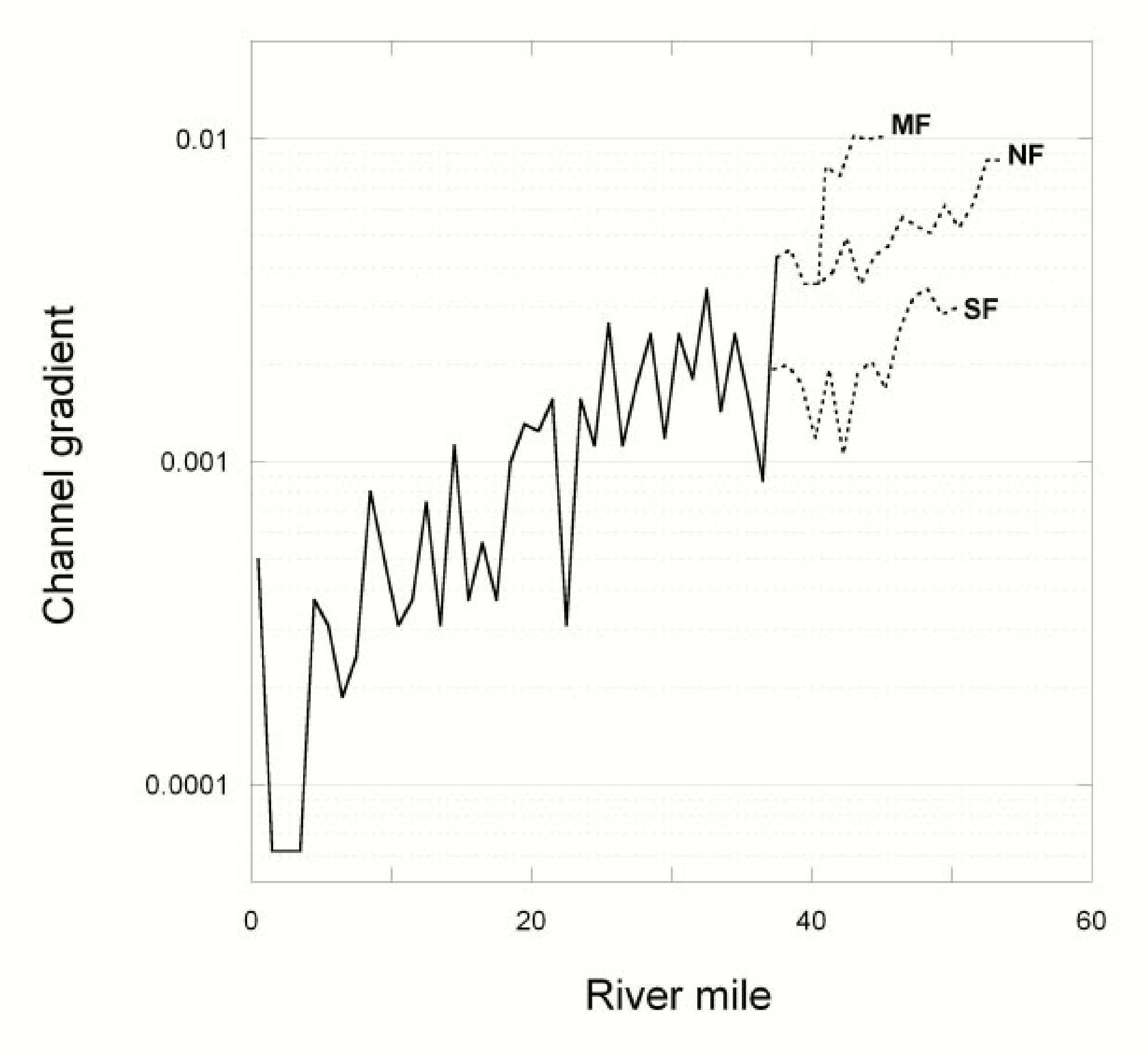


Figure 5. Average channel gradient, measured relative to River Mile marks on USGS 1:24,000 scale topographic maps, and elevations measured at 0.5 mile intervals from DEM described elsewhere in report.

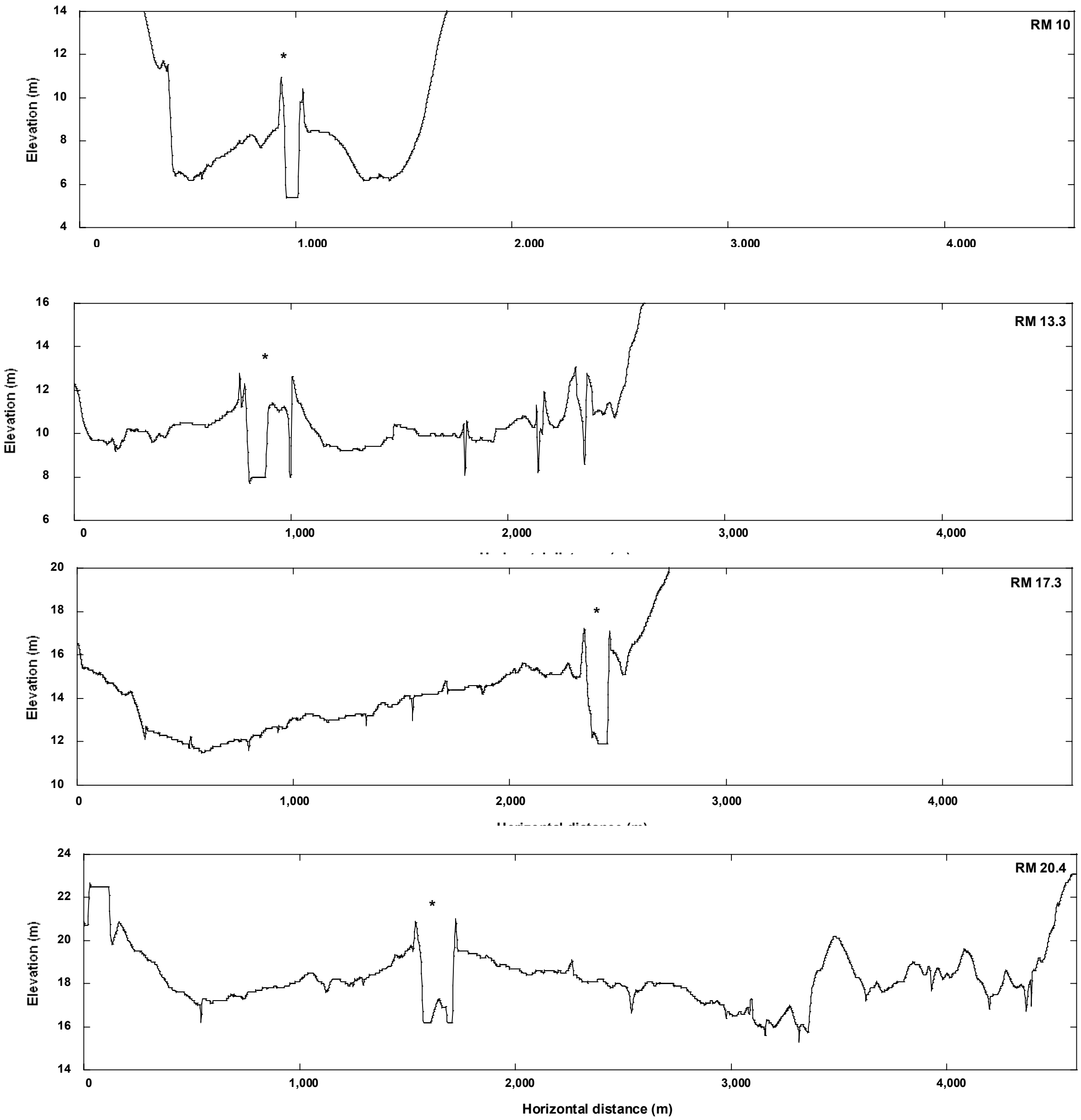


Figure 6a. Representative valley cross sections in the lower Nooksack River mainstem (RM6—RM24). Cross sections were created by sampling 2.5-m-cell size DEM created from 1993 photogrammetric data. “*” = Nooksack River; “+” = road. Vertical exaggeration = 100x.

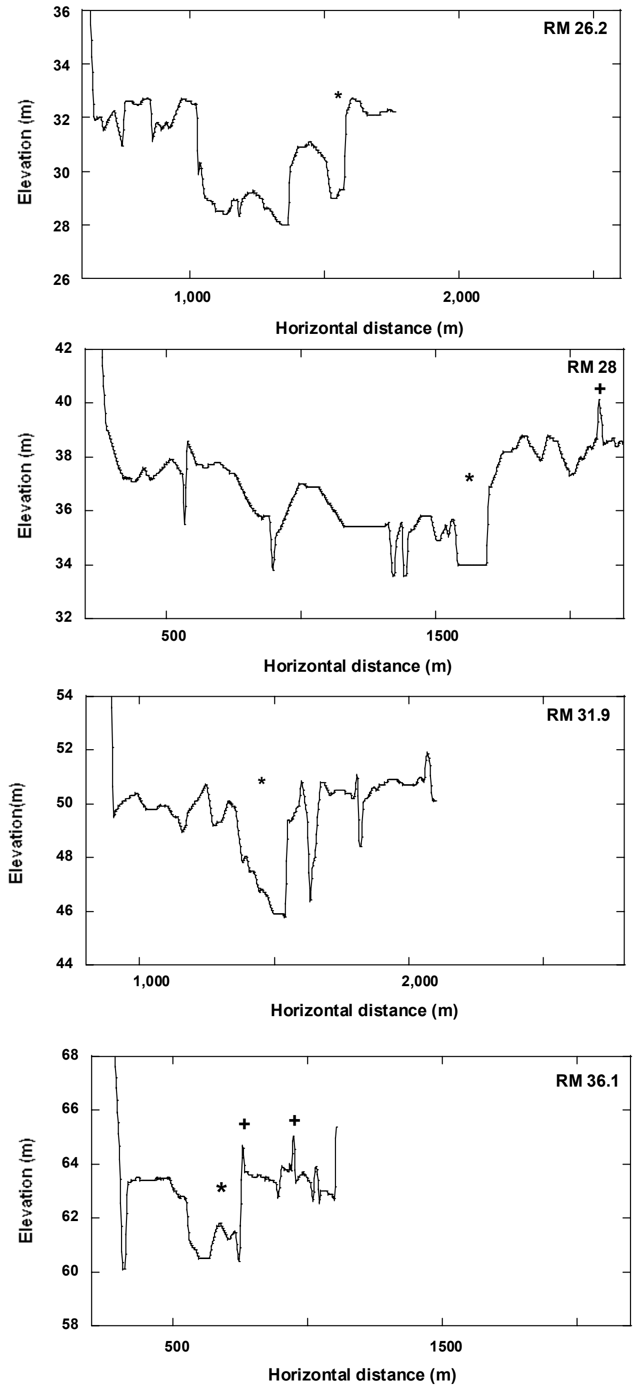


Figure 6b. Representative valley cross sections in the upper Nooksack River mainstem (RM24—RM37). Cross sections were created by sampling 2.5-m-cell size DEM created from 1993 photogrammetric data. "*" = Nooksack River; "+" = road. Vertical exaggeration = 100x.

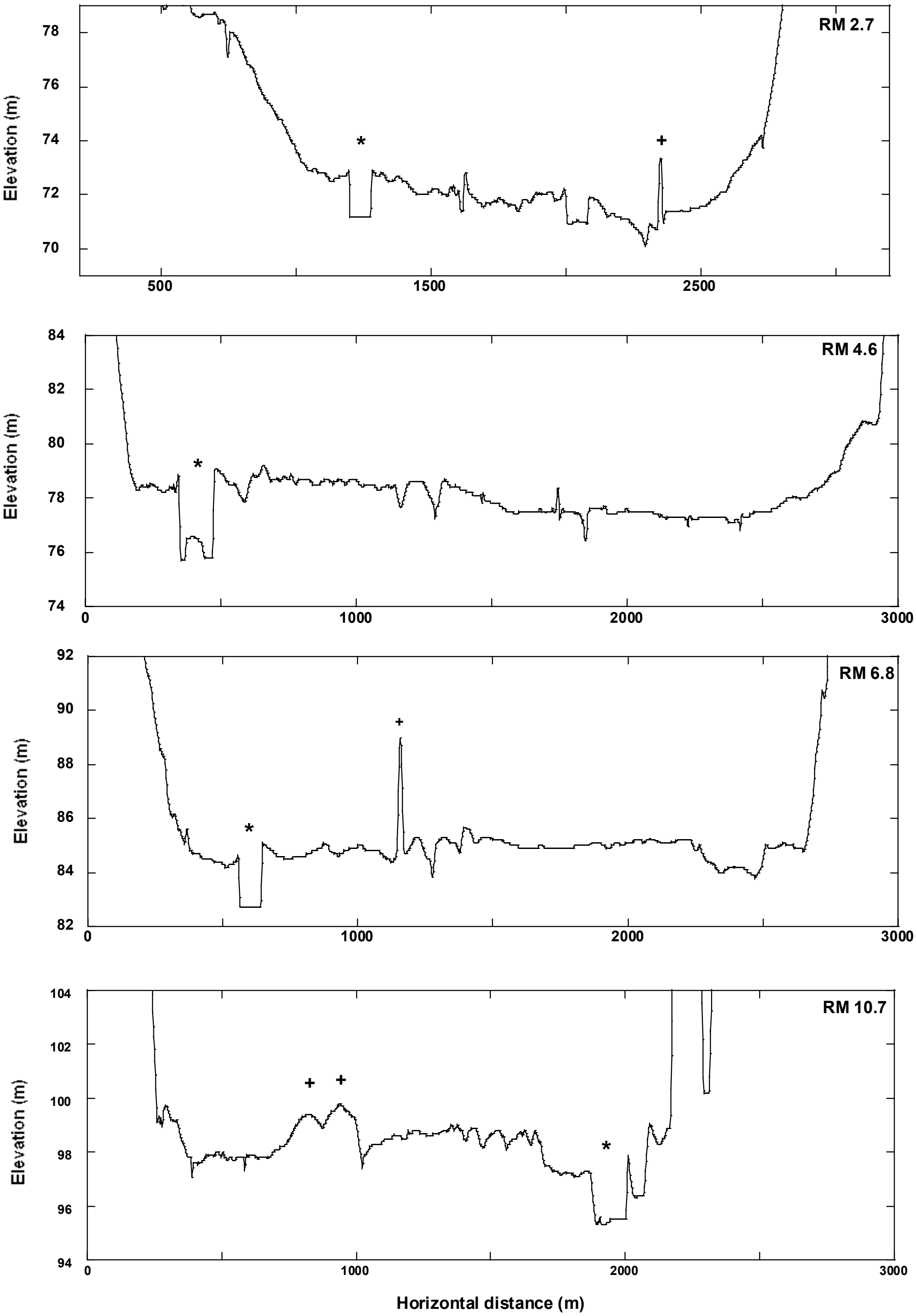


Figure 6c. Representative valley cross sections in the South Fork Nooksack River. Cross sections were created by sampling 2.5-m-cell size DEM created from 1993 photogrammetric data. "*" = Nooksack River; "+" = road or railroad. Vertical exaggeration = 100x.

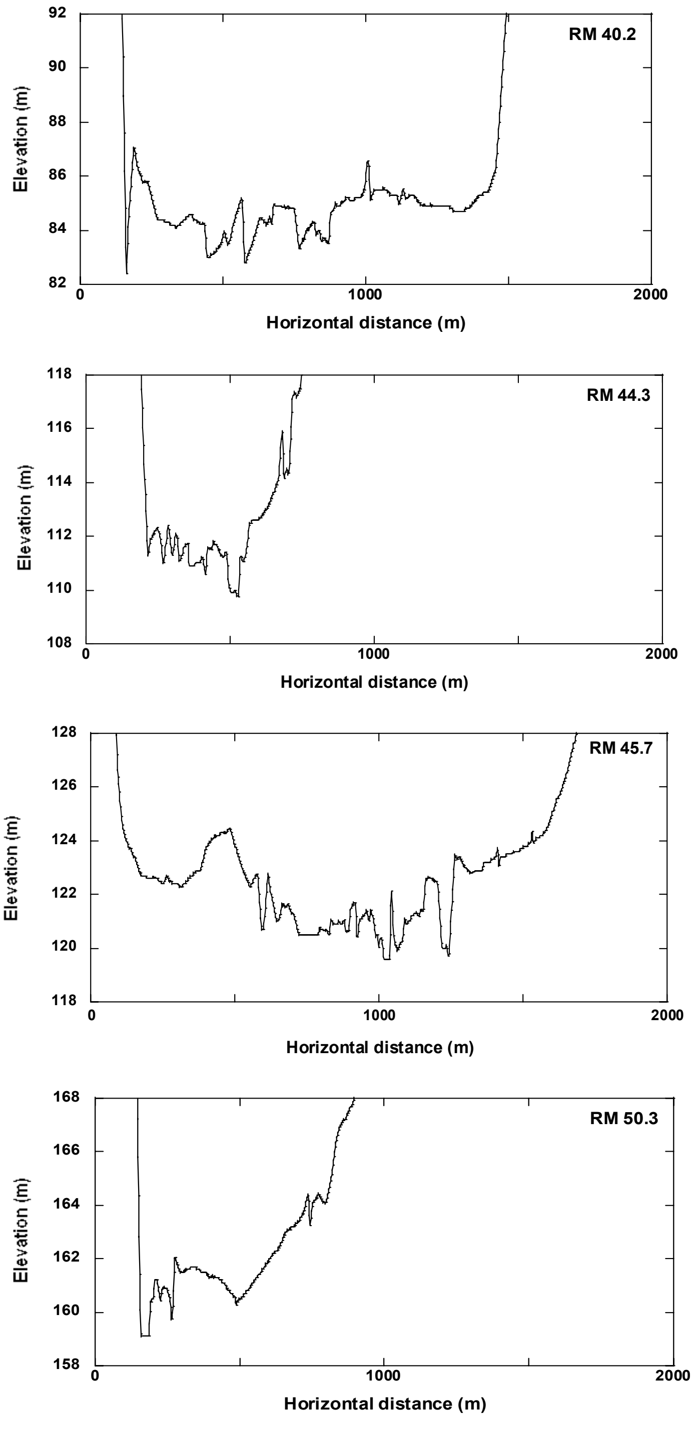


Figure 6d. Representative valley cross sections in the North Fork Nooksack River. Cross sections were created by sampling 2.5-m-cell size DEM created from 1993 photogrammetric data. "*" = Nooksack River; "+" = road or railroad. Vertical exaggeration = 100x.

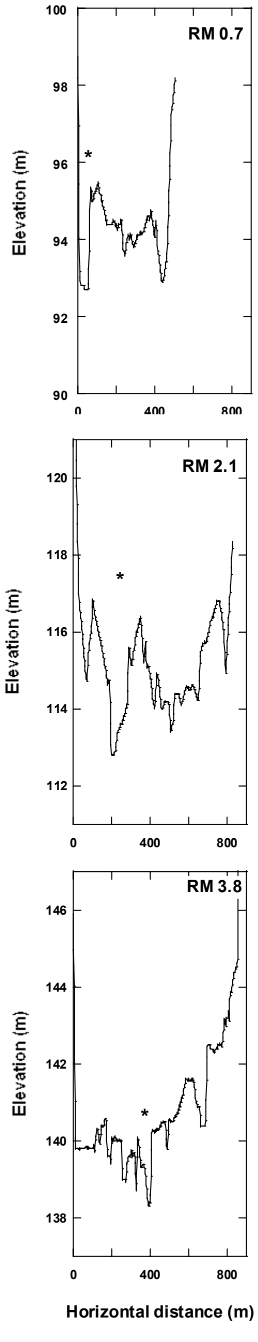


Figure 6e. Representative valley cross sections in the Middle Fork Nooksack River. Cross sections were created by sampling 2.5-m-cell size DEM created from 1993 photogrammetric data. "*" = Nooksack River; "+" = road or railroad. Vertical exaggeration = 100x.

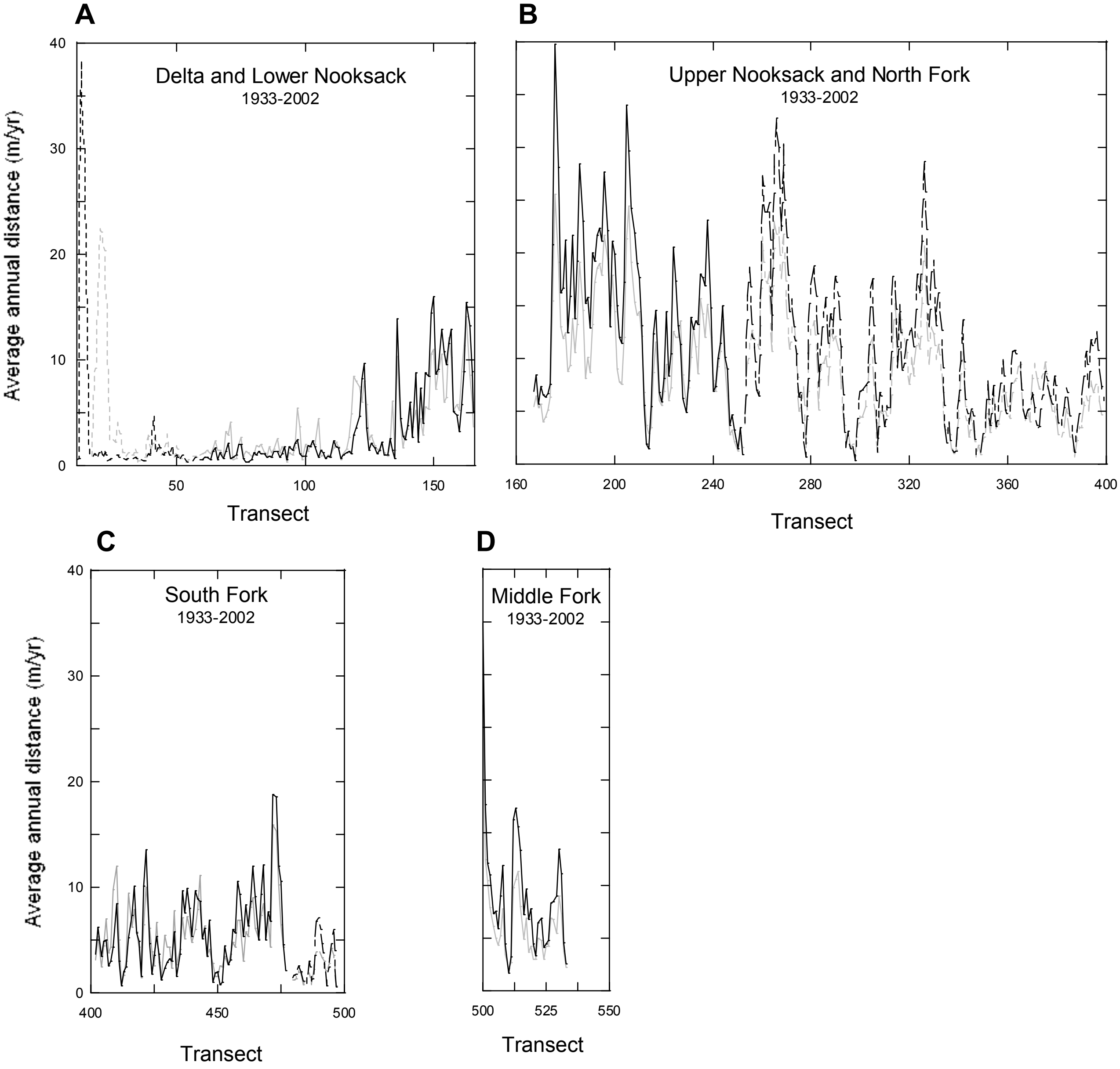


Figure 7. Weighted average annual distance moved by channel centerline since 1933 (average for entire period of record, including the GLO plat maps and early topographic maps, is shown with gray line), in (A) Delta (dashed line) and lower Nooksack (solid line), (B) Upper Nooksack (solid line) and North Fork (dashed line), (C) South Fork (solid line) and upper South Fork (dashed line), and (D) Middle Fork. Scale of vertical and horizontal axes is the same in each panel. See Collins and Sheikh (2004a) for detail on methods used to develop data.

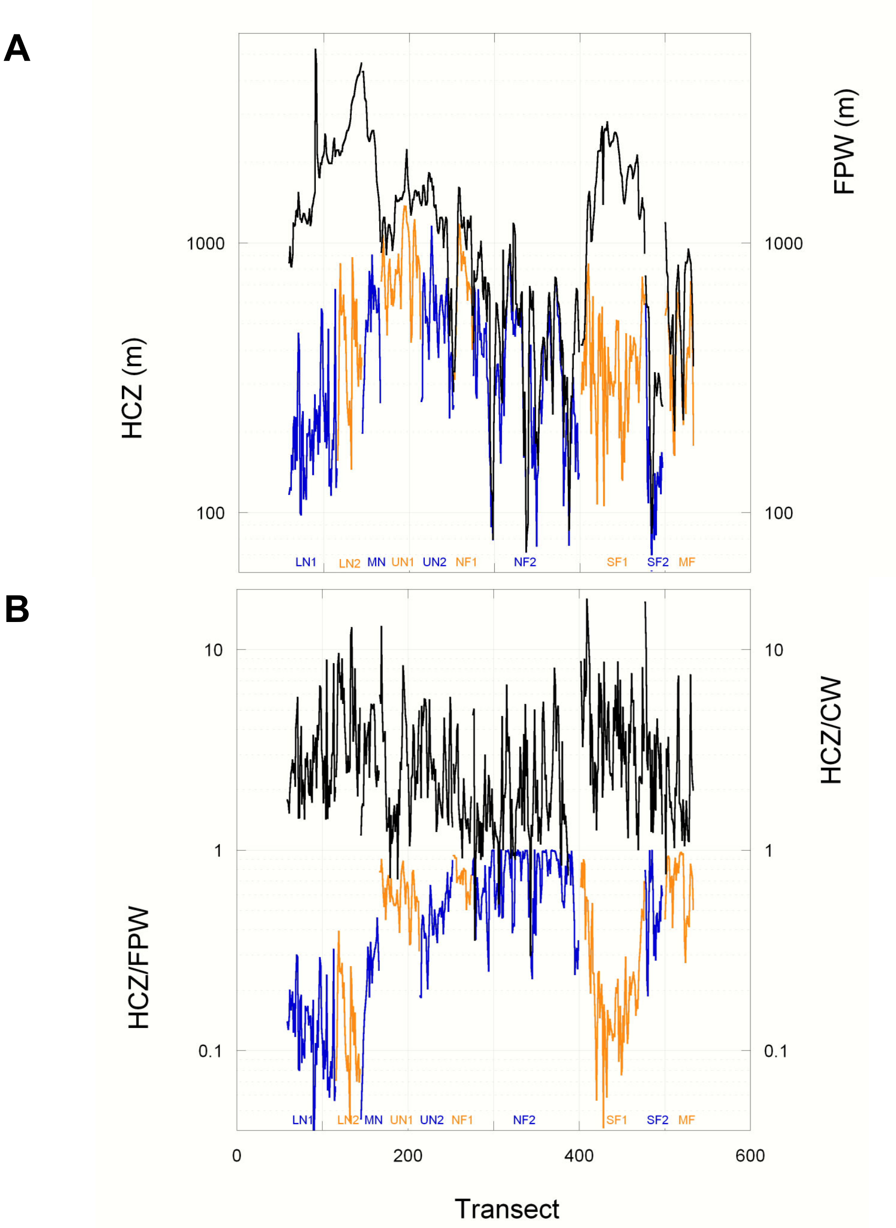


Figure 8. A: Floodplain width (upper, black line), and width of the historical channel zone (bottom line; segments are distinguished by alternating color), measured along transects, in meters. B: Ratio of the historical channel zone width to the floodplain width (upper, black line), and ratio of the historical channel zone width to the width of the active channel in 1998. The historical channel zone width includes channel positions for the period of record (1872-2002). Delta transects are excluded from both figures. See Collins and Sheikh (2004a) for detail on methods used to develop data.

METHODS

Data Sources

The historical interpretations in this report are based on a number of archival and modern sources. The most important of these are described below.

General Land Office Maps and Field Notes. Cadastral survey maps and field notes from the General Land Office (GLO) in the study area span the years 1859 to 1897 (Table 2). We obtained the survey maps and field notes, and integrated the maps into a GIS by georeferencing corners and quarter corners to current Washington Department of Natural Resources (WDNR) data.

The field notes and maps drawn from them reflect the directions given to surveyors. 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 (nor consistently transferred to the plat maps), it is important descriptive data, particularly for wetlands. For example, we use the date when surveyors observed water depths, and their notes on indicators of seasonal water depths, to characterize summer and winter water depths in wetlands. Limitations in using these data for reconstructing historical riverine environments are discussed in the next subsection of this chapter.

We also make 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. 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. (“Meandering” was the procedure by which land surveyors mapped navigable channels, by measuring distances and bearings along both streambanks.) 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.” Data reliability and bias are discussed in the following subsection of this chapter.

Coast Survey Charts. The US Coast & Geodetic Survey (USC&GS) published charts of estuarine areas of the greater Nooksack delta in the late 1880s. We made use of USC&GS sheets T-1871 (1888) and T-1798 (1887). Map patterns distinguish saltmarsh and freshwater marsh. Limited tideland diking had occurred by the time charts were made in the Nooksack delta area. We also referred to descriptive reports that accompany the T-sheets.

Annual Reports of the Army Engineers. The Army Corps of Engineers began investigating Puget Lowland rivers in 1874, and reached the Nooksack River in 1880. Subsequent to the reports of these initial investigations were annual reports of the Army’s snagboat operations, deployed to maintain the Nooksack and other Puget Sound rivers for commerce. The early descriptions, as well as the annual reports on the snagboat’s operations provide important information on early river conditions, including relating to in-channel wood.

Aerial Photographs and Digital Elevation Models. For the study area we made a 2.5-m DEM from elevations from photogrammetry provided by Whatcom County. We also orthorectified 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 also made use of 1998 USGS digital orthophotos.

Geologic, Topographic, and Soils Mapping. 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, NWI wetland inventory, and peat deposits mapped by Rigg (1958) in our wetland mapping. For ~1910 and 1938 coverages, we used the 1938 photos, USGS 15' topographic maps Van Zandt 1918, Sumas 1906, Blaine 1907, Wickersham 1918, and land use mapping by Mangum et al. (1909).

Methods, Assumptions, and Certainty in Mapping ~1880 Conditions

Our approach to using historical materials, and assumptions involved in doing so, differ for each type of map feature in the channel and land cover layer. In the GIS coverages we coded each feature to indicate the sources we used to draw the feature, the logic with which we used those sources, and an assessment of the relative certainty (or strength of evidence) we had in mapping the feature. Table 3 generalizes our approach to characterizing certainty. The following text and the GIS coverage metadata provide more detail.

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. This contrasts with small channels, which have not been meandered, and are accurately located only where they intersect section lines (see discussion of small channels below).

We interpret channel widths in the GLO survey to be from bank to bank. Some earlier workers making use of channel widths from GLO notes had concluded that GLO channel widths referred to the channel's wetted width (e.g., Knox 1977). We think widths in the Puget Sound region refer to bankfull for several reasons. Instructions indicate that rivers are to be meandered along "both banks" at the "ordinary high water mark" (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). Third, 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 consistent with modern topography as shown on the DEM, 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. 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. We also made use of relict channels, no longer inundated because of sea dikes, on early aerial photographs, to modify channels drawn on USC&GS charts. 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. Finally, a few channels not shown on the earliest source materials were drawn from early topographic maps or 1930s photographs.

Surveyors did not always accurately draw the plat maps from field notes. In north Puget Sound drainages, channels on plat maps in the study area were drawn as much as 119% wider and 46% narrower than the values recorded in the field notes; these figures are derived from comparisons of the map distances and field notes where section lines cross rivers. In the Nooksack River, on average map distances were greater than field-measured distances by 11.1% (median = 4.1).

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 did not generally walk out a channel, but instead sketched it between these points of intersection. Thus, the plat maps cannot be expected to accurately show channel locations except immediately adjacent to section lines or meandered channels. In many cases, channel locations on plat maps are plainly wrong in the context of modern topographic data. Smaller channels thus generally involve the most amount of 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. We considered the certainty level 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 the channels were not crossed by section lines.

We developed similar rules for assessing the relative certainty of channels charted by the USC&GS. We gave greater weight to the existence of 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.

We assigned our mapping of small channels a relatively low certainty in one of three circumstances. These were (1) when channels were not shown on the GLO maps, but were evident as relict channels on the GLO maps (these account 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 to connect upstream channel segments having a higher certainty level.

Wetlands. Our wetland classification follows Cowardin et al. (1979). The GLO surveyors viewed the landscape not through the lens of modern wetland classification, but 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, and 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 of these terms, nor is it clear if the terms were used consistently. As a result, in describing wetlands as emergent, scrub-shrub, or forested [following Cowardin et al. (1979)] we use these descriptors as secondary to bearing trees, vegetation descriptions, USC&GS mapping, and modern data (e.g. soils mapping; wetland remnant patches visible on 1937 aerial photos). Table 4 lists some of the descriptive terms encountered in the GLO notes and the wetland types we interpret from them in association with other data.

We used several certainty ratings for the presence and boundaries of wetlands. 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 current soils mapping and are shown on early topographic maps, or extrapolate USC&GS polygons into areas adjacent to the limit of USC&GS mapping. These are given a "moderate" certainty rating. Some other extrapolations lack confirmation on early topographic maps and have ambiguous indications in GLO notes, but have equivocal evidence on 1938 aerial photographs or are suggested by current soils mapping, and are topographically reasonable; these are given a "low" certainty coding.

Approach and Assumptions for Estimating Wetland Inundated Area. We consider a wetland "inundated" in winter or summer if a substantial amount of the wetland was described in original source materials as inundated, or can be inferred to have been inundated, by a foot or more of water. We developed rules for estimating inundated areas that we intend to be conservative. For example, if an area is described as "swamp" or "marsh" in GLO field notes, but the notes do not record water depths, or indicators of seasonal inundation, and we lack other direct evidence, we assume the wetland was not inundated. In other words, we generally take the absence of explicit information that indicates inundation to mean the area was not inundated. Many wetlands for which we have estimated no inundated area were certainly inundated in some (small or possibly large) part, but at this time we lack a supportable rationale for estimating these areas. Wetlands for which we considered that we had a higher level of evidence rely on field observations that allow at least a semi-quantitative estimate of inundation for a given season (see Appendix A).

The information available to describe wetted area varies widely in comprehensiveness and detail among wetlands. In general, the larger a wetland, the more likely the information we used allows us to synthesize a more comprehensive and detailed description compared to smaller wetlands. As a result we can have relatively high confidence in the aggregate inundated area estimates, because the larger wetlands tend to represent most of the cumulative area. On the other hand, estimates for individual, smaller wetlands commonly draw from less information, and have a lower certainty. It is also almost certain that our GIS mapping misses a large number of small and very small wetlands, owing to the nature of the available source materials; while this is not likely to affect the aggregate quantitative estimates, it may affect the view of historical aquatic habitat characteristics at a reach- or small sub-watershed scale.

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 interested 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” level-of-evidence 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.

Forests, Scrub-shrub and Grassland. 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 those natural (non-wetland) meadow clearings in the valley forest, either within section interiors or along section lines but not noted in field notes. Those non-forested areas that can be identified are mapped as scrub-shrub or grassland, based on field descriptions in the GLO notes or on USC&GS charts. Grassland was mapped by USC&GS or GLO, respectively. We mapped “tideflat” from USC&GS T-sheets.

Approach to Quantifying Habitat Area and Edge

Tidal Creeks. Estimating the channel area within the network of tidal creeks presented a special challenge. Excepting a few of the largest tidal channels, the GLO plat maps do not map tidal channel network in detail. The USC&GS charts in other western North America regions sometimes mapped tidal creeks in great detail, for example in the San Francisco Bay estuary (Grossinger 1995) and the Columbia River estuary (based on our examination of T-sheets of that area), but we have not found that uniformly to be the case in eastern Puget Sound; small tidal channels on the Nooksack T-sheets are not inclusive of all channels, and may not always have been drawn accurately.

To work within these limitations, we identified marshes in the Skagit and Snohomish estuaries where a large amount of tidal network remains, or remained at the time of the earliest aerial photos, and in those areas we mapped the channel network from orthorectified aerial photos. We mapped a portion of the Snohomish estuary in the Ebey Slough area from 1938 aerials, and parts of the South Fork and North Fork Skagit estuary, using 2001 aerials. We used the more recent aerials for the Skagit because, while less estuarine marsh remains in 2001 compared to 1937 (when the earliest photos were taken), the 2001 imagery is high resolution and color, which aided in mapping.

Mapping channels on recent imagery makes the assumption that the overall channel density remains relatively unchanged over a number of decades. This appears to be a good assumption in areas where there was not rapid sedimentation or other anthropogenic alteration, because we have compared active tidal channel networks on photos separated by 60-70 years and found in many cases remarkably little change. However, we have not systematically tested this assumption at this time.

We mapped channels to a minimum width of about 0.6 m, which was the lower limit at which we could consistently trace out the channel and measure a width on the aerials. We have not at this time made a rigorous assessment of the proportion of the channel network that we have missed by not mapping channels narrower than about 0.6 m. However, we made a rough assessment by comparing our GIS and aerial photo mapping to the field mapping of three tidal channel networks in the Skagit estuarine emergent zone in May 1997 (Collins unpublished data). Based on this examination, it appears that the aerial photo mapping probably underestimates the total channel network, but by several percent, not by several tens of percent. However, we have not at this time rigorously examined this, and so it should be understood that the tidal channel areas we are developing for this report are low by an unknown amount. Our mapping may more significantly underestimate the channel area in the scrub-shrub wetland where channels are more likely to be obscured by vegetation.

To integrate our aerial photo and GIS mapping of recent tidal networks with the USC&GS mapping, we identified the minimum width of distributary channels that the USC&GS consistently charted, and used this to define polygons in which we measured all channels. In practice, this appears to have been a fairly robust approach, as the US&GS mapped most of the distributary and connecting channels greater than about 15 m in width, and we found few distributaries or connecting channels narrower than this within our polygons. The great majority of channels we mapped were blind channels, with a smaller number of "blind/distributary" channels (see earlier channel classification description). We then excluded from our channel area calculations the tidal channels mapped by the USC&GS within those polygons (most of which appear in our GIS coverages), because the USC&GS tidal channels were not dependably mapped. Finally, we developed average ratios of channel area to polygon area (see below), and applied these to our polygon areas to develop channel area estimates. Based on our analysis of this data (Collins and Sheikh 2003), we have made provisional estimates of the ratio between channel area and marsh polygon area of 0.08 and 0.05 for relatively stable (e.g. not rapidly prograding; we excluded the North Fork Skagit, which has been created from sedimentation in the modern era) estuarine emergent and estuarine scrub-shrub wetland, such as in the Lummi River delta historically, respectively.

We could not apply this approach to estimating historical channel area in riverine-tidal wetlands because only small patches of this habitat had survived to the 1930s photos or to the present (e.g. Otter Island in the Snohomish estuary). Moreover, there appears to have been a great deal of variability in hydrological characteristics among north Puget Sound riverine-tidal wetlands (see Figure 2 and Appendix C in Collins and Sheikh 2003). For this reason we have estimated the tidal-freshwater blind channel network area by measuring the area of tidal channel mapped primarily from channels on 1930s aerials (including relict channels) and then doubling the channel area estimated in this way. This is a conservative estimate, because the relict channel network appears to underestimate the historical network by at least a factor of two, based on comparison of estimates of estuarine emergent and estuarine scrub-shrub made from adjoining diked area and undiked areas in the Snohomish River estuary (using relict channels and extant channels, respectively). The resulting ratio for the Nooksack is 0.012, or about one-quarter as much as the channel area ratio we used for the estuarine scrub-shrub zone.

To estimate channel edge in the estuary, we used the same data from the Skagit and Snohomish described above. We summed the length of channels drawn as arcs, and the length of centerlines drawn in channels depicted as polygons. The resulting average length of channels (excluding large distributaries, as described above) in the estuarine emergent zone in the South Fork Skagit and Snohomish was about 220 m/ha centerline of distance, or 440 m/ha of edge (excluding the North Fork Skagit, as described above). The average amount of edge in scrub-shrub areas was less than in emergent marsh (about 170 m/ha centerline distance or 340 m/ha edge), but not by as much as the channel area in the scrub-shrub wetland was less than that in the emergent wetland. We used these ratios to estimate historical edge in the Nooksack estuary.

These ratios of channel area (and channel edge) to marsh area are provisional, generalized approximations. We expect they can be refined as we measure channel and marsh areas in additional tidal wetlands, which would make it possible to understand the environmental variables that account for within-region differences in marsh area, and in turn use this understanding to better predict ratios for the Nooksack and other locations where there is little remaining tidal marsh.

Using Bearing Tree Records

We made use of bearing tree records in the General Land Office field notes to characterize species frequency and basal area in different mapping units (e.g., valleybottom forest, streamside forest, palustrine wetland, etc.) and with respect to elevation and landform. Basal area [basal area is calculated as $\pi\ (D/2)^2$ where D is diameter reported in the field notes] was aggregated for all trees of a species, and expressed as a percent of the total basal area of all trees in a given mapping unit.

Surveyors used common names for vegetation, creating potential ambiguity in 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 Pacific Northwest. "Fir" in the study area field notes 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 (Table 5). Surveyors also use "balm" on occasion, which we have taken to be the same tree as "cottonwood" (Black cottonwood, *Populus trichocarpa)*.

Less commonly-noted species include "white fir" which we assume is misidentified grand fir *(Abies grandis)*; white fir does not appear in the area's modern flora and grand fir does. "Poplar" may have referred to aspen (*Populus tremuloides*), because aspen occurred in the area, and it appears unlikely that surveyors would have used "poplar" redundantly with cottonwood. We assume "bearberry" is most likely Indian plum (*Oemleria cerasiformis).* Other uncommon species having more obvious equivalents also appear in Table 5.

Bearing tree records are not necessarily reliable proxies for historical forest conditions because surveyors did not select trees randomly, but instead used instructions that included several criteria. We interpret instructions to surveyors current in the region for the early 1870s within context of earlier instructions (White 1991), as emphasizing 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. [A chain is equal to 66 feet or 20.12 m.] We evaluated how well bearing trees represent forest composition by following 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, similar to the Lummi Reservation. 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. 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. 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 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 (Collins and Montgomery 2002).

However, when counted by basal area, there is less discrepancy between the two samples. The difference between the two samples for individual species was as great as 13% but averaged 4%. This suggests preliminarily (e.g., in absence of a larger data set) that percent basal area from bearing tree records is a reasonably accurate way to characterize the historical forest.

In the study area, 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 attached as attributes to the corresponding survey 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, for spatially delineating vegetation types (see Figure 13, later in this report). This general approach has been used to delineate savannah from woodland (Nelson 1997) or prairie from forest in river bottoms (Nelson et al. 1998).

Approach to Mapping ~1910, 1938 and 1998 Conditions

Approach to Mapping 1910 and 1938 Conditions. The ~1910 coverage was taken solely from 15’ USGS topographic maps and land-use mapping by Mangum et al. (1909). Because the data is taken directly from these sources, we did not characterize certainty. The topographic maps show gravel bars east of 122 ° 15 ' but not to the west of this line. Because of this inconsistency, gravel bars do not appear in the coverage below RM 34.

The 1938 coverage was mapped from previously described 1938 photos, with two exceptions. Most of the Middle Fork lacked photo coverage and was mapped using 1944 Army photomosaics made from

1943 photographs. To map the extent of tideflats in Lummi and Bellingham bays, we used 1952 Lummi Bay 7.5' USGS quadrangle and 1952 7.5' Ferndale USGS quadrangles; this was necessary because the 1938 photos were not taken at a low-enough tide to show the full extent of tideflats. Wetlands in the 1938 coverage were generally mapped if they were visible on the aerial photographs, and if they were shown on published wetland mapping (USF&WS 2004). We included on these layers only those wetlands having natural vegetation; in other words, we excluded areas that had been converted to other land uses.

Approach to Mapping 1998 Conditions. We created the 1998 coverage from USGS digital orthophoto quarter quadrangles (DOQQs) with supplemental information taken from 2002 1:10,080 scale color photos. To map the extent of tideflats in Lummi and Bellingham bays, we used 1989 US Coast Survey Bellingham Bay sheet. We used the same convention to map wetlands as with the 1938 coverage. We made use of the digital National Wetland Inventory database to help characterize wetlands.

Estimating Wetland Inundated Area for 1998 Conditions. To approximate wetland inundation in the 1998 coverage, we made use of the inundation codes in the NWI digital data base, which are based on the U. S. Fish & Wildlife Service classification system (see Cowardin et al. 1979; Mitsch and Gosselink 2000) to roughly categorize wetlands into one of four categories intended to be consistent with those we used in our historical mapping. These are winter inundated (inundated by water through most of the winter), summer and winter inundated (inundated by water through the summer), tidally inundated (inundated by saline, brackish, or freshwater through tidal influence), and not inundated. Unlike with the historical data, we had no field observations of inundation depth to determine a minimum inundated depth. In other words, for historical conditions, we considered an area to be winter or summer inundated if it was covered by at least one foot of water, but could not create a quantitative cutoff for the 1998 data.

Specifically to determine winter and summer inundation, we grouped the general NWI inundation codes "temporarily flooded" and "seasonally flooded" as "not inundated;" we grouped "seasonally inundated, saturated," "semi-permanently flooded," and "intermittently exposed" as "winter inundated;" and "permanently flooded" as "winter and summer inundated." We then used aerial photos from summer 2002 to spot check wetlands categorized as "winter and summer inundated" to determine there was a correspondence between the inundation apparent in summer on the aerial photos, and our categorization.

Uses and Limitations of Landscape-Scale Mapping

Our GIS mapping characterizes historical landforms, hydrographic features, land cover, and how each varied along and across the valley bottom, and changed through time. It is the basis for making quantitative estimates of aquatic habitat and its change through time at a landscape scale. Cautions for interpreting these estimates are given later in the report where habitat estimates are discussed. The mapping does not have the resolution needed for site characterization, which requires more detailed study, including field investigation. In addition to the uncertainty with which some features are mapped, other features have not been mapped at all, because they fall "between the cracks" of the available sources. It is equally important to use historical reconstructions with the knowledge that what is shown has inherent inaccuracies and with the knowledge that some landscape features that existed are not shown on the mapping because the sources we have available did not capture them.

Table 2. Maps and aerial photographs used in study, 1859-1998. Source: 1 = Whatcom County Public Works; 2 = Whatcom County Conservation District; 3 = UW libraries; 4 = US Army Corps of Engineers Seattle District; 5 = Bureau of Land Management; 6 = National Archives; 7 = online.

YEAR and SOURCE	TYPE & SCALE	TITLE	AREA	PRIMARY USES	NOTES
1859-1893[5]	General Land Office plat maps 1:31,680	T38N R2E (1859) T39N R2E (1871)	RM 0-12	Channel and land cover mapping; description of land cover, hydrology and land character.	Primary source for river valleys. Maps strongest for navigable (meandered) channels. Creeks and land cover reliable near section lines only. Field notes invaluable source of descriptive information.
		T39N R2E (1871) T40N R2E (1872) T40N R3E (1872)	RM12-RM 23		
		T40N R3E (1872) T39N R4E (1884) T39N R5E (1890) T38N R5E (1885)	RM 23-37		
		T38N R5E (1885) T39N R5E (1890) T40N R5E (1891) T40N R6E (1893) T39N R6E (1897) T39N R7E (1892)	RM 37-58		
		T38N R5E (1885) T37N R5E (1885)	SFRM 0-16		
		T39N R5E (1890) T38N R5E (1885)	MFRM 0-5		
1887[6]	US Coast & Geodetic Survey T-sheet 1:10,000	USC&GS T-1798 “Topography of Rosario Strait, North Part of Bellingham Bay”	RM 0- 2	Shoreline and nearshore channels and wetlands.	Primary source for estuary. Tidal creeks drawn on maps may be schematic only; can only be confirmed as accurate where relict channels are visible on early aerial photos Other features are drawn with consistently high accuracy.
1888[6]		USC&GS T-1871 “Topography of Gulf of Georgia, Village Point to Base of Sandy Point”			

Table 2 (continued). Maps and aerial photographs used in study, 1859-1998. Source: 1 = Whatcom County Public Works; 2 = Whatcom County Conservation District; 3 = UW libraries; 4 = US Army Corps of Engineers Seattle District; 5 = Bureau of Land Management; 6 = National Archives; 7 = online.

YEAR and SOURCE	TYPE & SCALE	TITLE	AREA	PRIMARY USES	NOTES
1906^3	15’ USGS topographic 1:62,500	Blaine	RM 0-14	Channel and land cover mapping.	Supplement to GLO for historical wetlands (GLO wetlands generally mapped only along section lines).
1906^3		Sumas	RM 14-34		
1918^3		Wickersham	SF RM 5-16		
1918^3		Van Zandt	RM 34-54 MF RM 0-5 SF RM 0-5		
1909^3	US Bureau of Soils Soil survey and land use classification maps	“Reconnaissance soil survey of the eastern part of Puget Sound”	Study area	Land cover mapping	
1938^4	BW photo 1:12,000		RM 0-51 SF RM 0-13	Relict channels; wetland remnants; ponds	Supplement to GLO for: small channels (small channels on GLO plat maps are unreliable except where crossed by section line); location and character of wetland remnants; refining pond size and shape.
2002^7	National Soil Survey Geographic (SSURGO) online database	“Soil Survey Geographic (SSURGO) database for Whatcom County Area, WA”	Study area	Hydric soils as an indicator of historical wetlands	Supplement to GLO for refining boundaries of historical wetlands.
2004^7	National Wetlands Inventory		Study area	Supplemental information for mapping historical wetlands; source for current wetlands	For historical mapping, used in a few cases to extend wetland boundaries or to map small historical wetlands with a low certainty.

Table 3. 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 GIS metadata 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 4. Typical descriptors used in GLO field notes, and equivalent wetland interpretation. Examples are from Nooksack and Skagit rivers.

WETLAND TYPE	TYPICAL DESCRIPTIVE TERM OR PHRASE 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 5. Trees and shrubs recorded as witness trees in GLO field notes in the Nooksack study area, and probable common and scientific names. Trees are listed in decreasing frequency of occurrence.

FREQUENCY	NAME USED IN GLO NOTES	PROBABLE COMMON NAME	PROBABLE SPECIES
High (>40%)	Alder	Red alder	*Alnus rubra*
Medium (1%-11%)	Willow	Willow spp.	*Salix* spp.
	Vine maple	Vine maple	*Acer circinatum*
	Crabapple	Pacific crabapple	*Malus fusca*
	Cedar	Western redcedar	*Thuja plicata*
	Maple	Bigleaf maple	*Acer macrophyllum*
	Spruce	Sitka spruce	*Picea sitchensis*
	Cottonwood, balm	Black cottonwood	*Populus trichocarpa*
	Fir	Douglas-fir	*Pseudotsuga menziesii*
	Hemlock	Western hemlock	*Tsuga heterophylla*
Low (<1%)	Poplar	Quaking aspen	*Populus tremuloides*
	Chittemwood	Cascara	*Rhamnus purshiana*
	Hazel	California hazel	*Corylus cornuta californica*
	Bearberry	Indian plum	*Oemleria cerasiformis*
	Birch	Paper birch	*Betula papyrifera*
	White fir	Grand fir	*Abies grandis*
	Cherry	Bitter cherry	*Prunus emarginata*
	Dogwood	Western flowering dogwood	*Cornus nuttalli*
	Balsam fir	Fir spp.	*Abies* spp.

THE ~1880 LANDSCAPE

The following describes the landscape as we mapped it for the period of early Euro-American settlement, or approximately 1880. A quantitative summary of aquatic environments is included in a later section of the report, and detailed narrative descriptions of wetlands can be found in Appendix 1.

Deltaic Dynamics and Environments

The Lummi River in the mid-19th century began near the downstream end of a persistent jam (commonly referred to as the "Portage Jam") in the Nooksack River. Commenting about the delta immediately downstream of the Lummi-Nooksack divergence, the GLO field survey party in 1859 wrote the "whole country [is] cut up by rapid, deep sloughs," which caused it to be "impassable." One of these sloughs was mapped on the GLO map, but many more are visible as relict channels on the 1938 photos, which is the basis for their inclusion on our mapping (Figure 9). These channels may reflect the effects of floodwaters diverted by the Portage Jam.

The Boundary Survey by the United States and Great Britain produced the first reliable map of the Nooksack River delta in the mid 1850s; it shows the Lummi as a large river and the Nooksack as no more than a creek (Figure 10). General Land Office plat maps from 1859 (T38N, R2E), 1871 (T39N, R2E) and 1873 (Lummi Indian Reservation) also show the Lummi River as the dominant channel. Deardorff (1992) discusses testimony in U.S. District court indicating the entire river had emptied into Lummi Bay in 1852. It is characteristic of deltaic environments that flows switch from one distributary channel to another through time, a process that was mediated by logjams in Puget Lowland rivers. Thus it is certain that at different times in the period prior to historic documentation that the location and dominance of various distributary channels has changed through time, and that the status of distributary channels at the time of first Euro-American settlement reflects a snapshot in time

In the late 19th century, near the time of our mapping, the majority of river flow switched to the Nooksack River. In 1892 the Army Engineers' Captain Symons assigns an approximate date to the flow change from the Lummi to the Nooksack channel, and indicates a cause:

> "Until about fifty years ago the Nooksack flowed out into Lummi Bay [through the Lummi River]...the present outlet [to Bellingham Bay] did not exist or was insignificant. A big jam of timber was formed in the river just below the junction, and forced the river to open its present channel, which has remained open ever since. The former outlet is now entirely closed." (Symons 1892)

The report of Assistant Engineer Robert Habersham, writing for the Army Engineers, also suggests that a natural drift accumulation closed the Lummi River:

> "The…[Lummi River] was closed 20 years ago by a raft of drift-wood, 4 miles above its outlet, which turned the entire volume of water into the [Nooksack River]…." (Habersham 1880)

A federal surveyor who was present at the time of the diversion provides an alternate explanation. In the early 1880s the Army began a river improvement program in Puget Sound that focused on clearing wood jams and snags from rivers' navigable portions. The Army's snagboat first reported working in the Nooksack River in September-December, 1886 (Chief of Engineers 1887). The same year, the U. S. Coast & Geodetic Survey was charting the Sound's nearshore waters and coastlines, having made small-scale reconnaissance maps in Puget Sound in the 1850s and 1860s, and larger scale, more detailed maps in the 1870s-1890s. Surveyors filed "Descriptive Reports" with their completed maps, describing the map area's physical and cultural features. Coast & Geodetic Survey Assistant J. J. Gilbert filed his map and report for the lower Nooksack River in 1887, and is likely to have been on the lower Nooksack River when the Engineers' snagboat worked there in 1886. Gilbert confirms the Lummi River was much larger than the Nooksack until the middle of the 19th century. But Gilbert makes an observation that Captain Symons omitted from his report, and which isn't found in the Army-commissioned history of the Seattle District (Willingham 1992):

> "One of the oldest Indians is authority for the statement that within his memory, the River had but one outlet, and that there was a much used Indian Trail along the course of the present outlet from Lummi Slough to Lummi Village—that a great fresh [flood] caused the river to cut a new channel across the marshes, following the course marked out by the trail…*When the U. S. snag boat operated on this river in 1886, it filled the outlet of Lummi Slough with snags, and now, at low stages of the river no water enters the slough* [emphasis added]." (Gilbert 1887)

This account by a credible federal surveyor who was present in the area at the time indicates that the Army Engineers plugged the Lummi River in 1886. The map record is consistent with Gilbert's statement. It is likely that natural jams had formed in the mouth of the Lummi River during a flood as Symons reported, but Gilbert's map (having an 1887 publication date, but probably made in the months prior to the September 1886 visit by the Army's snagboat) shows the Lummi River as a viable channel in 1886, approximately equal in size to the Nooksack, with a very small amount of drift symbolized in the channel's upper end.

The estuary had extensive riverine-tidal wetlands (Figure 9). [Our wetland classification scheme follows Cowardin et al. (1979); estuarine wetlands are tidal and saline, while riverine-tidal are predominantly freshwater wetlands that are influenced by the tidal backwater effect on freshwater riverine flows.] We distinguished these wetlands from estuarine wetlands using several criteria. The US Coast & Geodetic Survey charts use symbols that distinguish freshwater marsh and saltmarsh. Distinguishing patterns on the USGS 15' topographic sheet Blaine 1907 also confirms the difference in wetland type. We also used the previously described DEM to refine boundaries drawn from the other two map sources.

Estuarine wetlands were much more extensive in the Lummi River side compared to the Nooksack River side of the delta (Figure 9). This difference may reflect the Lummi River having been the dominant channel in the decades prior to the first map records, and having thus been more actively receiving sediment, and prograding low-elevation surfaces on which estuarine marshes could develop. It could also reflect different sedimentation patterns as a result of different current and wind conditions in the two sides of the estuary.

We map Sandy Point, the prominent point of land to the west of the Lummi delta, as primarily estuarine wetland with grassland (presumably in large part sand dunes) fringing the southern and western margin, based on US Coast Survey and GLO mapping. The tideflats shown in Figure 9 in the Lummi and Nooksack estuaries are the area between the estuarine marsh and the MLLW (Mean Lower Low Water) line depicted on Coast Survey T-sheets. The MLLW on T-sheets in the Puget Sound area is generally an approximation of the more precisely drawn lines on the Coast Survey's H-sheets (hydrographic sheets).

Environments of the Lower Nooksack (Ferndale to Everson)

The Nooksack River was relatively straight in the lower part of this area (approximately RM 5-RM 11), and meandering upstream to approximately RM 24. Upstream (see following section) the river historically anastomosed (branched).

Topographic depressions on the lower Nooksack's floodplain were sites of extensive freshwater wetlands (Figure 9). The GLO field surveyors commonly described these marshes as "hardhack swamp," "willow swamp," and "beaver swamp." Surveyors traversed the marshes in T40N R2E in early March 1872, and described several as "impassable," presumably because of standing water, and include notations such as "marsh overflowed in winter to depth of 6 feet." In upstream T40N R3E, surveyed in late November of the same year, notes include "2-4 feet water" and "swamp water" (see Appendix 1 for more detail). The field surveys intersected "prairie" areas on the north valley side, near the present-day site of Lynden, which we mapped as “grassland.” Indigenous populations may have created and maintained this forest opening (and likely other, small, unmapped openings) as was common in other Pacific Northwest environments (e.g., see Boyd 1999), or they may have been natural openings created by wet soils.

As indicated previously in the discussion of methods, floodplain creeks shown in the ~1880 conditions mapping are generally the least certain map features. Some channels that existed are probably not shown because they were not shown on early mapping and had been filled by the time of the earliest aerial photos. Other channels that are mapped may not be correctly located, because we reconstructed them from the incomplete traces of relict channels evident on the early photos. The network of floodplain streams should be viewed as a best estimate from the available sources, but not as a precise or complete representation.

Environments of the Upper Nooksack (Everson to the Forks)

As shown in Figure 11 and suggested by the topography represented in the valley cross sections (Figure 6), the Upper Nooksack historically anastomosed upstream of Everson. An anastomosing pattern has been associated elsewhere with the effects of wood jams (Harwood and Brown, 1993; Collins et al. 2002). The field descriptions of Assistant Engineer David B. Ogden, writing with an eye to navigability, wrote that the river was shallow and unnavigable upstream of Lynden:

> “…By reference to the maps it will be noticed that there are numerous shoals between Lynden and Everson, making this stretch of river practically unnavigable excepting during times of high water.” (Ogden 1894)

Numerous floodplain sloughs were associated with the river. Smaller sloughs shown on the GLO plat maps were not meandered (field surveyed), making it necessary in some cases to modify their locations using secondary information. In the upper Nooksack and other areas having extensive floodplain sloughs historically (e.g. the North, South and Middle forks), the map representations likely grossly under-represents the number of floodplain sloughs that existed. In reconstructing channel networks in similar forested valleys in Puget Sound river valleys where high-resolution DEMs made from Lidar are available, a dense network of floodplain channels can be mapped (e.g. Collins and Sheikh 2004b).

Environments of the Nooksack River Forks

The North and South fork valleys both include fans, terraces, and large landslides that in places narrow the valleys (Figures 2 and 11). The lower South Fork valley, which has a lower gradient than the forks elsewhere, included an extensive system of wetlands, small channels and ponds in the Black Slough area (Figure 11). The few bearing trees that fall within the wetland complex suggest it was dominantly a spruce-alder swamp. Descriptions in the GLO notes indicate it had "…dense timber and thick undergrowth" and was "swamp covered with skunk cabbage and very dense thickets of spruce and crabapple" (see Appendix 1 for more information).

As indicated above for the upper Nooksack, in mapping in Figure 11 for each of the forks, it can be assumed that many of the floodplain sloughs and tributary creeks that likely existed are not shown. Forested floodplains such as those of the three forks typically have many small sloughs and tributaries, and the GLO mapping was at too course of a scale to intersect all of them, and relatively few relict channels were evident on the 1938 photos because of the relatively rapid rate of migration and avulsion in the braided North Fork and Middle Fork.

Historical Forest Conditions

The following discussion of historical forest conditions is based primarily on the GLO bearing tree records. On riverbanks in the greater Nooksack delta, alder (red alder, *Alnus rubra;* on first use we cite the common name used by surveyors, and the probable species) was the most common tree (Figure 12A) Descriptions from an 1868 expedition by E. T. Coleman (Coleman 1869) describe the banks as "adorned with several species of willow, alder, the crab-apple," which are the three most common species in the GLO survey. Spruce (Sitka spruce, *Picea sitchensis*), however, accounted for by far the most basal area (Figure 12D), being the only large (if relatively infrequently occurring) tree.

In the Lummi estuary's extensive estuarine scrub-shrub wetlands (Figure 9), willow (*Salix* spp*.)*, crabapple (Pacific crabapple, *Malus fusca*), and red alder were common (Figure 12B); Sitka spruce again was the dominant tree by basal area (Figure 12E). Tree cover was patchy and sparser than elsewhere (Figure 13). Riverine-tidal wetlands had a species distribution similar to that in estuarine wetlands, with the addition of maple (bigleaf maple, *Acer macrophyllum*) and cedar (*western redcedar, Thuja plicata*), although the sample size is small. The tree cover was nearly as patchy and sparse as in the estuarine scrub-shrub wetland (Figure 13).

Alder was the most common tree throughout the lower Nooksack forests (alder accounted for 42% of all trees in the study area). In streamside forests, cottonwood (black cottonwood, *Populus trichocarpa*) was almost as common as alder (Figure 14A), and accounted for nearly as much of the basal area as spruce (Figure 14D), which, similar to the delta, had the greatest relative dominance among conifers. Confirming the historical abundance of cottonwood, Coleman (1869) saw "long rows of lofty cotton-wood trees."

Farther away from the stream, in the lower Nooksack's valley bottom (excluding wetlands), cedar dominated the forest in basal area with spruce the second most dominant (Figure 14E); alder remained the most common tree (Figure 14B). Within the lower Nooksack's extensive palustrine wetlands, species composition was similar to that in the streamside areas except that cottonwood was not present (Figure

14E), few trees were large (note scale on basal area plot in Figure 14F), and crabapple and birch (probably paper birch, *Betula papyrifera*; included in "other" category in Figure 14C and F) were present.

Compared to the lower Nooksack, cottonwood was less common in the upper Nooksack's streamside forests, where alder was the most common tree in valley bottom (Figure 15A) and streamside (Figure 15B) forests; cedar was nearly as common as alder in the valley bottom forests. In both areas cedar was the dominant tree by basal area (Figures 15C and 15D), and fir (probably Douglas fir, *Pseudotsuga menziesii*) was a significant constituent of basal area.

Alder was overwhelmingly the most common tree in the streamside forest of the three forks (Figure 16B and Figures 17B and 17C) and dominated by basal area, except in the South Fork where a few large cedars existed in the sample. The valley bottom forests were more diverse, and were dominated in basal area by conifers (Figure 16D and Figure 17D; the Middle Fork valley bottom is not shown in Figure 17 because the sample size was small), with all four of the common conifers well represented (Figure 16A and Figure 17A). The palustrine wetland complex mapped in the South Fork was similar to the streamside forest, with the addition of spruce (Figure 16C; note small sample size).

Throughout the entire study area, western redcedar were the largest trees (Figure 18A); the mean diameter was 82 cm (median 61 cm) and the largest was 305 cm. Sitka spruce (mean 60 cm, median 41 cm, maximum 183 cm) were the other large conifers. Black cottonwood was the only hardwood to attain a large diameter (mean 50 cm, median 37 cm, maximum 173 cm). No other species had a mean or median diameter greater than 30 cm. Red alder and bigleaf maple both had mean and median diameters greater than 20 cm (alder mean 27 cm, median 25 cm, maximum 76 cm; maple mean 34 cm, median 25 cm, and maximum 102 cm).

Tree species also had distinct elevation ranges (Figure 18B). For example, while it occurred within a fairly large range in elevation, most Sitka spruce grew at the lowest elevations among conifers on average, consistent with its importance on the delta and lower Nooksack. Western redcedar, Douglas fir, and western hemlock tended to grow at increasing elevations, respectively. Among hardwoods, crabapple, willow, and birch occurred at low elevations, reflecting their importance on the delta and lower Nooksack. Cottonwood's range was relatively restricted to moderate elevations, reflecting its importance in the lower Nooksack. Alder was ubiquitous, and had the widest elevation range among tree species.

These data indicate which species would have contributed large wood that potentially could function as key pieces for jams, and how this contribution varied along the river. On the delta, Sitka spruce would have been the one species large enough to be a key piece. In the lower Nooksack, cottonwood would have augmented spruce as a source of key pieces. In both the delta and the lower Nooksack, the rate of river migration was low (see later in the report), so the immediately streamside trees are the best indicator of potentially recruitable trees. In the upper Nooksack, cedar would have been the most common potentially recruitable key piece, and secondarily spruce, fir, cottonwood and larger maple. In the forks, cedar and fir would have been the most commonly available large wood, and secondarily cottonwood and maple.

In-Channel Wood

Field data from Pacific Northwest rivers that have remained relatively unmodified in the past few centuries (e.g. Abbe and Montgomery 1996; Collins et al. 2002) and archival studies (Sedell and Luchessa 1981; Sedell and Frogatt 1984; Collins et al. 2002) suggest that rivers such as the Nooksack would have had numerous wood jams. These jams would have had important functions at a wide range of scales, such as creating pools, causing avulsions and flow splits, and routing water and sediment at the valley scale (Collins et al. 2002; Montgomery et al. 2003). Comments in early settlers' accounts indicates that wood jams were prevalent, but with the exception of a few large and persistent wood jams (the Portage Jam previously discussed and a large jam above Lynden, described below) are not specific or detailed enough to specifically describe them or their effects on historical river conditions. Annual reports from field operations of the Army Engineers are another (limited) source of information. The following discussion summarizes these fragmentary information sources.

The “Portage Jam” or “Big Jam” was present, for as long as several centuries judging from reports of forest growing on it, at the head of the delta where the Lummi and Nooksack rivers diverged. Phoebe Goodell Judson describes the jam, as it existed in 1871:

> “That ‘jam’—how shall I describe it? It was three-quarters of a mile long; great logs and huge trees, in every conceivable position, piled high across a bend of the river, reaching from shore to shore. It was evident, by the large trees growing in the midst of it, that this “jam” had been accumulating for many years, and was still enlarging, as every freshet carried on its current a new supply of logs and uprooted trees.” (Judson 1984, p. 201-202)

As indicated earlier in this report, actions by settlers and possibly the Army Engineers in the early 1860s may already have significantly altered the extent and shape of this jam (e.g., Wahl 2001). But a decade later, this and other jams still presented a barrier for settlers, for example, causing Judson to write:

> “Night and day their ugly shapes haunted me like a spectre, barring our only avenue of intercourse with the outer world. If it were a possible achievement, they must be removed, and we determined to spare no effort for the accomplishment of that end.” (Judson 1984)

According to Mrs. Judson, Mr. Judson headed a petition drive to raise money for the jam’s removal, netting $1,500, and leading to the jam’s removal, according to Jeffcott (1949), in 1876 and early 1877.

The lower mainstem was described as “winding and narrow” (Judson 1984), with swift current. Judson described trees fallen into the river nearly obstructing passage:

> “Occasionally an immense tree lay athwart the stream, leaving a narrow place through which the

> water rushed like a mill race and the roar of a young cataract. In some places, the space between the log and the banks were so narrow that the canoe could barely wedge through." (Judson 1984)

A jam in the lower mainstem that required portage appearing in settlers' accounts as the "little jam" (Jeffcott 1949; Judson 1984), was located "near the mouth of Bertrand Creek" (Jeffcott 1949) at approximately RM 12. Settlers reportedly cleared this jam; Jeffcott puts the date in the late 1870s (Jeffcott 1949); Judson reports that her husband and the neighboring Mr. Klockie cleared the "little jam" with three months effort; the year is unclear. In any case, the jam was cleared prior to the Army Engineers' first visit. Assistant Engineer Habersham found few jams or snags in the lower mainstem, which may have in part reflected the earlier efforts of settlers to clear wood:

> "Below Linden a large tree is embedded in the bottom, extending clear across the stream, 2.5 feet under water, and a number of snags lodged in a sharp bend 12 miles from the mouth, are the only obstructions to navigation…As the Nooksack carries but little drift, it could be kept clear of the small annual accumulation by a month's work of a good snag-boat…" (Habersham 1880)

Upstream of this jam, Judson (1984), writing of her 1871 canoe trip upriver, describes a "great bend in the river a mile in circumference." She writes:

> "The passage through it was appalling. Angry waters rushed, roared and boiled in mad fury around the many fallen trees with which the bend was filled." (Judson 1984)

This description could have referred to one of several former bends (now cut off) at RM 15, RM 16, or RM 18. She describes the few river miles her party traversed upstream of this point as "comparatively free from obstructions."

The Nooksack was blocked by an "old and formidable" jam (Jefferson 1889) just above Lynden. According to Habersham, the presence of this jam (at approximately RM 19), "nearly a mile long," contributed to Lynden's being the head of navigation, and "the most important point in the Nooksack Valley." The Lynden jam [sometimes referred to as the "upper jam" (Jeffcott 1949)] blocked both channels where the flow split around an island. The Army snagboat worked on clearing the jam in late 1888 (Jefferson 1889), and the snagboat captain in the official Army report indicated that he had been informed that the jam was swept away by a subsequent flood, although Jeffcott (1949) mentions only the flood, not the Army's efforts.

E. T. Coleman, in an 1868 expedition to Mount Baker, described a channel in the upper mainstem, where one channel around an island was blocked up (Coleman 1869), presumably by wood. Morse (1883) reported that the upper mainstem had numerous jams and snags, as well as numerous boulders and "swift riffles," but no jams completely blocking the river. The Army Engineers described the upper mainstem as "wide and shallow, with numerous gravel bars for 15 miles…." (Habersham 1880).

Several settlers' accounts mention the abundance of logjams in the South Fork (e.g. Morse 1883; Jeffcott 1949; Royer 1982), particularly in the lower South Fork. These include mention of several drifts that required portage, and a logjam near Saxon that children walked across on their way to school (Royer 1982).

A quantitative indicator of the amount of wood that existed historically in the lower Nooksack River comes from the snagboat captain's reports included in the Army Engineers' annual reports. The rate at which snags were removed in the first years of the snagging program can provide some indication of at least relative wood quantity compared to other rivers. In the Nooksack River, the first snagging operation was conducted in 1886, clearing wood from the river mouth to Lynden, the head of navigation. Thus, the early snagging program began a decade or more after settlers had already accomplished a great deal of river clearing. Snagging took place on only three other years in the 1880s and 1890s (Table 7).

The initial snagging operation removed 871 snags from approximately 19 river miles, or 58 snags/river mile (Table 7). This cannot be translated into a wood load for the reach because their operations may have been limited to the snags in deep water, and excluded wood jams at channel margins, which likely contained the largest accumulations of wood. The 15-yr total of 2,310 snags, removed from approximately 19 river miles, averaged about 8 snags/river mile/year. Wood removed from the Nooksack in the first three decades of the snagging operation was roughly comparable on a watershed area basis for the Snohomish, Nooksack and Stillaguamish, and significantly greater in the Skagit watershed (Table 8). These data suggest that the Nooksack did not have an unusually large or small number of snags relative to other Puget Sound rivers in these early decades of the snagging operation.

Table 6. Summary of forest tree conditions suggested by GLO bearing tree records.

SUMMARY OF FOREST CHARACTERISTICS

OVERALL

- Hardwoods more common than conifers, especially in streamside areas. Alder was the most common tree species.
- While only one-fourth as common as alder, western redcedar was the most common conifer, and the largest tree on average.
- Trees had identifiable elevation ranges, with Sitka spruce being the lowest elevation conifer and western hemlock the highest. Among hardwoods, crabapple, willow and birch were lower elevation, cottonwood primarily moderate elevation, and alder ubiquitous.

DELTA

- Red alder was the most common streamside tree, but Sitka spruce was the only large-diameter tree and by far the dominant conifer.
- Estuarine wetlands were dominated by willow, crabapple, and alder, with Sitka spruce being the only large conifer.
- Riverine-tidal wetlands were similar in species composition to estuarine wetlands, with the addition of large cedar.

LOWER MAINSTEM

- Black cottonwood and Sitka spruce were large-diameter streamside trees.
- Western cedar was the largest tree in valley-bottom forests, with alder remaining the most common tree.
- Within extensive palustrine wetlands, species composition was similar to streamside, excepting cottonwood was absent, few trees were large, and birch and crabapple were more common.

UPPER MAINSTEM

- Alder was the most common streamside tree, with cedar the largest. Cottonwood was considerably less frequent than along the lower mainstem.
- Fir and cedar were the largest trees in the valley bottom forest in which alder and cedar were the most common trees.

FORKS

- Alder overwhelmingly most common tree in each of three forks.
- Valley bottom similar to upper mainstem, with addition of more hemlock.

Table 7. Snags removed from the Nooksack River, 1886-1900 (from Chief of Engineers, U. S. Army, Annual Reports of the Chief of Engineers). There were no snagging activities in the years that lack entries in the table.

YEAR	SNAGS & LEANING TREES REMOVED		LOCATION	COMMENTS
	SNAGS	LEANING TREES		
Sept.-Dec. 1886	871	97	Mouth to Lynden	"No work had previously been done on this part of the river"
Nov.-Dec. 1889	681	336	Mouth to Lynden	Removed jam near mouth, also worked at removing the Lynden jam
Oct. 1891	428	66	Mouth to Lynden	"…removing many dangerous snags and pretty thoroughly clearing the channel…"
Sept. 1893	330	30	Mouth to Lynden	"…the river pretty thoroughly cleaned of obstructions…"
1886-1900	2,310	529	-	-

Table 8. Snags removed from four north Puget Sound rivers, 1880-1910 (from Chief of Engineers, U. S. Army, Annual Reports of the Chief of Engineers).

RIVER	DRAINAGE AREA (km^2)	1881-1890	1891-1900	1901-1910	TOTAL 1881-1910
Skagit	7,800	776	21,553	14,369	36,698
Snohomish (including Snoqualmie and Skykomish)	4,645	920	2,898	6,527	10,345
Nooksack	2,072	1,462	758	1,850	4,070
Stillaguamish	1,770	87	956	1,021	2,064

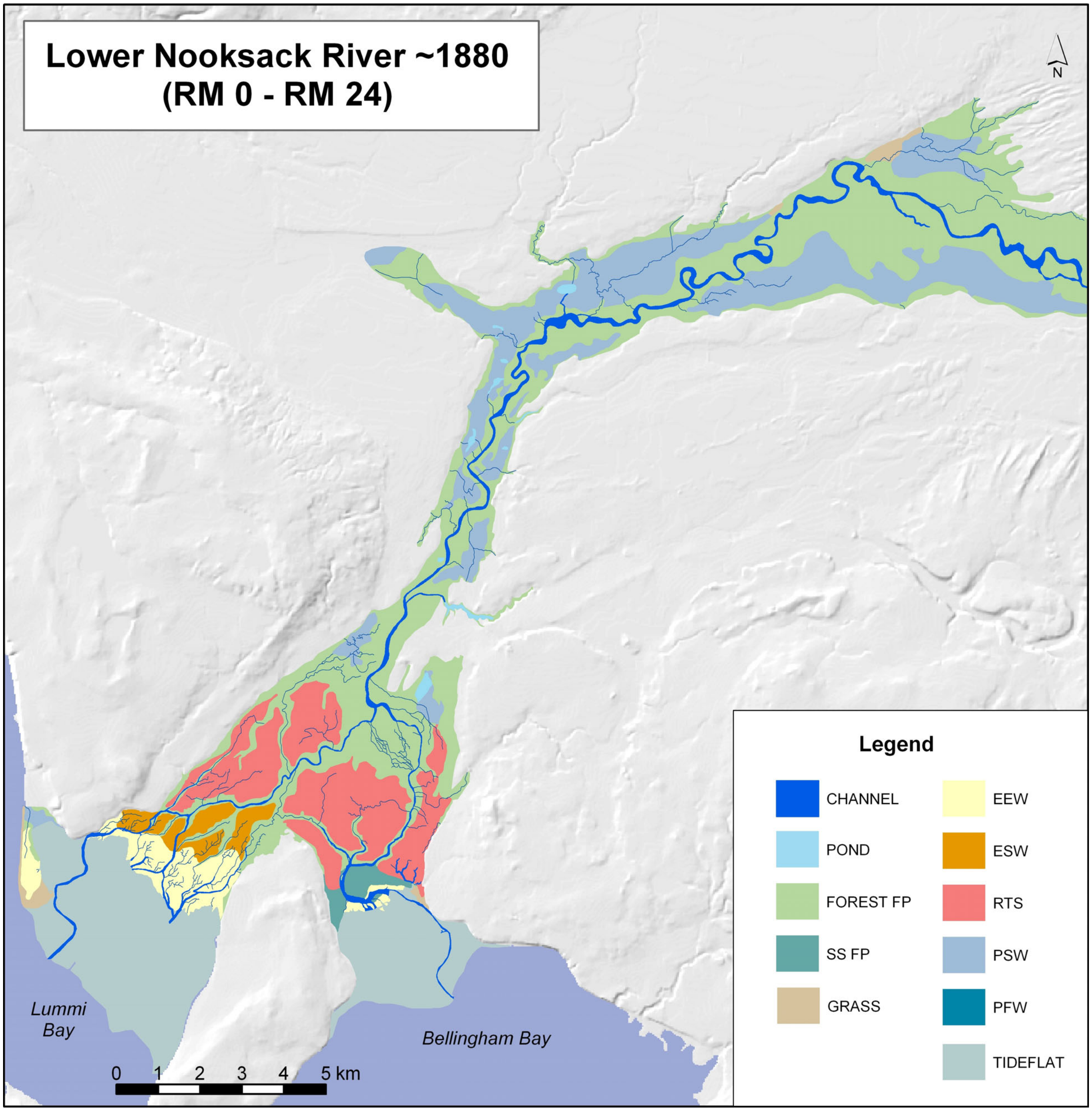


Figure 9. GIS mapping of the lower Nooksack valley, interpreted from archival sources, for approximately 1880. See report for mapping methods and limitations. FP = floodplain; EEW = estuarine emergent wetland; ESW = estuarine scrub-shrub wetland; RTS = riverine-tidal scrub-shrub wetland; PSW = palustrine scrub-shrub wetland; PFW = palustrine forested wetland.

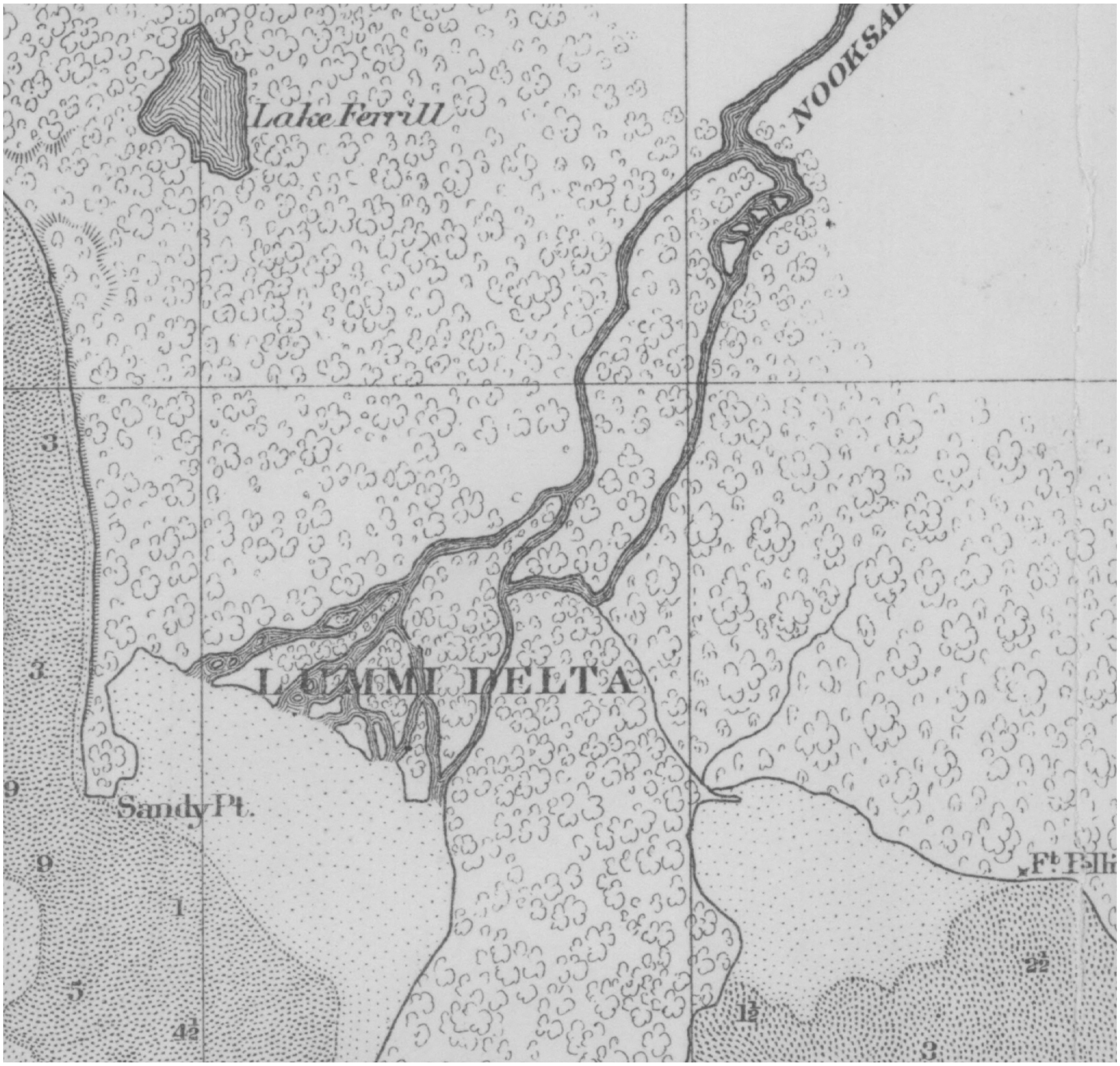


Figure 10. Nooksack River delta in approximately 1856-1858. Excerpted from "Map showing the line of boundary between the United States & British possessions, " published in 1868. The map appears to have been compiled from US-Canada Boundary Surveys conducted in 1856-1858. (See "Source Credits" for detail on source.).

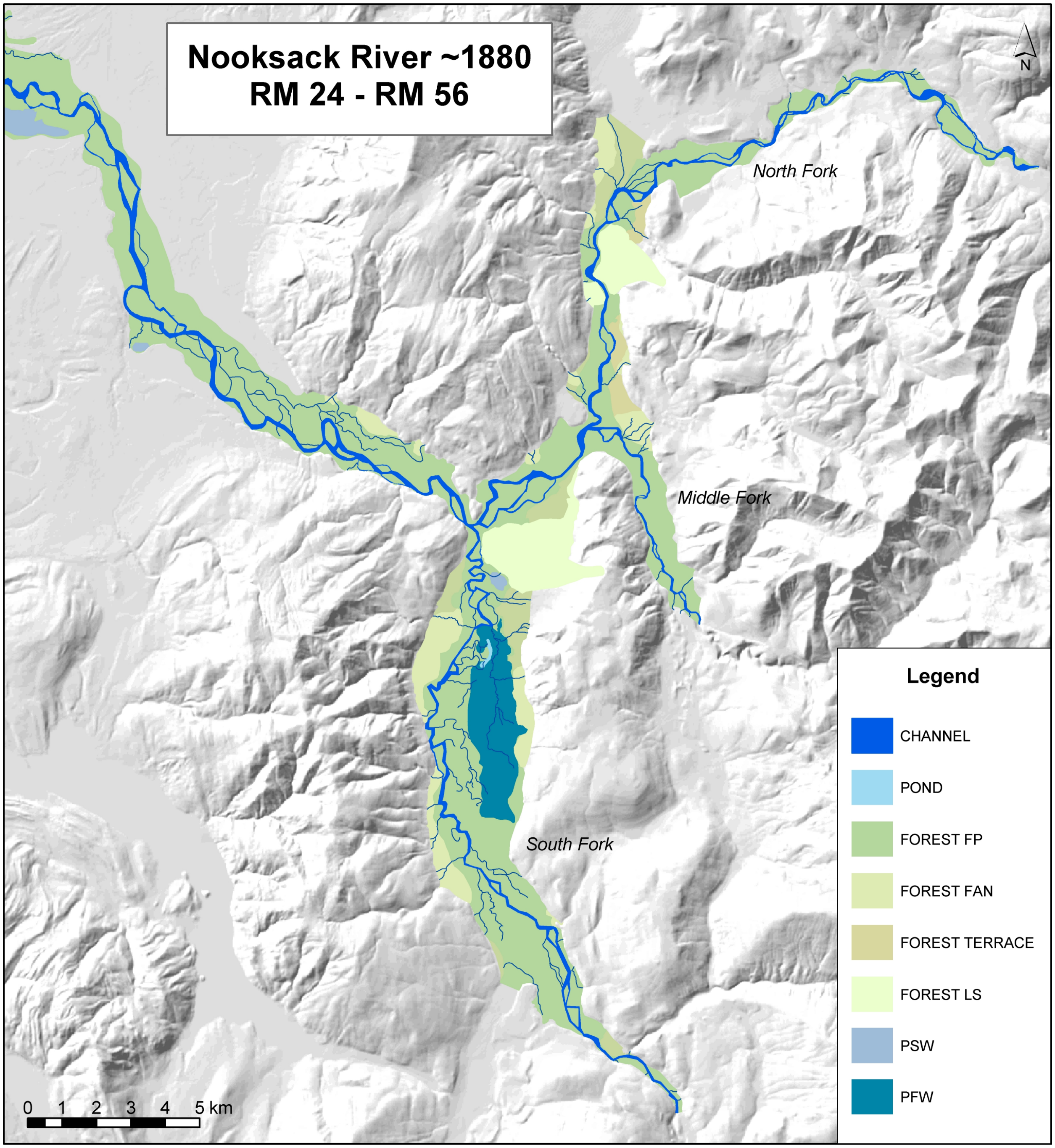


Figure 11. GIS mapping of the upper Nooksack valley, interpreted from archival sources, for approximately 1880. See report for mapping methods and limitations. LS = landslide; other units are as in Figure 10.

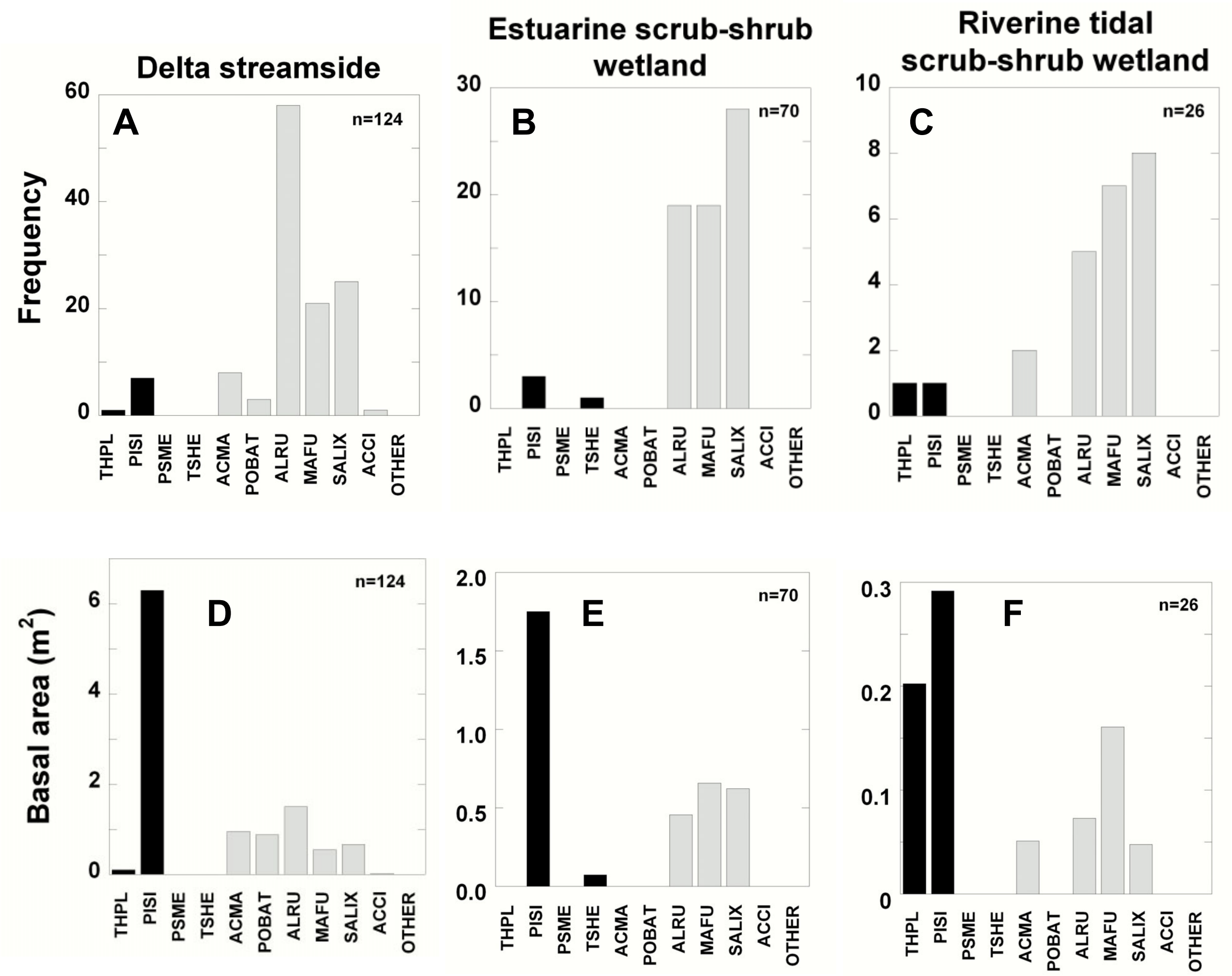


Figure 12. GLO bearing trees on the Nooksack delta. Frequency (A) and basal area (D) in streamside forests; frequency (B) and basal area (E) in estuarine scrub-shrub wetland, and frequency (C) and basal area (F) in riverine-tidal scrub-shrub wetland. Conifers have dark-shaded bar. THPL: western redcedar (*Thuja plicata)*; PISI: Sitka spruce (*Picea sitchensis)*; PSME: Douglas fir (*Pseudotsuga menziesii)* TSHE: western hemlock (*Tsuga heterophylla)*; ACMA: bigleaf maple (*Acer macrophyllum)*; POBAT: black cottonwood (*Populus trichocarpa)*; ALRU: red alder (*Alnus rubra)*; MAFU: Pacific crabapple (*Malus fusca)*; SALIX: willow (*Salix* spp.*);* ACCI: vine maple (*Acer circinatum)*.

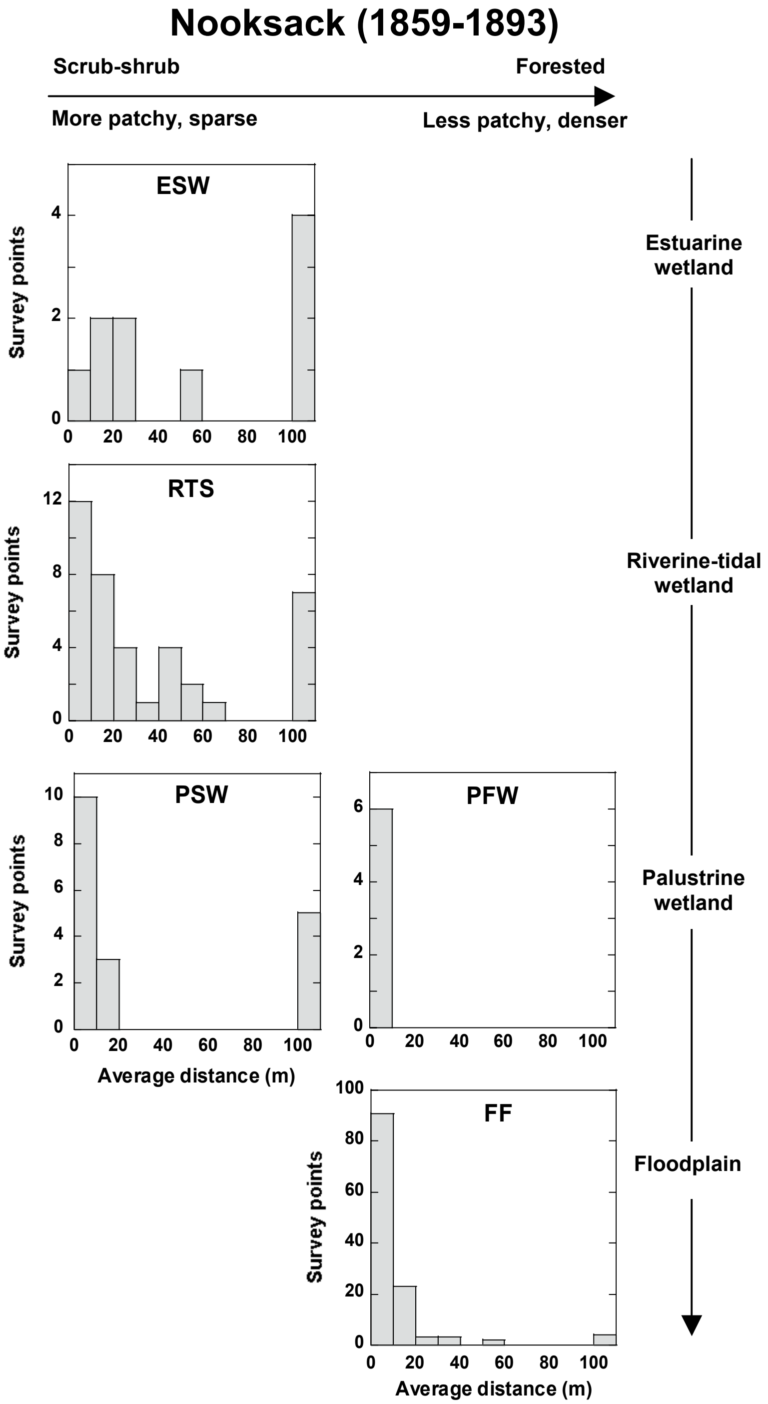


Figure 13. Bearing tree distance distributions for several cover types in the Nooksack River study area. ESW: estuarine scrub-shrub wetland; RTS: riverine-tidal scrub-shrub wetland; PSW: palustrine scrub-shrub wetland; PFW: palustrine forested wetland; FF: forested floodplain.

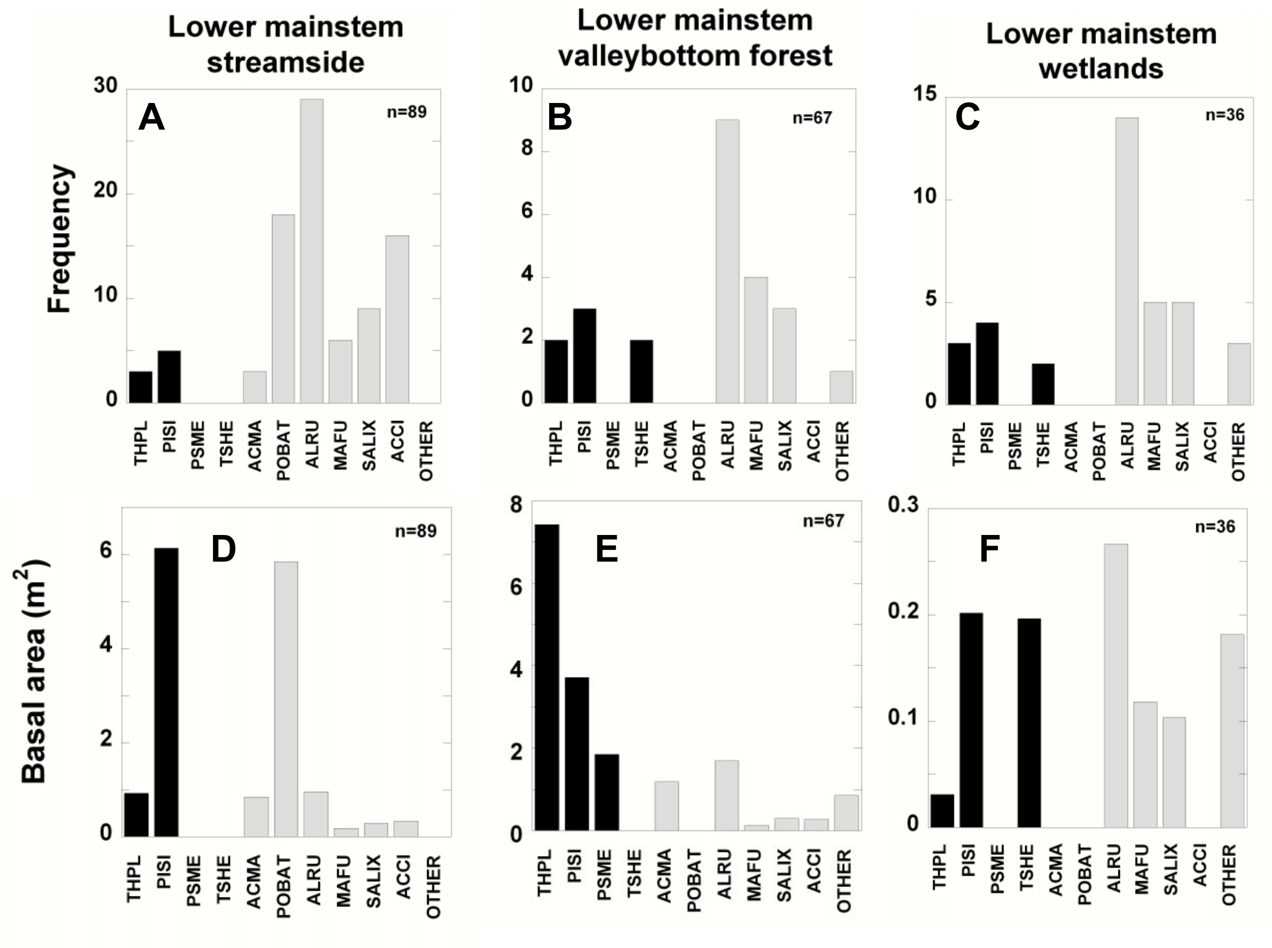


Figure 14. GLO bearing trees in the lower Nooksack River area. Frequency (A) and basal area (D) in streamside forests; frequency (B) and basal area (E) in valley bottom forests, and frequency (C) and basal area (F) in palustrine wetland (note the greatly differing scale in panel F). Conifers have dark-shaded bar. Species abbreviations are as in Figure 12. “Other” species in the valley bottom forest are Indian plum (*Oemleria cerasiformis*), California hazel (*Corylus cornuta californica*), cascara (*Rhamnus purshiana),* and Western flowering dogwood (*Cornus nuttalli);* in lower mainstem wetlands, “other” is paper birch (*Betula papyrifera).*

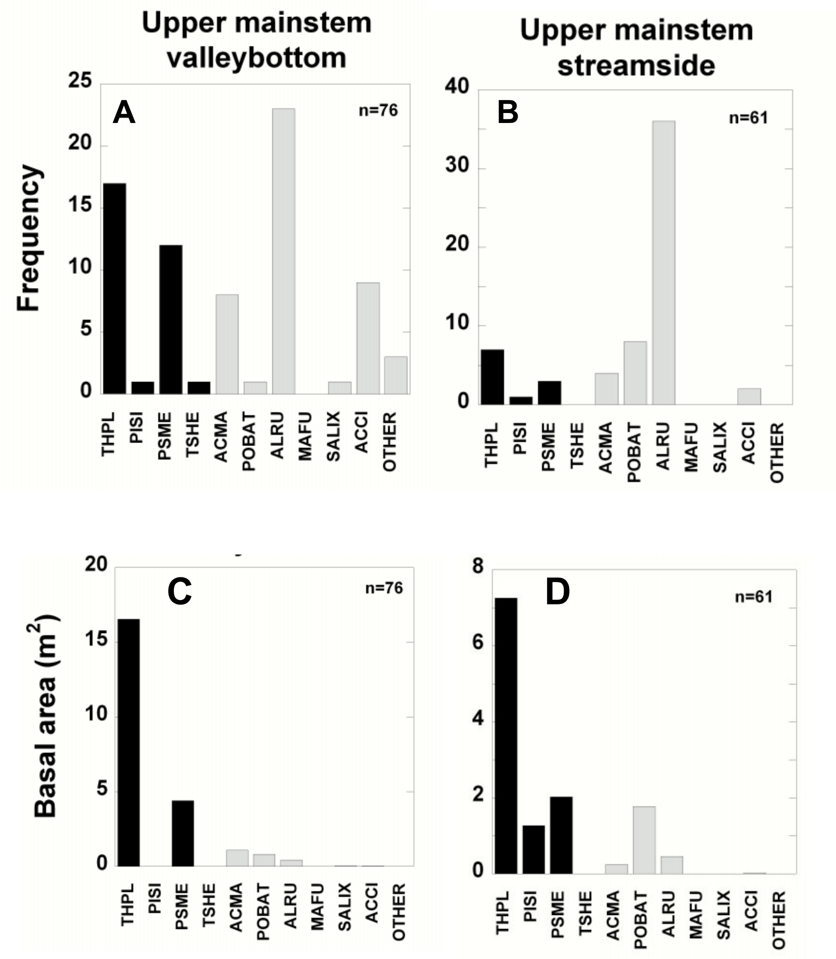


Figure 15. GLO bearing trees in the upper Nooksack River area. Frequency (A) and basal area (C) in valley bottom forests; and frequency (B) and basal area (D) in streamside forests. Conifers have dark-shaded bar. Species abbreviations are as in Figure 12.

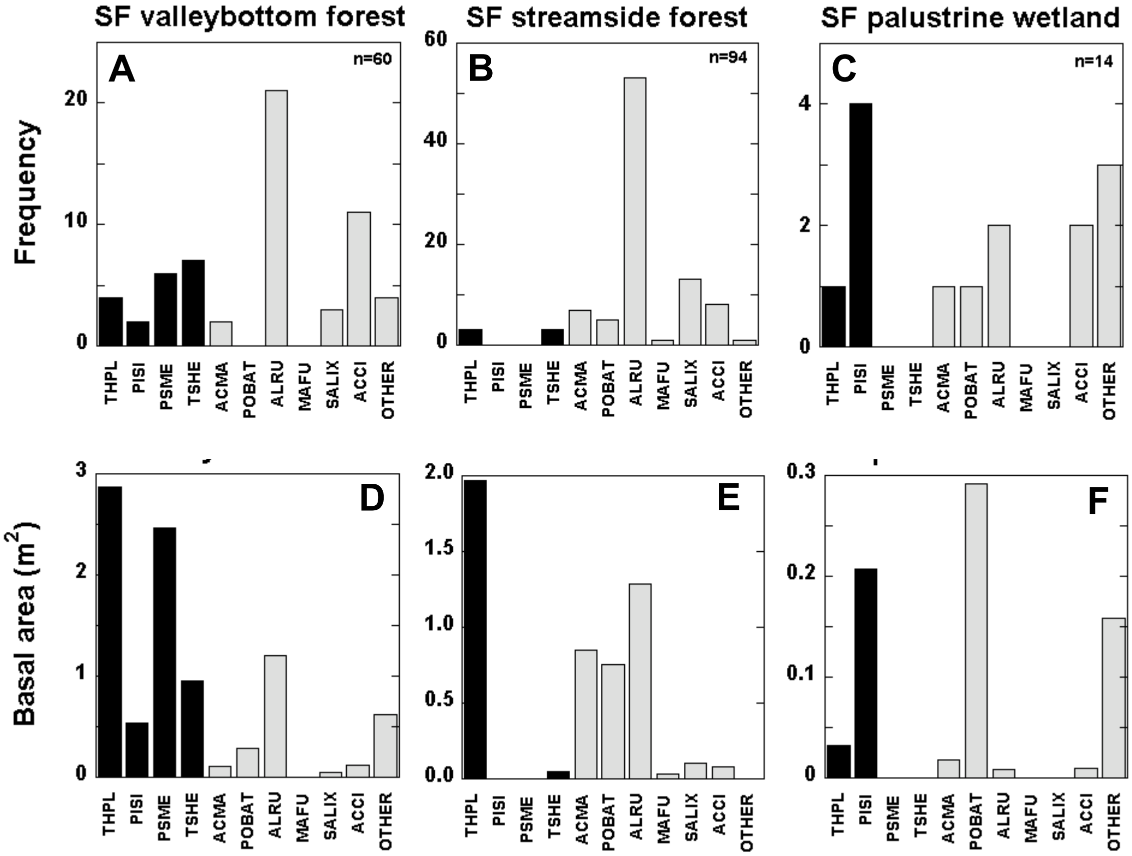


Figure 16. GLO bearing trees in the South Fork Nooksack River area. Frequency (A) and basal area (D) in valley bottom forests; frequency (B) and basal area (E) in streamside forests, and frequency (C) and basal area (F) in palustrine wetland. Conifers have dark-shaded bar. Species abbreviations are as in Figure 12. “Other” species in valley bottom forest are quaking aspen (*Populus tremuloides*), bitter cherry (*Prunus emarginata*), and Indian plum (*Oemleria cerasiformis*); in streamside forest grand fir (*Abies grandis);* in palustrine wetland bitter cherry, Indian plum, and California hazel (*Corylus cornuta californica*).

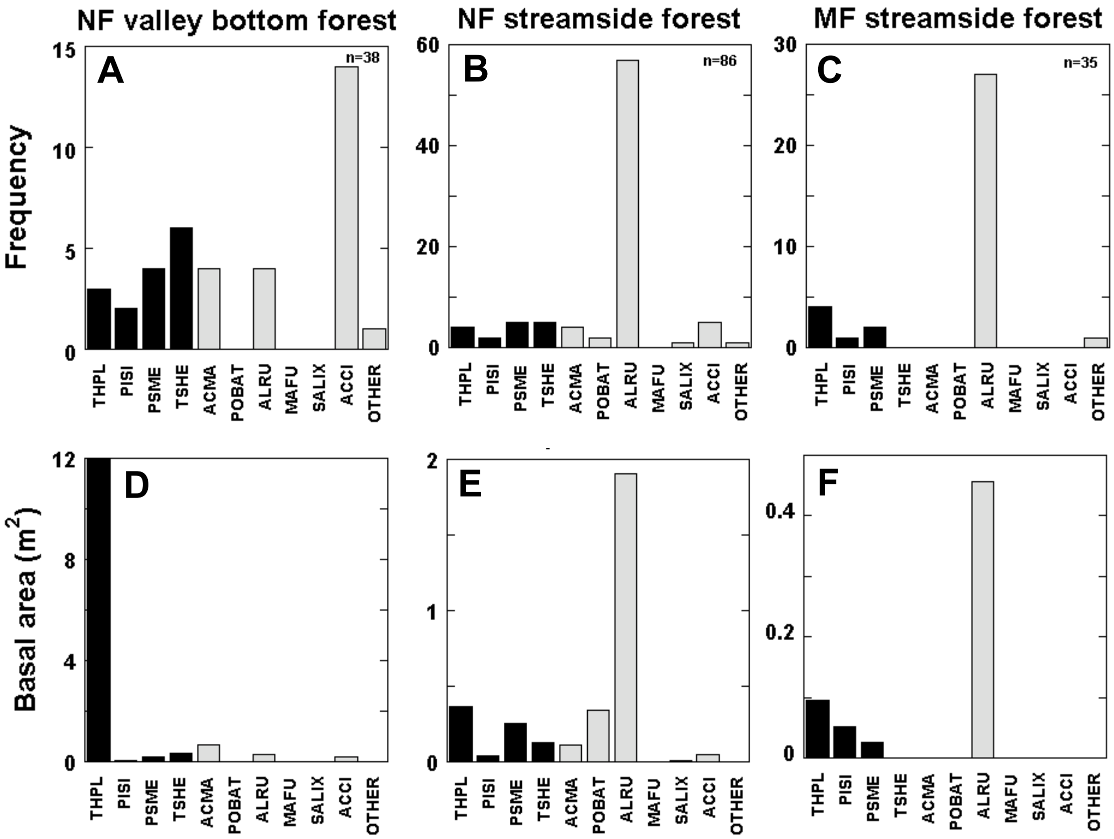


Figure 17. GLO bearing trees in the North and Middle Fork Nooksack River areas. Frequency (A) and basal area (D) in North Fork valley bottom forests; frequency (B) and basal area (E) in North Fork riparian forests; and frequency (C) and basal area (F) in Middle Fork riparian forests. Conifers have dark-shaded bar. Species abbreviations are as in Figure 12. “Other” species in each case is cascara (*Rhamnus purshiana).*

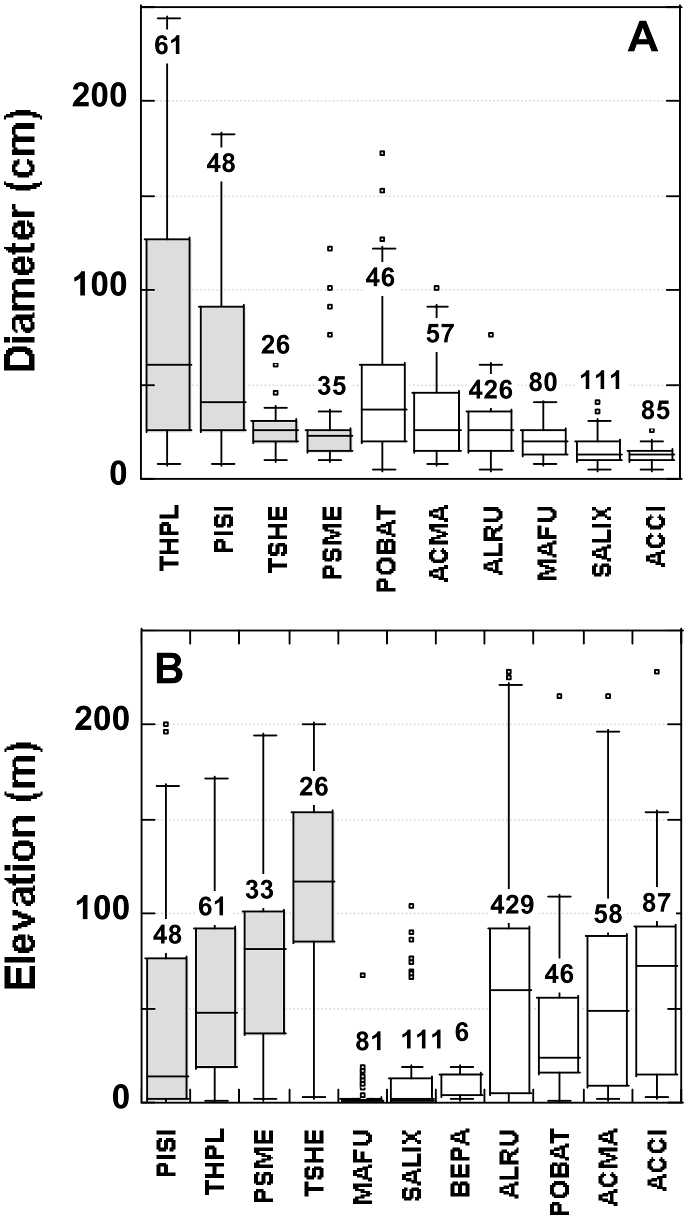


Figure 18. A) Distribution of bearing trees diameters in the study area. B) Elevation of bearing trees. Conifers have shaded bars. Numbers are sample size. Species abbreviations are as in Figure 12. See Figure 3 for explanation of format.

CHANGES IN CONDITIONS ~1880—1998

A general chronology of anthropogenic change to rivers and aquatic habitat in the Pacific Northwest (Sedell and Luchessa 1981) begins in the 1870s with snagging, jam clearing, and localized clearings by settlers, which is followed by the more systematic and large-scale snagging operations by the Army Corps (as described previously in this report) beginning in the 1880s. The logging of floodplain forests and ditching of floodplains also began in the same period.

Changes to land cover

By the beginning of the 20th century the native forest had been logged from river valleys throughout the region (Plummer et al. 1902). In the Nooksack River valley, the forest was largely logged or burned, and some of it converted to agriculture, by ~1910 (Figures 19 and 20). Most of the logging or burns had been prior to 1900, when federal forest stand mapping shows somewhat more forest remaining in the North and Middle forks (Plummer et al. 1902). By 1938 most land in the lower mainstem previously mapped as "logged/burned" had been converted to agriculture (Figure 21). In the upper mainstem and the forks, roughly half of these lands were converted to agriculture, especially in the South Fork, and the remainder reverted to forest (Figure 22).

By about 1910, wetlands in the lower mainstem had been almost entirely drained (Figure 19) and wetlands in the lower South Fork (Figure 20) were greatly diminished in size, and in each case converted primarily to agriculture. The Lummi Reservation Reclamation project resulted in 14.7 miles of dikes being built between 1926 and 1934, 4.4 miles along the Nooksack, 2.2 miles along Lummi Bay, 6.7 miles along the Lummi channel, and 1.7 miles along the Red River (Appendix 5, in Deardorff 1992). This diking project facilitated the draining of most of the wetlands on the greater Nooksack River delta by 1938 (Figure 21).

Log transport and log booms

Once naturally forming snags and jams were cleared from the river and valley-bottom logging proceeded upbasin, sawlogs and shingle bolts were transported down the Nooksack. In the early days of logging in the Pacific Northwest, essentially all logs were transported by water (Sedell and Duvall 1985). Some north Puget Sound rivers were substantially modified to facilitate log transport. For example, in the Samish River, to the immediate south of the Nooksack:

> "Since no logs had ever been driven down the Samish River before, E. E. and Milbourne Watkinson began the backbreaking task of cleaning out the river which was then a network of sloughs, islands and jams with no main channel." (Jordon 1962, in Sedell and Duvall 1985)

Even in rivers not heavily modified to accommodate log drives, repeated drives had substantial simplifying effects on channel morphology and aquatic ecology (see Sedell and Duvall 1985).

To gather logs driven down the Nooksack River, the Bellingham Bay Boom Company constructed a piling boom across the channel in 1890 at river's mouth (Deardorff 1992). Jams had begun to form prior to boom construction; the Army Engineers first cleared a jam in November 1888. Following the construction of booms, lengthy litigation followed regarding the boom's blockage of the river to navigation. In the 1890s and 1900s, jams formed frequently in the lower channel of the Nooksack River, accumulations at least in part caused by the log booms. These jams began forming as early as 1890, according to snagboat captain E. H. Jefferson:

> "…It was found that the entrance to the river was blocked by saw logs that had come down upon a recent freshet, and was being held by rival boom companies who were at war with each other, and that nothing could be done by the snag boat towards clearing the obstruction without

> inflicting damage to the booms, and thus causing a serious loss of logs to their owners." (Jefferson 1891)

Writing a few years later, Captain T. W. Symons indicated that these jams had made navigation nearly impossible:

> "The great trouble with the navigation of the river is at its mouth. Here, where the river debouches into the tide flats, booms have been built for catching saw logs, and these constructions, together with the logs and drift of all kinds caught thereby, have very effectually closed the river to ordinary navigation. It is now almost an impossibility for boats to get into the river." (Symons 1895)

The Army Engineers' annual reports include a map of the jam complex which was over two miles long (Figure 25A) and a later map showing the results of their snagboat's having opened a channel through the jam in 1903-1904 (Figure 25B). Deardorff (1992) summarizes testimony in Romaine v. U. S. (1918) indicating that between 1902 and 1908 the Nooksack changed its course by breaking through the chronic logjam at the river's mouth; the change, according to several witnesses, was caused or at least aided by dynamite. As described previously, systematic clearing of snags also occurred throughout the lower reaches of the Nooksack River (mouth to Lynden; Table 6).

Transport of shingle bolts to mills, and logs to tidewater for shipping, was common throughout Puget Sound rivers and elsewhere in the Pacific Northwest (Sedell and Duvall 1985) but on the Nooksack appears to be have been slight in comparison to other nearby rivers. In 1881, the Army's Major Gillespie wrote about the Nooksack River "the navigation which will be benefited by the improvement is small at present, and restricted to small river boats" but urged improvement nonetheless. However commercial use of the Nooksack never developed at a scale approaching anything like that on the rivers to the Nooksack's south. Statistics in the Army Engineers' Annual Reports show little commercial transport other than logs and shingle bolts, and the latter were transported in very modest quantities compared to the huge numbers of logs and bolts floated out of the three rivers to the south of the Nooksack. For example, in the five years for which any statistics were reported on the Nooksack River in the decade between 1903 and 1912, on average 2 MBF (million board feet) of saw logs were rafted down the Nooksack per year. By contrast, for the six years (1903-1908) in this same 10-yr period when figures were reported for the Snohomish River, on average 275 MBF/yr rafted downriver. In 1904, 39 tons of goods were exported or imported by river on the Nooksack, while 15,144 tons of goods were transported on the Snohomish.

Changes to hydrology and sedimentation in the Nooksack-Lummi Delta

The diversion of the flow from the Lummi to Nooksack River in the late 1880s (see earlier in this report) was later aided by the placement of fill in the upper end of the Lummi River channel (Deardorff 1992). In 1920, the Bureau of Indian Affairs began a land reclamation program on the Lummi River delta, which included permanently blocking the upper end of the Lummi River. L. M. Holt, the Supervising Engineer of the Irrigation and Drainage Division of the Bureau later wrote in a letter to the Commissioner of Indian Affairs, while the Bureau's diking project was underway, "the United States District Attorney in Seattle advised against damming the upper end of the Lummi channel where it was choked with a log jam," but meanwhile "the County has completely diked this channel so that no water passes down except through a small pipe through the dike" (Holt, in Deardorff, 1992).

Within only a few years after the river's switch to the Nooksack River side of the delta, Bellingham Bay began to fill with sediments so rapidly[(according to Captain Symons, writing in 1893, "Reliable parties state that the sand flats at the mouth of the Nooksack have extended out more than a mile within the past thirty years" (Symons 1893)]" that it compromised navigation, and a settler urged the Engineers to construct a dam that would switch the river back to its former path to Lummi Bay (Symons 1893).

While the Corps had attempted similar dams on the Skagit and Stillaguamish, they declined to do so on the Nooksack. In 1894, Assistant Engineer David B. Ogden observed “it will not be long before the river again makes its way into [the Lummi River] channel,” and recommended that the bank be protected with stone riprap (Ogden 1894). The change of flow dominance from the Lummi to the Nooksack distributary caused noticeable new accumulation of sediment in Bellingham Bay. Presumably, along with logging and agricultural development came increased erosion, which also would have increased the rate of sedimentation, but there is no direct measure of erosion rates in this early period.

The Army Engineers’ Captain Symons wrote about the problem of rapidly-growing tide flats, their adverse effects on navigation, and coupled with the accumulation of wood, their effects on increased flooding (see earlier in report).

By mid century, the low-flow channel of the Lummi River was isolated from upstream water influx from the Nooksack River, and the Nooksack delta had accreted substantially. Based on its appearance on 1938 aerial photos and the absence of tidal channels, most of the accreted land at that time appears to have been seasonally wet, not tidally inundated or regularly tidally influenced. Recent wetland mapping in the National Wetlands Inventory also supports this inference. The main Nooksack River channel avulsed into a shorter, more direct channel (Figure 21), at least in part through the efforts of local residents (Wahl 2001; Deardorff 1992). Newly accreted tidal marsh in the Nooksack River extended an additional approximately 800 m bayward between 1952 and 1998 (Figure 23).

Change to Channel Pattern and Morphology

Several broad changes in river morphology are apparent from the historical maps and aerial photos, including a general change from an anastomosing (or branching) channel to a simpler channel pattern. Figure 26 shows the number of forested islands, and the number of forested islands normalized by the channel length, for each of nine study segments. The number of forested islands is a surrogate for a branching pattern; “forested island” for this purpose is restricted to forested patches whose width is equal to or greater than the channel width. Except for the lower mainstem, which has remained meandering throughout the period of record, the number of forested islands has substantially decreased.

A second trend is a shortening of the lower mainstem. A plot of segment length through time (Figure 27) suggests a general shortening in nearly all segments, but the trend is only statistically significant (at the 95% confidence interval or greater) for the lower Nooksack. The linear regressions in Figure 27 show a statistically significant shortening in the LN1, LN2, and MN segments (i.e., the lower Nooksack River, to RM 24). Most of this shortening is due to meander cutoffs, apparent by comparing Figure 9 and Figure 19, which shows several meander bends had been cut off by ~1910; we did not determine how many of these cutoffs were through the efforts of settlers or by natural avulsion. Additional meanders were cut off by 1938 (Figure 21).

A third trend through time is for the channel area to increase (and by implication, for the channel width to increase) in the period between the GLO mapping and the 1933 aerial photographs (Figure 28). [As described earlier in this report, GLO plat maps generally depict the channel as wider than measured in the field, and the discrepancy varied locally, but it is likely that the GLO maps overestimate the actual channel area, which would cause the magnitude of pre-1930s channel widening in Figure 28 to be an underestimate. On the other hand, while we believe there is strong evidence supporting our interpretation that GLO channels represent the bankfull channel (i.e., including low-flow channel and gravel bars), we do not know how consistently this convention was observed. For the LN1, LN2, MN, and UN1 segments, the 1906 data in Figure 28 likely underestimates the actual channel area, because the Sumas 15’ quadrangle that these measurements were taken from only showed the low-flow channel.] After 1933, two different trends are evident. In most parts of the study area (except for the North and Middle forks), the channel area decreased gradually throughout the remaining period of record (Figure 28). While the channel area diminished through time, it remains substantially wider than the first (GLO) records indicate, except in the lower Nooksack (LN1, LN2, MN in Figure 28) where the channel area has returned to that in the mid-19th century. In the North and Middle forks, in contrast to elsewhere, the channel area continued to increase, rather than diminish, after 1933, with recent channel areas in individual segments as much as two to three times the area documented by the GLO survey (Figure 28).

While it is beyond the scope of this project to analyze the factors causing geomorphic change through time in the Nooksack River, there are several factors that could have influenced the historical trends described above. Flood history is the most obvious. An historical reconstruction of likely flood heights prior to record keeping in the Nooksack River is necessary to analyze this influence; records are available from the USGS Nooksack River at Deming gage from 1932, and continuously from 1935 through 2002. The 1932 peakflow is the largest on record (49,300 cfs), and could reasonably be expected to account for some of the widening trend apparent in the 1933 aerials. However, the second largest flood on record (48,900 cfs) was in 1996 and the third highest in 2002 (47,400 cfs); these two floods with similar magnitudes to the 1932 flood are not associated with a systematic increase in channel area in Figure 28 although they are consistent in timing with increases in the UN2, NF1, NF2, and MF segments.

A second, obvious potential factor is the history of riparian logging. The upper mainstem changed from a branching multiple channel to a braided single channel. In forested, mountain drainage basins, riparian logging (and the manner in which heavy equipment was used in the early decades of logging) can decrease bank strength, allow rapid bank erosion, and result in rapid channel widening (e.g. Roberts and Church 1986; Montgomery et al. 2003). The bank erosion and channel widening in turn contributes vast amounts of gravel- and cobble-sized sediment, and an increased load of coarse sediment causes rivers to braid. The early topographic maps already (1906 downstream of RM 34, and 1918 upstream of RM 34) suggest a braided pattern has replaced the historic anastomosing pattern, and this change follows in time by a few decades the clearing of riparian forests.

A third potential factor in the historical trend toward channel widening is the loss of large wood recruitment and the consequent loss of wood jams. As indicated earlier in the report, wood jams can be integral to creating and maintaining multiple channels. Finally, significant changes in the supply of coarse sediment could also have played a role, either from land-use-triggered landsliding, or naturally-increasing sedimentation, for example from pro-glacial headwater areas. The importance of these four, and potentially other, factors in causing the time trends shown in Figures 25-28 could likely be resolved in a different study of historical sediment budgets for the Nooksack River.

Changes to Aquatic Habitat Area

Detailed descriptions of historical wetlands, and the interpretations that were made for each, are included as Appendix 1. Methods to approximate the historical inundated area of wetlands are described previously in the report; specific criteria and assumptions are given in Appendix Table A. Wetland area, and inundated wetland area for ~1880 and 1998 are listed in Table 9.

In reviewing or using the data it is important to note that the methods we used to delineate wetlands historically and the methods we used to develop the 1998 data, and the resulting total wetland areas, are not comparable. The 1998 wetland criteria are considerably more inclusive than those we could develop from the historical information, so that the *total area* mapped for 1998 considerably overestimates the total area in terms of the historical estimates, especially for palustrine wetlands. We lack sufficient information to qualify the comparability of the inundated area estimates between the two time periods without field checking, but the two estimates of *seasonally inundated area* are probably broadly comparable.

The "winter inundation" area in 1998 was about 5% that of the 1880 estimates, and the area of "summer inundation" in 1998 was about 1% that of the 1880 estimate. This reflects substantial decreases in palustrine wetlands, particularly on the delta and lower Nooksack, and riverine-tidal wetlands.

The loss of estuarine wetlands includes substantial loss on the Lummi River estuary, but some gain on the Nooksack estuary, consequent to the Nooksack becoming the main distributary, and the substantial delta progradation. Integrating these two contrasting trends, the estuarine wetland area in 1998 was about 30% that of 1880.

Estimates of overall channel area are dominated by changes in “mainstem” channel, primarily freshwater (Tables 10 and 11). As described in the previous section, areas estimated for ~1880 and 1998 are two snapshots of a temporally dynamic system. The amount of main channel is greater overall in 1998; the overall increase reflects a reduction in channel area in the lower Nooksack (from meander bend cutoffs), little change overall in the South Fork, and substantial widening in the upper mainstem, North Fork and Middle Fork. In 1998 the proportion of the active channel accounted for by gravel bar ranged, in the study segments, from 75% in the Middle Fork and 67% in the North Fork, to 17% in the lower Nooksack (Table 15).

There was extensive loss of blind tidal channel area with the diking and draining of the Lummi River delta, both in the estuarine emergent zone and the estuarine scrub-shrub zone (Tables 10 and 11). This loss of small tidal creeks translates into a substantial loss in blind tidal channel edge and of channel edge overall on the delta (Tables 12 and 13). There was also some gain in mainstem and tributary channel area on the delta associated with the Nooksack River’s progradation, which causes the overall decline in channel area on the delta to be less than the loss of blind tidal channel area, resulting in a change in the relative areas and edge length of different habitats on the delta (Tables 10-13).

An overall increase in tributary area and edge between the two time periods is likely in large part to be an artifact of the different resolutions with which small channels could be mapped in the two time periods. It was possible to map more tributary creeks from the 1998 aerial photographs than it was from the earlier sources. The same data bias caused by better resolution from recent sources also confounds comparison of slough areas between the two time periods. To reliably compare edge habitat for small streams between the two time periods, it would be necessary to devise a method to quantitatively account for data source bias.

Tributaries in the 1998 mapping accounted for nearly half (47%) of channel edge. At least 43% of the total length of tributaries was diked (Table 14), with most of the length of ditched tributary being in the delta and lower mainstem. The amount of ditched tributary is an underestimate, because we did not map the smallest channels, not being able to consistently map ditches less than about 1 m in width, nearly all of which would have been ditched.

Table 9. Wetland and inundated wetland area in 1880 and 1998. EEM = estuarine-emergent wetland; ESS = estuarine scrub-shrub wetland; RT = riverine-tidal wetland; -P = palustrine wetland; W = winter inundation; S = summer inundation. See text for explanation.

	EEM	ESS	RT	RT (W)	RT (W &S)	P	P (W)	P (W &S)
~1880								
Delta	394	224	1217	*913*	*240*	105	*60*	*21*
Lower Nooksack	-	-	-	-	-	1880	1232	762
Upper Nooksack	-	-	-	-	-	10	-	-
South Fork	-	-	-	-	-	622	30	-
North Fork	-	-	-	-	-	-	-	-
Middle Fork	-	-	-	-	-	-	-	-
1998								
Delta	162	25	48	*25*	*6*	521	*7*	*20*
Lower Nooksack	-	-	-	-	-	160	24	4
Upper Nooksack	-	-	-	-	-	129	-	-
South Fork	-	-	-	-	-	359	5	3
North Fork	-	-	-	-	-	296	14	1
Middle Fork	-	-	-	-	-	86	1	0

Table 10. Channel areas (hectares) in ~1880. EEM = estuarine emergent zone; ESS = estuarine scrub-shrub zone; TF = tidal freshwater; V = variable salinity; F = freshwater.

TIME PERIOD and ZONE	DELTA (HA)	LOWER NOOKSACK (HA)	UPPER NOOKSACK (HA)	SOUTH FORK (HA)	NORTH FORK (HA)	MIDDLE FORK (HA)
EEM						
Blind	32	-	-	-	-	-
Distributary	16	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	-	-	-	-	-	-
Main	-	-	-	-	-	-
ESS						
Blind	11	-	-	-	-	-
Distributary	9	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	-	-	-	-	-	-
Main	-	-	-	-	-	-
TF						
Blind	15	-	-	-	-	-
Distributary	72	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	6	-	-	-	-	-
Main	-	-	-	-	-	-
F						
Slough	-	5	31	10	9	-
Tributary	6	47	4	25	3	1
Tributary-fan	-	-	-	0.5	1	2
Tributary-terrace	-	-	-	-	2	-
Main	17	291	316	224	349	58

Table 11. Channel areas (hectares) in 1998. EEM = estuarine emergent zone; ESS = estuarine scrub-shrub zone; TF = tidal freshwater; V = variable salinity; F = freshwater.

TIME PERIOD and ZONE	DELTA (HA)	LOWER NOOKSACK (HA)	UPPER NOOKSACK (HA)	SOUTH FORK (HA)	NORTH FORK (HA)	MIDDLE FORK (HA)
EEM						
Blind	3	-	-	-	-	-
Distributary	28	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	-	-	-	-	-	-
Main	-	-	-	-	-	-
TF						
Blind	9	-	-	-	-	-
Distributary	24	-	-	-	-	-
Slough	5	-	-	-	-	-
Tributary	4	-	-	-	-	-
Main	56	-	-	-	-	-
V						
Blind	-	-	-	-	-	-
Distributary	13	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	13	-	-	-	-	-
Main	-	-	-	-	-	-
F						
Distributary	-	-	-	-	-	-
Slough	-	1	7	1	10	11
Tributary	4	27	5	13	11	3
Tributary-fan	-	-	-	4	2	1
Tributary-terrace	-	-	-	0.2	1	-
Main	21	251	445	193	522	96

Table 12. Channel edge (kilometers) in ~1880. EEM = estuarine emergent zone; ESS = estuarine scrub-shrub zone; TF = tidal freshwater; V = variable salinity; F = freshwater.

TIME PERIOD and ZONE	DELTA (KM)	LOWER NOOKSACK (KM)	UPPER NOOKSACK (KM)	SOUTH FORK (KM)	NORTH FORK (KM)	MIDDLE FORK (KM)
EEM						
Blind	180.8	-	-	-	-	-
Distributary	9.6	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	-	-	-	-	-	-
Main	-	-	-	-	-	-
ESS						
Blind	76.1	-	-	-	-	-
Distributary	7.1	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	-	-	-	-	-	-
Main	-	-	-	-	-	-
TF						
Blind	71.7	-	-	-	-	-
Distributary	72.2	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	15.1	-	-	-	-	-
Main	-	-	-	-	-	-
F						
Slough	-	2.7	35.9	8.2	7.3	-
Tributary	16.1	98.3	23.5	80.0	15.1	5.5
Tributary-fan	-	-	2.0	6.0	4.0	5.4
Tributary-terrace	-	-	-	6.6	7.9	-
Main	4.5	70.7	64.2	61.7	85.7	20.3

Table 13. Channel edge (kilometers) in 1998. EEM = estuarine emergent zone; ESS = estuarine scrub-shrub zone; TF = tidal freshwater; V = variable salinity; F = freshwater.

TIME PERIOD and ZONE	DELTA (KM)	LOWER NOOKSACK (KM)	UPPER NOOKSACK (KM)	SOUTH FORK (KM)	NORTH FORK (KM)	MIDDLE FORK (KM)
EEM						
Blind	10.5	-	-	-	-	-
Distributary	11.5	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	-	-	-	-	-	-
Main	-	-	-	-	-	-
TF						
Blind	26.4	-	-	-	-	-
Distributary	14.6	-	-	-	-	-
Slough	8.9	-	-	-	-	-
Tributary	13.6	-	-	-	-	-
Main	12.9	-	-	-	-	-
V						
Blind	-	-	-	-	-	-
Distributary	15.6	-	-	-	-	-
Slough	-	-	-	-	-	-
Tributary	72.4	-	-	-	-	-
Main	-	-	-	-	-	-
F						
Distributary	7.0	-	-	-	-	-
Slough	-	9.6	30.7	6.4	37.2	19.2
Tributary	39.5	196.8	32.5	73.7	37.2	14.7
Tributary-fan	-	-	3.0	23.3	6.3	2.0
Tributary-terrace	-	-	-	2.8	8.2	-
Main	4.5	60.1	67.2	59.0	170.7	30.2

Table 14. Total length (kilometers) of ditched and unditched floodplain tributary channel mapped from 1998 aerial photographs. The length of ditched floodplain tributary is likely to be an underestimate, because we could not consistently map channels on aerial photos less than about 1 m in width.

	DITCHED (KM)	NOT DITCHED (KM)	PERCENT DITCHED
Lower Nooksack	71.7	26.7	73%
Delta	35.0	27.7	56%
South Fork	8.0	28.9	22%
Upper Nooksack	1.1	15.2	7%
Middle Fork	0.0	9.6	0%
North Fork	0.0	18.9	0%

Table 15. Area (hectares) of gravel bar and lowflow mainstem channels mapped from 1998 aerial photographs, in hectares, and percent of active channel accounted for by gravel bar.

	LOWFLOW (HA)	GRAVEL (HA)	PERCENT GRAVEL
Middle Fork	24	72	75%
North Fork	172	350	67%
Upper Nooksack	160	286	64%
South Fork	84	109	56%
Lower Nooksack	208	43	17%
Delta	21	0	0%

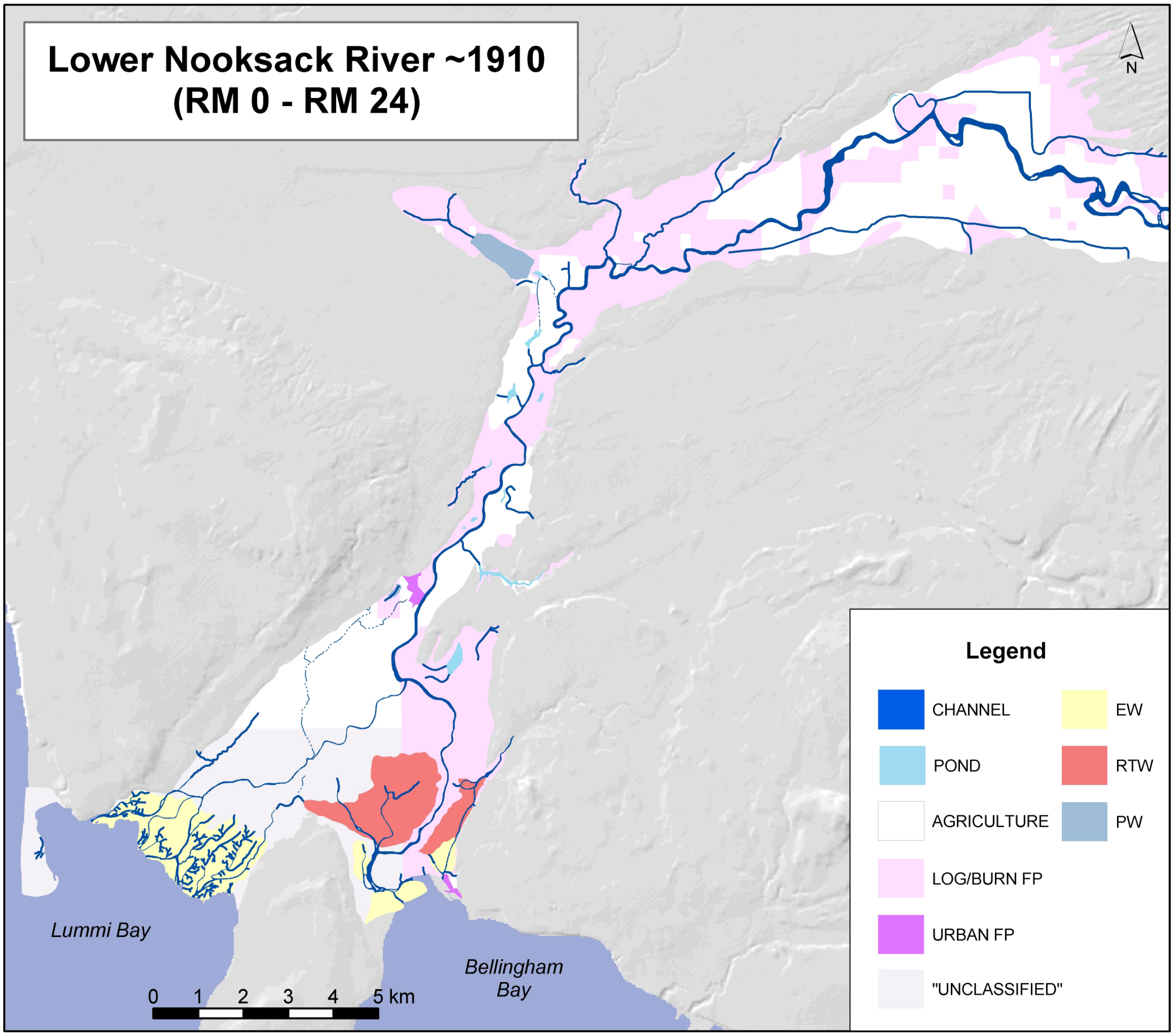


Figure 19. GIS mapping of the lower Nooksack valley, interpreted from archival sources, for approximately 1910. EW = estuarine wetland; RTW = riverine-tidal wetland; PW = palustrine wetland; AGRICULTURE = floodplain areas mapped as “cultivated land” by Mangum (1909); LOG/BURN FP = floodplain mapped as “logged off or burned over areas” by Mangum (1909); UNCLASSIFIED = mapped by Mangum (1909) as “unclassified;” no other land use information available; URBAN FP = areas shown as towns on Blaine 1907 USGS 15’ topographic map; other units are as in Figure 9.

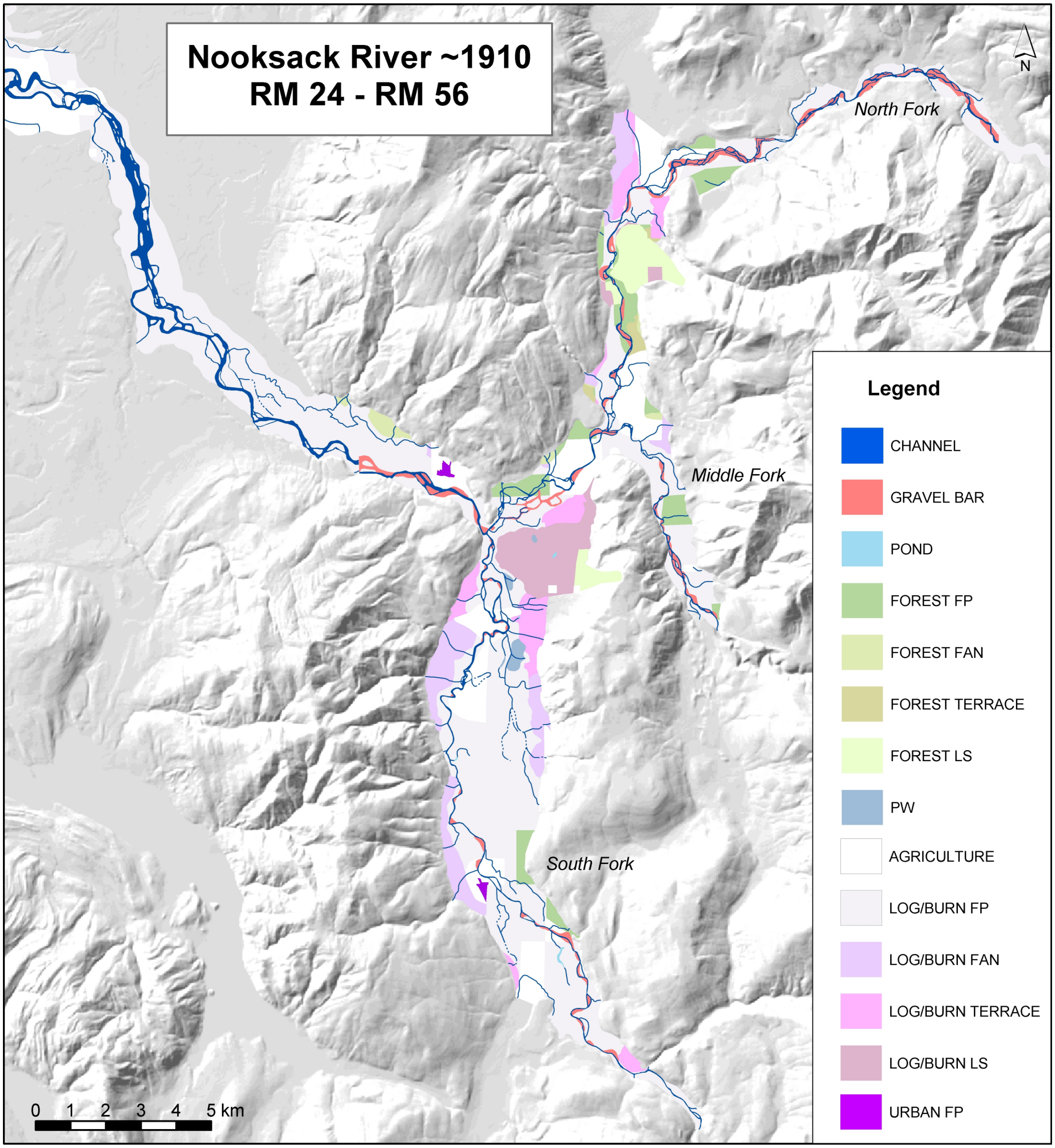


Figure 20. GIS mapping of the upper Nooksack valley, interpreted from archival sources, for approximately 1910.

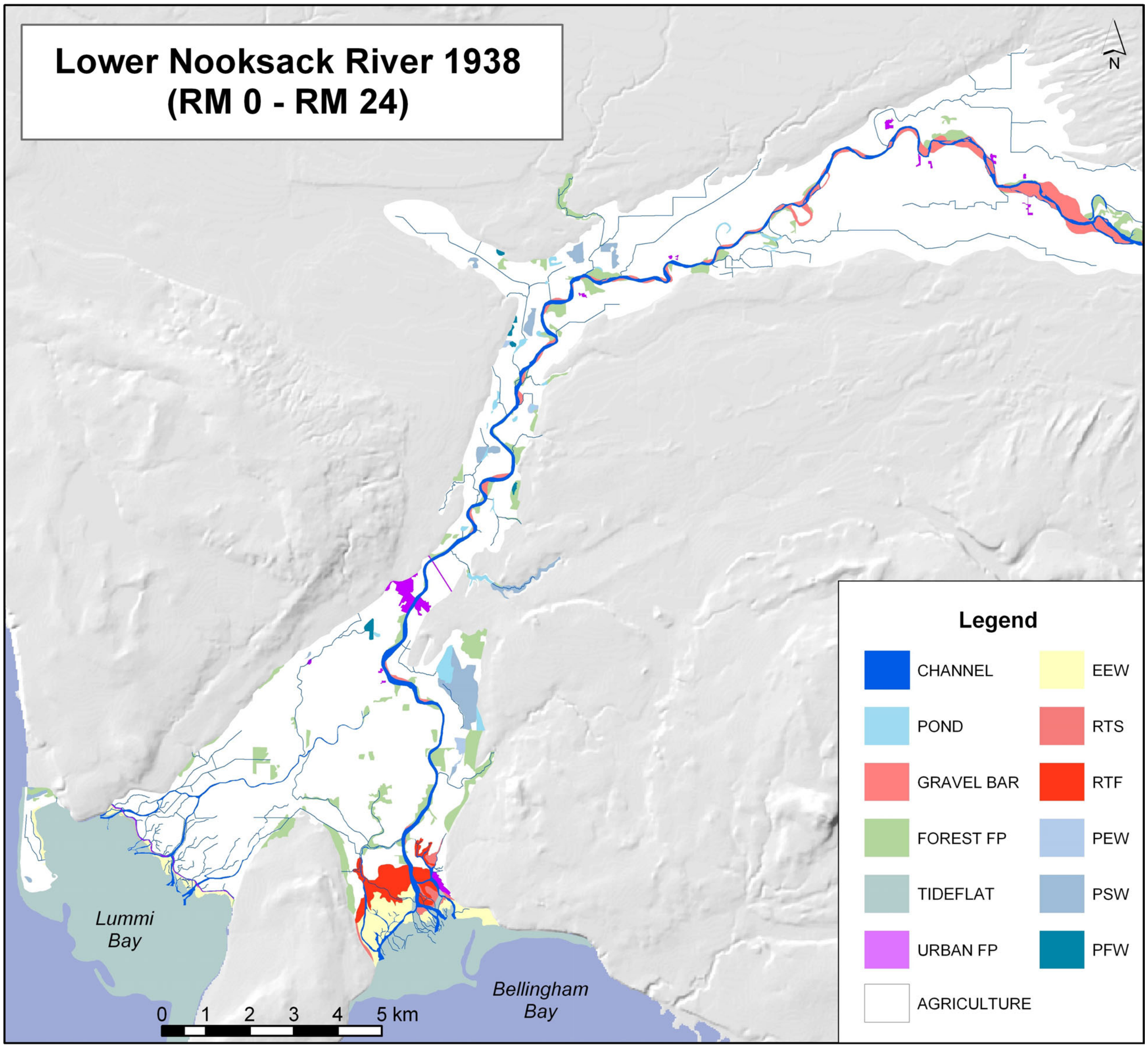


Figure 21. GIS mapping of the lower Nooksack valley, interpreted from 1938 aerial photos. Extent of tideflats is from 1952 7.5’ USGS topographic maps.

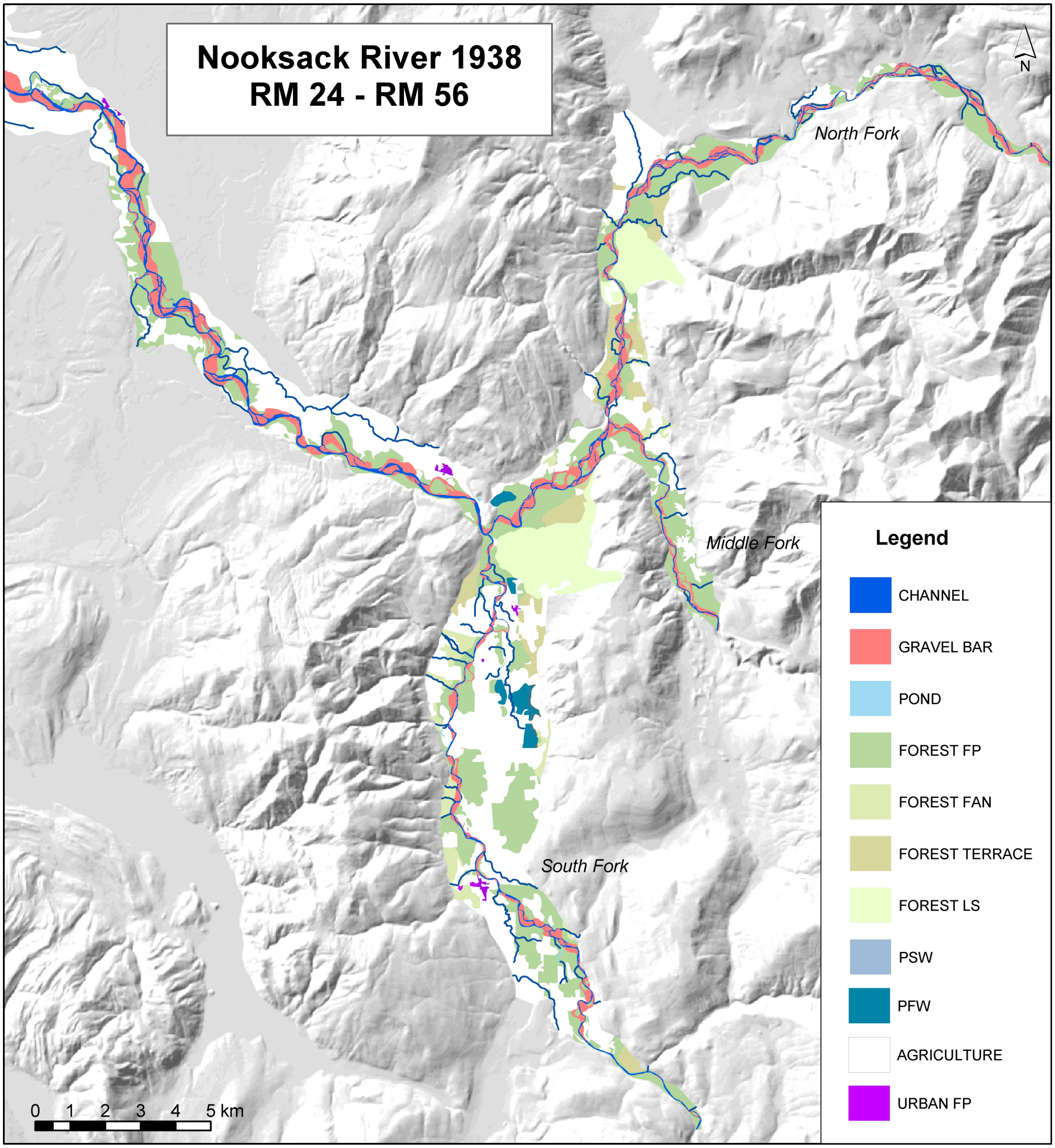


Figure 22. GIS mapping of the upper Nooksack valley, interpreted from 1938 aerial photos. Units are as defined previously.

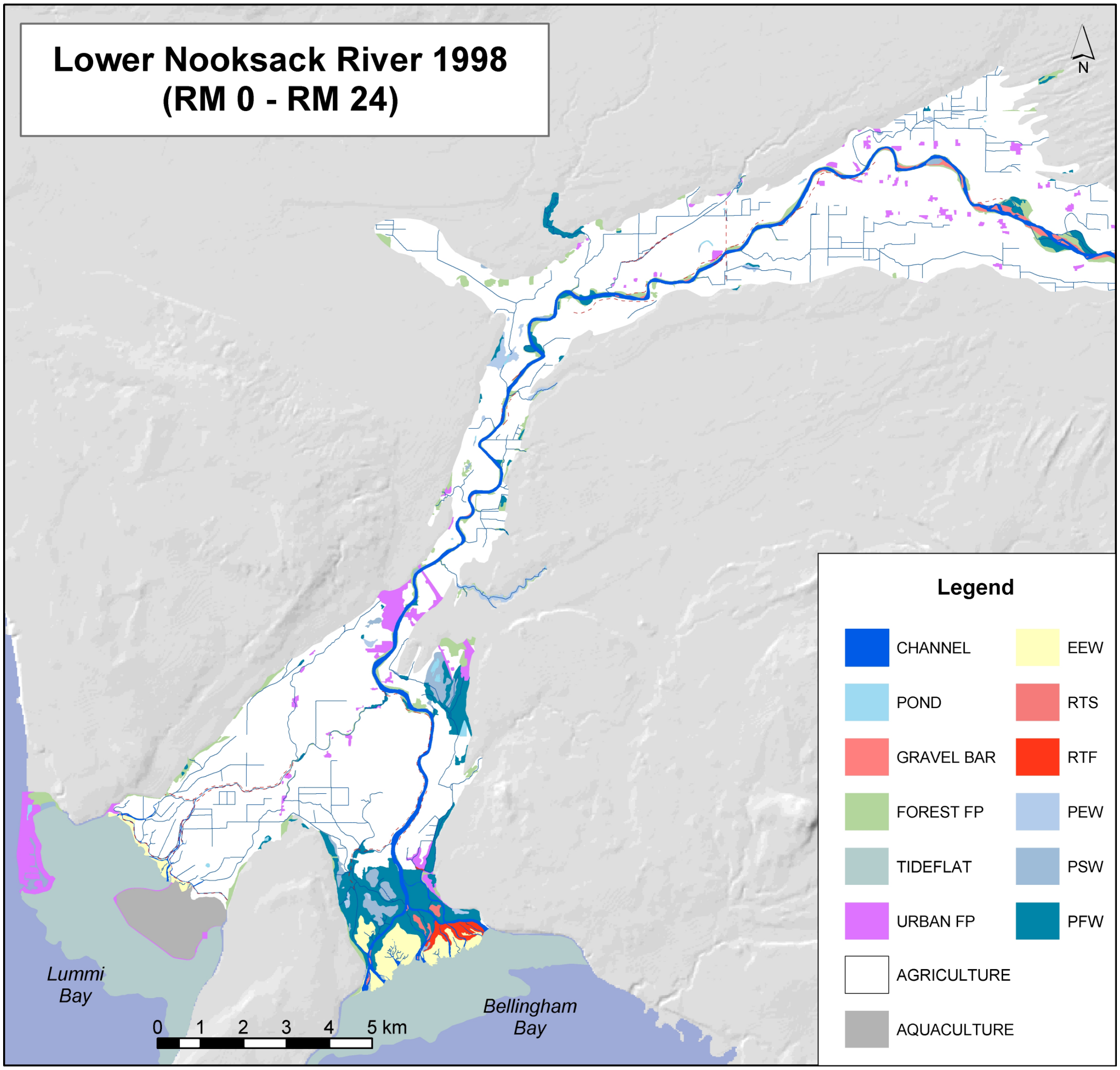


Figure 23. GIS mapping of the lower Nooksack valley, interpreted primarily from 1998 aerial photos. Extent of tideflats is from NOAA Bellingham Bay 1989.

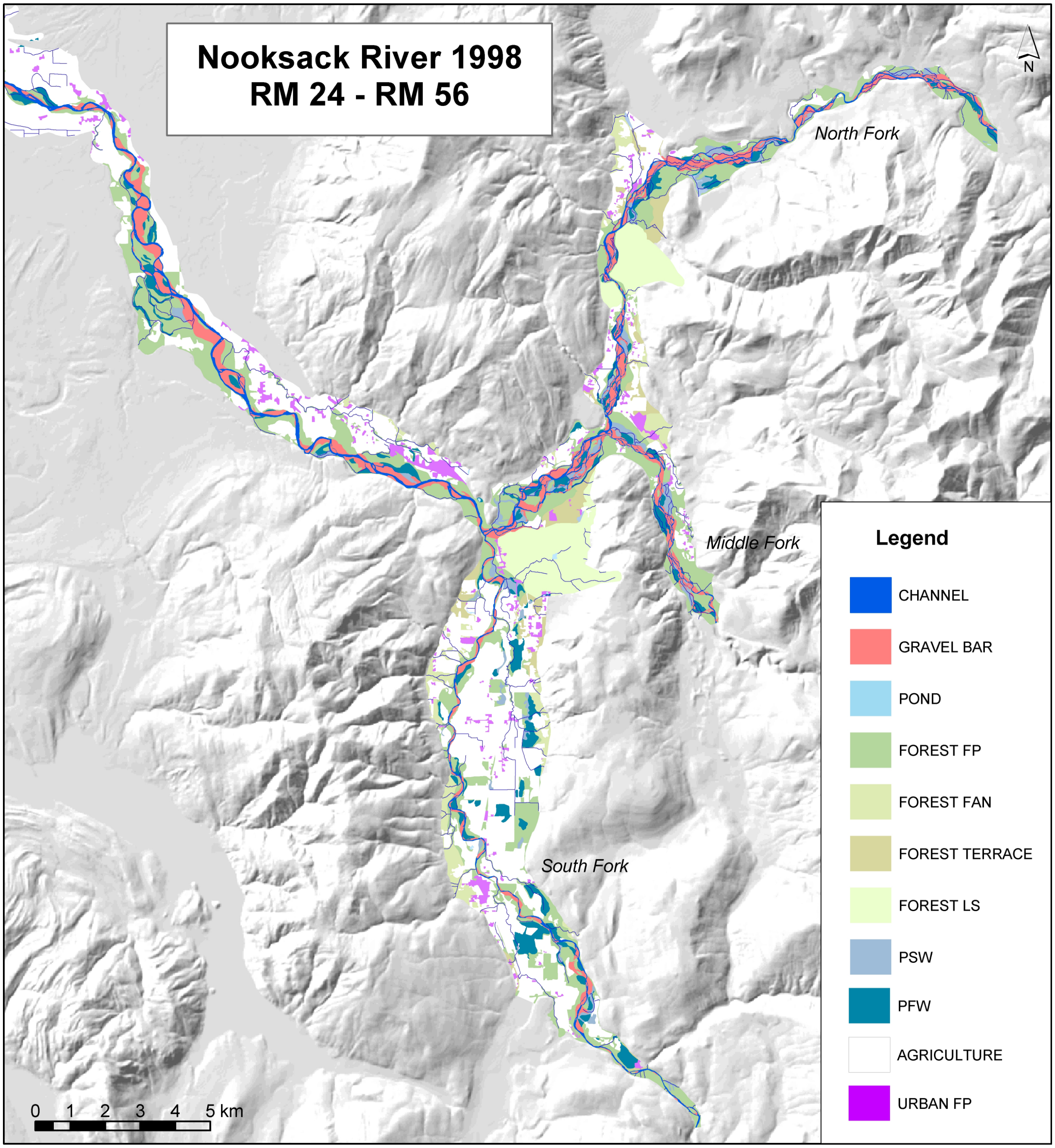
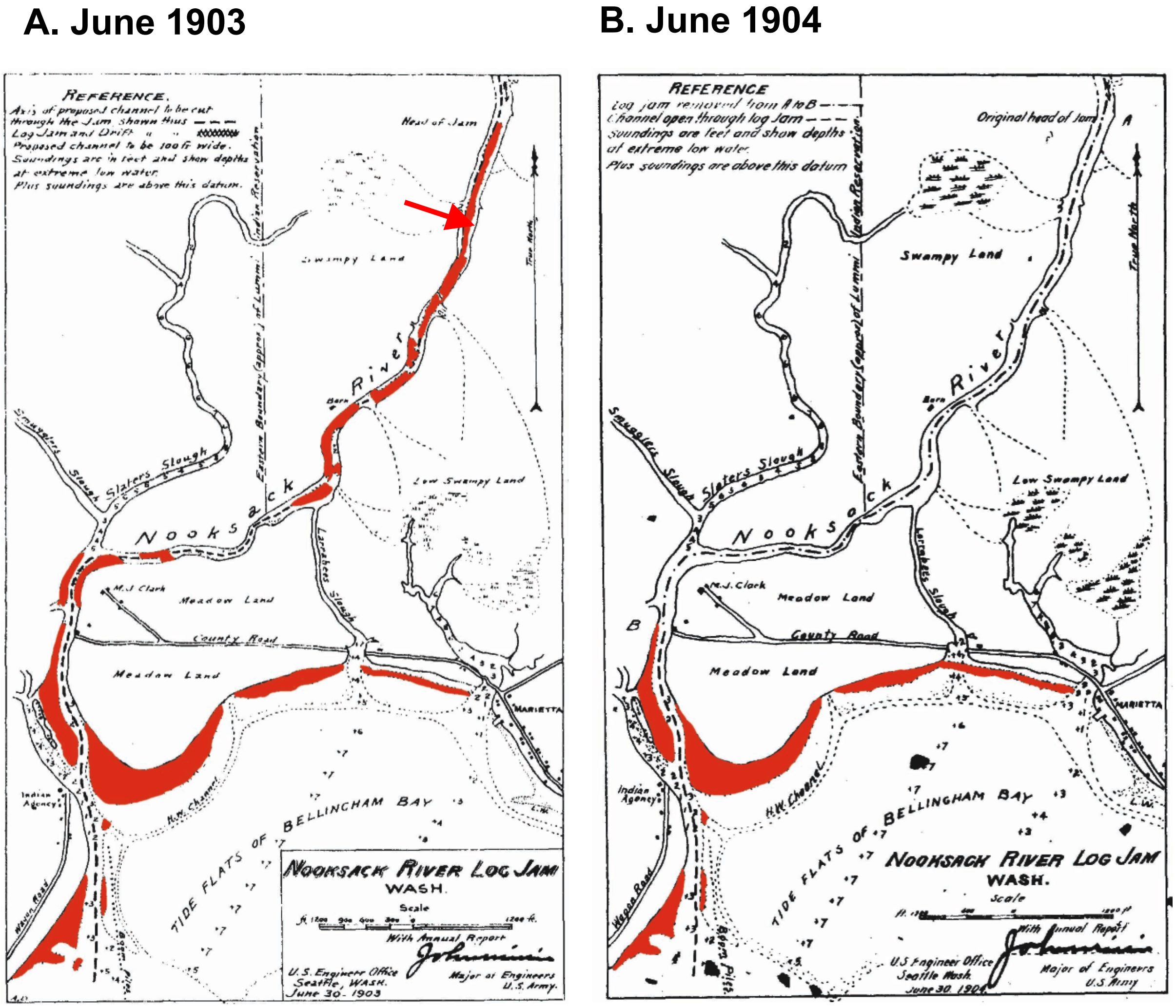


Figure 24. GIS mapping of the upper Nooksack valley, interpreted primarily from 1998 aerial photos.


A. June 1903

B. June 1904

Figure 25. Maps of the log jam at the mouth of the Nooksack River in June 1903 (A), prior to the clearing of a channel through the jam, and June 1904 (B), after the channel was created. From Chief of Engineers (1903; 1904). Jam area highlighted with red; arrow shows upper extent of jam in 1903.

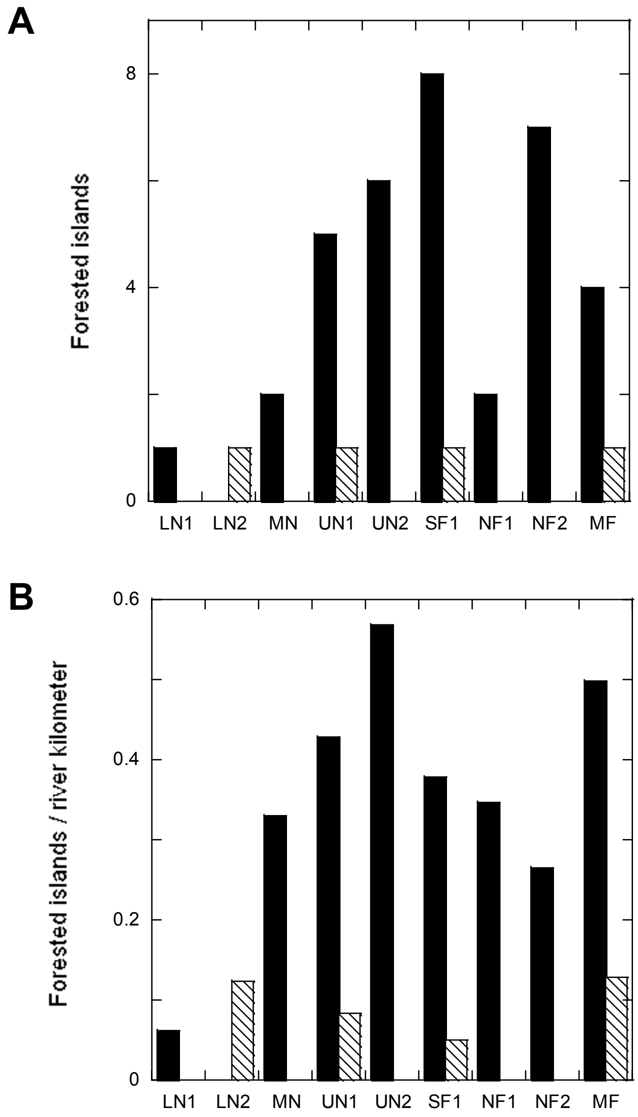


Figure 26. (A) Number of forested islands (island width approximately greater or equal in width to channel width) on GLO plat maps (solid bar) and on 1998 aerial photographs (striped bar). Segment abbreviations are as used elsewhere. (B) Same data as in panel A, but normalized by segment length as measured along lowflow channel centerline.

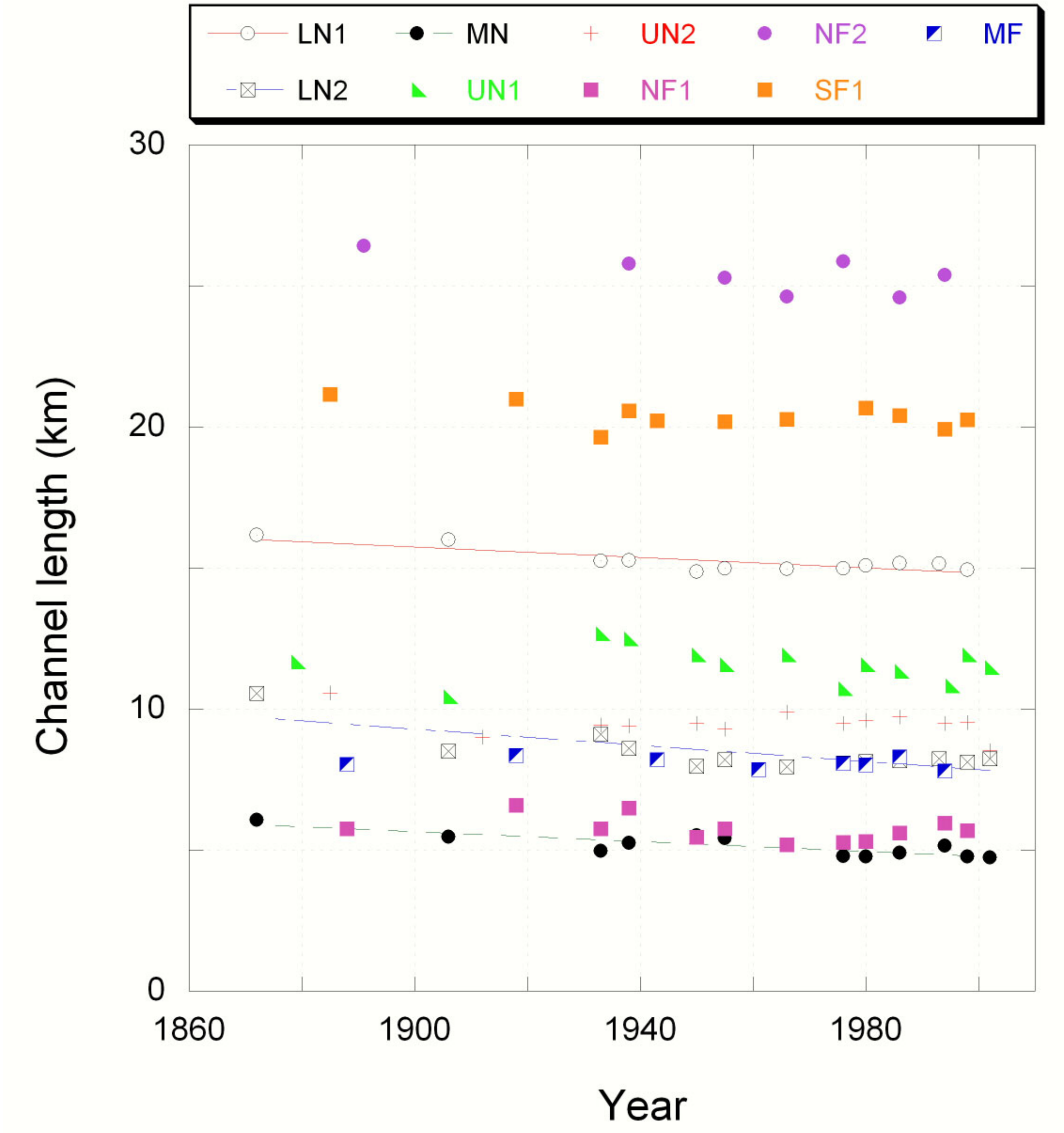


Figure 27. Change in channel length through time. Length is measured along low-flow channel centerline. Segment abbreviations are as used elsewhere. See text for explanation.

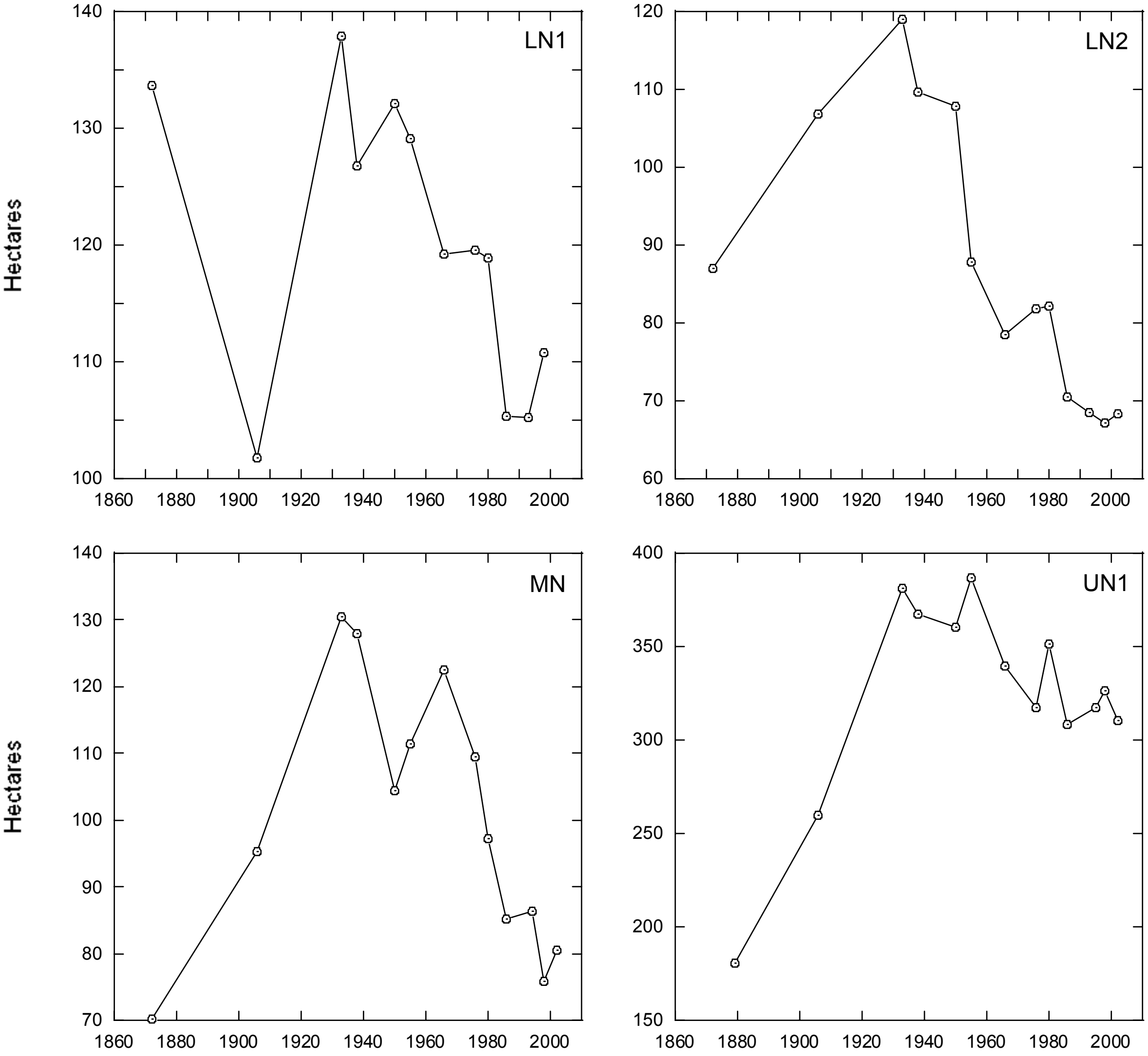
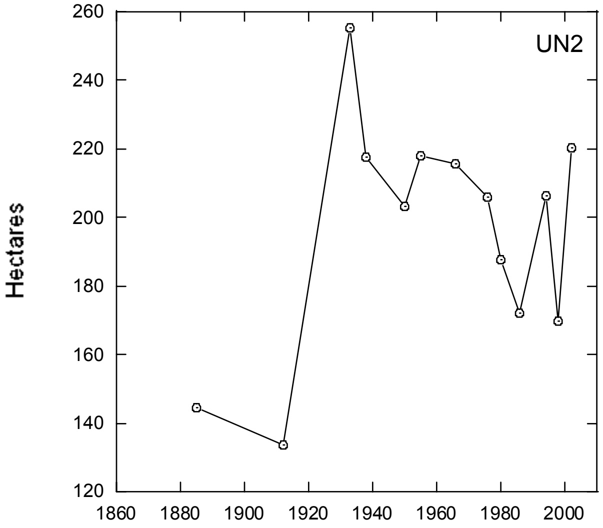
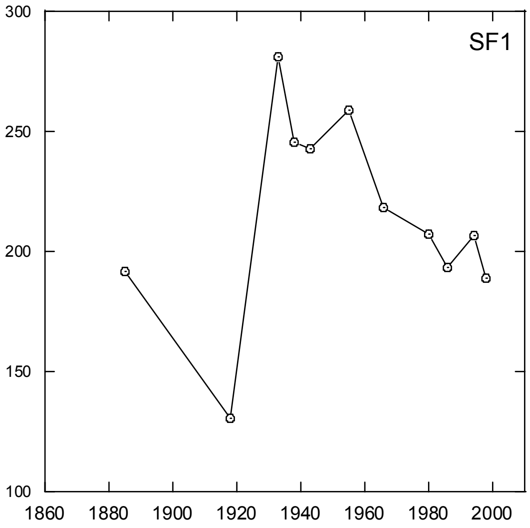


Figure 28 (continued on following page). Change in area of active channel (low flow channel and gravel bars) through time, for different study segments.


UN2
Hectares
260
240
220
200
180
160
140
120
1860
1880
1900
1920
1940
1960
1980
2000


SF1
300
250
200
150
100
1860
1880
1900
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1940
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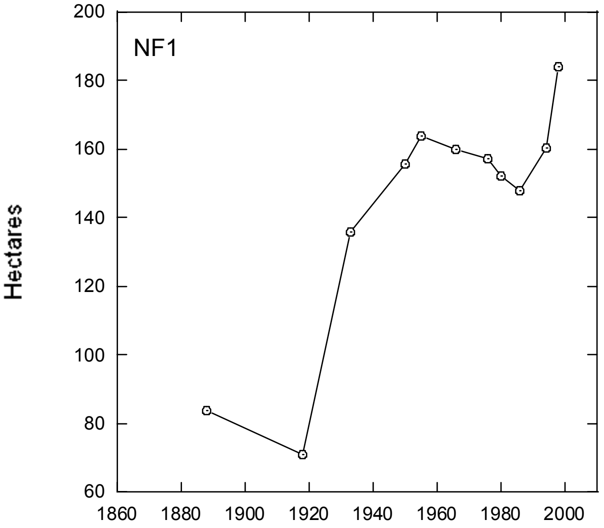
1980
2000


NF1
Hectares
200
180
160
140
120
100
80
60
1860
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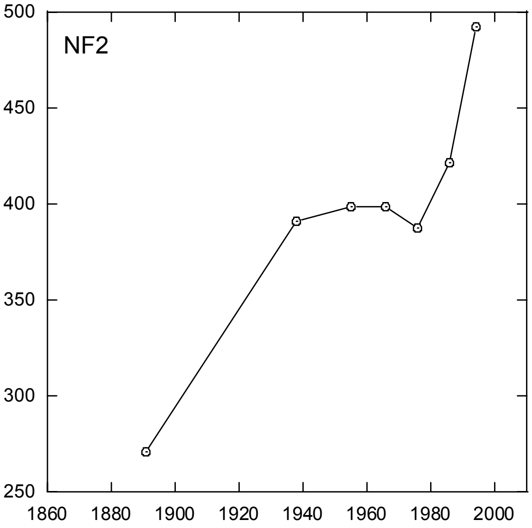
1940
1960
1980
2000


NF2
500
450
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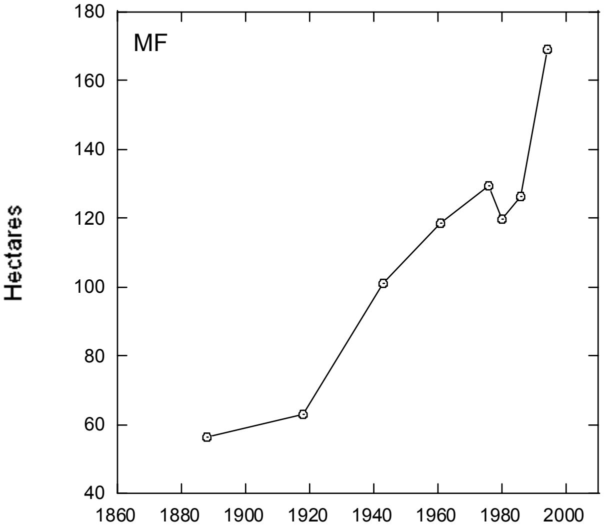
MF
Hectares
180
160
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1860
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DISCUSSION

Implications for Restoration

As shown in this report, the various river segments and their associated valley bottoms in the study area differ in fundamental character—in topography, landforms, river morphology and dynamics, and historical habitats. Restoring riverine processes and habitats differ between these contrasting settings. Collins et al. (2003) outline a broad difference in restoration emphasis between valleys such as the lower Nooksack and the upper Nooksack, for example. Emphasis is on hydrologic reconnection in the former, and on restoring a dynamic river-forest connection in the latter. In the lower Nooksack, opportunities exist to connect the river to the (few) meander cutoff oxbows, and to restore water to the historic wetlands in the topographic lows of the floodplain. Riparian restoration along rivers having migration rates that are small, (and predictable in direction and nature) as in the lower Nooksack, can effectively be confined to a relatively narrow streamside zone. In valleys, having a more dynamic channel migration and avulsion, and in which floodplain sloughs are an important habitat, emphasis is on a riparian restoration that involves a sequence of activities that bring about a linked "restoration succession" of the riparian forest, channel morphology and habitats, and a dynamic connection between river, forest and wood jams (Collins and Montgomery 2002). Different opportunities exist in the estuary, including the potential to recoup extensive distributary and blind tidal channel habitats by restoring flow to diked-off channels or land areas. Restoring lowland river valley habitats can be a critical part of restoring aquatic habitat to a watershed, because of the historic amount and variety of habitats that can be recouped, and because many lowland habitats are inherently buffered from headwater processes (Collins et al. 2003).

Notes to Users of Data

Historical habitat mapping, and quantitative measures made from it, will always be imperfect. There is not at this time a standard approach, and we have had to innovate. We can refine aspects of our estimates as we refine our methods and as other researchers develop new methods, and as we find it feasible to make finer-scale searches for local information. However, historical estimates will always be limited. We were not there to see the landscape, and those who were there—the GLO surveyors and others—were not employed to describe and quantify aquatic habitats. Because we are using data not intended for the use described herein, and because we do not always have reliable means of checking the data against other sources, there will always be uncertainty in historical characterization and estimates.

As described previously, we have made an effort to systematically identify uncertainty by making our mapping methods transparent and linking certainty and assumptions to each feature in the GIS coverages. It is important that users of this information interpret quantitative estimates in light of the uncertainties that we have identified, as well as be alert to additional uncertainties of which we may not yet be aware . This includes, when making quantitative comparisons of habitats between historical and current conditions, being aware of the biases introduced by the two time periods having been mapped using different materials and methods. Specific points to keep in mind in using the historical GIS products include:

(1) Each feature in our mapping has been given a source code that reflects the sources we used, the logic with which we used those sources, and the overall relative strength of evidence. The relative certainty varies in space and the nature of uncertainty differs between different types of feature.

(2) The GLO meandered (field-surveyed) large channels, but the channels were not always accurately drawn. While on average, this does not appear to introduce more than a few percent error in channel dimensions, locally the discrepancy can be greater.

(3) The GLO rarely mapped smaller floodplain creeks and tributaries. They simply noted the feature when they encountered it along a section line, or while meandering a river, and then sketched in the channels, "connecting the dots." We made use of 1930s aerial photos to adjust the channel locations

shown on the GLO maps, but this approach is limited by the detail with which channels or, more often, relict channels are shown on these early photographs, which is highly variable.

(4) In the study area, the Coast Survey rarely mapped tidal creeks in detail. We have mapped many historical tidal creeks from relict channels visible on 1930s photos in diked land, but cannot map all channels that existed. We have attempted to compensate for this incompleteness, in estimating tidal creek area and length, by extrapolating from recent tidal networks in other estuaries, as described. These extrapolations are provisional, made using data from only two areas. Higher-confidence extrapolations await the availability of more data from which to determine the variables controlling tidal creek network density and channel area.

(5) Recent field studies show that riverine environments of the Pacific Northwest include numerous floodplain sloughs, and that many of these are difficult to map except by thorough ground surveys or by high-resolution topographic data. It is certain that we have not mapped many of the smaller floodplain sloughs.

(6) We have used a coarse wetland classification, and there would have been quite a bit of variation historically among wetlands within the same map type. Our inundated area classification provides some functional refinement. While it is likely that we will be able to refine our wetland classification, it is important to keep in mind that within the existing scheme, one wetland within the same broad category may differ significantly from another in the same category.

(7) As indicated previously, the accuracy of our historical wetland descriptions (including wetland area and seasonally inundated area), generally improves as wetland size increases, and because of this inundation information is more reliable for a subwatershed in aggregate than for individual smaller wetlands.

Limitations imposed by the methods we used to create the more recent coverages are discussed earlier in the report. Of particular note is that the 1998 coverage was made entirely from aerial photographs, NWI wetlands mapping, and other sources, without benefit of field checking. The user can refine this data by reference to more detailed aerial photographs and with field checking.

ACKNOWLEDGMENTS

This project was funded by the Nooksack Indian Tribe, with a grant from the USDI Bureau of Indian Affairs, and is a contribution of the River History Project, supervised by D. R. Montgomery in the Department of Earth and Space Sciences at the University of Washington. We thank Treva Coe, Nooksack Tribe Natural Resources Department, for administering this project. Paula Cooper, Whatcom County Public Works, provided digital topographic information, from which Harvey Greenberg, University of Washington Department of Earth and Space Sciences, created the DEM used in this analysis. Charles Kiblinger created the georeferenced 1938 photomosaics from photographs made available by the Army Corps of Engineers, Seattle District. We benefited from discussions with Tim Wahl and his knowledge of the early history of the Nooksack and Lummi deltas and of early map sources. Data displayed in Figures 2, 3, 7, 8, 26, 27, and 28 were developed in part under a separate contract with Whatcom County Public Works and are described in Collins and Sheikh (2004).

Credit for Figure 5: Image is excerpted from map: “Map showing the line of boundary between the United States & British possessions: from the point where the 49th parallel of north latitude strikes the western coast of the continent "to the middle of the channel which separates the continent from Vancouver's Island and thence southerly through the middle of said channel" &c. to Fuca's Straits, in accordance with Treaty of June 15th, 1846 ;” publication date 1868; map scale 1: 300,000; map is from: Message of the President of the United States, communicating, In compliance with a resolution of the Senate of December 18, 1867, information in relation to the occupation of the island of San Juan, in Puget Sound. Washington, D. C. G.P.O., 1868. (Ex. Doc. / 40th Congress, 2d Session, Senate ; no. 29; from University of Washington Libraries Map Collection.

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APPENDIX 1: HISTORICAL WETLANDS

We synthesized historical field observations of wetland conditions in order to characterize their hydrology and whether they would provide habitat for salmonids in winter and summer. The descriptions, below, are followed by quantitative estimates of historical and recent inundated wetland area. The wetland codes given below correspond to codes in the historical GIS coverage.

Historical estuarine wetlands

There were no bearing trees near to four of the 10 survey points within the area mapped as scrub-shrub wetland, and the trees that were present averaged 20 m distance from the survey point (Figure 13).

NKS_LUM380101 Lummi Delta Estuarine Emergent (316 hectares) and *NKS_LUM380102 Lummi Delta Estuarine Scrub-Shrub* (224 hectares). The GLO surveyed the area in August 1859, then again in October 1873. The second survey included lines along 1/16-section boundaries because it was carried out in the Lummi Indian Reservation (see Collins et al. 2003 for explanation). The following lines are within the area we mapped as estuarine emergent wetland: Running south between S. 14 and S. 15 (T38NR1E) on August 22, 1859: "Through an open grass flat" and the line description of "Land level grass flat, good soil, but subject to overflow at extreme high tides;" then on October 2, 1873 "Land low tide prairie, subject to overflow of 3 ft." [Descriptive text quoted from the GLO notes are from the narrative written while the surveyors ran a line, and from the line summaries they wrote later for the entire lineSurveying west between S. 11 and S. 14, T38NR1E, on August 22, 1859, "Land level, low and wet, and with the exception of the last 20 chains, covered with willow and crabapple. Soil good but subject to overflow at extreme high tides." Between S. 10 and S. 15, T38NR1E, on August 22, 1859: "Overflowed at extreme high tides. It produces good grass. Timber a few dead willows" and on October 3, 1873 "Land low tide prairie, subject to heavy overflow." Through the south ½ of S. 10, T38NR1E, on October 8, 1873, surveyors noted “Wet tide prairie subject to overflow of 2 to 3½ feet” and through the center of the same section on the same day, “…low tide prairie subject to overflow of 18 in. to 3 ft.” Lines entirely within the area mapped as estuarine scrub-shrub include between S. 2 and S. 11, (T38NR1E), on October 4, 1873: “…tide prairie. Subject to overflow of 18 in. to 2 ft,” and between S. 11 and S. 12 (T38NR1E), “Low and swampy…willow and crabapple” on August 22, 1859. (For simplicity we use the surveyor’s common names for trees and other vegetation; see Table 5 for equivalent scientific names for commonly identified trees.) Between S. 3 and S. 10, T38NR1E, the line description is “Land except West 15 chains. Tide prairie with scattering crab apple” on October 8, 1873. Surveying east through the north ½ of S. 12, T38NR1E, the notes read “Land low bottom subject to overflow. Scattering spruce and cedar timber. Undergrowth Willow and Hemlock” on September 22, 1873, and through the north ½ of S. 11, T38NR1E, “…subject to light overflow…” on October 4, 1873. Survey lines that cross through the boundary we have mapped between emergent and scrub-shrub vegetation include between S. 10 and S. 11, T38NR1E, “Subject to overflow of 18 in to 2 ft” on October 3, 1873, and through the center of S. 11, T38NR1E, “…tide prairie subject to overflow of 12 in. to 18 in.” (October 4, 1873), and through the north ½ of section 10, T38NR1E, “Tide prairie subject to light overflow” on October 9, 1873.

NKS_SDY380104 Sandy Point Estuarine Emergent (49 hectares). We map Sandy Point, the prominent point of land to the west of the Lummi delta, as primarily estuarine wetland with grassland (presumably largely sand dunes) fringing the southern and western margin, based on U. S. Coast & Geodetic Survey (USC&GS) T-1871, surveyed in 1888, and GLO mapping. Their notes (from August 24, 1859) indicate for the line between S. 8 and S. 9, T38NR1E, running south, “At 8.39 chains leave swamp and enter grass flat…Thence across mud flat” and the line description includes, “ Land level, soil 3rd rate. Prairie of good grass but unsuited to agriculture.” The entry made identically for the lines between S. 9 and S. 16, between S. 8 and S. 17, and between S. 10 and S. 17: “Level prairie, soil gravelly and 3rd rate. Good grass cover.”

NKS_DLT380201 Nooksack Delta Estuarine Emergent Wetland (29 hectares). The USC&GS mapped a small amount of saltmarsh in the Nooksack River delta. The GLO survey along only one line crosses the area. Running north between S. 7 and S. 8, T38NR2E, the notes indicate "At 6 chains leave <u>tide prairie</u> [underlining added] and enter willow brush" on July 7, 1859.

Immediately upstream of the mapped emergent wetland we map a 103 hectare (ha) map unit of "scrub shrub floodplain," which we have not mapped as wetland. The USC&GS sheet T-1798 shows the area as forested. The symbol used on the chart in that era signified "Woods of any kind (or leaved Trees)" and is distinct from the symbols used to describe coniferous forests elsewhere on the sheet. The GLO field notes include descriptions of several lines crossing the area. Traveling north between S. 7 and S. 8, T38NR2E, the notes indicate [as they leave the area we map as estuarine wetland] "At 6 chains leave tide prairie and enter willow brush" and "at 23 chains enter rushes with little water" and at 28.5 chains the south bank of the Nooksack River. The line description is "Land level and subject to overflow (but to no great depth). No timber. Covered with willow, grass, rushes, and crabapple" in July 7, 1859; this line description includes the area north of the river, which we map as wetland. On the same day, surveying east between S. 7 and S. 18, T38NR2E, the notes indicate: "At 10.5 chains enter hardhack and willow." Notes from 1873 for the same line indicate at 20 chains "enter willow bottom" on October 21, 1873. Notes from the same year from a line surveyed through east through the center of S. 18, indicate "[at 27 chains] enter willow bottom" and "[at 38.5 chains] the beach." The 1938 aerial photographs have no meaningful information (e.g. relict tidal channels) because of the extent of deltaic progradation between the 1870s and 1938. While it is possible that the area was an estuarine or scrub-shrub wetland by today's criteria, in keeping with the USC&GS chart and the written descriptions by the GLO, we have mapped the area as simply scrub-shrub. Finally, USC&GS sheet T-1798 (surveyed 1887) shows a "Lummi village" in the NE ¼ of the NW ¼ of S. 18 (T38NR2E), which also supports the interpretation that the area was not a wetland.

We mapped the tideflats in Figure 9 in the Lummi and Nooksack estuaries as the area between the estuarine marsh and the MLLW line depicted on Coast Survey charts. We do not at this time have other confirming sources.

Historical riverine-tidal wetlands

The Lummi-Nooksack estuary had extensive riverine-tidal wetlands. We distinguished these wetlands using several criteria. The USC&GS charts use symbols that distinguish freshwater marsh and saltmarsh. Distinguishing patterns on the U. S. Geological Survey (USGS) 15' Blaine 1907 topographic sheet also show the difference between saltmarsh and freshwater marsh. We then used the GLO field notes and high-resolution DEM to refine boundaries shown on the other two map sources. The GLO bearing tree record indicates that trees were small and very widely spaced. Six of 39 survey points lacked nearby bearing trees. Of those with trees, the average distance from them to the survey point was 39 m. More than one-half of bearing trees (38 of 68) were willow, which averaged 13 cm in diameter. Crabapple (16 of 68) and alder (10 of 68) were the other common bearing trees. Detailed descriptions of riverine-tidal wetlands from GLO notes follow.

NKS_LUM380103 (314 hectares) *and NKS_LUM390201Riverine-Tidal Scrub-Shrub Wetland, Lummi Delta Side* (185 hectares). The GLO notes include the description of a line through the S ½ of S. 2, T38NR1E, on October 6, 1873 "Land level bottom subject to overflow of 2 to 4 ft [underlining added]. Timber spruce and alder. Undergrowth Willow and Rose bush," through the center of S. 2 on the next day "Land level bottom except West 10 chs. Subject to overflow of 1 to 3 ft. [underlining added] and covered with Willow thicket," and on the same day surveying east through the north ½ of S. 2, "[at 23.5 chains] Enter bottom," then "[at 37 chains] Open marsh brs. [bears] N. E. and S. W.," and "[at 44.5 chains] Enter Crab Apple thicket." The latter's line description includes "Spruce and Alder…with heavy undergrowth of Willow, Crabapple, and Rose bushes." Traveling north between S. 1 and S. 2, T38NR1E, the notes at

20 chains read “Enter swamp bearing NE and W,” and the line description is “Land level bottom. All subject to overflow from 2 to 5 ft [underlining added]. Timber spruce, Alder, and Willow. Undergrowth Willow” on September 23, 1873. The line through the S. ½ of S. 1, T38NR1E, is described as “West of river. Swamp covered with Willow & Tule. Subject to overflow of 3 to 5 ft [underlining added].” on September 25, 1873; through the center of S. 1, as “West side of river wet swamp covered with Willow & Tule…Timber, Spruce, Cedar and Alder. Undergrowth Willow Hardhack & Raspberry” on September 24, and through the N ½ of the section on September 25 “West of river. Swamp covered with Willow and Tule. Subject to overflow of 3 to 5 ft [underlining added].” On the north boundary of S. 1, T38NR1E, surveying west, the terrain at the start was described as “In swamp covered with dense growth of flag Willow and Hardhack. Water in pools [underlining added] …” and the line is described as “Land, marsh covered with Willow, Hardhack and Tule. …subject to overflow of 2 to 5 ft [underlining added].” on September 10, 1873. The line between S. 35 and S. 36, T39NR1E indicates at 36.5 chains “Leave marsh & enter dry ground and dead timber.”

NKS_DLT380202 Riverine-Tidal Scrub-Shrub Wetland, Nooksack Delta Side (718 ha). The GLO notes indicate, between S5 and S. 6, T38NR2E, “[moving southward, at 18.5 chains] Open marsh bears West and S. E.” and the line is described as “…subject to overflow from 2 to 4 ft [underlining added]” on October 16, 1873; on July 19, 1859, the line [traveling northward] was described as “…high water overflowed the 1st 65 chains “ [underlining added]. Surveying northward between S. 4 and S. 5, T38NR2E, the notes indicate “[at 5.5 chains] leave bush and enter open swamp N. E. and S. W.” and “[at 27.2 chains] enter timber E & W,’ then ending at 53.4 chains, at the “…edges of an impassable swamp…water from 2 to 4 feet deep [underlining added] and covered with hard hack and willow bush” on July 19, 1859. Between S. 5 and S. 8, the line is described on July 19, 1859 as “…subject to overflow to the depth of a foot except along the stream where it is higher [underlining added] …The whole will make good meadow land. Timber, Willow, Crabapple & alder in small clumps.” The northern 48.47 chains between S. 7 and S. 8, T38NR2E, is described as “…marsh with scattering willow and crabapple” on October 17, 1873. Within S. 7, a line through the center was "…covered with Willow and Crabapple" (October 22, 1873), through the N ½ was "…marsh covered with scattering clumps of Willow and Crabapple" (October 23, 1873); through the south ½ of S. 6 it was "…Marsh covered with clumps of Willow and Hardhack. Subject to overflow of 2 to 3 ft [underlining added]." (October 23, 1873), through the center of the section there was "Marsh covered with scattering Willow and Hemlock."

The field notes from summer 1859 suggest that at least part of this Nooksack-side wetland was inundated in summer. The Bellingham Bay side may have been wetter in summer than the Lummi side. This speculation is based in part on topography—the Bellingham Bay side wetland would probably have been lower in elevation than that of the terrain downstream, fronting Bellingham Bay which would have hindered drainage—and based on the rendering of wetlands on the delta on the Blaine 1907 USGS topographic map. The Blaine Quadrangle depicts about 60% of the area we map as riverine-tidal wetland in the Bellingham Bay with a wetland symbol. That none of the Lummi Bay side riverine-tidal wetland was depicted as wetland may reflect the effects of early diking (the Blaine 1906 quadrangle does not show diking, but does show roads along the Lummi River), or it may reflect drier conditions. The GLO notes indicate that both marshes are subject to inundation by 2-5 feet of water in the winter, which is comparable to the current relief in the marsh area. On the basis of these observations, we assume that about one-third of the NKS_DLT380202 wetland was inundated in summer, none of the NKS_LUM380103 and NKS_LUM390201 were summer-inundated, and that both were largely (three-quarters) inundated in winter (see Table A for summary of assumptions used in characterizing wetland inundation).

Table A. Assumptions used in developing inundated area estimates. Evidence for characterizing inundation is higher for those wetlands coded with "A" and lower for those coded with "B;" within both, lower code numbers have higher confidence than higher code numbers.

CODE	ASSUMPTION
A1	Derived from proportion of line in which water depth is recorded (e.g. if 8 km of 12 km cumulative length of line is noted as inundated, we infer that approximately 75% of the area is inundated).
A2	Field notes described the seasonality of inundation for the wetland as a whole (e.g. "overflowed from the beginning of the wet season until July").
A3	Wetland appears to have been inundated in the 1930s photographs, or more recent photographs, or part of the wetland appears inundated, with the amount estimated from the photos.
A4	Winter inundation is assumed if field notes or aerial photographs from summer observations indicate, with consistency throughout the wetland, that the area is subject to inundation, and the inundation is at least a few feet.
A5	Tidally influenced freshwater wetland for which field observations of overflow indicators (and hydrologic inference) indicate area is primarily inundated by river flooding for prolonged periods in winter.
A6	If there is field evidence for summer inundation, we assume that winter inundation is at least as great (more, if there is evidence to support that).
A7	Small wetland, for which relatively few field observations are available, but which indicate winter inundation; necessary to estimate the proportion of area inundated.
A8	Assume if the area is not inundated in the winter, it is not inundated in the summer.
B1	If flooding is noted to have been caused by beaver dams, it is assumed to include at least summer inundation.
B2	Lacking any other information, *forested* riverine-tidal wetlands are assumed to be inundated periodically in winter, during certain high tides and river floods only.
B3	*Forested* palustrine wetlands are assumed to be dry in the summer unless there is evidence to the contrary.
B4	If area is identified as swamp or marsh but no water depths are given and no indications of winter overflow are given, assume no winter inundation.
B5	Assumed similar to nearby, larger wetland for which more data is available.
B6	Summer field notes do not describe inundation.
B7	Soils information used to estimate summer inundation.
B8	Insufficient information to assume inundation.
B9	Estimate winter inundation from area mapped as wetland on topographic map.

Historical palustrine wetlands on the greater Nooksack delta

We mapped three smaller wetlands on the greater Nooksack delta area.

NKS_SDY380105 (21 hectares). The surveyors on August 23, 1859 described this area north of Sandy Point, surveying westward between S. 4 and S. 9, T38NR1E as "willow-hardhack swamp" from 61 chains to the corner. Westward between S. 5 and S. 8, the surveyors began in "dense swamp" which they characterized in the line description as "<u>dry in summer and wet in winter</u> [underlining added]. Hardhack-crabapple swamp." About one-fourth of the area was mapped as wetland on the Blaine 1906 quadrangle, and we have taken this as an estimate of winter inundation.

NKS_DLT390203 Tennant Lake area wetland (34 hectares). This area is identified as a "swamp" between S. 32 and S. 33, T39NR2E on October 6, 1871. On the 1938 aerials, taken in summer, conservatively one-fourth of the marsh appears inundated; we have taken this as an estimate of summer inundation. We have assumed a winter inundation based on the more-detailed information available for similar wetlands in the nearby lower mainstem wetlands (see below).

NKS_LUM390202 (50 hectares). The GLO surveyors traveling northward between S. 29 and S. 30, T39NR2E noted "[at 68 chains] Enter Hard Hack swamp" and "[at 80 chains] Corner cannot be established [on account of water] for sections 19, 20, 29, and 30" on October 13, 1871. Mid-October could either represent late dry season conditions, or winter conditions. Conservatively we have assumed the observations to represent winter conditions.

Historical palustrine wetlands along the Nooksack River mainstem

Topographic depressions on the floodplain of the lower Nooksack were sites of extensive freshwater wetlands (see Figure 9). The GLO field surveyors commonly described these marshes as "hardhack swamp," "willow swamp," and "beaver swamp" and noted standing water (see descriptions below). The eight entries below for the lower mainstem represent a total mapped wetland area of 1,880 hectares. We mapped all but one 6-hectare wetland (NKS390207) primarily from GLO field notes (summarized below) and plat maps. We refined wetland boundaries shown on GLO plat maps using SSURGO (USDA-NRCS Soil Survey Geographic Database) digital hydric soils mapping, which generally corresponded well with the GLO wetland mapping, and a high-resolution DEM.

NKS_LMA400201 (773 hectares). This wetland winds through the west and north side of the river valley between RM 8 and RM 17. The GLO notes are from three different years and times of year. Moving in an upstream direction on October 10, 1871, the notes indicate: traveling east between S. 9 and S. 16, T39NR2E "[at 20 chains] Hard Hack and toolie swamp" and "[at 44 chains] Enter willow and alder bottom subject to overflow to the depth of 2 to four feet in time of freshets of the river [underlining added]." East between S. 4 and S. 9, T39NR2E, "[at 27.5 chains] Leave burn and enter Alder & spruce bottom," then "[at 42 chains] Enter Hard Hack marsh," and "[at 62 chains] Leave marsh and enter willow bottom;" the line description indicates "Land in bottom subject to overflow 2 to 4 feet in winter [underlining added]" from October 10, 1871. Northward between S. 3 and S. 4, T39NR2E, the surveyors noted "[at 24 chains] Enter crabapple and willow bottom which is subject to overflow in time of freshets to the depth of 4 to 6 feet [underlining added]," and "[at 33.5 chains] The land becomes higher and is not subject to overflow," then "[at 41 chains] Enter bottom again subject to overflow [underlining added]" and "[at 60.7 chains] A lake with swamp beyond being impassable [underlining added]" on October 6, 1871.

On March 10, 1873, traveling north between S. 34 and S. 35 (T40NR2E), at 45 chains they noted "Willow swamp bears E & W water 2 feet deep [underlining added]," and they encountered a "lagoon" between 64.79 chains and 74.59 chains. Running east between S. 26 and S. 35, T40NR2E, they noted at 10 chains "a swamp water 18 in. deep [underlining added]" on March 10, 1873. On March 5, 1873 they note, "the corner to sections 25, 26, 35 & 36 [of T40NR2E] which it is impossible to establish on account of water [underlining added]…subject to overflow of 2 to 8 feet [underlining added] …Timber Willow, Alder & Spruce. Undergrowth Vine Maple & hardhack."

Traveling east on the north boundary of T39NR2E, the surveyors on August 6, 1859 ran "2 miles & 75 chains, intersect impassable swamp with water from 2 to 4 feet deep [underlining added] and a dense growth of Hemlock, Tasslewood Willow & Crabapple. The swamp bears N. W. and S. E." This description would apply to the easternmost 5 chains of the boundary between S. 33, T40NR2E and S. 4, T39NR2E. The next day, on August 7, 1859, they traveled west along the same line, and recorded "[at 7 chains] Leave belt of timber 150 lks wide N. W. and S. E. & enter swamp of hard hack & willow" then "[at 11.5 chains] leave swamp water from 1 to 3 feet deep [underlining added] & enter skunk cabbage swamp" and "[at 19.25 chains] Leave swamp S. E. & N. W." The same day (August 7), traveling east along the line between S. 34, T40NR2E and S. 3, T39NR2E, they noted in their line description "Land level and unfit for settlement or cultivation being overflowed by the water of the Nootsahk River [underlining added]. Timber Alder, with Hardhack undergrowth." Traveling south between S. 33 and S. 34, T40NR2E, at 40.5 chains they noted "Swamp covered with hardhack and willow. Water 2 to 3 feet deep rendering it impassible [underlining added]."

The eight surveyed lines given above represent three years and times of year. In March 1873, both of two lines were inundated; in August 1859, two of three were inundated; in October 1871, none mentioned inundation at the time of survey. The lines surveyed in October 1871 are in the southern (downstream) part of the wetland map unit. This may reflect that this portion of the wetland is less wet in summer than the central part of the wetland, or it may on the other hand reflect the failure of the surveyors in 1873 to note water depths. That none of the notes from 1873 on the delta include water depths, while the 1859 notes for the same era do, supports the latter interpretation. A conservative estimate of the inundated area in summer is the amount in which the surveyors described standing water (in March 1873 and August 1859), which is in about one-half of the map unit, as indexed by proportion of linear surveyed distance.

The surveyors mention typical winter inundation depths of between 2 and 8 feet throughout the wetland. We estimate that most (about three-quarters) of the wetland is winter inundated, and about one half is summer-inundated. We have applied these same proportions to several similar, smaller wetlands in the lower mainstem that follow below, totaling 225 hectares (*NKS_LMA390204*, *NKS_LMA390205, NKS_LMA390206, NKS_LMA390207,* and *NKS_LMA400202)*.

NKS_LMA390204 (74 hectares). Traveling east between S. 16 and S. 21 (T39NR2E), on October 9, 1871, the GLO surveyors noted "Enter swamp," and "[at 55 chains] Leave swamp and enter burn." The line notes indicate "Land on west side [of the Nooksack River] <u>subject to overflow in time of freshet to the depth of 2 to 4 feet</u> [underlining added]." Traveling south between S. 20 and S. 21, the notes indicate "[at 39 chains] Enter crabapple and willow swamp" and "[at 53 chains] Leave swamp and enter alder and vine maple bottom" on October 9, 1871.

NKS_LMA390205 (45 hectares). Traveling north between S. 9 and S. 10, T39NR2E, it is noted "[at 30 chains] Enter swamp covered with Hard hack flags & grass" and "[at 37.7 chains] <u>A lake it being impassable</u> [underlining added] " on October 5, 1871; the lake mentioned is shown on the plat map and appears in our GIS mapping.

NKS_LMA390206 (6 hectares). We mapped this small wetland using SSURGO hydric soils data and topography.

NKS_LMA390207 (68 hectares). Surveying north between S. 3 and S. 2, T39NR2E, the GLO notes indicate at 71 chains "Enter Hard Hack swamp" and then at the end of the line "The corner to sections 2, 3, 34, and 35 <u>cannot be established</u> [due to water; underlining added]" on October 4, 1871. Traveling west between S.2 (T29NR2E) and S. 35 (T40NR2E), on August 5, 1859, the surveyors noted "[at 40 chains] …<u>swamp overflowed in winter</u>…Enter <u>marsh overflowed in winter to a depth of 6 feet</u> [underlining added] with a dense growth of hardhack & alders."

NKS_LMA400202 (32 hectares). Surveying northward between S. 30 and S. 29, T40NR2E, the surveyors noted "[at 17 chains] Enter open marsh" until 42.5 chains on March 27, 1873.

NKS_LMA400301 (711 hectares). The wetland is elongate in an east-west direction, on the south valley side. Moving west to east, the GLO notes indicate: traveling north between S. 31 and S. 32, T40NR3E, "[at 50 chains] enter swamp water 2 feet deep [underlining added]" on December 4, 1872. Between S. 29 and S. 32, T40NR3E, on December 4, 1872, at the beginning of the line "enter swamp," and at 40 chains " Enter willow and hard hack swamp." At the end of the line, the notes indicate "The corner to Sections 29, 30, 31, & 32. Land swamp covered with willow and hardhack. Water 2 to 3 feet deep [underlining added]. Soil 1st rate." Between S. 32 and S. 33, T40NR3E, traveling north, at 60 chains "Enter burnt bottom bears E & W," and at 70 chains "Enter beaver swamp [underlining added] bears E & NW." The line description (which could include land south of the wetland) indicates "Timber Fir Cedar and Alder. Undergrowth Crabapple and Willow." Between S. 33 and S. 34, T40NR3E, moving north, at 50 chains "enter beaver swamp [underlining added], bears E & W," and at 75 chains "Leave swamp enter burn" on November 25, 1872. Between S. 34 and S. 27, T40NR3E, at 5 chains "enter willow bottom"; the line description reads: "Land level. Soil 1st rate. Timber Alder Willow and Crabapple" on November 26, 1872. Between S. 34 and S. 35, T40NR3E, at 50 chains the notes indicate "Enter spruce swamp," and the line description is "Land level. Soil 1st rate. Timber Fir Cedar and Spruce. Undergrowth Hard Hack and Willow."

The lines described as inundated by water are in the downvalley part of this wetland. On the basis of these line descriptions, we assume that less of this wetland was inundated than the wetlands described above, which are also farther downvalley than is this wetland. Consistent with this interpretation is that the topographic depression in the upper part of this wetland is not as deep as in the lower part of the wetland or the wetlands farther downvalley, suggesting the observations in the GLO notes may accurately describe inundated conditions. We assume that in winter about one-half of the area is inundated. Because the wetland is commonly described as beaver swamp, we also assume that a part (one-quarter) of the marsh is inundated in summer.

NKS_LMA400302 (171 hectares). The GLO survey traveled north between S. 21 and S. 22 (T40NR3E) and noted "[at 35 chains] enter swamp bears E & W. Water from 1 to 2 feet deep [underlining added]" on November 27, 1872. The line description indicates "Land subject to overflow from 2 to 6 feet deep [underlining added]. Soil 1st rate. Timber balm alder and maple. Undergrowth Hard Hack and Maple;" the line description includes land in the 35 chains south of the "swamp." Traveling east between S. 15 and S. 22 (T40NR3E), the notes begin "Enter swamp water from 2 to 6 feet deep [underlining added]" and continue "[at 65 chains] enter spruce and Hemlock bottom. Water from 1 to 2 feet deep [underlining added]." A small corner of the wetland crossed by the line between S. 15 and S. 16 is termed "swamp." Crossing a small section of the wetland between S. 22 and S. 23, traveling north, the notes read "[at 30 chains] enter Alder Swamp bears E and W" and "[at 47.5 chains] Leave overflowed land [underlining added]." On the basis of the extent of inundated land described along these survey lines we assume that most (about three-quarters) of the wetland was winter inundated.

The bearing tree records that fell within areas mapped as scrub-shrub palustrine wetlands, when grouped together, include about one-half (11 of 23) that lacked any trees near the survey point. At the remaining points, the average tree diameter was only 20 cm, and alder accounted for 42% of trees, the remainder being willow (14%), crabapple, spruce, birch, cedar (11% each), and hemlock (6%). The bearing trees were relatively closely spaced (average distance from survey point of 5.1 m; Figure 13), and their overall distribution suggests that the small trees were patchy and closely spaced within patches.

NKS_UMA390401 (10 hectares). The GLO surveyors mention the area as "swamp" between 46 chains and 60 chains, northward between S. 19 and S. 20, T39NR4E. No evidence of a wetland is visible in the 1938 photographs, when part of the area is under cultivation and part has been logged.

Historical palustrine wetlands in the South Fork

The lower South Fork valley, which has a lower gradient than the forks elsewhere, included an extensive system of wetlands, small channels and ponds in the Black Slough area (see Figure 10).

NKS_SFK380501 (604 hectares). The few bearing trees that fall within the wetland complex (Figure 16) suggest it was dominantly a spruce-alder swamp. Descriptions in the GLO notes indicate it had "…dense timber and thick undergrowth" and was "swamp covered with skunk cabbage and very dense thickets of spruce and crabapple." Traveling north between S. 29 and S. 30 (T38NR5E), the surveyors noted "[at 33 chains distance] Enter swamp covered with skunk cabbage and very dense thickets of spruce and crabapple" on May 9, 1885; the line description reads "Timber alder, cedar, spruce & maple very dense. Undergrowth same with skunk cabbage, vine maple and crabapple very thick." Surveying west between S. 20 and S. 29, T38NR5E, the field notes read "[at 13.8 chains] Enter swamp bears SE & NW" and the line description is "Timber Alder, Cedar and spruce, very dense. Undergrowth [illegible] with vine maple and crabapple very thick" on May 9, 1885. Between S. 17 and S. 20, moving west, at 28.5 chains the notes indicate "Enter swamp bears N. W. and S. E." and the line description is "Timber Alder and spruce very dense. Undergrowth same, with vine maple and crabapple very thick" on May 11, 1885. Surveying north between S. 19 and S. 20, the notes begin "Along edge of swamp, through dense timber and thick undergrowth," and then "[at 67 chains] Leave swamp bears E & W," and the line description is "Land low and swampy…Timber alder, cedar, spruce, and maple, very dense. Undergrowth vine maple, skunk cabbage, and crabapple very thick" on May 10, 1885. Running east between S. 19 and S. 30, "[at 70 chains] Enter swamp bears N & S" on May 10, 1885. West between S. 29 and S. 32, on May 7, 1885, the line is described as "Land low. Soil A.1. Timber Alder, cedar, maple and spruce very dense. Undergrowth same, with vine maple and crabapple very thick." For a minimum estimate of the amount inundated in winter, we have taken the area mapped as wetland on the Wickersham 1918 and Van Zandt 1918 15'

USGS topographic quadrangles (which were mapped after most of the wetland area had been converted to agriculture), or 30 hectares (about five percent of the total wetland map unit).

NKS_SFK380502 (18 hectares). This wetland was not crossed by the GLO survey, and was mapped because it is a forested wetland on recent Deming USGS quadrangle. For a minimum estimate of the amount inundated in winter, we have taken the area mapped as wetland on the Van Zandt 1918 15’ USGS topographic quadrangles (which was mapped after most of the wetland area had been converted to agriculture), or 9 hectares (about one half of the total wetland map unit).