# A New Look At The Quantities And Volumes of Instream Wood In Forested Basins Within Washington State

**Martin J. Fox**

**A thesis submitted in partial fulfillment of the**
**requirements for the degree of**

**Master of Science**

**University of Washington**

**2001**

**College of Forest Resources**

University of Washington

Graduate School

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Martin J. Fox

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and that any and all revisions required by the final
examining committee have been made.

Committee Members:

Loveday L. Conquest
Loveday L. Conquest

Susan M. Bolton

Peter A. Bisson
Peter A. Bisson

Date 17 August, 2001

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Not Another Paper on LWD?!
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## Abstract

# A New Look At The Quantities And Volumes of Instream Wood In Forested Basins Within Washington State

Martin J. Fox

Chair of the Supervisory Committee:

Professor Loveday Conquest

Aquatic and Fishery Sciences

Instream wood is recognized as an important feature linked to channel processes that benefit salmonids. Stream channel assessments and restoration/enhancement efforts often associate salmon habitat quality with the quantity and volume of woody debris. Existing wood targets used to assist resource managers do not adequately account for variations in quantity or volume due to differences in geomorphology, ecoregions, or disturbance regimes. To address this issue, field data on instream wood quantities and volumes from 150 stream segments draining unmanaged basins within Washington State (without logging, roads, dams, or other human-induced condition that may influence natural wood loading and retention rates) are used to develop target suggestions for management. Based on the assumption that streams draining unmanaged forest basins incorporate the range of conditions to which salmonids and other species have adapted, wood loads in these systems provide a defensible reference for management. Surveyed sites represent a wide array of geomorphic channel types, channel origins, natural disturbances, and climate regions where the process of wood input and distribution has most likely evolved under a natural rate of disturbance, with the exception of potential fire suppression.

Analyses of these data imply that the most consistent predictor of wood volumes and quantities is bankfull width (as a function of basin size) and ecoregion. Wood quantity, volume, and mean piece size increased with channel size due to the increased proclivity for fluvial transport and spatial accretion, along with greater lateral area for wood to accumulate. Forest stand characteristics such as stem density and diameter are influenced by distinctive climates particular to each ecoregion, which in turn influence the size and quantity of instream wood. Percentile distributions describe the range of wood quantities and volumes in streams draining unmanaged basins by discrete bankfull width classes for three distinguishable ecoregion groups. The data also support expanded definitions for minimum volumes of "Key Pieces." Due to both favorable and adverse conditions comprising wood loading ranges; we suggest that the 75th percentiles in each bankfull width

class and ecoregion should be used to represent the lower limit for optimum wood quantities and volumes as an index of habitat quality.

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# Acknowledgements

I wish to express my sincere appreciation to my research committee: Professor Loveday Conquest (chair), Associate Professor Susan Bolton, and Professor Peter Bisson for their helpful insight and guidance. I would also like to thank the Pacific Northwest Research Station and the Center for Streamside Studies for their financial support; my hardworking field crews: Lyle Almond, Lance Dibble, Jeff Steele, Emily Lang, and Jessica Trantham for their intrepid pursuit of data in remote locations, during inclement weather, and against hostile vegetation; my volunteer field assistance: Anne Savery, Jody Brauner, Brian Berkompas, and Cindy Carlson (who *still* married me!); and the Muckleshoot Indian Tribe. I would also like to thank Bob Bilby, Jan Henderson, Tom Quinn, Jim Agee, Richy Harrod, Ann Camp, and the many others who provided data, information, suggestions, input, and inspiration to my project.

# 1. INTRODUCTION

## *1.1.* The Importance of Instream Wood

The role of large woody debris (LWD) in Pacific Northwest streams is implicitly linked to channel processes that benefit salmonids. Woody debris plays an important role in controlling channel morphology, the storage and routing of sediment and organic matter, and the creation of fish habitat (Bisson et al. 1987). The geomorphic potential of the channel to process wood into features that benefit salmonids is often limited by the quantity and size of wood (Abbe and Montgomery 1996).

Large wood creates habitat heterogeneity by forming pools, back eddies, and side channels, and by increasing channel sinuosity and hydraulic complexity (Spence et al. 1996). Pools are perhaps one of the most important salmon habitat features formed by large woody debris (Keller and Swanson 1979). Pools provide slow water sites for rearing habitat for juvenile anadromous and resident salmonids, especially coho and chinook, allowing access to drifting food organisms with less swimming effort (Fausch 1984). Large pools also serve as resting stations for adult fish as they migrate upstream to spawn (Bjornn and Reiser 1991). Abbe and Montgomery (1996) found that pools formed by logjams are on the average deeper than free-formed pools. Numerous woody debris accumulations increase pool frequency (Lisle and Kelsey 1982; Montgomery et al. 1995; Beechie and Sibley 1997).

Channel responses to wood vary with geomorphic character of the stream, such as gradient and confinement (Murphy and Koski 1989; Robison and Beschta 1990). In high energy channels, large woody debris functions to retain spawning gravel and can also provide thermal and physical cover for salmonids (Schuett-Hames et al. 1994). Logjams can create sections of low gradients with alluvial substrates in bedrock channels by storing sediment upstream of the jam (Montgomery et al. 1996; Massong and Montgomery 2000), which can provide localized low-gradient habitats in steep valley segments where none would have existed.

Wood indirectly serves as an important food source for salmonids by providing nutrients and insects to the stream (Naiman and Sedell 1979; Spence et al. 1996) or by the retention of salmon carcasses (Cederholm et al. 1989; Bilby et al. 1996). Wood serves as cover for juvenile salmonids, which are particularly vulnerable to predators when migrating (Larsson 1985). Certainly, wood is an important component of channel morphology and salmonid habitat, and its presence contributes to the biological and geomorphological processes of a stream.

## *1.2.* Potential Sources of Variation for Instream Wood

The quantities and volumes of instream wood are highly variable. This variability is related to a number of factors including channel morphology, disturbance, and climate. The following section elaborates on these potential factors.

### 1.2.1. Geomorphological Influences

Channel size influences the quantity of instream wood. Bilby and Ward (1989) found that mean length and diameter of wood pieces increased as channel width increased, and that the frequency of occurrence of pieces declined as streams size increased in streams draining unmanaged basins. They also found that the frequency of instream wood ranged almost an order of magnitude, between 0.8 pieces/m in the smallest channels to 0.1 pieces/ m in the largest systems.

Channel size, often synonymous with bankfull width, is a function of basin size. Basin size is highly correlated with bankfull width as a function of precipitation (Sternes 1969), which in turn influences discharge in Washington streams (U.S. Water Resources Council 1981; Sumioka et al. 1998; Pleus 1999). Subsequently, bankfull width is often used as an indicator of basin size. However, caution should be heeded in channels where the hydrological or erosion processes have been altered by humans, or where recent disturbances have occurred. Disproportionate widening of the channels can result from land use practices such as timber harvest (MacDonald et al. 1991; Pleus and Schuett-Hames 1998), recent debris flows or dam-break floods (Coho and Burges1993), dredging or bank manipulation, or other factors not representative or typical of a channel in its natural state. As a result, these factors could alter the width or depth disproportionately to basin size, and thus bankfull width would not be a demonstrable determinant of basin size in these situations. Since the lateral boundaries used to measure bankfull width are identified by 1) channel scour, and 2) the presence, age, and species of adjacent vegetation (Pleus and Schuett-Hames 1998), the width of these boundaries are likely to vary within stream reaches. Despite the difficulty of consistent BFW estimates, bankfull width is widely used as an indicator of stream size, as well as a factor of basin size.

Channel reach morphology (Montgomery and Buffington 1997) also influences instream wood loads. Rot et al. (2000) found significantly more LWD pieces in forced pool-riffle channels than in bedrock or plane-bed channels; wood volume followed a similar trend. However, confinement was significantly related to LWD volume only in forced pool/riffle channels, where less wood was found in confined channels. Confinement had no effect on LWD volume in plane-bed channels.

### 1.2.2. Anthropogenic Influence

The difference in the distribution and characteristics of wood between managed and unmanaged basins has been clearly established. Wood can be limited due to riparian vegetation modifications (Ralph et al. 1991), whether due to forest practices, urban development, or agricultural practices. Unmanaged channels, often defined by streams draining un-roaded and unlogged basins, typically have more channel roughness due to instream wood than managed channels (Bilby and Ward 1991; Ralph et al. 1991), especially if the stream has been channelized. As sediment deposits behind wood obstructions (Swanson and Lienkaemper 1978; Montgomery et al. 1996; Massong and Montgomery 2000), low-gradient steps are formed that reduce stream energy. Lower stream energy has less potential to mobilize wood than high stream energy (Braudrick and Grant 2000). These factors, especially if peak flows are exacerbated due to land uses, may lead to less retention of recruited wood than in streams draining unmanaged basins.

### 1.2.3. Natural Disturbance

The quantity and volumes of instream wood vary over space and through time due to an array of natural processes. Instream wood may remain in the channel until it is lost to decay, achieving equilibrium over time with newly recruited wood. However, this balance is not often met due to the multiple types and rates of disturbances that influence this process. Riparian forest structure, composition, and spatial distribution through the network are driven by major disturbance processes (Fetherston et al. 1995). All channels have been affected by disturbance of some kind, whether historic or recent. Therefore, the characterization of wood from a single survey provides a temporal "snap-shot," documenting a single point in the patterns of fluctuation. Wood accumulations are not constant, but rather, fluctuate with disturbance cycles. The accretion of wood may continue over time until capacities exceed an ecological or morphological threshold, some of which result in a catastrophic removal by disturbance. The amount of instream wood, therefore, represents how recent the last disturbance was, and conditions during the recovery period. Four types of disturbances commonly found in forested streams of Washington State are discussed below:

*Fire*

Disturbance that kills some or all the vegetation in a particular location is an intrinsic part of ecosystem development (Raup 1957; Oliver 1981), and varies with climate, geomorphology, topography, soils, and vegetation (Swanson et al. 1988). The return intervals for fires, which vary by ecoregion (Agee 1993), affect timber age (Henderson et al. 1992). Timber age influences mean tree diameter (Rot et al. 2000), which in turn influences the diameter of instream wood (Rot et al. 2000). Timber age also influences tree height (Agee 1993; Henderson et al. 1992), and wood recruitment distance is a function of height (McDade et al. 1990). Thus fire affects instream wood diameter and recruitment.

Fires do not burn forests evenly. Patches of timber unscathed by a fire (often termed fire refugia) can diversify timber ages along stream riparian areas. Camp et al. (1996) found that late-successional fire refugia were more commonly found on North-aspect facing slopes. In some cases, the under-story is subject to fire mortality, leaving the dominant trees (Agee 1993). Fires contribute to the success of Ponderosa Pine, and prevent colonization of Douglas fir in the eastern Washington forest ecoregions (Ruha 1996). This leads to a multi-layered canopy that provides a multitude of ecological benefits in addition to variations in wood recruitment rates.

*Floods*

Floods entrain wood from areas adjacent to stream reaches. High flows associated with floods increase the shear stress upon instream wood and carry wood downstream or perhaps even completely out of a system. Braudrick and Grant (2000) found that wood entrainment is a primarily a function of piece angle relative to flow direction, the density of the log, and its length and diameter. Root wads can inhibit LWD movement by anchoring logs to the streambed, increasing drag and thus decreasing mobility (Abbe and Montgomery 1996). Floods not only remove wood from streams but can also recruit new trees. Palik et al. (1998) found an average of 22 new trees/km recruited into a coastal plain stream during a large flood.

#### *Debris Flows*

Debris flows and landslides are natural disturbances that affect stream channels and influence the quantity, quality, and distribution of instream wood. The often-violent mobilization of material in channels where this occurs may either transport wood out of a reach or bring in new wood from upstream sources. Debris flows tend to deposit wood on slopes of 3-6 degrees (approx. 5-10% gradient) (Ikeya 1981; Costa 1984; Benda and Cundy 1990). In older forests, large standing trees and instream logs can retard debris flow propagation and run-out lengths compared to debris flows in industrialized forests (Coho and Burges 1993).

#### *Snow Avalanches*

Snow avalanches also are natural channel process that recruit wood into streams (Keller and Swanson 1979) and influence the riparian vegetation (Fetherston et al. 1995). Snow avalanche paths are typically less confined than debris flows, and they often form a broad fan where the channel gradient flattens, such as at the channel bottom intersecting with the floodplain of a larger system. Snow avalanches are most common in small headwater channels (Keller and Swanson 1979). Due to the snow pack buffering the channel bed, substrates are often undisturbed following a snow avalanche; however, most trees larger than 10-15 cm in the path are sheared off at the level of snow depth. The loss of riparian vegetation is likely to influence instream wood quantities due to the disturbance of the recruitment source.

### 1.2.4. Riparian Influence

The characteristics of riparian trees obviously will influence instream wood. Rot et al. (2000) found the diameter of instream LWD increased with riparian stand age, and that stand age and mean stem diameter were correlated. Tree age varies considerably within older Western Hemlock/ Douglas fir forests. Tappeiner et al. (1997) found age in old-growth stands ranged between 50 and 414 years at one site, and median age differences of 187 years from 10 sites of the same region. Timber on the Olympic Peninsula, often older than 700 years (Henderson, unpublished data), can produce large diameter instream wood. Indeed, in streams draining old-growth forests, McHenry et al. (1998) found a mean LWD diameter of 0.3 m and diameters up to at least 2.5 m. These differences in riparian characteristics are a combination of many influences including fire, climate, and species.

### 1.2.5. Regional Influence

Adjacent forest vegetation, as noted above, influences the sizes and quantities of instream wood. Regional climatic variations that control the characteristics of forest vegetation can be grouped by a forest zone or forest series (Franklin and Dyrness 1973; Agee 1993), and they are hereafter referred to as "ecoregions." Ecoregions are characterized by climax species, tree size, and density of forest stands as influenced by climate and fire succession (Agee 1993). The distribution of tree species, tree heights, diameters, and stem densities in distinct ecoregions often differ due to variation in elevation, aspect, precipitation /soil moisture, and temperature (Henderson et al. 1992; Agee 1993). Seven major forest types comprising ecoregions across Washington State are identified in the literature and described as follows:

*The Sitka Spruce Forests*

This forest type is generally limited to the coastal west-slope of the Olympic Mountains due to the unique climate characteristics found there. The elevation of these forests is typically less than 300 m above mean sea level (amsl), and normally within 20 km from the coast; however, sites can be found further inland up low-elevation river valleys (Agee 1993). Dominant tree species are the Sitka Spruce (*Picea sitchensis*), with co-dominants of Western Hemlock (*Tsuga heterophylla*) and Western Red Cedar (*Thuja plicata*), and to a lesser degree, Douglas fir (*Pseudotsuga menziesii*) (Agee 1993). The annual precipitation of the Sitka Spruce (SS) region is 200-300 cm, and includes a component of fog-drip. The air temperatures are mild year-round (Franklin and Dyrness 1973). The large dense timber of this region is attributed to climate, which facilitates tree growth. Indeed, Edmonds et al. (1993) found stem densities in this region between 476-508/ha (>5cm dbh), and basal areas between 77 and 94 $m^2$/ha. The date of the last fire in these forests has been identified by some researches as over 1,100 years ago (Fahnestock and Agee 1983). Although this is not generally applicable to the entire Sitka Spruce forest type, it suggests that stand-replacement fires are rare.

*The Western Hemlock Forests*

This forest type is generally found in the interior low elevations of western Washington such as the greater Puget Sound and inland SW regions. The elevation of this forest type is typically less than 800 m (amsl), although this may vary ± 60 m depending on aspect and local climate differences (Henderson et al. 1992). Dominant tree species are the Western Hemlock, with Douglas fir co-dominant (Agee 1993). Although Douglas fir is dominant in the early seral stages following fire, it will eventually be succeeded by Western hemlock at late succession (Agee 1993; Henderson et al. 1992). The Western Hemlock (WH) forest type has greater extremes of moisture and temperature than the SS forest type (Franklin and Dyrness 1973). The dryer summers are reflected in the wide spectrum of plant associations across this zone (Zobel et al. 1976). Fire frequency intervals are generally less than 750 years, although ignitions from Native Americans may have increased this frequency in some areas (Agee 1992).

The physical characteristics of the timber in this forest type are well documented. Spies and Franklin (1991) reported that the average stem densities of Douglas fir (>100cm diameter at breast height [dbh]) in late-successional stands ranged from 18-29 trees/ha, while

Hershey (1995) reported 6-90 trees/ha of stems >54 cm. Tappeiner et al. (1997) reported basal areas in old-stands range between 46-91, with a median of 66 ($m^2$/ha). Tree heights for two common Plant Association Groups (PAGs) in this forest type average between 200-225 feet, with mean maximum heights reaching 285-feet after about age 300 (years) (Henderson unpublished 1996).

### *The Silver fir Forests*

This forest type is generally found at moderate to upper elevations on the west-slope of the Cascades. The typical elevation is between 800-1,200 m (amsl), although this may vary ± 60 m depending on aspect and local climate differences (Henderson 1992). Dominant tree species are the Pacific Silver fir (*Abies amabilis*), with Western Hemlock and Douglas fir co-dominant at lower elevations and Mountain Hemlock (*Tsuga martensiana*) co-dominant at upper elevations (Agee 1993). Winter temperatures are moderate, but with a 1-3 m winter snow-pack (Franklin and Dyrness 1973). Droughts are infrequent, and summer precipitation usually exceeds 15 cm (Minore 1979). Fire return intervals are estimated to be between 300-600 years, but can be more frequent at lower elevations (100-300 years) (Agee 1993). Silver fir (SF) trees seldom survive major fires (Agee 1993), thus, fire return intervals often are points of stand origin.

### *The Mountain Hemlock Forests*

This forest type is generally found on upper elevations to the west of the Cascade crest, but below Subalpine regions. There is substantial overlap with the Silver fir forests; however, Mountain Hemlock is generally more prevalent at higher elevations. The elevation of this forest type is typically between 1000-1,375 m (amsl), although this may vary ± 60 m depending on aspect and local climate differences (Henderson 1992). Dominant climax tree species are Mountain Hemlock, with the Pacific Silver fir and Subalpine fir (*Abies lasiocarpa*), as co-dominants (Agee 1993). Mountain Hemlock has been found up to 1,800 m in Washington where aspect, and latitude, and local climates are favorable. Winter temperatures are cool, but summer temperatures can reach extremes of 26-30$^{o}$C (Arno and Hoff 1989). Fire return intervals are estimated to be around 500 years (Dickman and Cook 1989).

### *Subalpine fir Forests*

This forest type is generally found along the Cascade crest, and the interior of the Pasayten Wilderness in the North Cascades at elevations above 1,300 m amsl (Henderson 1992; Agee 1993) although this may vary ± 60 m depending on aspect and local climate differences (Henderson 1992). The annual precipitation is typically between 100-200 cm (Agee 1993). The prolonged winter snow-pack (often between 7-8 m in wetter zones), along with the coldest winter temperatures of all Pacific Northwest forests, limits growth as compared to trees in lower elevation forests (Agee 1993). Summer temperatures can be relatively high, reaching 26-30$^{o}$C (Agee 1993). Mountain Hemlock is often found at the lower boundaries of this forest type. Dominant climax tree species are Subalpine fir (*Abies lasiocarpa*), with co-dominants of Mountain Hemlock, Lodgepole pine (*Pinus contorta*), and Engleman Spruce (*Picea englemanni*) (Agee 1993). Subalpine fir (SAF) and co-dominants are not well-adapted to surviving fires (Agee 1993) and fire return intervals, estimated to be around 250 years (Fahnestock 1976), or 109-137 years (Agee 1990), often are points of stand origin.

*Grand fir Forests*

Grand fir (GF) (*Abies grandis*) are typically found at elevations between 1100-1500 m east of the Cascade crest, although populations of Grand fir can be found at low elevations of inland western Washington (Agee 1993). The Grand fir forests generally separate the Ponderosa pine (*Pinus ponderosa*) forests from the SAF forests. A mixture of species characterizes this forest type, with Douglas fir as the climax dominant. Rarely is GF the late-successional dominant species. Hardwood species are often found as co-dominants. Fire intervals are frequent, often due to lightning strikes, producing a return interval of 50-100 years in drier sites.

*Ponderosa Pine Forests*

This species is typically found in dry, lower elevation (1,200-1,800 m) sites east of the Cascades (Franklin and Dyrness 1973). Ponderosa pine (PP) (*Pinus ponderosa*) forests contain a large co-dominant component of Douglas fir (Agee 1993). Douglas fir is always the co-dominant species in this forest type, and is typically suppressed by fire (Agee 1993). A natural fire-recurrence interval is typically between 11-24 years (Agee 1993). Due to frequent burns, fires are typically of low intensity; therefore, the older Ponderosa Pines are rarely killed unless fires are fueled by excess wood build-up in the under-story (Agee 1993). Camp et al. (1996) found Ponderosa Pines in portions of these forests (Swauk Late Successional Reserve) to have ages between 13-597 years, with a mean of 127 and a standard deviation of 100. Fire refugia are common in this forest type, and are typically found on north-aspect slopes and in confined channels (Camp et al. 1996). With fire suppression, beginning in 1909 in the Wenatchee Mountains (Holstine 1992), Douglas fir has become more prevalent in many areas (Harrod, pers. comm. 2000). Ponderosa pine typically can reach 35-45 m in height with some exceeding 55 m (WWPA 1995).

## *1.3.* Wood as an Indicator of Habitat Quality

Stream channel assessments often associate the size, distribution, and abundance of woody debris to salmon habitat quality based on data from old-growth forests as an "index of resource condition" for determining habitat condition (Peterson et al. 1992). Subsequently, several key assessment methods based on such target conditions were developed to evaluate the adequacy of wood quantities in the state of Washington. The targets established in the diagnostics of the Washington Forest Practices Board (WFPB) Manual (1997) for conducting "Watershed Analysis" rate the condition of streams based on wood quantity in terms of "pieces per channel width," using >2 pieces as "Good," 1-2 pieces as "Fair," and <1 pieces as "Poor" condition for channels < 20 m bankfull width (BFW). A qualifying wood piece must be >10 cm diameter and 2 m in length. The WFPB manual criteria for "Key Pieces" are >0.3 pieces per channel width in streams <10 m BFW, and >0.5 pieces per channel width in streams 10-20 m BFW. The WFPB (1997) describes key pieces as a necessary component of wood quantities for use in state Watershed Analysis, and it defines "key pieces" as a log and/or root wad that is:

1) independently stable in the stream bankfull width (not functionally held by another factor, i.e., pinned by another log, buried, trapped against a rock or bed form, etc., and

2) retaining (or has the potential to retain) other pieces of organic debris.

Table 1 lists the minimum piece volume criteria WFPB uses to define key pieces based on BFW.

The National Marine Fisheries Service considers >80 pieces/mi. (>50 pieces/km) that are >50 ft [15.2 m] in length and >24 inches [0.6 m] in diameter necessary for western Washington streams to meet a "Properly Functioning Condition" for instream wood conditions in their Pacific Coast Salmon Plan (1998), and to address ESA listed aquatic species such as salmon as part of their Matrix of Pathways and Indicators (NMFS 1996).

### 1.3.1. Perspectives in Units Used To Quantify Wood Loading

Various units are used to describe existing instream quantities or volumes of wood to express wood targets. Some researchers express quantities and volumes of wood per unit channel length. For example, Rot et al. (2000) and Montgomery et al. (1995) measured pieces or volumes per 100 m of channel length, while Bilby and Ward (1989) used pieces per meter. NMFS scales wood by units of channel length with "pieces per mile." Others (Montgomery et al. 1995; Beechie and Sibley 1997) explored different means to express wood quantities, such as pieces per unit area (e.g., pieces per square meters of stream channel). The WFPB (1997) bases target references for wood quantities upon a sliding scale according to channel size, such as "pieces per channel width." Most methods scale these various units of wood with bankfull width as a means to control for channel size.

## *1.4.* Use of Wood Targets for Stream Evaluation, Enhancement, and Restoration

A common application for wood targets is for stream evaluation, or the design of enhancement and restoration projects. Placing wood into the channel to achieve conditions assumed to be favorable to salmonids may refer to targets for a desired quantity and/or volume of wood (Beech 1999). The success of LWD enhancement projects to provide habitat for salmonids may be based on piece stability (Braudrick and Grant 2000), longevity (Frissell and Nawa 1992), and ultimately, the preference of local fish species (Riley and Fausch 1995; Cederholm et al. 1997). Combined with prudent design and the consideration of variables that influence the success of these projects, the placement of wood according to a quantity and volume perceived as favorable to salmonids will likely improve aquatic habitats. Therefore, knowledge of the natural variation of instream wood loads among different stream types and regions should improve restoration activities as well as improve the validity of evaluation.

## *1.5.* Potential Problems With Existing Management Targets

The LWD piece quantity targets now used frequently as management standards were developed with the most complete data available for relating wood frequency to channel width in Pacific Northwest streams (Peterson et al. 1992). However, Spence et al. (1996) notes that those targets do not fully consider potential sources of variation found throughout their application range, and they should only be applied to the types of streams for which they were derived. Because the currently existing targets do not fully account for this variation and are applied generically, they may be inappropriate for some channel types and regions outside the region where the targets were developed. A stream enhancement project may place wood in a stream channel based on the quantities recommended by target references, but these efforts may not provide the quantities or volumes of wood representative of conditions to which salmonids have adaptated or meet an optimum for production. Because of the reliance upon wood targets by resource managers for critical decision-making, a need exists to re-evaluate existing wood targets, and refine these values where appropriate.

## *1.6.* Objectives

This project 1) evaluates existing management targets for geomorphic and regional compatibility, and 2) develops reference ranges along with some suggested target values as a resource management tool to assess, protect, restore, and enhance salmon habitat in streams as it relates to wood. These references are based on variations in geomorphic and regional characteristics for streams both east and west of the Cascade Mountains in Washington State. Inferences drawn from the analysis of these data will help forest and stream resource managers to:

1) develop a clearer understanding of the quantity, volume, and size distribution of wood required in streams over time;
2) develop land use regulations, ordinances, and laws to protect and manage salmon habitat
3) provide a sound basis for long-term planning, prioritizing, implementation, and evaluation of habitat, restoration projects, mitigation requirements, and stream enhancement.

# 2. METHODS

## *2.1.* Site Selection

### 2.1.1. Criteria

To best characterize natural quantities and volumes of instream wood within Washington State, survey sites were chosen within stream basins relatively unaffected by anthropogenic disturbance. Selected basins are characterized by forests that are loosely termed as “old-growth” that also meet the following criteria: 1) no part of the basin upstream of the survey site was ever logged using forest practices common after European settlement; and 2) the basin upstream of the survey site contains no roads or human-made modifications to the landscape that potentially could affect the hydrology, slope stability, or other factors potentially affecting the natural processes of wood recruitment, delivery, or transport in streams. These basins will hereafter be referred to simply as “unmanaged basins,” although it is acknowledged that some basins are “managed” to remain pristine, and they may also include fire suppression. Recreational trails and moderately “improved” back-country camp-sites are also land-use features potentially modifying basin characteristics; however, these uses are assumed to have a minimal effect on the over-all processes pertaining to instream wood loads.

#### *Assumptions*

By choosing sites in unmanaged forested basins, we are assuming that natural wood loading rates and disturbance cycles found in these basins are those to which salmonids and other aquatic species have adapted. They should provide a defensible reference condition for quantities and volumes of instream wood.

### 2.1.2. Geomorphological Representation

Sites were chosen to represent a broad array of channel geomorphologies. With the use of a desktop mapping software (Delorme 1999), streams in unmanaged basins within the previously defined forest types were delineated into 6 gradient, 6 drainage, 3 confinement, and 2 origin classes (Table 2). The delineations of gradient and confinement classes were conducted in accordance to the TFW Monitoring Program Methods Manual (TFW-MPMM) for Stream Segment Identification (Pleus and Schuett-Hames 1998). Drainage classes were defined in terms of basin area: 0-2 km$^2$, 2-4 km$^2$, 4-8 km$^2$, 8-20 km$^2$, 20-100 km$^2$, and >100 km$^2$ upstream of the surveyed reach, as determined from United States Geological Survey (USGS) 7.5-minute maps using the aforementioned software. These classes were determined by a pilot study regressing bankfull width and basin size. Using bankfull with classes as defined in by Pleus and Schuett-Hames (1998), corresponding basin size classes were determined. Origin classes were determined by a basin assessment of the dominant source of stream flow and channel morphology, and classified as either 1) glacial melt or 2) snow/rain. Although other sources of stream origin exist such as groundwater dominated, rain dominated zones, etc.), we assume the most influential processes on channel morphology can be characterized by the rudimentary classifications of glacial and snow/rain. Determinations for stream origin were based on the 1) the presence and size of the glacier (and subsequent water input to the stream) at the head of the stream relative to non-glacial tributary input, and 2) channel characteristics typical of glacial influence (e.g. a high degree of braiding, high glacial sediment loads, and other features providing contrast between glacial and non-glacial origin streams). This served to characterize the channel in relation to the dominant mechanism that drives fluvial geomorphology and subsequent process on instream wood.

### 2.1.3. Ecoregion Representation

Survey sites were chosen to represent the range of forest vegetation types found in Washington State. Because the quantities and volumes of instream wood are often reflected by the forest character, the concept of "ecoregions[1] was adopted to characterize forest type regions adjacent to the survey sites. Based on the stand structural similarities such as tree diameter, density, and fire recurrence intervals, forest types were grouped to form the following five ecoregions for the purpose of this analysis:

1) The Sitka spruce and the Western Hemlock forest types: (SS/WH ecoregion)
2) The Silver fir and the Mountain Hemlock forest types: SF/WH ecoregion
3) The Subalpine fir: SAF ecoregion
4) The Grand fir: GF ecoregion
5) The Douglas-fir and the Ponderosa pine forest types: DF/PP ecoregion

Classification of field sites into respective ecoregions were accomplished by riparian tree species data, as well as using the physical descriptions cited in the literature (Section 1.2.5). Although the descriptions of each ecoregion referenced in Section 1.2.5 will generally enable a person to correctly classify the appropriate ecoregion adjacent to a stream reach, there is risk of error due to local variations in climate, aspect, or other site-specific features. Therefore, we recommend using these descriptions in concert with an assessment of the local riparian species, in combination with descriptions provided by ecologists such as Agee (1993), Henderson et al. (1992), or Franklin and Dyrness (1973) to best identify the most applicable ecoregion for a stream reach.

### 2.1.4. Random Design

After segments were delineated for streams within a potential survey area, streams with similar morphologies and ecoregions were grouped. From these groups, segments were "pseudo-randomly" chosen using a computer number generator for the purpose of selecting an even distribution of morphologies if group size allowed it. Each selected segment was then split into three equal partitions. Each partition was divided into survey reaches. Each survey reach was 100-meters in length for channels up to 20 m in bankfull width (BFW), and 200-300 m long

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[1] Adopted from Agee (1993), which is also similar to the concept of "Plant Association Groups" from Henderson et al. (1992)

reaches for channels >20 m in BFW. Using the same random method, a minimum of one reach per partition was selected. This partition design served to avoid inadvertent clumping of reaches in a segment, providing a more even distribution. A minimum sample length was 20 channel widths in order to fully represent repetitive patterns of the stream (Leopold et al., 1964; MacDonald et al. 1991; Montgomery and Buffington 1997); however, in channels approaching 100 m in width, surveys ceased at cumulative distances of approximately 1 km due to time and personnel constraints.

## *2.2.* Field Methods

### 2.2.1. The TFW Monitoring Program Method Manual

Survey methods used many components of the TFW Monitoring Program Method Manual (MPMM). Bankfull width and depth measurements, reach lengths, and photographic documentations, were conducted in accordance to the TFW-MPMM Reference Point Survey (Pleus and Schuett-Hames 1998). Methods for quantifying and measuring wood are described in the TFW-MPMM Large Woody Debris Survey (Schuett-Hames et al. 1999) for Level 2 surveys. All wood meeting the minimum size definition of 10 cm in diameter and 2 m in length were counted and measured if at least 0.1 m protruded into Zone 2, as stated in these methods. Sample field forms are included in Appendix 9.2.

### 2.2.2. Additions and Modifications to the TFW-MPMM

Several components of the TFW-MPMM were eliminated or modified, and several additional data collection methods were employed to better meet the study objectives. Photo documentation was conducted on upstream views only, rather than an additional downstream photo at each reach end. This was primarily done to reduce film costs. Tags, nails, or markings that may interfere with the aesthetics of the stream and forest were not placed at reference point ends to conform to the Parks and Wilderness area policies. Instead, detailed latitude and longitudinal coordinates were obtained as best as possible from mapping software, and verified with USGS maps (7.5-minute). Methods for obtaining riparian shade estimates and documenting pool-forming functions of wood are beyond the scope of this study and were not recorded. The option of counting log pieces that only protrude zone 3 and therefore outside the area of channel influence was not employed. Modifications to the TFW MPMM were also applied to channel orientation, zone position of logs to account for taper, and discharge measurements; however, these elements are inconsequential to the results of this analysis and are therefore not discussed.

Surveys for logjams (hereafter simply referred to as “jams”) described in the TFW-MPMM also included additions and modifications. A >70cm diameter class was added to refine the classification of large pieces. The order of jam groups relative to other instream wood was also recorded so that spatial distribution information was not lost when integrating data. Ten evenly distributed wood pieces from each of the four diameter classes were sampled for length. This was accomplished by prompts from the data recorder to the data caller for a log length measurement at 10% intervals of initial quantity estimates of each diameter class. The request for the length came *after* the diameter was declared for tallying to avoid potential biases. This maintained a degree of randomness in the sampling, yet provided for an even distribution of measurements throughout a jam. If fewer than 10 pieces for any diameter class were found, *all* pieces in that class were measured for length. The purpose of obtaining lengths was to 1) provide higher accuracy when quantifying instream wood volumes, 2) assist in the identification and quantification of key pieces based on volume, and 3) enable future analysis of piece lengths and size distributions in jams.

Channel units were assigned to each channel with indications of inundation at normal high flow. These units provide a reference for channel position of wood since a habitat survey, which typically collects this information, was not conducted concurrently. Channel positions will be simplified into mainstem and side channel units. Channel units were numbered as "1" for mainstem, with each side channel sequentially numbered thereafter within the reach (Figure 1). Wood quantities and volumes assessed for a channel segment includes all wood from associated side channels.

Each reach was also categorized in the field for channel reach morphology. A stream channel was identified as 1) a Pool/Riffle, 2) a Plane-Bed, 3) a Step-Pool, or 4) a Cascade, using the classification methodology described by Bisson and Montgomery (1996) and Montgomery and Buffington (1997).

Finally, each reach was characterized in the field as either “alluvial” or “bedrock.” These channel types are essentially self-explanatory; however, further details on the identification of these channels are described by Montgomery et al. (1996). Channels were classified as alluvial if the dominant streambed substrate was comprised of alluvial material, even if the underlying morphology appeared to be bedrock based on the observance of outcrops or other indications.

### 2.2.3. Riparian Surveys

Riparian surveys were conducted to characterize the adjacent timber stands that potentially recruit wood to the stream. To accomplish this, the Point-Centered Quarter (PCQ) method (Mueller-Dombois and Ellenberg 1974) was used to quantify stem density, species, and basal area. According to this method, a perpendicular transect is established on both sides of the stream, beginning 5 m from the bankfull width. Five center-points are established along this line, spaced 15 m apart for a total distance of 65 m from the BFW. The distances of these transects are intended to characterize the zone of influence loosely based on potential tree heights. However, the height of the dominant trees in portions of NW coniferous forests can reach heights of 70-90 m (Franklin and Waring 1980), but a transect of 70 m is still within the riparian forest zone of influence (Meehan et al. 1977). Although the distance used in the PCQ method does not quite extend a full site-potential tree height at all locations, we assume that it will accurately characterize the riparian stand features such as species distribution, diameter classes, and density.

Tree heights were also obtained to help characterize riparian areas. Tree heights were determined by trigonometric means. This required the location of a tree in the riparian area that has a simultaneously visible top and base from a distance equal or greater than its height. The purpose of maintaining this horizontal distance is to reduce error associated with the sensitivity of a hand-held clinometer when obtaining angles, and clearly being able to identify the tree top without obstruction of branches. Trees were chosen to represent the mean height of the upper riparian canopy. More detail on determining tree height is provided in Appendix B. 2 “The Trigonometric Tree Height Estimation Form.”

### 2.2.4. Disturbance Identification

Assuming the differences in wood quantity are the most dramatic following a recent disturbance, we surmised that channels exhibiting some form of recent disturbance must be identified to adequately qualify instream wood loads. Therefore, the type, frequency, and magnitude of four types of significant disturbances found in unmanaged basins were evaluated in the field. These types are 1) fires, 2) floods, 3) debris flows, and 4) snow avalanches. Other forms of disturbances such as catastrophic wind throw, insect and disease mortality, or other causes of tree mortality are acknowledged as significant sources of wood recruitment to streams; however, were not found significantly in the surveys. The following describes how these four disturbances were documented in the field.

*Fire*

Fires that preclude or induce stem recruitment to a stream are likely to influence the amount of wood found in a channel. The age of timber as induced by stand-replacement fires influences tree size and other riparian characteristics that affect the quantities and volumes of instream wood. Assuming that all forests burn at some frequency, the significance to instream wood is likely related to the length of recovery following fire. Assuming instream wood quantities and volumes recover with time following fires, our objective was to determine the date of the last stand-replacement fire. The date of the last major forest fire was difficult to determine in the field unless the fire was relatively recent. Such evidence indicating recent fires found during the riparian inventories were tree scarring, a young, homogenous stand age with scorched logs in the under-story, and blackened stumps. Ages of the fires were estimated by counting tree whirls or by counting stump-rings created by trail-blazing, as in the case of even-age regeneration. Most commonly, however, the date of the last fire was not known in the field. In many stands, the date of forest origin due to fire is over 900 years, such as the Hoh and Quinault River regions on the western Olympic Peninsula (Henderson, pers. comm. 2001). Therefore, local foresters and ecologists proved most valuable for obtaining this information.

### *Floods*

Floods influence the wood quantities and volumes if wood becomes mobilized. The documentation of the time and magnitude of floods recorded at the time of the survey may help qualify the amount and distribution of instream wood. Evidence of floods was seldom encountered in the field, or at least could not be dated unless very recent (<1-year). Evidence of floods typically was in the form of detritus and matted vegetation due to surface water outside the normal area of high flow. Wood accumulations outside this the area of normal high flows also was an indicator; however, it was difficult to determine how recent the flood occurred based only on wood. In most cases, evidence of recent floods found in the stream merely provided anecdotal documentation until further investigations on flood history could be conducted. Most of these data were obtained through USGS gaging station records rather than in the field (see Section 2.6.2).

### *Debris Flows*

Stream channels with debris flows were also identified in order to characterize the effects of this disturbance upon the quantity and volume of instream wood. Because debris flows have likely occurred in all channels with conducive gradient and confinement at some point in time, only debris flows occurring within the last 15-years prior to surveys were documented. This period was established to minimize the uncertainties of debris flow identification that increase with time induced by re-vegetation, and to standardize the effects of this form of disturbance without the added variability of differential recovery periods (beyond some period of recovery, instream debris flow tracks may not be distinguishable from other forms of disturbance such snow avalanches). Ages of debris flows were determined by whirl counts on alder and maple trees in the disturbance path. Debris flows were identified by streambed and bank disturbance, adjacent riparian disturbance, and the presence of scour down to bedrock in the steeper channels. Scarps in headwall areas also provided source indications of debris flows, as verified by aerial photo interpretation.

### *Snow avalanches*

Stream channels subjected to snow avalanches were documented in order to characterize the effects of this disturbance upon the quantity and volume of instream wood. Stream channels affected by snow avalanches are likely to have regular occurrences of this disturbance due to topographic and climatic features upslope. However, 15-years was set as the maximum age to minimize the uncertainties of snow avalanche identification that increase with time and re-vegetation, and to standardize the effects of this form of disturbance without the added variability of differential recovery periods. Ages of snow avalanches were determined by whirl counts on alder and maple trees in the disturbance path. Snow avalanches were identified by riparian vegetation breakage, often with minimal channel bed disturbance. The lack of visible scarps in the channel heads and the dissipated fan in the unconfined valley bottoms were also effective indicators. Often, vine maple and slide alder were present in the avalanche paths.

### 2.2.5. Verification of Gradient and Confinement

In the field, mapped determinations of gradient and confinement were verified. To confirm the mapped gradients, survey crews moved downstream while recording the total drop in elevation as measured with a hand-held level and a stadia rod following a segment survey. Levels were often braced against a solid object such as staff, and the distance between the level and the stadia rod for each distance increment was kept to a minimum (not exceeding the readability range of the stadia rod by the "caller") in order to maximize accuracy. The total drop in elevation was then divided by the distance surveyed to calculate gradient. To confirm mapped confinement classifications, the number of potential channel widths within a valley bottom were assessed in the field according to the TFW-MPMM.

### 2.2.6. Quality Assurance/Quality Control

"QA/QC" surveys were conducted on each of the field crews for the above methods by the author. The results of the QA/QC surveys suggest that the differences between the evaluator and the surveyor are within approximately 10% of each other; therefore, confidence in the quality and accuracy of the data are high.

## *2.3.* Methods of Analysis

### 2.3.1. Data Handling

Field data were entered into MS Excel® spreadsheets to facilitate numeric manipulations and calculations. QA/QC was conducted on the data entry (self-assessments) at regular intervals to ensure accuracy.

*Spreadsheet Methods*

Spreadsheets were used to estimate certain data parameters that field methods could not feasibly achieve. The distribution of LWD piece lengths within jams was estimated by statistical means. Where more than 10 pieces of any of the four diameter classes were found, the ten sampled lengths of those classes were used to estimate lengths of the unmeasured pieces. This was accomplished by normalizing the sample lengths with a $\log_{10}$ transformation, and estimating the proportion of the remaining lengths according to a t-distribution, with 9 degrees of freedom in each case (Zar 1999). This is assuming that the sample lengths are representative of each diameter class. Piece volumes were estimated by $\Pi r^2 L$, where L is the piece length and r is the midpoint mean radius. The volumes of root wads were not included in volume calculations due to the irregularity of their shapes. Therefore, volume estimations of pieces with root wads are likely underestimated.

*Data Normalization*

Nearly all the data collected for this analysis are log-normally distributed, as determined by initial analysis using Kolmogorov-Smirnov tests, histograms, and Q-Q plots (Appendix A. 1). Therefore, to gain statistical benefits for testing hypotheses from normally distributed populations, data were normalized with a $\log_{10}$ transformation.

### 2.3.2. Choice of Units for Characterizing Wood Loads

Due to the various means of expressing the quantities and volumes of wood illustrated in the literature (Section 1.3.1), the most appropriate units for this analysis must first be determined. To accomplish this, three common units for quantities and volumes of wood were evaluated with regressions using the independent variable of bankfull width. These methods are: 1) wood per 100 m of channel length (a unit of length that does not change with increases in BFW), 2) wood per $m^2$ (a unit of area that increases exponentially with BFW), and 3) wood per channel width (same as bankfull width) of length (a unit of length that increases linearly with BFW). Other methods found in the literature were of the same scale as these methods. For example, "wood per meter" or "wood per mile", another common method used to scale wood quantity and volume, is similar to "wood per 100 m" for evaluation purposes as a fixed unit of channel length. Thus, testing other units of fixed channel length scales would be redundant. In the analysis of these regressions, we used wood volume as the dependent variable; however, the use of wood quantity has very similar relationships to increases in BFW using these methods, and therefore is assumed to follow a similar pattern.

Based on the results of this regression analysis, which is presented later in Section 3.4 and the relevant discussion (Section 4.1), we chose to use pieces and volumes of LWD per 100 m of channel length. This choice of unit affords a reasonable "fit" in which to predict wood loads, and yet also facilitates manageable groups of variables statistically, due to the moderate regression slope (as discussed later in Section 4.1).

### 2.3.3. Choice of Geomorphic Expression

*Bankfull Width vs. Basin Size*

The ability to predict wood quantities and volumes was compared between the independent variables of basin size and bankfull width. Comparisons of the coefficients of determination (i.e. $R^2$) for regression "fit" were conducted to test for significance (at 95% confidence [$\alpha = 0.05$]) using a paired t-test (Zar 1999) to determine the best predictor variable of instream wood parameters.

The relationship between bankfull width and basin size was also explored. This relationship was assessed for interchangeability when predicting wood parameters, and how it may vary regionally. This was accomplished by tests for significance (at 95% confidence [$\alpha = 0.05$]) using simple linear regressions on normalized ($\log_{10}$-transformed) data. An evaluation of regional differences in this relationship was also conducted by testing the interaction between western and eastern Washington basins by the use of indicator variables (ANCOVA) with linear regressions to test differences in slope (Neter et al. 1990).

Finally, the relationship of bankfull width to channel cross-sectional area was verified. As with basin size, channel cross-sectional area may also serve interchangeably with BFW as a predictor of wood parameters. The verification of this relationship is necessary to indicate the size of the upstream basin, but to also predict the area of high flow using BFW. This also serves to establish proportional relationships of channel shape using BFW measurements (e.g. characterization of channel width to depth). To accomplish this, tests for significance ($\alpha = 0.05$) using simple linear regressions on normalized ($\log_{10}$-transformed) data were conducted.

### *Field Gradients Rather Than Mapped Gradients*

To help prevent losses in accuracy when characterizing channel gradients, field gradient are used rather than gradients obtained from maps during the site selection process (Section 2.1.2). The choice to use this method is based on the deviation from a 1:1 slope of the linear regression between field gradient and map gradient (Figure 2), and our belief that more credence should placed on field measurements due to the finer resolution in scale.

## *2.4.* Methods to Characterize Riparian Timber by Ecoregion

The influence of riparian trees on instream wood likely differs among ecoregions due to climatic distinctions. Therefore, a means to describe how riparian areas differ among ecoregions was developed to facilitate analytical inferences regarding the regional relationship with instream wood loads. Data collected from the riparian surveys were used to describe 1) riparian basal area ($m^2$/hectare), 2) mean tree height of the dominant canopy, 3) tree density (number of trees/hectare), and 4) mean tree diameter (dbh). Percentile distribution plots, also referred to as “box plots”, were constructed to illustrate the relative comparison of ranges, medians, and distribution of these parameters among ecoregions.

## *2.5.* Grouping the Sitka Spruce and Western Hemlock Forest Regions

Due to the differences in tree species, climate influences, and disturbance cycles, the incorrect grouping of forest regions seemingly could lead to fallacious characterizations of the riparian areas adjacent to streams. Perhaps of particular interest, the grouping of the SS and WH forests (SS/WH) of western Washington may cause concern in regards to the multitude of restoration and enhancement efforts within the urban environment. For example, this could especially be of concern to management, if asked to evaluate, enhance, or restore streams based on references to streams draining SS forests such as on the west slopes of the Olympic Peninsula. Therefore, data for streams within the SS/WH ecoregion were assessed separately by respective forest types of SS and WH based on species presence, elevation, climate, and other specific descriptions characterized in the literature (Agee 1993; Henderson et al. 1992; Franklin and Dyrness 1973).

Riparian characteristics of tree diameter and basal area, and instream characteristics of LWD volume and quantity were compared between the two forest types using an analysis of variance (ANOVA) and regressions on normalized data, assuming the samples are drawn from a similar geomorphic distribution. Although deserving of equal attention, the SF/MH and the DF/PP groupings were not analyzed to this level of detail, and we assume that the two forest types in each ecoregion are analogous based on similarities in elevation, climate, species composition, and other components described in the aforementioned literature.

## *2.6.* Methods to Analyze Process and Trends

### 2.6.1. Geomorphological Influences

Due to the many potential geomorphologies of streams, features that have the most influence on instream wood quantity and volume must be determined to facilitate analysis. This was accomplished by first assessing the range of morphologies found. Not all combinations in the "matrix of possibilities" are likely to be present; therefore the distribution was expressed by simple scatter-plots. Next, we evaluated the influence of each geomorphological characteristic upon instream wood. For this procedure, we chose to use the parameter of wood *volume* per 100 m based on the unit choice method described in Section 2.3.2, although using wood *quantity* would likely yield similar results based on the strong correlation ($p<0.001$) of these two parameters (Figure 3). General processes and trends of wood volumes per 100 m were compared to a range of gradients, confinements, and basin sizes using bar charts in order to incorporate simultaneous variables. The variability of wood volume was also assessed as it relates to channel type, stream origin, and bed-form, using bar charts and box plots. Statistical inferences are made if the sample size is sufficiently large; however, where sample sizes were small, the power-of-tests are evaluated to determine the likelihood for a Type II error (Zar 1999). If a low test power suggests low accuracy in statistical tests, inferences regarding the trends and process were made simply using the bar charts and box plots.

### 2.6.2. Influences by Channel Disturbance

Also as a potential source of variation for instream wood quantities and volumes, the four types of channel disturbances previously cited were assessed for their influence on instream wood. Graphical methods were used to characterize the influence of each type of disturbance, using wood volume as the response variable. Statistical inferences are made if the sample size is sufficiently large; however, where sample sizes were small, the power-of-tests are evaluated to determine the likelihood for a Type II error (Zar 1999). If a low test power suggests low accuracy in statistical tests, inferences regarding the trends and process were made simply using the graphical methods. Specific means to assess these forms of disturbances are as follows:

### *Fire*

To assess how fires and the subsequent timber age influences instream wood, relationships between LWD volume and quantity per 100 m and timber ages due to stand-replacement fires were analyzed using scatter plots and simple linear regression. Timber age is expressed by the year of origin induced by stand-replacement fire. Due to the availability of timber age information, only the SS/WH, SF/MH, and SAF ecoregions were assessed, with the assumption that general trends would also apply to the GF and DF/PP ecoregions [we recognize the fact that fire is more frequent in these eastern Washington ecoregions (as compared to western Washington), but they do not commonly kill over-story trees with each burn]. Markers to identify individual ecoregions were used in these regressions to assess relationships not only for the total population, but also within ecoregions. Data for LWD volume and quantity per 100 m were normalized with a $\log_{10}$ transformation to facilitate statistical analysis.

Due to the fact that the adjacent riparian area influences the quantity and volume of instream LWD (Section 1.2.4), relationships between riparian characteristics and timber ages due to stand-replacement fires were also assessed. The parameters of mean tree diameter (dbh) and basal area ($m^2$/ha) were used to establish these relationships by regressions with timber age. Data for basal area were normalized with a $\log_{10}$ transformation to facilitate statistical analysis; however, mean tree diameter in its original state follows a normal distribution and therefore was not transformed.

### *Floods*

To assess the effects of floods on instream wood, the correlation of the year and magnitude of floods to the quantity and volumes of wood recorded at the time of the survey was assessed. To accomplish this, the annual peaks recorded at the nearest unregulated gage downstream of the site were obtained for the period of record preceding the surveys. In all cases, US Geological Survey (USGS) operates these gages. Probabilities and return periods for peak discharges were estimated using the Log-Pearson Type III distribution (U.S. Water Resources Council 1981). English units for discharge were used as a matter of convention towards consistency with USGS methodology. The year and magnitude of the largest three floods over the period of record were noted, along with their expected return intervals. The expected magnitude of a one-year flood return was also included as a scale for reference. Additionally, streams were assessed to whether a major flood had occurred within the ten years preceding the instream wood surveys. A "major flood" for the purpose of this analysis constitutes of any event equal or exceeding a 25-year return period (exceedence probability = 0.04). The selection of a 25-year flood magnitude and the 10-year period prior to wood surveys is based on 1) a flood magnitude that is exceptionally large within the period of record, 2) a sufficiently short recovery period to fully explicate the effects of the flood in relation to instream wood, and 3) the ability to maintain an adequate sample size for streams with and without major floods in order to represent the range of channel morphologies (as characterized by bankfull widths). Finally, basins of the survey sites upstream (or nearest) of these gages were noted, indicating which survey sites these floods potentially affected. Although basins other than those of the surveyed stream reaches influence some gages, our assumption is that the occurrence of floods recorded at these gages indicate events such as heavy precipitation or "rain-on-snow" (often causing floods) likely encountered in the surveyed reaches. Regressions of both the quantity and volume ($m^3$) of LWD per 100 m of channel length to bankfull width (m) were conducted on streams with and without major floods within the 10-years preceding surveys to compare slopes and intercepts.

*Debris Flows*

To assess the effects of debris flows on instream wood, the quantity and volume of wood per 100 m was compared between stream channels with debris flows disturbance and those without any sign of recent disturbance. To analyze the effects of debris flows in different gradients, channels with this form of disturbance were separated into two gradient classes: 1) <6%, and 2) >10% to distinguish between depositional and transport reaches, respectively. The assessment of the effects of debris flows upon instream wood volumes was achieved using box plots and an analysis of variance with normalized data.

*Snow avalanches*

To assess the effects of snow avalanches on instream wood, the quantity and volume of wood per 100 m was compared between stream channels with snow avalanche disturbance and those without any form of recent disturbance. Similarly to the analysis of debris flows effects, channels affected by snow avalanches were assessed using gradient classes of <6% and >10% to distinguish between depositional and transport reaches, respectively. The assessment of the effects of snow avalanches upon instream wood volumes was achieved using box plots and an analysis of variance with normalized data.

### 2.6.3. The Selection of Predictor Variables

Based on 1) the results of the trend analysis with wood volumes with increasing basin size (Section 3.7), 2) the correlation of bankfull width to basin size and cross-sectional area, and 3) the demonstration that bankfull width has slightly better predictive qualities than basin size for instream wood (Section 3.5.1), **bankfull width** is determined to be the best defensible geomorphological indicator to predict instream wood volumes and quantities. Based on the results and discussion pertaining to the analysis of channel disturbances (Sections 3.7.1 and 4.6, respectively), the influence by climate and riparian processes (Section 4.5), conclusions were drawn that the variable of **ecoregion** is also a viable indicator to predict instream wood volumes and quantities. These two variables will serve as the primary indicators to evaluate wood quantities and volumes for the purpose of this analysis.

## *2.7.* Methods to Test the Adequacy of Existing Wood Targets

As described in Section 1.5, targets for the quantity of wood pieces currently used by resource managers do not accurately reflect wood distributions found in all channel types and regions within Washington State. Based on the assumption that salmonids and other aquatic species have adapted to instream wood characteristics of local systems, it is important that streams are evaluated, enhanced, or restored based on this condition. To determine the viability of current management targets towards meeting these conditions, targets were compared to the data collected in this study. We are making the assumption that the data collected in this study are representative of wood found in unmanaged basins, and will provide a reasonable reference to the quantities of instream wood favorable to aquatic species. Two existing management targets were used for comparisons: 1) the NMFS targets, and 2) the Washington Forest Practices Board targets for conducting Watershed Analysis. The following provides the detail of the methods used for comparative testing:

### 2.7.1. The NMFS Targets

Pieces of wood meeting the minimum size qualifications for both the western and eastern Washington targets were counted and scaled to "pieces per mile." All data were used except for those from the SAF ecoregion, due to the fact that this ecoregion often straddles the Cascade crest. These data perhaps do not lend themselves to a classification system that divides the State into "east and west" partitions, and may not represent either side effectively. Using a one-sample t-test, the mean quantity of pieces per mile for each side of the state were tested against the NMFS targets of 80 (W. WA) and 20 (E.WA) pieces per mile (quantity needed for a "Properly Functioning Condition"). For this test, data were normalized using a $\log_{10}$ transformation to attain the benefits of parametric test procedures. Further analysis was conducted by partitioning the data into two bankfull width classes, if the data distribution suggested the targets might be more applicable to channels of a certain size. These partitions were individually tested in the same manner as the combined data. Box plots and their statistical summaries were used to illustrate the percentile distribution of the data as compared to the target values for the purpose of discussion.

### 2.7.2. The Washington Forest Practices Board targets

*Large Woody Debris Quantity*

Pieces of wood meeting the minimum piece size qualification for western Washington were counted and scaled to pieces per channel width. Using a one-sample t-test, the mean quantities of pieces per channel width (CW) were tested against the WFPB targets of 2 pieces per channel width (quantity needed for a "good" habitat condition). For this test, data were normalized using a $\log_{10}$ transformation to attain the benefits of parametric test procedures. Further analysis was conducted by partitioning the data into three bankfull width classes, if the data distribution suggested the targets might be more applicable to channels of a certain size. These partitions were individually tested in the same manner as the combined data. Box plots and their statistical summaries provided an illustration of percentile distributions of the data as compared to the target values for the purpose of discussion. Linear regression was used to illustrate the relationship of piece quantity/CW to bankfull width. Both variables were also normalized ($\log_{10}$) prior to analysis. In these regressions, markers labeling each ecoregion were used to illustrate the relative contribution of each ecoregion to the regression.

*Key Piece Quantity*

Pieces of wood meeting the minimum key piece size qualification in terms of volume ($m^3$) for western Washington were counted and scaled to "pieces per channel width." Using a one-sample t-test, the mean quantity of pieces per channel width was tested against the WFPB targets of 0.3 and 0.5 pieces/CW for 0-10 m and 10-20 m BFW, respectively (quantity needed for a "good" habitat condition). Also for this test, data were normalized using a $\log_{10}$ transformation to attain the benefits of parametric test procedures. Further analysis was conducted with box plots and the associated statistical summaries to illustrate the percentile distribution of the data as compared to the target values for the purpose of discussion. Linear regression was used to illustrate the relationship of key piece quantity/CW to bankfull width. In these regressions, markers labeling both western Washington ecoregions (i.e. SS/WH and SF/MH) were used to illustrate the relative contribution of each ecoregion to the total regression.

## *2.8.* Methods to Develop References for Instream Wood

### 2.8.1. General Trends

Prior to specific analyses of instream wood quantity and volume, several basic relationships and trends were established to illustrate the general process. Regressions were used to describe the relationship of instream LWD quantity and volume to bankfull widths, and how this varies regionally. An evaluation of mean piece size (in terms of volume) as it relates to different sized streams (in terms of BFW) was also accomplished by regressions. Regressions were also conducted between total wood volume and the quantity of LWD pieces to further assess the relationship between mean piece size and bankfull width. All regressions were accomplished with normalized variables, and assessed with a significance level of 0.05.

### 2.8.2. Defining Minimum Key Piece Volumes

The current standards for key pieces do not apply to all streams within the State of Washington. Therefore, to facilitate the further development of references for the quantities of key pieces, we must first establish the minimum piece volumes to define key pieces for streams greater than 20 m bankfull width, where standards currently do not exist. Secondly, the use of these minimums, as well as the existing WFPB minimum volumes defining key pieces, must either be validated for eastern Washington streams or new minimums must be defined. To achieve this end, the following was conducted:

*Western Washington, channels >20 m BFW*

To define key piece minimum volume for channels >20 m BFW, twenty-one streams were surveyed to identify wood pieces that met the definition of key pieces (WFPB 1997, and as described in Section 1.3). Surveyed channels ranged between 22 and 100 m bankfull width. One hundred and sixty-five wood pieces meeting the WFPB (1997) definition were measured, and their volumes calculated. Each piece was also noted if a root wad was attached. Box plots were constructed to illustrate the range of volumes for three bankfull width classes based on differences in variances as determined with F-tests. The separation of bankfull width classes, even if the means were not significantly different (as determined using an ANOVA on log-normalized data), was useful to assess potential changes in the range and distribution of volumes as channels become larger. To determine minimum volumes to define key pieces in these channels, the lowest value from the middle 50% of the distribution (i.e. the 25th percentile) was used. The 25th percentile represents the smallest volume of the central distribution, and for this reason, is a logical choice to define the minimum volume for a wood piece as having the functions of a key piece. These minimum volumes were then plotted with the existing key piece minimum volumes defined by WFPB (1997) to illustrate the trend with increasing channel size. The proportion of pieces having root wads attached was assessed with bar charts, and minimum volumes were recalculated using the above methods for pieces without root wads. This served to document the minimum volume required of a piece of wood to provide the functions of a key piece if a root wad is not attached.

*Eastern Washington Channels*

Rather than replicate the efforts of defining minimum key piece volumes in western Washington, the applicability of the existing minimums defined by WFPB (1997) were assessed for use in eastern Washington. This was accomplished by several means. First, we evaluated the proportion of wood in both eastern and western Washington ecoregions that met the minimum volume criteria defined by WFPB. If the definitions for key piece minimum volume were set too high or low, one would expect a difference in the total percent of wood that meets these qualifications. This was assessed using an ANOVA on each of the five ecoregions, with post-hoc tests of Tukey's Honestly Significant Difference (HSD) and Student-Newman-Keuls (SNK) (Zar 1999). The variances of the data, in the form of percents and thus binomial, were stabilized using an arcsine square root transformation prior to testing. Second, assuming stream power, piece volumes, piece shapes, and channel position are proportionately the same due to the sampling design, the force required to mobilize a piece of wood is left to the physical density of the wood (Braudrick 2000). To assess potential differences in wood densities among ecoregions, tabled mean dry wood densities of species found in each ecoregion, weighted by the proportions found during the riparian surveys, were compared. Comparisons were facilitated using an ANOVA. The same test was performed on data grouped into two categories: 1) eastern and 2) western Washington in order to assess potential regional disparities that could affect the application of the minimum key piece volume criteria to eastern Washington.

### 2.8.3. Combining Ecoregions

In order to increase statistical power gained by a larger sample size, ecoregions were combined if the critical components influencing instream wood were similar. Combinations are based on the similarities between 1) riparian basal area ($m^2$/ha), a characteristic of the diameter and densities of trees potentially recruited to the channel, and 2) instream wood volumes ($m^3$/100m), a characteristic of the amount of wood found in a channel). Similarities among ecoregions were determined statistically by an ANOVA and post-hoc comparisons (Tukey's HSD and SNK) of the mean (log-transformed). Both parameters must be statistically similar for combinations to take place. This criterion is intended to prevent unnecessary loss of unique characteristics contributing to regional variability.

### 2.8.4. Delineation of Bankfull Width Classes

Bankfull width classes were formed to facilitate statistics on discrete channel units rather that rely on equations to characterize wood quantities and volumes. Bankfull width classes were initially delineated into increments of 3-5 m based on 1) sample representation, and 2) differences in medians and percentile distribution as visually assessed with box plots. To increase statistical power gained by a larger sample size, and to avoid unwieldy quantities of BFW classes potentially used by resource managers, BFW classes were combined based on similarities in 1) the means, and 2) the variances, of wood quantity (for both LWD and key pieces), and volume, per 100 m of channel length. This was accomplished with ANOVA and subsequent post-hoc tests of Tukey's HSD, and SNK methods on the means, and F-tests on the variances. Wood data were normalized prior to testing using $\log_{10}$ transformations. The procedure for grouping of BFW classes began with the smallest increments (3-5 m), combining adjacent classes that met the above criteria. Adjacent BFW classes were not combined if at least one of the above criteria were not met. Significance levels indicating differences in either the mean or variance were set at a 90% confidence level ($\alpha = 0.10$). This deviation from the common standard of $\alpha = 0.05$ was set in order to not unduly lump BFW classes and potentially lose refinement. Probabilities for F-tests were determined using a web-based probability distribution calculator (Pezzullo 2001). Combinations ceased when all remaining BFW classes differed by either of the criteria. Combining BFW classes were conducted for each wood parameter for each ecoregion, since the same combinations did not necessarily apply to each.

### 2.8.5. Defining Wood Targets

Reference conditions identified from the data can potentially serve as targets for the management of instream wood. The defined ecoregion groups and bankfull width classes for each of the wood parameters: 1) LWD quantity per 100 m, 2) Key piece quantity per 100 m, and 3) LWD volume ($m^3$) per 100 m were expressed in the form of percentile distributions (box plots). The 25th and 75th percentiles of the distribution were used to define the range of conditions that characterize each parameter of wood in unmanaged systems subject to the natural disturbance regime. Because not all streams in unmanaged basins have optimal habitat based on wood loads, the 75th percentile is a reasonable reference point to define target quantities or volumes. For example, if following the WFPB system of "good, fair, and poor" for wood diagnostics, the 75th percentile and greater would serve to define the "good" condition, the range from the 25th percentile to the 75th percentile would serve to define the "fair" condition, and below the 25th percentile would serve to define less than optimum conditions or "poor." In a few cases where the sample size and wood quantities were small, such as in the DF/PP ecoregion, the 25th percentile for some parameters was zero. In this case, the defining point between "poor and fair" used the median value rather than zero.

# 3. RESULTS

## *3.1.* Site Summary

One hundred fifty sites were surveyed, totaling nearly 38 km of stream length. Given the site selection criteria described in Section 2.1.1, most sites were located in the parks and wilderness areas within Washington State. Sampled stream gradients ranged between 0.04% and 49%, and basin drainages ranged between 0.4 km$^2$ and 325 km$^2$. A total of 21,671 LWD pieces were counted and measured. Site elevations ranged between 6.6 m and 1,906 m (above mean sea level). Riparian trees adjacent to surveyed reaches had stem densities ranging from 6 to 523 trees per acre, and basal areas ranging from 0.12 to 116 m$^2$ per acre. Tree heights ranged from 3 to 74 m, with a max height of 85 m measured in the SS/WH ecoregion. The general distribution of sites within each ecoregion of Washington State is illustrated in Figure 4, and the site elevation ranges in terms of percentile distributions for each ecoregion in Figure 5. Detailed site maps are provided in Appendix 9.4. The riparian characterizations for riparian tree diameter/height, trees per acre, and basal area among ecoregions are presented in Figure 6, Figure 7, and Figure 8, respectively.

## *3.2.* Site Distribution

Many combinations of channel morphologies do not exist, were not found during the surveys, or are rare. Unconfined streams were most frequently found at lower gradients, and often had large drainage basins. Unconfined streams originating from smaller basins were less frequently observed, and often were found within the flood plains of larger streams. Little evidence of avulsion and channel migration was observed in these channels. High gradient streams were mostly observed as originating from smaller basins, and typically had a greater confinement. Unconfined, high gradient streams draining small basins were less frequently observed, but when present, often were observed to flow over lithic features that prevented significant channel incision. Confined, high gradient channels draining large basins were equally as rare, and typically occurred in brief reaches where the valley walls and stream bed is composed of bedrock. Often, these streams also had significant portions of unconfined stretches of channel comprised of lower gradients upstream and/or downstream of the surveyed sites. Only 25 bedrock channels were surveyed throughout the ecoregions, and only 7 streams surveyed had an origin fed by glacial-dominated headwaters.

## *3.3.* Ecoregion boundaries

Based on the findings in the field as well as references from the literature, rough boundaries defining ecoregions for the purpose of instream wood characterizations are presented in Figure 4. Although this Figure when used in conjunction with the descriptions in Section 1.2.5 provides a broad characterization of ecoregion boundaries for most practical purposes when characterizing instream wood, finite resolution in the classification of vegetation is lost. Therefore, we recommend referencing the work of ecologists such as Agee (1993), Henderson et al. (1992), or Franklin and Dyrness (1973) for further detail on defining forest types characterizing each ecoregion.

## *3.4.* Comparing Wood Loading Units

Figure 9 presents regressions for three units used in current literature to express wood volume with increasing bankfull width, as well as the equations for each. Although it appears that each of these units are different, a comparison of these methods concludes that all predict identical results. For example, inserting a bankfull width value of "20 m" for x in each of the regression equations presented in Figure 9 yields 46.8 $m^3$ per 100 m, 0.0234 $m^3$ per $m^2$, and 9.36 $m^3$ per channel width. Converting these values to a common unit such as volume per 100 m will yield the identical quantity of 46.8 $m^3$ for each method (i.e. 0.0234 $m^3$ x 20 x 100, and 9.36 $m^3$ x 5). Although each of these methods produce identical outcomes, presenting the relationship in terms of $m^3$ per *channel width* affords the perception of the best "fit" in relationship to bankfull width as the predictor variable. This is evident by the higher coefficient of determination ($R^2$) when volume is expressed in this manner, as compared to regressions using a fixed unit channel length (e.g. $m^3$/100 m) or unit area (e.g. $m^3/m^2$).

## *3.5.* Geomorphic Expression

### 3.5.1. Bankfull Width

Bankfull width is a significantly better predictor of wood parameters than basin size (p=0.05). The error in the regressions of wood volume per 100 m is explained better (i.e. higher $R^2$) in all regions when bankfull width is used as the independent variable rather than basin size, and in two of the three regions for wood quantity (Table 3). It must be noted, however, that this error is high in both variables as indicated by the generally low $R^2$ values (Table 3). Subsequently, there is likely little difference in predictive qualities between the two variables when scaled per 100 m. A more significant difference ($p<0.001$) exists when scaling by pieces per channel width (for all data), in addition to having a higher $R^2$ value at this scale (Section 3.4). Because bankfull width is a better predictor of wood quantity and volume than basin size, bankfull width is mostly used as the independent variable for further analysis in this study.

A strong correlation exists between basin size and bankfull width (Figure 10); therefore, basin size may also be used as a predictor of wood parameters if BFW measurements are unavailable. This is justified by the high error unexplained in the regressions when scaled per 100 m; therefore, regression predictions with either are likely within the same variance. However, regional differences in the relationship between bankfull width and basin size suggests that this application should only be applied intra-region. For example, a significant difference exists between the slope of this relationship in eastern Washington compared to western Washington (P = 0.002). Linear regressions suggest that for every unit increase in basin size, the bankfull width increases by 0.551 units in western Washington, but only by 0.442 units in eastern Washington. The full equations for predicting bankfull widths are presented in equations 1 and 2,

$$Y_{WWA} = 3.27x^{0.55} \quad (1)$$

and $$Y_{EWA} = 2.72x^{0.44} \quad (2)$$

where $Y_{wwa}$ and $Y_{Ewa}$ is the predicted bankfull width in meters for western and eastern Washington streams respectively, and x is the basin size in $km^2$. Therefore, using bankfull width as a predictor of basin size must distinguish, at a minimum, between eastern and western Washington streams. The same holds true for basin size to predict instream wood loads.

The relationship of channel cross-sectional area to bankfull width is also strongly correlated ($R^2=0.93$) and highly significant ($p<0.001$), and suggests that the cross-sectional area of high flow can be predicted by a bankfull width measurement. The equation

$$Y_{xs} = 0.174\, x^{1.42} \quad (3)$$

where $Y_{xs}$ is the predicted cross-sectional area ($m^2$) and x is the bankfull width (m), will provide a reasonable estimate for cross-sectional area in both western and eastern Washington streams. Due to the development of this relationship in unmanaged streams, caution is needed if applied to streams in managed basins, human modified channels, or recently disturbed channels as discussed in Section 2.3.3.

### 3.5.2. Field Gradient vs. Mapped Gradient

Discrepancies were often found when comparing mapped channel gradients to field gradients (Figure 2). Based on the slope of this regression (i.e. $\beta_1=0.88$), it would appear that map interpretations more frequently over-estimate channel gradient, since we would expect a slope near 1.0. Although mapped gradients were used to select field sites prior to surveys, actual field gradients were used to characterize the channel for analytical purposes.

## *3.6.* The Validity of Grouping the Sitka Spruce and the Western Hemlock Forest Types

We determined that the predominant drivers for instream wood loads are similar between the SS and the WH forest types. Although there are significant differences in the mean tree diameters between the SS and WH forest types ($p<0.001$), there are no significant differences between 1) mean basal area ($p=0.697$), 2) LWD quantity/100 m ($p=0.624$), 3) LWD Volume/100 m ($p=0.051$), or between the regression slopes in the relationship of LWD quantity and volume per channel width to bankfull width ($p=0.067$ and 0.411, respectively). Even though the riparian trees differ in mean diameter, we conclude that grouping these two forest types is feasible due to the similarities of instream wood produced by the processes of these forests. Figure 11 presents these comparisons by "box plots." The complete statistical output can be found in Appendix A. 4.

## *3.7.* Regional and Geomorphological Processes of Instream Wood

Channel geomorphology plays a complex role in the quantities and volumes of instream wood. The range of possible morphologies is equally as great as the variability to which wood is found in these channels. In addition, instream wood quantities and volumes respond uniquely within each ecoregion. Figure 12A suggests that the median volumes of instream wood per 100 m are greater in western Washington ecoregions as compared to eastern Washington ecoregions, and increase as drainage area increases. Figure 12A also suggests that more wood volume per 100 m is found in unconfined streams than in confined streams. Increased wood volume is evident to a lesser extent as predicted by gradient among ecoregions (Figure 12B); however, the relationship between wood volume and basin size is more evident at low gradients with decreased confinement (Figure 13). This figure suggests that low-gradient channels accumulate more wood volume per 100 m than high gradient channels, especially in confined and unconfined channels (Figure 13). In all but the small basins (<4 km$^2$), more wood volume is observed in alluvial channels as compared to bedrock channels (Figure 14[A]), a result that is generally applicable only to confined channels (Figure 14[B]) because 23 of the 25 bedrock channels surveyed are in confined valleys. Figure 14(B) suggests that alluvial channels have more wood volume per 100 m than bedrock channels in all gradient classes when comparing only confined channels.

In basin drainages of 70 km$^2$ or more, streams originating from glacial sources have more wood volume per 100 m than streams fed predominantly with snowmelt and rain, as suggested by Figure 15. This may be related to the larger number of side channels in streams originating from glacial sources, which averaged 3 per stream (n=7) as compared to only 1.8 in snow/rain-dominated channels (n=17). There is no clear relationship between channel reach morphology and volume of wood; however, we found that pool/riffle channels commonly exhibit greater volume per 100 m than plane-bed, step-pool, or cascade morphologies (Figure 16).

### 3.7.1. Disturbance history

The surveyed channels have a broad range of natural disturbance history, assumed to have occurred at a natural rate. The types of disturbances observed or known to have occurred in the surveyed streams within the time-frames described in Section 2.2.4 are: 1) fire, 2) floods, 3) snow avalanches, and 4) debris flows. The following results serve to document the extent of disturbances found in the sampled streams, and describes conditions that may influence the quantities and volumes of wood recorded at the time of the surveys.

### *Fire*

Stand-replacement due to fire succession ranged between 35-years (the Cutthroat/Early Winters Creek basins, SAF ecoregion) and >900-years (the Hoh R., SS/WH ecoregion). Patches of timber escaping fire, also referred to as fire-refugia, were visible along incised tributaries and north-facing slopes when age disparities provided palpable contrast. For example, within the Mission Creek basin (DF/PP ecoregion), patches of timber in several steep north-facing canyons had several acres of large diameter timber encompassed within vast stands of trees with visibly smaller diameters and heights. Although not typically a dominant forest component within basins incurring recent fire disturbance, these refugia are often noteworthy features within riparian areas. The age of timber stands for surveyed sites within the SS/WH, SF/MH, and SAF ecoregion, as a reflection of basin fire history disturbance, is presented in Table 4. As expected, riparian characteristics are influenced by timber age. With younger trees, both the mean tree diameter (dbh) and basal area ($m^2$/ha) decrease.

Regression analysis suggests that instream wood volumes are correlated with timber age; however, the number of LWD pieces does not have a similar relationship. As the year of stand origin becomes more recent, the volume of instream LWD per 100 m decreases ($p=0.013$). This relationship is also significant in a separate regression of the SF/MH ecoregion ($p=0.047$); however, the relationship is not significant with separate regressions on either the SAF and SS/WH ecoregions. The SF/MH ecoregion also is significantly correlated with timber age for the number of LWD pieces per 100 m ($p=0.050$), although there is no significant relationship with either the remaining ecoregions or the combined data. With the SF/MH ecoregion, with younger timber age, the quantity of LWD per 100 m decreases. These relationships are expressed graphically in Figure 17, and with statistical test output in Appendix A. 2.

### *Floods*

Surveyed sites also have encountered a broad range of storms that have produced flooding as recorded by downstream flow gages. The maximum mean return period calculated with the data from the nearest downstream gage over the period of record ranges between 15 and >1000-years. A compilation of the largest flood events and their exceedence probabilities for the period of record as recorded by downstream unregulated gages (or nearest gage) of surveyed reaches is presented in Table 5.

Floods appear to have little effect on instream wood in the streams surveyed. The comparison of regression slopes between streams with recent floods to stream without recent floods suggests that floods do not significantly decrease the quantity and volume of instream wood per 100 m. The plots of these regressions are presented in Figure 18. The complete statistical output is included in Appendix A. 3.

Based on observation, many wood pieces found in the stream channel appeared to be quite old (based on decay or distortion), and were likely to have endured various large floods. In the larger channels, this often was attributed to the size of the logs or jams, which resisted mobility during floods. In mid-sized channels, older wood was more prevalent in channels with high quantities of roughness elements, such as other wood pieces and jams. In small channels, older wood pieces were commonly found unless a recent disturbance had occurred such as a debris flow, snow avalanche, or fire.

### *Snow Avalanches and Debris Flows*

Disturbances due to snow avalanches and debris flows were also observed in the surveyed sites. Of the 150 streams surveyed, 7 had recent (<15-years) debris flows, 15 had recent (<15 years) snow avalanches, and one had evidence of both. These types of disturbances were observed in three of the five ecoregions. Four streams in the SF/MH ecoregion were observed to have had debris flows (7.14%), and 3 in the DF/PP ecoregion (21.5%). The GF ecoregion had the highest number of snow-avalanches (10), amounting to 25% of all streams surveyed in this ecoregion, while the SF/MH had four streams with this disturbance (7.14%). Observations of these types of disturbances occurring earlier than the 15-year time frame were uncommon, or at least not evident. Most likely, snow avalanches occur at frequent intervals in certain channels, maintaining this level of disturbance. Most channels experiencing debris flows were disturbed either recently, and likely repeatedly based on irregular patterns in the younger vegetation. Only a few channels with indications of old debris flows (>15-years), and none since those events, were observed during these surveys.

The quantity and volume of LWD per 100 m of channel length are compared between channels with snow avalanches and debris flows to channels without recent disturbance, grouped by ecoregion, and presented in Figure 19 and Figure 20, respectively. Due to the small sample size for these types of disturbances, differences in wood quantities and volumes could not be detected with statistical significance (power <20% in most cases); however, these figures suggest several potential trends and processes. As observed during the surveys, quantities of instream LWD in channels that recently endured either snow avalanche or debris flow disturbances ranged from "near-complete removal" to "massive depositions." From Figure 19 and Figure 20, the median quantities and volumes of wood per 100 m in channels that have experienced debris flows is roughly the same as channels that have not experienced disturbance in gradients less than 6%. However, the median quantities and volumes of wood per 100 m are much *less* in channels experiencing debris flows than in channels that have not experienced any recent disturbance in gradients greater than 10%. Channels impacted by snow avalanches have nearly the same quantity of wood per 100 m as channels with no recent disturbance in gradients <6%; however, the wood volume between disturbed and undisturbed channels differs to a much greater degree. Both the median quantity and volumes of wood per 100 m are less in channels with snow avalanches compared to channels without disturbance in steep channels (>10% gradient).

## ***3.8.*** **Comparison of Data to Existing Management Standards**

As described in Section 1.3, various regulatory agencies use wood targets to define favorable habitat for salmonids. The following presents the results of comparing these target values with the data collected in this study.

### 3.8.1. The National Marine Fisheries Service Targets:

*To achieve a "Properly Functioning Condition:"*
*Western Washington: >80 pieces/mi. Qualifying wood must be >50ft. [15.24 m] in length and >24" [0.61 m] in diameter. Eastern Washington: >20 pieces/mi. Qualifying wood must be >35ft. [10.67 m] in length and >12" [0.305 m] in diameter.*
The distribution of the number of qualifying wood pieces per sampled site is presented in Figure 21 for western, or "Coastal Washington," and in Figure 23 for eastern Washington. Of the 78 streams sampled in western Washington, only 11 met the requirements of 80 pieces per mile put forth by NMFS for "Properly Functioning Condition" (PFC). However, in eastern Washington, 30 of the 54 streams sampled met the NMFS PFC requirements (56%). The means of both these samples grouped for both eastern and western Washington are significantly different from their respective PFC target ($p<0.001$ for W.WA and $p=0.020$ for E.WA). From the percentile distributions and one-tailed t-tests, the data suggest that the sample mean of qualifying wood pieces per mile is significantly lower than the NMFS target for western Washington (Figure 22[A]), but significantly higher for eastern Washington samples (Figure 24[A]). The data also suggest that the mean of the data is similar to the PFC standard only in channels greater than 40 m BFW in western Washington (Figure 22[B]). The target of 20 pieces per mile in Eastern Washington is near the 75th percentile for streams equal or less than 5 m BFW, but only near the 25th percentile in streams 5-50 m BFW (Figure 24[B]). A summary comparing the NMFS wood targets to the data collected in this study is presented in Table 6[A].

### 3.8.2. The Washington Forest Practices Board Targets for Watershed Analysis

*Large Woody Debris Quantity:*
*To achieve a "good" habitat quality rating: 2 pieces per channel width (<20 m in width, >2 m length x 10cm diameter.).*

Comparing the mean of our data for instream LWD quantities (channels <20 m BFW) to the WFPB target of 2 pieces per channel width, we found no significant difference (t-test) ($p=0.969$, $n=121$). Figure 25 represents the percentile distribution of these data. The distribution of data (Figure 26) suggests that this target is not appropriate for all channel widths less than <20 m, due to the significantly positive regression slope ($p<0.001$) described by the equation

$$Y=0.191x^{1.29} \tag{8}$$

where Y is the predicted number of LWD pieces per channel width and x is the bankfull width in meters. Using the scatter distribution of LWD quantity from Figure 26[A] to define three bankfull width classes, we find that the WFPB target is higher than the data distributions for channels with a bankfull width <3 m, but the target is lower for channels >12 m BFW (Figure 26[B]). A summary comparing the WFPB targets to the data collected in this study for LWD per channel width is presented in Table 6[B].

*Key Piece Quantity:*
*To achieve a "good" habitat quality rating: 0.3 pieces per channel width (channels 0-10 m BFW), and 0.5 pieces per channel width (channels 10-20 m BFW) for pieces meeting the definition (Section 1.3).*

T-tests suggest that the log-normal mean of our data is not significantly different from the WFPB target of 0.3 key pieces per channel width for channels 0-10 m BFW (p=0.897); however, the mean for key pieces per channel width in channels 10-20 m bankfull width is significantly different from the WFPB target of 0.5 pieces per channel width (p=0.001). The percentile distribution (Figure 27) suggests the data mean in channels 10-20 m BFW is *less* than the WFPB target. The relationship of the number of key pieces per channel width to bankfull width (Figure 28), is not significant (p=0.625). A summary comparing the WFPB targets to the data collected in this study for key pieces per channel width is presented in Table 6[C].

## *3.9.* Reference Conditions for Instream Wood Quantity and Volume

### 3.9.1. Minimum Key Piece Volumes

The development of targets for the quantity of key pieces must first establish: 1) minimum piece volumes that define key pieces for streams greater than 20 m bankfull width, where no standards currently exist, and 2) the use of these minimums, as well as the existing WFPB minimum volumes defining key pieces, must either be validated for eastern Washington streams or new minimums must be defined.

*Western Washington, Channels >20 m BFW*
The range of volumes for wood pieces meeting the definition for key piece function (WFPB 1997) in channels greater than 20 m BFW is presented in the form of percentile distribution plots (box plots) in Figure 29. From this distribution, the minimum volumes, as defined by the 25th percentiles, are approximately 9.75 $m^3$ for the 20-30 m BFW class, 10.50 $m^3$ for the 30-50 $m^3$ BFW class, and 10.75 $m^3$ for channels greater than 50 m BFW (see data summary table, Figure 29). A plot of these minimum volumes, including those currently defined by WFPB (1997), is presented in Figure 30.

<u>The Influence of Root Wads</u>
Of the pieces composing the volume percentile distributions presented in Figure 29 and the minimum volume curve in Figure 30, it would appear that the minimum volumes defining key pieces are very similar in all channels with BFWs greater than 20 m. As channels become larger, one would expect that wood mobility also increases due to wood buoyancy and typically greater stream power. The reason this is not reflected by an increase in the minimum key piece volumes in larger channels is likely due to the presence of root wads, which compensate for stability in lieu of volume increases. Indeed, 96% of the wood pieces meeting the WFPB definition for key pieces in channels greater than 50 m BFW had root wads attached to them. In channels with bankfull widths between 30-50 m, 91% of the pieces had root wads, and in channels with

bankfull widths between 20-30, 71% had root wads attached. The percentages of pieces meeting the WFPB definition for key pieces that had root wads attached in channels greater than 20 m is presented in Figure 31[A]. The percentile distribution of Figure 29 is recreated, only selecting for pieces without attached rood wads Figure 31[B]. The change in the distribution of wood volumes for pieces meeting the key piece definition is the most dramatic for channels greater than 50 m. Here, the 25th percentile (defining minimum volumes for key pieces in channels >20 m) is over 26 $m^3$ per piece (n=3).

*The Application of Key Piece Minimum Volumes to Eastern Washington*

As described in Section 1.3, the minimum volume required for a piece of wood to achieve independently stability as defined by WFPB (1997) currently applies only to western Washington streams <20 m in bankfull width. Based on the minimum key piece volume definitions from WFPB (<20 m BFW channels), and the results presented in this section for >20 m channels), key piece quantities for all channel types are assessed in terms of percents. The results suggest that the definition of minimum key piece volumes intended for use in western Washington streams is reasonable to apply to eastern Washington streams. Firstly, if the definitions for key piece minimum volumes were set too high or low, one would expect to see a difference in the total percent of wood that meets these qualifications. Sorting wood pieces based on the defined minimum volume requirement, we found that the mean percent of all wood meeting this definition is proportionately the same in nearly all ecoregions (Figure 32), although a significant difference was found between the SS/WH and the GF ecoregions (Tukey's HSD, p=0.001). Secondly, assuming stream power and piece volumes are proportionately the same due to the sampling design, the force required to mobilize a piece of wood is left to the physical density of the wood. In a comparison of the mean dry wood densities of species found in each ecoregion, weighted by the proportions found during the riparian surveys, we found no significant difference in the density of wood of the riparian species among ecoregions (p=0.998). Lumping these data into two categories: 1) eastern and 2) western Washington, the mean differences in riparian wood densities remain insignificant (p=0.993). A compilation of wood density statistics for species identified from the riparian surveys, along with the statistical results, is presented in Table 7.

### 3.9.2. Grouping of ecoregions

Based on the previously described statistical methods, we found similarities between the SS/WH and SF/MH ecoregions, and between the SAF and GF ecoregions. Although the SAF and DF/PP ecoregions were similar according to basal area per hectare, they were significantly different in LWD volume per 100 m. Therefore, the DF/PP ecoregion remains separated. Figure 33(A) illustrates the percentile distribution of mean basal area per hectare by ecoregion, and Figure 33(B) illustrates the percentile distribution of mean instream wood volume per 100 m. The complete output from the post-hoc statistical tests is presented in Appendix A. 19.

Based on the similarities of basal area and wood volumes per 100 m, the SS/WH and the SF/MH ecoregions are grouped to form the "Western Washington Region", and the SAF and the GF ecoregions are grouped to form the “Alpine Region.” Since the DF/PP ecoregion did not have significant similarities to be grouped with any of the other ecoregions, it remains simply as the “DF/PP ecoregion.”

### 3.9.3. A Modeled Approach to Predict Wood Quantities and Volumes

Because it was determined that the three units of scale commonly used in the literature are essentially the same (confounded equally by a common factor in the y-axis) (Section 3.4), using the regression with the best “fit” is the most logical to correlate the relationship of wood volume and quantity to bankfull width. Therefore, scaling by *unit channel width* may provide the best means to predict the quantity or volume of wood due to the least amount of error in the regression. The results of regressions using this unit scale for LWD quantity and volume for each of the grouped ecoregions are presented in Table 8.

### 3.9.4. A Classification Approach to Predict Wood Quantities and Volumes

This section presents the ranges of the quantities and volumes of wood found in the unmanaged forested regions of 1) the Western Washington Region, 2) the Alpine Region, and 3) the DF/PP ecoregion for discrete bankfull width classes. Based on our statistical methods, this approach is more practical as a management tool than a modeled approach, since a range of conditions is provided rather than a single point-estimate.

*LWD Per 100 m*

Western Washington Region

Based on our statistical analysis, we identified three distinct bankfull width classes for LWD quantity per 100 m within the Western Washington Region: 0-6 m, 6-30 m, and 30-100 m. The respective median quantity of LWD pieces per 100 m of channel length is approximately 29, 52, and 106 for these groups. The middle 50% of the data range is between approximately 26 and 38 pieces per 100 m for the 0-6 m BFW class, 29-63 pieces per 100 m for the 6-30 m BFW class, and 57-208 pieces per 100 m for the 30-100 m BFW class. The percentile distributions and data summaries for LWD per 100 m in the Western Washington Region are presented in Figure 34.

Alpine Region

We identified distinct bankfull width classes of 0-3 m, 3-30 m, and 30-50 m in this region for LWD quantity. The middle 50% of the data range is between approximately 15 and 28 pieces per 100 m for the 0-3 m BFW class, 24-56 pieces per 100 m for the 3-30 m BFW class, and 22-63 pieces per 100 m for the 30-50 m BFW class. The percentile distributions and other data summaries for the Alpine Region are presented in Figure 35.

### DF/PP Ecoregion

We could only statistically distinguish between two bankfull width classes of 0-6 m and 6-30 m in this ecoregion due to the sample size. The middle 50% of the data range is between approximately 5 and 29 pieces per 100 m for the 0-6 m BFW class, and 5-35 pieces per 100 m for the 6-30 m BFW class. The percentile distributions and other data summaries for the DF/PP ecoregion are presented in Figure 36.

## *Key Piece Quantity Per 100 m*

### Western Washington Region

Based on our statistical analysis, we identified discrete bankfull width classes of 0-10 m and 10-100 m for key pieces per 100 m within this region. The median quantity of key pieces per 100 m of channel length is approximately 6 for channels 0-10 m BFW, and 1 key piece per 100 m for channels 10-100 m BFW. The middle 50% of the data range is between approximately 4 and 11 pieces per 100 m for the 0-10 m BFW class, and 1 and 4 pieces per 100 m for the 10-100 m BFW class. The percentile distributions and other data summaries for key pieces per 100 m in the Western Washington Region are presented in Figure 37).

### Alpine Region

For this region, we identified distinct bankfull width classes of 0-15 m and 15-50 m. The middle 50% of the data range is between approximately 0.5 and 4 key pieces per 100 m for the 0-15 m BFW class and 0-1 pieces per 100 m for the 15-50 m BFW class. The percentile distributions and other data summaries for the Alpine Region are presented in Figure 38.

### DF/PP Ecoregion

We could not statistically distinguish more than one bankfull width class in the DF/PP ecoregion, likely due to the small sample size. For channels 0-30 m BFW, the middle 50% of the data range is between 0-2 for the quantity of key pieces per 100 m. The percentile distributions and other data summaries for the DF/PP Ecoregion are presented in Figure 39.

## *LWD Volume Per 100 m*

### Western Washington Region

Based on our statistical analysis, we identified two discrete bankfull width classes of 0-30 m, and 30-100 m for LWD volume per 100 m within the Western Washington Region. The middle 50% of the data range is between approximately 28-99 $m^3$ per 100 m for the 0-30 m BFW class, and 44-317 $m^3$ per 100 m for the 10-100 m BFW class. The percentile distributions and other data summaries for LWD volume per 100 m in the Western Washington Region are presented in Figure 40.

### Alpine Region

For this region, we also identified two distinct bankfull width classes of 0-3 m, and 3-50 m. The middle 50% of the data range is between approximately 3 and 10 $m^3$ per 100 m for the 0-3 m

BFW class and 11-30 $m^3$ per 100 m for the 3-50 m BFW class. The percentile distributions and other data summaries for the Alpine Region are presented in Figure 41.

DF/PP Ecoregion

Again for the DF/PP Ecoregion, we could not statistically distinguish more than one bankfull width class. For channels 0-30 m BFW, the middle 50% of the data range is between 2-15 $m^3$ for the volume of LWD per 100 m. The percentile distributions and other data summaries for the DF/PP Ecoregion are presented in Figure 42.

# 4. DISCUSSION

## *4.1.* Perspectives in Unit Selection for Wood Loading

As illustrated in Figure 9, the equations describing the relationships of wood volume to bankfull width in the units tested produce identical responses. Each of these units perhaps produces confounding relationships due to proportional influence upon one another by having a factor common in both the x and y-axis. The common factor in each of these cases is channel area. With each increase in bankfull width, the unit area also increases. More channel area can result in more wood accumulations if compared to a fixed unit of channel length such as "wood per 100 m" or "wood per channel width", but can result in a perceptional decrease if compared to the exponential increases of area such as "wood per $m^2$." In terms of pieces per 100 m (or any unit of channel length), as the bankfull width increases, there is exponentially more area for wood to accumulate along the 100 m length of channel. Therefore, one would *expect* wood quantities and volumes to increase with bankfull width if the spatial density of wood remains the same. In terms of pieces per $m^2$ (or any unit of channel area), this relationship may also have interacting biases due to the exponential factoring of area for each unit of bankfull width. Beechie and Sibley (1997:p 220) discuss why the quantity and volume of LWD *decreases* when scaling by square meters:

> "However, when LWD abundance is expressed as number of LWD/$m^2$ (e.g. Montgomery et al. 1995), this explanation is partially confounded by the interaction between channel size and number of LWD recruited to a reach. That is, in channels with similar supply of LWD but differing width, one expects a negative correlation between number of LWD/$m^2$ and channel width simply because channel area increases with increasing channel width."

Therefore, it is potentially erroneous to interpret any of these relationships as "larger channels have *more* (or *less*) wood" than smaller channels. Certainly, the contrast of the negative and positive regression slopes expressing wood by volumes per $m^2$ and volumes per 100 m or per channel width, respectively (Figure 9), suggest this interpretation is not necessarily valid. Consequently, expressing wood quantity or volume in terms or "more" or "less" using these relationships are valid only within the units in which they are presented.

Since the units discussed herein are fundamentally the same (equally biased), using the unit that has the least residual error associated with the regression may prove useful as a management tool when predicting wood quantities or volumes. For example, scaling parameters of wood according to *unit of channel width* rather than a *unit of length* affords the least variability for response variable prediction. Indeed, this unit is currently used in management (WFPB 1997), and is a familiar method of instream wood assessment. However, this scale of "best fit" by unit channel width also has the steepest regression slope. This could lead to disadvantages if attempting to group variable categories (e.g. bankfull width groups) based on wood per CW, due to the multitude of significant differences between finite categories. In this respect, this expression of units will afford the analyst with the least ability to statistically group classes or categories if so desired. Aside from the potential confoundments incurred by any form of the units discussed herein, the quantities and volumes predicted by the regression models are reasonably similar and will conclude with the same results. Hence, the choice in the units is not likely critical, since the end result will be proportionately the same. Thus, it is seemingly the most appropriate to choose one that is best suited for the desired objectives, and to maintain the context for which it applies.

## *4.2.* Geomorphic Expression

### 4.2.1. The Relationship of Bankfull Width to Basin Size

The relationship of bankfull width to basin size is demonstrable. A larger catchment typically produces larger, wider stream channels as presented in Figure 10. The differences in regression slope between eastern Washington and western Washington is due to climatic differences, especially precipitation. Although the annual quantity of snow and rain vary locally on each side of the State, the topographic divide of the Cascades causes clouds to release precipitation (due to topographic lift) prior to reaching eastern Washington (with the normal west-east movement of weather patterns of the State). Therefore, eastern Washington, as a whole, receives less annual precipitation than does western Washington. As a result, catchment basins in eastern Washington are not likely to yield as much annual stream flow as are western Washington basins of the same size. Consequently, bankfull widths are not likely to be as larger for a given basin size in eastern Washington as compared to western Washington, resulting in the divergence of regional regression slopes as basins become larger (Figure 10). As such, regional considerations are incorporated when using bankfull width to basin size relationships.

### 4.2.2. Field Gradient vs. Mapped Gradient

The departure from a 1:1 slope between field gradients and mapped gradients is likely due to the difference in resolution. Although the 7.5-minute USGS maps are relatively detailed in a larger scale, the contours on topographic maps tend to “smooth” out abrupt changes in gradient. This reduces the ability of map interpretations to detect finite topographic features such as small lower gradient terraces in channels that may dominate local slopes of a survey reach. These low-gradient terraces are perhaps more often reflected by segment field measurements, which is perhaps why map interpretations are slightly higher in gradient. As such, field gradients are the parameter of choice for analysis (see Section 2.3.3).

## *4.3.* The Validity of Grouping the Sitka Spruce and Western Hemlock Forest Types

Although the mean diameters of trees in the SS forest type appears to be significantly larger than in the WH forest type, the instream wood loads are similar (Figure 11). Regarding instream wood quantity and volume as the “end result” of the processes delivering wood to these channels, a moderate difference in the character of tree species seems relatively insignificant to the objective of characterizing instream wood. Furthermore, the data suggest that both the quantities and volumes of wood in streams draining these forest type are similar, thus we can conclude that the mean piece sizes are also similar. Most likely, the SS forests will recruit larger diameter trees than the WH forests on occasion; however, this does not appear to significantly affect instream wood loads as a whole between these forest types. Therefore, for the purpose of this analysis, the grouping of the SS and WH forest type seems logical for characterizing instream wood.

## *4.4.* Geomorphological Influences on Instream Wood

Geomorphologic influence on instream wood is evident from the analysis. These affect the process of recruiting wood to the stream, and the ability to retain wood for channel process.

The distribution of survey sites relative to the combinations of specific morphologies offers insight to how riparian recruitment process may be affected. The data suggest that as the drainage basin becomes larger, the range of gradients and confinements becomes smaller. Although unconfined streams draining small basins were found, they appear to lack the energy and dynamics to form flood plains. Due to the inability of these channels to laterally migrate, they are perhaps more similar to confined channels in their ability to acquire trees to the channel. Because of this characteristic, these channels are likely to obtain a significant proportion of riparian trees for instream wood by bole breakage and passive tree mortality, rather than by active recruitment such as lateral bank avulsion. Similarly, confined streams draining large basins are also likely to obtain wood in this passive manner. Often, these reaches were observed to have rocky banks, which resisted avulsion as compared to banks composed of unconsolidated material. Due to the resistance to lateral migration, trees adjacent to these channels are afforded greater intervals between disturbances, and thus have the potential to grow older and perhaps larger (given conducive soils and climate). As a result, confined channels often have greater potential to recruit larger trees than unconfined channels where the lateral migration rate within the flood plain limits tree growth.

The increase in wood volumes with increased basin size and decreased confinement (particularly in W. WA) could be attributed to the fact that larger unconfined basins have proportionately more area for wood to accumulate, and hence process more volume per 100 m of channel length. This is especially true if multiple jams are found laterally distributed in a channel, which is often the case in unconfined channels due to the propensity for wood to accumulate in multiple channels and islands (or be the cause of).

Gradient, by itself, is not a strong influence on instream wood loads; however, this relationship appears to be stronger when combined with confinement. Figure 13 suggests that in confined reaches, low-gradients accrue more wood. This is perhaps due to fluvial transport from an above reach with higher wood-transport capacities (e.g. higher gradients). In the unconfined channels, few high-gradient reaches were available for sampling; however, those that were sampled contained less wood than low-gradient reaches.

Based on the analysis, bedrock channels appear to accumulate less wood in all gradients and basin sizes, except in drainages less than 4 $km^2$. The narrow bankfull width and low stream power of channels in these small basins likely result in the reduced routing of wood. Because of this tendency, bedrock channels are likely to have near-equal amounts of wood volumes as alluvial channels of the same size. In steep gradients (>20%), bedrock channels have proportionately much less wood per 100 m than alluvial channels as compared to other gradient classes (Figure 14). This factor may be due to the absence of coarse alluvial material to stabilize wood.

Wood in bedrock channels is typically less frequent than in alluvial channels. When wood is present in these channels, it is typically in the form of large jams. In many bedrock channels, it is often not possible to determine whether the absence of wood allows a channel to scour down to bedrock, or if the presence of bedrock discourages the retention of wood (i.e. “the chicken or the egg” analogy). Additionally, wood in bedrock channels is most commonly distributed in the form of jams, which frequently store alluvial material in a wedge upstream. This often led to difficulty when classifying the channel type, since they would be classified as alluvial if the material fully covered the underlying bedrock morphology. These wedges, in combination with natural channel constrictions, were observed to extend upstream of jams >75 m in some streams, a majority of a 100-meter survey reach length.

Streams from glacial origins proportionately have more wood volume per 100 m than snow-rain dominated systems, probably for several reasons. Because glacial streams have more side channels, there is more channel area to accumulate wood per fixed length of channel. Since wood is frequently found at the heads of side channels, more side channels often relates to more wood laterally distributed in a reach. More side channels per unit channel length also suggest a broader flood plain, and channels that have frequent interactions with their associated flood plain vegetation are likely to recruit more trees by channel migration than channels of the same size with a narrower floodplain. Therefore, a combination of factors contributes to the higher quantities of wood per 100 m found in streams from glacial origins.

The fact that there is no clear relationship between wood volumes and channel reach morphology may be influenced by interaction with other variables. For example, a cascade in a bedrock channel may have very little wood, but a cascade in an alluvial channel may have high quantities of wood in the form of jams. Additionally, a plane-bed channel may have little wood in small drainages, but may accumulate high quantities in larger drainages. This was observed in several of these channel reach morphologies in large drainages, where massive accumulations of wood were found in jams, boosting the median volume of wood proportionately to other morphologies (Figure 16). These types of interactions impose difficulties for analyzing the isolated effect of these variables without sampling specifically for these purposes; however, the general trends as suggested by the results provide useful relationships worthy of consideration for future studies of this potential influence.

## *4.5.* Regional Influences on Instream Wood

Clearly, the wet, temperate climate of western Washington influences the production of large, dense timber in the stream riparian areas. Conversely, the dry, severe climate of eastern Washington promotes smaller, less densely spaced riparian trees (Figure 6, Figure 7, and Figure 8). This in turn appears to have an influence on the volume of instream wood as in viewing Figure 12 from top to bottom. This trend corroborates the findings of other researches such as Rot et al. (2000) who found the character of the riparian vegetation (such as diameter) is directly correlated with volumes instream wood. With larger trees in the riparian areas, larger trees are recruited to the channel. Certainly in Figure 8, the basal area of riparian stands on the west side of the state are greater than those on the east side, which likely contributes to the reported trends.

## *4.6.* Disturbance History

The presence of multiple types of disturbance found in the random samples clearly illustrates that disturbance is a common feature in unmanaged forested watersheds. Disturbance may indirectly lead to factors such as increased wood inputs, the recruitment of fresh gravels, channel morphological diversity, and other benefits contributing to favorable salmonid habitat, or on the contrary, may lead to factors that adversely impact habitat. Merely because these streams are found in basins virtually unaltered by humans (with the exception of fire suppression), conditions promoting habitat in relation to instream wood are not necessarily conducive to salmonid life history requirements; however, the effect of natural disturbance on salmon habitat are beyond the scope of this study. The following discusses each of these disturbance types and their influence on quantities and volumes of wood recorded at the time of the surveys.

### 4.6.1. Fire

The variability in timber age due to stand-replacement fires confirms that “old-growth” forests are clearly not homogenous in their life cycles among ecoregions, or within basins. Forest growth frequently is interrupted prior to the maximum life span of many trees in forested basins, as suggested by the heterogeneity in forest ages within ecoregions (Figure 17 and Table 4). This likely adds diversity in tree sizes, densities, and stem exclusion and mortality rates. In riparian stands that are completely replaced by a new generation following fire, succession as the trees mature is an important process that selectively thins stands, which in turn recruits wood into streams (often referred to as the “stem exclusion stage”, occurring in stands <220 years old (Rot et al. 2000). Trees recruited to a stream by stem exclusion are likely to be smaller since they have been “out-competed” by larger, more dominant trees. This may explain why LWD volumes per 100 m decrease as stands become younger, since recruited trees are smaller. Furthermore, there is no correlation with the *number* of pieces and stand age, suggesting that decreased wood volume with younger tree age is a result of smaller tree size rather than fewer recruited trees. This is also supported by the literature (Section 1.2.4), which suggests that instream wood is influenced by riparian characteristics such as tree diameter. Since tree age is strongly correlated with mean tree diameter and basal area (a function of diameter and density), one would expect larger wood pieces (in terms of volume) to be recruited to channels with older riparian timber.

Due to the propensity for unstable wood to move downstream (especially in larger rivers), the source of instream wood is not influenced only by the adjacent riparian stands. Therefore, the ages of the adjacent timber may not accurately reflect basin processes of wood recruitment. Because of this, the quantities and volumes of wood found in stream channels may be influenced by the timber age of the entire basin. Consequently, caution should be heeded when applying these relationships to predict wood volumes (and quantities such as for the SF/MH ecoregion), since the source of instream wood may in fact be from an upstream stands of a different age.

### 4.6.2. Floods

Because shear stress on wood increases during high flows, unstable pieces are likely to be flushed out of a system during floods; however, the regressions presented in Appendix A. 3 and Figure 18 suggest that the net effect is insignificant in the streams sampled. This may be explained by two observations: One, much of the wood in these systems has resisted mobility during large floods, as broadly interpreted by the over all age of pieces (as estimated by decay classifications) found in the channel during the surveys. Even small pieces of wood in some streams had advanced decay that suggests these pieces have also prevailed within the system despite floods. Two, floods may replace wood flushed from a system with newly recruited trees from bank avulsion, debris flows, or upstream sources. Thus, net loss of wood from floods may not occur in unmanaged basins.

The lack of significant differences in wood loads between streams with and without recent floods could also be attributed to other factors. For one, the magnitude of a flood, as determined by the closest unregulated downstream gage, may have been primarily influenced by an adjacent basin (e.g. a larger or a highly managed basin). A storm that could register as a flood in these adjacent basins may not have had a similar effect in the surveyed basin due to differences in water storage, interception, evapo-transpiration, or other hydrological processes. Another explanation could be that unmanaged streams may have on the average more channel roughness due to the high quantities of instream wood compared to a highly managed basin that has little wood. These roughness elements can dissipate stream energy by terracing local gradients, thus decreasing wood mobility of wood during floods.

The lack of evidence supporting significant effects on instream wood loads due to floods could also be attributed to the difficulty of isolating this variable. The effects of floods identified in this study are perhaps poorly defined due to the lack of equal replication of sites containing similar morphologies and regional characteristics. Without controlling for these variables, relationships are likely biased by one or multiple regional and geomorphic influences. To determine the true influence of flooding on wood loads and distribution, the isolation of flood influence is likely only possible with successive sampling at each site. For example, the sites identified in this study would be re-surveyed following a flood. In that manner, the differences in wood quantities between the two data sets could be attributed independently to the effects of the flood.

In conclusion, these findings suggest that floods are not a significant cause of variability in wood quantity or volumes, or at least the instream wood represented by these data do not appear to be influenced by floods. Table 5 illustrates that the study sites encountered a broad range of flood magnitudes prior to surveys, and therefore should provide adequate representation of this type of channel disturbance. Although channels with and without flooding independently illustrate high variability in wood quantity and volume (Figure 18), the robust sample size has likely "smoothed" temporal surplus/deficit fluctuations. Based on the assumption that the surveyed streams are disturbed by floods at natural recurrence rates, the associated wood quantities and volumes are accurately characterized in streams subject to the natural flood disturbance regime. Subsequently, this rationale supports the decision not to incorporate this factor as a predictor of wood quantities or volumes.

### 4.6.3. Debris Flows and Snow Avalanches

The results depicted in Figure 19 and Figure 20 illustrate wood loads in channels with and without snow and debris flow disturbances. The box plots suggest that wood quantities and volumes of wood per 100 m are nearly the same for debris flow-channels as compared to non-disturbed channels in low gradient channels (<6%), but are lower in the higher gradient channels (>10%), implying that wood is more likely to deposit in the lower gradients. This is especially true if a lower gradient reach is immediately downstream of a section of high gradient. Certainly, transport and deposition are processes one expects to find in channels with debris flows. The results also suggest that wood volume, but not wood quantity, is different in channels impacted by snow avalanches as compared to non-disturbed channels at low gradients (<6%). This suggests that the instream wood is small, perhaps due to either 1) the breakage associated with the force of the snow avalanche, or 2) a product of the immature riparian trees often found in snow avalanche paths, which are often the sole source of wood recruitment.

Statistically, the differences among wood loads are not significant. However, the lack of detection may be due to the small sample size, which provides a test power of less than 0.20, resulting in an 80%+ probability of a Type II error (i.e., in this case, the Type II Error can be interpreted as "not rejecting the hypothesis that the mean quantities and volumes are the same between disturbed and non-disturbed channels, when in fact they are different"). Additionally, the large variance associated with the large sample size on channels without disturbance typically includes the range for the disturbed sites. Therefore, statistical tests are likely too weak as a result of the small sample of disturbed sites to determine with confidence that there is a difference between disturbed and undisturbed channels. Differences between disturbed and undisturbed channels appear evident in the trends depicted in Figure 19 and Figure 20, but a larger sample size is needed to confirm or deny the differences statistically.

## *4.7.* Choice of Predictor Variables

### 4.7.1. Geomorphic Influence

Although channel types, bed-form, origin, gradient, and confinement appear to influence instream wood quantities and volumes by the trend analysis, the sample stratification is insufficiently large in each geomorphic category to isolate the effects of these factors for making statistical inferences. Further refinement regarding these influences will require further sampling of these morphologies; however, a potential trend is perhaps established by this initial analysis. We will therefore assume that the variability attributable to the range of morphological conditions is adequately represented in the sample, as well as the frequency to which they are observed in unmanaged basins.

#### *Bankfull Width Rather Than Basin Size*

The strong correlation of bankfull width to basin size (Figure 10) confirms the validity of using bankfull width as a predictor of basin size; however, bankfull width and basin size do not predict wood quantities and volumes equally (Table 3). This suggests that the quantities and volumes of wood are more closely tied to discharge in relation to channel geometry rather than catchment size. Discharge, in combination with slope, influences stream power (Yang and Song 1979). This in turn influences the force acting upon instream wood, thus increasing the likelihood for wood to be mobilized. Larger wood pieces are known to be more resistant to higher discharges while smaller unstable piece are more readily mobilized (Section 1.2.3). Because bankfull width indicates the normal high flow, it may better serve to make inferences on instream wood stability and characterization rather than basin size. However, as noted in Section 3.5.1, the error associated with the regressions of these variables is high (as indicated by the low $R^2$ values). Therefore, because of the strong relationship between BFW and basin size, predictions using either independent variable are likely similar due to their broad variances.

Using bankfull width rather than basin size to predict wood loads is also best applicable if the channel has a relationship to cross-sectional area similar to equation 3. This helps verify that the bankfull discharge is proportional to other streams with similar morphology and basin size, rather than due to a form of disturbance.

Furthermore, channel morphology is often related to the size of the channel. For example, a large channel is often associated with an unconfined valley-bottom, low gradients, and pool/riffle or plane-bed morphology, while small channels are often confined, and more frequently are of higher gradients. Thus, BFW often represents other morphological conditions rather than merely basin size and cross-sectional area.

Although basin size and bankfull width are nearly interchangeable as independent variables, BFW is demonstrated to be a slightly better predictor of instream wood loads. Because of this advantage, BFW is recommended as the best single geomorphological predictor of instream wood loads.

### 4.7.2. Influence of Disturbance

*Fire*

Based on the results and discussion on the analysis of channel disturbances regarding fire (Section 3.7.1 and 4.6.1, respectively), we concluded ecoregion is a viable indicator to predict instream wood volumes and quantities due to fire disturbance. Clearly, from this analysis, the ages of trees related to fire history increases with wetter climates, corresponding to changes in ecoregion characteristics. Because the adjacent riparian trees demonstrably influence instream wood, and the characteristics of riparian trees as influenced by fire recurrence are represented by ecoregions, we found ecoregion to be the best indicator for predicting instream wood loads in relation to fire disturbance.

*Floods*

From our data, floods do not appear to have a significant influence on wood, and therefore are inconsequential to predictor variable selection. As noted in Section 4.6.2, a thorough assessment on the effect of floods on instream wood will require a different form of analysis, which is beyond the scope of this study. We assumed that the samples are evenly stratified to represent the range of conditions due to floods, and hence are reflected evenly in the data as a component of the natural disturbance regime. Therefore, the use of flood frequency as a predictor variable was not used for this analysis.

*Debris flows and snow avalanches*

Debris flows and snow avalanches may have some influence on instream wood loads as noted in the trend analysis; however, this influence could not be verified statistically. Therefore, the use of debris flows and snow avalanches as predictor variables cannot be justified for this data set. As noted in the results (Section 3.7.1), the frequency in occurrence of snow avalanches are predominantly found in the GF ecoregion, and perhaps already represented by characteristics of this ecoregion. Thus, the variable of ecoregion may serve to include the characterization of this form of channel disturbance. Also, both debris flows and snow avalanches initiate and carry in channels with relatively steep gradients, which is often correlated with channel size. In most cases, steep channels capable of carrying debris flows and snow avalanches originate in small basins. Therefore, these types of disturbances may be included in the characterization of small channels, as best represented by the geomorphic attribute of bankfull width. Nevertheless, we will assume that the samples are evenly stratified to represent the range of conditions due to debris flows and snow avalanches, and hence are reflected in the data as a component of the natural disturbance regime.

### 4.7.3. Regional Influence

As noted in Section 1.2.5, climate influences the characteristics of riparian trees such as stem density, diameter, and tree height. As noted in Section 4.5, these riparian characteristics influence instream wood quantities and volume. Streams adjacent to larger and more densely spaced riparian trees tend to have more wood in terms of piece quantity and volume per 100 m of channel length. This supports the use of ecoregion as a predictor of instream wood loads by the fact that larger, denser riparian timber stands provide higher quantities of larger trees.

## *4.8.* The Feasibility of the NMFS Targets

### 4.8.1. Western (Coastal) Washington

Figure 21 illustrates that few of the sampled streams in western Washington are able to meet the minimum NMFS target to achieve "Properly Functioning Condition." The homogenous distribution of both the western Washington ecoregions in this figure, as illustrated by the scatter of the data markers, suggests that grouping the SF/MH and SS/WH ecoregions is reasonable for testing the NMFS target for western Washington. The mean is significantly different from the target mean of 80 pieces per mile for the combined sampled streams. Indeed, the entire middle 50% of the sample is less than 52 pieces per mile (Figure 22 [A]), suggesting that the mean of the sampled data is significantly less than the NMFS target value. The highest proportions of streams that do meet the NMFS standard are greater than 40 m BFW (42% greater than 40 m BFW). Realizing that not all streams in unmanaged forests are expected to be ideal habitat, an ideal "target" value should be located somewhere near the upper portion of the distribution (e.g. near the 75th percentile). This is the case only for streams greater than 40 m BFW, and therefore 80 pieces per mile seems to be an achievable target only for the larger streams (Figure 22 [B]). Conversely, the NMFS target appears to be unreasonable for streams less than 40 m BFW, based on the relative distribution of the data (Figure 22 [B]). As applied, these targets do not differentiate between bankfull width classes and apply to *all* streams subject to the NMFS targets; therefore, we conclude that as a reasonable target of "natural" or normally attainable wood loads, the NMFS target is inappropriate for small streams in western Washington.

### 4.8.2. Eastern Washington

Figure 23 illustrates that over one-half (56%) of the sampled streams in eastern Washington are able to meet the minimum NMFS target to achieve "Properly Functioning Condition." The homogenous distribution of both eastern Washington ecoregions in this figure, as illustrated by the scatter of the data markers, suggests that grouping the DF/PP and GF ecoregions is reasonable for testing the NMFS target for eastern Washington. As presented in the results, the mean is significantly different from the target mean of 20 pieces per mile for the combined sampled streams. The median (as well as the log-normalized mean used in the statistical tests) and the larger proportion of the middle 50% of the sample is greater than 20 pieces per mile

(Figure 24[A]), suggesting that the mean of the sampled data is significantly larger than the NMFS target value. As noted in the previous discussion for western Washington streams, not all streams in unmanaged forests are ideal habitat. Therefore, an ideal "target value" should be located somewhere near the upper portion of the distribution (e.g. near the 75th percentile). By defining two bankfull width classes, the target is near the 75th percentile for streams 0-5 m BFW, but only near the 25th percentile for streams 5-50 m BFW (Figure 24[B]). Thus, for the sampled streams, the NMFS target seems to be appropriate in the smaller streams but too low in the larger streams. As applied, however, these targets do not differentiate between bankfull width classes, and the standards apply to all streams (i.e. those with potential to provide habitat for salmonid species). Because these data suggest that the application of a "one size fits all" target is not defensible, we conclude that the NMFS target for eastern Washington is not ideal for all streams. Additionally, the consideration to how these quantities may vary with channel morphology would also likely improve the accuracy of management decisions based on these values.

## *4.9.* The Feasibility of the WFPB Targets

### 4.9.1. Large Woody Debris Quantity

Based on the statistical tests, the mean of the sample data is not significantly different from the WFPB target of 2 pieces of LWD per channel width for channels <20 m in bankfull width. Using the 75th percentile as a target value, this target is set too low. A more appropriate interpretation of the Fair" condition as defined by WFPB correlates with the range between the 25th and 75th percentiles.

Additional disparities may exist among bankfull width classes when applying the WFPB target. Indeed, if 2 pieces per channel width is applicable to all channels, one would expect the regression slope of the data, as depicted in Figure 26(A), to be relatively "flat" (i.e. insignificant slope). This is not the case, as the slope of the regression is significantly different from zero ($p<0.001$). The positive slope and the distribution of data suggest that the mean is less than 2 pieces per channel width in the smaller channels and greater in the larger channels. Figure 26 [B] illustrate these differences, and suggest that homogenous applications of the targets are not appropriate for all bankfull width classes. Below 3 m BFW, it appears that 2 pieces per channel width is set too high for these small channels, but set too low for channels greater than 12 m BFW. Furthermore, the distribution of LWD per channel width among ecoregions is not even, as shown by Figure 26[A]. This suggests that there is also regional variability, in addition to the variability associated with channel width. Therefore, because these data suggest that the application of the WFPB target should not be homogenously applied to all stream bankfull width classes (<20 m), nor to all ecoregions, we conclude that this target will potentially lead to erroneous wood quantity goals. Furthermore, channels equal to or greater than 20 m do not have references for wood quantity. Modifying the WFPB targets to adjust for variations in channel width and ecoregion would likely improve the accuracy of management decisions based on these values.

### 4.9.2. Key Piece Quantity

Using the 75th percentile as a target, the key piece target suggested by WFPB for channels 0-10 m BFW is set too low. This quantity, near the center of the percentile distribution, is within the expected range of conditions but perhaps not representative of "Good" habitat quality. Conversely, the standards set for channels 10-20 m BFW appear to be too high, and hence unreasonable for these channels. The relative location of each of these targets upon the data distribution would almost imply that these values are reversed. The target of 0.3 pieces per channel width would be a more appropriate target for channels 10-20 m BFW, while 0.5 pieces per channel width better fits channels 0-10 m BFW.

Due to the adjusting scale of minimum wood volumes defining key pieces, no clear relationships between key piece quantity and channel width could be established. Figure 28 illustrates the lack of this relationship. The difference in "fit" of the regressions between LWD per unit channel width as compared to key pieces per unit channel width (Figure 26[A] and Figure 28, respectively) is most likely due the variable size scale defining key pieces. Key pieces sizes, by an applied management definition, are already adjusted for increases in bankfull width. The minimum volume requirement of key pieces is based on an assessment of stability in a variety of channel sizes (WFPB 1997); thus, the minimum size for key piece qualification indirectly adjusts with stream power. Because the minimum qualifying piece volume increases with increasing bankfull width classes (WFPB 1997), the frequency of qualifying pieces becomes further restricted. Therefore, the quantities meeting these size requirements are proportionately less per unit area. This nullifies the trend for increasing wood quantities based on this scale. Indeed, based on the discussions of scale (Section 4.1), one would expect the quantity of wood to increase per channel width with increases in bankfull width using this scale, due to the linear increase in area for wood to accumulate. Due to this applied management condition that adjusts key piece quantities with increasing minimum size standards, we would not expect the relationship in quantity to be similar to the total number of LWD per unit channel width.

## *4.10.* References for Instream Wood Quantity and Volume

### 4.10.1. General

The differences in wood quantities and volumes between the east and west side of the state as related to changes in bankfull width indicate that the relationships in these two regions operate under different processes. As noted previously, the disparities among state regions are evident and worthy of separation when describing relationships of wood quantities to bankfull width. The increase in the mean volume per LWD piece with increasing channel width may be attributed to increasing stream power. With increasing channel size comes increased stream power during high flows that will likely mobilize proportionately small and unstable pieces. Therefore, fewer small pieces remain, which proportionately increases the mean volume. However, this relationship must be viewed with caution, since the mean piece volume represented by each data point is likely derived from a non-normally distributed data summary. Nevertheless, this relationship seems logical, and is consistent with the literature.

As expected, the relationship of wood quantity to wood volume is significant (Figure 3). One would expect with increasing numbers of pieces comes increased volume. More importantly however, the verification of this relationship dispels speculation that sizeable total wood volumes are perhaps comprised of a small number of large pieces. Conversely, this suggests that lower wood volumes are not typically comprised of a large number of small pieces. This infers that piece sizes are highly diverse in all channel widths, and a heterogeneous distribution of sizes is characteristic of wood found in natural systems. As previously assessed, the mean volume per piece increases as channels become larger, seemingly conflicting with this relationship of volume diversity. This is still possible, however, since the difference in these two relationships can be explained by a shift in intercepts rather than slope, thus maintaining the validity of both relationships. As a management consideration, both of these relationships may prove useful in the design of restoration and enhancement projects.

## *4.11.* Developing New Standards

### 4.11.1. Defining Key Piece Minimum Volumes

The minimum volumes established in Figure 29 illustrate that the size of the pieces in channels >20 m do not follow the same slope as the minimum defined volumes in channels between 0-20 m. This inflection, perhaps beginning with the minimum volumes defined for channels between 15-20 (i.e. 9 $m^3$), suggests that the relationship between bankfull width (as a function of stream power) and wood volume (as a function of mobility) is not linear. Certainly, one would expect that wood must be larger to counter the increases in stream power as channels become larger. Since this is not the case, a logical explanation is the presence of root wads, which help to anchor logs. This can compensate for the need of increased volume for stability, as evident by the prevalence of this feature found on independently stable pieces without sizable increases in piece volume. Figure 31 [B] suggests that without root wads attached, the minimum volume required to meet the definitions for key pieces may indeed follow the near-linear relationship with bankfull width established by the WFPB in channels 0-15 m bankfull width (Figure 30). The minimum volume of 26.5 $m^3$ characterizing stable piece without a root wad for channels >50 m is clearly along the linear path of this regression slope. However, this relationship may not be fully realized due to the fact that the number of large pieces without root wads in our sample is only three logs. This is because 1) trees seldom grow (and recruit into the channel) to sizes producing these volumes (i.e. 26 $m^3$), and 2) most wood meeting the definitions for key pieces in channels greater than 50 m bankfull width *have* root wads. This makes it difficult to find samples for the purpose of isolating this factor.

### 4.11.2. The Application of Key Piece Minimum Volumes to Eastern Washington

The definitions for minimum key piece volumes used in western Washington are reasonable to apply to eastern Washington streams. This definition is merely a function of individual piece stability during high flows. Stream power is a function of discharge and stream gradient, which tests log stability during high flows. Stream power is assumed to be the same in eastern Washington streams as it is in western Washington streams, when the gradient and flows are similar. Therefore, the minimum size need for a piece to remain stable during high flows should be the same. The only potential difference between eastern Washington streams and western Washington streams may be on the types of wood that are recruited to the channel. Different tree species may have different physical properties such as wood density (i.e. $kg/m^3$), which may influence mobilization. However, as noted in the results (Table 7), the mean wood density of present species is not different within each ecoregion, or between eastern and western Washington ecoregions. We assume that because of the similarities in wood density, the saturation rates of wood between ecoregions are also similar. Therefore, the instream wood recruited from these riparian areas is likely to mobilize at the same rate with a given stream power. Based on the similarities in stream power and wood density, the process relating to the function (as defined by WFPB [1997]) of key pieces is similar for both western and eastern Washington streams.

The similarities in key piece proportions between ecoregions further supports applying the western Washington standards of minimum qualifying key piece volumes to eastern Washington. The mean percent of wood meeting the key piece definition is not significantly different between ecoregions, except between the SS/WH and the GF ecoregions. The fact that this percent differs only between these two ecoregions (based on the data constructing Figure 32), does not indicate a clear difference between the east and west sides of the state. Rather, this is likely an artifact of another local characteristic such as mean riparian tree size (as a source for stream input) adjacent to the sites surveyed. Certainly the difference in mean riparian tree height is the greatest between these two ecoregions, and the difference between mean riparian tree diameters is also among greatest (Figure 6). These characteristics most likely influence the size of wood recruited to the channel, which in turn could influence the quantity of key pieces. However, if this were a characteristic that differentiates between eastern and western Washington, this discrepancy would also be salient between the other east vs. west ecoregions. Other differences in wood properties between east and west streams, such as decay rate, would be reflected in key piece *quantity* rather than a minimum size definition. Based on the similarities in stream power, wood density, and the proportionate key piece quantities between eastern and western Washington streams, we conclude that the standards for defining key pieces currently in place for western Washington are reasonable to apply to eastern Washington.

### 4.11.3. The Grouping of Ecoregions

The grouping of ecoregions into three regions is logical for the purpose of characterizing the quantities of instream wood. The increased statistical power gained by a larger sample size per channel width class within each region increases confidence levels, and will not likely mischaracterize the instream wood load based on the similarities of instream wood volume.

Although some ability to finely characterize the riparian vegetation will be lost by grouping ecoregions, at least the riparian characteristic of basal area in the ‘lumped region” will be representative of the ecoregions that comprise it. Furthermore, the intent of grouping ecoregions is to represent how the riparian areas load wood into a channel. As determined from the results presented in Figure 33[B] and Appendix A. 19, the volume of instream wood found in the ecoregions comprising each group is statistically the same. Therefore, the grouped ecoregions comprising the “Western Washington” and Alpine Regions, and maintaining the DF/PP ecoregion as previously described, will likely characterize instream wood quantities and volumes accurately.

## *4.12.* Management Recommendations

The percentile (box-plot) distributions for LWD quantity, volume, and key piece quantity (Figure 34 through Figure 42) illustrate the range of conditions in unmanaged systems that can be envisioned as targets for habitat restoration, enhancement, regulation, and evaluation. These data represent the range of conditions found in streams draining unmanaged forests subject to a natural rate of disturbance (except for fire suppression). This range includes undisturbed and recently disturbed streams (fire, floods, snow avalanches, and debris flows). The development of target values for wood quantities must consider that this “snapshot” of conditions may not represent the full range of habitat quality as it relates to wood loads. Therefore, we recommend that the ranges established between the 25th and 75th percentiles of the data distribution, representing the typical range found in these systems, should be considered indicative of a “fair” condition. The top of these distributions, the 75th percentile, is a logical point at which conditions begin to exceed this normal range. Therefore, we recommend values at this point and above represent the equivalent of a “good” condition as it relates to wood loads. Following this logic, wood quantities and volumes below the 25th percentile would represent the equivalent of a “poor” condition as it relates to instream wood loads.

The precise quantities and volumes of wood needed by salmonids for successful production is not well understood. Statistically sound studies to link instream wood loads to salmonid production would not be expensive and have high levels of uncertainty due to the multiple variables influencing salmon production. However, we do know that salmon populations used to be much higher, and as noted earlier, we can assume that unmanaged forests offer the best source of information on wood loads, as one component of habitat, to which salmonids have adapted. In streams where management is needed to restore favorable conditions, wood loads are either no longer found in the upper distribution of these ranges, or the distribution is centered around a lower mean. Thus for management purposes intending to restore natural wood loading conditions, establishing instream wood targets based on the upper portion of the distribution rather than the lower is both prudent and reasonable.

Conceivably, unmanaged streams are in fact “managed” for the 100th percentile of our observed distributions, but with geomorphic variability, natural disturbance regimes, and other factors influencing instream wood loads, wood actually exists in the ranges we found (Figure 34 to

Figure 42). Therefore, managing for less than the 100th percentile could in fact reduce the potential for streams to achieve these distributions. However, because the 100th percentile may represent extremes and outliers, the targets suggested herein are conservatively reduced to the 75th percentile as a practical, reasonable, and in many cases, an attainable objective as a management tool.

Minimum piece volumes used to define a key piece should also consider the role root wads play in achieving stability. In channels greater than 30 m BFW, >91% of all key pieces had root wads attached. Therefore, in order to meet the objective of defining a key piece, not only do the prescribed minimum volumes need to be met, but root wads must also be considered in this definition. Without root wads to stabilize key pieces, the minimum volume needed for stability in large channels would be very large (Figure 31[B]), and subsequently quite rare. This minimum volume identified in Figure 31[B], based on the limited data (n=3), is 26.5 $m^3$. For illustration, a log meeting this minimum volume is 40 m (135 ft.) long and 1 m (3 ft.) mid-point diameter. Indeed, when considering restoration practices of importing wood, logs of this size are likely impossible to obtain, let alone transport and position into a channel. Therefore, we recommend that for channels greater than 30 m, a log must have a root wad attached to be defined as a key piece, in addition to meeting the minimum volume requirements defined as the 25th percentiles in Figure 29. Although over 70% of the logs in channels between 20-30 m BFW had root wads, the difference in minimum volumes did not change significantly when the selecting pieces without root wads (Figure 31[B]). Although having a rood wad attached to a log placed in a stream channel as part of restoration or enhancement efforts adds stability and longevity (Braudrick and Grant 2000), we cannot justify from these data that all pieces in 20-30 m BFW channels require an attached root wad in addition to meeting the minimum volume requirement (i.e. 9.75 $m^3$ per piece).

Table 9 summarizes our recommendations for instream wood loading based on the methods, results, and rationale presented in this study. These values offer targets and typical ranges of conditions for the quantities and volumes of wood found within the historical range of watershed conditions, given the natural disturbance regime for regions both east and west of the Cascade Mountains in Washington State. We believe that wood loads within this range form and maintain favorable habitat conditions. Therefore, these quantities provide a guide to wood loads likely to promote natural stream processes that form salmonid habitat. These values should be used: 1) to assess current instream wood condition and ratings for the evaluation of stream habitat; 2) to identify target wood loading levels for restoration, enhancement, and mitigation projects; and 3) to develop land-use regulations, ordinances, and laws to protect and manage salmonid habitat.

## *4.13.* Additional Management Considerations

Prior to stream enhancement or restoration projects, and perhaps also as an improved means to assess the quality of aquatic habitats as it relates to wood, several other aspects of instream LWD loading should be addressed. Two of the most noteworthy of these components are 1) spatial distribution, and 2) orientation. The following briefly discusses the importance of each.

The spatial distribution of wood can significantly influence the quality of the resulting habitat. The distribution of wood pieces is also influenced by channel size. In larger channels wood is often found distributed in the form of jams, while in smaller channels, wood may be found distributed in smaller groups of as few as 1-2 pieces. This form of distribution is mostly attributed to the effects of stream power, which is the driver of piece mobility. Streams with higher power will tend to mobilize less stable pieces and accumulate them against larger logs, such as key pieces, which often act as the catalyst for jams in larger channels. Therefore, enhancement or restoration project attempting to mimic natural conditions will benefit by incorporating the typical longitudinal distribution within a stream reach.

Lateral LWD distribution is also an important feature to consider. Instream wood can be associated with one or more of the four channel zones (Schuett-Hames et al. 1999), which range from the low-flow channel to the infrequently inundated floodplains. Wood in lower zones have increased interaction with flow. “Low-zone” wood can provide more effective summer rearing habitat, in addition to winter refuge for salmonids; however, this may also subject the wood to greater shear stresses induced by the flow and so require more consideration to the maintenance of wood stability. If the wood is only located in the low-flow zone (i.e. Zone 1) and none in the high-flow zone (i.e. Zone 2), it may also compromise winter rearing habitat due to the lack of roughness in the channel margins. Distributing wood in the four zones to mimic the characteristics of unmanaged channels, therefore will likely achieve the best results during restoration or enhancement projects.

Wood orientation also can influence the quality of habitat. The orientations of logs are also influenced by channel size. Logs that are perpendicularly oriented in a channel have greater interaction with stream flow to form features such as scour pools (Abbe and Montgomery 1996), increase the pool/riffle interface for salmonid feeding habitat, and the increased ability to store spawning gravels; however, this orientation is more subject to stream shear stresses (Braudrick and Grant 2000). As noted in the literature, the orientation of wood changes with stream size. Logs have an increased propensity to orient themselves parallel to the flow in larger streams (Bilby and Ward 1989). Furthermore, a log positioned perpendicularly in the channel with the large end (due to taper flare) towards the center of the channel will likely yield more interaction with flows; however, the smaller, lighter end of the log may offer less stability from the stream bank compared to having the large end on the bank. Therefore, as with wood distribution, the orientation of wood pieces must also be considered for instream wood projects or habitat evaluations. Perhaps the best restoration or enhancement design also mimics piece orientations found in natural systems. Additionally, habitat evaluations should also consider how wood is orientated in natural systems as a means for comparison.

# 5. CONCLUSION

Analysis of these data suggest that the wood targets presented in the NMFS "Matrix of Pathways and Indicators" (NMFS 1996) and the WFPB "Standard Methodology for Conducting Watershed Analysis (WFPB 1997) are not appropriate for all streams within Washington State. This is due to the variability in wood quantities and volumes found in streams with different channel sizes and regional climates. Subsequently, we found that the most consistent predictor of wood volumes and quantities is basin size (as correlated with bankfull width) and ecoregion, and therefore provides an improved means to develop wood targets. Wood quantity, volume, and mean piece size were found to increase with channel size due to the tendency for wood to transport and densely accumulate in jams, along with a greater lateral area for wood to accumulate. Riparian stand characteristics such as stem density and diameter are influenced by climates particular to each ecoregion, which in turn was found to influence the size and quantity of instream wood. Although trends in wood quantity and volumes were observed between all geomorphic classes and disturbance types, these factors were not used as independent variables due to either 1) the lack of statistical significance, or 2) the co- linearity of these factors with bankfull width or ecoregion (thus already partially represented). We found that percentile distributions best describe the range of wood quantities and volumes in streams draining unmanaged basins. The 75th percentile is chosen as a suggested target reference due to the fact that the samples represented by these distributions include all ranges of wood loading conditions found in unmanaged systems, some of which are not likely conducive to favorable salmonid habitat. Therefore, a reasonable identification point of a favorable wood loading condition is the upper portion of the central distribution (i.e. the 75th percentile) rather than the middle (as typically represented by the median or mean). These distributions are delineated into discrete bankfull width classes for three distinguishable ecoregion groups, as summarized in Table 9. We also found these data to support expanded definitions for minimum volumes of "Key Pieces", also summarized in Table 9. Because these references for instream wood incorporate sources of regional and geomorphic variability, they improve existing targets for stream evaluation, restoration, and enhancement.

*Suggestions For Future Research*
To improve stream restoration and enhancement projects, as well as the means to assess the quality of aquatic habitats as it relates to wood, further research on several other aspects of instream wood would be beneficial. Two issues related directly to the physical properties of instream wood are spatial distribution and log orientation. Quantifying how wood is distributed both longitudinally and laterally in a channel may provide guidelines for how to design habitat improvement projects, or how to evaluate the condition of managed streams compared to natural streams.

Additionally, further research on the linkage of instream wood to riparian processes would be useful for managers. If we accept that managing instream wood to the ranges salmonids have adapted to is appropriate, then managing the recruitment sources of wood based on the character of a natural system is a logical means to this end. Characterizing the riparian stands and understanding the sources of variability in recruitment processes in these systems would offer insight on how to manage wood in these streams.

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# 7. FIGURES

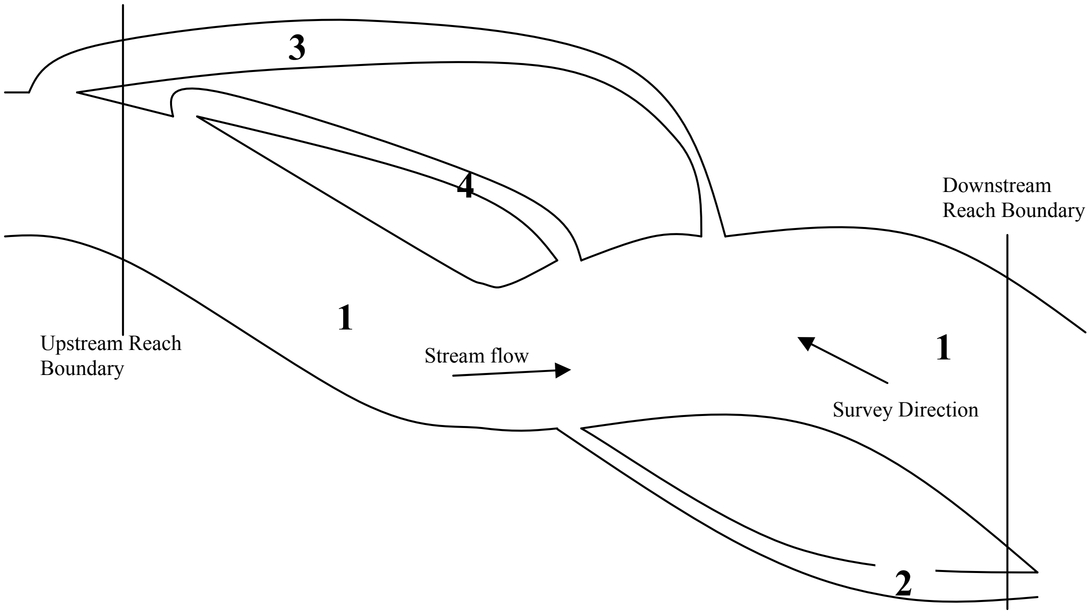


**Figure 1. A plan-view illustration of a stream and side channels, exemplifying the methods used to numerate successive side channels within a reach during instream wood surveys.**

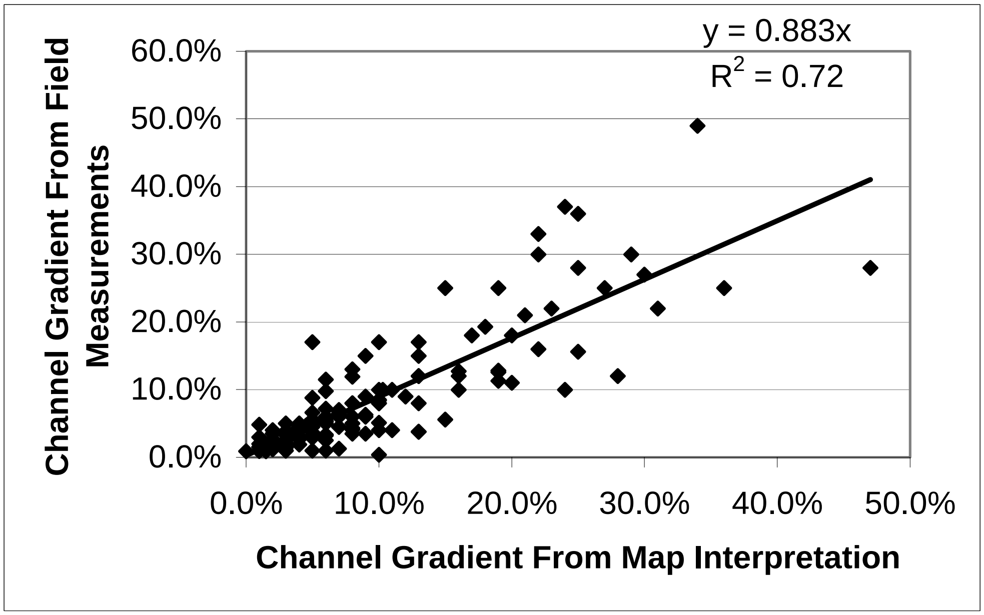


**Figure 2. The relationship of channel gradients as interpreted from a topographic map to channel gradients measured in the field.**

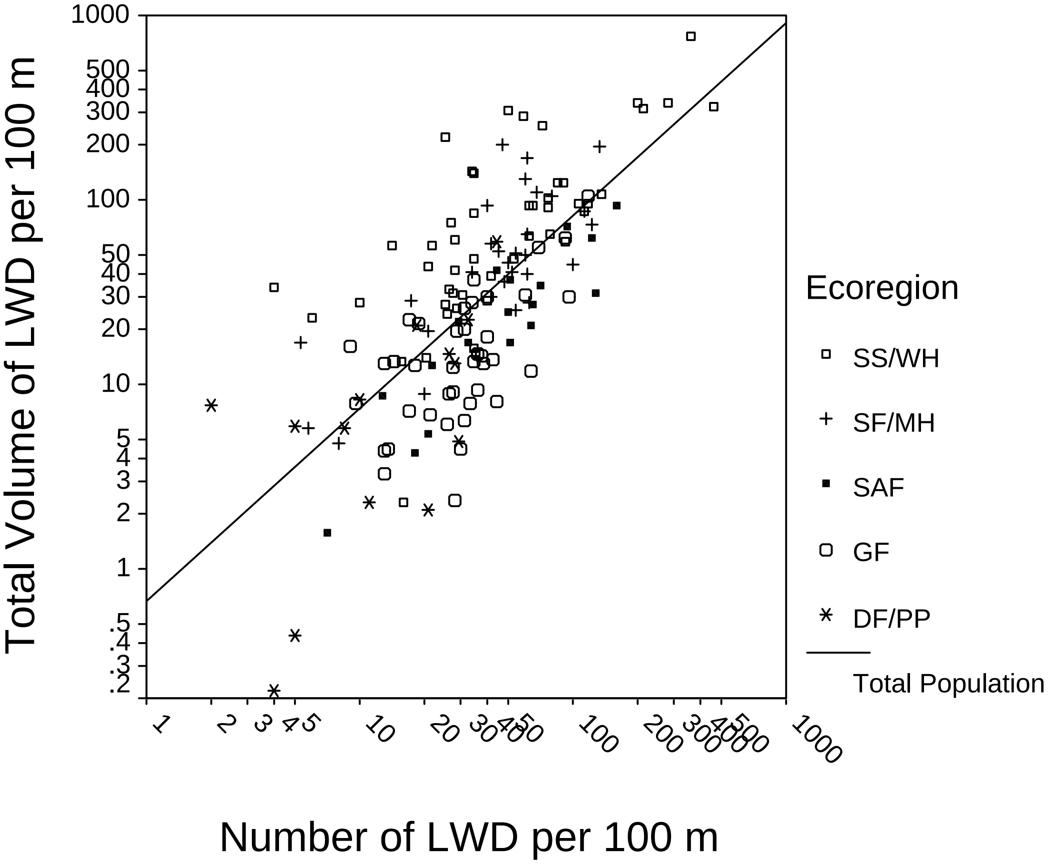


**Figure 3. The relationship of total wood volume to the total number of pieces per 100m (presented in logarithmic scale). The relationship is significant (p<0.001). Differentiating data points by ecoregions illustrates the regional contribution to this relationship. The statistical output for this relationship can be found in Appendix A. 5. SS/WH= Sitka Spruce/ Western Hemlock, SF/MH=Silver Fir/ Mountain Hemlock, SAF=Sub-Alpine Fir, GF=Grand Fir, DF/PP=Douglas Fir/ Ponderosa Pine**

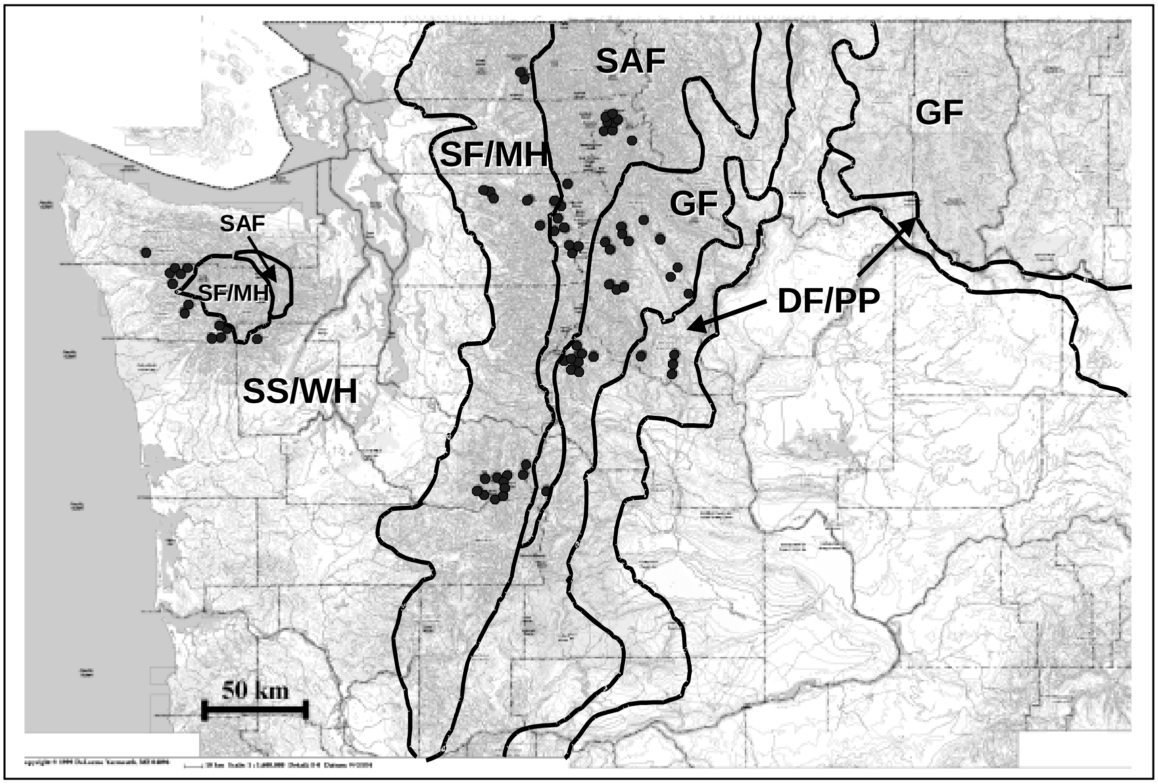


**Figure 4. The distribution of survey sites within Washington State. Each point represents one or more streams (n = 150). The labeled polygons represent ecoregions, a classification largely based 1) natural fire succession and tree species, 2) elevation, and 3) climate. The ecoregion boundaries depicted in this illustration are greatly simplified, and multiple plant associations used to characterize ecoregions can be found isolated within these polygons due to local elevation, aspect, climate, and species transitional zones. SS/WH= Sitka Spruce/ Western Hemlock, SF/MH=Silver Fir/ Mountain Hemlock, SAF=Sub-Alpine Fir, GF=Grand Fir, DF/PP=Douglas Fir/ Ponderosa Pine**

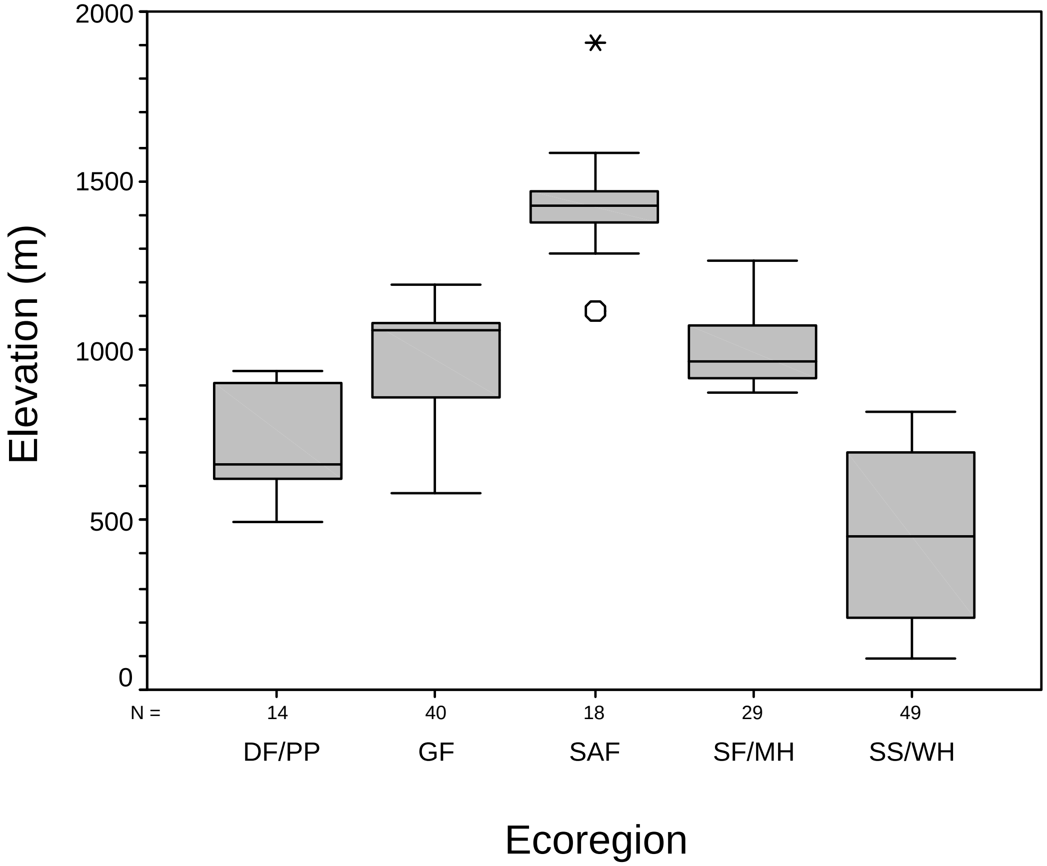


**Figure 5. The percentile distribution (box plot) of the elevations from surveyed sites within each ecoregion. The shaded box represents the middle 50% distribution (i.e. between the 25th and 75th percentiles), the bar within this distribution represents the median, the "whiskers" represent the 10th and 90th percentiles, the "o" represent outliers, and the "*" represent the extremes. SS/WH= Sitka Spruce/ Western Hemlock, SF/MH=Silver Fir/ Mountain Hemlock, SAF=Sub-Alpine Fir, GF=Grand Fir, DF/PP=Douglas Fir/ Ponderosa Pine**

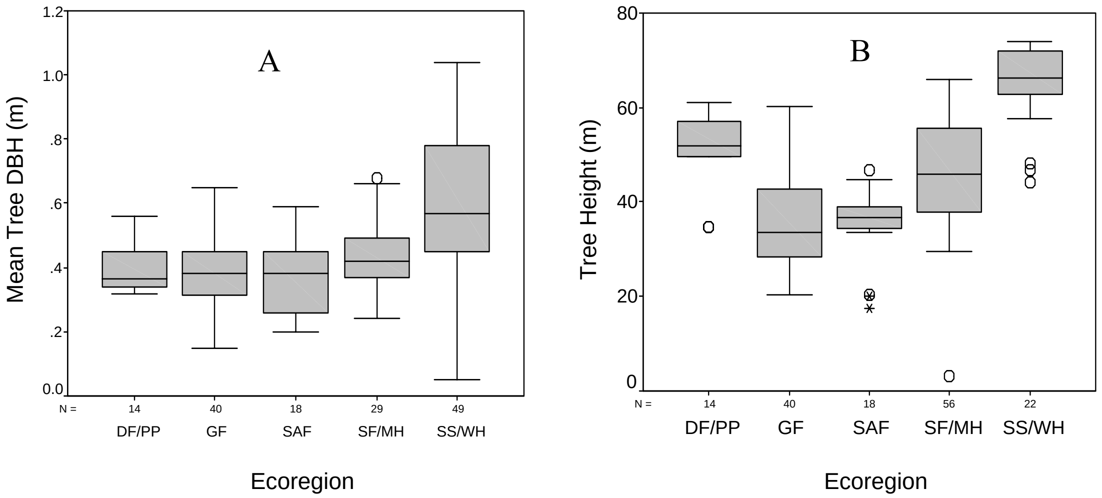


**Figure 6. Box plots of A) mean riparian tree diameter (m) at breast height (dbh), and B) mean tree height in the site-adjacent riparian stands, grouped by ecoregion. SS/WH= Sitka Spruce/ Western Hemlock, SF/MH=Silver Fir/ Mountain Hemlock, SAF=Sub-Alpine Fir, GF=Grand Fir, DF/PP=Douglas Fir/ Ponderosa Pine**

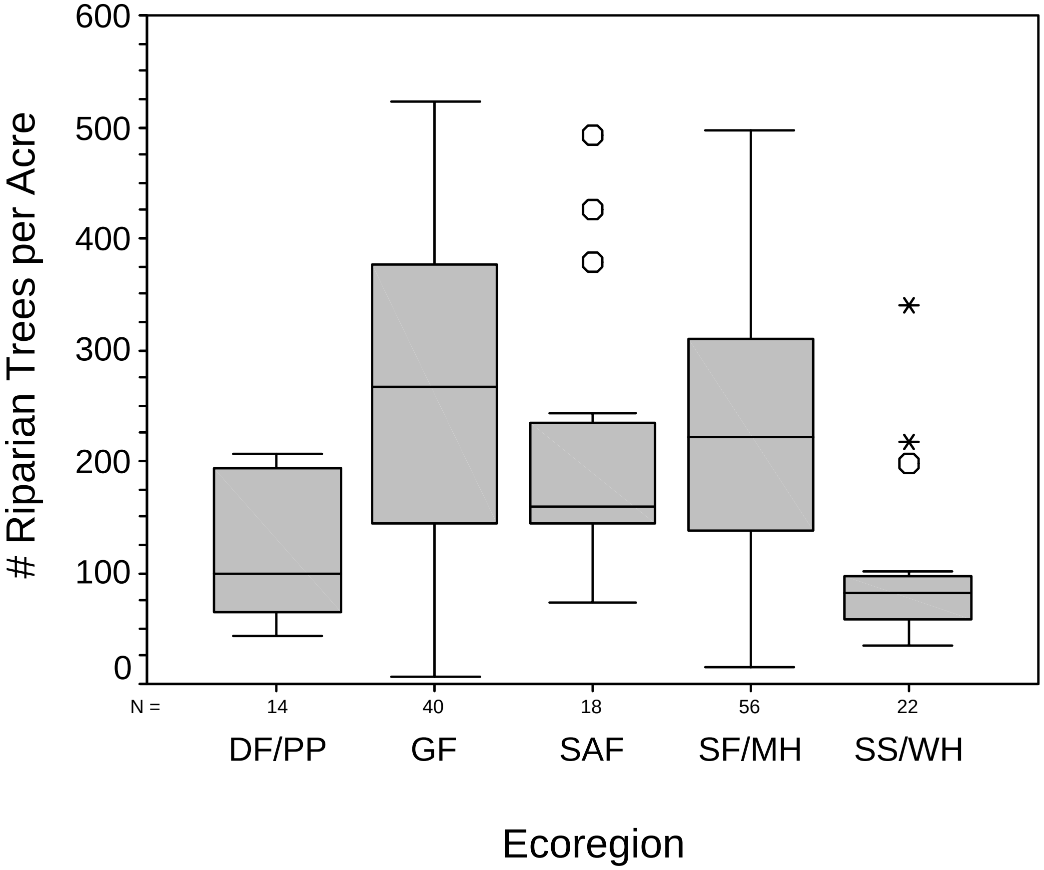


**Figure 7. Box plots representing the site-adjacent number of riparian trees per hectare within each ecoregion. SS/WH= Sitka Spruce/ Western Hemlock, SF/MH=Silver Fir/ Mountain Hemlock, SAF=Sub-Alpine Fir, GF=Grand Fir, DF/PP=Douglas Fir/ Ponderosa Pine**

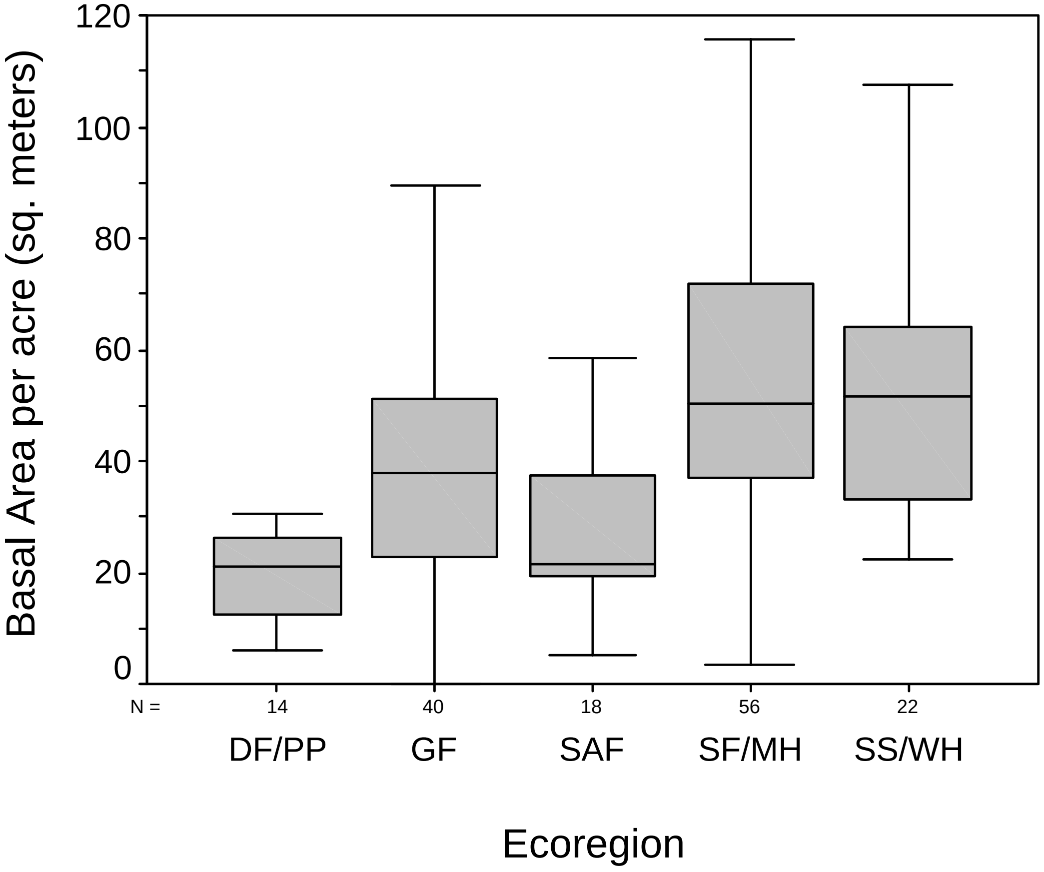
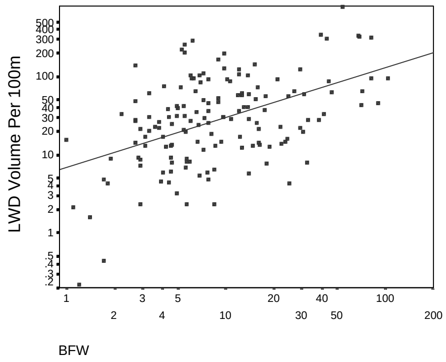
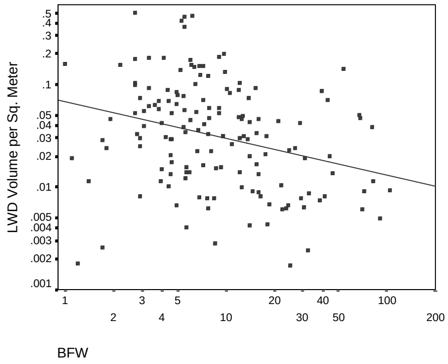


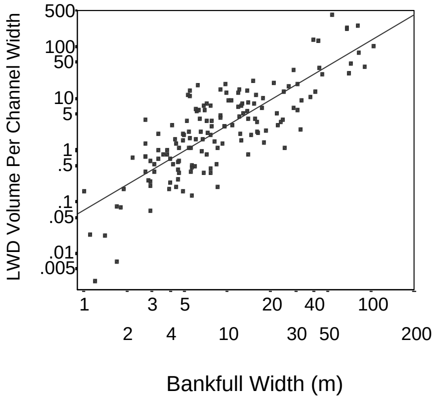
**Figure 8. Box plots representing the site-adjacent riparian basal area ($m^2$) per hectare within each ecoregion. SS/WH= Sitka Spruce/ Western Hemlock, SF/MH=Silver Fir/ Mountain Hemlock, SAF=Sub-Alpine Fir, GF=Grand Fir, DF/PP=Douglas Fir/ Ponderosa Pine**



$Y=6.84x^{0.642}$ $R^2=0.22$



$Y=0.0684x^{-0.358}$ $R^2=0.08$



$Y=0.0684x^{1.642}$ $R^2=0.66$

**Figure 9. Three examples found in the literature to express wood quantities per unit of bankfull width: Wood Volume ($m^3$) per 100m (top), per $m^2$ (center), and per channel width (bottom). The equations represent back-transformed linear regressions from log-normalized data for each example. Proportionately, each equation predicts the same quantity of wood. Statistical output can be found in Appendix A. 11.**

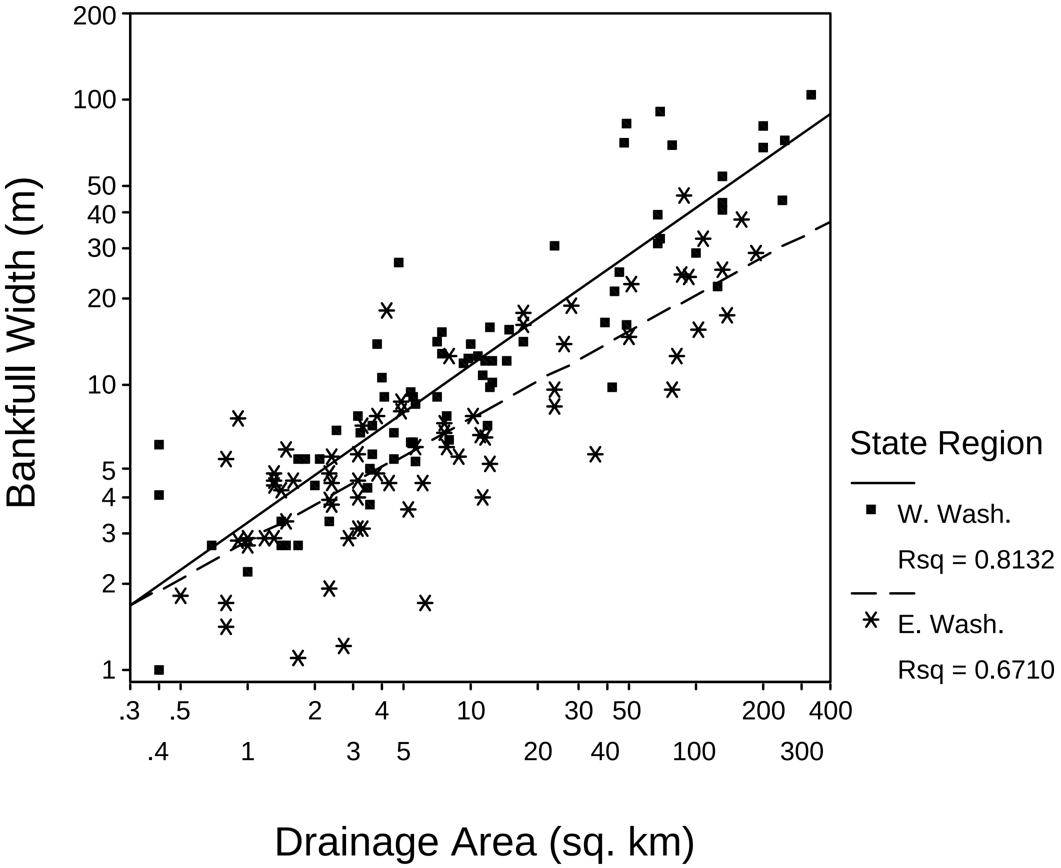


**Figure 10. The relationship of bankfull width to basin size for both eastern and western Washington. The difference in the slope of the regressions between these regions is significant (p=0.002), and both regression slopes are significantly different from zero (p<0.001). Statistical output can be found in Appendix A. 6.**

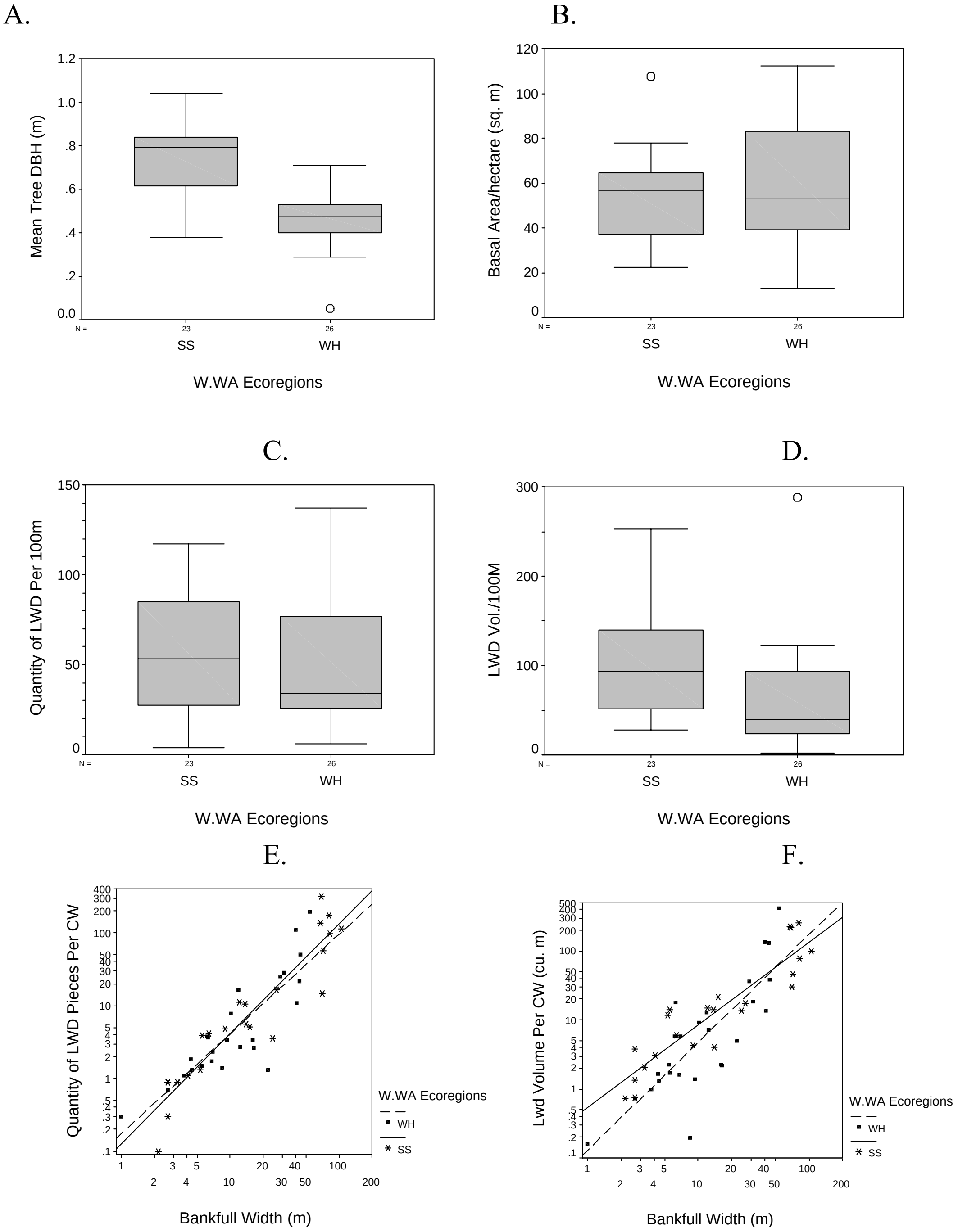


**Figure 11. The comparison of the Sitka Spruce (SS) and the Western Hemlock (WH) forest types: A) mean tree diameter (at breast height [dbh]), B) mean basal area ($m^2$/ha), C) the quantity of LWD pieces/100m, D) the volume of LWD/100m ($m^3$), E) the quantity of LWD pieces per channel width to BFW, and F) LWD volume ($m^3$) per channel width to bankfull width. Statistical tests on the above variables suggest that the means between these two ecoregions are different only in tree diameter ($p<0.001$). SS/WH= Sitka Spruce/ Western Hemlock; SF/MH= Silver Fir/ Mountain Hemlock**

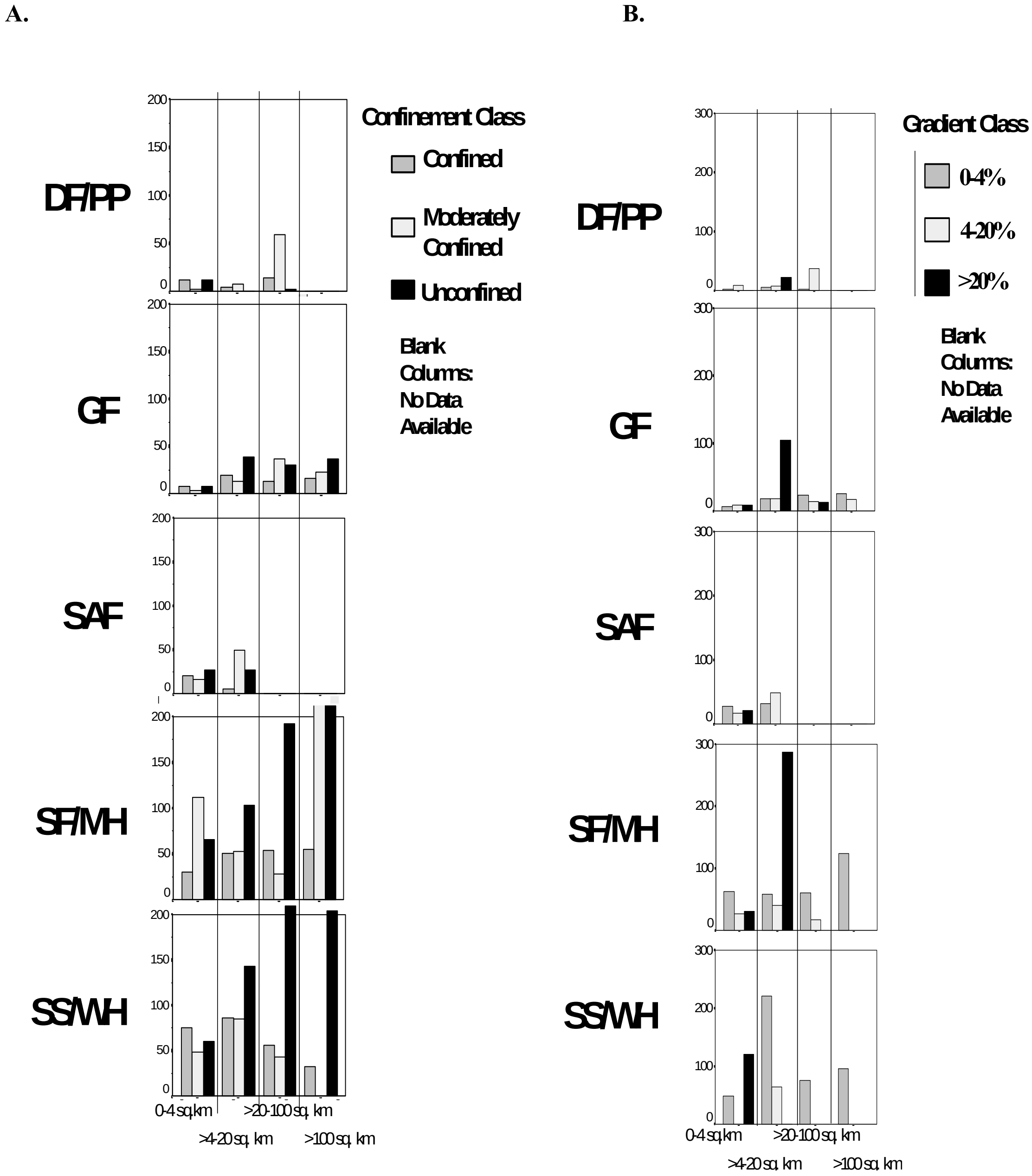


**Figure 12. The effects of confinement (left), and gradient (right), upon the median volume ($m^3$) of LWD per 100m of channel length with respect to basin size (x-axis) and ecoregion (y-axis). SS/WH: Sitka Spruce/ Western Hemlock; SF/MH: Silver Fir/ Mountain Hemlock; SAF: Sub-Alpine Fir; GF: Grand Fir; DF/PP: Douglas Fir/ Ponderosa Pine**

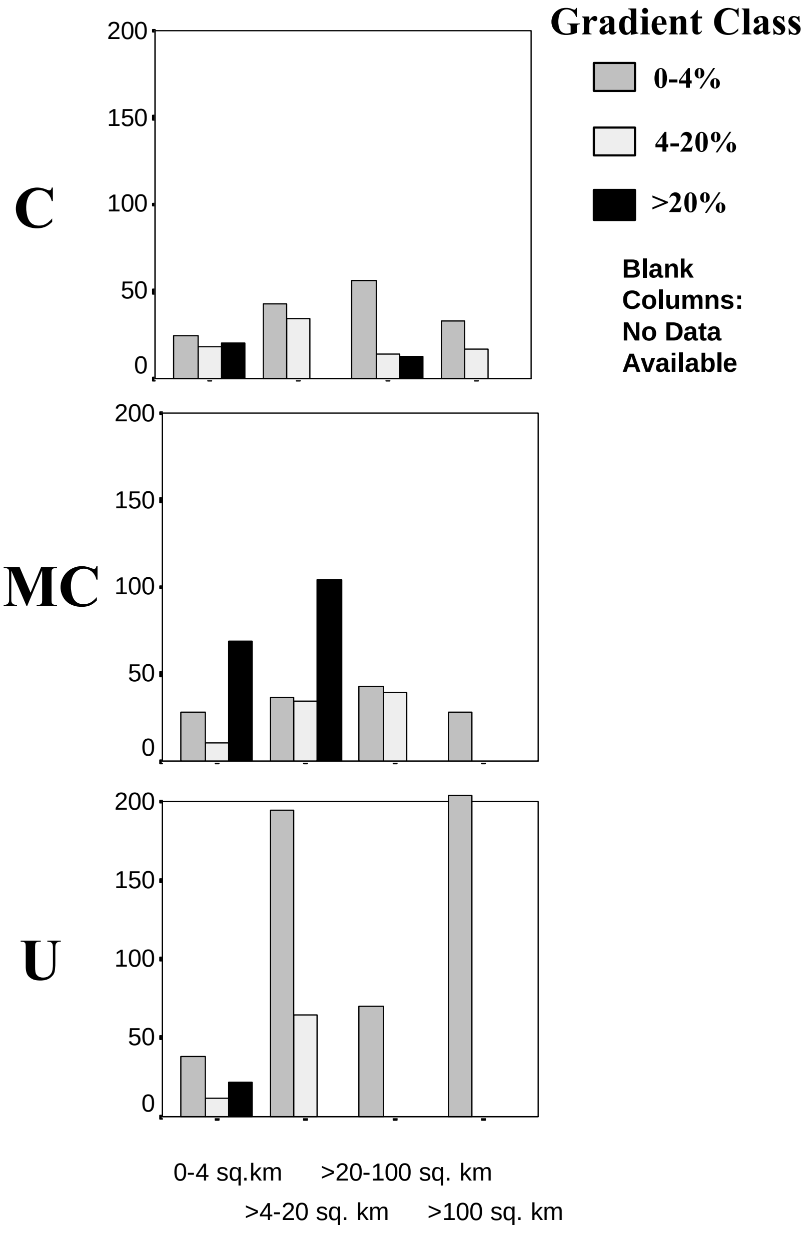


**Figure 13. The combined relationship of gradient and confinement upon the median volume ($m^3$) of instream wood per 100m of channel length. U = Unconfined, MC = moderately confined, C = Confined.**

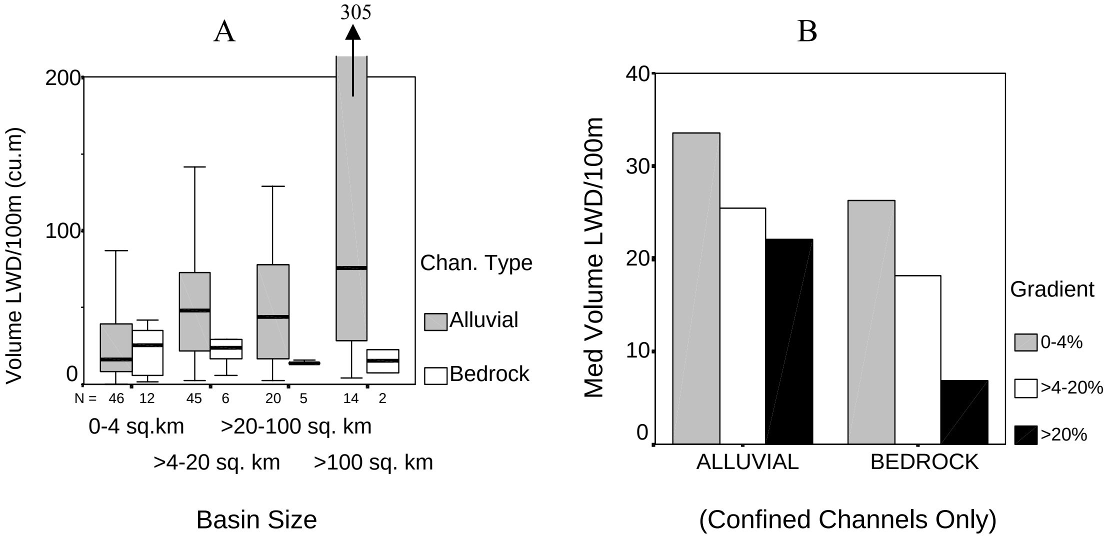


**Figure 14. Comparison of instream wood volume between alluvial and bedrock channels, as grouped by basin size classes (A); and among gradient classes, as grouped by channel type for confined channels only (B).**

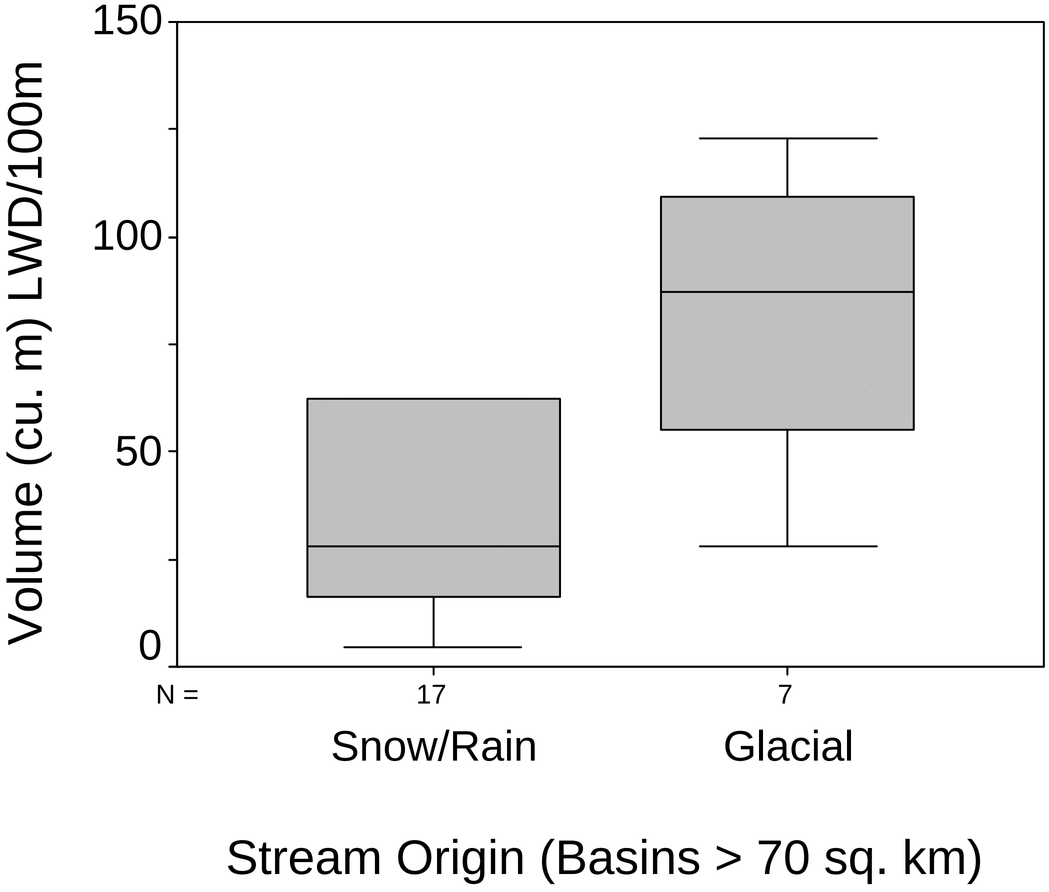


**Figure 15. The comparison of instream wood volumes between channels predominantly originating from snow/rain-dominated systems and those predominantly originating from glacial sources.**

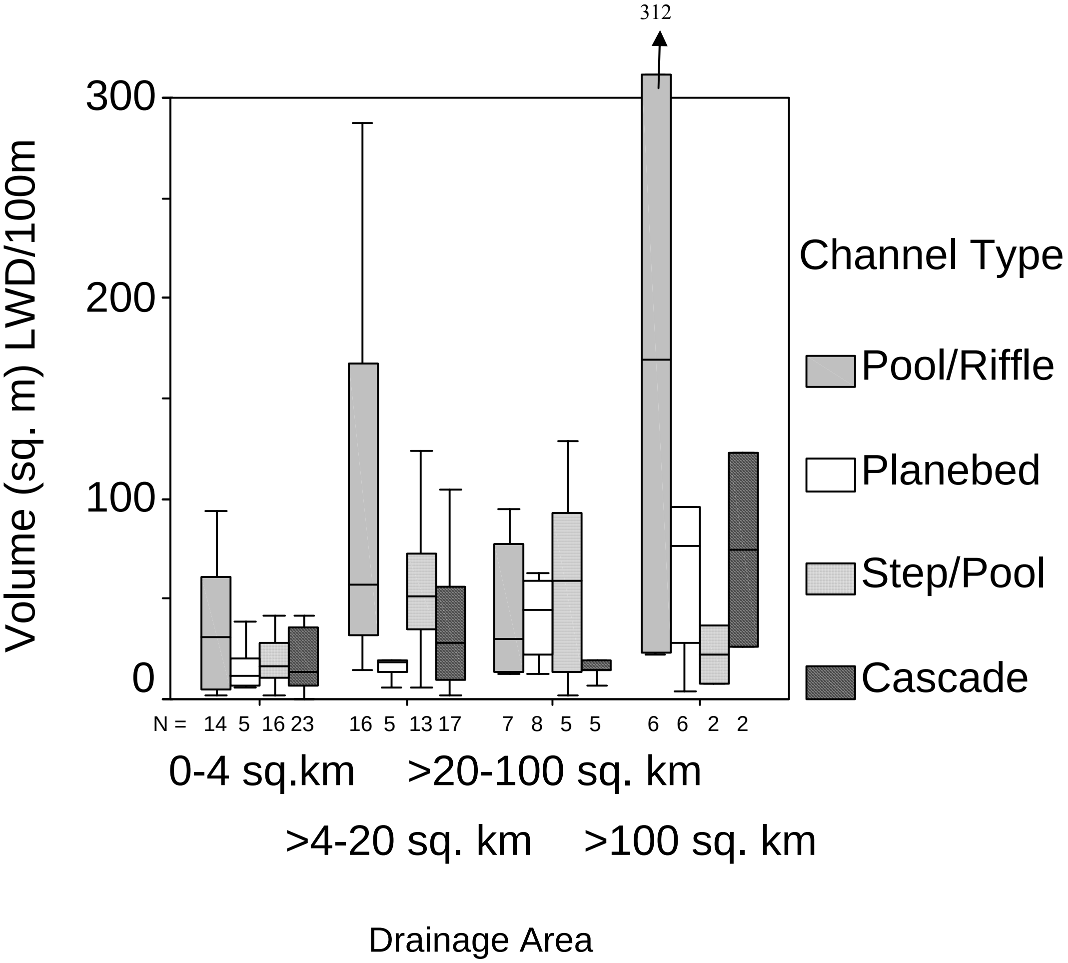


**Figure 16. The percentile distribution of wood volumes ($m^3$) per 100m of channel length for 4 types of channel morphologies.**

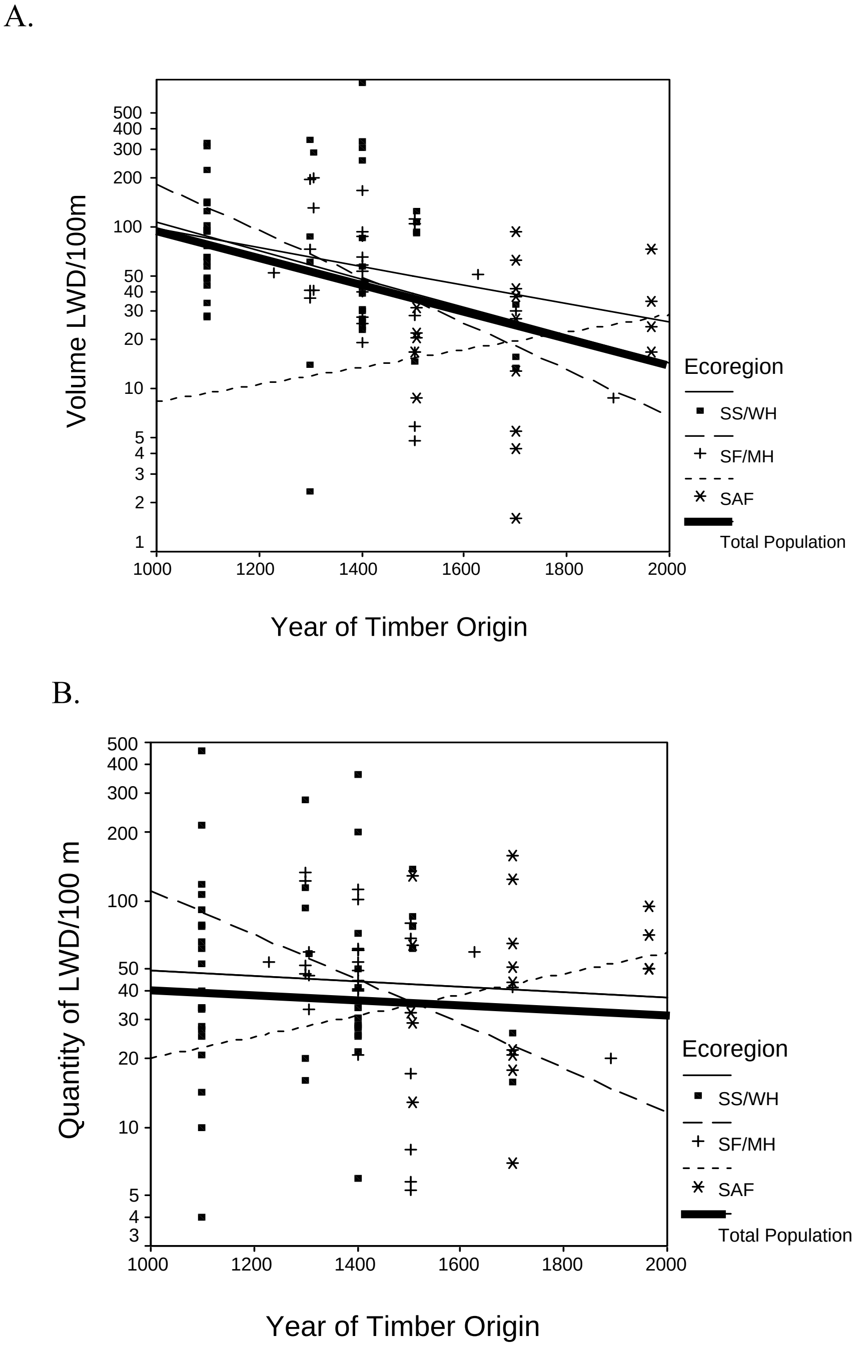
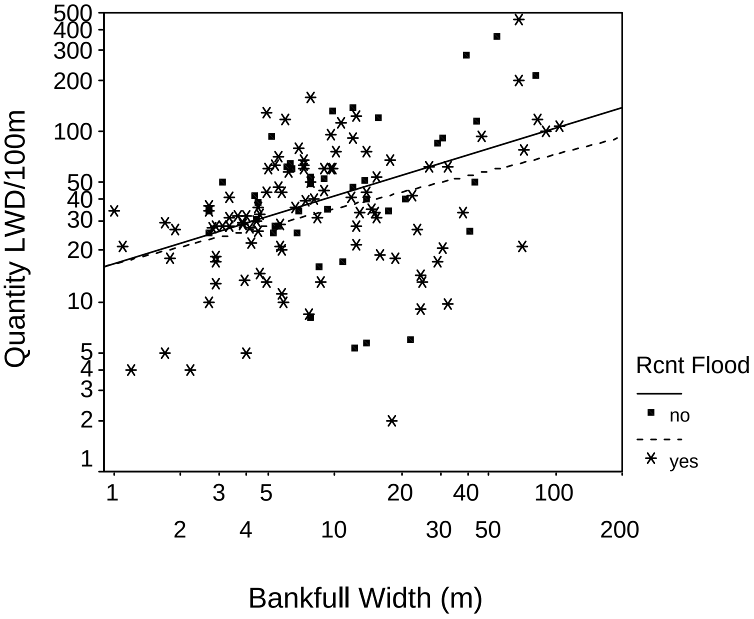


**Figure 17 . The Influence of fire (as a function of timber age) upon instream LWD in terms of (A) Volume ($m^3$) (p=0.013 [total]), and (B) Quantiy (p=0.205 [total]) of LWD per 100 m of channel length. Regressions for the same relationships are also presented for three ecoregions (where fire history information was available) to illustrate regional disparities. See Appendix A.2 for complete statistical output.**

A.



B.

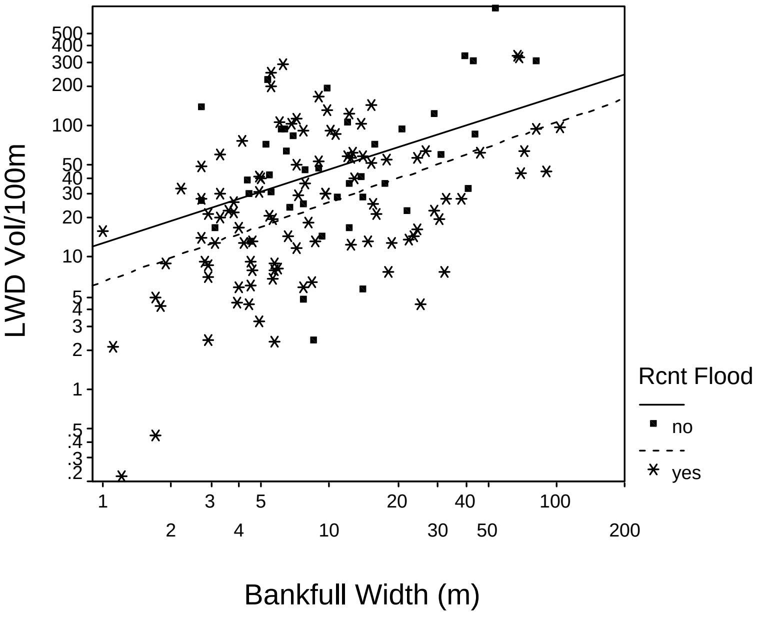


**Figure 18. Comparing the effects of floods with the relationships of instream wood quantity (A) and volume (B) to bankfull width. Streams with and without floods ≥25-year return period within the 10-years prior to surveys are compared. Neither the slope nor y-intercepts of each pair of regressions are not significantly different from each other (for slope: p=0.64 and 0.85; and for intercepts, p=0.96 and 0.26 for wood quantity and volume, respectively). See Appendix A. 3 for complete statistical output.**

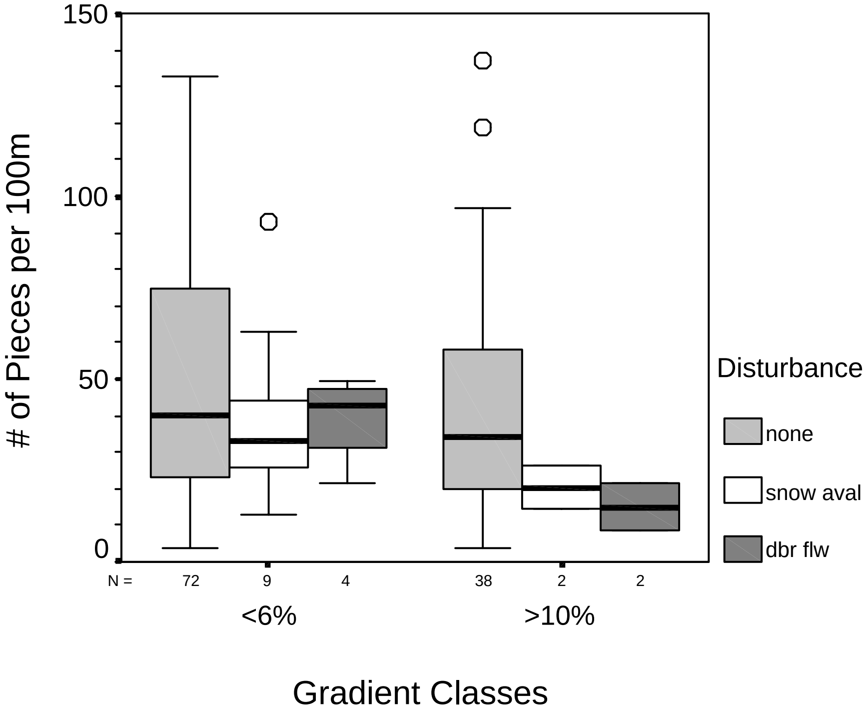


**Figure 19. Box plots of the quantity of wood per 100m of channel length comparing two types of recent (<15-years) channel disturbance: 1) snow avalanche and 2) debris flows, to channels without recent disturbance.**

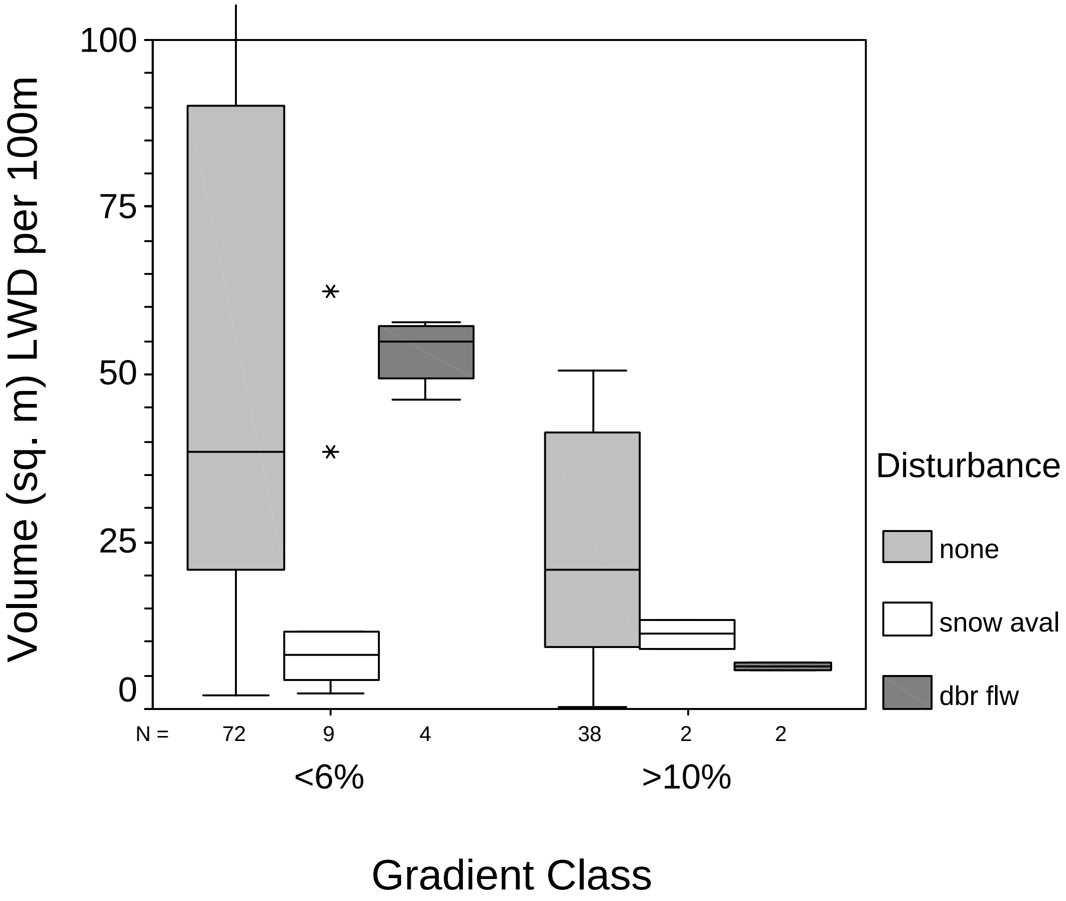


**Figure 20. Box plots of the volume of wood per 100m of channel length comparing two types of recent (<15-years) channel disturbance: 1) snow avalanche and 2) debris flows, to channels without recent disturbance.**

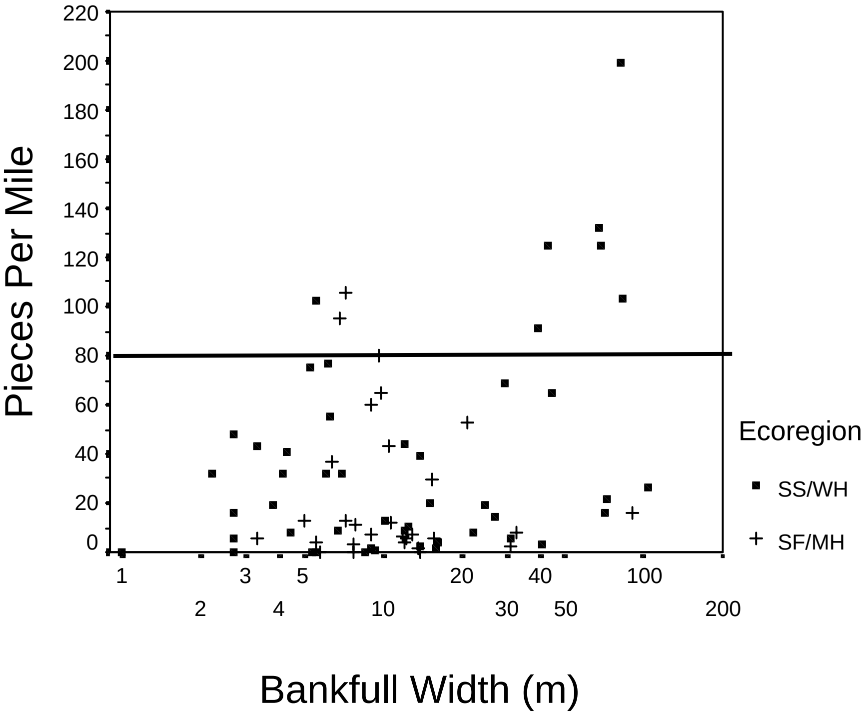
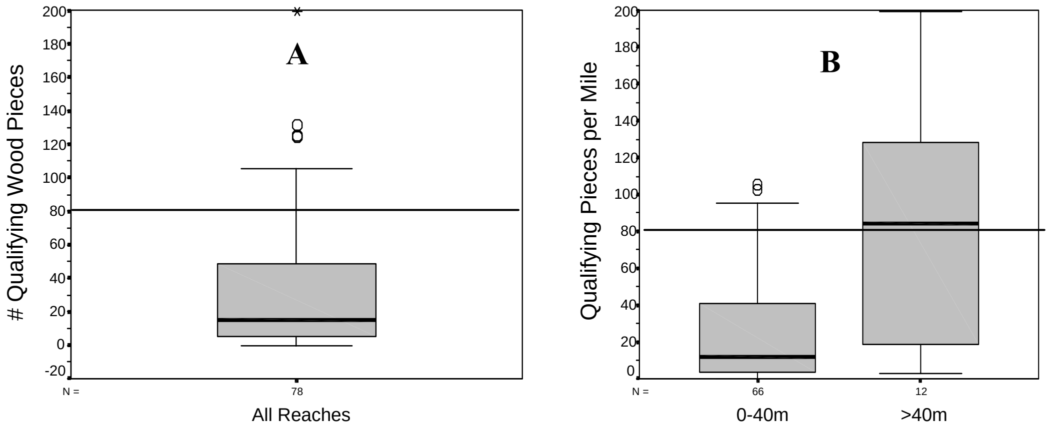


Figure 21. The distribution of sites (n=78) indicating the number of qualifying instream wood pieces that meet the NMFS criteria (80 pieces per mile [50 per km] that are >50ft. [15.2m] in length and >24" [0.6m] diameter) for Coastal or western Washington. The horizontal bar represents the lower threshold for streams meeting a "Properly Functioning Condition" (NMFS 1996). SS/WH=Sitka Spruce/Western Hemlock; SF/MH=Silver Fir/Mountain Hemlock



Western (Coastal) Washington

Bankfull Width Classes

(Statistical summary for plot A)

| Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|
| 18.7* | 15.20 | 5.04 | 51.05 | 4365.48 | 78 | 105.30 |

*Back-transformed from the log-normalized distribution

**Figure 22. Box plots for the number of NMFS qualifying pieces per sampled site (western Washington) (A). The mean of these samples is not equal to the standard of 80 pieces per mile as suggested by the results of a one-sample t-test ($p<0.001$) $n=70$ for log-normalized data. Similar analyses are conducted by dividing sites into two bankfull width classes (B). The horizontal bar in each plot represents the lower threshold for streams meeting a “Properly Functioning Condition” (NMFS 1996). Statistical output can be found in Appendix A.12.**

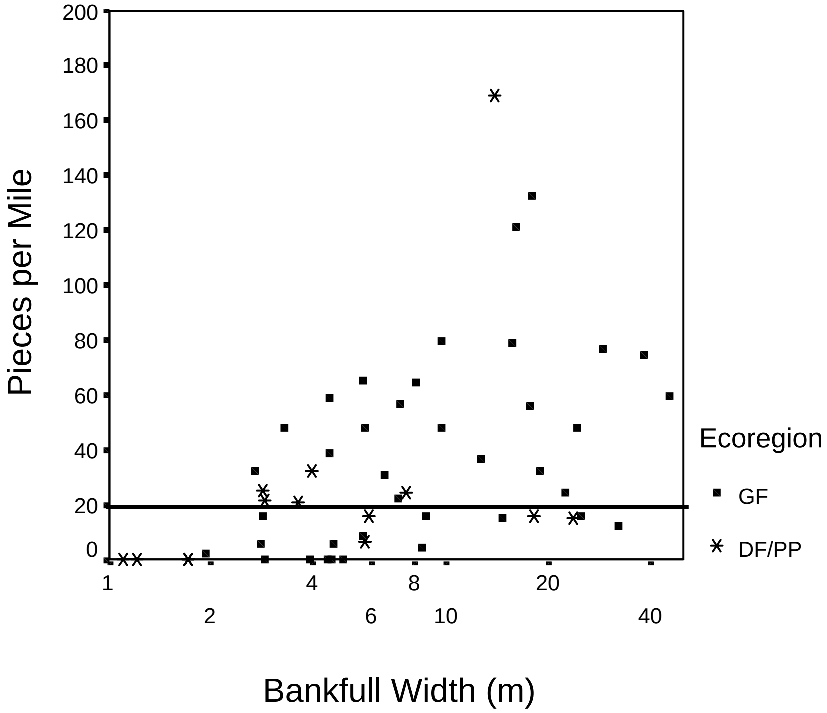
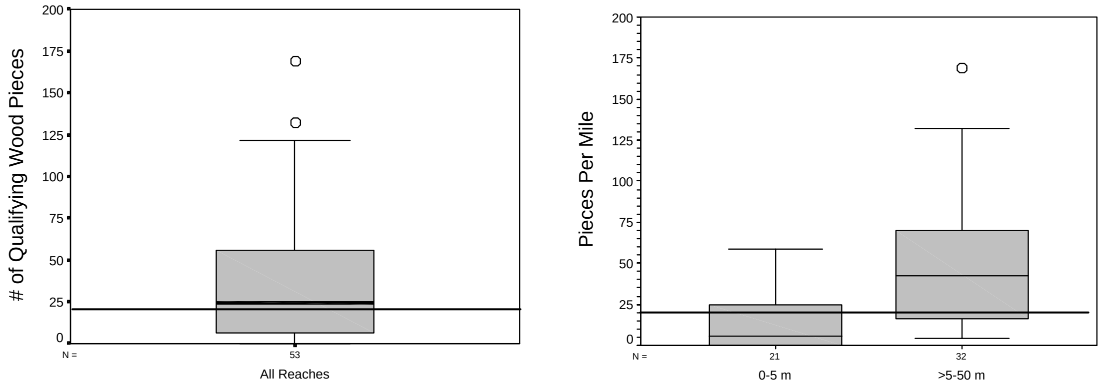


**Figure 23. The distribution of sites (n = 53) indicating the number of qualifying instream wood pieces that meet the NMFS criteria (>35ft. [10.7 m] in length and >12" [0.31 m] diameter) for eastern Washington. The horizontal bar represents the lower threshold for streams meeting a "Properly Functioning Condition" (NMFS 1998).**



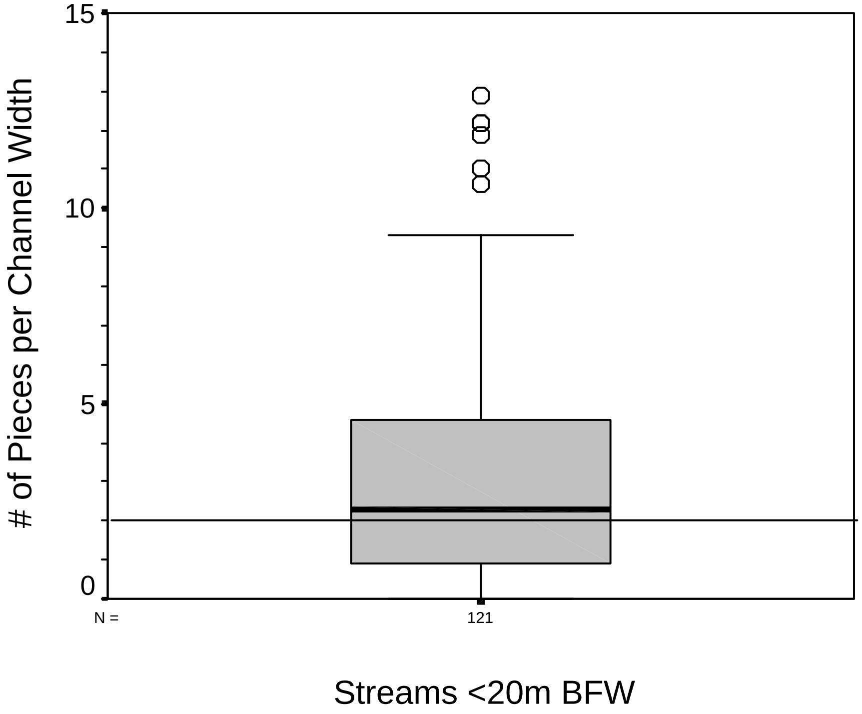
Eastern Washington

Bankfull Width Classes

| Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|
| 28.8* | 23.8 | 6.1 | 56.8 | 2379.5 | 54 | 122.0 |

*Back-transformed from the log-normalized distribution

**Figure 24. Box plot for the number of NMFS qualifying pieces (n=45) per sampled site for eastern Washington (A), and for two bankfull width classes (B). The horizontal bar represents the lower threshold for streams meeting a "Properly Functioning Condition" (NMFS 1996). The mean of the combined data is not equal to the standard of 20 pieces per mile as suggested by the results of a one-sample t-test ($p<0.020$, $\log_{10}$ data).**



| Mean* | Median | Percentile 25 | Percentile 75 | Variance | Range | Count |
|---|---|---|---|---|---|---|
| 1.99 | 2.28 | .90 | 4.72 | 13.07 | 19.30 | 121 |

*Back-transformed from the log-normalized data

**Figure 25. Box plot of LWD pieces per channel width for channels less than 20m in bankfull width. The horizontal line represents the WFPB (1997) target of 2 pieces per channel width. T-tests suggest that the mean is not significantly different from the WFPB standard (p=0.969, n=121). Statistical output can be found in Appendix A. 13.**

**A.**

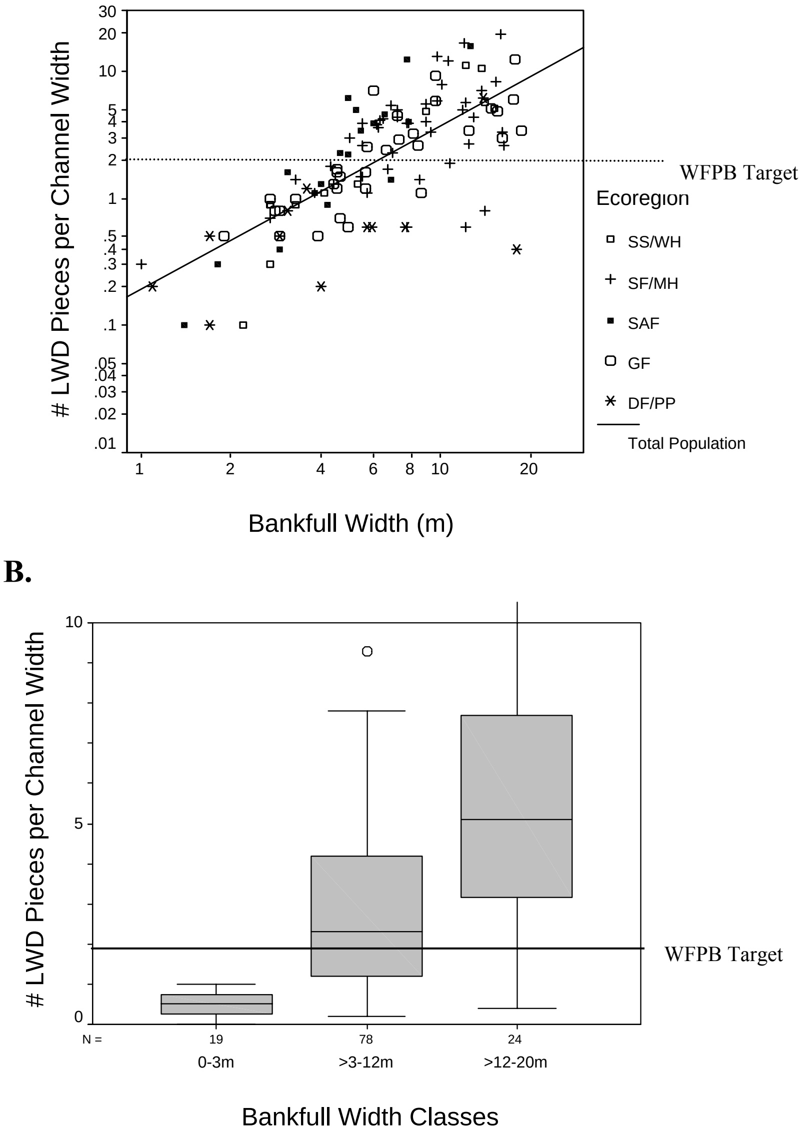


**Figure 26. The number of LWD pieces per channel with by bankfull width for channels <20m in BFW. The target index of two pieces of LWD per channel width (WFPB 1997), as indicated by the horizontal line, is the quantity indicating "Good" habitat quality. Statistical output can be found in Appendix A. 14.**

**A. Each data point represents the mean quantity per sample, labeled to identify discrete ecoregions. The slope of the regression through the points is significant ($p<0.001$). $R^2$ (adjusted)= 0.536, n=121.**

**B. The range of data illustrates non-uniform relationships to the target value among discrete bankfull width classes.**

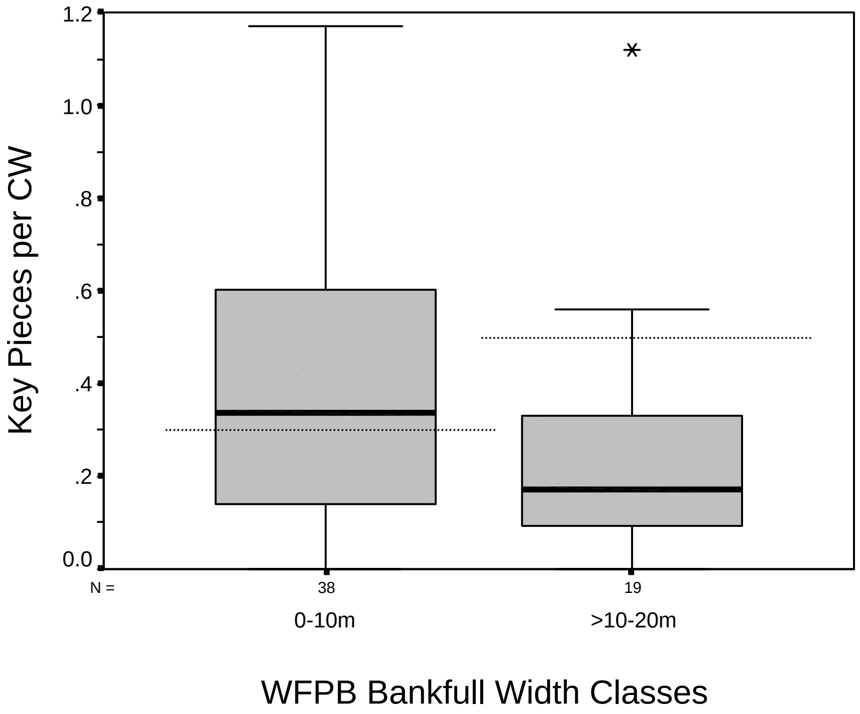


**Figure 27. The data distribution as compared to the WFPB targets for key piece quantities per channel width. The dashed horizontal line represents the WFPB target pertaining to each of these bankfull width classes. Appendix A. 15.**

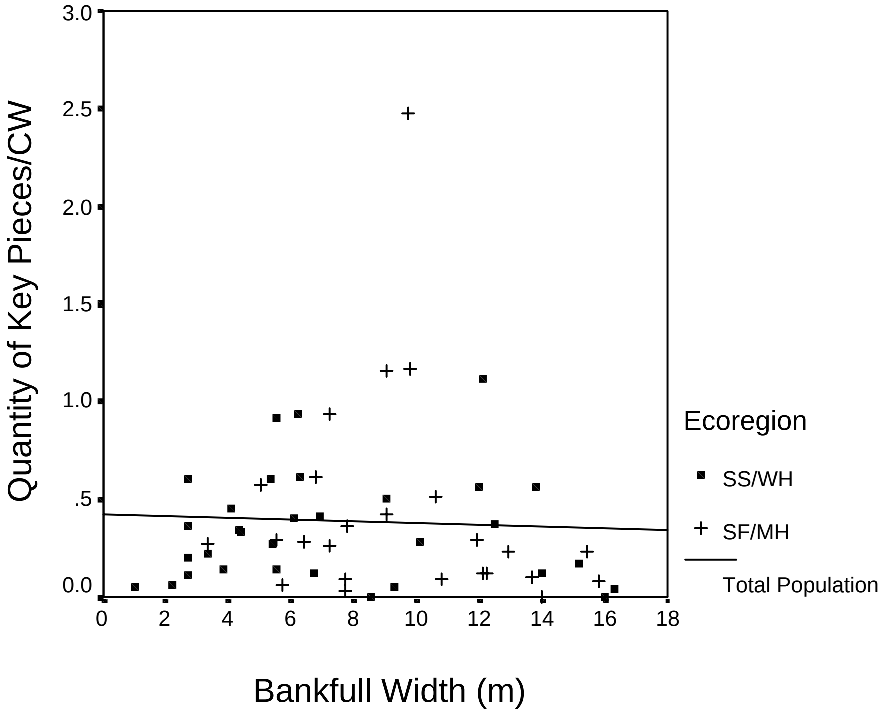
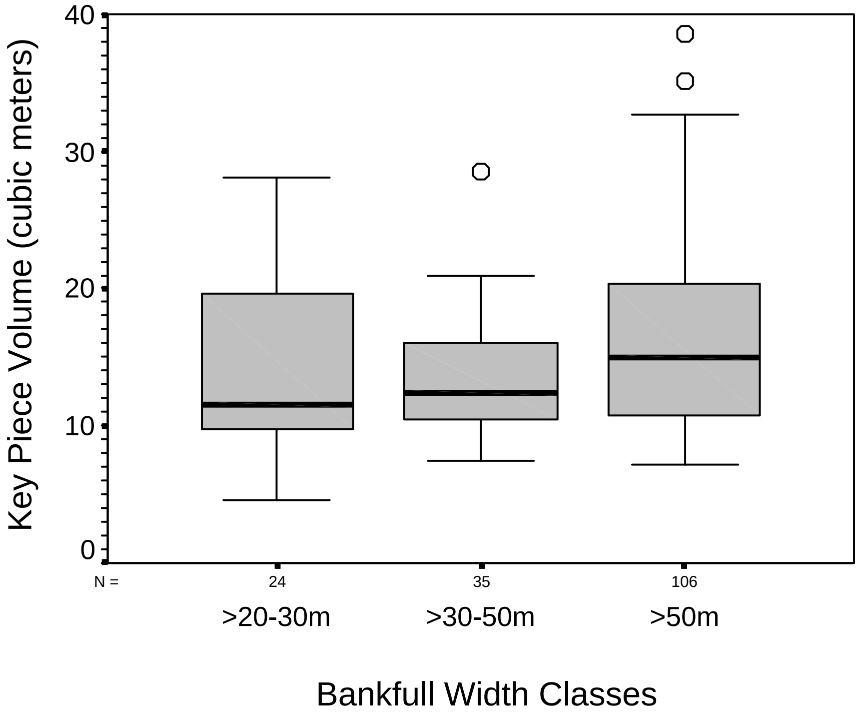


**Figure 28. The relationship of the number of key pieces per channel width to bankfull width for channels 0-20 m bankfull width in western Washington. The regression is not significant (p=0.625; $r^2$=0.002; n=53). Statistical output can be found in Appendix A. 16. Note: data representing the outlier (2.48 key pcs./CW) includes a reach containing a high proportion of jams.**



(data summary)

| | | Median | Percentile 25 | Percentile 75 | Variance | Range | Count |
|---|---|---|---|---|---|---|---|
| >20-30m | | 11.64 | 9.74 | 21.01 | 53.80 | 23.51 | 24 |
| >30-50m | | 12.47 | 10.48 | 17.63 | 140.85 | 53.20 | 35 |
| >50m | | 15.17 | 10.73 | 20.64 | 289.56 | 124.00 | 106 |

**Figure 29. The percentile distribution of instream wood volumes for pieces meeting the definition of "independent stability" (WFPB 1997) for channels with BFW >20 m, using data from both eastern and western Washington streams. According to our methods, the minimum volume for key pieces in channels greater than 20 m is defined using the 25th percentile.**

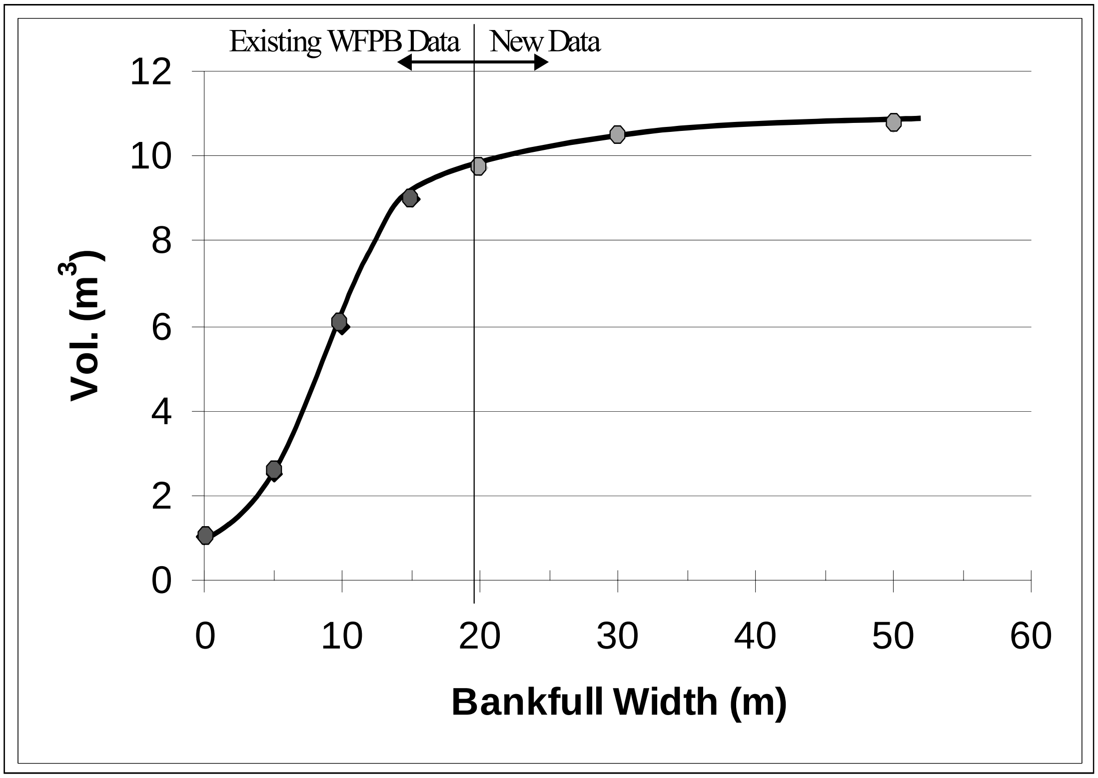
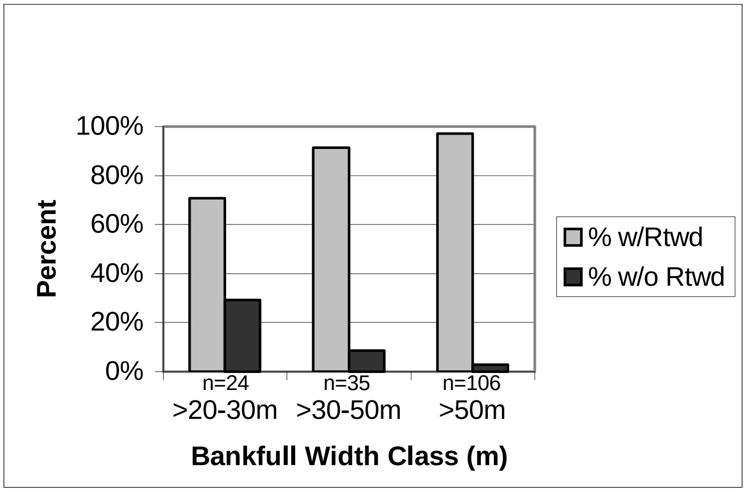


**Figure 30. Plot of the minimum wood volumes used to define key pieces. The points to the right of the vertical line represent the new minimum volumes defined in this analysis, and the points to the left represent existing values currently used in the State of Washington's Watershed Analysis for western Washington (WFPB 1997). The analysis suggests that these minimum volumes are applicable to both eastern and western Washington streams.**

**A.**



**B.**

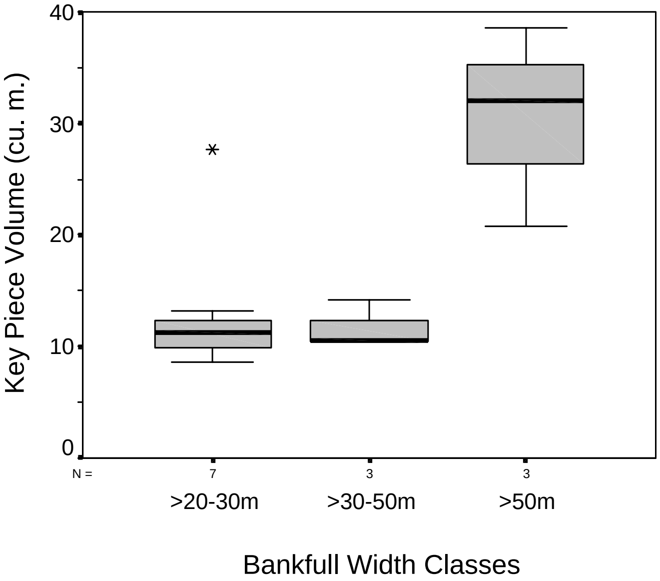


**Figure 31. The percentages of pieces meeting the WFPB definition for key pieces that had root wads attached in channels greater than 20m (A), and minimum volumes defining key pieces in channels >20m BFW *without* root wads attached (B) using data from both eastern and western Washington streams.**

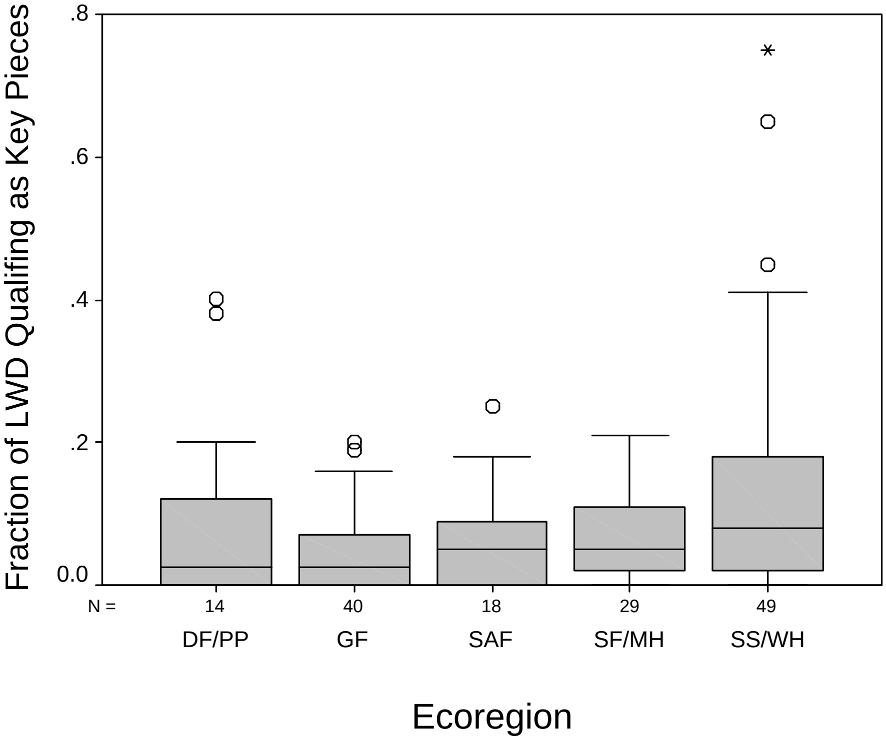


**Figure 32. The fraction of all LWD pieces found per surveyed site that met the minimum volume qualifications to be considered "key pieces." The mean percent between all ecoregions are similar, with the exception of the SS/WH and the GF ecoregion (p=0.001). Statistical output can be found in Appendix A. 17. SS/WH: Sitka Spruce/ Western Hemlock; SF/MH: Silver Fir/ Mountain Hemlock; SAF: Sub-Alpine Fir; GF: Grand Fir; DF/PP: Douglas Fir/ Ponderosa Pine**

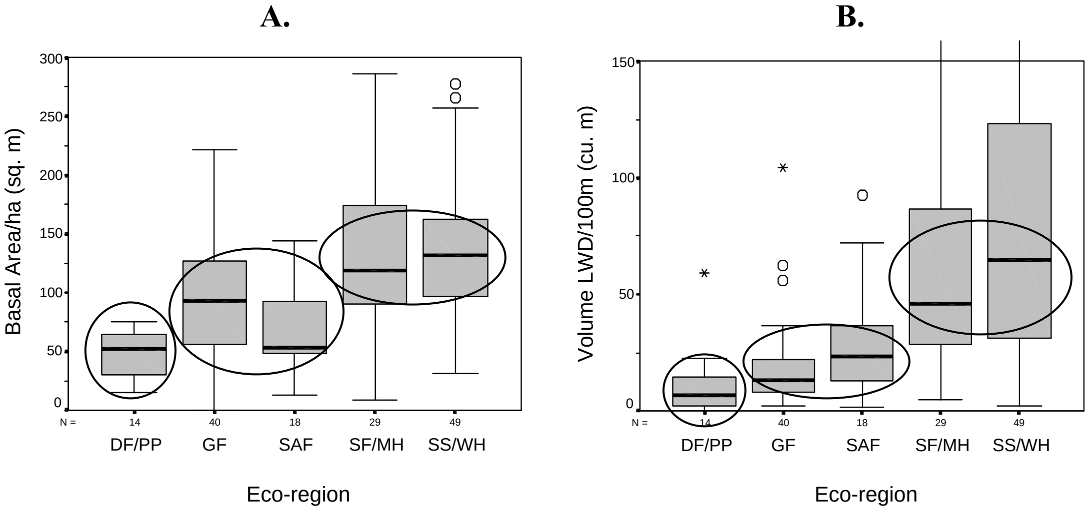
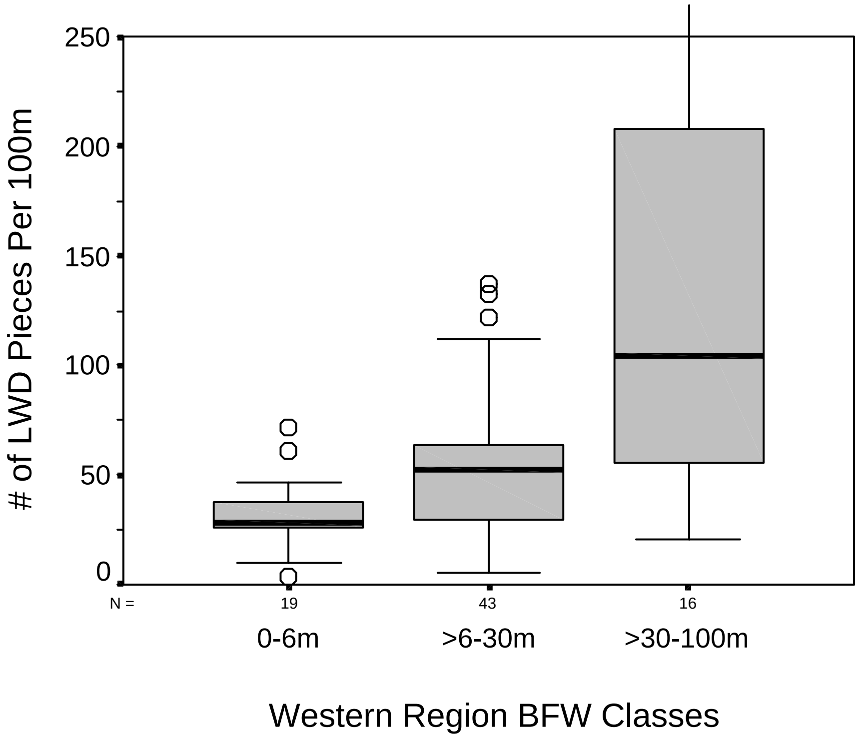


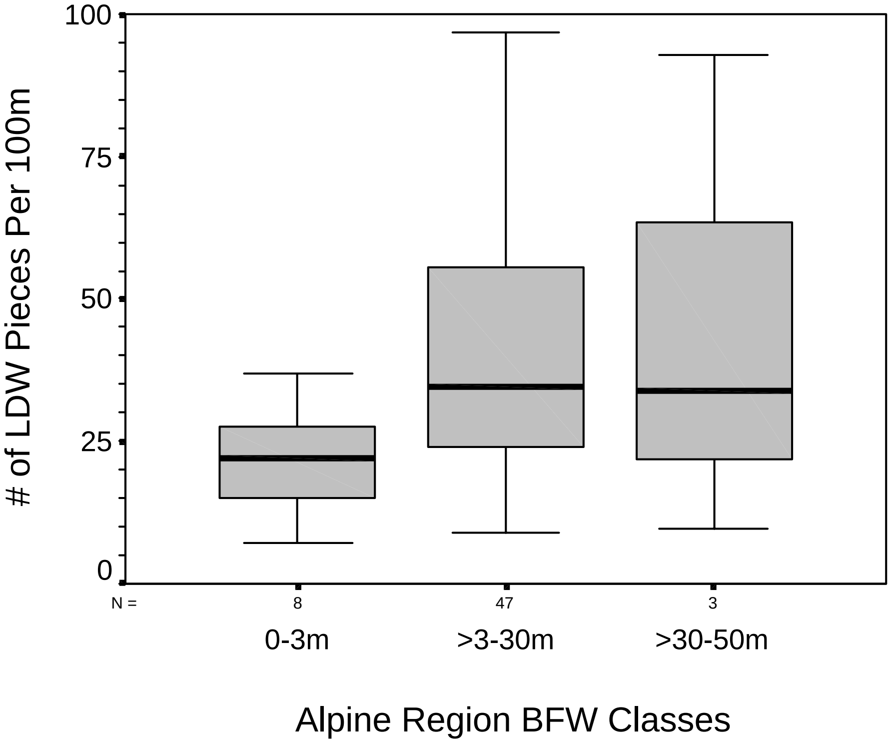
**Figure 33. Percentile distributions based on basal area ($m^2$) per hectare (A), and LWD volume ($m^3$) per 100m of channel length for each ecoregion (B). Based on statistical comparisons of the means for these components, ecoregions are combined into the circled groups. Statistical output can be found in Appendix A. 19.**



(data summary)

| | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|
| 0-6m | 32.5 | 29.0 | 25.5 | 37.9 | 243.2 | 19 | 67.5 |
| >6-30m | 52.0 | 52.3 | 29.2 | 63.4 | 1092.0 | 43 | 131.7 |
| >30-100m | 143.8 | 105.6 | 56.5 | 208.3 | 16159.3 | 16 | 435.3 |

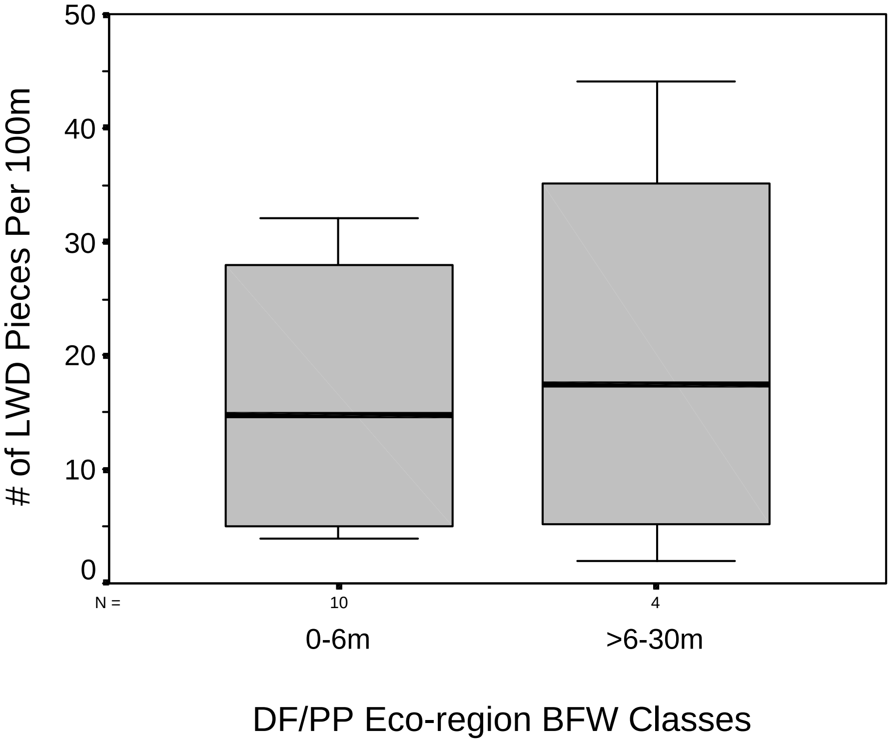
**Figure 34. The percentile distribution of the quantity of LWD per 100m for the Western Washington Region. BFW classes are distinguished by significant differences between either the means or the variances. Statistical output can be found in Appendix A.21.**



(data summary)

| | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|
| 0-3m | 21.7 | 22.3 | 14.9 | 27.9 | 93.9 | 8 | 30.0 |
| >3-30m | 45.6 | 35.1 | 24.5 | 55.5 | 1134.8 | 47 | 150.0 |
| >30-50m | 45.5 | 34.2 | 21.6 | 63.3 | 1839.5 | 3 | 83.3 |

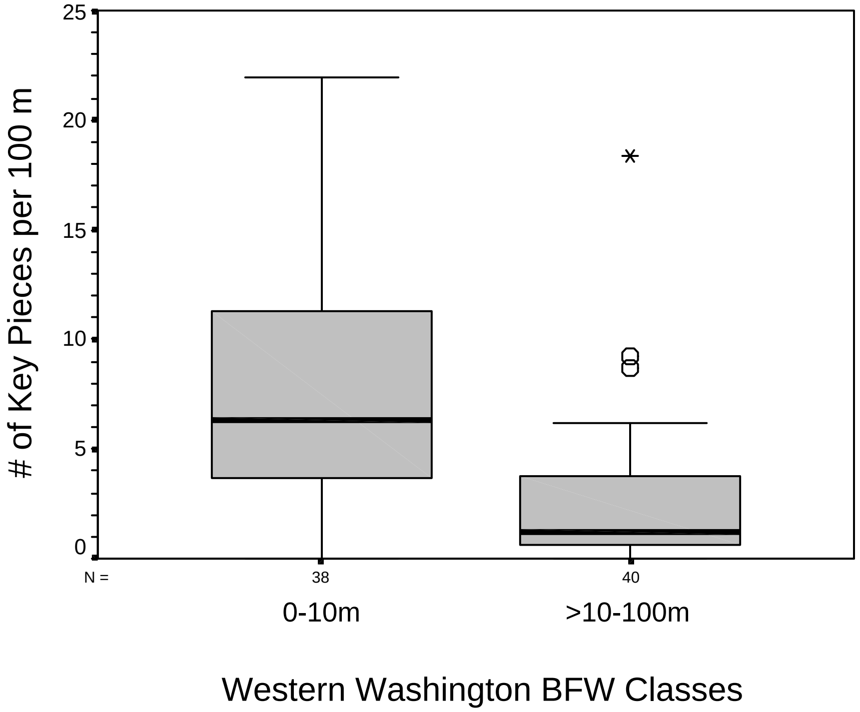
**Figure 35. The percentile distribution of the quantity of LWD per 100m for the Alpine Region. BFW classes are distinguished by significant differences between either the means or the variances. Statistical output can be found in Appendix A.21.**



(data summary)

| | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|
| 0-6m | | 16.4 | 15.0 | 5.0 | 28.6 | 116.2 | 10 | 28.0 |
| >6-30m | | 20.2 | 17.4 | 5.1 | 35.1 | 357.4 | 4 | 42.0 |

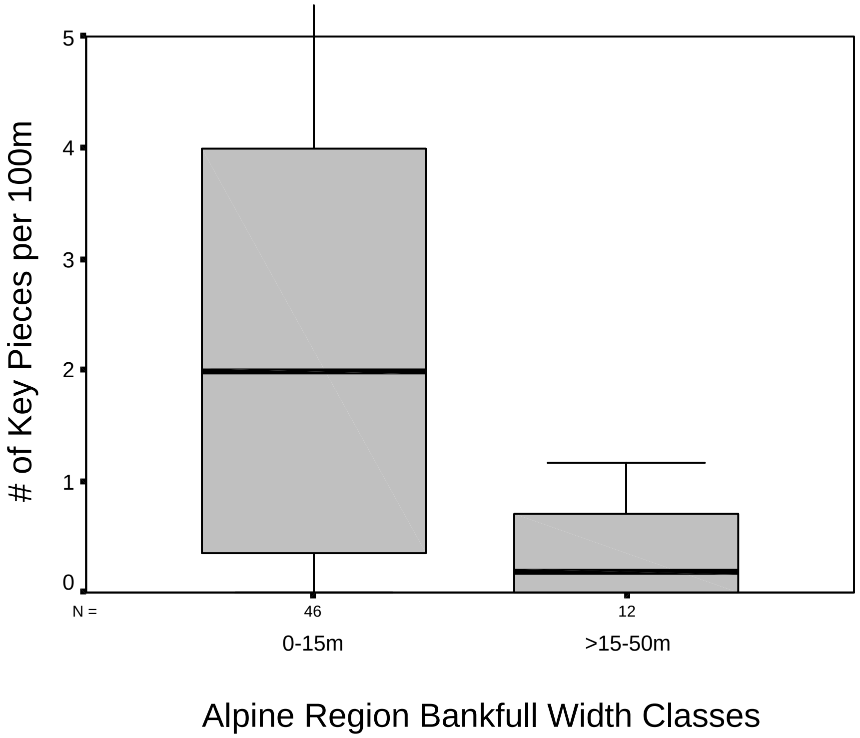
**Figure 36. The percentile distribution of the quantity of LWD per 100m for the DF/PP Ecoregion. BFW classes are distinguished by significant differences between the means. Statistical output can be found in Appendix A.21.**



(data summary)

| | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|
| 0-10m | Key Pieces per 100m | 7.6 | 6.4 | 3.7 | 11.4 | 33.8 | 38 | 25.6 |
| >10-100m | Key Pieces per 100m | 2.6 | 1.3 | .8 | 3.9 | 12.0 | 40 | 18.4 |

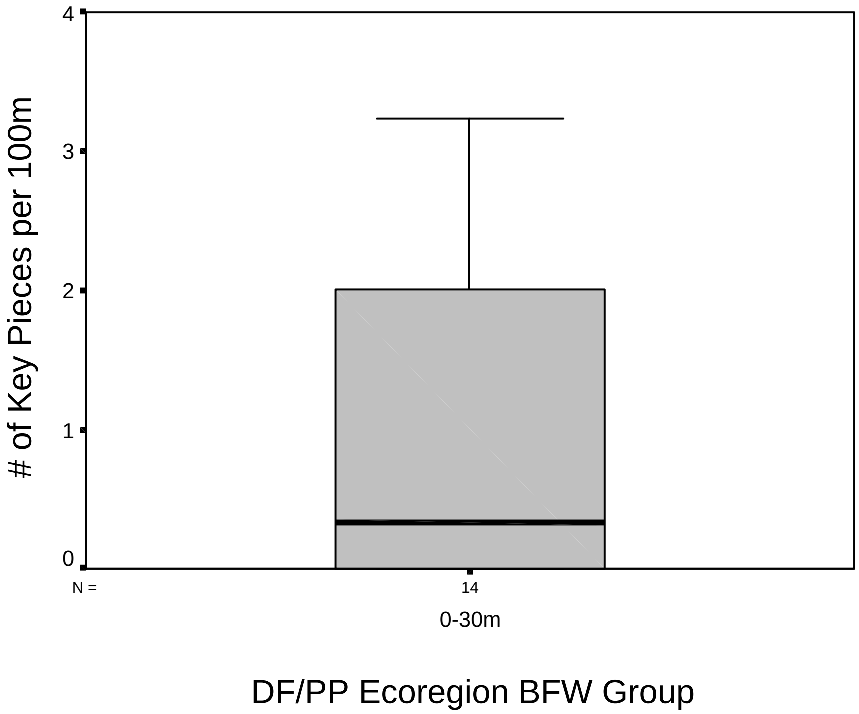
**Figure 37. The percentile distribution of the quantity of Key Pieces per 100m for the Western Washington Region. BFW classes are distinguished by significant differences between the variances. Statistical output can be found in Appendix A. 21.**



(data summary)

| | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|
| 0-15m | Key Pieces per 100m | 2.8 | 2.0 | .3 | 4.1 | 9.1 | 46 | 12.5 |
| >15-50m | Key Pieces per 100m | .4 | .3 | .0 | .9 | .2 | 12 | 1.2 |

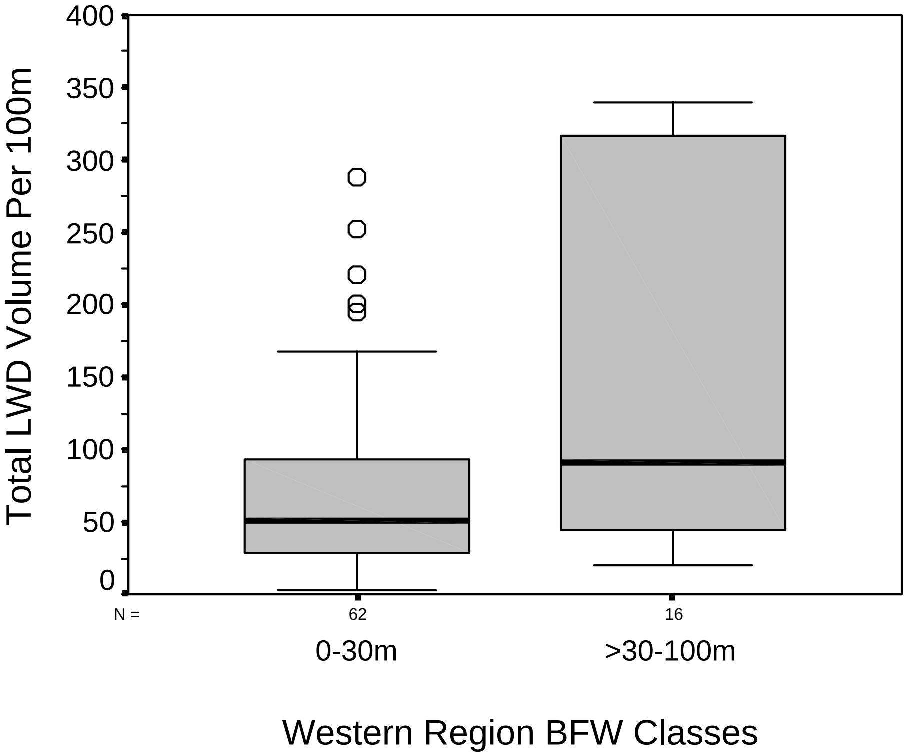
**Figure 38. The percentile distribution of the quantity of Key Pieces per 100m for the Alpine Region. BFW classes are distinguished by significant differences between the means. Statistical output can be found in Appendix A. 21.**



(data summary)

| | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|
| 0-30m | Key Pieces per 100m | 1.6 | .4 | .0 | 2.0 | 5.7 | 14 | 7.0 |

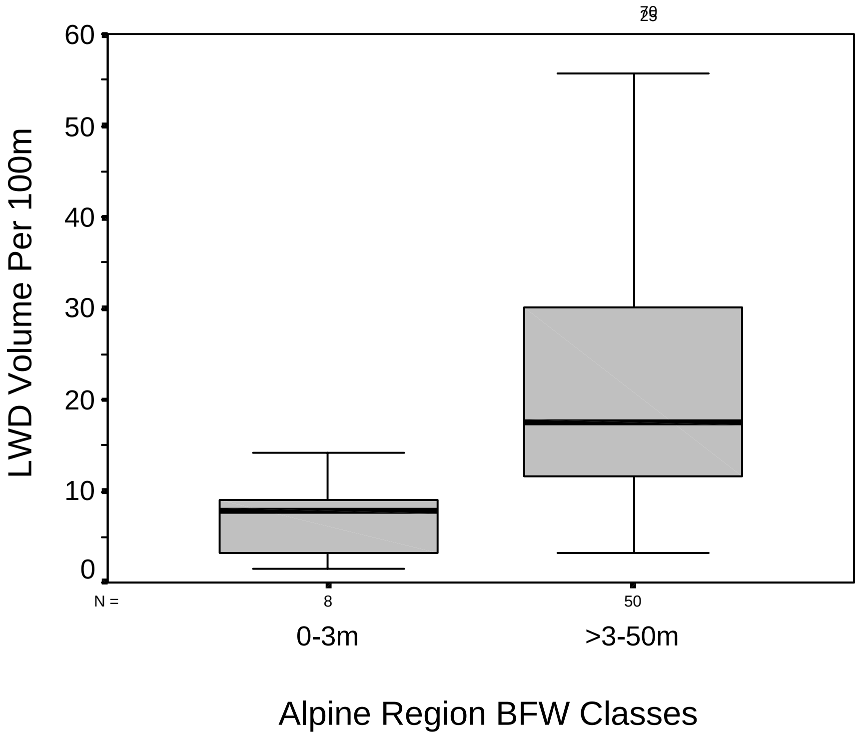
**Figure 39. The percentile distribution of the quantity of Key Pieces per 100m for the DF/PP Ecoregion. Further delineations of BFW groups could not be statistically identified. Statistical output can be found in Appendix A. 21.**



(data summary)

|  |  |  | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|---|
| westvol bfw class | 0-30m | Volume LWD/100m | 71.3 | 51.3 | 28.3 | 99.3 | 3842.8 | 62 | 285.4 |
|  | >30-100m | Volume LWD/100m | 184.8 | 92.8 | 43.9 | 317.3 | 40587.9 | 16 | 749.8 |

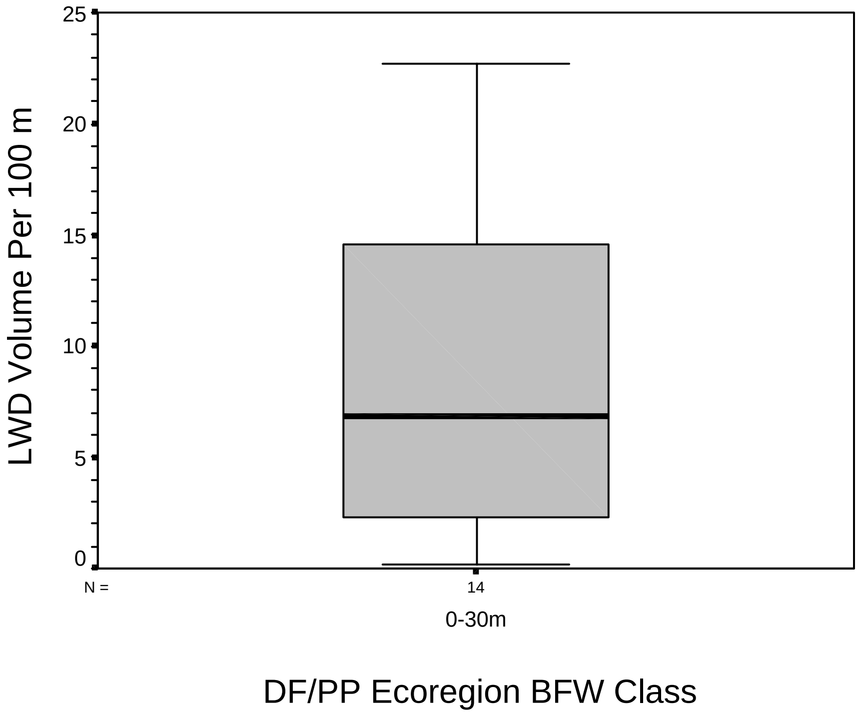
**Figure 40. The percentile distribution of the volume (in $m^3$) of LWD per 100m for the Western Washington Region. BFW classes are distinguished by significant differences between the means. Statistical output can be found in Appendix A. 21.**



(data summary)

| | | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|---|
| alpinevol bfw class | 0-3m | Volume LWD/100m | 7.1 | 8.3 | 3.1 | 9.8 | 17.5 | 8 | 12.7 |
| | >3-50m | Volume LWD/100m | 24.5 | 18.0 | 11.4 | 30.2 | 482.7 | 50 | 101.3 |

**Figure 41. The percentile distribution of the volume of LWD per 100m for the Alpine Region. BFW classes are distinguished by significant differences between the means. Statistical output can be found in Appendix A. 21.**



(data summary)

| | | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|---|
| eastvol bfw class | 0-30m | Volume LWD/100m | 12.0 | 6.9 | 2.3 | 14.7 | 235.3 | 14 | 59.0 |

**Figure 42. The percentile distribution of the volume of LWD per 100m for the DF/PP Ecoregion. Further delineations of BFW groups could not be statistically identified. Statistical output can be found in Appendix A. 1**

# 8. TABLES

**Table 1. WFPB definitions for "key pieces", as defined in Table F-4 of the 1997 Methods Manual.**

| **Bankfull Width (m)** | **Min. Vol. ($m^3$)** |
|---|---|
| 0-5 | 1 |
| >5-10 | 2.5 |
| >10-15 | 6 |
| >15-20 | 9 |

**Table 2. Drainage area, confinement, and origin classes used to classify surveyed stream reaches**

| Gradient (%) | Drainage area (km$^2$) | Confinement[1] | Origin |
|---|---|---|---|
| $\leq$1 | 0-2 | Confined | Snow melt/Rain |
| >1-2 | >2-4 | Moderately Confined | glacial melt |
| >2-4 | >4-8 | Unconfined | |
| >4-8 | >8-20 | | |
| >8-20 | >20-100 | | |
| 20 | >100 | | |

[1] As defined in Pleus and Schuett-Hames (1998)

**Table 3. The comparison of regression coefficients ($R^2$) between the independent variables of drainage area and bankfull width, grouped by ecoregions. Each dependent variable is in units of wood per 100 m of channel. Using a pair-sample t-test, the differences are significant ($P=0.05$).**

| | | **R-squared values** | |
|---|---|---|---|
| **Region[1]** | **Dependent Variable** | **Drainage area** | **Bankfull Width** |
| Western Washington | LWD Quantity | 0.13 | 0.20 |
| | LWD Volume | 0.07 | 0.10 |
| Alpine | LWD Quantity | 0.001 | 0.006 |
| | LWD Volume | 0.12 | 0.15 |
| DF/PP | LWD Quantity | 0.12 | 0.01 |
| | LWD Volume | 0.16 | 0.37 |
| All Data | LWD Quantity | 0.08 | 0.14 |
| | LWD Volume | 0.11 | 0.23 |

[1] Grouped ecoregions, as presented in Section 3.9.2

**Table 4. Date of timber origin due to stand-replacement fires for the SS/WH, SF/MH, and SAF ecoregions. Data are mostly from the Mt. Baker-Snoqualmie National Forest and the Olympic National Forest, courtesy of Jan Henderson, USFS (unpublished).**

| Year of Origin of Adjacent Timber | Basin/Region | Associated survey sites (see Appendix C) |
|---|---|---|
| 1508 | Blum Cr. | 275 |
| 1400 | Bogachiel R. | 76 |
| 1300 | NF. Sauk | 609 |
| 1300 | Sloan Cr. | 601, 602 |
| 1300 | Cadet Cr. | 605 |
| 1300 | Boulder R. (lower) | 71 |
| 1701 | Boulder R. (upper) | 72 |
| 1300 | Lost Cr. (NF. Sauk) | 610, 611 |
| 1508 | Cougar Cr | 604 |
| 1508 | White Chuck R. | 603 |
| 1300 | Suiattle R. | 612 |
| 1403 | Chinook R. | 23,24,24a,25 |
| 1701 | Washington Pass | 270,344-351 |
| Est. 1965[1] | Cutthroat Basin | 340, 342 |
| Est. 1965[1] | Upper Early Winters | 269 |
| 1228 | Paradise R. | 18 |
| 1503 | Fish Cr. | 15,16 |
| 1508 | Surprise Cr.(Stevens Pass) | 330-333 |
| 1508 | Mill Cr. (Stevens Pass) | 230 |
| 1628 | Lost Cr. (White R.) | 8 |
| 1308 | Huckleberry Cr. (White R.) | 720 |
| 1701 | Little Ranger and Dry Cr. | 0,1 |
| 1403 | Upper White R. | 80, 80a |
| 1403 | Frying Pan Cr. | 81 |
| 1403 | Klickitat R. (White R.) | 21,22 |
| 1890 | Crystal (White R.) | 32 |
| 1308 | Upper Ipsut (Carbon R.) | 12,14 |
| 1403 | Lower Ipsut (Carbon R.) | 8 |
| 1403 | Upper Ranger Cr. (Carbon R.) | 3, 3a |
| 1308 | Lower Ranger Cr. (Carbon R.) | 2 |
| 1403 | Falls Kr (Carbon R.) | 4 |
| 1503 | Sunrise Cr. (White R.) | 144 |
| Est. 1701[2] | N.F. Skokomish | 65 |
| <1100 | Quinault R. and Tributaries. | 515, 516, 277, 278,180 |
| <1100 | Queets R. | 78,79 |
| 1403 | Ohanepecosh Tributaries (Stevens Canyon entrance, Mt. R. NP) | A-1,2, B |
| 1503 | Ohanepecosh River and Tributaries, Mt. R. NP) | 26-33a |
| <1100 | Hoh R. | 77, 501-513 |

Source: Henderson et al. unpublished

[1] Based on nearest age-classified timber

[2] Based on tree whirl counts

**Table 5. Major floods recorded by unregulated (except the Yakima gage) downstream stream gages, based on a Log-Pearson Type III probability distribution. These floods document the magnitude of disturbance over the last 50-years that potentially influenced wood distributions recorded during the surveys. Units are in English to maintain consistency with USGS units. cfs= cubic feet per second.**

| Gage Number and Description | Period of Record | Basin Area (above) (mi$^2$) | 1-yr. Event (for ref.) (cfs) | Largest Event in the 10-years Prior to Surveys: | | Major Floods Within the Period of Record | | | Potentially Affected Sub-Basins Upstream of Gage [1] |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Year | Ret. Per. | Year | Q (cfs) | Return Period | |
| White Chuck 12186000 | 1917-1997 | 152 | 1,882 | 1990 | 24 | 1980 | 40,100 | 102 | Sauk |
| | | | | | | 1949 | 30,200 | 37 | |
| | | | | | | 1921 | 29,100 | 33 | |
| Greenwater 12097500 | 1911-1997 | 73.5 | 211 | 1996 | 31 | 1977 | 10,500 | 307 | White, Huckleberry, Klickitat |
| | | | | | | 1996 | 5,900 | 31 | |
| | | | | | | 1959 | 5,360 | 25 | |
| Skykomish 12134500 | 1930-1997 | 535 | 5,429 | 1990 | 32 | 1990 | 102,000 | 32 | Surprise |
| | | | | | | 1980 | 90,100 | 21 | |
| | | | | | | 1933 | 80,700 | 19 | |
| Carbon nr Fairfax 12094000 | 1930-1997 | 78.9 | 449 | 1990 | 53 | 1990 | 13,000 | 53 | Ranger, Falls |
| | | | | | | 1996 | 12,000 | 37 | |
| | | | | | | 1933 | 11,000 | 25 | |
| Baker R. at Concrete 12193500 | 1910-1997 | 297 | 590 | 1995 | 6 | 1962 | 36,600 | 15 | Baker, Blum |
| | | | | | | 1949 | 35,200 | 12 | |
| | | | | | | 1979 | 31,200 | 8 | |
| Nisqually R. ab Alder 12082500 | 1942-1997 | 133 | 778 | 1996 | 80 | 1996 | 21,200 | 80 | Tahoma, Paradise |
| | | | | | | 1997 | 17,100 | 31 | |
| | | | | | | 1974 | 15,000 | 18 | |
| Cowlitz 14226500 | 1911-1999 | 287 | 1,993 | 1996 | 23 | 1933 | 36,600 | 31 | Ohanepecosh, Chinook |
| | | | | | | 1977 | 36,200 | 30 | |
| | | | | | | 1959 | 34,300 | 25 | |
| Queets nr Clearwater 12040500 | 1931-1998 | 445 | 21,285 | 1999 | 37 | 1999 | 133,000 | 37 | Queets, Hoh, Bogachiel |
| | | | | | | 1935 | 130,400 | 33 | |
| | | | | | | 1955 | 118,400 | 22 | |
| Quinault at Lk 12039500 | 1909-1998 | 264 | 3,616 | 1997 | 24 | 1909 | 52,600 | 45 | Quinault, N.F. Quinault, |
| | | | | | | 1955 | 50,200 | 34 | |
| | | | | | | 1997 | 46,400 | 24 | |
| N.F. Skokomish 12056500 | 1924-1999 | 57.2 | 1,013 | 1994 | 13 | 1934 | 27,000 | >1000 | N.F. Skokomish |
| | | | | | | 1949 | 24,200 | 111 | |
| | | | | | | 1986 | 16,500 | 21 | |
| Yakima at Umtanum[2] 12484500 | 1906-1998 | 1594 | 1,433 | 1996 | 33 | 1906 | 41,000 | >1000 | Cle Elum, Cooper, Waptus |
| | | | | | | 1933 | 32,200 | 75 | |
| | | | | | | 1948 | 27,800 | 36 | |
| Wenatchee at Peshastin 12459000 | 1929-2000 | 1000 | 1,630 | 1995 | >100 | 1995 | 41,300 | >1000 | Mission, Icicle, Nason, Ingalls, Wenatchee |
| | | | | | | 1990 | 40,000 | >1000 | |
| | | | | | | 1948 | 32,300 | >1000 | |
| Stehekin 12452800 | 1911-1998 | 321 | 1,311 | 1995 | >100 | 1995 | 20,900 | >1000 | Bridge, Copper |
| | | | | | | 1948 | 18,900 | 115 | |
| | | | | | | 1949 | 18,400 | 85 | |
| Methow at Pateros 12449950 | 1948-1976 & 1998-2000 | 1772 | 392 | 1999 | 1[3] | 1948 | 46,700 | 61 | Early Winters, Porcupine, Cutthroat |
| | | | | | | 1972 | 28,800 | 9 | |
| | | | | | | 1974 | 24,000 | 6 | |
| Entiat at Ardenvoir 12452800 | 1958-1998 | 203 | 100 | 1997 | 3 | 1972 | 6,430 | 89 | Entiat, Anthem |
| | | | | | | 1974 | 5,540 | 22 | |
| | | | | | | 1983 | 4,670 | 8 | |

[1] Or an adjacent Basin, if a gage data was unavailable. See Appendix C for further detail of associated basins and surveyed sites.

[2] Regulated by upstream reservoirs

[3] Gage out of service from 1976-1999

**Table 6. Summary of findings in this study scaled for comparison to existing management targets of instream wood. Comparisons are made to the (A) NMFS "Properly Functioning Condition for instream wood, (B) the WFPB diagnostic for "good" habitat condition used in State Watershed Analysis for LWD quantity, and (C) and key pieces.**

### A. Pieces[1] per Mile (NMFS)

| **Source** | **Bankfull Width Class[2]** | **Western Washington[3]** | **Eastern Washington[4]** |
|---|---|---|---|
| *This study*:<br>Range[5]/Median of data | 0-40 m | 4.0-40.5/11.5 | |
| | >40-100 m | 18.9-128.5/84.0 | |
| | 0-5 m | | 0-24.9/5.0 |
| | >5-50 m | | 16.2-70.0/42.5 |
| NMFS (1996): "Properly Functioning Condition" | all channels evaluated for salmonid habitat | 80 | 20 |

[1] Qualifying pieces are 50 ft. in length and 2 ft diameter for W.WA, and 35 ft. in length and 1 ft diameter for E.WA
[2] Based on the data partitions expressed in Figure 22[B] (W.WA), and derived from the scatter plot Figure 23 (E.WA)
[3] Combined SS/WH and SF/MH ecoregions
[4] Combined DF/PP and GF ecoregions
[5] Defined by the 25th and 75th percentiles

### B. LWD Pieces[1] per Channel Width (WFPB)

| **Source** | **Bankfull Width Class[2]** | **Western Washington[3]** | **Alpine Region[4]** | **Eastern Washington[5]** |
|---|---|---|---|---|
| *This study*:<br>Range[6]/Median of data | 0-3 m | 0.3-0.9/0.5 | 0.32-0.8/0.5 | 0.1-0.5/0.2 |
| | >3-12 m | 1.5-4.8/3.6 | 1.25-3.93/2.2 | 0.6-0.8/0.6 |
| | >12-20 m | 2.7-8.3/5.4 | 3.4-9.1/5.0 | 0.4-6.1/3.25 |
| WFPB (1997): Diagnostic rating for a "good" condition | 0-20 m | 2 | 2 | 2 |

[1] Qualifying pieces are 2 m in length and 0.1 m at midpoint diameter
[2] Based on the data partitions expressed in Figure 26[B]
[3] Combined SS/WH and SF/MH ecoregions
[4] Combined SAF and GF ecoregions
[5] DF/PP ecoregion
[6] Defined by the 25th and 75th percentiles

### C. Key Pieces[1] per Channel Width (WFPB)

| **Source** | **BFW Class** | **Western WA** |
|---|---|---|
| *This study*:<br>Range[2]/Median of data | 0-10 m | 0.15-0.6/0.33 |
| | >10-20 m | 0.1-0.33/0.18 |
| WFPB (1997) Diagnostic rating for a "good" condition | 0-10 m | >0.3 |
| | 10-20 m | >0.5 |

[1] Minimum qualifying key pieces volumes vary according to bankfull width (see Table 9)
[2] Defined by the 25th and 75th percentiles

**Table 7. Summary of wood densities for riparian tree species commonly encountered during surveys. The percent occurrence of each species in each ecoregion, based on the survey data, was used to weight the mean density of wood potentially recruited into the channel. The results suggest that there is no significant difference in riparian wood density among ecoregions, or between eastern and western Washington regions. The complete statistical output is provided in Appendix A. 18**

|  |  |  | **Mean fraction of occurrence within riparian stands by ecoregion*** |  |  |  |  |
|---|---|---|---|---|---|---|---|
| **Tree Species** | **Species Name** | **Wood Dry Density ($kg/m^3$)**** | **DF/PP** | **GF** | **SAF** | **SF/MH** | **SS/WH** |
| Black Cottonwood | *Populus trichocarpa* | 433 | 2.0% | 0.6% | 0.0% | 1.2% | 0.0% |
| Red Alder | *Alnus rubra* | 370 | 1.0% | 0.2% | 0.0% | 5.4% | 13.4% |
| Maple | *Acer rubrum* | 547 | 6.0% | 0.6% | 0.0% | 0.7% | 5.2% |
| Silver Fir | *Abies amabilis* | 416 | 0.0% | 34.2% | 10.4% | 22.6% | 0.6% |
| Western Red Cedar | *Thuja plicata* | 344 | 0.2% | 5.0% | 0.0% | 8.2% | 5.0% |
| Western Hemlock | *Tsuga heterophylla* | 420 | 1.5% | 0.1% | 1.1% | 16.3% | 36.2% |
| Mountain Hemlock | *Tsuga mertensiana* | 481 | 2.0% | 11.9% | 13.3% | 29.9% | 16.3% |
| Douglas Fir | *Pseudotsuga menziesii* | 513 | 57.8% | 9.3% | 2.7% | 10.9% | 6.3% |
| Sitka Spruce | *Picea sitchensis* | 420 | 0.0% | 0.0% | 0.0% | 0.1% | 15.8% |
| Engleman Spruce | *Picea englemanni* | 370 | 0.0% | 1.6% | 5.8% | 0.0% | 0.0% |
| Subalpine Fir | *Abies lasiocarpa* | 321 | 0.0% | 0.1% | 48.3% | 0.0% | 0.0% |
| Grand Fir | *Abies grandis* | 411 | 2.9% | 23.7% | 3.1% | 1.4% | 0.0% |
| Lodgepole Pine | *Pinus contorta* | 431 | 0.0% | 2.4% | 3.2% | 0.0% | 0.0% |
| Ponderosa Pine | *Pinus ponderosa* | 380 | 22.2% | 0.3% | 0.0% | 0.0% | 0.0% |
| Noble Fir | *Abies procera* | 370 | 0.0% | 8.6% | 11.4% | 1.4% | 0.0% |

* Based on riparian survey data. Note: insignificant quantities of miscellaneous species (occurrence of <0.1%) were not included in these fractions.

**Sources: Alden (1997); Simpson and TenWolde (1999); Seely (2001), USDA Forest Service (1987); Haygreen and Bowyer (1996); Forest Products Laboratory (1999).

**Table 8. Summary of equations describing the relationship of LWD quantity and volume per unit channel width (as a measure of channel length) to bankfull width for each region. In both cases presented below, x is the bankfull width in meters. The probabilities of all regressions that the slope is equal to zero is <0.01 unless otherwise indicated. Statistical output is provided in Appendix A.20.**

| Ecoregion | Equation | $R^2$ (adjusted) | n |
|---|---|---|---|
| **Y= The Predicted Number of LWD Pieces per Unit Channel Width** | | | |
| DF/PP* | $Y=0.16x^{0.88}$ | 0.43 | 14 |
| Alpine | $Y=0.30x^{0.99}$ | 0.59 | 58 |
| Western WA | $Y=0.76x^{2.22}$ | 0.74 | 78 |
| | | | |
| **Y= The Predicted Volume of LWD ($m^3$) per Unit Channel Width** | | | |
| DF/PP | $Y=0.014x^{1.94}$ | 0.69 | 14 |
| Alpine | $Y=0.065x^{1.44}$ | 0.65 | 58 |
| Western WA | $Y=0.027x^{1.30}$ | 0.63 | 78 |

*(p=0.009)

**Table 9. Summary of ranges for instream wood quantity and volumes according to BFW classes and region based on the box plots in Figure 34 to Figure 42. Wood quantities and volumes greater than the 75th percentile of the distribution are recommended as a target for "Good" conditions, the range between the 25th and 75th percentiles are recommended as a target for "Fair" conditions, and below the 25th percentile is recommended as a definition of "Poor" conditions. LWD is defined as a piece >10 cm diameter and >2 m in length. Volumes are estimated by Πr$^2$L where L is the piece length, and r is the piece radius at the mid-point. Statistical output is provided in Appendix A. 21.**

**LWD Piece Quantity: Number of Pieces Per 100 m of Channel Length**

| Region | BFW Class | Good | Fair | Poor |
|---|---|---|---|---|
| Western WA | 0-6 m | >38 | 26-38 | <26 |
| | >6-30 m | >63 | 29-63 | <29 |
| | >30-100 m | >208 | 57-208 | <57 |
| Alpine | >0-3 m | >28 | 15-28 | <15 |
| | >3-30 m | >56 | 25-56 | <25 |
| | >30-50 m | >63 | 22-63 | <22 |
| DF/PP | 0-6 m | >29 | 5-29 | <5 |
| | >6-30 m | >35 | 5-35 | <5 |

**LWD Volume: Cubic Meters Per 100 m of Channel Length**

| Region | BFW Class | Good | Fair | Poor |
|---|---|---|---|---|
| Western WA | 0-30 m | >99 | 28-99 | <28 |
| | >30-100 m | >317 | 44-317 | <44 |
| Alpine | >0-3 m | >10 | 3-10 | <3 |
| | >3-50 m | >30 | 11-30 | <11 |
| DF/PP | 0-30 m | >15 | 2-15 | <2 |

**Key Piece Quantity: Number of Pieces Per 100 m of Channel Length**

| Region | BFW Class | Good | Fair | Poor |
|---|---|---|---|---|
| Western WA | 0-10 m | >11 | 4-11 | <4 |
| | >10-100 m | >4 | 1-4 | <1 |
| Alpine | >0-15 m | >4 | 0.5-4 | <0.5 |
| | >15-50 m | >1 | 0.5-1 | <0.5 |
| DF/PP | 0-30 m | >2 | 0.5-2 | <0.5 |

**Minimum Piece Volume to Define Key Pieces (all regions)**

| Bankfull Width Class | Minimum Piece Volume (m$^3$) |
|---|---|
| 0-5 m | 1* |
| >5-10 m | 2.5* |
| >10-15 m | 6* |
| >15-20 m | 9* |
| >20-30 m | 9.75 |
| >30-50 m | 10.5** |
| >50-100 m | 10.75** |

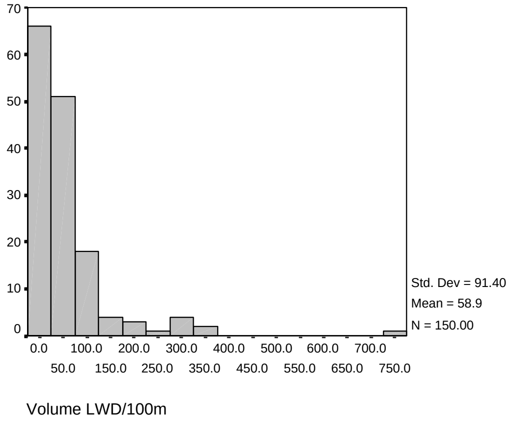
* Existing WFPB (1997) definitions ** Wood piece must have an attached root wad

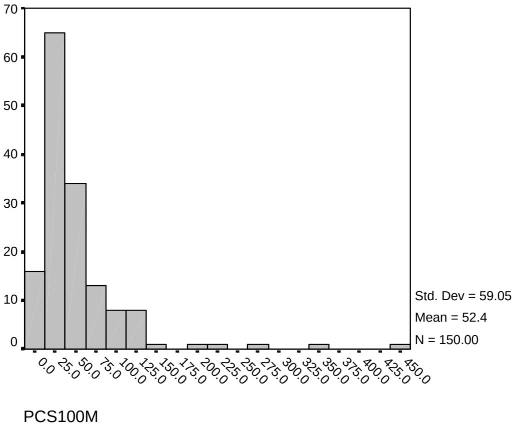
# 9. APPENDICES

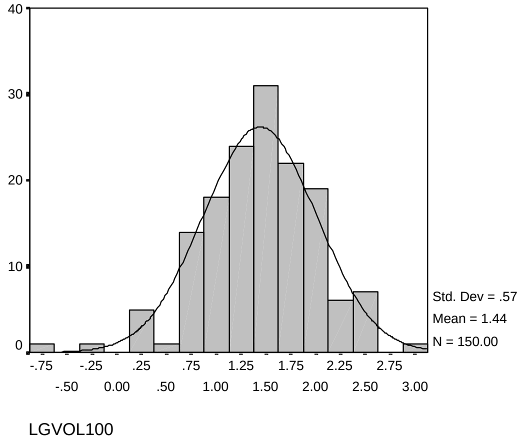
# *9.1.* Appendix A. Statistical Tests and Output

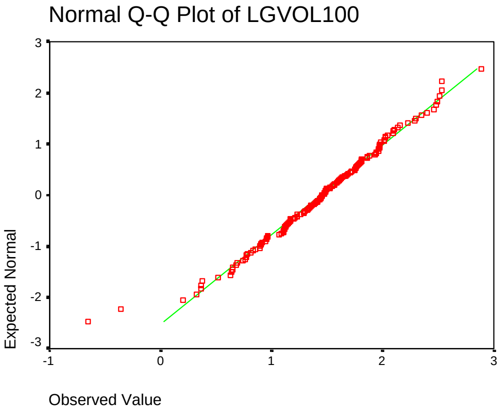
### Appendix A. 1. The Normalization of data.

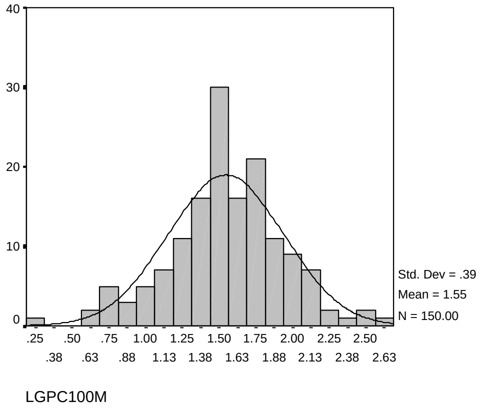
The first two histograms below illustrate the log-normal distributions of volume and quantity of pieces per 100 m of channel length. The histograms following these two illustrate the near-normal distribution after a $\log_{10}$ transformation. In addition to volume and quantity, the normalization of bankfull width (see below), basal area, drainage area, piece lengths and piece volumes were also conducted; however, a few parameters such as mean tree diameter did not require normalization (see below).



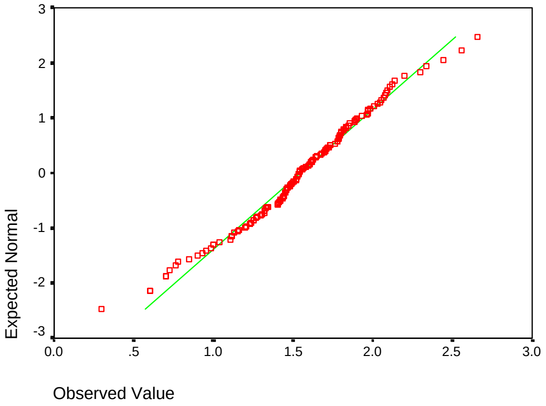


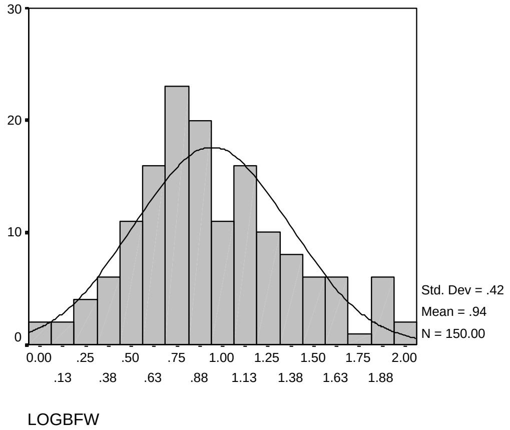


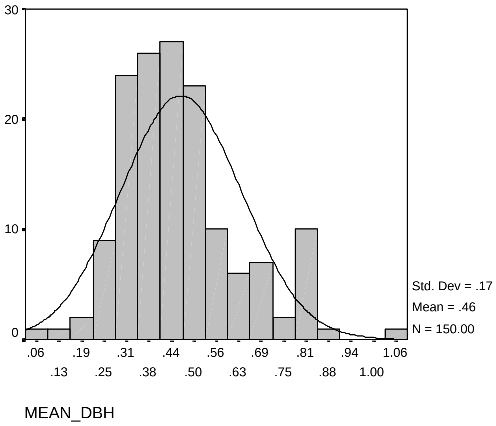




Normal Q-Q Plot of LGPC100M







**Appendix A. 2. The Influence of Fire History/Timber age upon Instream LWD.**

Regressions for the relationships of quantities and volumes ($m^3$) of LWD per 100 m with year of origin for adjacent timber. The independent variable presented in years represents ages of timber, based on regeneration following a stand-replacement fire. $\beta_1$ = regression slope.

The relationship of LWD Volume ($m^3$) to timber age (year of origin)

$H_o$: $\beta_1=0$

$H_A$: $\beta_1\neq 0$

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 68789.828 | 1 | 68789.828 | 6.404 | .013 |
| | Residual | 1009715.797 | 94 | 10741.657 | | |
| | Total | 1078505.625 | 95 | | | |

a Predictors: (Constant), Date of Stand Origin

b Dependent Variable: LWD Vol./100 m (cu. m)

Coefficients

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 248.433 | 66.442 | | 3.739 | .000 |
| | Date of Stand Origin | -.118 | .047 | -.253 | -2.531 | .013 |

a Dependent Variable: LWD Vol./100 m (cu. m)

**Conclusion: Do not reject Ho: p=0.013**

Comparison of regression slopes among ecoregions for the relationship of LWD vol./100 m to volume and year of origin for adjacent timber. $\beta_1$ = regression slope and $\beta_0$ = regression intercept.

$H_o$: $\beta_1=\beta_2$

$H_A$: $\beta_1\neq \beta_2$

$H_o$: $\beta_0=\beta_0$

$H_A$: $\beta_0\neq \beta_0$

Using the SAF ecoregion for the base of comparison:

Coefficients

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | .379 | 1.087 | | .349 | .728 |
| | Date of Stand Origin | 5.394E-04 | .001 | .255 | .850 | .398 |
| | SFMH_REG | 3.303 | 1.389 | 3.152 | 2.379 | .019 |
| | SSWH_REG | 2.183 | 1.171 | 2.268 | 1.864 | .066 |
| | SFMHINTR | -1.963E-03 | .001 | -2.692 | -2.244 | .027 |
| | SSWHINTR | -1.115E-03 | .001 | -1.525 | -1.555 | .124 |

a Dependent Variable: Log LWD Vol./100 m

**Conclusion: Do not reject the Ho: that the SS/WH ecoregion is significantly different from the SAF ecoregion for volume of LWD/100 with decreasing timber age p=0.124 (slope) and p=0.066 (intercept), but reject the Ho: between the SF/MH and SAF ecoregions: p=0.027 (slope) p=0.019 (intercept).**

Using the SF/MH ecoregion for the base of comparison:

Coefficients

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 3.682 | .864 | | 4.262 | .000 |
| | Date of Stand Origin | -1.423E-03 | .001 | -.672 | -2.363 | .020 |
| | SAF_REG | -3.303 | 1.389 | -2.679 | -2.379 | .019 |
| | SSWH_REG | -1.120 | .968 | -1.164 | -1.158 | .250 |
| | SAF_INTR | 1.963E-03 | .001 | 2.730 | 2.244 | .027 |

| | | | | | |
|---|---|---|---|---|---|
| SSWHINTR | 8.475E-04 | .001 | 1.159 | 1.230 | .222 |

a Dependent Variable: Log LWD Vol./100 m

**Conclusion: Do not reject the Ho: that the SS/WH ecoregion is significantly different from the SF/MH ecoregion for volume of LWD/100 with decreasing timber age p=0.222 (slope) and p=0.250 (intercept).**

The relationship of LWD Quantity/100 m to timber age (year of origin)

$H_o$: $\beta_1$=0

$H_A$: $\beta_1 \neq 0$

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 7715.687 | 1 | 7715.687 | 1.632 | .205 |
| | Residual | 444281.393 | 94 | 4726.398 | | |
| | Total | 451997.080 | 95 | | | |

a Predictors: (Constant), Date of Stand Origin

b Dependent Variable: Quantity of LWD/100 m

Coefficients

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 120.155 | 44.073 | | 2.726 | .008 |
| | Date of Stand Origin | -3.944E-02 | .031 | -.131 | -1.278 | .205 |

a Dependent Variable: Quantity of LWD/100 m

**Conclusion: Do not reject the Ho (p=0.205)**

**Appendix A. 3. Flood Effects upon Instream LWD**

Comparison of regression slopes for quantities and volumes ($m^3$) of LWD per 100 m between channels with and without recent major floods (>25-year return period) to bankfull width (m). Both variables are $\log_{10}$-transformed to achieve a normal distribution. $\beta_1$ = regression slope and $\beta_0$ = regression intercept

LWD Quantity per 100 m between streams with and without recent floods

$H_o$: $\beta_1$=$\beta_2$

$H_A$: $\beta_1 \neq \beta_2$

$H_o$: $\beta_0$=$\beta_0$

$H_A$: $\beta_0 \neq \beta_0$

Coefficients

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 1.216 | .173 | | 7.028 | .000 |

| | B | Std. Error | Beta | t | Sig. |
|---|---|---|---|---|---|
| LOGBFW | .404 | .157 | .436 | 2.574 | .011 |
| FLOODYES | 8.586E-03 | .192 | .010 | .045 | .964 |
| FDYESINT | -8.311E-02 | .177 | -.117 | -.469 | .640 |

a Dependent Variable: LOGPC100

Conclusion: Do not reject both Ho: p=0.640 (slope) p=0.964 (intercept)

LWD Volume per 100 m between streams with and without recent floods

$H_o: \beta_1=\beta_2$

$H_A: \beta_1 \neq \beta_2$

$H_o: \beta_0=\beta_0$

$H_A: \beta_0 \neq \beta_0$

Coefficients

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 1.107 | .233 | | 4.747 | .000 |
| | LOGBFW | .558 | .211 | .418 | 2.638 | .009 |
| | FLOODYES | -.293 | .259 | -.233 | -1.133 | .259 |
| | FDYESINT | 4.593E-02 | .239 | .045 | .192 | .848 |

a Dependent Variable: LGVOL100

**Conclusion: Do not reject both Ho: p=0.848 (slope) p=0.259 (intercept)**

**Appendix A. 4. Tests to compare the means between the SS and WH ecoregions. The response variable data are normalized with a log10 transformation in order to achieve normality in all cases except for mean tree diameter.**

For each test:

$H_o: \mu_1 = \mu_2$

$H_A: \mu_1 \neq \mu_2$

ANOVA

TREE_DBH (mean tree diameter)

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .803 | 1 | .803 | 33.342 | .000 |
| Within Groups | 1.131 | 47 | 2.407E-02 | | |
| Total | 1.934 | 48 | | | |

**Conclusion: Reject Ho at $P_{0.05}$<0.001**

ANOVA

LOGBASAL

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 6.902E-03 | 1 | 6.902E-03 | .153 | .697 |
| Within | 2.116 | 47 | 4.502E-02 | | |

| | | | | | |
|---|---|---|---|---|---|
| Groups | | | | | |
| Total | 2.123 | 48 | | | |

**Conclusion: Do not reject Ho at $P_{0.05}$=0.697**

ANOVA
LGPCS100

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 4.357E-02 | 1 | 4.357E-02 | .243 | .624 |
| Within Groups | 8.433 | 47 | .179 | | |
| Total | 8.477 | 48 | | | |

**Conclusion: Do not reject Ho at $P_{0.05}$=0.624**

ANOVA
LGVOL100

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .861 | 1 | .861 | 4.091 | .051 |
| Within Groups | 9.895 | 47 | .211 | | |
| Total | 10.755 | 48 | | | |

**Conclusion: Do not reject Ho at $P_{0.05}$=0.051**

Comparison of regression slopes between ecoregions for the relationship of pieces of LWD per channel width to bankfull width (log-transformed)

$H_o$: $\beta_1=\beta_2$

$H_A$: $\beta_1\neq \beta_2$

Coefficients

| | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|
| Model | B | Std. Error | Beta | | |
| 1 (Constant) | -.642 | .147 | | -4.355 | .000 |
| LOG_BFW | 1.290 | .113 | .801 | 11.432 | .000 |
| WH_eco | .308 | .113 | .228 | 2.728 | .009 |
| WH_inter | -.237 | .126 | -.146 | -1.878 | .067 |

a Dependent Variable: LOGPCSCW

**Conclusion: Do not reject Ho at $P_{0.05}$=0.067**

Comparison of regression slopes between ecoregions for the relationship of LWD volume ($m^3$) per channel width to bankfull width (log-transformed)

$H_o$: $\beta_1=\beta_2$

$H_A$: $\beta_1\neq \beta_2$

Coefficients

| Unstandardized Coefficient | | Standardized Coefficient | t | Sig. |
|---|---|---|---|---|

| Model | s<br>B | Std. Error | s<br>Beta | | |
|---|---|---|---|---|---|
| 1 (Constant) | -.550 | .199 | | -2.763 | .008 |
| LOG_BFW | 1.237 | .174 | .769 | 7.118 | .000 |
| SS_ECO | 7.820E-02 | .214 | .048 | .365 | .717 |
| SS_INTER | .141 | .170 | .132 | .829 | .411 |

a  Dependent Variable: LGVOLCW

**Conclusion: Do not reject Ho at $P_{0.05}$=0.411**

**Appendix A. 5**

Regression of the relationship between LWD volume ($m^3$) per 100 m and the number of LWD per 100 m.  Both the response and predictor variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1 = 0$

$H_A$: $\beta_1 \neq 0$

Variables Entered/Removed

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | LGPC100 m | . | Enter |

a  All requested variables entered.

b  Dependent Variable: LGVOL100

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .722 | .522 | .518 | .3958 |

a  Predictors: (Constant), LGPC100 m

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 25.282 | 1 | 25.282 | 161.364 | .000 |
| | Residual | 23.188 | 148 | .157 | | |
| | Total | 48.469 | 149 | | | |

a  Predictors: (Constant), LGPC100 m

b  Dependent Variable: LGVOL100

Coefficients

| | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|
| Model | B | Std. Error | Beta | | |
| 1 (Constant) | -.178 | .131 | | -1.355 | .177 |
| LGPC100 | 1.046 | .082 | .722 | 12.703 | .000 |

m

a Dependent Variable: LGVOL100

**Conclusion: Reject Ho at $P_{0.05}$<0.001**

## Appendix A. 6

Regression of the relationship between drainage basin size (km$^2$) and bankfull width (m) for western Washington. Both the response and predictor variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1 \neq 0$

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 11.870 | 1 | 11.870 | 330.907 | .000 |
| | Residual | 2.726 | 76 | 3.587E-02 | | |
| | Total | 14.597 | 77 | | | |

a Predictors: (Constant), LOGDRAIN

b Dependent Variable: LOGBFW

Coefficients

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |
| 1 | (Constant) | .514 | .037 | | 13.748 | .000 |
| | LOGDRAIN | .551 | .030 | .902 | 18.191 | .000 |

a Dependent Variable: LOGBFW

**Conclusion: Reject Ho at $P_{0.05}$<0.001**

Regression of the relationship between drainage basin size (km$^2$) and bankfull width (m) for eastern Washington. Both the response and predictor variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1 \neq 0$

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 6.397 | 1 | 6.397 | 142.760 | .000 |
| | Residual | 3.137 | 70 | 4.481E-02 | | |
| | Total | 9.534 | 71 | | | |

a Predictors: (Constant), LOGDRAIN
b Dependent Variable: LOGBFW

Coefficients

| Model | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|
| 1 (Constant) | .448 | .039 | | 11.557 | .000 |
| LOGDRAIN | .433 | .036 | .819 | 11.948 | .000 |

a Dependent Variable: LOGBFW

**Conclusion: Reject Ho at $P_{0.05}<0.0001$**

Testing for differences in regression slopes between eastern and western Washington for the relationship between basin size and bankfull width. Both the response and predictor variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=\beta_2$
$H_A$: $\beta_1\neq\beta_2$

ANOVA

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| 1 Regression | 20.990 | 3 | 6.997 | 174.228 | .000 |
| Residual | 5.863 | 146 | 4.016E-02 | | |
| Total | 26.854 | 149 | | | |

a Predictors: (Constant), LOGBASIN, WWAREG, WWA_INTR
b Dependent Variable: LOGBFW

Coefficients

| Model | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|
| 1 (Constant) | .448 | .037 | | 12.209 | .000 |
| WWAREG | 6.643E-02 | .054 | .078 | 1.232 | .220 |
| WWA_INTR | .118 | .047 | .200 | 2.515 | .013 |
| LOGBASIN | .433 | .034 | .722 | 12.622 | .000 |

a Dependent Variable: LOGBFW

**Conclusion: Reject Ho at $P_{0.05}=0.013$**

## Appendix A. 7

The relationship of channel cross sectional area to bankfull width. Both the response and predictor variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=\beta_2$

$H_A$: $\beta_1\neq\beta_2$

```
Model Summary
        Model          R   R SquareAdjusted R   Std. Error
                                       Square       of the
                                                  Estimate
            1       .965        .931      .931       .1648
a  Predictors: (Constant), LOGBFW

ANOVA
        Model                Sum of         df        Mean           F          Sig.
                            Squares                 Square
            1  Regressio     54.409          1      54.409    2003.867          .000
                       n
                Residual      4.019        148  2.715E-02
                   Total     58.428        149
a  Predictors: (Constant), LOGBFW
b  Dependent Variable: LOGX_S

Coefficients
                          Unstandar              Standardiz            t          Sig.
                               dized                     ed
                          Coefficient           Coefficient
                                    s                     s
        Model                       B  Std. Error      Beta
                  (Constant)     -.760       .033                -23.142          .000
                    LOGBFW       1.423       .032      .965       44.765          .000
a  Dependent Variable: LOGX_S
```

**Conclusion: Reject Ho at $P_{0.05}<0.001$**

**Back-transformed equation: $Y=0.1737x^{1.423}$**

## Appendix A. 8

# Pieces LWD per 100 m vs. bankfull width (m)

Pieces per 100 m vs. BFW (all ecoregions)

The response and predictor variable data are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1\neq 0$

```
Variables Entered/Removed
        Model  Variables  Variables     Method
                 Entered    Removed
            1  LOGBFW             .      Enter
```

a All requested variables entered.
b Dependent Variable: LGPC100 m

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .376 | .141 | .136 | .3661 |

a Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 3.267 | 1 | 3.267 | 24.377 | .000 |
| | Residual | 19.835 | 148 | .134 | | |
| | Total | 23.102 | 149 | | | |

a Predictors: (Constant), LOGBFW
b Dependent Variable: LGPC100 m

Coefficients

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |
| 1 | (Constant) | 1.218 | .073 | | 16.693 | .000 |
| | LOGBFW | .349 | .071 | .376 | 4.937 | .000 |

a Dependent Variable: LGPC100 m

**Conclusion: Reject Ho at $P_{0.05}$<0.001**

### Appendix A. 9

Volume of LWD per 100 m vs. bankfull width (m)

Volume ($m^3$) per 100 m vs. BFW (all ecoregions)

The response and predictor variable data are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1 \neq 0$

Variables Entered/Removed

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | LOGBFW | . | Enter |

a All requested variables entered.
b Dependent Variable: LGVOL100

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the |
|---|---|---|---|---|

| | | | | Estimate |
|---|---|---|---|---|
| 1 | .478 | .228 | .223 | .5028 |

a  Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 11.059 | 1 | 11.059 | 43.751 | .000 |
| | Residual | 37.410 | 148 | .253 | | |
| | Total | 48.469 | 149 | | | |

a  Predictors: (Constant), LOGBFW
b  Dependent Variable: LGVOL100

Coefficients

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |
| 1 | (Constant) | .835 | .100 | | 8.335 | .000 |
| | LOGBFW | .642 | .097 | .478 | 6.614 | .000 |

a  Dependent Variable: LGVOL100

**Conclusion: Reject Ho at $P_{0.05}<0.001$**

Volume ($m^3$) per 100 m vs. BFW (eastern Washington ecoregions)

The response and predictor variable data are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1 \neq 0$

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 1.329 | 1 | 1.329 | 7.014 | .010 |
| | Residual | 14.401 | 76 | .189 | | |
| | Total | 15.730 | 77 | | | |

a  Predictors: (Constant), LOGBFW
b  Dependent Variable: LGVOL100
c  Selecting only cases for which EASTWA =  1.00

Coefficients

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |
| 1 | (Constant) | 1.433 | .132 | | 10.892 | .000 |
| | LOGBFW | .302 | .114 | .291 | 2.648 | .010 |

a  Dependent Variable: LGVOL100
b  Selecting only cases for which EASTWA =  1.00

**Conclusion: Reject Ho at $P_{0.05}$=0.010**

### Volume ($m^3$) per 100 m vs. BFW (western Washington ecoregions)

The response and predictor variable data are $\log_{10}$ transformed in order to achieve normality.
$H_o$: $\beta_1=0$
$H_A$: $\beta_1\neq 0$

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 3.644 | 1 | 3.644 | 22.692 | .000 |
| | Residual | 8.351 | 52 | .161 | | |
| | Total | 11.996 | 53 | | | |

a Predictors: (Constant), LOGBFW
b Dependent Variable: LGVOL100
c Selecting only cases for which EASTWA = .00

Coefficients

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |
| 1 | (Constant) | .463 | .130 | | 3.550 | .001 |
| | LOGBFW | .667 | .140 | .551 | 4.764 | .000 |

a Dependent Variable: LGVOL100
b Selecting only cases for which EASTWA = .00

**Conclusion: Reject Ho at $P_{0.05}<0.001$**

Comparison of regression slopes between eastern and western Washington for volume (m3) per 100 m
$H_o$: $\beta_1=\beta_2$
$H_A$: $\beta_1\neq \beta_2$

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 21.923 | 3 | 7.308 | 41.112 | .000 |
| | Residual | 22.752 | 128 | .178 | | |
| | Total | 44.674 | 131 | | | |

a Predictors: (Constant), WWAINT, LOGBFW, WESTWA
b Dependent Variable: LGVOL100

Coefficients

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |
| 1 | (Constant) | 1.433 | .127 | | 11.245 | .000 |

```
                LOGBFW       .302       .110       .223     2.734        .007
                WESTWA      -.970       .187      -.820    -5.180        .000
                WWAINT       .365       .184       .304     1.983        .049
a  Dependent Variable: LGVOL100
```

**Conclusion: Reject Ho at $P_{0.05}$=0.049**

**Appendix A. 10**

Regression of mean LWD volume per piece by bankfull width for all ecoregions. The response and predictor variable data are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1\neq 0$

```
Variables Entered/Removed
      Model  Variables  Variables    Method
               Entered  Removed
          1  LOGBFW             .     Enter
a  All requested variables entered.
b  Dependent Variable: LGMPCVOL

Model Summary
      Model          R   R Square Adjusted R  Std. Error
                                      Square      of the
                                                Estimate
          1       .316       .100       .094       .3766
a  Predictors: (Constant), LOGBFW

ANOVA
      Model                Sum of         df        Mean          F        Sig.
                          Squares                 Square
          1  Regressio      2.329          1       2.329     16.421        .000
             n
               Residual    20.988        148        .142
                  Total    23.316        149
a  Predictors: (Constant), LOGBFW
b  Dependent Variable: LGMPCVOL

Coefficients
                        Unstandar             Standardiz          t        Sig.
                             dized                    ed
                        Coefficient           Coefficient
                                 s                     s
      Model                      B  Std. Error      Beta
          1 (Constant)        -.384       .075                -5.121        .000
                LOGBFW         .294       .073       .316      4.052        .000
a  Dependent Variable: LGMPCVOL
```

**Conclusion: Reject Ho at $P_{0.05}$<0.001**

**Appendix A. 11**

Three methods found in the literature of expressing wood quantities per unit area by bankfull width.

## Volume per 100 m vs. BFW

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .478 | .228 | .223 | .5028 |

a Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 11.059 | 1 | 11.059 | 43.751 | .000 |
| | Residual | 37.410 | 148 | .253 | | |
| | Total | 48.469 | 149 | | | |

a Predictors: (Constant), LOGBFW
b Dependent Variable: LGVOL100

Coefficients

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .835 | .100 | | 8.335 | .000 |
| | LOGBFW | .642 | .097 | .478 | 6.614 | .000 |

a Dependent Variable: LGVOL100

**Back-transformed equation: $Y=6.84x^{0.642}$ where Y= the predicted volume ($m^3$) per 100 m, and x= bankfull width (m)**

## Volume per $m^2$ vs. BFW:

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .290 | .084 | .078 | .5031 |

a Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 3.440 | 1 | 3.440 | 13.588 | .000 |
| | Residual | 37.466 | 148 | .253 | | |
| | Total | 40.906 | 149 | | | |

a Predictors: (Constant), LOGBFW
b Dependent Variable: LOGVLSQM

Coefficients

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -1.166 | .100 | | -11.628 | .000 |
| | LOGBFW | -.358 | .097 | -.290 | -3.686 | .000 |

a Dependent Variable: LOGVLSQM

**Back-transformed equation: $Y=0.0684x^{-0.358}$ where Y= the predicted volume ($m^3$) per $m^2$, and x= bankfull width (m).**

**Volume per channel width vs. BFW:**

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .812 | .660 | .657 | .5023 |

a Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 72.383 | 1 | 72.383 | 286.870 | .000 |
| | Residual | 37.343 | 148 | .252 | | |
| | Total | 109.726 | 149 | | | |

a Predictors: (Constant), LOGBFW
b Dependent Variable: Log Volume LWD per CW

Coefficients

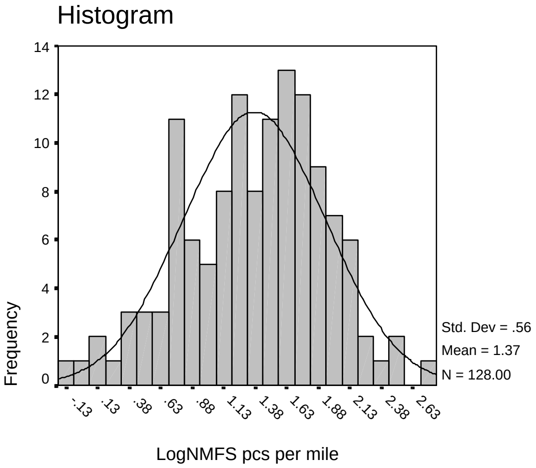
| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -1.165 | .100 | | -11.645 | .000 |
| | LOGBFW | 1.642 | .097 | .812 | 16.937 | .000 |

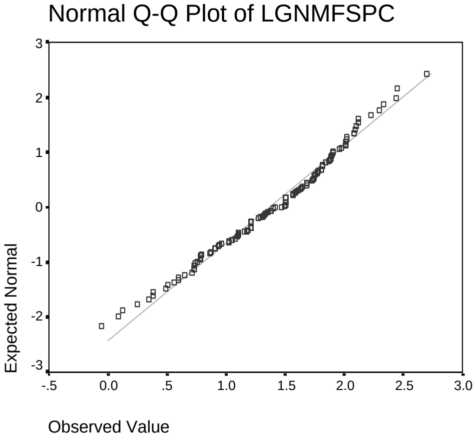
a Dependent Variable: Log Volume LWD per CW

**Back-transformed equation: $Y=0.0684x^{1.642}$ where Y= the predicted volume ($m^3$) per channel width, and x= bankfull width (m).**

**Appendix A. 12**

## Testing the NMFS targets. The data are $\log_{10}$ transformed to achieve normality.





Testing targets for western Washington with a one-sample t-test:

$H_o$: $\mu_1 = \log_{10}(80) = 1.903$

$H_A$: $\mu_1 \neq 1.903$

One-Sample Statistics

| | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| LGNMFSPC | 70 | 1.2722 | .5944 | 7.105E-02 |

One-Sample Test

| | Test Value = 1.903 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| LGNMFSPC | -8.879 | 69 | .000 | -.6308 | -.7726 | -.4891 |

**Conclusion: Reject Ho ($P_{0.05}$<0.001).**

Testing targets for eastern Washington with a one-sample t-test:
$H_o$: $\mu_1 = \log_{10}(20) = 1.301$
$H_A$: $\mu_1 \neq 1.301$

One-Sample Statistics

| | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| LGNMFSPC | 45 | 1.4600 | .4426 | 6.598E-02 |

One-Sample Test

| | Test Value = 1.301 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| LGNMFSPC | 2.410 | 44 | .020 | .1590 | 2.607E-02 | .2920 |

**Conclusion: Reject Ho ($P_{0.05}$=0.020).**

## Appendix A. 13

## Testing the Washington Forest Practices Board targets in the Methods for Conducting Watershed Analysis (1997)

### LWD per channel width (<20 m channels)

Testing targets of 2 pieces per channel width (log2=0.301) with a one-sample t-test:
$H_o$: $\mu_1 = 0.301$
$H_A$: $\mu_1 \neq 0.301$

One-Sample Statistics

| | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| LOG10PCW | 120 | .2992 | .4918 | 4.490E-02 |

One-Sample Test

| | Test Value = .301 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| LOG10PCW | -.039 | 119 | .969 | -1.7628E-03 | -9.0662E-02 | 8.714E-02 |

**Conclusion: Do not reject Ho ($P_{0.05}$=0.969).**

**Appendix A. 14**

### The relationship of LWD pieces per channel width and bankfull width (m) for channels <20 m BFW.

LWD pieces per CW vs. BFW. The response and predictor variable data are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1$=0

$H_A$: $\beta_1 \neq 0$

```
Variables Entered/Removed
      Model  Variables  Variables     Method
               Entered   Removed
          1  LOGBFW            .       Enter
a  All requested variables entered.
b  Dependent Variable: LOG10PCW

Model Summary
      Model           R  R SquareAdjusted R  Std. Error
                                     Square      of the
                                               Estimate
          1        .735      .540      .536       .3351
a  Predictors: (Constant), LOGBFW
ANOVA
      Model              Sum of          df        Mean           F        Sig.
                        Squares                  Square
          1  Regressio   15.533           1      15.533     138.316        .000
                     n
              Residual   13.251         118        .112
                 Total   28.784         119
a  Predictors: (Constant), LOGBFW
b  Dependent Variable: LOG10PCW

Coefficients
                       Unstandar             Standardiz           t        Sig.
                            dized                    ed
                       Coefficient          Coefficient
                                s                     s
      Model                     B  Std. Error      Beta
          1 (Constant)      -.720        .092                -7.834        .000
              LOGBFW        1.292        .110      .735      11.761        .000
a  Dependent Variable: LOG10PCW
```

**Conclusion: Reject Ho ($P_{0.05}$<0.001).**

### One sampleT-tests for BFW classes of 0-3 m, 3-12 m and 12-20 m against the standard of 2 pieces per channel width (WFPB 1997)

$H_o$: $\mu_1 = 0.301$ (log 2) pieces per channel width)

$H_A$: $\mu_1 \neq 0.301$

One-Sample Test (0-3 m BFW)

| | Test Value = .301 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| LOG10PCW | -8.955 | 17 | .000 | -.7071 | -.8737 | -.5405 |

**Conclusion: Reject Ho ($P_{0.05}<0.001$).**

$H_o$: $\mu_1 = 0.301$ (log 2) pieces per channel width)
$H_A$: $\mu_1 \neq 0.301$

One-Sample Test (3-12 m BFW)

| | Test Value = .301 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| LOG10PCW | 1.310 | 77 | .194 | 5.580E-02 | -2.9042E-02 | .1406 |

**Conclusion: Do not reject Ho ($P_{0.05}=0.194$).**

$H_o$: $\mu_1 = 0.301$ (log 2) pieces per channel width)
$H_A$: $\mu_1 \neq 0.301$

One-Sample Test (12-20 m BFW)

| | Test Value = .301 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| LOG10PCW | 7.996 | 52 | .000 | .7151 | .5356 | .8945 |

**Conclusion: Reject Ho ($P_{0.05}<0.001$).**

**Appendix A. 15**

## T-Test: key pcs/cw test against WFPB targets for 0-10 m BFW channels.

One-Sample Test (0-10 m BFW channels)

| | Test Value = -.523 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| LOG10KEY | -.130 | 36 | .897 | -9.3785E-03 | -.1559 | .1371 |

One-Sample Test(10-20 m BFW channels)

| | Test Value = -.301 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| LOG10KEY | -4.198 | 16 | .001 | -.3824 | -.5756 | -.1893 |

## Appendix A. 16

The relationship of the number of key pieces per channel width vs. bankfull width in channels <20 m BFW in western Washington.

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .068 | .005 | -.015 | .4258 |

a Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 4.382E-02 | 1 | 4.382E-02 | .242 | .625 |
| | Residual | 9.430 | 52 | .181 | | |
| | Total | 9.473 | 53 | | | |

a Predictors: (Constant), LOGBFW

b Dependent Variable: LOG10KEY

Coefficients

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |

| | | | | | |
|---|---|---|---|---|---|
| 1 (Constant) | -.674 | .199 | | -3.379 | .001 |
| LOGBFW | .111 | .227 | .068 | .492 | .625 |

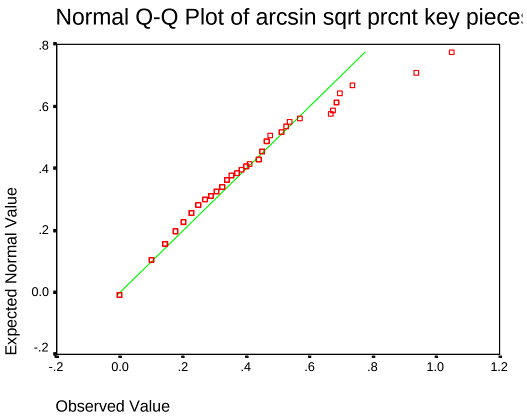
a Dependent Variable: LOG10KEY

**Appendix A. 17**

An analysis of variance for the percent of wood that qualifies as a “key piece” (as defined by WFPB 1997) by each of the five ecoregions. The response variable data are normalized with an arcsine square root transformation in order to achieve normality.

$H_o$: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$

$H_A$: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$



ANOVA
arcsin sqrt prcnt key pieces

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .628 | 4 | .157 | 4.193 | .003 |
| Within Groups | 5.427 | 145 | 3.743E-02 | | |
| Total | 6.055 | 149 | | | |

Multiple Comparisons (Tukey’s HSD).
Multiple Comparisons
Dependent Variable: arcsin sqrt prcnt key pieces

| | | | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | (I) ECOREG | (J) ECOREG | | | | Lower Bound | Upper Bound |
| Tukey HSD | DF/PP | GF | 4.672E-02 | 6.008E-02 | .937 | -.1172 | .2106 |
| | | SAF | -3.9090E-03 | 6.894E-02 | 1.000 | -.1920 | .1842 |
| | | SF/MH | -3.2775E-02 | 6.296E-02 | .985 | -.2045 | .1390 |
| | | SS/WH | -.1167 | 5.863E-02 | .271 | -.2766 | 4.326E-02 |

| | | | | | | |
|---|---|---|---|---|---|---|
| GF | DF/PP | -4.6724E-02 | 6.008E-02 | .937 | -.2106 | .1172 |
| | SAF | -5.0633E-02 | 5.491E-02 | .888 | -.2004 | 9.915E-02 |
| | SF/MH | -7.9499E-02 | 4.719E-02 | .443 | -.2082 | 4.921E-02 |
| | SS/WH* | -.1634 | 4.123E-02 | .001 | -.2759 | -5.0937E-02 |
| SAF | DF/PP | 3.909E-03 | 6.894E-02 | 1.000 | -.1842 | .1920 |
| | GF | 5.063E-02 | 5.491E-02 | .888 | -9.9152E-02 | .2004 |
| | SF/MH | -2.8866E-02 | 5.805E-02 | .988 | -.1872 | .1295 |
| | SS/WH | -.1128 | 5.332E-02 | .214 | -.2582 | 3.269E-02 |
| SF/MH | DF/PP | 3.278E-02 | 6.296E-02 | .985 | -.1390 | .2045 |
| | GF | 7.950E-02 | 4.719E-02 | .443 | -4.9212E-02 | .2082 |
| | SAF | 2.887E-02 | 5.805E-02 | .988 | -.1295 | .1872 |
| | SS/WH | -8.3896E-02 | 4.533E-02 | .344 | -.2075 | 3.975E-02 |
| SS/WH | DF/PP | .1167 | 5.863E-02 | .271 | -4.3259E-02 | .2766 |
| | GF* | .1634 | 4.123E-02 | .001 | 5.094E-02 | .2759 |
| | SAF | .1128 | 5.332E-02 | .214 | -3.2692E-02 | .2582 |
| | SF/MH | 8.390E-02 | 4.533E-02 | .344 | -3.9748E-02 | .2075 |

* The mean difference is significant at the .05 level.

* The mean difference is significant at the .05 level.

**Conclusion: Reject Ho ($P_{0.05}$=0.003).**

**Post-hoc test conclusion: Only the mean of SS/WH is significantly different from GF (p=0.001), and the rest of the ecoregions are similar, as stated in the Ho.**

**Appendix A. 18**

The following analysis tests the variation in mean wood density found among ecoregions.

$H_o$: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$

$H_A$: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$,

where each mean represents an ecoregion.

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 247.1659 | 4 | 61.79148 | 0.023579 | 0.998894 | 2.502659 |
| Within Groups | 183443.3 | 70 | 2620.618 | | | |
| Total | 183690.4 | 74 | | | | |

Conclusion: Do not reject Ho (p=0.999)

**The following analysis tests the variation in mean wood density found grouped ecoregions**.

$H_o$: $\mu_1 = \mu_2$

$H_A$: $\mu_1 \neq \mu_2$,

where each mean represents eastern and western Washington, respectively.

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 16.95696 | 1 | 16.95696 | 0.006739 | 0.934797 | 3.972048 |
| Within Groups | 183673.5 | 73 | 2516.075 | | | |
| | | | | | | |
| Total | 183690.4 | 74 | | | | |

Conclusion: Do not reject Ho (p=0.935)

Regression of the mean volume of LWD per $m^2$ to bankfull width. Both the predictor and response variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1 \neq 0$

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 3.440 | 1 | 3.440 | 13.588 | .000 |
| | Residual | 37.466 | 148 | .253 | | |
| | Total | 40.906 | 149 | | | |

a Predictors: (Constant), LOGBFW

b Dependent Variable: LOGVLSQM

Coefficients

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |
| 1 | (Constant) | -1.166 | .100 | | -11.628 | .000 |
| | LOGBFW | -.358 | .097 | -.290 | -3.686 | .000 |

a Dependent Variable: LOGVLSQM

**Conclusion: Reject Ho at $P_{0.05}$<0.0001**

### Appendix A. 19

Post-hoc comparisons used to justify the grouping of the five ecoregions into three regions. Tukey's HSD and the SNK tests were used to make comparisons among ecoregions using mean basal area per hectare (A), and mean instream LWD volume per 100 m (B).

A.

LGBASLHA

| | ECOREG | N | Subset for alpha = .1 | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 |
| Student-Newman-Keuls | DF/PP | 14 | 1.6351 | | | |
| | SAF | 18 | 1.7397 | 1.7397 | | |
| | GF | 40 | | 1.8868 | 1.8868 | |
| | SF/MH | 29 | | | 1.9971 | 1.9971 |
| | SS/WH | 49 | | | | 2.0926 |
| | Sig. | | .274 | .124 | .249 | .318 |
| Tukey HSD | DF/PP | 14 | 1.6351 | | | |
| | SAF | 18 | 1.7397 | 1.7397 | | |
| | GF | 40 | | 1.8868 | 1.8868 | |
| | SF/MH | 29 | | | 1.9971 | |
| | SS/WH | 49 | | | 2.0926 | |
| | Sig. | | .810 | .538 | .199 | |

Means for groups in homogeneous subsets are displayed.
Groups without significant differences in their means are aligned by columns.
a Uses Harmonic Mean Sample Size = 24.169.
b The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

**B.**

LGVOL100

| | ECOREG | N | Subset for alpha = .05 | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 |
| Student-Newman-Keuls | DF/PP | 14 | .7456 | | | |
| | GF | 40 | | 1.1263 | | |
| | SAF | 18 | | 1.2995 | | |
| | SF/MH | 29 | | | 1.6500 | |
| | SS/WH | 49 | | | 1.8197 | |
| | Sig. | | 1.000 | .179 | .188 | |
| Tukey HSD | DF/PP | 14 | .7456 | | | |
| | GF | 40 | | 1.1263 | | |
| | SAF | 18 | | 1.2995 | 1.2995 | |
| | SF/MH | 29 | | | 1.6500 | 1.6500 |
| | SS/WH | 49 | | | | 1.8197 |
| | Sig. | | 1.000 | .663 | .051 | .680 |

Means for groups in homogeneous subsets are displayed.
Groups without significant differences in their means are aligned by columns.
a Uses Harmonic Mean Sample Size = 24.169.
b The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

**Appendix A. 20. Regressions for LWD Pieces and Volumes per Unit Channel Width**

## Pieces Per Channel width

Regression of the LWD pieces per channel width to bankfull width (DF/PP ecoregions). Both the predictor and response variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$
$H_A$: $\beta_1 \neq 0$

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| | ECOREG_3 = Eastern Wash. (Selected) | | | |
| 1 | .689 | .475 | .427 | .3935 |

a Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 1.539 | 1 | 1.539 | 9.943 | .009 |
| | Residual | 1.703 | 11 | .155 | | |
| | Total | 3.243 | 12 | | | |

a Predictors: (Constant), LOGBFW
b Dependent Variable: LOG10PCW
c Selecting only cases for which ECOREG = DF/PP

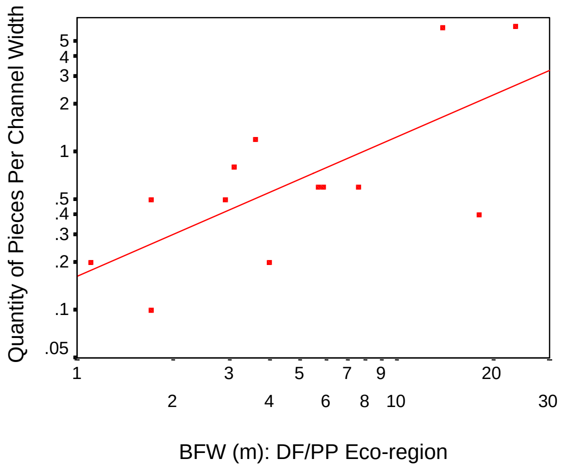
Coefficients

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -.787 | .218 | | -3.613 | .004 |
| | LOGBFW | .878 | .279 | .689 | 3.153 | .009 |

a Dependent Variable: LOG10PCW
b Selecting only cases for which ECOREG = DF/PP

**Conclusions: Reject Ho: ($P_{0.05}$=0.009)**

Back-transformed equation: $y=0.166x^{1.396}$



Regression of the LWD pieces per channel width to bankfull width (Alpine Region). Both the predictor and response variables are $\log_{10}$ transformed in order to achieve normality.
$H_o$: $\beta_1=0$
$H_A$: $\beta_1\neq 0$

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| | ECOREG_3 = Alpine (Selected) | | | |
| 1 | .770 | .593 | .586 | .3067 |

a Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 7.687 | 1 | 7.687 | 81.743 | .000 |
| | Residual | 5.266 | 56 | 9.404E-02 | | |
| | Total | 12.954 | 57 | | | |

a Predictors: (Constant), LOGBFW
b Dependent Variable: LOG10PCW
c Selecting only cases for which ECOREG_3 = Alpine

Coefficients

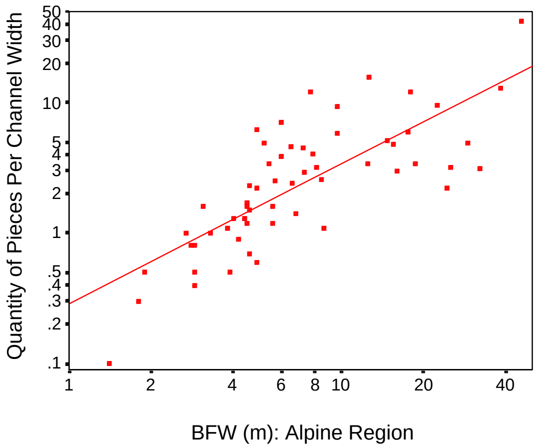
| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |
| 1 | (Constant) | -.539 | .107 | | -5.016 | .000 |
| | LOGBFW | 1.070 | .118 | .770 | 9.041 | .000 |

a Dependent Variable: LOG10PCW

b  Selecting only cases for which ECOREG_3 =  Alpine

**Conclusions: Reject Ho: ($P_{0.05}$<0.001)**

Back-transformed equation: $y=0.289x^{1.07}$



Regression of the LWD pieces per channel width to bankfull width (Western WA Regions). Both the predictor and response variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1 \neq 0$

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| | ECOREG_ 3 = Western Wash. (Selected) | | | |
| 1 | .864 | .746 | .743 | .3570 |

a  Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| | Regression | 28.456 | 1 | 28.456 | 223.266 | .000 |
| | Residual | 9.686 | 76 | .127 | | |
| | Total | 38.143 | 77 | | | |

a  Predictors: (Constant), LOGBFW

b  Dependent Variable: LOG10PCW

c  Selecting only cases for which ECOREG_3 =  Western Wash.

Coefficients

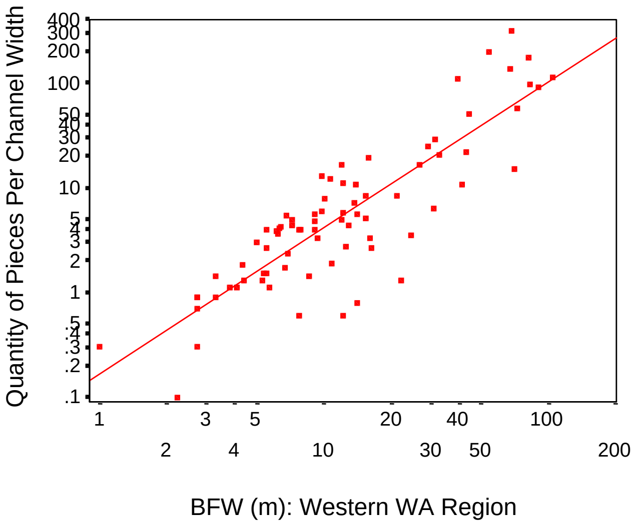
| | Unstandardized Coefficient | | Standardized Coefficient | t | Sig. |
|---|---|---|---|---|---|

| Model | | s<br>B | Std. Error | s<br>Beta | | |
|---|---|---|---|---|---|---|
| 1 | (Constant) | -.779 | .108 | | -7.217 | .000 |
| | LOGBFW | 1.396 | .093 | .864 | 14.942 | .000 |

a  Dependent Variable: LOG10PCW
b  Selecting only cases for which ECOREG_3 =  Western Wash.

**Conclusions: Reject Ho: ($P_{0.05}$<0.001)**

Back-transformed equation: $y=0.166x^{1.396}$



## Volume Per Channel width

Regression of the LWD Volume ($m^3$) per channel width to bankfull width (DF/PP ecoregion). Both the predictor and response variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1 \neq 0$

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| | ECOREG_3 = Eastern Wash. (Selected) | | | |
| 1 | .847 | .717 | .693 | .5370 |

a  Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 8.767 | 1 | 8.767 | 30.399 | .000 |
| | Residual | 3.461 | 12 | .288 | | |
| | Total | 12.228 | 13 | | | |

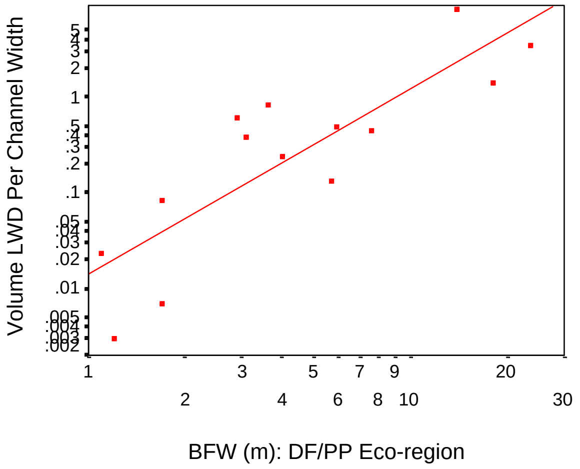
a  Predictors: (Constant), LOGBFW
b  Dependent Variable: Log Volume LWD per CW
c  Selecting only cases for which ECOREG_3 =  Eastern Wash.

Coefficients

| | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | | |
| 1 | (Constant) | -1.852 | .265 | | -6.981 | .000 |
| | LOGBFW | 1.941 | .352 | .847 | 5.514 | .000 |

a  Dependent Variable: Log Volume LWD per CW
b  Selecting only cases for which ECOREG_3 =  Eastern Wash.

**Conclusions: Reject Ho: ($P_{0.05}<0.001$)**
Back-transformed equation: $y=0.0141x^{1.941}$



Regression of the LWD Volume ($m^3$) per channel width to bankfull width (Alpine Region). Both the predictor and response variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$
$H_A$: $\beta_1\neq 0$

Model Summary

| | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| Model ECOREG_3 = Alpine | | | | |

| | | | | |
|---|---|---|---|---|
| | (Selected) | | | |
| 1 | .808 | .653 | .647 | .3624 |

a  Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 13.844 | 1 | 13.844 | 105.424 | .000 |
| | Residual | 7.354 | 56 | .131 | | |
| | Total | 21.197 | 57 | | | |

a  Predictors: (Constant), LOGBFW
b  Dependent Variable: Log Volume LWD per CW
c  Selecting only cases for which ECOREG_3 =  Alpine

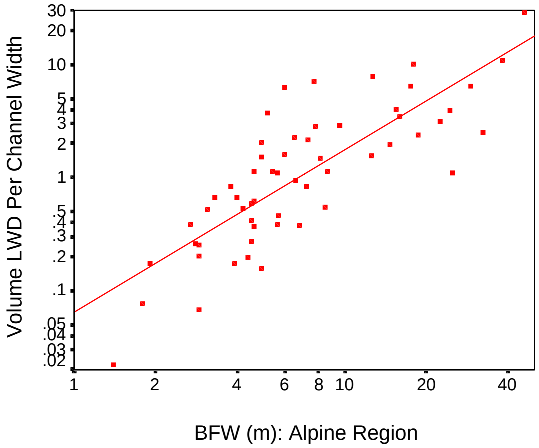
Coefficients

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -1.187 | .127 | | -9.349 | .000 |
| | LOGBFW | 1.436 | .140 | .808 | 10.268 | .000 |

a  Dependent Variable: Log Volume LWD per CW
b  Selecting only cases for which ECOREG_3 =  Alpine

**Conclusions: Reject Ho: ($P_{0.05}$<0.001)**

Back-transformed equation: $y=0.166x^{1.396}$



Regression of the LWD Volume ($m^3$) per channel width to bankfull width (Western Washington Region). Both the predictor and response variables are $\log_{10}$ transformed in order to achieve normality.

$H_o$: $\beta_1=0$

$H_A$: $\beta_1\neq 0$

Model Summary

| Model | R<br>ECOREG_3 = Western Wash. (Selected) | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .795 | .632 | .628 | .4353 |

a Predictors: (Constant), LOGBFW

ANOVA

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| | Regression | 24.770 | 1 | 24.770 | 130.730 | .000 |
| | Residual | 14.400 | 76 | .189 | | |
| | Total | 39.170 | 77 | | | |

a Predictors: (Constant), LOGBFW
b Dependent Variable: Log Volume LWD per CW
c Selecting only cases for which ECOREG_3 = Western Wash.

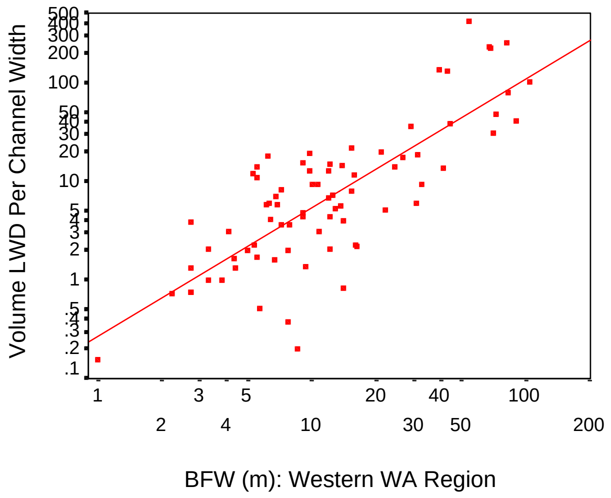
Coefficients

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -.568 | .132 | | -4.313 | .000 |
| | LOGBFW | 1.303 | .114 | .795 | 11.434 | .000 |

a Dependent Variable: Log Volume LWD per CW
b Selecting only cases for which ECOREG_3 = Western Wash.

**Conclusions: Reject Ho: ($P_{0.05}$<0.001)**

Back-transformed equation: $y=0.166x^{1.396}$



**Appendix A. 21. Quantity and Volumes of LWD per 100 m for 1) the Western Washington Region, 2) the Alpine Region, and 3) the DF/PP Ecoregion.**

Multiple Comparisons
Dependent Variable: LGPC100 m

| | | | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | (I) WESTLWD | (J) WESTLWD | | | | Lower Bound | Upper Bound |
| Tukey HSD | 0-6 m | >6-30 m | -.1535 | 9.704E-02 | .260 | -.3856 | 7.852E-02 |
| | | >30-100 m* | -.5414 | .1195 | .000 | -.8273 | -.2556 |
| | >6-30 m | 0-6 m | .1535 | 9.704E-02 | .260 | -7.8522E-02 | .3856 |
| | | >30-100 m* | -.3879 | .1032 | .001 | -.6346 | -.1413 |
| | >30-100 m | 0-6 m* | .5414 | .1195 | .000 | .2556 | .8273 |
| | | >6-30 m* | .3879 | .1032 | .001 | .1413 | .6346 |

* The mean difference is significant at the .05 level.

## Tables: Variance significantly different between the 0-6 m and 6-30 m BFW classes; $F_{obs}$=1.86, p=.072 (at alpha =0.10)

**(Log-transformed units)**

| | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|
| 0-6 m | 1.51 | 1.46 | 1.41 | 1.57 | .07 | 19 | 1.25 |
| >6-30 m | 1.71 | 1.72 | 1.46 | 1.80 | .13 | 43 | 1.41 |
| >30-100 m | 2.16 | 2.02 | 1.75 | 2.32 | .17 | 16 | 1.34 |

**(Original units)**

| | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|
| 0-6 m | 32.53 | 29.00 | 25.54 | 37.85 | 243.19 | 19 | 67.50 |
| >6-30 m | 52.03 | 52.25 | 29.15 | 63.44 | 1091.96 | 43 | 131.67 |
| >30-100 m | 143.83 | 105.55 | 56.50 | 208.29 | 16159.26 | 16 | 435.25 |

Bankfull width groupings for the Alpine Region, pcs/100 m

Multiple Comparisons
Dependent Variable: LGPC100 m

| | | | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | (I) ALPINLW | (J) ALPINLW | | | | Lower Bound | Upper Bound |

| | D | D | | | | | |
|---|---|---|---|---|---|---|---|
| Tukey HSD | 0-3 m | >3-30 m* | -.2726 | .1127 | .049 | -.5440 | -1.1795E-03 |
| | | >30-50 m | -.2048 | .1994 | .563 | -.6852 | .2756 |
| | >3-30 m | 0-3 m* | .2726 | .1127 | .049 | 1.180E-03 | .5440 |
| | | >30-50 m | 6.775E-02 | .1754 | .921 | -.3548 | .4903 |
| | >30-50 m | 0-3 m | .2048 | .1994 | .563 | -.2756 | .6852 |
| | | >3-30 m | -6.7748E-02 | .1754 | .921 | -.4903 | .3548 |

* The mean difference is significant at the .05 level.

**Tables: Alpine pcs/100 m: significant difference in variance between 3-30 and 30-50: $F_{obs}$=2.67, p=.056 (alpha= 0.10)**

**(Log-transformed units)**

| | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|
| 0-3 m | 1.34 | 1.34 | 1.17 | 1.45 | .05 | 8 | .72 |
| >3-30 m | 1.65 | 1.54 | 1.39 | 1.74 | .09 | 47 | 1.25 |
| >30-50 m | 1.65 | 1.53 | 1.33 | 1.80 | .24 | 3 | .98 |

**(Original units)**

| | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|
| 0-3 m | 21.69 | 22.25 | 14.87 | 27.91 | 93.85 | 8 | 30.00 |
| >3-30 m | 45.64 | 35.13 | 24.50 | 55.51 | 1134.76 | 47 | 150.00 |
| >30-50 m | 45.46 | 34.24 | 21.57 | 63.30 | 1839.52 | 3 | 83.33 |

Bankfull width groupings for the DF/PP ecoregion, pcs/100 m

**Tables: variances are different: $F_{obs}$=2.92, p=0.077 (alpha=0.10)**

**(Log-transformed units)**

| | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|
| 0-6 m | 1.21 | 1.17 | .70 | 1.46 | .12 | 10 | .90 |
| >6-30 m | 1.31 | 1.24 | .71 | 1.55 | .35 | 4 | 1.34 |

**(Original units)**

| | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|
| 0-6 m | 16.35 | 14.96 | 5.00 | 28.63 | 116.21 | 10 | 28.00 |
| >6-30 m | 20.21 | 17.43 | 5.14 | 35.12 | 357.38 | 4 | 42.00 |

Quantity of Key Pieces per 100 m for the Western Washington Region, the Alpine Region, and the DF/PP Ecoregion.

Western Washington Region, Key Pieces per 100 m:

The response variable is $\log_{10}$ transformed to achieve normality.

$H_o$: $\mu_1 = \mu_2$

$H_A$: $\mu_1 \neq \mu_2$

ANOVA

LGPC100 m vs. 2 bfw classes

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .540 | 1 | .540 | 3.574 | .062 |
| Within Groups | 11.484 | 76 | .151 | | |
| Total | 12.024 | 77 | | | |

**Conclusions: Means are not significantly different ($P_{0.05}$=0.062)**

However, the variances are significantly different:

**Tables: Variance differ: $F_{obs}$=2.06, p=.014 (alpha=0.10)**

(log-transformed data)

| | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|
| 0-10 m | log key pcs/100 m | .88 | .81 | .56 | 1.06 | .18 | 38 | 1.89 |
| >10-100 m | log key pcs/100 m | .41 | .10 | -.12 | .59 | .37 | 40 | 2.96 |

(Original Data)

| | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|
| 0-10 m | Key Pieces per 100 m | 7.61 | 6.42 | 3.67 | 11.37 | 33.82 | 38 | 25.57 |
| >10-100 m | Key Pieces per 100 m | 2.56 | 1.25 | .76 | 3.87 | 11.97 | 40 | 18.37 |

**Alpine Region, Key Pieces per 100 m:**

The response variable is $\log_{10}$ transformed to achieve normality.

$H_o$: $\mu_1 = \mu_2$

$H_A$: $\mu_1 \neq \mu_2$

ANOVA

log key pcs/100 m vs. 2 bfw classes

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 2.367 | 1 | 2.367 | 8.435 | .006 |
| Within Groups | 12.069 | 43 | .281 | | |
| Total | 14.436 | 44 | | | |

**Conclusions: Means are significantly different ($P_{0.05}$=0.006)**

**(original data)**

| | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|
| 0-15 m | Key Pieces per 100 m | 2.77 | 1.99 | .34 | 4.08 | 9.08 | 46 | 12.50 |
| >15-50 m | Key Pieces per 100 m | .38 | .27 | .00 | .87 | .20 | 12 | 1.16 |

**DF/PP Ecoregion, Key Pieces per 100 m:**

**No significant differences in the means or variances could be identified for any sub-BFW group.**

**(original data)**

| | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|
| 0-30 m | Key Pieces per 100 m | 1.60 | .43 | .00 | 2.02 | 5.71 | 14 | 7.02 |

Volume of LWD per 100 m for the Western Washington Region, the Alpine Region, and the DF/PP Ecoregion.

*Western Washington Region, LWD Volume per 100 m:*

The response variable is $\log_{10}$ transformed to achieve normality.

$H_o$: $\mu_1 = \mu_2$

$H_A$: $\mu_1 \neq \mu_2$

ANOVA

LGVOL100 vs. 2 bfw classes

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 1.494 | 1 | 1.494 | 7.977 | .006 |
| Within Groups | 14.236 | 76 | .187 | | |
| Total | 15.730 | 77 | | | |

**Conclusions: Means are significantly different ($P_{0.05}$=0.006)**

**(original data)**

| | | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|---|
| westvol bfw class | 0-30 m | Volume LWD/100 m | 71.32 | 51.31 | 28.25 | 99.27 | 3842.82 | 62 | 285.37 |
| | >30-100 m | Volume LWD/100 m | 184.84 | 92.75 | 43.89 | 317.27 | 40587.93 | 16 | 749.84 |

*Alpine Region, LWD Volume per 100 m:*

The response variable is $\log_{10}$ transformed to achieve normality.

$H_o$: $\mu_1 = \mu_2$

$H_A$: $\mu_1 \neq \mu_2$

ANOVA

LGVOL100 vs. 2 bfw classes

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 1.645 | 1 | 1.645 | 13.214 | .001 |
| Within Groups | 6.973 | 56 | .125 | | |
| Total | 8.619 | 57 | | | |

**Conclusions: Means are significantly different ($P_{0.05}$=0.001)**

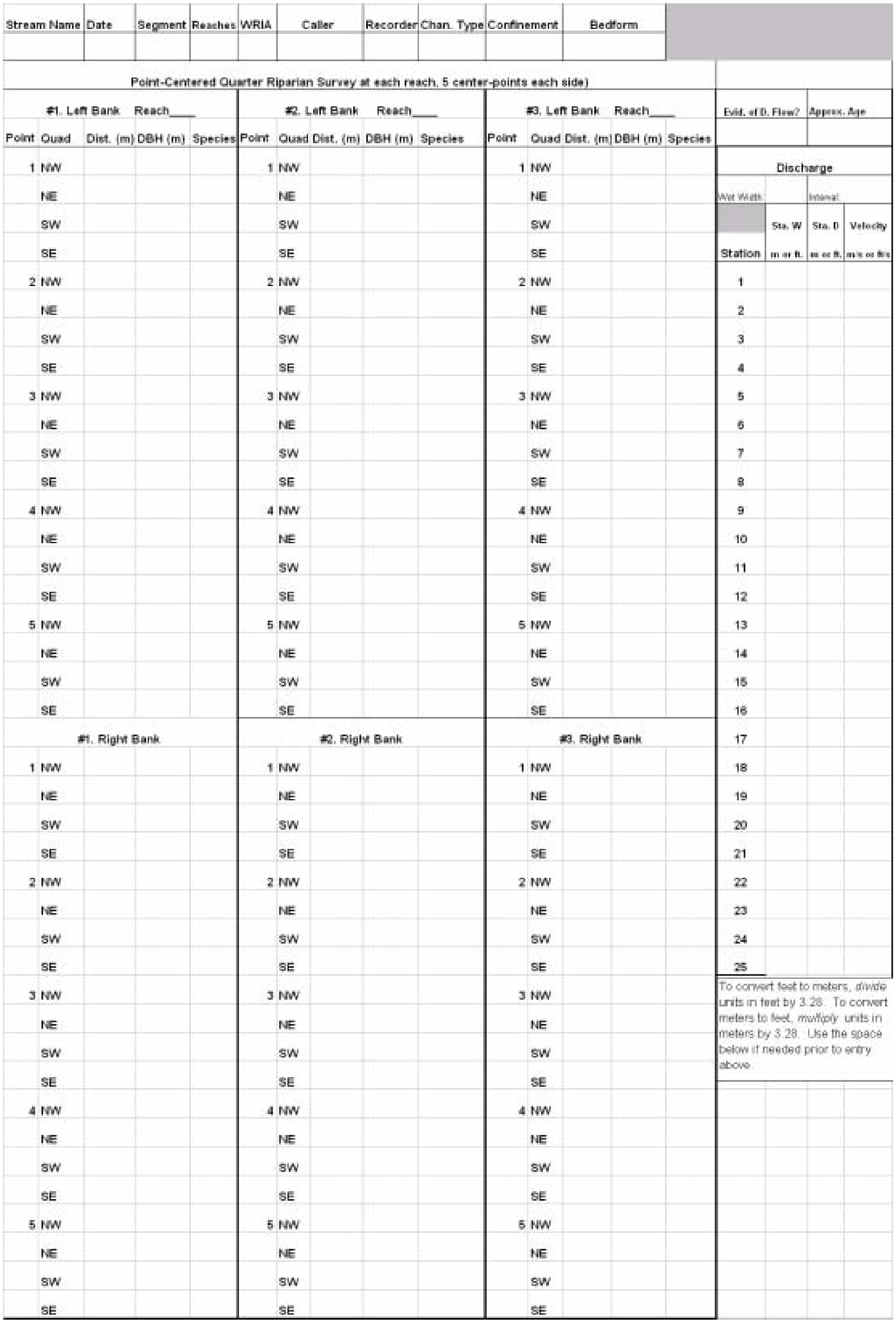
DF/PP Eco-regioin, LWD Volume per 100 m:

Further delineations of BFW groups could not be statistically identified.

| | | | Mean | Median | Percentile 25 | Percentile 75 | Variance | Count | Range |
|---|---|---|---|---|---|---|---|---|---|
| eastvol bfw class | 0-30 m | Volume LWD/100 m | 12.02 | 6.93 | 2.28 | 14.69 | 235.27 | 14 | 59.03 |

## *9.2.* Appendix B. Field Forms

### Appendix B. 1. Segment Summary Form



| Stream Name | Date | Segment | Reaches | WRIA | Caller | Recorder | Chan. Type | Confinement | Bedform |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

Point-Centered Quarter Riparian Survey at each reach, 5 center-points each side)

| #1. Left Bank Reach____ | | | | | #2. Left Bank Reach____ | | | | | #3. Left Bank Reach____ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | Quad | Dist. (m) | DBH (m) | Species | Point | Quad | Dist. (m) | DBH (m) | Species | Point | Quad | Dist. (m) | DBH (m) | Species |
| 1 | NW | | | | 1 | NW | | | | 1 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |
| 2 | NW | | | | 2 | NW | | | | 2 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |
| 3 | NW | | | | 3 | NW | | | | 3 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |
| 4 | NW | | | | 4 | NW | | | | 4 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |
| 5 | NW | | | | 5 | NW | | | | 5 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |
| #1. Right Bank | | | | | #2. Right Bank | | | | | #3. Right Bank | | | | |
| 1 | NW | | | | 1 | NW | | | | 1 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |
| 2 | NW | | | | 2 | NW | | | | 2 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |
| 3 | NW | | | | 3 | NW | | | | 3 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |
| 4 | NW | | | | 4 | NW | | | | 4 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |
| 5 | NW | | | | 5 | NW | | | | 5 | NW | | | |
| | NE | | | | | NE | | | | | NE | | | |
| | SW | | | | | SW | | | | | SW | | | |
| | SE | | | | | SE | | | | | SE | | | |

| Evid. of D. Flow? | Approx. Age |
|---|---|
| | |

| Discharge | | | |
|---|---|---|---|
| Wet Width: | | Interval: | |
| Station | Sta. W m or ft. | Sta. D m or ft. | Velocity m/s or ft/s |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
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| 12 | | | |
| 13 | | | |
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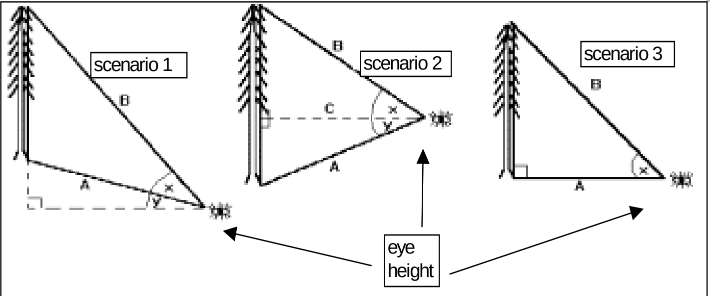
| 15 | | | |
| 16 | | | |
| 17 | | | |
| 18 | | | |
| 19 | | | |
| 20 | | | |
| 21 | | | |
| 22 | | | |
| 23 | | | |
| 24 | | | |
| 25 | | | |

To convert feet to meters, *divide* units in feet by 3.28. To convert meters to feet, *multiply* units in meters by 3.28. Use the space below if needed prior to entry above.

## Appendix B. 2. Riparian Tree Height Form

| Stream Name | Date | Segment | Reach | WRIA # | Caller | Recorder |
|---|---|---|---|---|---|---|
| | | | | | | |

**Methods for calculating tree height using a trigonometric method:**
Use a hand-held clinometer for angles, and a range-finder (if available) for the distances (triangle sides). If you don't have a range-finder, a hip-chain with the right combination of measurements will suffice. Be aware that angles x and y are not always the same number you see in the clinometer, since the clinometer is merely the angle from zero degrees. For example, in scenario 1, looking to the top of the tree will only give you x+y You must subtract angle y from the total angle (as observed by the clinometer angle) to get angle x (i.e. Clinometer angle-y=x). In all scenarios, angle y is always the absolute value (positive) from zero degrees.



Select a tree height scenario from the diagrams pictured. The first scenario is looking upslope to the base (ground surface) of a tree, the second scenario is looking downslope to the base of a tree, the third scenario is eye level to the base of the tree (0 degrees). **Choose the most accurate combination of measurements available with each scenario.** The further the "side A", the more accurate your "angle x" is likely to be. For best results, move away from the tree until angle x is < 45 degrees.

**Scenario 1** Obtain the most accurate combination:
1. angle x, side A and B
2. angle x and y, side A or B

**Scenario 2** Obtain the most accurate combination:
1. angle x and y, and any one side
2. angle x, and sides (A and B) or (A and C)
3. angle y, and sides (A and B) or (B and C)
4. side A, B, and C

**Scenario 3** Obtain the most accurate combination:
1. angle x, side A or B
2. side A and B

| angle x | angle y | side A | side B | species | angle x | angle y | side A | side B | side C | species | angle x | side A | side B | species |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |
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## Appendix B. 3. Wood Survey Forms

| Stream Name | Date | Segment | Reach | Reach Length | WRIA | BFW | BFD | Photo # | Sketch Ma | English or Metric (Circle one) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |

| Caller | Recorder | Reach Elevation Gains | Total |
|---|---|---|---|
| | | | |

| Group # | Channel unit | Dist. Upstr. of ref. Pt. | Piece # | Piece type | Zone 1 length | Zone 2 Length | Zone 3 Length | Zone 4 Length | Midpoint Diam. | End in Lowest Zone | Orientation | End closest to channel center | Species | Decay Class | Piece Stability | | | | Sediment Storage? | Identifiable Source ? | Small Woody Debris Counts in diameter class (cm) | | | Notes: | SWD Lengths (each 20th piece of class)(cm) | | | Bankfull Depth | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | R | B | P | U | | | 2-5 | 5-10 | >10 | | 2-5 | 5-10 | >10 | Interval= | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | Sta. | Dep. |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 9 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 10 | |
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## Appendix B. 4. Jam Survey Forms

| Stream Name | Date | Segment | Reach | WRIA # | Caller | Recorder | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | SWD (diameter classes) | | | LWD (diameter classes) | | | | | Jam |
| Group # | 2-5 cm | >5-10cm | >10cm* | Rtwd | >10-20cm | >20-50cm | >50-70cm | >70cm | Zone % |
| | | | | | | | | | Z1: |
| tallies: | | | | | | | | | Z2: |
| Totals: | | | | | Key Pieces: | Key Pieces: | Key Pieces: | Key Pieces: | Z3: |
| Ten Lengths (m): | 2-5 cm | 5-10cm | >10cm* | Rtwd | >10-20cm | >20-50cm | >50-70cm | >70cm | Z4: |
| 1 | | | | | | | | | Sediment |
| 2 | | | | | | | | | Storage? |
| 3 | | | | | | | | | |
| 4 | | | | | | | | | Notes: |
| 5 | | | | | | | | | |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | |
| 8 | | | | | | | | | |
| 9 | | | | | | | | | |
| 10 | | | | | | | | | *<2m length |
| | SWD (diameter classes) | | | LWD (diameter classes) | | | | | Jam |
| Group # | 2-5 cm | >5-10cm | >10cm* | Rtwd | >10-20cm | >20-50cm | >50-70cm | >70cm | Zone % |
| | | | | | | | | | Z1: |
| tallies: | | | | | | | | | Z2: |
| Totals: | | | | | Key Pieces: | Key Pieces: | Key Pieces: | Key Pieces: | Z3: |
| Ten Lengths (m): | 2-5 cm | 5-10cm | >10cm* | Rtwd | >10-20cm | >20-50cm | >50-70cm | >70cm | Z4: |
| 1 | | | | | | | | | Sediment |
| 2 | | | | | | | | | Storage? |
| 3 | | | | | | | | | |
| 4 | | | | | | | | | Notes: |
| 5 | | | | | | | | | |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | |
| 8 | | | | | | | | | |
| 9 | | | | | | | | | |
| 10 | | | | | | | | | *<2m length |

## 9.3. Appendix C. Site Summary Table

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Little Ranger Cr. | White R. @94.1 | Puyallup R. @16.6 | Puget Sound (P.S.) | 0 | 0.145-0.3 | 6/24/2000 | N47 1.399' | W121 32.010 |
| Dry Cr. | White R. @ 95.9 | Puyallup R. @ 16.6 | P.S. | 1 | 0.4-0.9 | 6/25/1999 | N47 0.469' | W121 31.101 |
| Ranger Cr. | Carbon R. @ 43.04 | Puyallup R. @28.9 | P.S. | 2 | 0.49-1.06 | 7/2/1999 | N46 59.407 | W121 50.906 |
| Ranger Cr. | Carbon R. @ 43.01 | Puyallup R. @28.9 | P.S. | 3 | 2.11-2.32 | 7/12/1999 | N46 58.830' | W121 51.428' |
| Falls Cr. | Carbon R. @ 40.9 | Puyallup R. @ 28.9 | P.S. | 4 | 0.1-0.54 | 6/29/2009 | N46 59.624 | W121 52.535' |
| Lost Cr. | Huckleberry Cr. @ 9.9 | White R. @ 85.4 | Puyallup R. @ 16.6 | 10 | 1.2-2.2 | 6/29/1999 | N47 0.00' | W121 36.25' |
| Ipsut Cr. | Carbon R. @ 45.6 | Puyallup R. @ 28.9 | P.S. | 8 | 0.26-0.8 | 7/13/1999 | N46 58.544 | W121 49.886 |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Unnamed | White R. @99.62 | Puyallup R. @ 16.6 | P.S. | 9 | 0.0-0.2 | 6/30/1999 | N46 59.675 | W121 32.374 |
| Ipsut Cr. | Carbon R. @ 45.6 | Puyallup R. @ 28.9 | P.S. | 12 | 1.5-1.9 | 7/14/1999 | N46 57.951 | W121 50.164 |
| Ipsut Cr. | Carbon R. @ 45.6 | Puyallup R. @ 28.9 | P.S. | 14 | 1.5-2.7 | 7/19/1999 | W46 57.4791 | W121 51.283 |
| Fish Cr. | Tahoma Cr. @4.6 | Nisqually R. | P.S. | 15 | 0.0-2.0 | 7/7/1999 | N46 47.052 | W121 53.256 |
| Fish Cr. | Tahoma Cr. @4.6 | Nisqually R. | P.S. | 16 | 2.0-2.9 | 7/7/1999 | N46 46.414 | W121 53.333 |
| Paradise R. | Nisqually R. @ | P.S. |  | 18 | 0.68-1.43 | 10-112-99 | N46 45.999' | W121 46.804 |
| Klickitat Cr. | White R. @109.2 | Puyallup R. @16.6 | P.S. | 21 | 0.6-1.7 | 10/26/1900 | N46 54.020' | W121 33.058 |
| Klickitat R. | White R. @109.2 | Puyallup R. @16.6 | P.S. | 22 | 1.73-2.9 | 7/23/1999 | N46 53.5 | W121 32.98 |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Chinook Cr. | Ohanepecosh R. 19.35 | Cowlitz R. | Columbia R. | 23 | 2.8-4.5 | 2,8,15 | N46 49.747' | W121 37.608 |
| Chinook Cr. | Ohanepecosh R. @ 15.94 | Cowlitz R. @ 215.6 | Columbia R. @ 109.5 | 24 | 0.76-1.8 | 7/20/1999 | N46 50.738 | W121 32.138 |
| Needle Cr. | chinook Cr. @ 4.75 | Ohanepecosh R. @ 15.94 | Cowlitz R. @ 215.6 | 25 | 0-1.1 | 7/13/1999 | N46 50.235 | W121 32.656 |
| Unnamed | Ohanepecosh R. @13.65 | Cowlitz R. @215.6 | Columbia R. @109.5 | 26 | 0.45-0.92 | 7/30/1999 | N46 45.385' | W121 33.877' |
| Falls Cr. | Ohanepecosh R. @14.05 | Cowlitz R. @215.6 | Columbia R. @109.5 | 27 | 0.6-0.7 | 8/3/1999 | N46 45.753' | W121 33.693' |
| Falls Cr. | Ohanepecosh R. @14.05 | Cowlitz R. @215.6 | Columbia R. @109.5 | 28 | 0.94-1.06 | 8/4/1999 | N46 45.910' | W121 33.811' |
| Ollallie Cr. | Ohanepecosh R. @ 12.49 | Cowlitz R. @ 215.6 | Columbia R. @109.45 | 29 | 0.0-0.2 | 8/4/1999 | 46 46.427' | W121 33.189' |
| Ollallie Cr. | Ohanepecosh R. @ 12.49 | Cowlitz R. @ 215.6 | Columbia R. @109.45 | 30 | 2.5-3 | 8/2/1999 | 46 46.500' | W121 35.135' |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Ohanepecosh R. | Cowlitz R. @ 215.6 | Columbia R. @ 109.45 | Pacific | 31 | 15.37-15.57 | 10/10/1999 | N46 46.246 | W121 33.046 |
| Crystal Cr. | White R. @106.7 | Puyallup R. @ 16.6 | P.S. | 32 | 1.1-1.5 | 7/21/1999 | N46 55.255 | W121 31.817 |
| Unnamed | Ohanepecosh R. @ 15.63 | Cowlitz R. @ 215.6 | Columbia R. @ 109.45 | 33 | 0.3-0.5 | 8/3/1999 | N46 47.614 | W121 33.568 |
| Deadwood Cr. | White R. @108.7 | Puyallup R. @16.6 | Puyallup R. @16.6 | 34 | 0.98-1.4 | 7/28/1999 | N46 54.229 | W121 32.305 |
| Cle Elum R. | Yakima R. @298.8 | Columbia R.@ 537.7 | Pacific Ocean | 35 | 55.7-56.4 | 8/13/1999 | N47 32.860' | W121 6.447' |
| Unnamed | Cle Elum R. @56.0 | Yakima R. @ 298.8 | Columbia R. @ 537.7 | 37 | 0.4-0.8 | 8/9/1999 | N47 33.353 | W121 6.295 |
| Unnamed | Cle Elum R.@ 56.0 | Yakima R. @ 298.8 | Columbia R. @537.7 | 38 | 0.8-1.3 | 8/10/1999 | N47 33.3022' | W121 5.893 |
| Unnamed | Cle Elum R. @56.4 | Yakima R. @298.8 | Columbia R. @537.7 | 39 | 0.1-0.3 | 8/10/1999 | N47 33.447 | W121 6.672 |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Unnamed | Cle Elum R. @ 56.4 | Yakima R. @ 298.8 | Columbia R. @ 537.7 | 40 | 0.4-0.8 | 8/11/1999 | N47 33.474' | W121 6.280' |
| Unnamed | Cle Elum R/ @57.4 | Yakima R. @298.8 | Columbia R. @537.7 | 41 | 0.0-0.2 | 8/9/1999 | N47 33.632' | W121 6.943' |
| Cle Elum R. | Yakima R.@ 298.8 | Columbia R. @ 537.7 | Pacific Ocean | 42 | 59.0-59.0 | 8/19/1999 | N47 34.619' | W121 7.923 |
| Unnamed | Cle Elum R. @59.0 | Yakima R. @ 298.8 | Columbia R. @537.7 | 43 | 0.0-0.1 | 8/23/1999 | N47 34.666' | W121 8.240' |
| Unnamed | Cle Elum R. @59.5 | Yakima R. @ 298.8 | Columbia R. @ 537.7 | 44 | 0.1-0.2 | 8/18/2000 | N47 34.797' | W121 8.135' |
| Unnamed | Cle Elum R. @ 59.5 | Yakima R. @ 298.8 | Columbia R. @ 537.7 | 45 | 0.1-0.4 | 8/17/1999 | N47 34.861' | W121 78.833' |
| Unnamed | Cle Elum R. @58.5 | Yakima R. @298.8 | Columbia R. @ 537.7 | 46 | 58.0-58.5 | 8/24/1999 | N47 34.336' | W121 7.652' |
| Unnamed | Chiwawa R. @ 46.5 | Wenatchee R. @77.9 | Columbia R. @753.7 | 49 | 0.3-0.8 | 9/2/1999 | N48 3.831' | W120 50.741' |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Waptus R. | Cle Elum R. @35.0 | Yakima R. @298.8 | Columbia R. @ 537.7 | 50 | 3.0-3.8 | 8/25/1999 | N47 26.168 | W121 6.784 |
| Chiwawa R. | Wenatchee R. @ 77.9 | Columbia R. @ 753.7 | Pacific | 51 | 50.5-51.1 | 8/31/1999 | N48 5.465' | W120 52.102' |
| Waptus R. | Cle Elum R. @ 35.0 | Yakima R. @298.8 | Columbia R. @537.7 | 53 | 3.5-3.8 | 8/16/1999 | N47 26.437 | W121 7.153 |
| Hour Cr. | Waptus R. @ 3.5 | Cle Elum R. @35.0 | Yakima R. @298.8 | 57 | 0.0-0.3 | 8/17/1999 | N47 26.3691' | W121 7.218' |
| Hour Cr. | Waptus R. @ 3.5 | Cle Elum R. @ 35 | Yakima R. @298.8 | 58 | 0.6-0.9 | 8/18/1999 | N47 26.519' | W121 7.583' |
| NF Skokomish R. | Skokomish R @ 11.0 | Puget Sound |  | 65 | 17.97-19.3 | 9/7/1999 | N47 31.51 | W123 20.68 |
| White R. | Wenatchee R. @ 94.2 | Columbia R. @753.7 | Pacific Ocean | 68 | 63.0-63.8 | 9/4/1999 | N47 58.503 | W120 57.273 |
| Boulder R. | N.Fk Stillaguamish R. @ 41.8 | Stillaguamish R. @ 28.6 | P.S. | 71 | 10.1-10.6 | 9/7/1999 | N48 14.027 | W121 48.306 |

| **Stream Name** | **Trib. To (at Rkm)** | **Trib. To (at Rkm)** | **Trib. To (at Rkm)** | **Reach Number** | **RKm to Rkm** | **Date Surveyed** | **Latitude (Reach Midpoint) (degrees, min., sec.)** | **Longitude (Reach Midpoint) (degrees, min., sec.)** |
|---|---|---|---|---|---|---|---|---|
| Boulder R. | N.Fk Stillaguamish R. @ 41.8 | Stillaguamish R. @ 28.6 | P.S. | 72 | 10.8-11.3 | 9/8/1999 | N48 13.210 | W121 46.912 |
| Hoh R. | Pacific Ocean | | | 77 | 56.3-59 | 9-33-99 | N47 51.82 | W123 54.90 |
| Queets R. | Pacific Ocean | | | 78 | 38.3-41.7 | 8-16-99,10-18-99 | N47 37.62 | W123 59.95 |
| Sams Cr. | Queets R. @ 23.0 | Pacific Ocean | | 79 | 0.25-0.45 | 10/19/1999 | N47 37.276' | W124 0.699' |
| White R. | Puyallup R. @ 16.6 | P.S. | | 80 | 111.2-114.1 | 9/14/1999 | N46 53.988' | W121 34.599' |
| Frying Pan Cr. | White R.@113.1 | Puyallup R. | Commencement Bay | 81 | 0.85-1.65 | 9/13/1999 | N46 53.094 | W121 36.711 |
| Ingalls Cr. | Peshastin Cr. @ 14.2 | Wenatchee R. @27.1 | Columbia R. @ 743 | 99 | 1.69-2.39 | 10/4/1999 | N47 27.541' | W120 41.110' |
| Bumping R. | Naches R. @45.8 | Yakima R. @80.25 | Columbia R. @321 | 101 | 36.0-36.2 | 10/16/1999 | N46 50.13' | W121 22.36 |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Bumping R. | Naches R. @45.8 | Yakima R. @80.25 | Columbia R. @321 | 102 | 35.7-35.9 | 10/16/1999 | N46 49.855' | W121 22.669' |
| Bumping R. | Naches R. @45.8 | Yakima R. @80.25 | Columbia R. @321 | 103 | 36.7-36.9 | 10/16/1999 | N46 49.388' | W121 22.846' |
| Bogachiel R. | Pacific Ocean | | | 115 | 27.1-28.9 | 10/25/1999 | N47 52.930 | W124 13.756 |
| Sunrise Cr. | White R.@100.8 | Puyallup R. @16.4 | Puget Sound | 144 | 4.84-6.0 | 9/23/1999 | N46 56.098 | W121 34.409 |
| Quinault R. | Pacific Ocean | | | 180 | 22.04-23.9 | 9/25/1999 | N47 33.486 | W123 36.651 |
| Icicle Cr. | Wenatchee R @35.72 | Columbia R. @753.7 | Pacific O. | 185 | 19.1-19.7 | 10/2/1999 | N47 37.010' | W120 57.323 |
| Mill Cr. | Lankam Cr. @0.3 | Nason Cr. @ 32.24 | Wenatchee R. | 230 | 7.8-8.0 | 11/1/1999 | N47 43.574 | W121 4.191 |
| Early Winters Cr. | Methow R.@111.0 | Columbia R. @ 833 | | 269 | 24.9-25.1 | 11/2/1999 | N48 30.825 | W121 38.486 |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Bridge Cr. | Stehekin R. @22.5 | Lake Chelan | Columbia R. | 270 | 19.2-19.5 | 11/2/1999 | N48 30.309 | W120 43.312 |
| Blum Cr. | Baker R. @ 33.3 | Skagit R. @ 88.0 | P.S. | 275 | 0.3-0.5 | 11/5/1999 | N48 45.186' | W121 32.610' |
| Unnamed | Quinalt R. @86.0 | Pacific Ocean | | 277 | 0.3-0.9 | 11/6/1999 | N47 33.113 | W123 37.427 |
| Unnamed | NF Quinault R. @4.6 | Quinault R. 82 | Pacific Ocean | 278 | 0.1-0.4 | 11/6/1999 | N47 34.132 | W123 39.266 |
| Snow Cr. | Icicle Cr. @8.73 | Wenatchee R. @41.2 | Columbia R. @743 | 288 | 2.3-3.0 | 10/3/1999 | N47 31.691 | W120 42.8791 |
| Mission Cr. | Wenatchee R. @ 16.0 | Columbia R. @743 | Pacific | 311 | 16.52-17.5 | 8/28/2000 | N47 23.670 | W120 30.086 |
| Unnamed | Mission Cr. @ 2.91 | Wenatchee R. @16.0 | Columbia R. @753.7 | 312 | 0.01-0.11 | 8/28/2000 | N47 22.430' | W120 30.862' |
| Unnamed | Mission Cr. @ 3.17 | Wenatchee R. @16.0 | Columbia R. @743 | 313 | 0.05-0.25 | 8/28/2000 | N47 22.266' | W120 30.802 |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Unnamed | Mission Cr. @ 7.39 | Wenatchee R. @16.0 | Columbia R. @753.7 | 314 | 0.025-0.125 | 8/29/2000 | N47 20.439 | W120 29.356 |
| Mission Cr. | Wenatchee R. @16.0 | Columbia R. @ 743 | Pacific | 315 | 7.39-8.29 | 8/29/2000 | N47 20.450 | W120 29.248 |
| Unnamed | Mission Cr. @6.68 | Wenqatchee R. @16.0 | Columbia R. @753.7 | 316 | 0.16-0.216 | 8/29/2000 | N47 20.554 | W120 29.692 |
| Unnamed | E.Fk Mission Cr. @ 2.7 | Mission Cr. @16.42 | Wenatchee R. @16 | 318 | 0.15-0.55 | 8/31/2000 | N47 22.558 | W120 28.892 |
| Rag Cr. | E.Fk Mission Cr. @ 2.31 | Mission Cr. @16.42 | Wenatchee R. @ 16.0 | 319 | 0.02-0.42 | 8/31/2000 | N47 22.769' | W120 28.977' |
| Unnamed | Sand Cr. @ 1.6 | Mission Cr. @ 12.3 | Wenatchee r. @ 16.0 | 320 | 0.70-0.27 | 8/31/2000 | N47 25.880' | W120 31.603' |
| Bridge Cr. | Icicle Cr. @15.4 | Wenatchee R. @ 41.2 | Columbia R. @ 753.7 | 321 | 0.13-0.26 | 8/31/2000 | N47 33.766' | W120 46.736 |
| Chatter Cr. | Icicle Cr. @ 27.1 | Wenatchee R. @41.2 | Columbia R. @743 | 322 | 0.67-0.87 | 8/31/2000 | N47 36.743' | W120 53.328' |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Surprise Cr. | Tye R. @ 13.4 | S.Fk. Skykomish R. @ 31.5 | Skykomish R. @ 19.63 | 330 | 0.7-1.1 | 9/2/2000 | N47 42.328' | W121 9.395 |
| Unnamed | Surprise Cr. @ 4.9 | Skykomish R. @ 80.47 | Snohomish R. @ 41.8 | 331 | 0.45-0.65 | 9/3/2000 | N47 39.672' | W121 8.707' |
| Unnamed | Surprise Cr. @ 4.9 | Skykomish R. @ 80.47 | Snohomish R. @ 41.8 | 332 | 1.1-1.2 | 9/3/2000 | N47 39.735 | W121 8.353 |
| Unnamed | Surprise Cr. @ 4.9 | Skykomish R. @ 80.47 | Snohomish R. @ 41.8 | 333 | 0.21 to 0.61 | 9/3/2000 | N47 40.114 | W121 8.258 |
| Cutthroat Cr. | Early Winters Cr. @ 18.64 | Methow R. @ 111 | Columbia R. @ 833 | 340 | 3.83 - 4.23 | 9/5/2000 | N48 32.858 | W121 40.373 |
| Pine Cr. | Early Winters Cr. @17.0 | Methow R @ 111.0 | Columbia R. @833.0 | 341 | 0.2 to 0.4 | 9/5/2000 | N48 34.693 | W120 37.693 |
| Cutthroat Cr. | Early Winters Cr. @ 18.64 | Methow R. @ 111.0 | Columbia R. @833 | 342 | 4.68-4.78 | 9/5/2000 | N48 32.565 | W120 40.864 |

| **Stream Name** | **Trib. To (at Rkm)** | **Trib. To (at Rkm)** | **Trib. To (at Rkm)** | **Reach Number** | **RKm to Rkm** | **Date Surveyed** | **Latitude (Reach Midpoint) (degrees, min., sec.)** | **Longitude (Reach Midpoint) (degrees, min., sec.)** |
|---|---|---|---|---|---|---|---|---|
| Blue Lake Cr. | State Cr. @ 2.68 | Bridge Cr. @18.75 | Stehekin R. @ 24.75 | 344 | 1.53-1.73 | 9/6/2000 | N48 30.497 | W120 40.338 |
| Blue Lake Cr. | State Cr. @ 2.68 | Bridge Cr. @18.75 | Stehekin R. @ 24.75 | 345 | 0.26-0.96 | 9/6/2000 | N48 30.809' | W120 41.141 |
| Lewis Cr. | Granite Cr. @26 | Ruby Cr. @8.75 | Ross Lake (Skagit @ 170) | 346 | 0.01 to 0.81 | 9/6/2000 | N48 31.795 | W120 45.249 |
| Copper Cr. | Bridge Cr. @ 18.49 | Stehekin R. @24.75 | Lake Chelan @ 81.5 | 347 | 0.34-0.54 | 9/7/2000 | N48 29.526 | W120 41.971 |
| Rainy Cr. | Bridge Cr. @20.6 | Stehekin R. @24.75 | Lake Chelan @81.5 | 348 | 0.55 - 0.65 | 9/7/2000 | N48 30.324 | W120 43.739 |
| Unnamed | Bridge Cr. @ 21.27 | Stehekin R. 24.75 | Lake Chelan 81.5 | 349 | 0.18 | 9/7/2000 | N48 30.671 | W120 44.104 |
| Lake Ann Cr. | Bridge Cr. @20.64 | Stehekin R.@24.75 | Lake Chelan @81.5 | 350 | 0.5-0.6 | 9/7/2000 | N48 30.295 | W120 43.722 |
| Porcupine Cr. | Granite Cr. @ 26.25 | Ruby Cr. @8.75 | Ross Lake (Skagit @170) | 351 | 0.3-0.7 | 9/7/2000 | N48 31.869 | W120 44.741 |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Jackson Cr. | Hoh R. @37.5 | Pacific Ocean |  | 501 | 0.84-1.44 | 9/14/2000 | N47 50.990 | W123 55.117 |
| Unnamed | Hoh R. @34.8 | Pacific Ocean |  | 502 | 1.63-1.83 | 9/14/2000 | N47 50.420' | W123 55.903 |
| Unnamed | Hoh R. @34.8 | Pacific Ocean |  | 503 | 0.33-0.73 | 9/14/2000 | N47 50.769 | W123 56.539 |
| E. Twin | Twin Cr. @ 0.3 | Hoh R. @32.6 | Pacific Ocean | 504 | 0.38-0.78 | 9/12/2000 | N47 50.135 | W123 59.324 |
| Unnamed | E. Twin Cr. @0.33 | Hoh R. @32.6 | Pacific Ocean | 505 | 0.39-1.19 | 9/12/2000 | N47 50.130 | W123 59.390 |
| Twin Cr. | Hoh R. @32.6 | Pacific Ocean |  | 507 | 0.06-0.36 | 9/12/2000 | N47 49.979 | W123 59.485 |
| Cougar Cr. | Hoh R. @40.7 | Pacific Ocean |  | 508 | 0.11-0.41 | 9/13/2000 | N47 51.804 | W123 51.382 |
| Cougar Cr. | Hoh R. @40.7 | Pacific Ocean |  | 509 | 0.5-0.8 | 9/13/2000 | N47 51.922 | W123 51.922 |

| **Stream Name** | **Trib. To (at Rkm)** | **Trib. To (at Rkm)** | **Trib. To (at Rkm)** | **Reach Number** | **RKm to Rkm** | **Date Surveyed** | **Latitude (Reach Midpoint) (degrees, min., sec.)** | **Longitude (Reach Midpoint) (degrees, min., sec.)** |
|---|---|---|---|---|---|---|---|---|
| Unnamed | Hoh R. @41.85 | Pacific Ocean | | 510 | 0.02 to 0.22 | 9/13/2000 | N47 52.188 | W123 50.112 |
| Mount Tom Cr. | Hoh R. @39 | Pacific Ocean | | 511 | 0.87 | 9/13/2000 | N47 51.680 | W123 53,247 |
| Mount Tom Cr. | Hoh R. @39.0 | Pacific Ocean | | 512 | 1.8-2.4 | 9/13/2000 | N47 51.361 | W123 52.923 |
| Mount Tom Cr. | Hoh R. @39 | Pacific Ocean | | 513 | 2.67 to 3.67 | 9/13/2000 | N47 51.158 | W123 57.319 |
| Cannings Cr. | Quinault R. @47.1 | Pacific Ocean | | 515 | 0.23-0.33 | 9/14/2000 | N47 31.926 | W123 40.606 |
| Cannings Cr. | Quinault R. @47.1 | Pacific Ocean | | 516 | 0.33-0.43 | 9/14/2000 | N47 31.878 | W123 40.597 |
| Sloan Cr. | N.Fk. Sauk R. @ 44.2 | Sauk R. @ 64.2 | Skagit R. @ 108.0 | 601 | 10.61-10.81 | 9/21/2000 | N48 0.192 | W121 14.847 |
| Sloan Cr. | N.Fk. Sauk R. @ 44.2 | Sauk R. @ 64.2 | Skagit R. @ 108.0 | 602 | 10.81-11.41 | 9/21/2000 | N47 59.934 | W121 12.887 |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| White Chuck R. | Sauk R. @52.5 | Skagit R.@ 108 | PS | 603 | 20.23-21.0 | 9/22/2000 | N48 9.126' | W121 15.204' |
| Cougar Cr. | N.Fk. Sauk R. @ 8.0 | Sauk R. @ 64.2 | Skagit R. @ 108 | 604 | 0.013-0.213 | 9/20/2000 | N48 4.713' | W121 18.782 |
| Unnamed | Cadet Cr. @ 0.9 | Sloan Cr. @4.07 | N.F. Sauk @75.5 | 605 | 0.29-0.49 | 9/21/2000 | N48 1.321 | W121 18.210 |
| NF Sauk R. | Sauk R. @ 64.2 | Skagit R. @ 108 | P.S. | 608 | 75.6-76.6 | 9/21/2000 | N48 3.211 | W121 16.935 |
| NF Sauk R. | Sauk R. @ 64.2 | Skagit R. @ 108 | P.S. | 609 | 76.6-77.1 | 9/21/2000 | N48 3.190 | W121 16.422 |
| Lost Cr. | N.F. Sauk R. @ 6.91 | Sauk R. @ 64.2 | Skagit R. @ 108 | 610 | 4.3-4.78 | 9/19/2000 | N48 6.149 | W121 15.970 |
| Lost Cr. | N.F. Sauk R. @ 6.91 | Sauk R. @ 64.2 | Skagit R. @ 108 | 611 | 4.78-5.33 | 9/19/2000 | N48 6.164 | W121 16.128 |
| Suiattle R. | Sauk R. @23.4 | Skagit R. @108 | P.S. | 612 | 43.1-44.8 | 9/22/2000 | N48 13.906' | W121 10.595 |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Unnamed | Cle Elum R. @ 36.1 | Yakima R. @ 298.8 | Columbia R. @ 537 | 701 | 0.1-0.2 | 9/28/2000 | N47 34.248 | W121 7.691 |
| Delate Cr. | Cooper R. @14.79 | Cle Elum R. @30.9 | Yakima R. @298.8 | 703 | 0.0-0.06 | 9/29/2000 | N47 27.350 | W121 12.914 |
| Spanish Cr. | Icicle Cr. @ 35.72 | Wenatchee R. @41.19 | Columbia R. @753.7 | 706 | 0.24-0.44 | 10/1/2000 | N47 38.203' | W120 57.595 |
| Lemah Cr. | Cooper R. @16.57 | Cle Elum R. @30.9 | Yakima R. @298.9 | 708 | 3.2-3.7 | 9/29/2000 | N47 28.578' | W121 15.121 |
| Chiwaukum Cr. | Wenatchee R. @ 57.76 | Columbia R. @ 753.7 | Pacific Ocean | 710 | 2.08-2.28 | 10/1/2000 | N47 41.219 | W120 44.794' |
| Huckleberry Cr. | White R.@ 85.4 | Puyallup R. @16.6 | Commencement Bay, Puget Sound | 720 | 9.8-10.1 | 10/3/2000 | N46 59.781' | W121 37.142' |
| Buck Cr. | Chiwawa R. @55.25 | Wenatchee R. @ 77.9 | Columbia R. @753.6 | 721 | 0.3-0.4 | 10/6/2000 | N48 6.428 | W120 53.512 |
| Buck Cr. | Chiwawa R. @55.25 | Wenatchee R. @ 77.9 | Columbia R. @753.6 | 722 | 0.2-0.3 | 10/6/2000 | N48 6.426 | W120 53.402' |

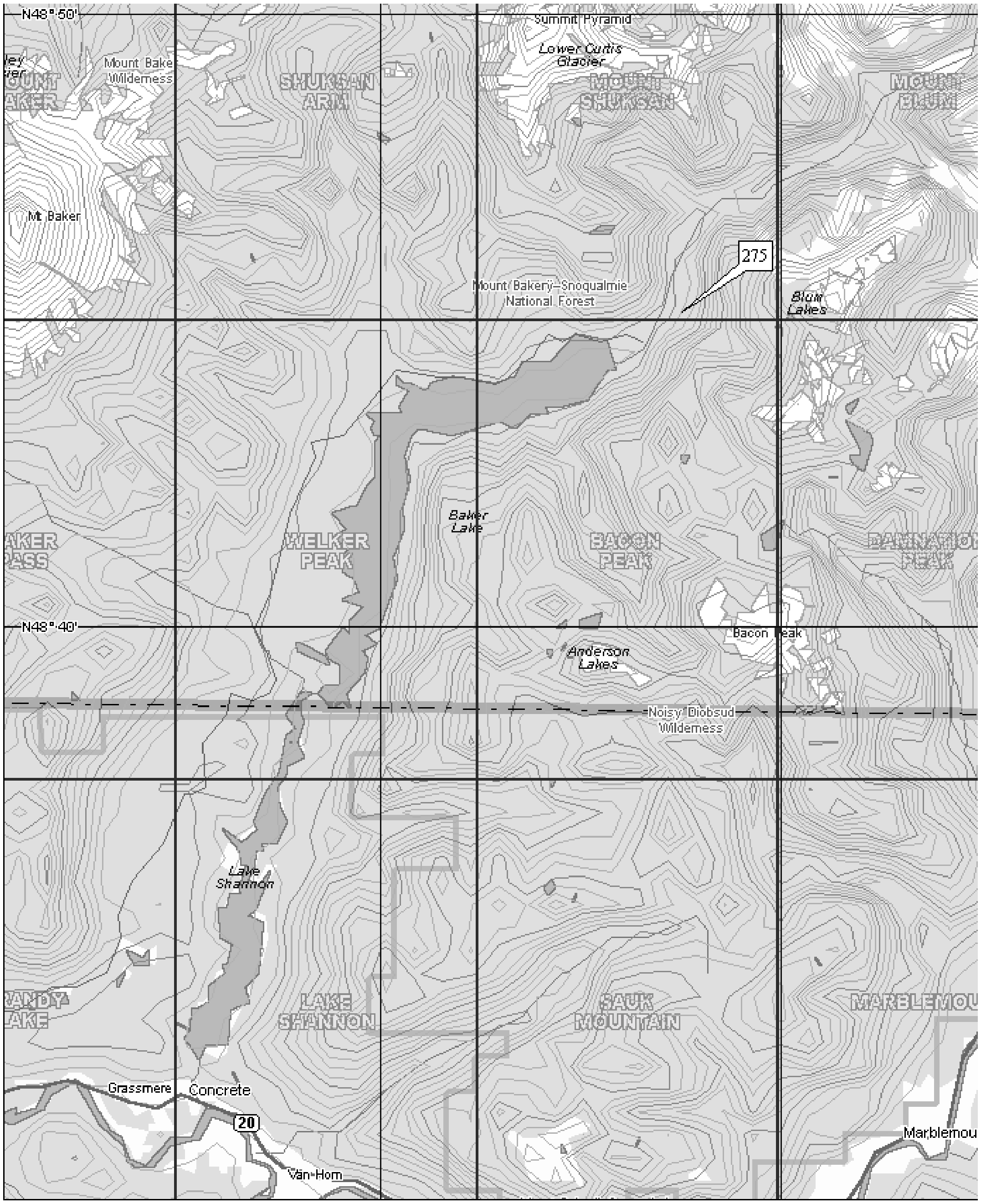
| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Unnamed | Chiwawa R. @ 49.0 | Wenatchee R. @77.9 | Columbia R. @ 753.7 | 723 | 0.97-1.27 | 10/6/2000 | N48 3.979' | W120 51.033' |
| Anthem Cr. | Entiat R. @66.83 | Columbia R. @ 778.1 | Pacific | 724 | 0.01-0.31 | 10/7/2000 | N48 2.713' | W120 41.562' |
| Entiat R. | Columbia R. @778.1 | Pacific | | 725 | 63.21-63.51 | 10/7/2000 | N48 1.491 | W120 39.468 |
| Chinook Cr. | Ohanepecosh R. @ 15.94 | Cowlitz R. @ 215.6 | Columbia R. @ 109.5 | 24a | 4.8-5.5 | 7/12/1999 | N46 50.258' | W121 32.332' |
| Falls Cr. | Ohanepecosh R. @14.05 | Cowlitz R. @215.6 | Columbia R. @109.5 | 27a | 0.7-0.9 | 8/3/1999 | N46 45.845' | W121 33.718 |
| Falls Cr. | Ohanepecosh R. @14.05 | Cowlitz R. @215.6 | Columbia R. @109.5 | 28a | 1.06-1.26 | 8/4/1999 | N46 45.915' | W121 33.932' |
| Ollallie Cr. | Ohanepeocsh R. @ 12.49 | Cowlitz R. @ 215.6 | Columbia R. @ 109.45 | 29a | 0.2-0.3 | 8/4/1999 | N46 46.449 | W121 33.359 |
| Unnamed | E.Fk Mission Cr. @1.72 | Mission Cr. @16.42 | Wenatchee R. @16 | 319a | 0.13-0.23 | 8/31/2000 | N47 22.807' | W120 29.392 |

| **Stream Name** | **Trib. To (at Rkm)** | **Trib. To (at Rkm)** | **Trib. To (at Rkm)** | **Reach Number** | **RKm to Rkm** | **Date Surveyed** | **Latitude (Reach Midpoint) (degrees, min., sec.)** | **Longitude (Reach Midpoint) (degrees, min., sec.)** |
|---|---|---|---|---|---|---|---|---|
| Ohanepecosh R. | Cowlitz R. @ 215.6 | Columbia R. @ 109.45 | Pacific | 31a | 15.7-15.9 | 10/10/1999 | N46 46.336 | W121 33.007 |
| Ohanepecosh R. | Cowlitz R. @ 215.6 | Columbia R. @ 109.45 | Pacific | 31b | 15.77-15.97 | 10/10/1999 | N46 46.670 | W121 33.219 |
| Unnamed | Ohanepecosh R. @ 15.63 | Cowlitz R. @ 215.6 | Columbia R. @ 109.45 | 33a | 0.2-0.3 | 8/3/1999 | N46 47.606 | W121 33.411 |
| Unnamed | Cle Elum R. @56.4 | Yakima R. @298.8 | Columbia R. @537.7 | 39a | 0.0-0.2 | 8/10/1999 | N47 44.445 | W121 6.771' |
| Ranger Cr. | Carbon R. @ 43.04 | Puyallup R. @28.9 | P.S. | 3a | 2.32-2.52 | 7/12/1999 | N46 58.798 | W121 51.502' |
| Unnamed | Cle Elum R. @ 57.4 | Yakima R. @ 298.8 | Columbia R. @537.7 | 41a | 0.3-0,4 | 8/9/1999 | N47 33.618' | W121 66.840 |
| Unnamed | Cle Elum R. @59.0 | Yakima R. @ 298.8 | Columbia R. @537.7 | 43a | 0.1-0.2 | 8/23/1999 | N47 34.672' | W121 8.223' |
| Unnamed | Cle Elum R. @59.0 | Yakima R. @ 298.8 | Columbia R. @537.7 | 43b | .3-0.4 | 8/23/1999 | N47 34.670 | W121 8.362' |

| Stream Name | Trib. To (at Rkm) | Trib. To (at Rkm) | Trib. To (at Rkm) | Reach Number | RKm to Rkm | Date Surveyed | Latitude (Reach Midpoint) (degrees, min., sec.) | Longitude (Reach Midpoint) (degrees, min., sec.) |
|---|---|---|---|---|---|---|---|---|
| Unnamed | Cle Elum R. @59.5 | Yakima R. @ 298.8 | Columbia R. @537.7 | 44a | 0.2-0.3 | 8/18/1999 | N47 34.838' | W121 8.255' |
| Unnamed | Cle Elum R.@59.5 | Yakima R. @56.0 | Columbia R.@ 537.7 | 44b | 59.5-59.7 | 8/18/1999 | N47 34.824 | W121 8.421 |
| Chiwawa R. | Wenatchee R. @ 77.9 | Columbia R. @753.7 | Pacific | 50a | 50.1-50.6 | 8/30/1999 | N48 5.199' | W120 51.951' |
| White R. | Puyallup R. @ 16.6 | P.S. | | 80a | 111.0-111.2 | 9/15/1999 | N46 53.694' | W121 35.507 |
| Laughingwater Cr. | Ohanepecosh R. @ 9.1 | Cowlitz R. @ 215.6 | Columbia R. @109.45 | A-1 | 1.64-1.8 | 8/5/1999 | N46 45.260' | W121 32.576' |
| Laughingwater Cr. | Ohanepecosh R. @ 9.1 | Cowlitz R. @ 215.6 | Columbia R. @109.45 | A-2 | 1.8-2.0 | 8/5/1999 | N46 45.304' | W121 32.441' |
| Laughingwater Cr. | Ohanepecosh R. @ 9.1 | Cowlitz R. @ 215.6 | Columbia R. @109.45 | B | 1.56-1.8 | 8/6/1999 | N46 45.2441' | W121 32.599' |
| Cooper R. | Cle Elum R @ 31.24 | Yakima R. @ 298.8 | Columbia R. @537.7 | C | 2.25-2.61 | 8/26/1999 | N47 24.490' | W121 6.367' |

## *9.4.* Appendix D. Site Maps

In addition to these maps, please reference Appendix C for further detail



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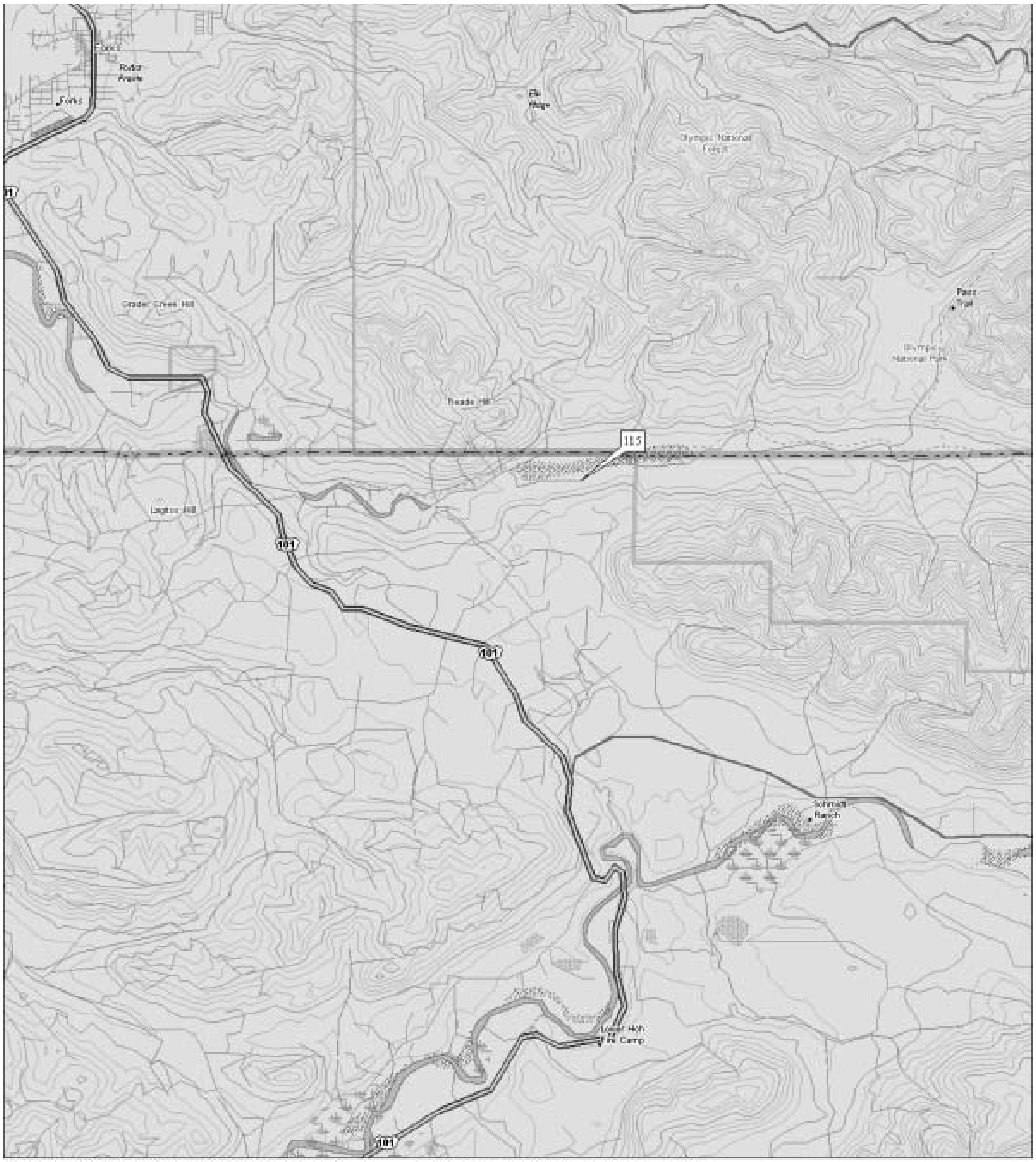
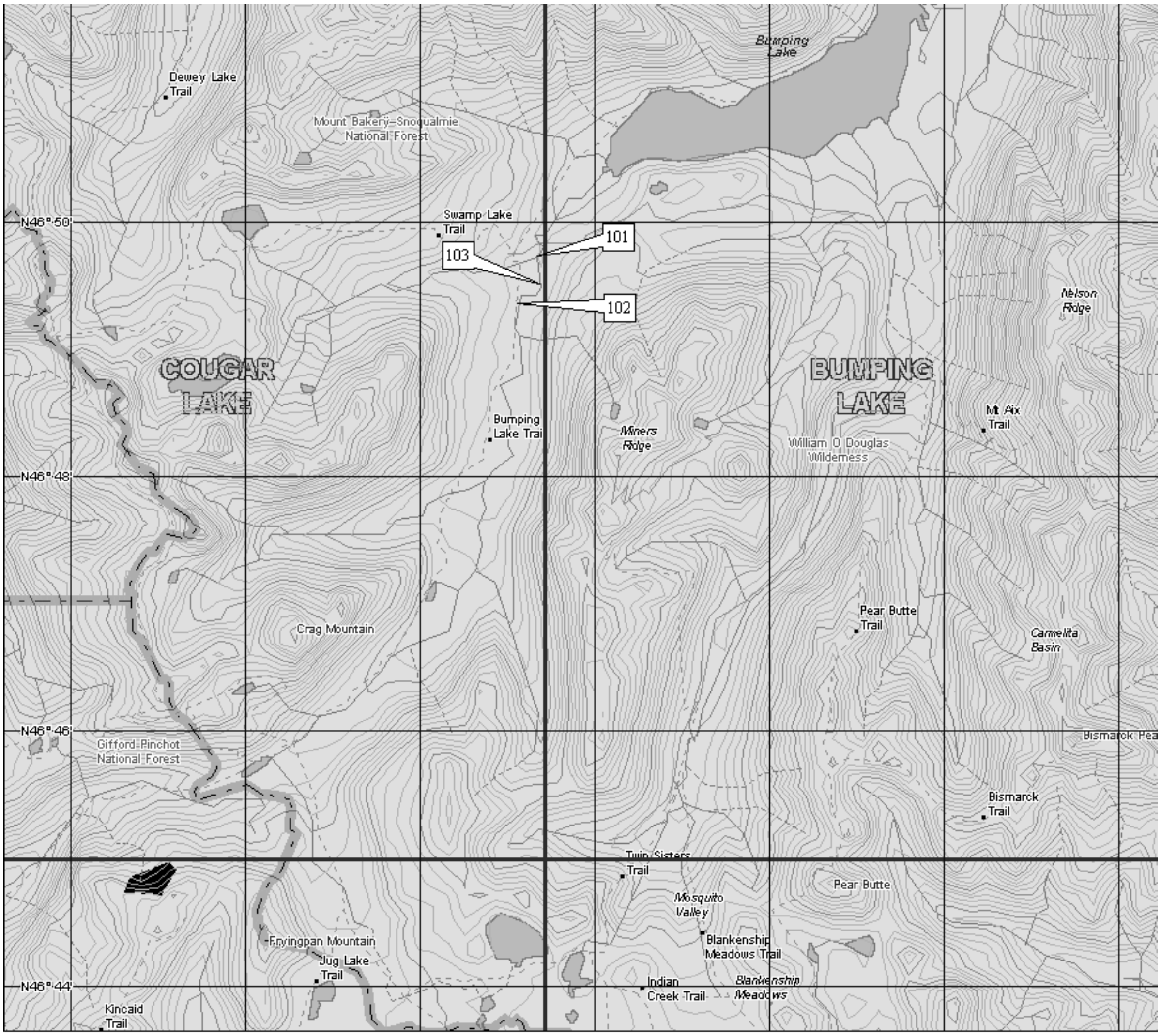
**1 mi Scale: 1 : 225,000 Detail: 9-7 Datum: WGS84**

Blum Creek, tributary to the Baker River, N. Cascades



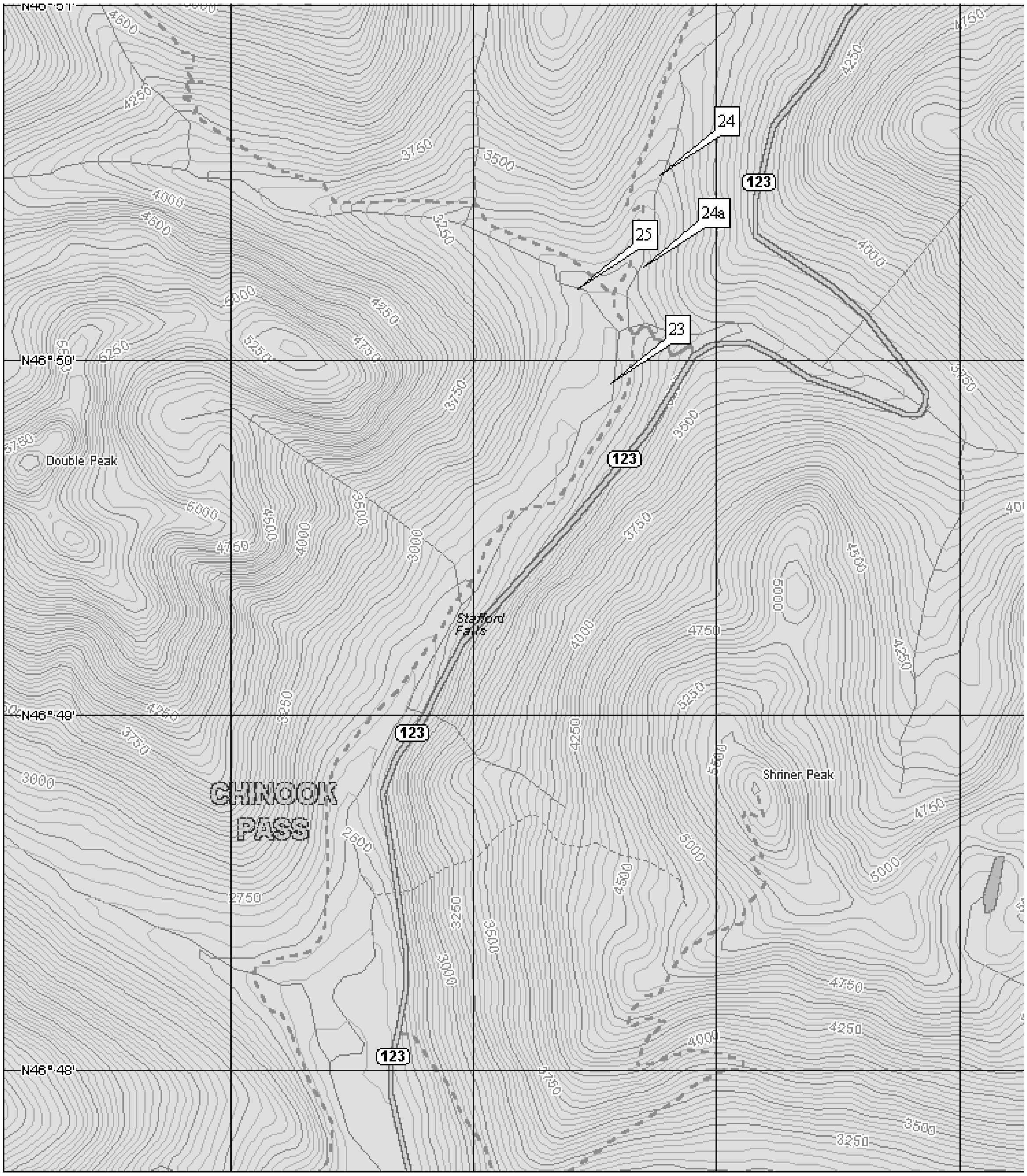
3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 3000 ft Scale: 1 : 100,000 Detail: 11-0 Datum: WGS84

Bogachiel River, western Olympic Peninsula



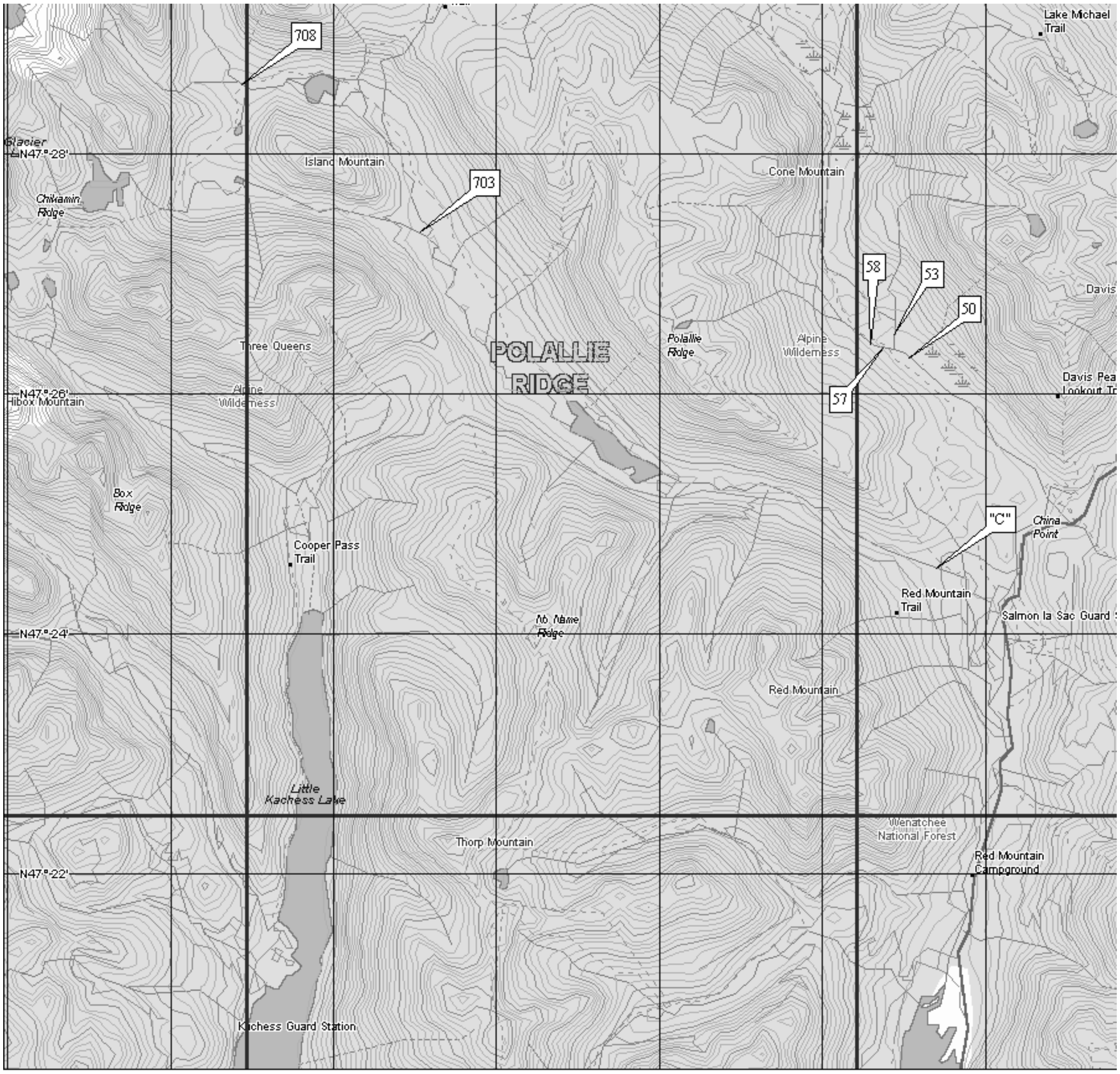
**3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096** **3000 ft Scale: 1 : 100,000 Detail: 11-0 Datum: WGS84**

Bumping Lake, south-central Cascades



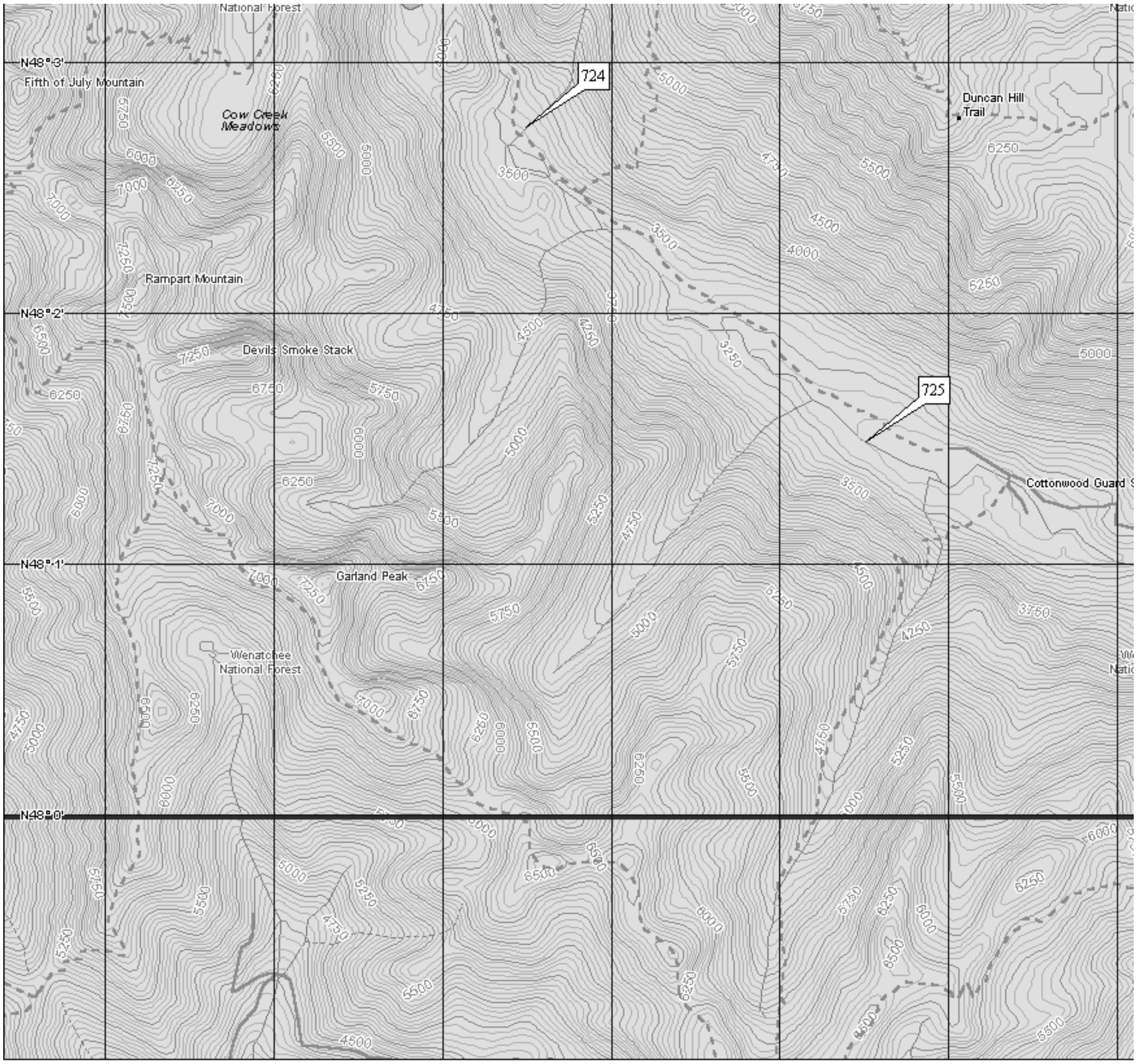
3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 1000 ft Scale: 1 : 37,500 Detail: 12-4 Datum: WGS84

Chinook Cr., Mt. Rainier N.P.



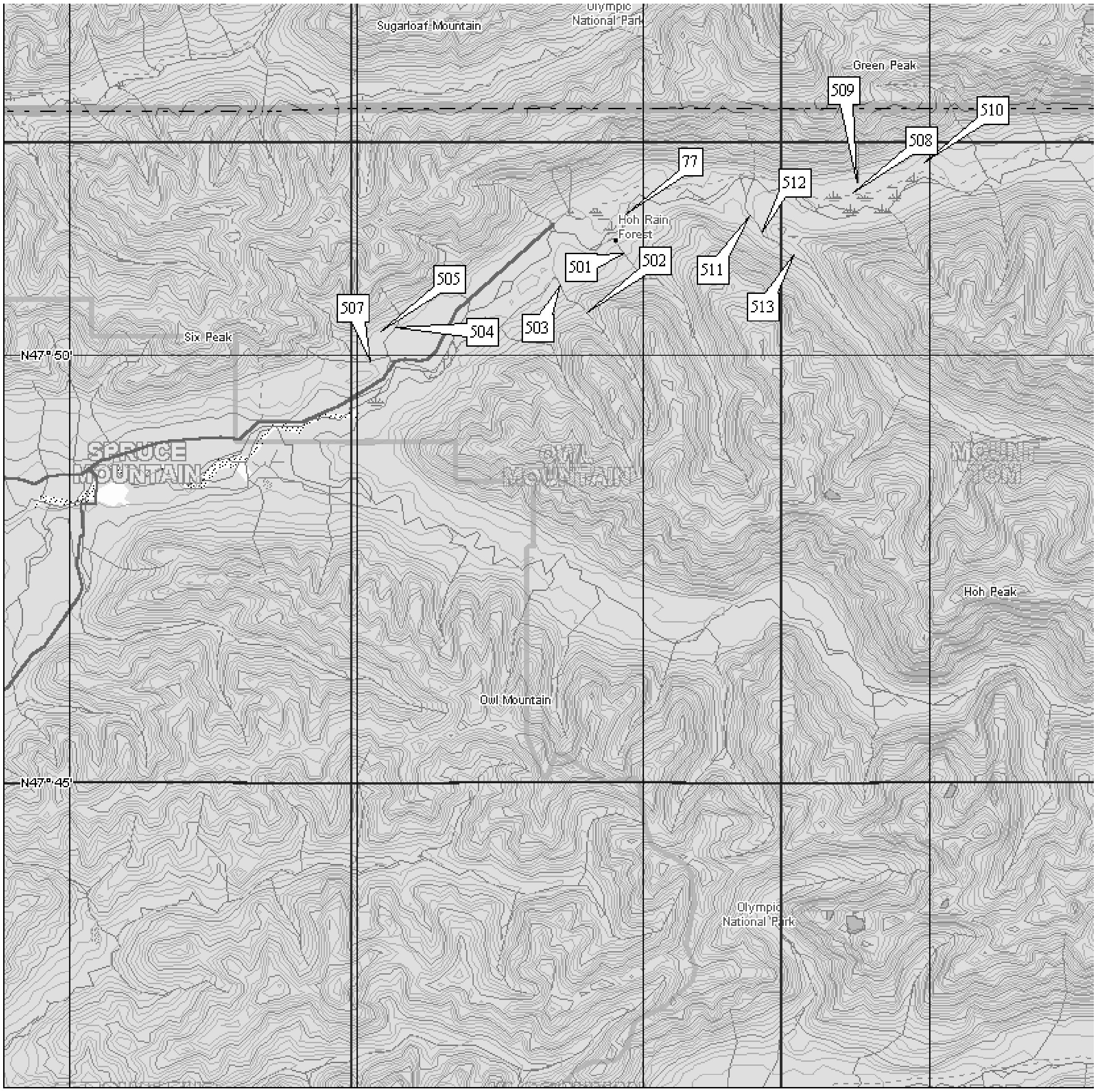
3000 ft Scale: 1 : 175,000 Detail: 10-2 Datum: WGS84

Cooper Lake, Alpine Lakes Wilderness



1500 ft Scale: 1 : 50,000 Detail: 12-0 Datum: WGS84

Entiat River

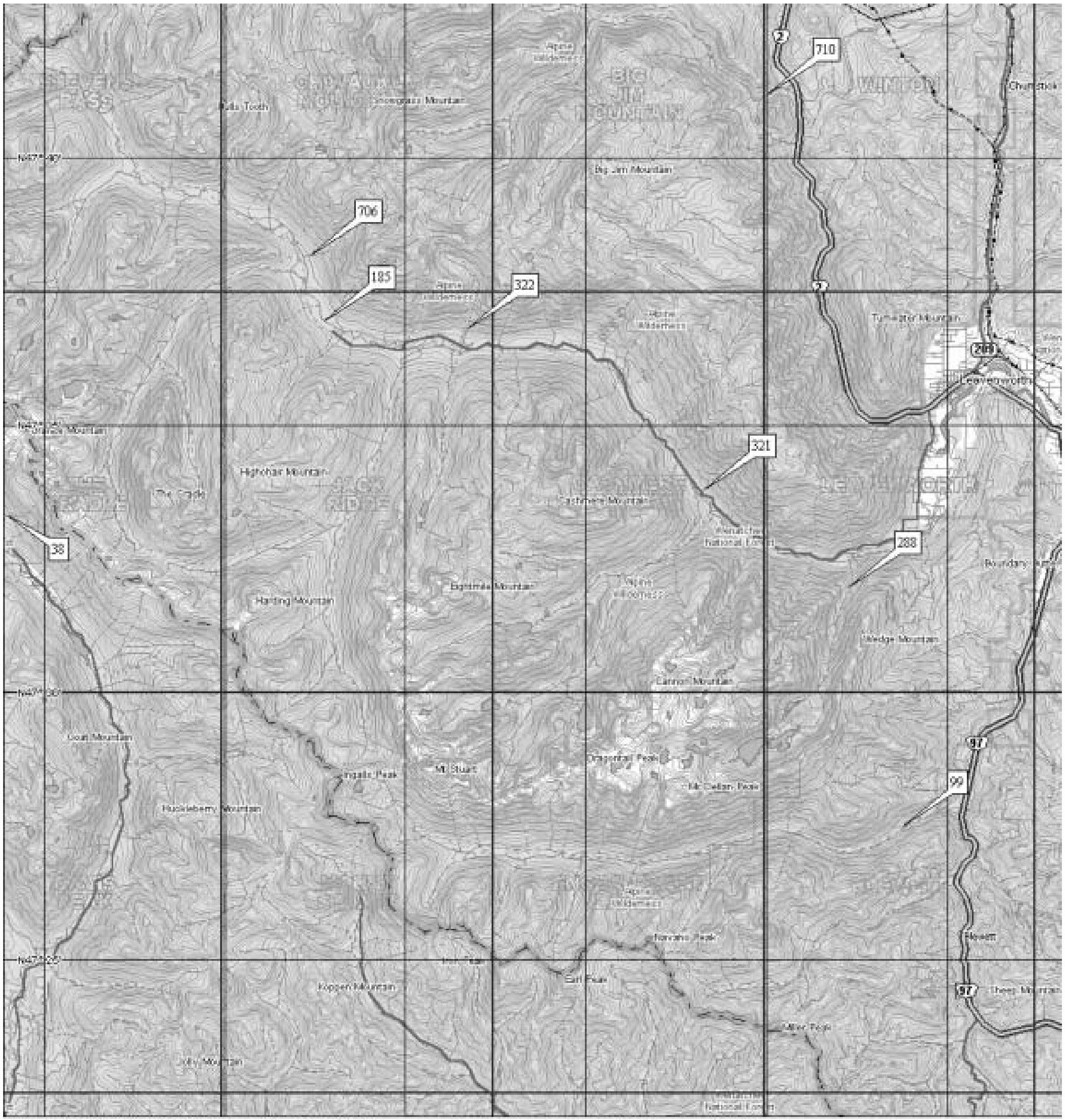


4500 ft Scale: 1 : 150,000 Detail: 10-4 Datum: WGS84

Hoh River

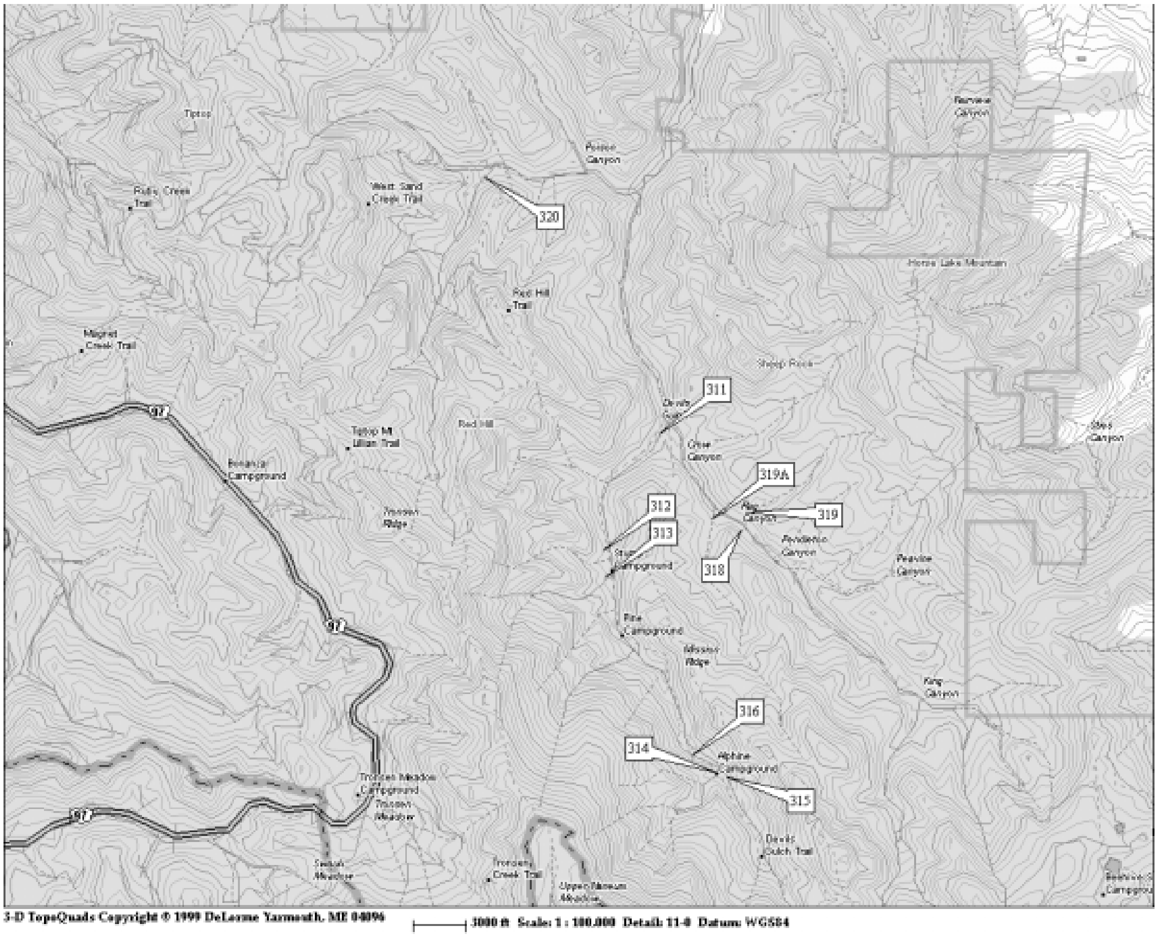
3000 ft Scale: 1 : 112,500 Detail: 10-5 Datum: WGS84

Hyas Lake, Cle Elum R., Alpine Lakes Wilderness

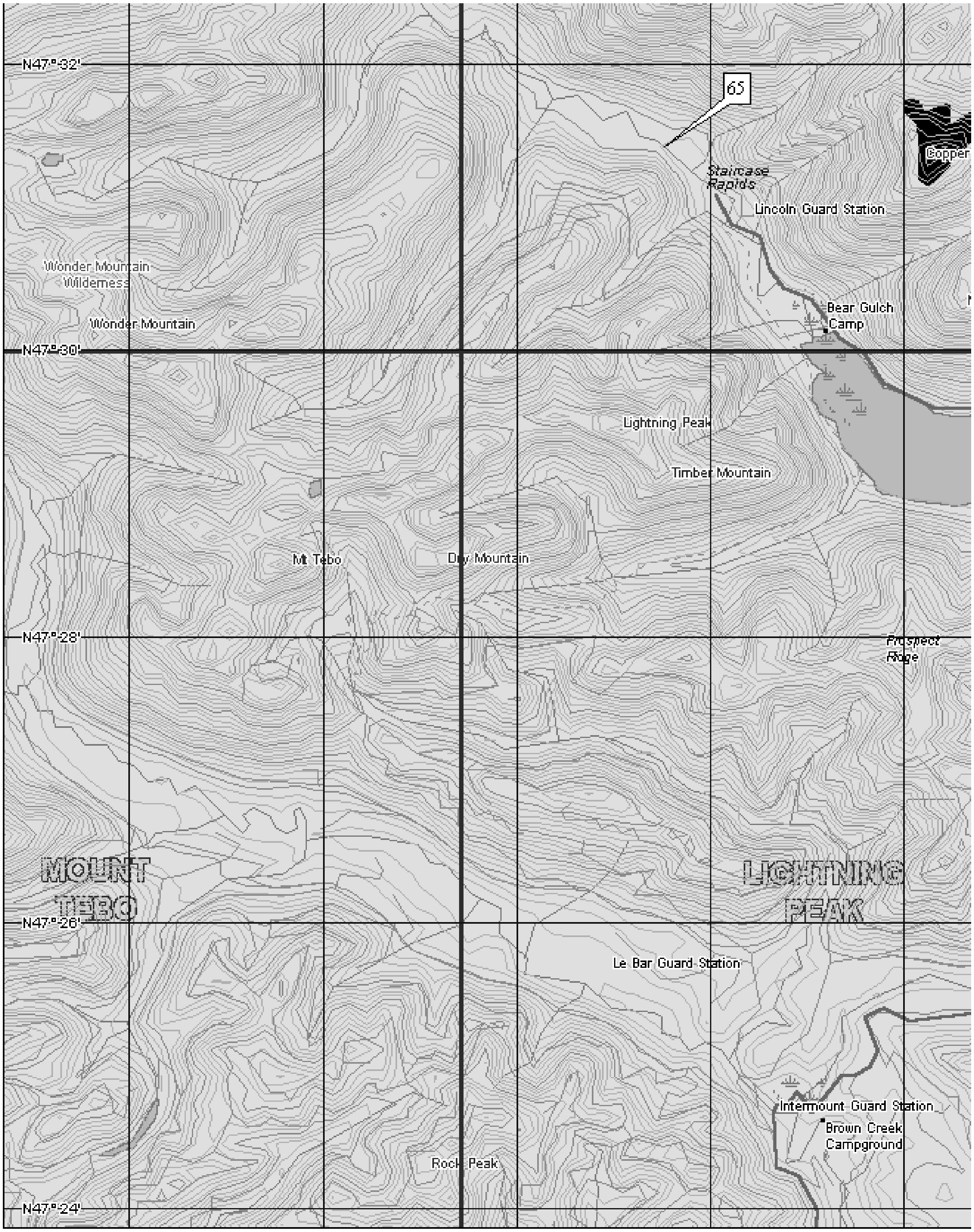


**3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096** **1 mi Scale: 1 : 200,000 Detail: 10-0 Datum: WGS84**

Icicle R., Chiwawa, and Ingalls Cr.



Mission Creek and Tributaries, Swauk Late-Successional Reserve

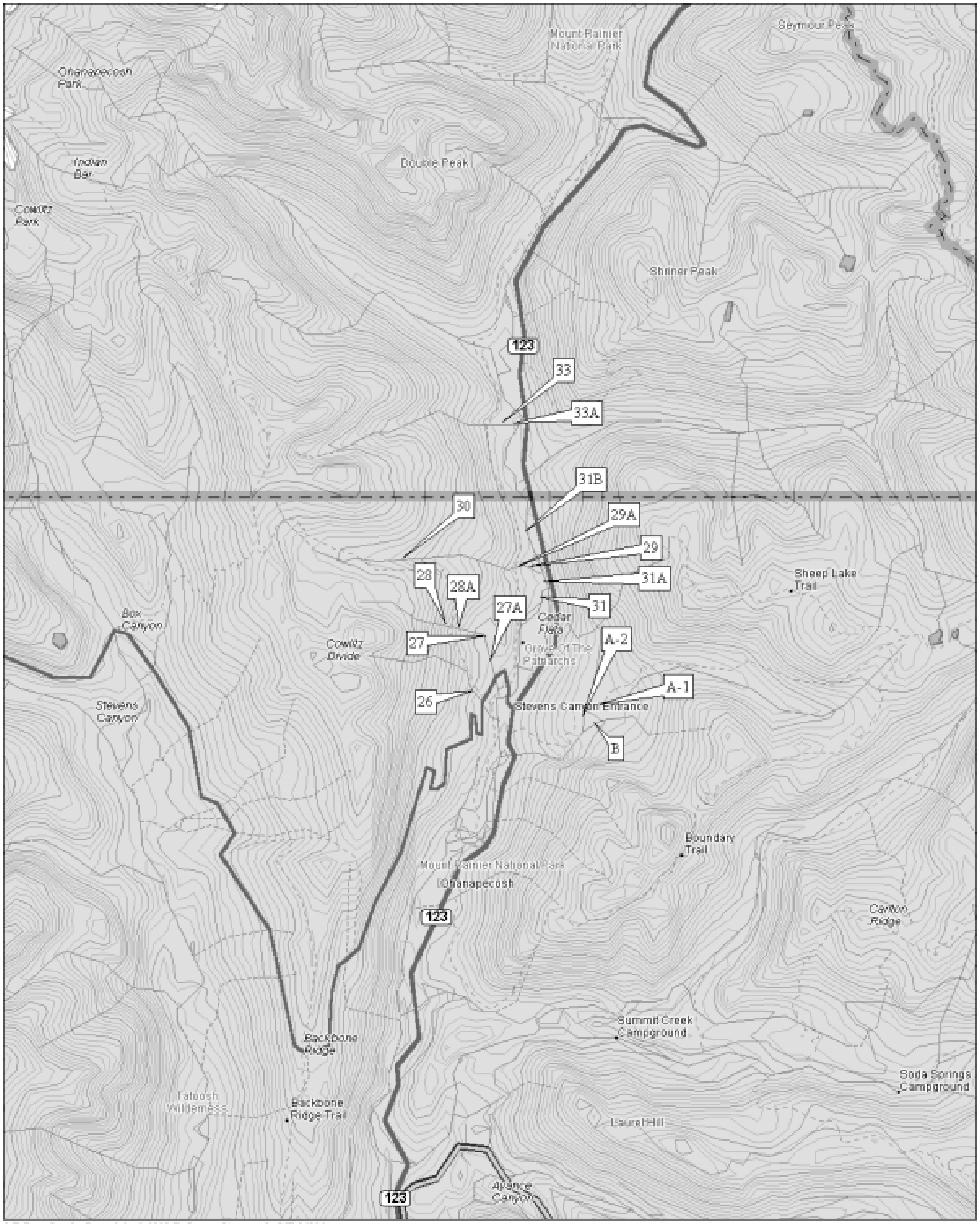


**3000 ft Scale: 1 : 100,000 Detail: 11-0 Datum:**

N.F. Skokomish R.

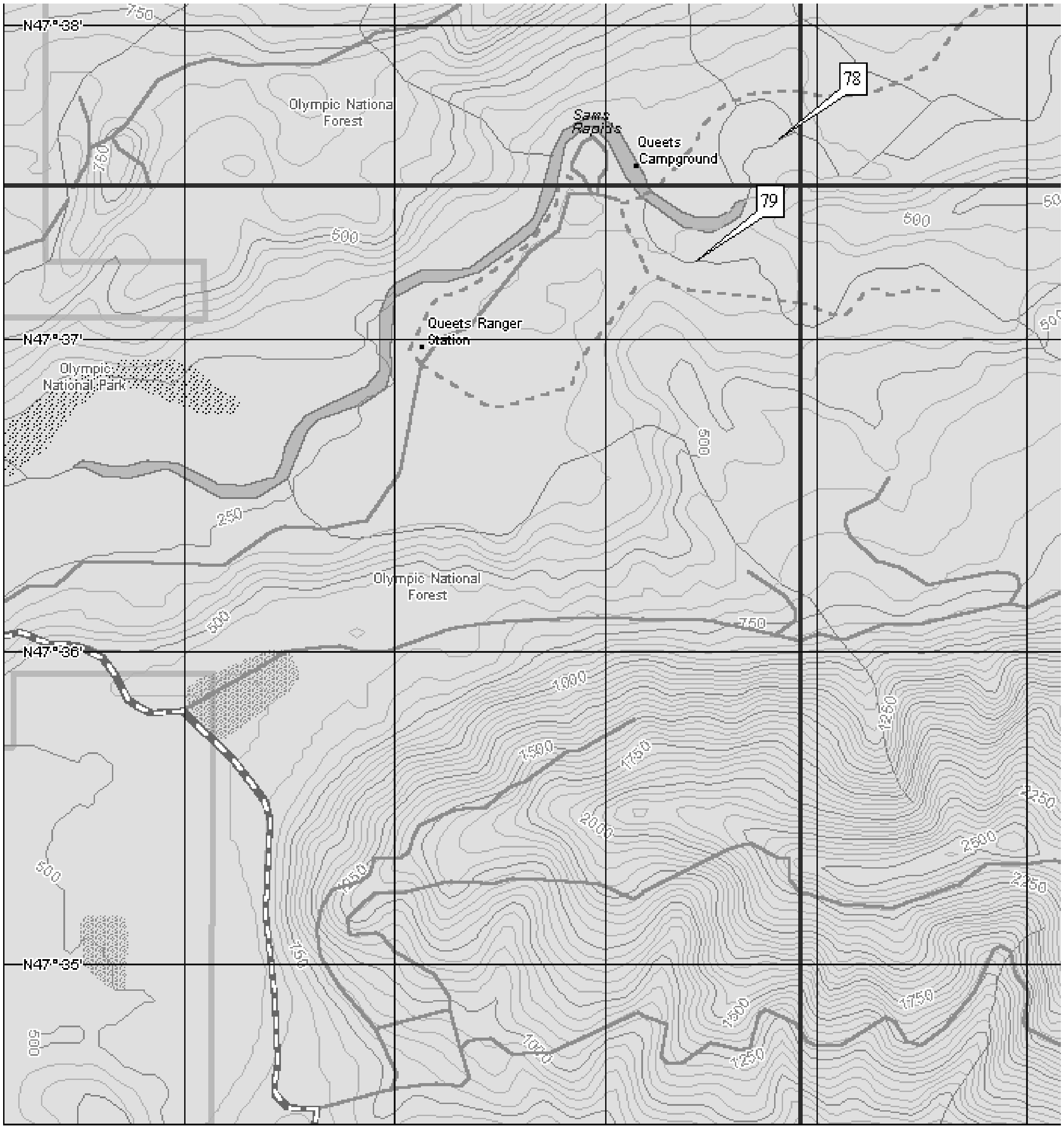
1500 ft Scale: 1 : 62,500 Detail: 11-6 Datum: WGS84

NW Mt. Rainier N.P.



2000 ft Scale: 1 : 75,000 Detail 11-0 Datum WGS84

Ohanepecosh River and Tributaries, Mt. Rainier N.P.



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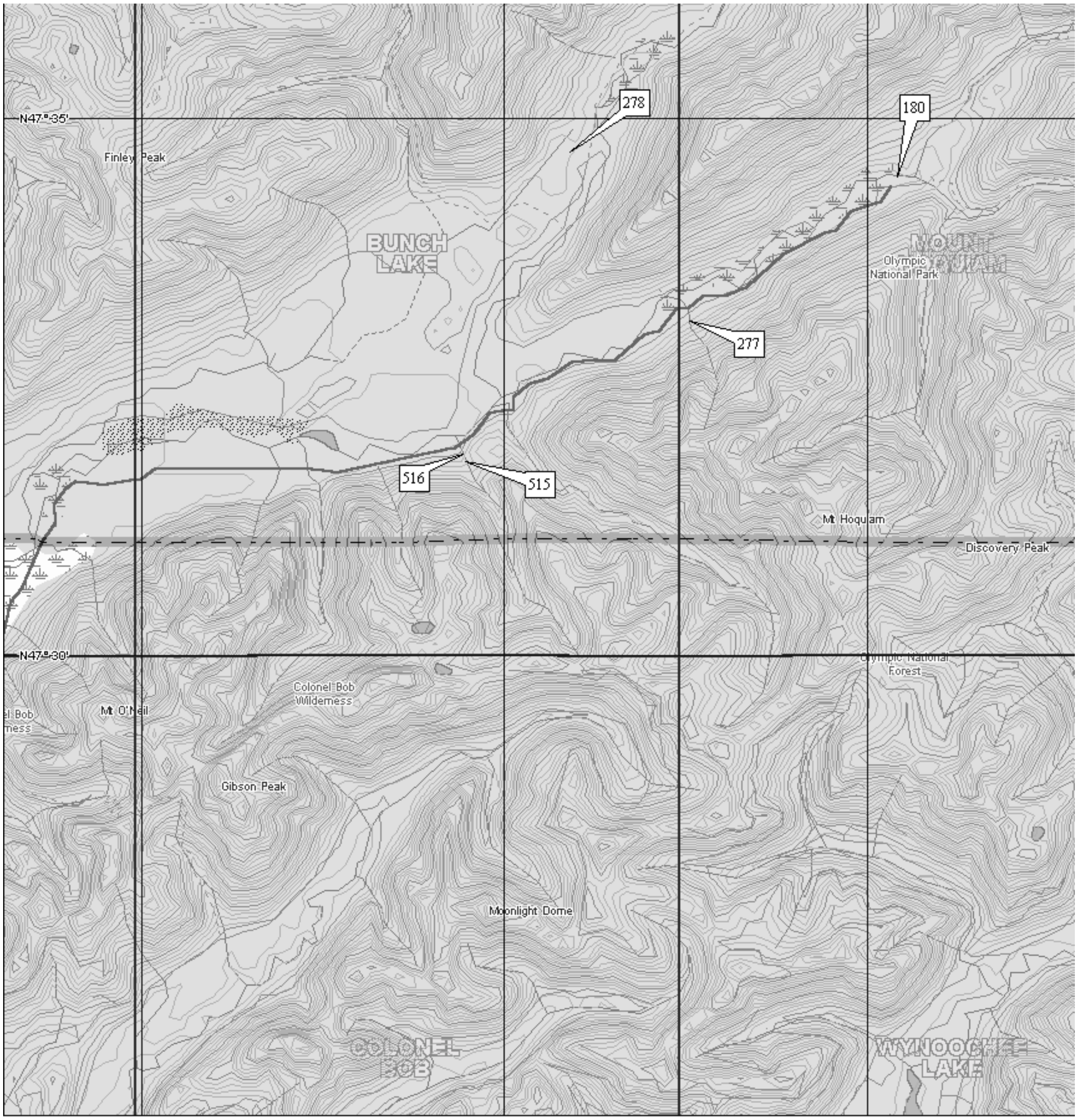
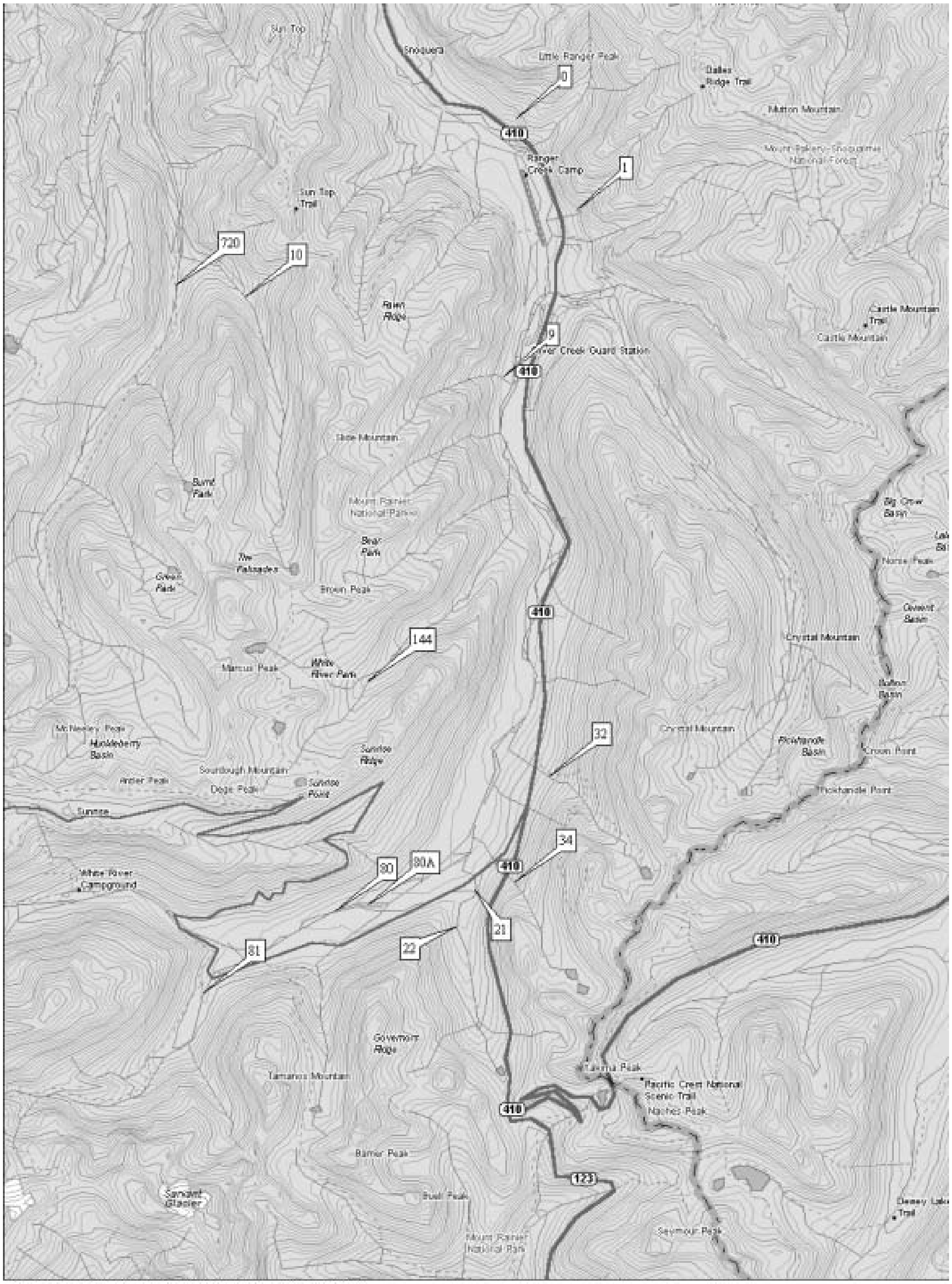
Queets R. and Sam's Creek, western Olympic Peninsula



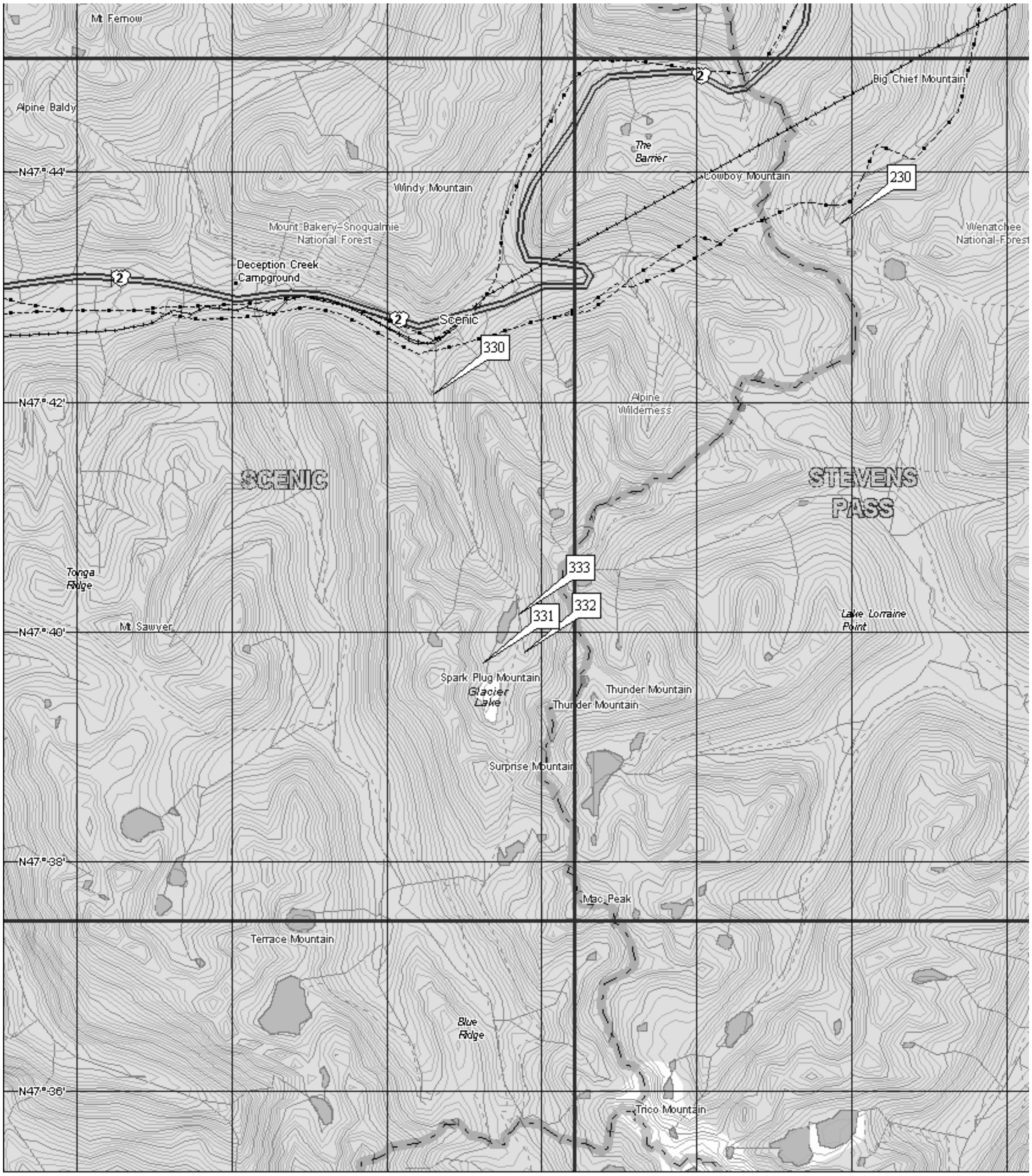
**3000 ft Scale: 1 : 112,500 Detail: 10-7 Datum: WGS84**

Quinault R. and Tributaries, western Olympic Peninsula



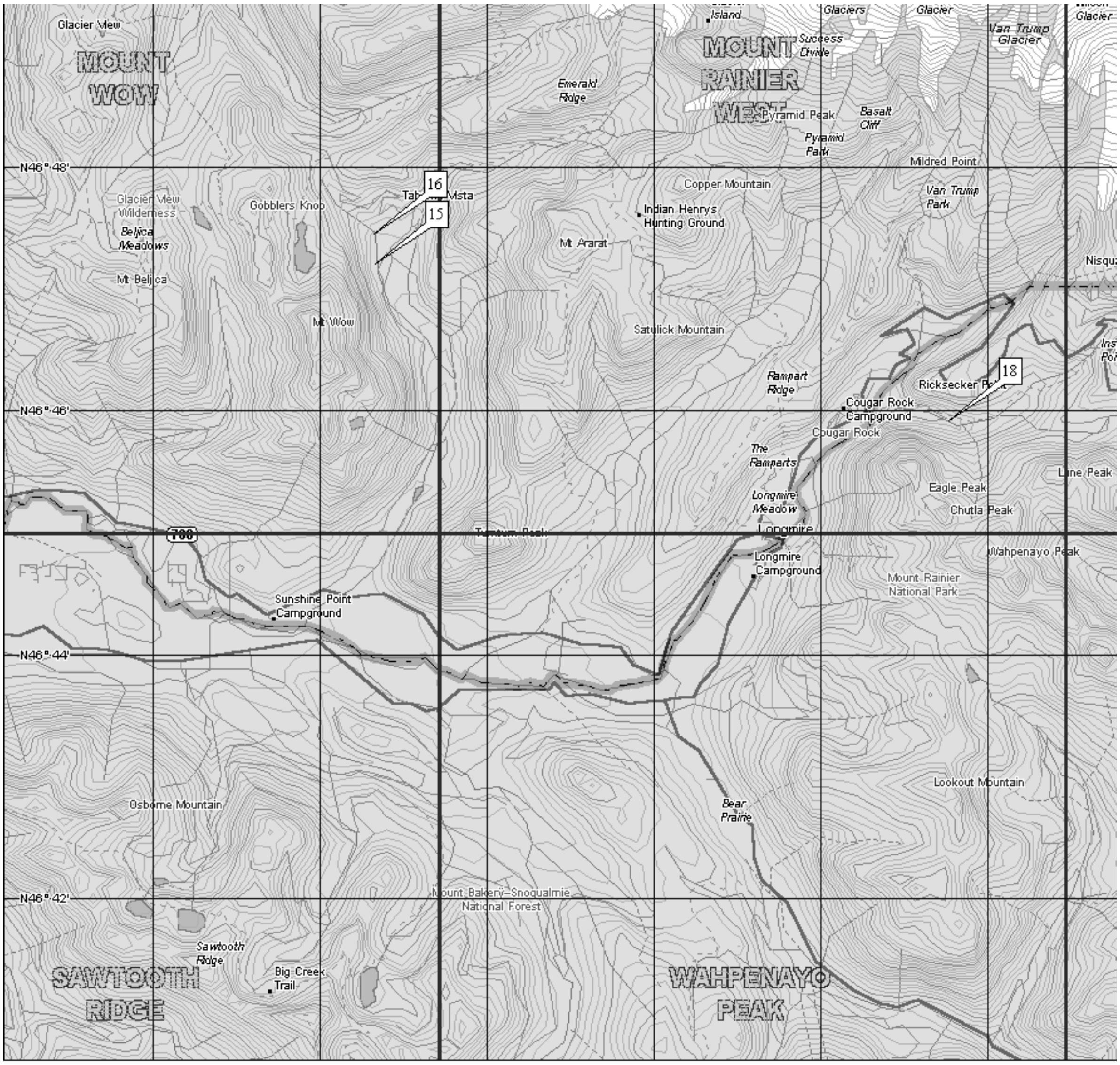
3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 3000 ft Scale: 1 : 100,000 Detail: 11-0 Datum: WGS84

Ranger Creek and White River, NE of Mt. Rainier N.P.



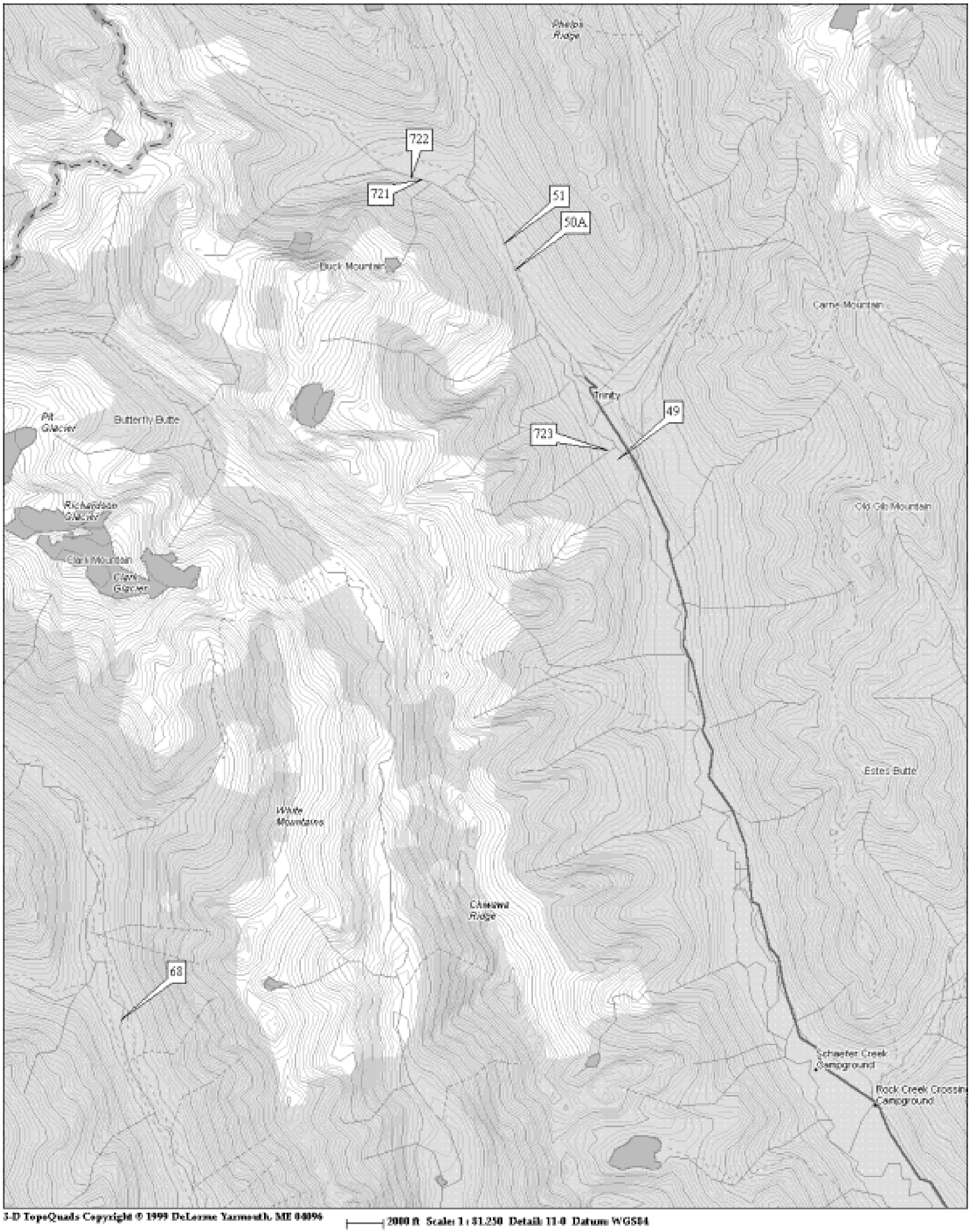
**3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096** **3000 ft Scale: 1 : 100,000 Detail: 11-0 Datum: WGS84**

Stevens Pass Area



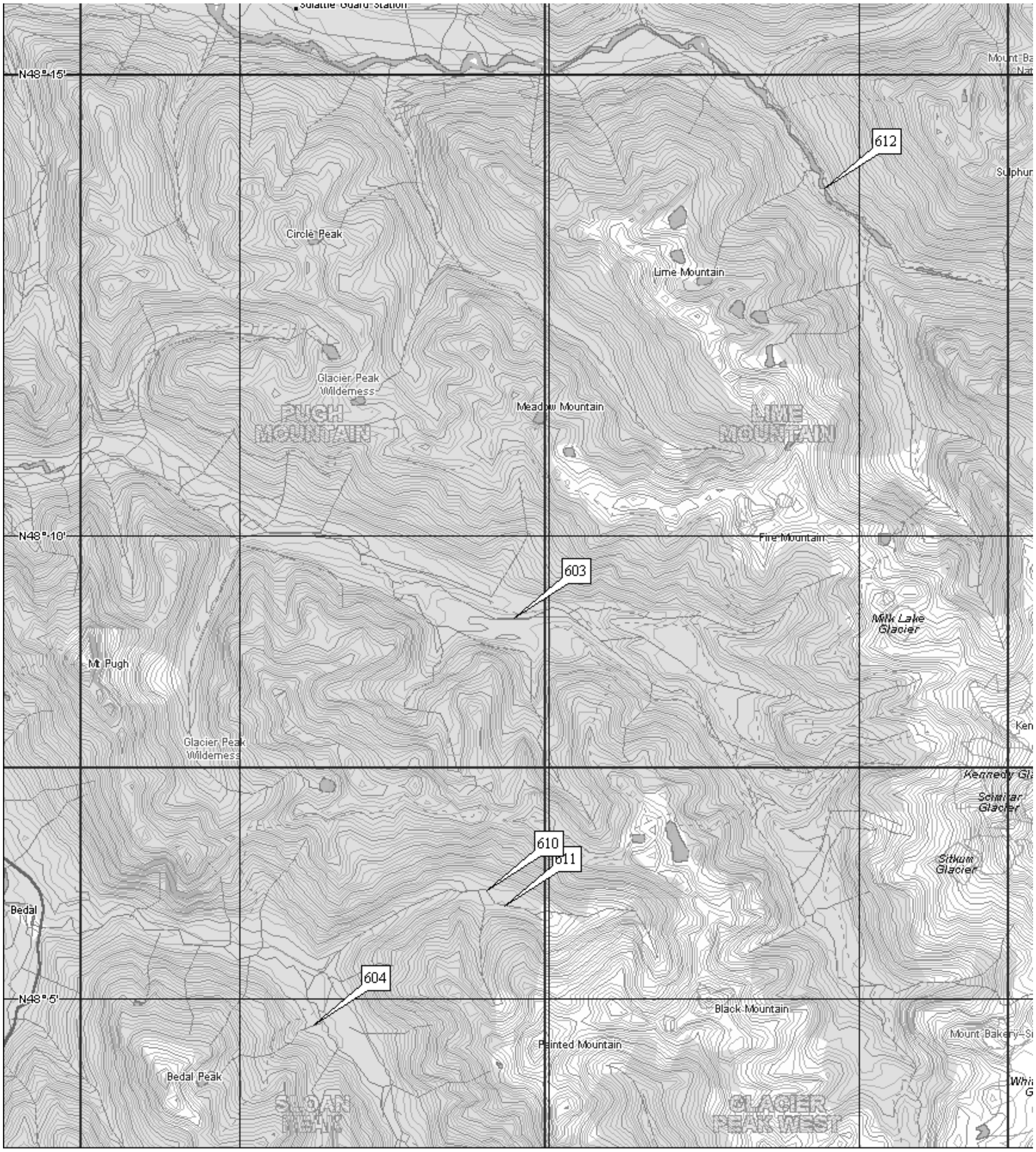
3000 ft Scale: 1 : 100,000 Detail: 11-0 Datum: WGS84

SW Mt. Rainier N.P.



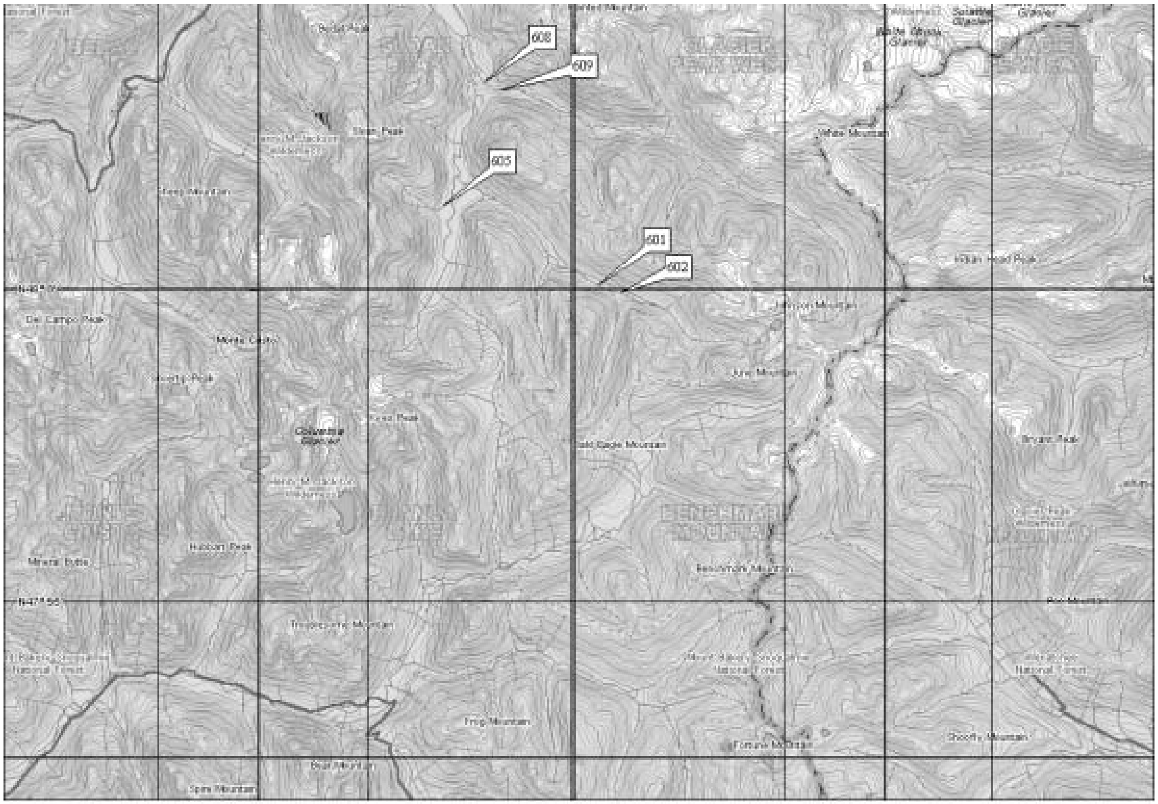
Trinity area and the Chiwawa R., and the White River, Glacier Peak Wilderness.

Washington Pass Area, North Cascades



**3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096** **3500 ft Scale: 1 : 125,000 Detail: 10-6 Datum: WGS84**

White Chuck, Suiattle area and the N. F. Sauk River



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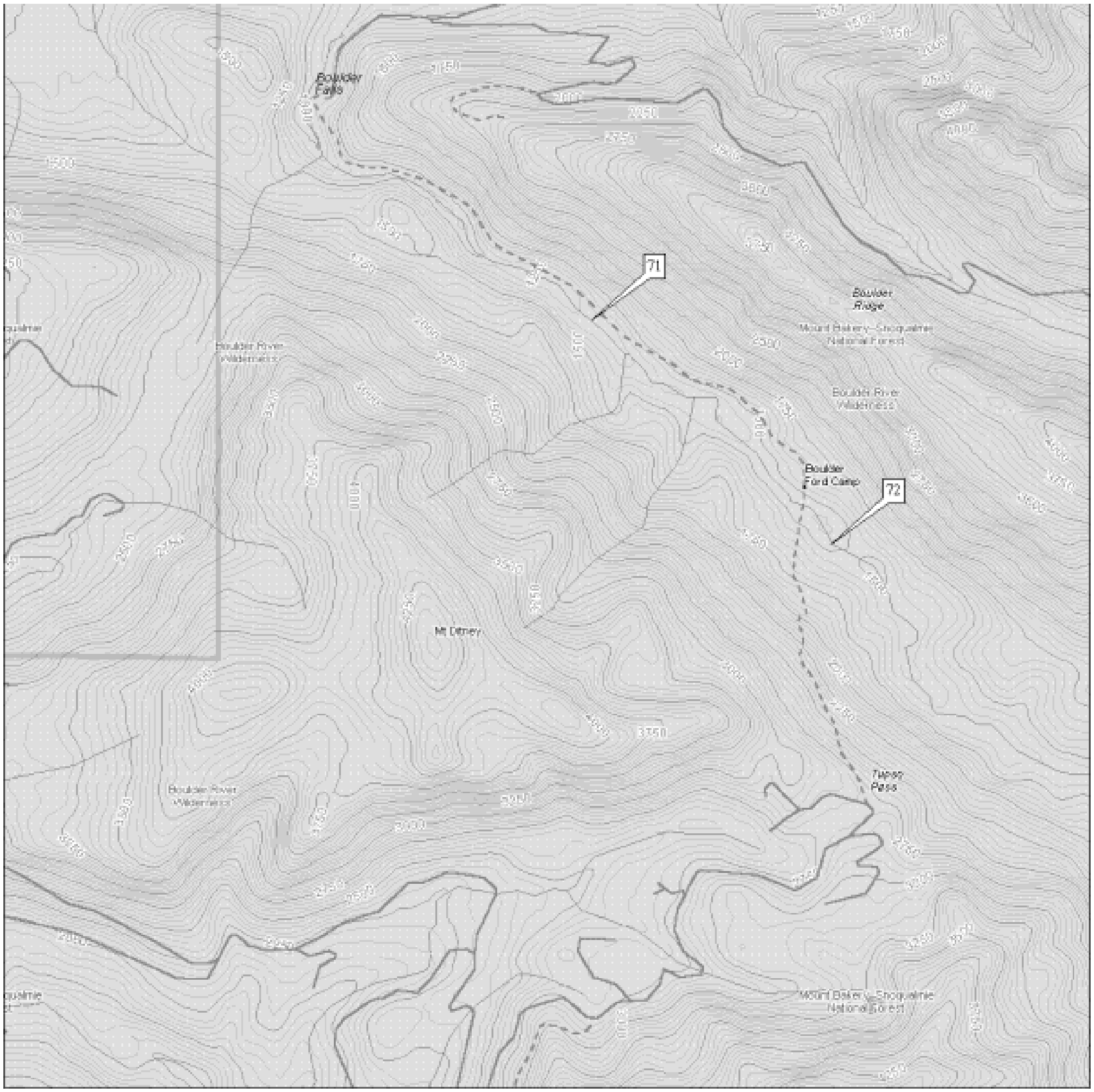
5000 ft Scale: 1 : 175,000 Detail: 10-2 Datum: WGS84

NF. Sauk, Sloan and Cadet Creeks



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096    1000 ft  Scale: 1 : 40,625  Detail: 12-0  Datum: WGS84

Boulder River Wilderness