740 - Yurok Tribe, Restoration of Lower Klamath River Habitats

Yurok Tribe Technical and Scientific Documentation Table		
Technical and Scientific Document Name	**Document Description**	**Relevant page #**
R.A. Fiori (CA Licensed Geologist/Fiori GeoSciences) and S. Beesley (Yurok Tribal Fisheries Program). Yurok Restoration Design Plan. February 2013.	Document provides the project narrative and design plan for the proposed project.	All
S. Beesley and M. Hiner. Yurok Monitoring and Data Sharing Plan. February 2013.	Document describes data collection, storage, and sharing methods for the monitoring components proposed for this project.	All
Supporting Documents provided digitally via the BMS upload and by CD		
Abbe, T.B., A.P. Brooks, and D.R. Montgomery. 2003a. Wood in River Rehabilitation and Management. *In* S. Gregory, K. Boyer, & A. Grunell (*eds*) The Ecology and Management of Wood in World Rivers. AFS Symposium 37: Bethesda, Maryland; 367-389.	Describes the functional roles and beneficial processes created by wood jams and the principles and benefits of engineered log jam technology for river restoration.	All
Abbe, T.B., G.R. Pess, D.R. Montgomery and K. Fetherston. 2003b. Integrating Engineered Log Jam Technology into Reach-Scale River Restoration. *In* D.R. Montgomery, S. Bolton, D.B. Booth, L. Wall (*eds*) Restoration of Puget Sound Rivers. University of Washington Press: Seattle, Washington; 443-482. http://Rocky2.ess.washington.edu/grg/publications/pdfs/Abbe.pdf	Describes the functional roles and beneficial processes created by wood jams and the principles and benefits of engineered log jam technology for river restoration.	All
S. Beesley (Yurok Tribal Fisheries Program) and R.A. Fiori (CA Licensed Geologist/Fiori GeoSciences). Lower Terwer Creek Riparian Revegetation Project. 2012.	Describes similar project implemented in the Terwer Creek Valley by Mr. Fiori and YTFP.	All
Cederholm, C.J., R.E. Bilby, P.A. Bisson, T.W. Bumstead, B.R. Fransen, W.J. Scarlet and J.W. Ward. 1997. Response of Juvenile Coho Salmon and Steelhead to Placement of Large Woody Debris in a	Describes an assessment of juvenile salmonid response to addition of wood in a small coastal stream in Washington. Found that winter coho populations increased significantly in reaches with complex wood	Pages 947-963

Coastal Washington Stream. North American Journal of Fisheries Management. Vol. 17: 947-963.	structures.	
Pess, G.R., M.C. Liermann, M.L. McHenry, R.J. Peters, and T.R. Bennett. 2011. Juvenile Salmon Response to the Placement of Engineered Log Jams (ELJs) in the Elwha River, Washington State, USA. River Research and Applications. John Wiley & Sons, Ltd. wileyonlinelibrary.com	Describes an assessment of juvenile salmonid use of engineered log jams (ELJs) in the Elwha River, Washington. Results indicated that ELJs were successful at restoring salmonid habitats.	All
Yurok Tribal Fisheries Program. Lower Terwer Creek Streambank and Riparian Restoration - U.S. Fish and Wildlife Service – Tribal Landowner Incentive Program Project. 2010.	Describes similar project implemented in the Terwer Creek Valley by Mr. Fiori and YTFP.	All
California Department of Fish and Game. Recovery Strategy for California Coho Salmon. 2004. Recovery task list is available on-line at http://nrm.dfg.ca.gov/coho/coho_tasks.aspx	Document describes the status of California coho populations, limiting factors, and sets species recovery priorities for the evolutionary significant unit (ESU).	High Priority Recovery Tasks: KR-KG-16 KR-KG-17 KR-KG-23 KR-KG-23
National Oceanic and Atmospheric Administration. Recovery Plan for the Evolutionarily Significant Unit of Southern Oregon/Northern California Coast Coho Salmon. 2012. Public Draft Version: January 2012. http://www.swr.noaa.gov/recovery/soncc_draft/SONCC_Coho_DRAFT_Recovery_Plan_January_2012.htm	Document describes the status of SONCC coho populations, limiting factors, and sets species recovery priorities for the evolutionary significant unit (ESU).	Volume II Chapter 18 Recovery Tasks: SONCC-LKR.2.1.1 SONCC-LKR.2.2.4

Yurok Restoration Design Plan

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Project Title: Restoration of Lower Klamath River Habitats

Lower Klamath River Sub-basin habitats are extremely important to the survival of multiple Klamath Basin fish populations, including fall run chinook salmon managed under the Magnuson-Stevens Fishery Conservation and Management Act, and coho salmon that are listed under the Endangered Species Act (ESA). Anthropogenic activities over the past century have resulted in substantial declines to Klamath fish runs and drastically degraded associated habitats. Declining fish populations is a significant cultural and economic concern for the Yurok People who have relied on the basin's resources for their livelihood since time immemorial.

In the Lower Klamath River Sub-basin, historic logging and subsequent stream clearing activities have resulted in significant losses of streamside forests, fluvial wood accumulations, and wood recruitment to tributary and riverine systems. This severe loss of habitat complexity and channel structure resulting from the loss of fluvial stored wood and streamside forests is a primary limitation to the survival of native fish of the Klamath River, especially salmonids. Fluvial deposited wood and log jams are critically important in the formation and maintenance of productive habitats and geomorphic processes within streams of the Pacific Northwest (Abbe et al. 2003; Montgomery et al. 2003). These structural elements facilitate pool formation and floodplain connectivity, promote development of productive and resilient riparian forests, and sort and meter sediment in ways that support vital processes such as formation and retention of high quality salmonid spawning gravels and storage of fine-grained materials on floodplains.

The Yurok Tribal Fisheries Program (YTFP) is likely the largest Tribal fisheries management entity in California and has a proven track record of implementing innovative and effective fisheries restoration throughout the Klamath River Basin. Since 2002, YTFP has been working closely with Rocco Fiori (Fiori GeoSciences) to prioritize, design, and implement process-based habitat restoration within the Lower Klamath River Sub-basin. Our stream and floodplain enhancement efforts are recognized throughout the state as being cutting edge and are implemented to directly and significantly benefit wild runs of coho salmon, chinook salmon, steelhead trout, coastal cutthroat trout, lamprey, eulachon, and green sturgeon; as well as terrestrial species including the marbled murrelet, the Northern spotted owl (NSO), and several species of migratory birds (i.e. **Target Species**). In the Lower Klamath, coho salmon, the marbled murrelet, and the NSO are listed under the federal ESA.

YTFP is requesting funding to continue our efforts to restore Lower Klamath habitats to levels that support robust, self-maintaining populations of target species. Specifically, we are proposing to enhance fluvial and riparian habitats within two coastal Lower Klamath tributaries by installing constructed wood jams (CWJs), implementing bioengineering, and planting native trees. These restorative measures are identified as high priority coho salmon recovery measures in the state's *Recovery Strategy for California Coho Salmon* (CDFG 2004), and NOAA's *Recovery Plan for the Evolutionarily Significant Unit of Southern Oregon/Northern California Coast Coho Salmon* (NOAA 2012). These measures are also identified as high priority fisheries recovery activities in the *Klamath Basin Restoration Agreement* (KBRA 2010) and the *Lower Klamath River Sub-basin Watershed Restoration Plan* (Gale and Randolph 2000).

Project Location

Hunter Creek and Terwer Creek are fourth order watersheds that enter the north side of the Klamath River ~1.2 and 5.6 river miles upstream of the Pacific Ocean, respectively (Figures 1-2). Both watersheds support wild runs of coho salmon, chinook salmon, steelhead trout, coastal cutthroat trout, and several species of lamprey. The lower reaches of these watersheds also provide critically valuable rearing habitat for juvenile coho from throughout the Klamath Basin (non-natal fish) (Silloway 2010; Hiner et al. 2011; Silloway and Beesley 2011) and the tributary confluences of provide thermal refugia for several native fish migrating through the river.

The proposed project would continue our on-going habitat restoration efforts in these priority coastal watersheds. YTFP and Mr. Fiori recently completed a wood loading and riparian habitat enhancement project in East Fork Hunter Creek. In addition, we enhanced an off-channel habitat feature in Hunter Creek and are currently in the process of installing numerous CWJs in 4.0 miles of Hunter Creek. Since 2003, YTFP and Mr. Fiori have been addressing channel and riparian dysfunction in the Terwer Creek Valley and planting riparian habitats throughout the watershed to improve conditions for Tribal Trust fish and wildlife (Beesley and Fiori 2008). In 2009-2010, we worked with USFWS, NOAA, and other restoration partners to install the first large-scale CWJs and off-channel wetlands in the valley to improve winter rearing conditions for natal and non-natal fish (YTFP 2010; Hiner et al. 2011). Subsequently, we have constructed three additional large-scale CWJs in the valley and are currently assessing the feasibility of creating additional off-channel habitat features to further promote long-term species recovery.

Measurable Outcomes

Restoration actions were developed to promote once prevalent natural processes and therefore we expect to provide immediate and long-term (self-maintaining) benefits to target species.

- Enhance anadromous fisheries habitat in Hunter Creek by installing 48 CWJs in one mile of the stream and improving 20 acres of riparian habitats by planting 250 native trees and installing numerous native willow baffles (1,000 ft) to benefit target species.

- Enhance anadromous fisheries habitat in Terwer Creek by installing 58 CWJs in one mile of the stream and improving 20 acres of riparian habitats by planting 250 native trees and installing numerous native willow baffles (2,500 ft) to benefit target species.

- We anticipate increasing pool frequency (20-50%), average pool depth (20-30%), instream shelter complexity (>1 point), and percent instream cover (20-50%).

- We anticipate that proposed restoration will substantially increase the abundance of juvenile salmonids in the treatment reaches during the winter months, especially in habitat units corresponding with large wood structures. Similar restoration projects and monitoring studies in the Pacific Northwest and worldwide have reported a positive correlation between salmonid fry (chinook, coho, and trout) densities and wood cover (Slaney et al. 1994; Peters et al. 1998) and the positive response of juvenile salmonid abundance and density to wood placement (Slaney et al. 1994; Peters et al. 1998; Inoue and Nakano 1998; Roni and Quinn 2001; Lehane et al. 2001; Miyakoshi et al. 2002; Pess et al. 2005).

- We anticipate that the abundance of adult chinook and coho in the treatment reaches will increase, especially in habitat units corresponding with large wood structures. A similar study conducted by Pess et al. (2005) reported that adult chinook redistributed themselves into newly constructed log jams after construction.

Environmentally Compatible Socio-Economic Benefits
Implementing fisheries habitat restoration and associated monitoring in the Lower Klamath provides resource based employment opportunities for Tribal members and other local professionals. Mr. Fiori also provides watershed assessment and heavy equipment training to Yurok Tribal member employees to help build their skill set and Tribal capacity. We also use local vendors to the greatest extent possible to further stimulate local economies (e.g. fuel, project supplies, heavy equipment leases, engage small and Tribally owned buisnesses).

A primary goal of our work is to restore aquatic habitats to levels capable of supporting robust native fish populations and sustainable fishing opportunities. The Lower Klamath fishery, once restored could bring in significant amounts of local revenue annually via ecotourism and fishing. Klamath River communities rely heavily on these types of recreation and have been severely impacted by the loss of income related to decreased fishing opportunities and associated tourism. For example, the recent runs of adult chinook salmon in the Klamath River has allowed for a fairly substantial commercial fishery for Yurok Tribal members (e.g. nealry $3 million in revenue generated in 2012). Watershed stewardship and businesses driven by fishing and tourism are the primary employment opportunities for people living in these river communities. These job opportunities are especially important to Tribal members wanting to stay and support their families on their ancestral lands and maintain a close tie to the river and their culture.

Technical/Scientific Merit
The primary restoration tool proposed for this project is installing CWJs on a reach-scale within Hunter Creek and Terwer Creek. CWJs proposed for this project are a variation of Engineered Log Jams (ELJs) described by Abbe et al. (2003a, 2003b, 2005); and will mimic naturally occurring features such as bar apex jams (large-scale CWJ), deflector jams, and bar roughness jams. CWJs are constructed using the same geomorphic and engineering principles as ELJs; where mechanically driven logs, riparian trees, stumps, and other landforms are used to create a geometry of interlocking logs and/or whole trees that provides the resisting elements necessary for maintaining stability and function under a variety of flows.

The proposed CWJs will incorporate and enhance naturally occurring features including side channels and gravel bars, use large riparian trees and in-situ old growth redwood stumps to increase jam stability and function, and use native alluvium and locally derived whole tree materials and live willow as the primary building materials. Mr. Fiori has designed and implemented a similar approach in lower Terwer Creek and other streams of North Coast California (Figures 3-10). Project designs are based on a factor-of-safety analysis and over two decades of experience conducting similar restoration work in geomorphically dynamic systems.

The use of CWJs and ELJs to recover habitat complexity and protect streambanks and riparian forests within river systems is widely applied in Washington and Oregon (Abbe et al. 2003b). A driving principle in ELJ technology is that habitat restoration is more likely to be effective and sustainable if done in a manner that mimics natural geomorphic processes (Abbe et al. 2003b). Wood accumulations (i.e. jams) in dynamic fluvial habitats can act as stable foundations and protective elements capable of facilitating forest development and providing long-term forest refugia (Abbe and Montgomery 1996; Abbe et al. 2003a, 2003b & 2005). Rehabilitating resilient streamside forests in the Lower Klamath is a critical measure for providing long-term benefits for target species. Resilient riparian forests help reduce channel instability, provide long-term recruitment of wood to fluvial habitats, and help drive food webs.

Positive responses by salmonids to wood jams, especially by juveniles, are well documented in the Pacific Northwest (Cederholm et al. 1997; Roni and Quinn 2001; Pess et al. 2011; YTFP Unpublished Data). Wood jams create low-velocity microhabitats with complex overhead and instream cover for fish. Salmonids use these areas as velocity refugia to conserve energy and as predator protection elements and have been shown to increase juvenile salmonid density and reduce competition for rearing habitat by providing visual isolation of conspecifics (Beechie et al. 2005; Imre et al. 2002; Roni and Quinn 2001; Lestelle 2007).

Also intrinsic to ELJ technology is jam stability and ensuring a factor of safety to allow for construction in areas where protection of infrastructure is critically important (Abbe et al 2003a). CWJ and ELJ construction may also employ the use of threaded rebar or chain anchor systems rather than using imported quarry rock and/or cable to maintain jam stability in areas where infrastructure protection is required (Abbe et al 2003a). Washington State Department of Transportation employs ELJs to protect highway infrastructure against erosion (WSDOT 2006).

The project also proposes to implement bioengineering techniques such as installing willow baffles and roughening floodprone surfaces with buried wood as well as planting riparian areas with native trees. These actions are complimentary to installing CWJs and the combination has proven effective in reducing channel instability and increasing off-channel and floodplain habitat complexity in lower Terwer Creek (Beesley and Fiori 2012; Hiner et al. 2011; YTFP 2010).

Although Lower Klamath tributaries remain primarily within a working landscape (e.g. timber production), the land use practices that resulted in severe impacts to fisheries habitats have dramatically improved. Green Diamond Resource Company (GDRC) now owns a majority of the Hunter and Terwer watersheds where we are proposing to conduct fisheries habitat restoration. GDRC is our restoration partner and we work in a coordinated manner to address instream and upslope habitat impairments in the Lower Klamath. In addition, GDRC's Aquatic Habitat Conservation Plan requires greater streamside forest protection and improved road management practices that have dramatically reduced sediment delivery to streams and set up conditions where riparian forests can provide the necessary processes (e.g. increased wood recruitment, bank stability, allochthonous input, and stream shading) to facilitate improved channel conditions. Although land use practices have improved, there is still a critical need to build back channel complexity and increase riparian forest protection and resiliency.

Feasibility

Mr. Fiori designed the proposed restoration tasks and will be the lead operator of heavy equipment when installing the CWJs and willow baffles. Mr. Fiori has over 30 years experience operating heavy equipment in sensitive wildland and riverine environments. He has licences as a professional geologist (CA PG 8066) and timber operator (A10991). Since 2007, he has been providing heavy equipment operation training to YTFP Tribal member staff in the field of fisheries habitat restoration (e.g. wood loading and off-channel habitat construction projects) (Gale 2008 & 2009; Beesley and Fiori 2012; Hiner et al. 2011; YTFP 2010). He received training in ELJ principles and construction from Tim Abbe (expert in ELJ technology) in 2008 and has since collaborated with Mr. Abbe as part of the Trinity River Restoration Program.

YTFP has been planning and implementing instream and riparian restoration projects in the Lower Klamath River Sub-basin for over a decade. The infrastructure of YTFP is sound and has a proven track record of performance, grant management, and fiscal accountability. YTFP is comprised of qualified and professional employees dedicated to restoring fisheries resources of the Klamath Basin (http://www.yuroktribe.org/departments/fisheries/FisheriesHome.htm). Examples of similar work conducted by YTFP and Mr. Fiori include recently implemented habitat restoration in lower Terwer Creek (Beesley and Fiori 2012; Hiner et al. 2011; YTFP 2010) and on-going habitat restoration (i.e. wood loading) within Hunter Creek.

Climate Change Considerations
Implementation actions were designed to provide long-term, sustainable benefits including protection and enhancement of riparian soils and forests to help maintain high quality, cold water habitats for native salmonids in the face of climate change. Planting streamside trees and increasing riparian forest resiliency will sequester significant quantities of carbon, while CWJs will facilitate increased flood retention and groundwater recharge (surface water: "slow it, spread it, sink it"), and help meter sediment delivery and reduce pool and thermal refugia filling events.

Work Plan
YTFP is proposing to enhance fisheries habitats within one mile of Hunter Creek and one mile of Terwer Creek, both high priority coastal tributaries of the Lower Klamath River. We are proposing to install multiple CWJs, implement extensive bioengineering, and plant native riparian trees within both of the proposed restoration reaches (Table 1). Although there are two separate reaches, the implementation strategy will be the same for both tributaries and thus will be described simultaneously. The project timeline is presented in Figure 11. YTFP worked with Mr. Fiori to assess limiting conditions within these watersheds and to develop feasible restoration strategies (Beesley and Fiori 2007 & 2008). Mr. Fiori designed the proposed CWJs and complimentary bioengineering and he will work with YTFP to implement these designs. Work within the two reaches will be comprised of three components conducted over a three year period: 1) Project preparation, 2) Project Monitoring, and 3) Restoration Implementation.

Table 1. Restoration Treatments Proposed for Hunter and Terwer creeks.

Type	**Quantities**	
	Hunter Creek	**Terwer Creek**
Bar Apex Jams	8	8
Deflector Jams	20	10
Bar Roughness Jams	20	40
Willow Baffles (ft)	1,000	2,500
Native Trees Planted	250	250

<u>Component 1 – Project Preparation</u>

Project preparation will consist of working with funding and permitting agencies to refine best management practices (BMPs), obtain regulatory compliance, and secure quality wood and willow sources. This process has already begun and a description of our regulatory compliance strategy is presented below. YTFP has a successful track record of working with other Tribal departments, and state and federal resource agencies to develop effective BMPs and obtain the necessary permits to conduct these types of restoration in Lower Klamath tributaries.

NEPA – Not Started Yet. We anticipate working with the USFWS to obtain a Categorical Exclusion for all restoration activities. We will begin this process in fall 2013 if funded and anticipate obtaining a signed NEPA checklist from USFWS by early summer 2014.

NOAA Section 10 Consultation for SONC Coho Salmon - Our monitoring activities are currently covered under the Trinity River Restoration Program's programmatic permit. We are also currently in consultation for coverage for YTFP monitoring activities under section 4(d) of the ESA and expect this consultation will be complete prior to the start of this project.

NOAA Section 7 Consultation for SONC Coho Salmon – Not Applied for Yet. We anticipate working with USFWS/NOAA to apply for coverage in fall 2013 as part of the NEPA process.

Section 404 Clean Water Act – Not Applied For Yet. We anticipate the project will qualify for authorization under ACOE Nationwide Permit Number 27 as part of the USFWS NEPA process.

NHPA – We worked with the Yurok Tribe Cultural Department to obtain clearance for Hunter Creek activities and are in the process of obtaining clearance for Terwer Creek. We anticipate NHPA clearance by fall 2013. USFWS will also obtain clearance through their NEPA process.

CEQA – Not Started Yet. We anticipate working with the California Department of Fish and Wildlife (CDFW) to obtain a Categorical Exemption (CE) for proposed restoration activities. CDFW has provided YTFP with CE determinations on numerous projects that were similar in scope and nature. We anticipate obtaining CEQA clearance by early summer 2014.

Ca. Dept. of Fish and Wildlife (CDFW) Streambed Alteration Agreement 1602 Permit – Restoration activities are covered in Green Diamond Resource Company's (GDRC) Master Agreement for Timber Operations (No. 1600-2010-0114-R1) between GDRC and CDFW.

State Water Quality 401 Certification for Small Habitat Restoration Projects – Not Applied For Yet. We anticipate applying for 401 permits in fall 2013 if awarded funding and receiving clearance for proposed restoration by early summer 2014.

Beginning in spring 2013, YTFP and Mr. Fiori will work with GDRC to identify potential whole tree material harvest areas. YTFP will initiate a competitive bid process to select and hire a qualified and GDRC approved logging contractor to produce, transport, and stockpile whole tree materials near the project areas prior to and concurrent with restoration construction in 2014. Whole tree materials will be harvested from timberlands that have an active Timber Harvest Plan by a licensed timber operator and conform to the California forest practice rules. Whole tree materials will be transported to pre-approved landing areas within each project area by large end-dump trucks operated by qualified contractors. Transport operations will conform to all state, federal, and private landowner regulations and requirements.

Component 2 – Project Performance Assessment

2.1 Physical Habitat

Prior to restoration implementation, YTFP will conduct 3-D topographic surveys of the channel profile and establish permanent cross sections in both project reaches to document baseline conditions. All topographic surveys will be conducted using an optical total station and will be tied into long-term channel monitoring reaches located within the treatment watersheds to increase our ability to assess larger-scale restoration effectiveness into the future. Repeat surveys will be conducted immediately following log jam construction to document as-built conditions (e.g. jam locations, dimensions, position of key logs), and during the first two summers post-construction to document conditions following winter flow events. YTFP will also conduct photographic monitoring from geo-referenced locations to further document baseline and post-project habitat conditions and to help assess log jam function under various flows. All of the survey data will be analyzed using Trimble Geomatics Office, ESRI GIS, and Excel software and incorporated into YTFP GIS to produce maps and monitor changes in wood position and channel morphology over time. Key parameters assessed via the topographic survey data are pool frequency, average pool depth, and channel profile diversity.

Instream shelter within the treatment reaches will be rated by YTFP biologists according to methods outlined in Flosi and others (1998). Instream shelter consists of features (e.g. instream wood, boulders, bedrock ledges, undercut banks) that provide juvenile salmonids protection from predators, areas of slow velocity, and/or separation between territorial units (Flosi et al. 1998). YTFP will document 1) instream shelter complexity, and 2) instream shelter percent cover prior to enhancement and following project implementation. Instream shelter will be assessed during winter base flows 1) prior to commencing implementation activities, and 2) during the first winter post-construction to document juvenile salmonid rearing conditions during this critically important season. Since flows are limiting or subsurface within both reaches during summer, a useful quantification of rearing habitat complexity during this period is not feasible.

2.2 Biological Metrics

Juvenile Salmonids

YTFP will assess the effects of restoration activities on juvenile salmonid both prior to and after restoration implementation to assess restoration effectiveness. YTFP will evaluate the effects of LWD placement on juvenile salmonid species presence, densities, and habitat use within treatment reaches by conducting snorkel surveys in both treatment and control reaches (Pess et al. 2005). Prior to restoration implementation, YTFP will conduct one year of baseline surveys to monitor juvenile salmonid use in both project reaches to determine baseline conditions and continue monitoring during the first and second year post-treatment. Surveys will be conducted once monthly during January, March, and May. Treatment and control reaches will be divided into sections of similar size, called snorkel lanes, each lane snorkeled by a single diver, as described in methodology in Pess et al. (2005). During surveys, divers will identify all salmonids to species and estimate fish lengths for each observation. In addition, nighttime dives will also be conducted at treatment (ELJ) and control sites once monthly during January, March, and May before restoration occurs and during years one and two post-treatment.

Adult Salmonids

Prior to restoration implementation, YTFP will assess chinook and coho spawning activity in both Hunter and Terwer Creeks. Weekly spawning surveys will be conducted between November and January to encompass both chinook and coho spawning activities. After restoration implementation, spawning surveys will be conducted during the first and second year post-treatment to determine if the addition of LWD into the reaches had an effect on the number of adult salmonids using treatment versus control areas. YTFP will scan any adult coho carcasses retrieved with a PIT tag scanner to determine whether they were tagged as juveniles as part of the Coho Salmon Ecology Project that the Yurok and Karuk Tribes have been conducted throughout the Klamath Basin since 2007.

All survey reaches locations will be documented using hand-held GPS units and data will be saved in ESRI GIS. All datasheets will be digitally scanned after returning from the field and data will be entered into Microsoft Excel. YTFP will assess short-term biological differences between treatment and control reaches such as: 1) species composition of juvenile salmonids (chinook, coho, steelhead, cutthroat); 2) densities of juvenile salmonids (chinook, coho, steelhead, cutthroat); 3) habitat preference of juvenile salmonids (chinook, coho, steelhead, cutthroat); and 4) adult salmonid (chinook and coho) spawning activity.

Component 3 – Project Implementation

3.1 Safety Training

Prior to heavy equipment operations, we will review safety protocols related to working with heavy equipment and associated hazards including injury prevention, general safety, fire prevention, emergency medical helicopter evacuation, equipment lockout policy, and a hazardous substance contingency plan. Daily and/or weekly safety meetings will occur during equipment operations. Every piece of heavy equipment and each vehicle will be equipped with fire suppression gear, a first aid kit, hazmat spill kit, and emergency communications. Each employee will receive and be required to use the proper safety gear during all field operations.

3.2 Log Jam Construction and Bioengineering

Mr. Fiori and YTFP will use heavy equipment (e.g. excavators, loaders, dozers, site trucks) to haul whole tree materials and live willow cuttings to the project sites and to construct the CWJs and willow revetment baffles within the two proposed treatment reaches. CWJs installed for this project will include bar apex jams (~large-scale CWJ: 18-35 key LWD pieces), deflector jams (3-5 key LWD pieces), and bar roughness jams (3-5 key LWD pieces). A majority of the key pieces used in these structures will be logs with rootwads attached to ensure greater jam stability and effectiveness. Mechanically embedded log posts (piling) will also be used to increase jam stability. Log posts (20-25 ft with a 12 in average diameter) will be embedded in the channel bed with an excavator (Figure 10). Live willow cuttings will also be incorporated in the CWJs to increase complexity and longer-term stability as well as to promote riparian forest development.

Bar apex jams (BAJs) will be constructed using mechanically embedded pilings, native alluvium, and bioengineering as principle resisting elements (Figure 12). BAJs will be sited at the head of selected bars and other channel locations to induce scour at the jam face, partition a portion of mainstem flows into side channels, and facilitate/protect the development of riparian forests and soils (Figures 1-2). This type of feature can be large and depending on conditions at each site and intended benefits will require 18-35 key pieces, several loads of rack materials, and willow.

Stability of deflector jams will be achieved by weaving key logs into standing riparian trees and/or against in-situ old growth redwood stumps so moderate and high flows interlock the jam materials against the restraining elements. Mechanically embedded pilings will also be used if additional stability is deemed necessary. During storm flows the interwoven jam materials will rise and fall with changes in flow stage and the jam will operate like a sluice gate weir. Deflector jams will be sited at the base of riffles in mainstem habitats to use the energy of the hydraulic drop to scour and extend pool length and depth and provide cover (Figure 7). This jam type will also be used on meander bends to partition flows away from the stream bank and induce scour under the jam, and in side channels to provide cover. Examples of deflector jams similar to the jams proposed for this project are provided as Figures 7-9.

Bar roughness jams (BRJs) are small to mid-sized jams and will be installed on the medial and distal portions of large bar features. BRJs will be built with 3-5 key logs and rack materials. BRJs will be used in conjunction with willow baffles and BAJs to accumulate and protect riparian soils and facilitate development of forested islands (Figure 3). The role of BRJs will be to rack and store fluviatile wood on floodprone surfaces. Increasing residence time of wood on these otherwise transient surfaces will create positive feedback mechanisms necessary to rebuild soils and resilient riparian forests.

Rack material consists of course and fine woody materials that include small logs, branches, and willow clumps. In the faces of CWJs, rack material acts as a shock absorber defending the jam against scour, it also provides complex habitat fish cover and substrate for primary and secondary production (Figures 4-5). In the jam interior, rack material aids in retaining alluvial ballast and provides a moisture source for vegetation planted into the jam.

Live willow cuttings and baffles will be incorporated into many of the proposed CWJs to increase the complexity of these features as well as to help promote riparian forest development and jam stability. Willow baffles are a common bioengineering treatment used to reduce stream velocities and trap fine sediments and small woody materials. Willow revetment baffles will be installed in strategic locations throughout the project reaches according to standard methods (Flosi et al. 1998) with the exception that no quarry rock will placed at the base of the baffles. Instead, we will use woody debris at the base of the baffles when possible to facilitate improved growing conditions by providing a complex structure for willow roots to attach to and thereby reduce potential failure by scour. The use of the woody materials will provide an organic sponge to absorb water during wet months and release it slowly to improve growing conditions for the willow during dry months and reduce the need for supplemental watering (YTFP 2010). Examples of willow baffles similar to those proposed are provided as Figures 3-6.

All willow used for this project will be obtained from approved sites in the Lower Klamath to ensure genetic integrity and will be harvested in a sustainable manner to ensure no impacts to existing willow forest habitats. Willow cuttings will be harvested and transported by YTFP using Tribal equipment and vehicles. Harvest and transport operations will conform to all state, federal, and private landowner regulations and requirements. YTFP crews will water the willow baffles and cuttings within the CWJs in August, September, and October during the implementation season and during the first two low flow seasons post-construction to increase survival (Figure 11). Water will be obtained from approved drafting areas located nearby and will be transported to the sites using a water truck. The watering schedule will be dependent on vegetation conditions (stress) and weather patterns (e.g. fog vs dry/hot weather).

Two construction teams will be formed to work on the Hunter and Terwer Creek projects concurrently. All heavy equipment operations will be conducted by experienced and trainee YTFP heavy equipment operators lead by Mr. Fiori. Willow cutting and transport operations will be conducted by YTFP technicians and guided by a qualified YTFP technicians and Mr. Fiori. YTFP Biologists will provide project management and logistical support.

Construction will occur in late summer to take advantage of subsurface flow conditions within the treatment reaches to minimize and/or avoid impacts to fish and riparian resources. CWJ and willow baffle construction areas will be accessed by equipment via the dry channel bed whenever possible to avoid riparian impacts. Construction will occur by working equipment from the dry channel and gravel bars. We may need to develop a few temporary access trails through riparian areas to avoid impacts to natural habitat features existing in the channel (e.g. wood accumulations, vegetation). Temporary access trails will be less than 15 feet wide with alignments created to cause the least damage possible to vegetation and soils. Location of access trails will be determined based on site conditions at the time of construction.

All vehicle and equipment maintenance and fueling will take place on pre-existing roadways. Vehicles and equipment will be maintained and operated to be leak free. Spill kits will be available for all vehicles and equipment and crews will be ready and trained to deal with any spills. All trails and work sites will be erosion proofed prior to rain storms capable of producing $\geq$ 1.5 inches. Once the project is completed, all access trails will be removed by restoring natural contours and spreading slash and/or weed free straw over disturbed surfaces.

3.3 Riparian Tree Planting

YTFP will plant riparian habitats within the two project reaches with native conifer and hardwood saplings. We estimate planting 250 trees within each reach during the first wet season post-CWJ construction. Trees will be purchased from local native plant nurseries or grown in the Yurok Tribal Native Plant Nursery to ensure they are from regionally appropriate stock. Tree species will include coastal redwood, Douglas fir, Western red cedar, black cottonwood, and big-leaf maple which are all common within these watersheds. Trees will be planted using hand tools according to standard methods (Flosi et al. 1998). Crews will take precaution to properly stabilize the trees when burying root systems to prevent “J” rooting. Trees will be spaced 8-10 feet apart with crews selecting the most favorable microsites to promote healthy growth. Ideal planting sites include areas where soil conditions are favorable for holding water and areas shaded by other landscape features. YTFP crew leaders will record daily tree planting information on datasheets and field maps.

3.4 Maintenance & Augmentation

The Yurok Tribe takes a long-term perspective towards restoration and resource management and is dedicated to ensuring their cultural connection to the river persists indefinitely. Therefore, adaptive management and maintenance of restorative measures are essential practices of YTFP. Enhancement of constructed log jams may be conducted during this proposed project if deemed necessary (e.g. addition of wood). If deemed necessary, we will re-enter the construction areas during the low flow period in 2015 to add wood to previously constructed sites following all the above guidelines and approved best management practices. As previously mentioned, these construction activities will also include watering willow baffles within the two project reaches. Future restoration phases (following this project) will include addition of whole tree materials in reaches upstream of the proposed project reaches to mimic natural wood recruitment while riparian forests mature to levels capable of sustaining that natural process.

Milestones and Timeframe
Spring 2013 – Spring 2014: Complete Regulatory Compliance
Winter 2013 – Spring 2014: Complete Baseline Physical & Fisheries Assessments
Summer – Fall 2014: Complete CWJ & Bioengineering Restoration in Hunter and Terwer
Fall 2014: Complete As-Built Physical Performance Monitoring, Water Willow Baffles/Cuttings
Winter 2014 – 2015: Plant Native Trees in Riparian Habitats of Hunter and Terwer
Winter 2014 – Spring 2015: Complete Year 1 Performance Physical & Fisheries Assessments
Summer – Fall 2015: Augment CWJs & Water Willow Baffles/Cuttings
Winter 2015: Complete Tree Planting Performance Documentation
Winter 2015 – Spring 2016: Complete Year 2 Performance Physical & Fisheries Assessments
Fall 2016 - Water Willow Baffles/Cuttings & Final Report Development

Data management and project reporting will be conducted throughout the project's duration to meet the needs of the various funding and permitting entities. Development of a final project report will be conducted during the last year of the grant and made available within 90 days following project completion or sooner if required by the funding and permitting entities. The final report will also be posted to YTFP's website and available for download following review and approval by these entities. YTFP will be seeking additional funding to continue our physical and biological monitoring of these project reaches to document long-term trends, assess long-term effectiveness of restoration, and to help guide on-going and future restoration.

Project Costs
The proposed project will be carried out in a three year period with an anticipated start date of November 1, 2013 (Figure 11). The project will rely on multiple funding sources including NOAA, California Proposition 84 funds, USFWS, USBOR, and possibly PacifiCorp's Klamath River Coho Enhancement Funds and CDFW's Fisheries Restoration Grant Program. YTFP has made a best faith effort to solicit multiple funding sources to reduce the amount requested from any one source and ensure the best use of limited resource dollars. We have been conducting these types of projects for nearly 20 years and have extensive experience developing accurate and cost-effective budgets. All expenses will go directly towards implementing the proposed habitat restoration, associated effectiveness monitoring, and management of the project.

The project may be viewed by some as expensive relative to other wood loading projects in California; however, a majority of the wood loading projects conducted in California have not included the use of whole tree materials (i.e. logs with rootwads attached) and consist of very simple log structures (2-3 manufactured logs or poles, rootwads with no stems attached, quarry rock) (Flosi et al. 1998). Recent studies conducted in northern California and elsewhere show that CWJs using whole tree materials perform better in terms of promotion of beneficial geomorphic processes and positive salmonid response than simple structures (Cederholm et al. 1997; Roni and Quinn 2001; Manners et al. 2007; Benegar 2011). Conducting such extensive and comprehensive habitat restoration in these two tributaries is justified based on the fairly unique opportunity to implement large-scale restoration in watersheds within close proximity of the Pacific Ocean, and the ability to benefit both natal and non-natal salmonid populations, other anadromous fish populations migrating through the Lower Klamath River, and other wildlife.

Outreach and Education

Yurok People rely heavily on river resources for their subsitence and economic livelyhoods and the economy of the local communities is also very dependent on resource-based activities (e.g. watershed restoration, fishing, ecotourism). Therefore, this project was designed to provide multiple benefits including helping to meet state, federal, and tribal fisheries recovery objectives; providing high quality resource-based employment; and stimulating local economies on both short- and long-term timescales through project implementation and species recovery.

This project relies on a diversity of partners including the landowner (Green Diamond Resource Company), resource professionals (Fiori GeoSciences, Biostream Environmental), the Karuk Tribe, and state and federal resource agencies and orginizations (USFWS, NOAA, NCIRWMP, Department of Water Resources, USBOR). Mr. Fiori is recognized throughout California as a leader in fisheries habitat restoration and in 2010 the Salmonid Restoration Federation presented him with the “Golden Pipe Award” for his innovative wood loading techniques and off-channel habitat construction in Northern Califronia streams. Restoration efforts led by YTFP and Mr. Fiori have been recognized as effective and innovative by both state and federal congressional representatives. California Assemblyman Wesley Chesbro and U.S. Congressman Jared Huffman have both provided letters of support for this particular project (Letters Attached).

YTFP and Mr. Fiori have a proven track record of sharing information and providing local and broad-based outreach opportunities to help promote fisheries restoration and recovery. As part of this project we will continue to present findings and lessons learned as part of field trips for local high school and college students, local residents, and restoration practitioners; or via formal presentations provided for students, local communities, Yurok Council and Tribal members, and at professional science conferences. Specifically, YTFP will work with the USGS Cooperative Extension at Humboldt State University to provide multiple field-based courses focused on fisheries restoration and effectiveness monitoring to students enrolled in natural resource fields.

In addition, we will also continue 1) strengthening our collaborative research and restoration programs with other Klamath Basin partners including the Karuk Tribe, the Mid-Klamath Watershed Council, and the Trinity Restoration Program; 2) building collaborative partnerships with non-Klamath restoration practioners and stakeholders to ensure transfer of knowledge; and 3) engaging political entities and state/federal resource agencies to ensure innovative and effective salmonid recovery actions are encouraged and supported throughout the state.

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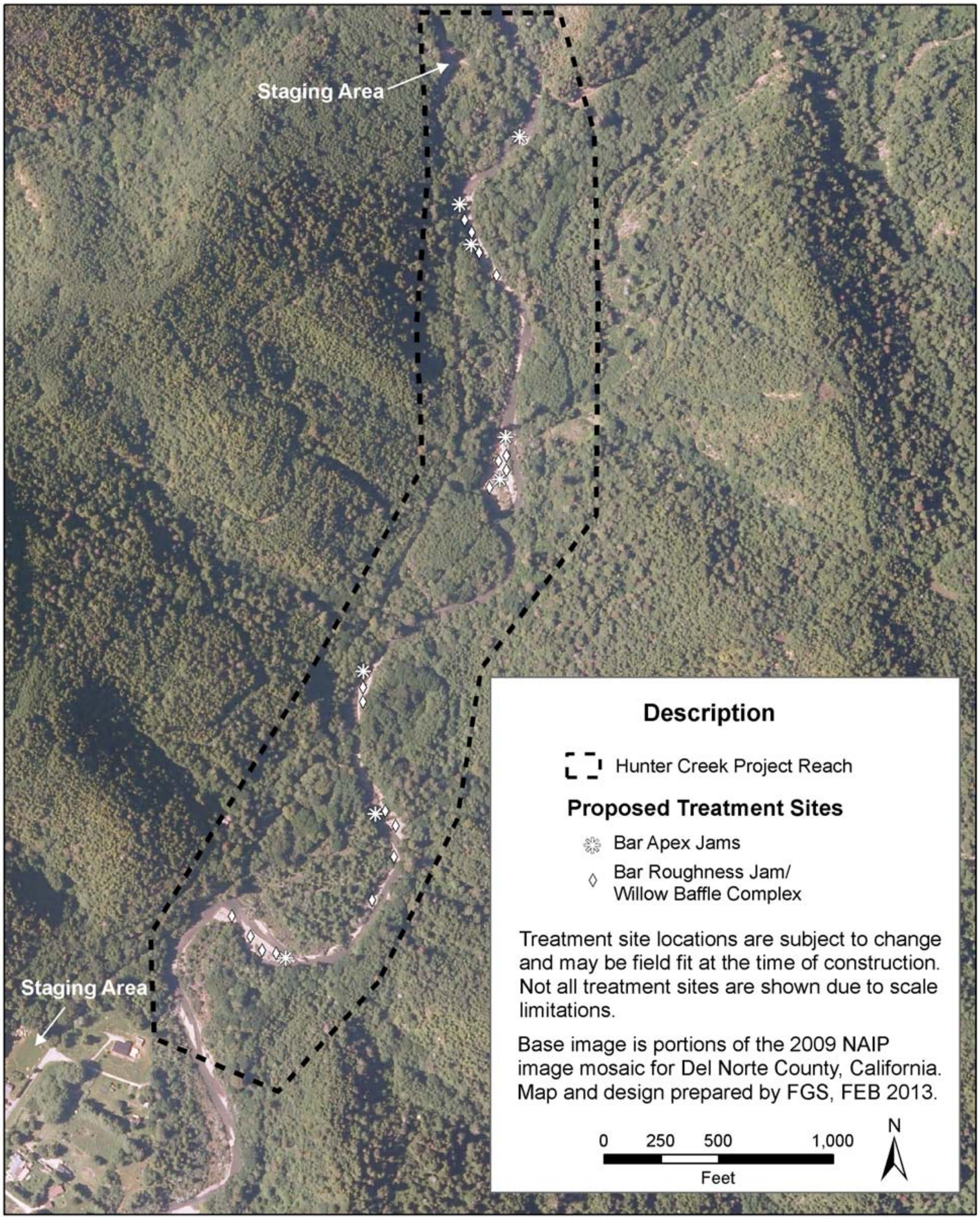


Figure 1. Hunter Creek Project Reach and Proposed Treatment Site Map.

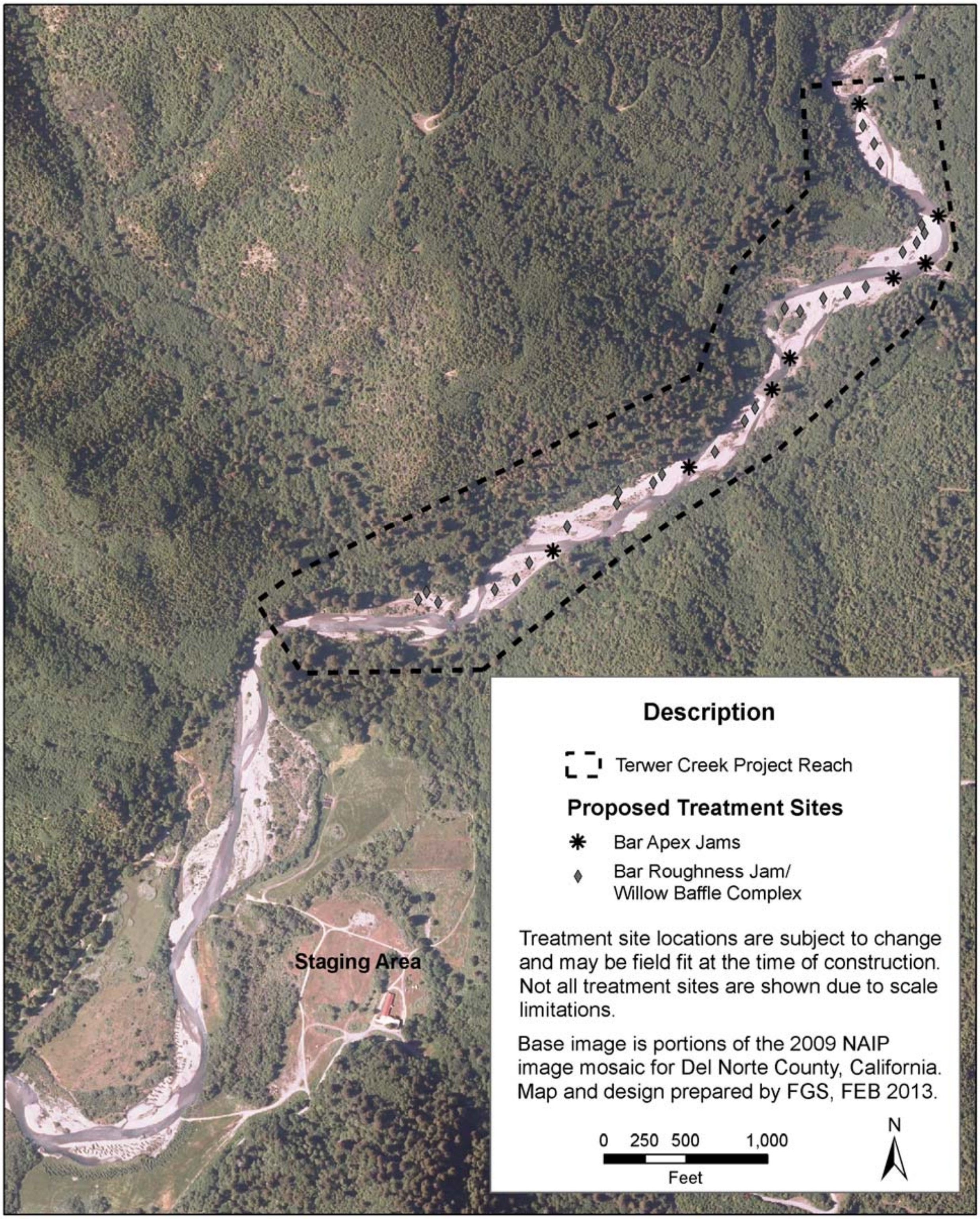


Figure 2. Terwer Creek Project Reach and Proposed Treatment Site Map.

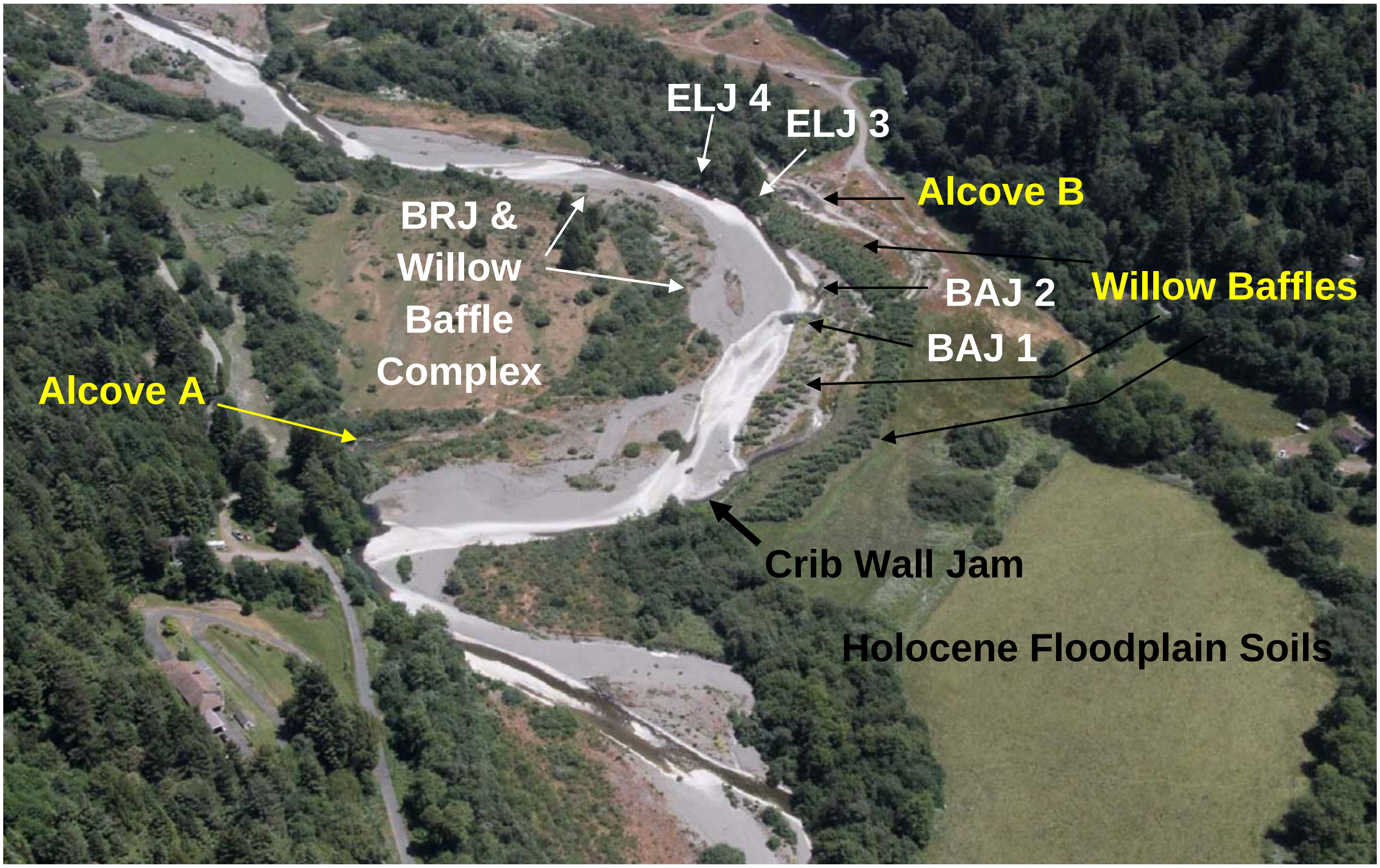
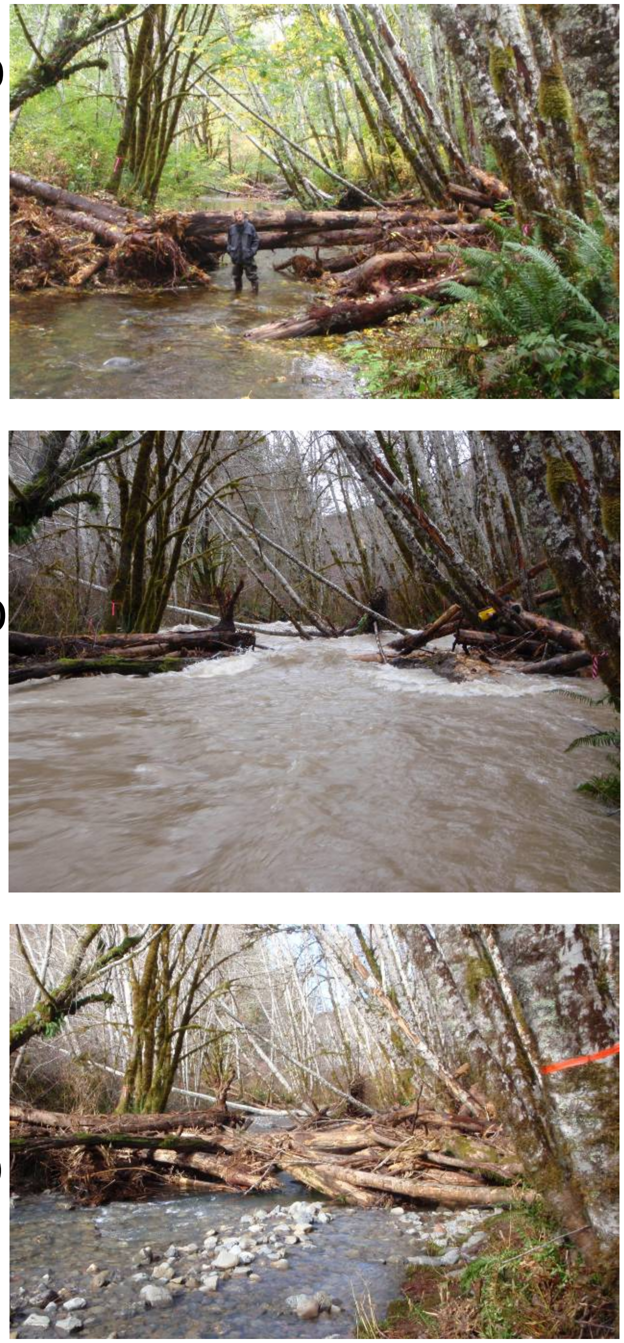


Figure 3. Integrated use of Engineered Log Jams, Bioengineering and Constructed Alcoves in Lower Terwer Creek, Klamath River, California.

Figure 4. Downstream view of Terwer BAJ1 and willow baffles protecting a side channel and Holocene terrace soils and creating low velocity habitat (01/01/10 near bankfull event ~1,600 cfs).

Figure 5. Upstream view from Terwer Cribwall ELJ showing rack material at jam face, willow baffles and side channel during winter flows (2010).

Figure 6. Upstream view of floodprone surfaces following willow baffle construction and a high flow event, Terwer Creek, Lower Klamath River, California, Photo date January 2010.

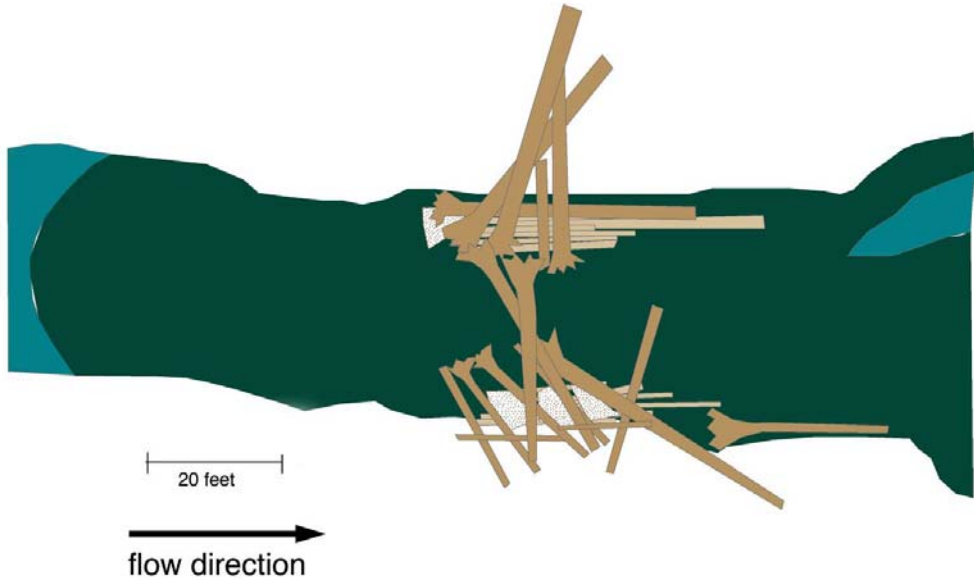


a)

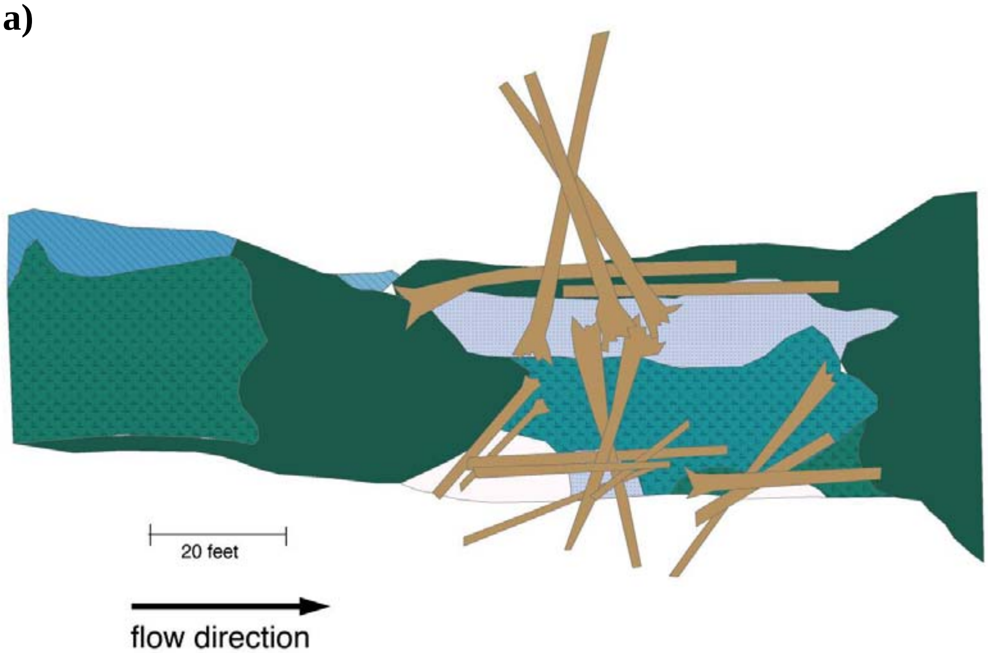
b)

c)

Figure 7. Oblique monitoring photographs showing deflector jam and channel conditions at a constructed jam Site 2, East Fork Mill Creek, Smith River, California: a) post construction, b) during a bankfull flow event (~650 cfs), and c) after winter high flows (2009).



a)



b)

Figure 8. Plan view maps of jam architecture and streambed facies at a constructed wood jam Site 2, East Fork Mill Creek, Smith River California (Top); and following winter flows that included two bankfull flow events (≥650 cfs).

Figure 9. Deflector Jam on right bank and Bar Apex Jam (inducing flow split at photo center) adjacent to the outlet of a constructed alcove in Hunter Creek, Klamath River, California. Photo from Nov. 2012.

Figure 10. Log posts embedded during Engineered Log Jam construction in Terwer Creek.

Year 1 Tasks - 2013-2014	**November**	**December**	**January**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**
Project Permitting												
Topographic Surveys								Baseline Surveys			As-Built Surveys	
Photo-Monitoring	Baseline Photos								Baseline/Project/As-Built Photos			
Winter Habitat Asssments		Baseline Assessment										
Juvenile Snorkel Surveys			Baseline		Baseline		Baseline					
Adult Spawner Surveys	Baseline Surveys											
CWJ & Bioengineering									Restoration Implementation			
Water Willow Baffles										Water Willows		
Data Management/Reporting												
Year 2 Tasks - 2014-2015	**November**	**December**	**January**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**
Topographic Surveys								Topographic Surveys				
Photo-Monitoring		Photo-monitoring						Photo-monitoring				
Winter Habitat Asssments		Performance Assessment										
Juvenile Snorkel Surveys			Year 1		Year 1		Year1					
Adult Spawner Surveys	Year 1 Performance Surveys											
ELJ & Bioengineering												
Water Willow Baffles										Water Willows		
CWJ Augmentation									Augment Constructed Wood Jams			
Native Tree Planting		Tree Planting										
Data Management/Reporting												
Year 3 Tasks - 2015-2016	**November**	**December**	**January**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**
Topographic Surveys								Topographic Surveys				
Photo-Monitoring		Photo-monitoring						Photo-monitoring				
Native Tree Planting		Performance Assessment										
Winter Habitat Asssments		Performance Assessment										
Juvenile Snorkel Surveys			Year 2		Year 2		Year 2					
Adult Spawner Surveys	Year 2 Performance Surveys											
Water Willow Baffles										Water Willows		
Data Management/Reporting												

Figure 11. Proposed timeline for the "Restoration of Lower Klamath River Habitats" project.

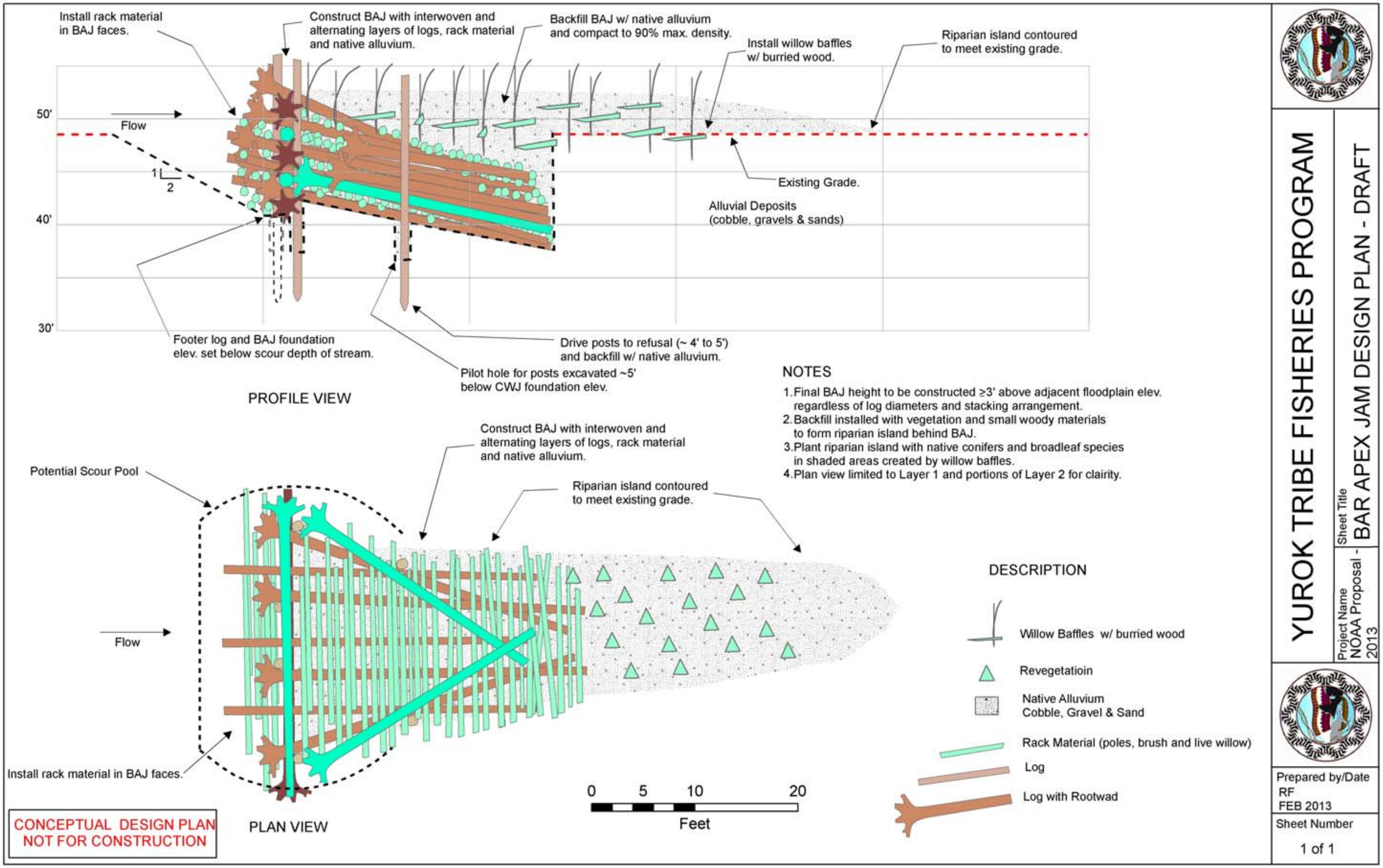


Figure 12. Design plan for Bar Apex Jam.

Congress of the United States
House of Representatives
Washington, DC 20515-3605

February 14, 2013

Melanie Gange
NOAA Coastal and Marine Habitat Restoration Project Applications
NOAA Restoration Center, NOAA Fisheries,
1315 East West Highway, Rm. 14873
Silver Spring, MD 20910

Re: Letter of support for the Yurok Tribal Fisheries Programôs proposal to NOAAôs FY 2013 Coastal and Marine Habitat Restoration Project solicitation

Dear Ms. Gange:

I am writing to support the Yurok Tribal Fisheries Program (YTFP) proposal to continue restoring Lower Klamath River habitats to support robust, self-sustaining populations of anadromous fish.

The Lower Klamath River is vital to the survival of Klamath Basin fish populations, including several fish stocks managed under the Magnuson-Stevens Fishery Conservation and Management Act, and protected under the Endangered Species Act (ESA). YTFPôs project would directly and significantly benefit wild runs of coho salmon, Chinook salmon, steelhead trout, coastal cutthroat trout, lamprey, eulachon, and green sturgeon. The riparian restoration activities proposed will also benefit marbled murrelets, Northern spotted owls, migratory birds, and other tribal trust fish and wildlife.

YTFP has a proven track record of effective fisheries restoration throughout the Klamath Basin. Since 2002, YTFP has worked with Rocco Fiori of Fiori GeoSciences to prioritize, design, and implement cutting-edge habitat restoration in the Lower Klamath River. For this NOAA proposal, YTFP proposes to rehabilitate several miles of important instream and riparian habitats in Lower Klamath tributaries.

The innovative work of YTFP and Fiori GeoScience will serve as a model for restoring anadromous fish habitats in Northern California. Please give this proposal your full and fair consideration.

Sincerely,

JARED HUFFMAN
Member of Congress

Biostream Environmental
Liberty Bay Marina • 17791 Fjord Drive NE – Suite AA • Poulsbo • WA • 98370-8483
360-697-6702 • lestelle@nwbiostream.com

February 15, 2013
Re: Letter of support for the Yurok Tribe's proposal to NOAA's FY 2013 Coastal and Marine Habitat Restoration Project solicitation

ATTN: NOAA Coastal and Marine Habitat Restoration Project Applications - c/o Melanie Gange
NOAA Restoration Center, NOAA Fisheries
1315 East West Highway, Rm. 14873
Silver Spring, MD 20910

Dear Ms. Gange:

I am writing to give my support for a proposal being submitted by the Yurok Tribe in response to a solicitation by NOAA for habitat restoration projects. The Yurok Tribal Fisheries Program (YTFP) is requesting funding to continue to restore habitats in the lower Klamath River basin vital to anadromous salmonids in that river. These habitats are particularly important to the recovery of ESA-listed coho.

The Klamath basin is an important producer of anadromous salmonids on the west coast of North America. The basin still supports the largest run of natural coho in California, though the population is in long-term decline and is now at a critically low abundance. The population is listed as threatened by the ESA. The Klamath coho run is essential to maintaining the southern end of the range of coho in North America. Riverine habitat restoration undertaken by the Yurok Tribe in recent years is providing much needed benefit to coho performance in the basin, based on results of on-going monitoring and research. The efforts of the tribe are aimed at restoring habitat function required by coho that has been severely diminished over the past century by forest harvest, flow regulation, and other watershed activities.

The proposal submitted by the Yurok Tribe seeks to restore large wood to two major tributaries to the lower Klamath River. The work would use state-of-the-art restoration methods combined with monitoring and evaluation methods consistent with those used as part of an on-going research project initiated in 2006. The proposed effort would significantly improve the quality of habitats in these tributaries and would be expected to have a corresponding benefit to coho survival.

I am a consulting research scientist with 40 years of experience in assessing effects of watershed practices and restoration practices on anadromous salmonids, and particularly on coho salmon. Since 2006 I have been the technical advisor on a research project in the Klamath basin to assess coho life history patterns and habitat-fish performance relationships in the river basin. As a result of this work, I conclude that the proposed restoration effort of the tribe's is much needed and would be highly beneficial. Moreover, I feel it is important to also note that the YTFP is highly qualified to carry out the restoration work and to perform the monitoring and evaluation that need to also occur.

Thank you for your consideration.

Sincerely,

Larry Lestelle

Larry Lestelle
Principal

COMMITTEES
NATURAL RESOURCES, CHAIR
SELECT COMMITTEE ON DISABILITIES, CHAIR
SELECT COMMITTEE ON WINE, CHAIR
JOINT COMMITTEE ON FISHERIES AND
AQUACULTURE, CHAIR

BUDGET
BUDGET SUBCOMMITTEE #1
JOINT LEGISLATIVE BUDGET
ENVIRONMENTAL SAFETY AND
TOXIC MATERIALS
GOVERNMENTAL ORGANIZATION

Assembly
California Legislature

WESLEY CHESBRO
ASSEMBLYMEMBER, FIRST DISTRICT

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DISTRICT OFFICES
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50 "D" STREET, SUITE 450
SANTA ROSA, CA 95404
(707) 576-2526
FAX (707) 576-2297

200 SOUTH SCHOOL STREET, SUITE D
UKIAH, CA 95482
(707) 463-5770
FAX (707) 463-5773

January 29, 2013

ATTN: NOAA Coastal and Marine Habitat
Restoration Project Applications - c/o Melanie Gange
NOAA Restoration Center, NOAA Fisheries,
1315 East West Highway, Rm. 14873, Silver Spring, MD 20910

Re: Support for the Yurok Tribal Fisheries Program's (YTFP) proposal to NOAA's
FY 2013 Coastal and Marine Habitat Restoration Project solicitation

Dear Ms. Gange,

I am writing in support of the proposal submitted by the Yurok Tribe to NOAA's Coastal and Marine Habitat Restoration Project solicitation. The funding requested will help conduct comprehensive instream and riparian habitat restoration within Lower Klamath River tributaries (Hunter and Terwer Creeks).

Lower Klamath River habitats are extremely important to multiple fish populations, including stocks managed under the Magnuson-Stevens Fishery Conservation and Management Act, as well as species listed under the Endangered Species Act. YTFP's project would directly and significantly benefit wild runs of coho salmon, Chinook salmon, steelhead trout, coastal cutthroat trout, lamprey, eulachon, and green sturgeon. The riparian restoration activities will benefit marbled murrelet, Northern spotted owl, migratory birds, and other Tribal Trust fish and wildlife.

YTFP has a proven track record of implementing innovative and effective fisheries restoration throughout the Klamath Basin. YTFP has been working closely with Rocco Fiori (Fiori GeoSciences) to prioritize, design, and implement process-based habitat restoration within the Lower Klamath River. Their stream and floodplain enhancement efforts are recognized as being cutting edge and continue to serve as a model for restoring anadromous fish habitats in California.

I wholeheartedly support the Yurok Tribe's efforts to restore and protect cultural, environmental and economically vital habitats NS species. The Klamath River watershed and the people of our region would benefit from the Tribe's work.

I urge you to support this most worthwhile project. If you have any questions, please do not hesitate to contact my office.

Respectfully,

WESLEY CHESBRO
Assemblyman, 2nd District

WC: tw: mh

Cc: Ms. Sarah Beesley, Yurok Tribe Fisheries Program

Yurok Monitoring Data Sharing Plan
Project Title: Restoration of Lower Klamath River Habitats

The "Restoration of Lower Klamath River Habitats" project, implemented by the Yurok Tribal Fisheries Program (YTFP) and our restoration consultant Rocco Fiori will generate environmental data including pre- and post-restoration assessments of physical habitat via 3-dimensional topographic surveys, photo-monitoring, and habitat surveys; juvenile salmonid species composition, densities, and habitat use via direct observation methods; and adult salmonid habitat use and spawning activity via direct observation methods.

Physical datasets will provide baseline and post-restoration information such as pool frequency, maximum pool depth, instream shelter complexity, and instream shelter percent cover. Topographic survey data will be collected by YTFP survey crews using standard channel surveying protocols (Harrelson et al. 1994). Instream shelter within the treatment reaches will be rated by YTFP biologists according to methods outlined in Flosi and others (1998). Instream shelter consists of features (e.g. instream wood, boulders, bedrock ledges, undercut banks) that provide juvenile salmonids protection from predators, areas of slow velocity, and/or separation between territorial units (Flosi et al. 1998). YTFP will document 1) instream shelter complexity, and 2) instream shelter percent cover prior to enhancement and following project implementation.

Topographic surveys will be conducted during the low flow season prior to commencing implementation activities, immediately following engineered log jam construction to document as-built conditions, and during the first two summers post-project to document conditions following winter flows. Instream shelter will be assessed during winter base flows 1) prior to commencing implementation activities, and 2) during the first winter post-construction to document juvenile salmonid rearing conditions during this critically important season. Since flows are limiting or subsurface within both reaches in summer, a useful quantification of rearing habitat complexity during this period is not feasible.

Biological surveys will be conducted one year prior to restoration activities to collect baseline data and repeated the first and second year post-restoration. Surveys to estimate juvenile salmonid densities will be conducted once monthly during January, March, and May. Snorkel counts will be conducted according to methodology outlined in Pess et al. (2005). Adult salmonid spawning surveys will be conducted during November, December, and January using standard fisheries techniques (Flosi et al. 1998).

All written data collected during this project will be entered onto YTFP datasheets and/or field notebooks that will be photocopied, stored in YTFP file cabinets, and scanned electronically. Written data will also be entered electronically into established YTFP databases. Electronic data and associated databases will be stored on multiple Yurok Tribe maintained data storage devices (e.g. computer hard drives) and subsequently backed up onto CDs. All spatial informational data collected data will be stored in YTFP databases and in the Yurok Tribe's GIS database and backed up on CDs.

Upon request, Senior Biologist (Monica Hiner: mhiner@yuroktribe.nsn.us) will make project data available to project funding and permitting entities once the data have undergone data quality assurance/quality control (QA/QC). If data is needed earlier by these entities, then it will be provided with the caveat that it not be shared or used in any formal manner until it has undergone more formal QA/QC. All data will be summarized and presented within project progress reports and the final report to project funding and permitting entities for review and approval. Project reports will be made available for wider distribution once they have been reviewed and approved by the funding and permitting entities. The final report will be posted to YTFP's website (http://www.yuroktribe.org/departments/fisheries/FisheriesHome.htm) and available for download no later than two years following project completion if not sooner.

YTFP and Mr. Fiori (sub-contractor) have a proven track record of sharing information and providing local and broad-based outreach opportunities to help promote fisheries restoration and recovery. As part of this project we will continue to present findings and lessons learned as part of field trips for local high school and college students, local residents, and restoration practitioners; or via formal presentations provided for students, local communities, Yurok Council and Tribal members, and at professional science conferences. Specifically, YTFP will work with the USGS Cooperative Extension at Humboldt State University to provide multiple field-based courses focused on fisheries restoration and effectiveness monitoring to students enrolled in natural resource fields.

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Lower Terwer Creek Riparian Revegetation Project

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Introduction

The Yurok People have relied upon Klamath River and coastal resources for their subsistence, cultural, and economic livelihood since time immemorial. Central to Yurok culture is the harvest of anadromous fish. Runs of anadromous fish currently returning to spawn in Lower Klamath tributaries are depressed when compared with historical numbers. Extensive timber removal and road building activities has resulted in chronic sedimentation of streams and floodplains; a significant loss of channel-stored wood and riparian conifers; and a concomitant loss of habitat diversity and production potential in the sub-basin (Payne & Associates 1989; Gale and Randolph 2000; Beesley and Fiori 2007 & 2008; Gale and Beesley 2006; Voight and Gale 1998).

In the Klamath River, all runs of chinook salmon (*Oncorhynchus tshawytscha*), green sturgeon (*Acipenser medirostris*), and Pacific lamprey (*Lampetra tridentata*) are on the decline and coho salmon (*O. kisutch*) are listed as "threatened" under the Endangered Species Act. The Yurok Tribe is dedicated to rehabilitating degraded instream and riparian habitats to levels that support robust, self-sustaining populations of native anadromous fish. To help address this need, the Yurok Tribe's Fisheries (YTFP) and Watershed (YTWRD) programs have been conducting fisheries and watershed assessments; and implementing instream and upslope restoration activities in the Lower Klamath River Sub-basin since the late 1990s.

Initial restoration planning efforts included developing the Lower Klamath Sub-Basin Watershed Restoration Plan that prioritized upslope restoration and identified tributary specific restoration objectives for each Lower Klamath tributary (Gale and Randolph 2000). Sub-basin restoration objectives included: 1) reducing sediment inputs from upslope sources by treating high priority watershed road segments and stream crossings; 2) restoring native, conifer-dominated riparian forests; and 3) enhancing freshwater aquatic habitats. Since 2007, YTFP has been working with Rocco Fiori of Fiori GeoSciences (FGS) to design and implement innovative stream and floodplain enhancement projects in priority Lower Klamath tributaries. Treatments have included installation of constructed wood and engineered log jams (CWJs & ELJs) to facilitate formation and maintenance of productive fish habitats (e.g. spawning beds, deep pools with cover, slow velocity habitats), and enhancing off-channel habitats to increase salmonid rearing capacity (YTFP 2010; Fiori 2010; Fiori et al. 2009, 2010, 2011a & 2011b; Hiner et al. 2011).

In 2009-2010, YTFP and FGS partnered with the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) (Coastal and Marine Habitat Restoration Program - American Recovery and Reinvestment Act Funds). Primary objectives of these partnerships were to implement priority instream, riparian, and off-channel habitat restoration treatments in lower Terwer Creek to improve conditions for native fish and wildlife (YTFP 2010; Hiner et al. 2011; Beesley and Fiori 2012). All work was conducted in the Lower Arrow Mills project reach of Terwer Creek (Figures 1-2). In 2009, YTFP and FGS constructed two ELJs (ELJ 1 & Crib Wall Jam) and extensive bioengineering to help protect valuable riparian habitats by reducing stream velocities in the reach (Figures 3-6). In 2010, treatments included enhancement of two off-channel habitat features to increase juvenile salmonid winter rearing capacity (Figures 6-8). Physical habitat monitoring data collected in the Lower Arrow Mills project reach by YTFP since 2005 indicates positive habitat response (e.g. reduced soil loss along eastern bank, pool formation) to implemented treatments (Gale 2009; Hiner et al. 2011).

Project Overview

The current project was a partnership with YTFP, FGS, USFWS (Partners for Fish and Wildlife – Arcata, CA), California Department of Fish and Game's Fisheries Restoration Grant Program (CA Adaptive Watershed Improvement Funds), and the U.S. Bureau of Reclamation (Native American Affairs Program) to continue bioengineering and stream restoration efforts in the Lower Arrow Mills project reach (Figure 2). Terwer Creek is a fourth order watershed draining approximately 31.8 square miles of steep, forested terrain. Terwer Creek flows into the north side of the Lower Klamath River 5.6 river miles upstream of the Pacific Ocean (Figure 1). The watershed supports anadromous populations of chinook and coho salmon, steelhead (*O. mykiss*), coastal cutthroat trout (*O. clarkii clarkii*), and multiple species of lamprey. East Fork Terwer Creek is the largest tributary in the watershed and supports populations of coho, steelhead, coastal cutthroat trout, and lamprey species.

Terwer Creek is located in the Klamath Glen Hydrologically Significant Area, which was given the highest priority rating in the Recovery Strategy for California Coho Salmon (CDFG 2004). The priority California coho recovery task addressed by this project is KR-KG-15 – implementing instream and riparian restoration in priority Lower Klamath River tributaries. For this project instream habitat restoration activities were conducted during late summer - fall 2010 (August – October) and during fall – early winter 2011 (October - December). No fish relocation was necessary to perform project tasks and all other permit requirements were met.

Lower Terwer Creek Riparian Revegetation Project objectives included:

- Increasing habitat complexity and stream channel stability in lower Terwer Creek by installing willow siltation baffles, and constructing ELJs and small fish habitat structures;
- Evaluating project effectiveness to facilitate adaptive management of the project area; and
- Creating high quality, resource-based employment opportunities for Yurok tribal members.

Willow Revetment and Tree Planting

In fall-winter 2010, YTFP crews used heavy equipment and hand labor to construct willow revetment baffles in association with recently constructed off-channel ponds (Figure 9). Willow baffles were constructed according to standard methods outlined in Flosi and others (1998). A total of ~220 feet of willow baffles were constructed in association with Terwer Pond A (West Side) and another 800 feet of willow baffles were constructed in association with Terwer Pond B (East Side) (Figure 10). Crews also planted ~300 willow sprigs around the off-channel ponds. Objectives of these efforts included providing immediate high quality bird habitat, reducing stream velocities within the project area to protect valuable riparian and off-channel habitats, and increasing salmonid rearing habitat complexity in the recently constructed ponds. In winter 2011-2012, YTFP crews planted red alder, cottonwood, and an additional 315 willow sprigs in riparian habitats located within the Lower Arrow Mills project area. These plantings were implemented to further promote increased bank stability and reduce near-bank sheer stress.

Fish Habitat Structures

In 2010, YTFP and FGS constructed 23 small fish habitat structures in association with the two constructed off-channel ponds and side channel in the Lower Arrow Mills project area (Figures 11-12). These small fish habitat structures consisted of large wood and/or rootwads with live willow cuttings incorporated to promote increased habitat complexity. Structures were also positioned in key areas to help reduce stream velocities and scour potential in the project area.

Engineered Log Jams

In summer 2011, YTFP and FGS used heavy equipment, whole tree materials, and live willow cuttings to augment an existing ELJ (Terwer ELJ 1 – Lat: 41.5256, Long: -123.9872) and to construct an additional ELJ (Terwer ELJ 2 – Lat: 41.5258, Long: -123.9870) upstream of the existing ELJ (Figures 3-13). Terwer ELJ 1 was initially constructed by YTFP and FGS during summer 2009 to help protect valuable riparian habitats and improve mainstem conditions for native fish (Figure 3). Augmentation of ELJ 1 included adding whole tree materials along the east side of the jam to increase the ability of this structure to protect valuable off-channel and riparian habitats. Terwer ELJ 2 was constructed to help further separate high flows at this site to promote maintenance of the side channel located just downstream of ELJ 1 – 2, reduce stream velocities and bank erosion, and to increase mainstem habitat complexity and velocity refuge.

Physical Monitoring

YTFP conducted detailed topographic surveys in the Lower Arrow Mills project area to document both baseline and post-project conditions. For these surveys, YTFP and FGS established a network of permanent bench marks and several cross sections in the project area using a real time kinematic GPS total station, an optical total station, and various survey related computer software. All of the topographic surveys were conducted using the optical total station and a Recon data recorder. Baseline topographic surveys were conducted in the Lower Arrow Mills project area during July 2011. Surveys were repeated in February 2012 to document conditions following winter flow events. Survey data was then imported into YTFP GIS and Microsoft Excel to assess changes in the stream longitudinal profile.

In December 2011, there was a high flow event that resulted in a substantial amount of channel change through the project reach (Figures 14-16). Shifts in thalweg position and changes in bed topography were evident throughout the project reach (Figures 14-16). Substantial scour occurred at ELJ 2 and the Crib Wall Jam following this flow event. The other notable change was the migration of the main channel away from Terwer ELJ 1 (Figure 14). Analysis of cross section data collected in the reach strongly indicates that the ELJs and willow baffles constructed in the Lower Arrow Mills project area have resulted in reduced erosion rates along the eastern bank and increased protection of valuable side channel and off-channel habitats (Figure 16) (Gale 2009; Hiner et al. 2011). In winter 2012, fairly substantial erosion did however occur along the eastern bank upstream of ELJ 2 (Figures 14 & 16). There is a critical need to build more ELJs along the eastern bank upstream of ELJ 2 to increase channel roughness and reduce stream velocities and bank erosion in this reach. YTFP is currently seeking the funding and whole tree materials necessary to conduct this work in summer 2012 and/or summer 2013.

YTFP also established seven permanent photographic monitoring sites in the project area using a hand-held GPS receiver (sub-meter accuracy) (Table 1; Figures 3-4, 7-8, 13, 17-20). These sites will allow YTFP to document short- and long-term habitat changes in the project area and are part of a larger network of permanent photo-points that exists in the Terwer Creek valley. Physical monitoring activities will be repeated in summer 2012 to document conditions following spring floods and then every 2-5 years depending on funding and flow events.

Performance Measures

USFWS Metrics

1. Overall stream length affected: 2,200 feet
2. Stream length planted or protected: 2,200 feet
3. Riparian zone planted or protected (length x width): 2,200 feet x 50-150 feet
4. Total fencing: N/A
5. Trees planted (number, by species): 34 Coastal Redwood, 64 Douglas Fir, 92 Sitka Spruce, 22 Western Red Cedar, 21 Port Orford Cedar, 148 Cottonwood, 6 Big Leaf Maple, and 61 Red Alder
6. Non-native vegetation removed (length x width): N/A
7. Stream bank restoration sites (number, length of stream, and technique): N/A
8. Instream habitat structures installed (number, type): ~15 willow and large wood structures
9. Road stream crossings removed/upgraded (number, type of treatment): N/A
10. Number fish barriers removed: N/A
    a. Length of upstream habitat made accessible: N/A
11. Quantity of off-channel pond/wetland habitat enhanced or created: 1.5 acres

CDFG Metrics

1. Total miles of instream habitat treated: 0.42 miles
2. Type of materials used for channel structure placement: Engineered Log Jams consisting of whole trees and logs with ballast materials (native bed materials) and live willow added.
3. Miles of stream treated with channel structure placement:
4. Number of instream pools created by structure placement: 2
5. Number of structures placed in channel: 2
6. Type of monitoring: Physical monitoring (Topographic Surveys, Photo-Monitoring)
7. Location of monitoring: Onsite

Recommendations

Priority recommendations for future work in lower Terwer Creek include constructing more ELJs within mainstem habitats to continue reducing stream velocities and bank erosion by increasing flow separation (e.g. multiple high flow channels) and channel roughness in this reach. All ELJ work should include a comprehensive bioengineering component to help promote forested island development and increased riparian forest productivity and resiliency. There is a critical need to construct a minimum of three additional ELJs in the Lower Arrow Mills project reach to help protect the newly constructed off-channel ponds and the rehabilitated riparian habitats. Physical and biological monitoring should also be continued in the project reach to allow for long-term assessments of restoration effectiveness and to help guide future efforts.

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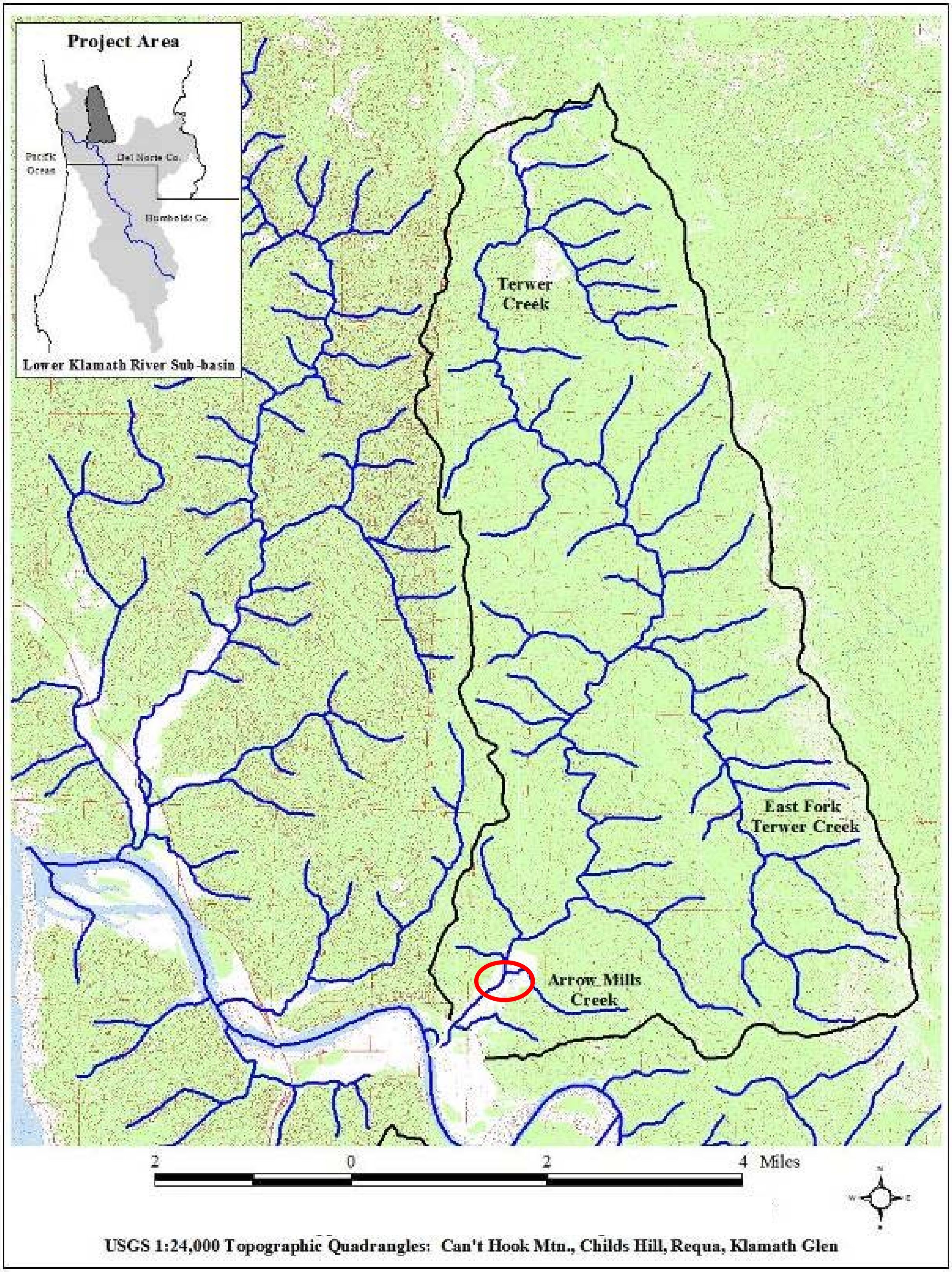


Figure 1. Terwer Creek project location map (area in the red oval), Lower Klamath River.

Figure 2. The Lower Arrow Mills Project Reach in Terwer Creek, Lower Klamath River, California (Base image: 2005 NAIP Aerial Imagery).

Figure 3. An engineered log jam (ELJ 1) in lower Terwer Creek following construction (Top – Fall 2019) and two years post-construction (Bottom – Fall 2012), Lower Klamath River.

Figure 4. An engineered log jam (Crib Wall Jam) in Terwer Creek during construction (Top – Looking Downstream, Fall 2010) and two years post-construction (Middle & Bottom – Looking Upstream, Fall 2012 & March 29, 2012 – Photo Site: TC CribWall-A), Lower Klamath River.

Figure 5. Looking upstream at engineered log jams in lower Terwer Creek (Winter 2010).

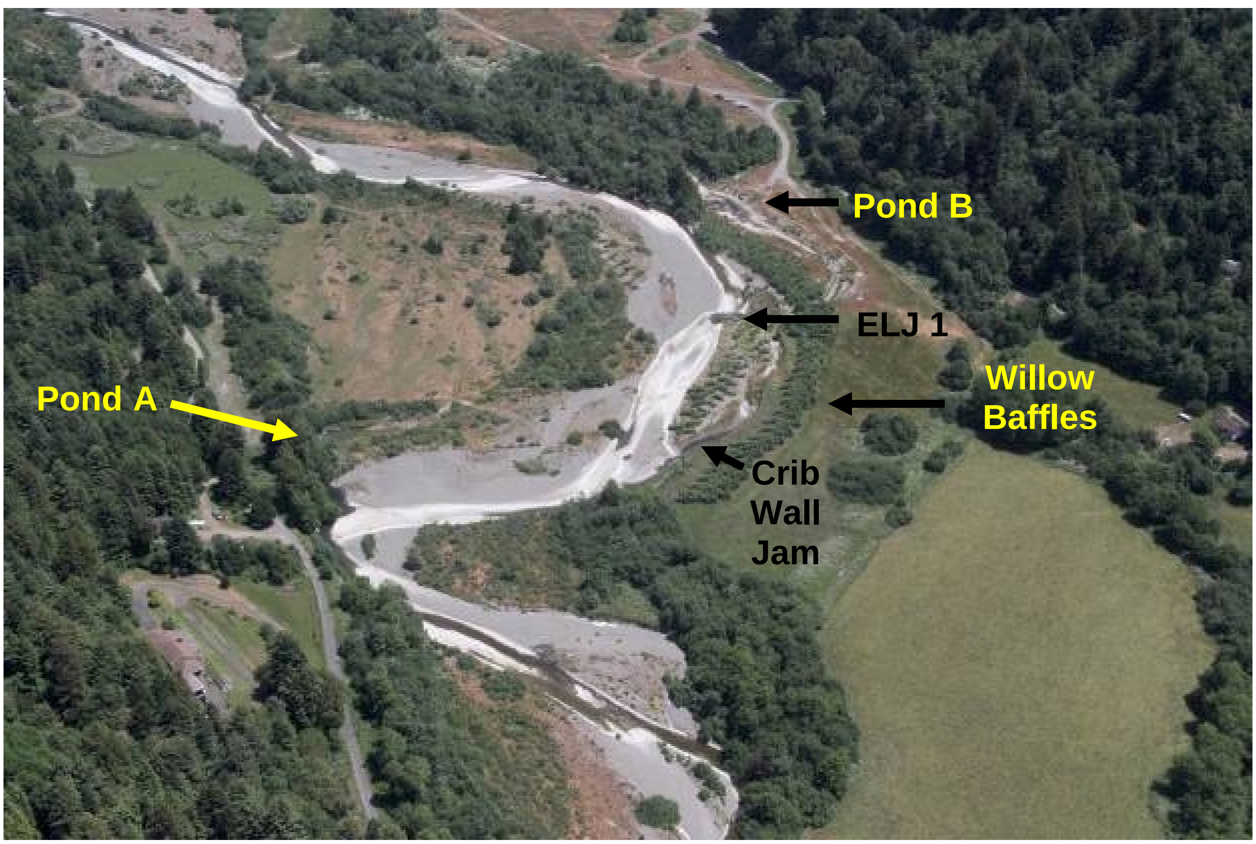


Figure 6. Oblique aerial photograph of the Lower Arrow Mills Project Reach in Terwer Creek, Lower Klamath River (Summer 2011).

Figure 7. Photographs of Pond A constructed during 2010 in Terwer Creek, Lower Klamath River (Photo Site: TC Pond A-1; Dates: a) July 15, 2010, b) July 27, 2010, and c) 10/30/10).

Figure 8. Photographs of Pond B constructed during 2010 in Terwer Creek, Lower Klamath River (Photo Site: TC Pond B-1; Dates: a) 7/15/10, b) 7/28/10, and c) 10/31/10).

Figure 9. Excavator (left) and site truck (right) used to haul willow, rootwads, and other materials related to implementing bioengineering activities in lower Terwer Creek.

Figure 10. Willow baffles constructed along the inlet channel to Terwer Creek Pond A (Top - 2010) and along the outlet channel of Terwer Creek Pond B (Bottom – Summer 2011).

Figure 11. Small fish habitat structures constructed with large wood and live willow in Terwer Creek Pond A (Top – Fall 2012) and Terwer Creek Pond B (Bottom – Fall 2012).

Figure 12. Photographs of large wood and willow structures installed in a constructed side channel feature of lower Terwer Creek (Fall 2012).

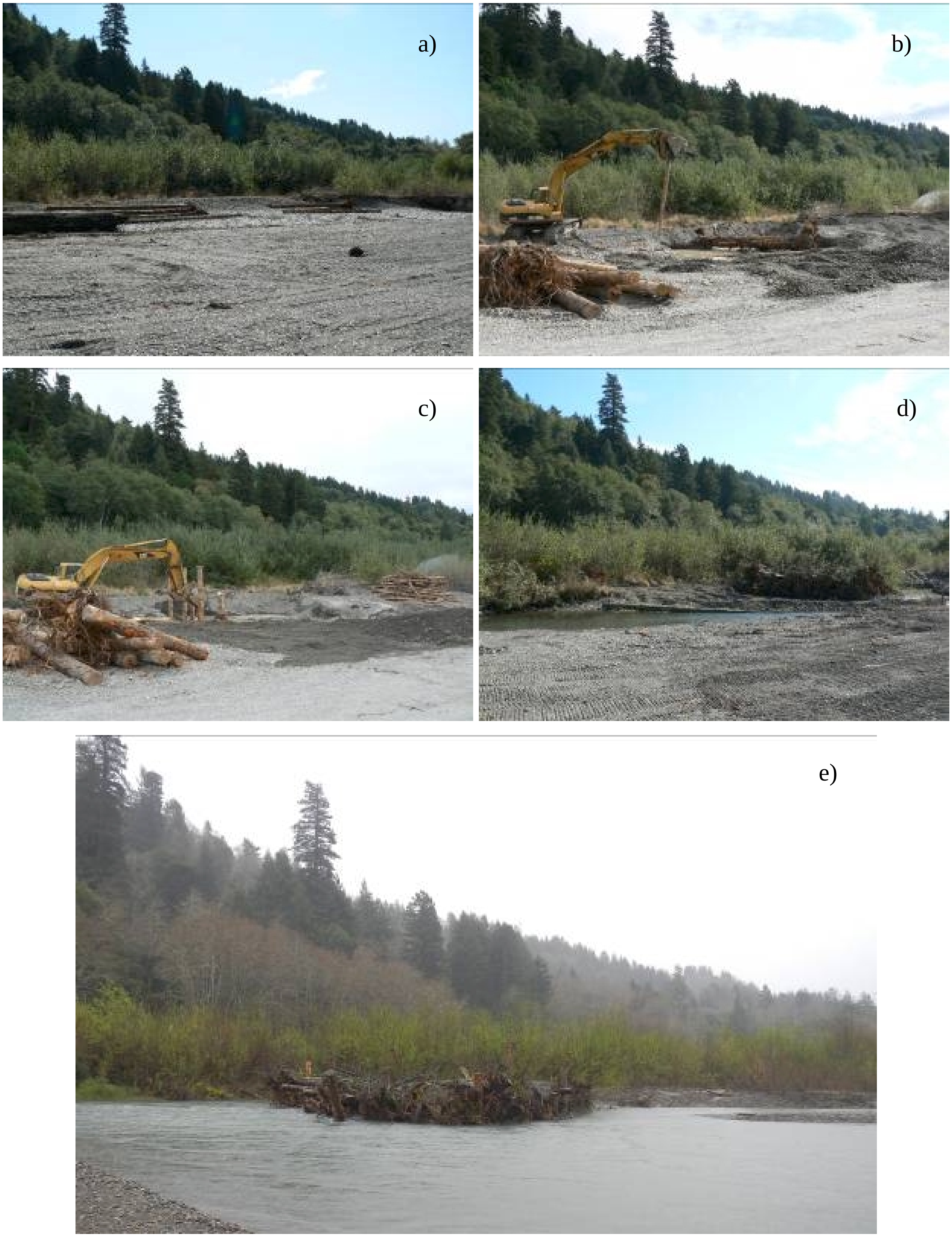


Figure 13. Photographs of ELJ 2 constructed during 2011 in Terwer Creek, Lower Klamath River (Site: TC ELJ2-A; Photo dates: a) 10/6/11, b) 10/8/11, c) 10/8/11, d) 10/14/11, e) 3/29/12).

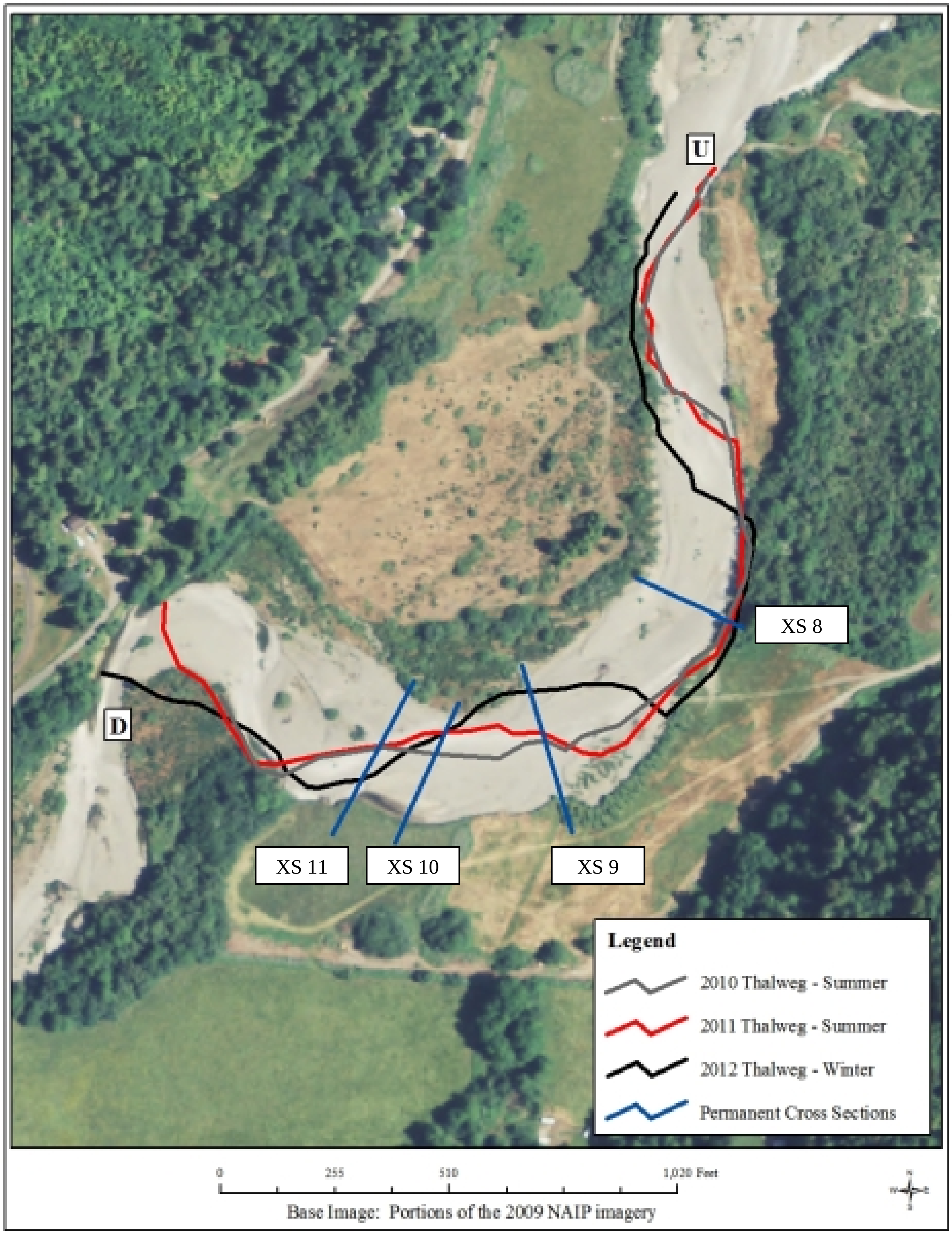


Figure 14. Longitudinal profiles and cross sections surveyed during 2010 - 2012 in the Lower Arrow Mills project reach in Terwer Creek, Lower Klamath River.

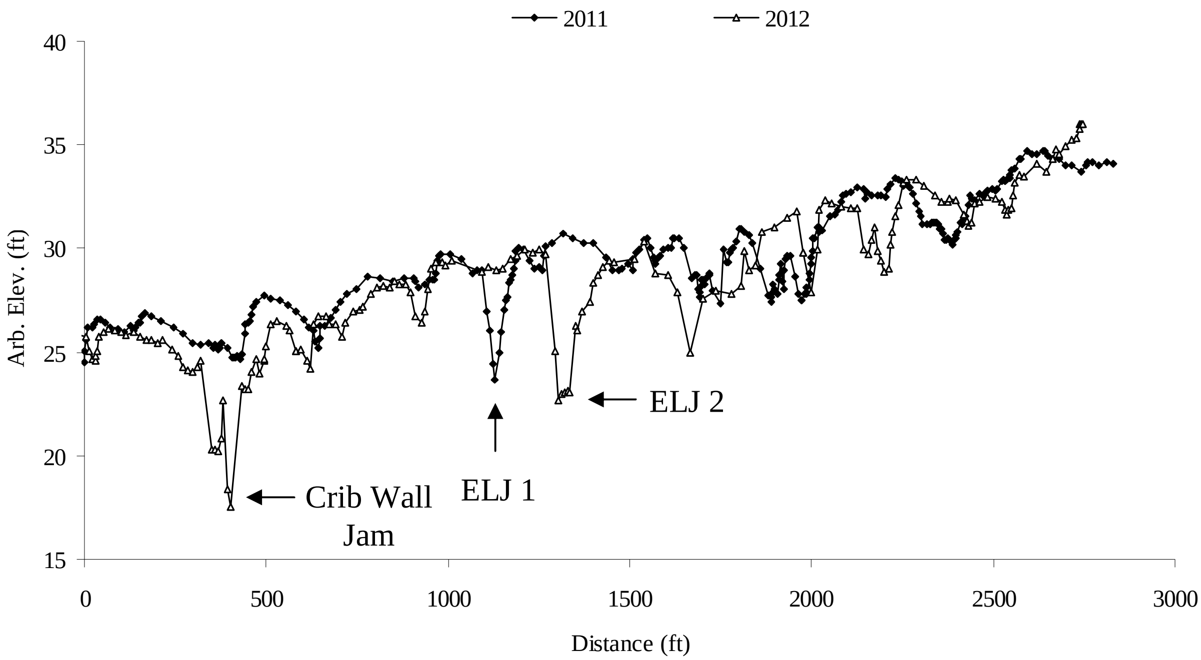


Figure 15. Longitudinal profile of Terwer Creek prior to 2011 restoration activities (2011 Plot) and following the first high flows post-construction (2012 Plot).

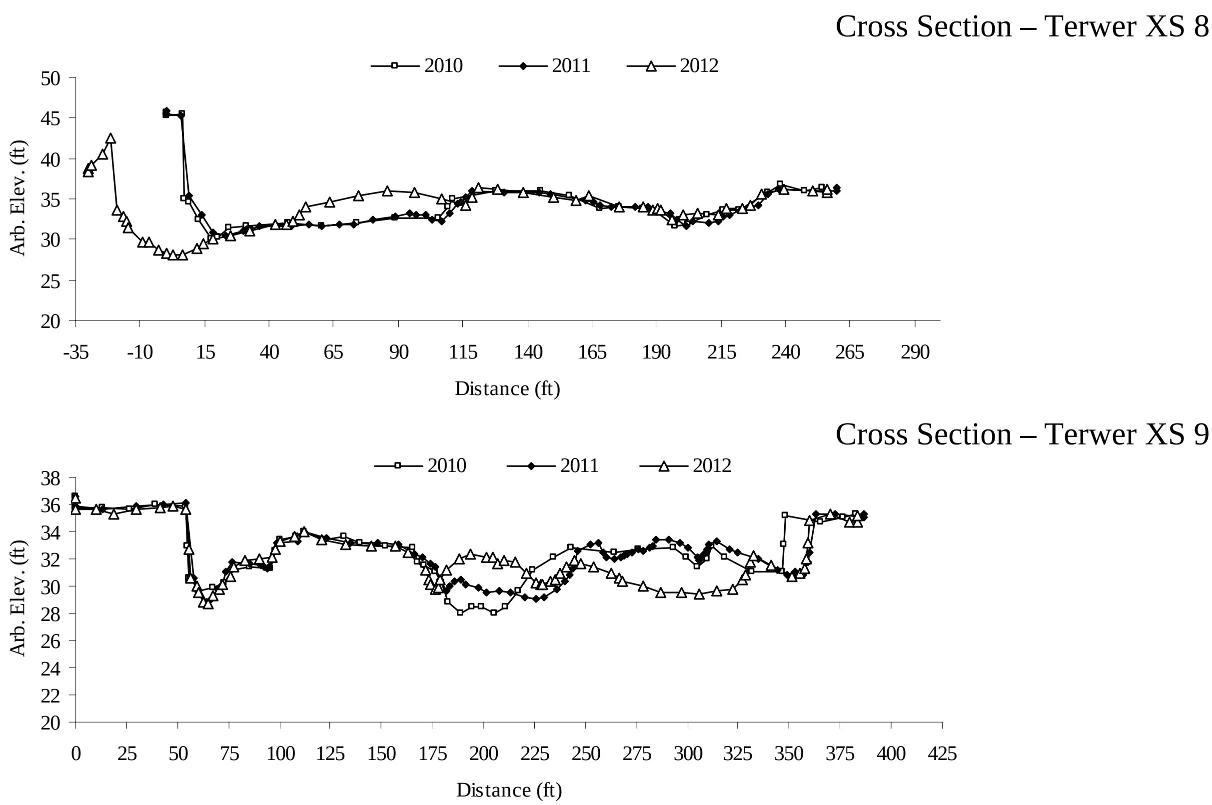
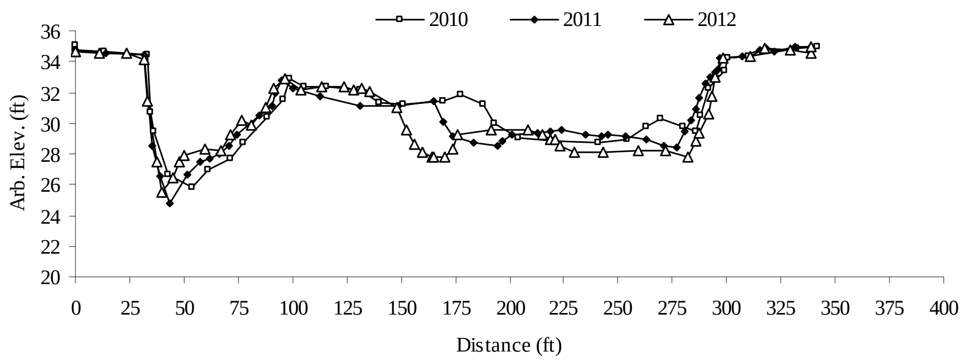


Figure 16. Cross section data collected in the Lower Arrow Mills project reach in Terwer Creek, Lower Klamath River (Fall 2010 - February 2012).

Cross Section – Terwer XS 10



Cross Section – Terwer XS 11

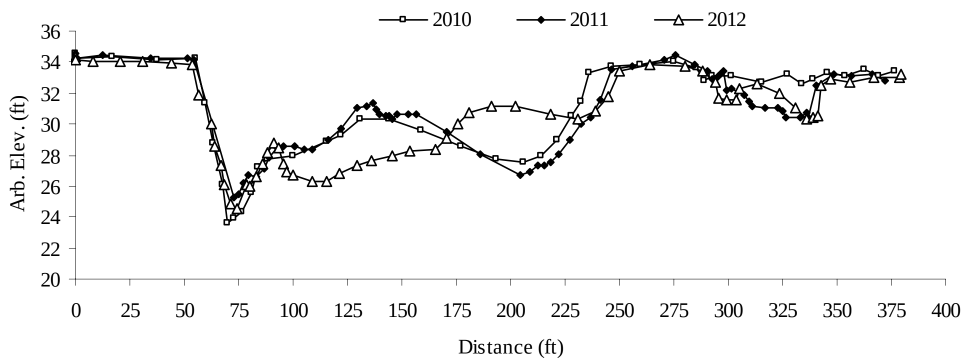


Figure 16. Continued.

Table 1. Photographic monitoring site information for the "Lower Terwer Creek Riparian Revegetation Project", Lower Klamath River (2010-2012).

File Name	Date	Site Name	Description	Lattitude	Longitude	Orientation
TC Pond A-1-071510	7/15/2010	TC Pond A-1	Pre-Project	41.5265	-123.9900	West-Towards Road
TC Pond A-1_072710	7/27/2010	TC Pond A-1	During Project	41.5265	-123.9900	West-Towards Road
TC Pond A-1_103010	10/30/2010	TC Pond A-1	As-Built	41.5265	-123.9900	West-Towards Road
TC Pond B-1_071510	7/15/2010	TC Pond B-1	Pre-Project	41.5262	-123.9859	South, Towards Pond B
TC Pond B-1_072810	7/28/2010	TC Pond B-1	During Project	41.5262	-123.9859	South, Towards Pond B
TC Pond B-1_103110	10/31/2010	TC Pond B-1	As-Built	41.5262	-123.9859	South, Towards Pond B
TC Pond B-1_032912	3/29/2012	TC Pond B-1	Pre-Project	41.5262	-123.9859	South, Towards Pond B
TC Pond B-1_033012	3/30/2012	TC Pond B-1	Pre-Project	41.5262	-123.9859	South, Towards Pond B
TC Bio526-A_063010	6/30/2010	TCBio526-A	Pre-Project	41.526	-123.986	West-Towards Creek
TC Bio526-A_050211	5/2/2011	TCBio526-A	Post-Project	41.526	-123.986	West-Towards Creek
TC Bio526-A_033012	3/30/2012	TCBio526-A	Post-Project	41.526	-123.986	West-Towards Creek
TC ELJ1-A_101509	10/15/2009	TC ELJ1-A	As-Built	41.5257	-123.9874	East-Towards Road
TC ELJ1-A_100611	10/6/2011	TC ELJ1-A	Post-Project	41.5257	-123.9874	East-Towards Road
TC ELJ2-A_100611	10/6/2011	TC ELJ2-A	Pre-Project	41.5259	-123.9874	East-Towards Road
TC ELJ2-A_100811a	10/8/2011	TC ELJ2-A	During Project	41.5259	-123.9874	East-Towards Road
TC ELJ2-A_100811b	10/8/2011	TC ELJ2-A	During Project	41.5259	-123.9874	East-Towards Road
TC ELJ2-A_032912	3/29/2012	TC ELJ2-A	Post-Project	41.5259	-123.9874	East-Towards Road
TC ELJ1-2-East_100611	10/6/2011	TC ELJ1-2-East	Pre-Project	41.5259	-123.9874	East-Towards Road
TC ELJ1-2-East_032912	3/29/2012	TC ELJ1-2-East	Post-Project	41.5259	-123.9874	East-Towards Road
TC CribWall-A_101411	10/14/2011	TC CribWall-A	Post-Project	41.5254	-123.9900	South-East-Towards CribWall
TC CribWall-A_032912	3/29/2012	TC CribWall-A	Post-Project	41.5254	-123.9900	South-East-Towards CribWall

Figure 17. Map depicting permanent photo-monitoring sites established in the 2010 - 2012 Terwer Creek bioengineering project reach, Lower Klamath River.

Figure 18. Photographs taken from a permanent photo-monitoring site in Terwer Creek, Lower Klamath River (Site: TC Bio526-A: Top-June 2010, Middle-May 2011, Bottom-March 2012).

Figure 19. Photographs taken from a permanent photo-monitoring site in Terwer Creek, Lower Klamath River (Site: TC Pond B-1: Top-March 29, 2011; Bottom-March 30, 2012).

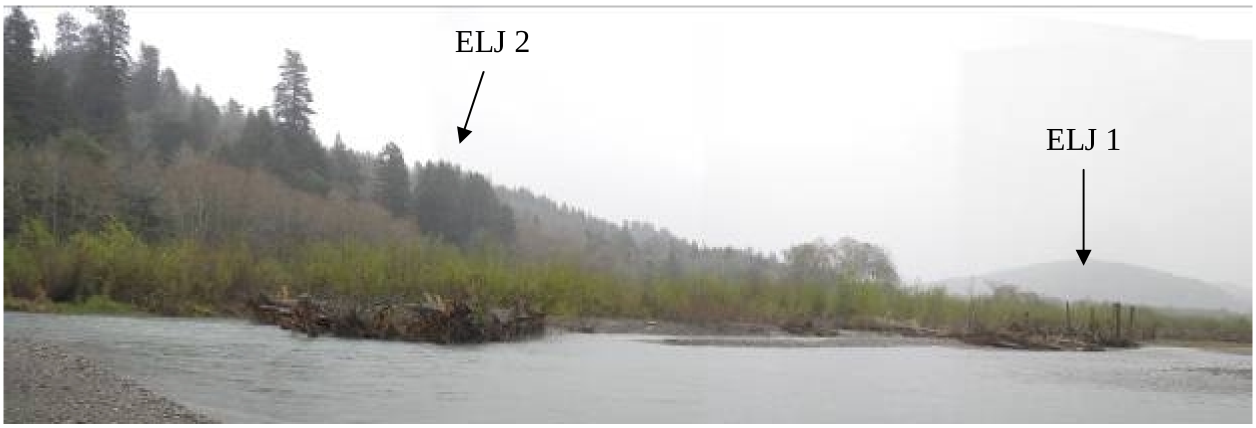


Figure 20. Photographs taken from a permanent photo-monitoring site in lower Terwer Creek (Site: TC ELJ1-2-East: Top – 10/6/11, Bottom – March 29, 2012).

Lower Terwer Creek Streambank and Riparian Restoration - U.S. Fish and Wildlife Service – Tribal Landowner Incentive Program Project

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Acknowledgements

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Yurok Fisheries Technician II, Steven Nova, giving a big "thumbs up" for the willow baffle construction in Terwer Creek

Introduction

The Yurok People have relied upon Klamath River for their subsistence, cultural, and economic livelihood since time immemorial. Central to Yurok culture is the harvest of anadromous fish, especially salmon and steelhead. Runs of anadromous fish currently returning to spawn in the Lower Klamath tributaries are depressed when compared with historical numbers. Extensive timber removal and road building activities has resulted in chronic sedimentation of streams and floodplains; a significant loss of channel-stored wood and riparian conifers; and a concomitant loss of habitat diversity and production potential in the sub-basin (Payne & Associates 1989; Gale and Randolph 2000; Beesley and Fiori 2007 and 2008; Voight and Gale 1998). The Yurok Tribe is dedicated to rehabilitating degraded river, tributary, and estuary habitats to levels that support robust, self-sustaining populations of native anadromous fish. To help address this need, the Yurok Tribe's Fisheries (YTFP), Watershed (YTWP), and Environmental Programs have been conducting fisheries and watershed assessments; and restoration in Lower Klamath habitats since the late 1990s.

Terwer Creek enters the Lower Klamath River 5.5 river miles upstream of the Pacific Ocean (Figures 1-2). Terwer Creek is a fourth order watershed draining approximately 31.8 square miles of steep, forested terrain (Figures 1-2). YTFP considers this a priority watershed for receiving upslope and fluvial rehabilitation activities (Gale and Beesley 2006, Gale and Randolph 2000; Gale 2007, 2008, and 2009; Beesley and Fiori 2008). Terwer Creek supports runs of late fall-run chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead (*O. mykiss*), coastal cutthroat trout (*O. clarki clarki*), and multiple lamprey species (Voight and Gale 1998; YTFP Unpublished Data 1997-2010). Coho in the Klamath Basin are listed as threatened under the Endangered Species Act, while Klamath Basin runs of chinook, steelhead, and cutthroat have been previously petitioned for listing.

Lower Klamath River tributaries, especially coastal streams and those draining to the estuary, also provide critically important rearing and staging habitat for non-natal salmonids (Beesley and Fiori 2004; Hiner and Brown 2004; Beesley and Fiori 2007; Soto et al. 2008; YTFP 2009; Hiner 2009; Hillemeier et al. 2010; Silloway 2010). Off-estuary and coastal tributaries provide fish refuge from high water velocities or poor water quality occurring in the river; and offer diverse habitats for fish to forage or stage prior to initiating ocean entry or upriver migration. These areas are especially important to non-natal juvenile salmonids during winter - spring and directly influence fish growth just prior to ocean entry (Hillemeier et al 2010). Studies conducted in Oregon suggest ocean survival of juvenile chinook salmon was greatly increased when fish entered the ocean at larger sizes (120-160 mm) (Nicholas and Hankin 1989). YTFP recently documented overwinter use of off-channel habitats of lower Terwer Creek by natal and non-natal juvenile coho (YTFP Unpublished Data 1997-2010).

Historic logging and road building activities resulted in the removal of virtually all riparian conifers and loss of channel-stored wood and naturally formed wood jams. A moderate to severe forest fire occurred in the watershed in the late 1980s and the burn areas were then subjected to salvage logging. Aerial image analysis of Terwer Creek reveals numerous relic and active hillslope failures, substantial channel-stored sediment, and widespread riparian dysfunction (Fiori Unpublished Data). To help address upslope concerns, YTWP completed a road system inventory in the watershed that prioritized treatment of all potential road-related sediment delivery sites; and they began treating priority road segments in 2007.

Riparian forest productivity and channel complexity in lower Terwer Creek has been further compromised as a result of cattle and timber mill operations occurring in the valley since the late 1800s. Currently, several actively managed cattle pastures exist in the valley (Figure 3); and at least one reproducing population of feral cattle resides in the lower watershed. Given the close proximity to the estuary and the potential to create a significant amount of quality overwinter rearing habitat in the valley for natal and non-natal salmonids; YTFP has worked with landowners and resource partners to begin rehabilitating relic riparian pastures and heavily impacted stream banks in 2005 (Gale and Beesley 2006, Gale 2007, 2008, and 2009; Beesley and Fiori 2008). YTFP has focused on using bioengineering techniques and constructing large wood and/or boulder structures to stabilize highly erosive stream banks; and building fences to exclude cattle from sensitive riparian areas of the Terwer valley.

This report focuses on stream and riparian enhancement work conducted for the U.S. Fish and Wildlife Service's (USFWS) Tribal Landowner Incentive Program (TLIP) grant (Federal Assistance # I-13-NA-1) (Figure 3). YTFP also obtained funds from California Department of Fish and Game's (CDFG) Fisheries Restoration Grant Program and USFWS Partner's for Fish and Wildlife funds to conduct this effort. Recently, YTFP obtained an American Recovery Act grant from the National Oceanic and Atmospheric Administration and additional USFWS funds to continue and expand our enhancement efforts in this critically important watershed. For report purposes the TLIP project area was divided into the upper and lower portions (Figure 4); and into individual project sites (Figure 5).

Project Objectives

The primary objectives of the TLIP project were to work with the landowners, which included Green Diamond Resource Company (GDRC) and a local cattle manager, to implement stream and riparian enhancement activities in the Terwer Creek valley that promote long-term channel stability and riparian resiliency. Specific activities included constructing willow mattresses and siltation baffles; propagating native seed, cuttings, and bareroot trees in the Yurok Tribal Native Plant Nursery (YTNPN); planting native conifers and deciduous trees in riparian habitats; and constructing large wood/boulder structures and engineered log jams (ELJs) to protect stream banks and riparian habitats. YTFP has worked hard to establish mutually beneficial partnerships with landowners in the Terwer Creek watershed. Stream and riparian enhancement conducted in the valley continues to demonstrate that habitat rehabilitation and working landscapes can operate in ways that result in long-term benefits to landowners and Tribal Trust fish and wildlife. Another primary objective was to provide quality employment opportunities to YTFP staff that involve improving conditions for local residents, the Yurok Tribe, and for native fish and wildlife.

Methods and Results

- Willow Baffle and Mattress Construction

A total of 112 willow siltation baffles and one 80 foot long willow mattress were constructed in the project area (Figures 5-6). Willow siltation baffles and the willow mattress were constructed using standard bioengineering methods (Engber 2005; Flosi et al. 1998). The willow mattress was constructed along an eroding bank located in the upper portion of the project reach (Site A) (Figures 5, 7-12). Exotic blackberry was removed from the site, the bank was outsloped to reduce erosion potential, and willow baffles were constructed behind the mattress to further promote improved riparian conditions in the reach (Figures 7-15).

Baffles were constructed at specific angles based on the direction of the main flow paths at each site to facilitate effective velocity reduction at each baffle. Willow baffles were constructed on several floodprone surfaces located within the project area to reduce stream velocities, promote fine sediment deposition and riparian growth, increase riparian forest function, and immediately improve conditions for native fish and wildlife (Figures 7-23).

Baffles were constructed by digging a 5-6 foot deep trench with a backhoe, lining the trench with a thick layer of vertically-placed willow cuttings (1-2 inch diameter) and posts (4-8 inch diameter), with the butt ends placed at the bottom of the trench (Figure 6). Baffles averaged ~ 20 feet in length and were spaced at various intervals depending on site conditions and objectives. Willows were angled slightly downstream in the trench and then a backhoe was used to backfill the trenches with the excavated material. Baffles were constructed to protect stream banks and riparian habitats from excessively high stream velocities. Some of the baffle sets were armored with quarry rock at their base in an attempt to minimize scour and increase willow survival. Large and small woody debris (LWD and SWD) salvaged from nearby road decommissioning projects were placed at the base of select baffle sets and into the bed between baffles to increase surface roughness. Buried and projecting wood provides increased soil moisture and nutrients to the willows, shade for willows, reduced stream velocities within the baffles, and promotes long-term riparian resilience and productivity.

- Log-Boulder Structure Construction

Eight log-boulder structures were constructed along an eroding bank located in the mid-portion of the project reach in 2007-2008; and an additional five were constructed in fall 2009 (Sites B - C) (Figures 5, 24-25). The log-boulder structures were constructed using an excavator according to methods detailed in Flosi et al. (1998) using both LWD and large quarry rocks (3+ ton) (Figure 25). Each log was placed in an excavated trench and angled upstream to deflect stream flows away from the bank (Figure 25). To increase bank stabilization, live willow posts and brush were incorporated into select structures where soil conditions were adequate to facilitate vegetation survival.

- Engineered Log Jams and Crib Wall Construction

YTFP worked with Rocco Fiori (Fiori GeoSciences (FGS)), a Licensed California Geologist, to implement more intensive bank protection techniques in the lower portion of the project reach (Site D) (Figures 5, 26-31). In fall 2009, FGS designed and constructed two ELJs according to methods outlined in Abbe et al. (2003). The ELJs were constructed in place of the proposed bioengineering approach based on recent channel changes (bank loss) and the resulting need to greatly reduce near bank shear stress along the left bank (looking downstream). YTFP worked with USFWS TLIP staff to change the scope of work to include the ELJs. A ~90 foot long crib wall ELJ was constructed along the highly impacted stream bank located in the lower reach (Figures 28-30). Recent channel shifts had forced flows directly into this bank and resulted in significant erosion at this site. Another ELJ was constructed upstream of the crib wall to deflect the main flow path away from the left bank and reduce the erosion potential downstream of the structure (Figures 26-27). The ELJs had live willow extensively incorporated into the structures to promote forest development and long-term channel and bank stability. These structure types were necessary to facilitate improved channel and riparian function and improve fisheries habitat at the in this reach.

In addition to providing significant bank protection, the ELJs have created valuable slow and deep water habitat for juvenile and adult salmonids during winter high flows (Figures 26-30). This was the first time that ELJs have been constructed in the Lower Klamath. YTFP plans to continue working with FGS to design and install more ELJs in lower Terwer Creek based on the performance of these structures during winter 2009-2010. Next summer, FGS and YTFP will construct two off-channel ponds in the lower portion of the project reach to increase overwinter rearing capacity for natal and non-natal salmonids. Additional ELJs will be constructed in the valley to promote multiple forested islands, further reduce stream velocities, protect the rearing ponds from erosion, and greatly improve conditions for fish.

- Conifer & Deciduous Tree Planting and Maintenance

Over 2,000 native conifers and a few hundred native deciduous trees were planted in the project area (Table 1; Figure 5). Species planted included Douglas fir (*Psuedotsuga menziesii*); Sitka spruce (*Picea sitchensis*); big leaf maple (*Acer macrophyllum*); and black cottonwood (*Populus balsamifera*) (Table 1). All conifer and deciduous planting was conducted in late winter through early spring using standard tree planting techniques. Crews properly stabilized the trees and took care when burying root systems to prevent "J-rooting" and to increase survival and productivity. Planting occurred in sites rich in deposited organic material and protected from high flows to increase growth rates and survivability. Hand tools were used to clear existing vegetation from each planting site and trees were planted using hoedads or tree planting spades. Extensive clumps of exotic (non-native) Himalayan blackberries were mechanically removed from throughout the project area prior to implementing bank protection activities and planting native trees. The above ground portions of the blackberries were removed with gas powered weed trimmers or heavy equipment and then hand crews removed root crowns using hand tools. Areas cleared of non-native plants were either treated with willow baffles and/or planted with native trees.

Crews watered select baffle sets and newly planted trees during summer months to aid survival while the plants established viable root systems. Areas were watered using a truckbed water tank and irrigation hose. Where tributary flow was available, YTFP constructed gravity fed water irrigation systems to transport water to the planting sites. YTFP plans to inspect planted areas in lower Terwer to assess annual survival and identify future planting sites. YTFP will continue watering activities and planting YTNPN trees over the next few years to ensure high tree survival and facilitate long-term riparian productivity in the area. YTFP will also continue monitoring riparian development and diversity in the project area to learn from past treatments and to guide future riparian enhancement activities.

- Yurok Tribal Native Plant Nursery

In 2005, YTFP began a native tree nursery at our office in Klamath, California (Figure 32). Since this time, the Yurok Tribal Native Plant Nursery (YTNPN) has provided an opportunity to train staff members in collection and propagation of local seed and cuttings, and nursery operation and maintenance. The YTNPN also allows YTFP to grow trees to larger sizes prior to planting to promote increased survival rates. For this project YTFP crews propagated over 2,000 big leaf maples, red alder (*Alnus rubra*), and black cottonwood. A total of 3,200 bareroot conifers were transplanted to 5-gallon pots to grow out at the YTNPN for future planting efforts in Terwer Creek and other priority Lower Klamath tributaries. YTFP crews received valuable training on all aspects of nursery operations and seed/cutting collection and propagation.

- Channel Monitoring and Evaluation

YTFP began conducting channel surveys in lower Terwer Creek in 2005. All surveying was conducted using an optical total station and the resultant topographic data was brought into Trimble Geomatics Office and exported to ArcView and Microsoft Excel for data analysis and to plot longitudinal profiles and cross sections. Permanent benchmarks were established in the reach to allow repeat surveying. Surveys were repeated in the project reach annually. Surveys conducted prior to 2007 were considered baseline surveys or pre-project surveys.

YTFP has established a total of eight permanent cross sections in the project reach since 2005 (Figures 33-34). A majority of these cross sections were established in 2006. Cross sections 9 - 10 were established in the lower portion of the project reach in late fall 2005; while cross sections 8 and 11 were added in 2007. Cross sections 9 - 11 were surveyed in October 2009 to document conditions in the lower portion of the project reach prior to constructing the ELJs (Figures 33). YTFP plans to conduct intensive channel surveys through lower Terwer Creek in summer 2010. Repeat surveys of this reach are critical for assessing effectiveness of enhancement activities and developing future treatment techniques.

Cross section data collected in the upper portion of the project reach showed gradual filling of the secondary channel along the right bank and a deepening of the main channel along the left bank (Figure 34). Data collected at cross section 6 showed erosion occurred along both banks and bar and right bank channel elevations increased (Figure 34). Data collected at cross sections 4 - 7 revealed channel migration from the right bank to the left, while cross sections 8 - 9 showed another avulsion of the channel from the left bank to the right (Figure 34). Cross section 9 data revealed a loss of over 150 feet of the right bank, an increase in secondary channel and bar elevations, and an increase in the number of channels (Figure 34). Data collected in the lower portion of the project reach showed a huge loss of the left bank and continual channel development on the right bank (Figure 34).

Cross section 10 showed the loss of ~100 linear feet of bank from November 2005 to fall 2009 (Figure 34). Data collected at cross section 11 indicates similar lateral instability, with the loss of 35 linear feet of bank during winter 2007-2008 (Figure 34). The left bank in this reach is composed of layered beds of river gravels and silt, clay hardpan, and mill deposits (Figure 35). Based on channel surveys conducted in the lower portion of the project reach from 2005 – 2008, an estimated ~30,000 cubic yards of fine-grained sediment was delivered to the channel. Bank heights (distance above the channel bed) in this reach range from three to ten feet and pasture grass dominated this surface prior to initiating enhancement activities. Intensive treatment of this site (i.e. ELJ/willow baffle construction and riparian planting) was conducted in fall 2009 to provide increased protection of this productive floodprone surface.

- Vegetation Transect Assessment

GIS-based vegetation transects were created in the project area using ArcView and rectified aerial imagery. Five transect locations were randomly selected in the project reach to document short- and long-term changes in channel stability and riparian function (Figure 36). Cover types were mapped along each transect in ArcView using high resolution aerial imagery from 2005 (Pre-Project) and spring of 2009 (During Final Project Phases). Cover types identified included several vegetation classes and the active channel. The distance each cover type occupied along a given transect was digitized and calculated for 2005 and 2009. The amount of ground protected was estimated for every cover type identified in 2005 and 2009. Cover types were also classified by height: Class 0 (No Cover); Class I (0-15 feet); Class II (15-25 feet); and Class III (>25 feet). Field surveys were conducted in the project area pre-project (2007) and in early summer 2009 to verify the GIS-based mapping effort.

Seven cover types were identified during the vegetation transect mapping effort: Active Channel, Grass, Exotic Blackberry, Shrub, Shrub/Willow, Willow, Willow Mix (Figures 37-38). The Active Channel cover type was classified as a Class 0 (No Cover). Willow Mix was the only Class II (15-25 feet) cover type mapped in the reach; all other vegetation cover types were mapped as Class I (1-15 feet). There were no Class I Willow Mix cover types mapped. Dominant cover types for both years mapped were Grass and Active Channel. Bank erosion occurring in the project reach from 2005 to 2009 resulted in a decrease in Grass and Shrub cover types and a corresponding increase in the Active Channel cover type. The other differences to note included the elimination of Exotic Blackberry along the vegetation transects in 2009; and the addition of the Willow cover type in 2009 (Figures 37-38). The Willow cover type mapped in 2009 was comprised entirely of willow baffles constructed by YTFP (Figure X). YTFP plans to conduct field-based surveys of all vegetation transects in late summer 2010 and repeat them every two to five years to document long-term changes.

- Demonstration Project

Lower Terwer Creek is comprised mostly of small-scale ranches and industrial timberlands. This project was one of the first times YTFP coordinated with both Green Diamond Resource Company (GDRC) and a private landowner, Mr. Ken Farley, to conduct stream and riparian enhancement efforts in this watershed. GDRC owns a substantial portion of the Lower Klamath River Sub-basin. Therefore, the Yurok Tribe helped form the Lower Klamath Watershed Restoration Partnership in 1995 with GDRC, the California State Coastal Conservancy, and the Northern California Indian Development Council to address state and federal mandates by developing innovative solutions to resource management issues. The Yurok Tribe's Fisheries, Environmental, and Watershed Programs have since been coordinating with GDRC staff to conduct watershed monitoring; stream and riparian enhancement projects; and road decommissioning activities since 1997. GDRC continues to approve of our enhancement efforts in lower Terwer Creek and is currently working with us to develop future phases, and to generate the wood sources necessary to complete the work.

Mr. Farley's goals included protecting valuable infrastructure such as his well house and the pastures located along the creek (Figures 7-15). YTFP used willow baffles constructed upstream of Mr. Farley's well house to show local landowners, resource agency staff, and the community examples of bioengineering treatments and discuss how the treatments function to improve conditions for native fish and wildlife; while protecting valuable private property. This first "demonstration area" allowed Mr. Farley to see how the treatments looked and functioned and to gain confidence in the approach. During this project, YTFP and Mr. Farley have built a strong relationship that has resulted in significant fisheries and riparian habitat improvements. YTFP continues to use lower Terwer Creek as a "demonstration area" to promote the use of innovative ranch management techniques (i.e. using willow baffles to protect pastures, fencing cattle out of the creek). The success of this project has allowed YTFP to continue planning and implementing stream and riparian enhancement projects on Mr. Farley's property. FGS and YTFP are currently working with Mr. Farley to design and construct an off-channel pond on his property to increase the amount of overwinter habitat available to natal and non-natal juvenile salmonids. Mr. Farley is very supportive of using his property as a "demonstration area" and promoting the approach to other landowners.

In addition to the site being a "demonstration area", YTFP worked with Klamath River Early College of The Redwoods (KRECR) staff to develop and implement a fisheries management and restoration based curriculum for enrolled students. Several students participated in field visits to lower Terwer Creek during project implementation to learn about the project and discuss the importance of fisheries habitat rehabilitation in the Lower Klamath River. KRECR students were exposed to all the various stages of the project including project planning, monitoring, and implementation of several different enhancement techniques including tree planting, nursery management, willow harvesting, and baffle construction. YTFP continues to work closely with KRECR staff and students to promote a tribally based approach to fisheries science and native fish habitat restoration in the Klamath Basin.

Discussion and Recommendations

Enhancement treatments implemented during this project were designed to provide immediate and long-term benefits to Tribal Trust fish and wildlife. Objectives included increasing bank and channel stability, promoting diverse and resilient riparian habitats and forested islands, and improving water quality by reducing bank erosion through this reach. The use of willow bioengineering techniques in combination with ELJ construction resulted in significant bank protection and immediate aquatic and terrestrial habitat improvements. YTFP and FGS will continue and expand these efforts in the lower portion of the project reach this summer. In addition to promoting bank and channel stability, future enhancement activities will focus on increasing the amount of high quality, slow velocity overwinter rearing and staging habitat for natal and non-natal salmonids.

Future recommendations for lower Terwer Creek includes 1) maximizing the amount of high quality overwinter rearing and staging habitat for natal and non-natal salmonids; 2) constructing ELJs in the reach located upstream of the TLIP project reach to the Dandy Creek confluence; 3) continue tree planting activities within the lower valley and upstream of the Dandy Creek confluence; and 4) promoting forested islands in the Terwer Creek valley. Effectiveness monitoring should be continued and expanded in this watershed to facilitate an adaptive approach to habitat rehabilitation. This type of approach will ensure that techniques applied on-the-ground will be effective over short- and long-term timescales; and allows the information gained to be applied in other coastal watersheds of the Lower Klamath River.

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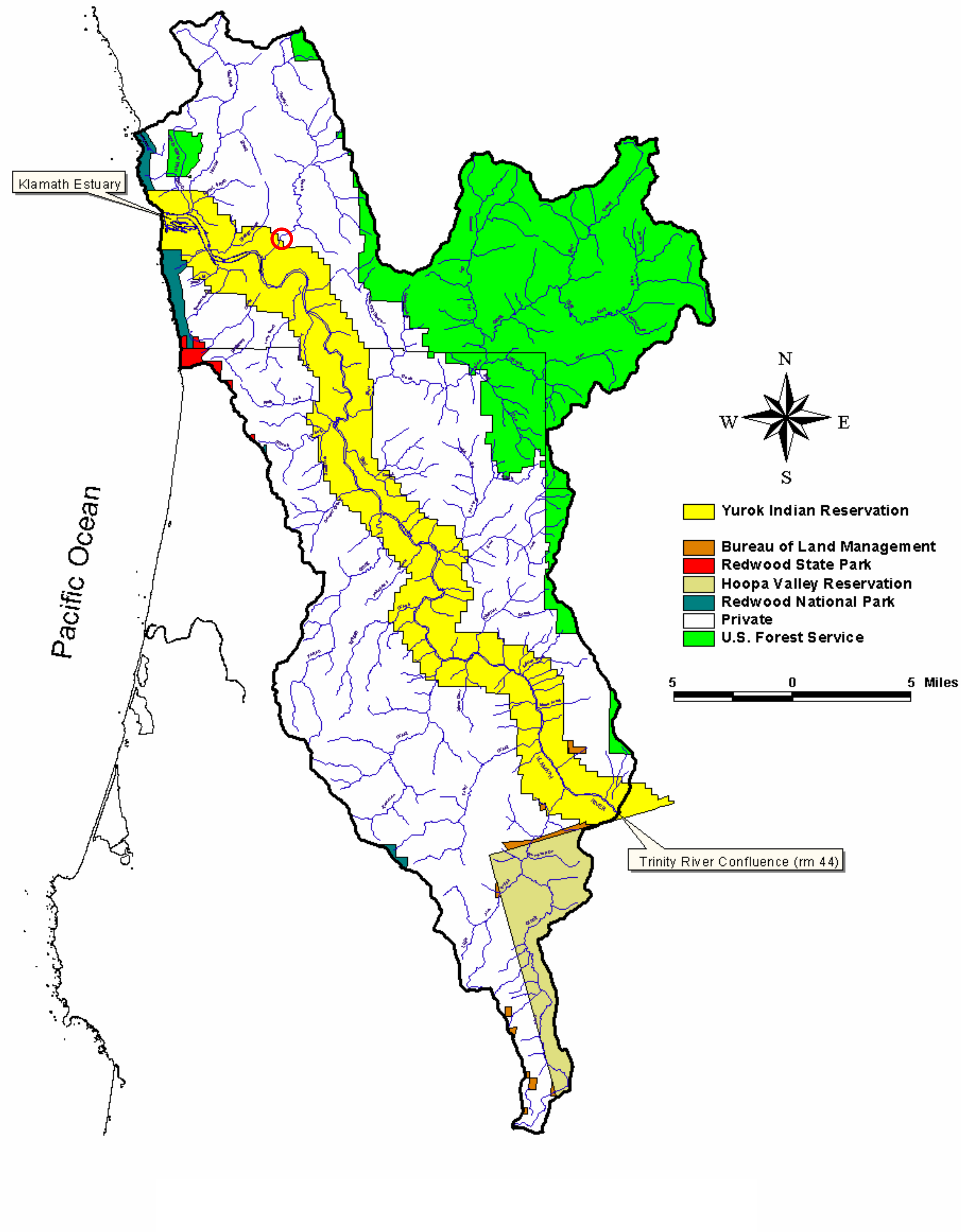


Figure 1. Map of the Lower Klamath River Sub-basin, California with the Terwer Creek project area circled in red.

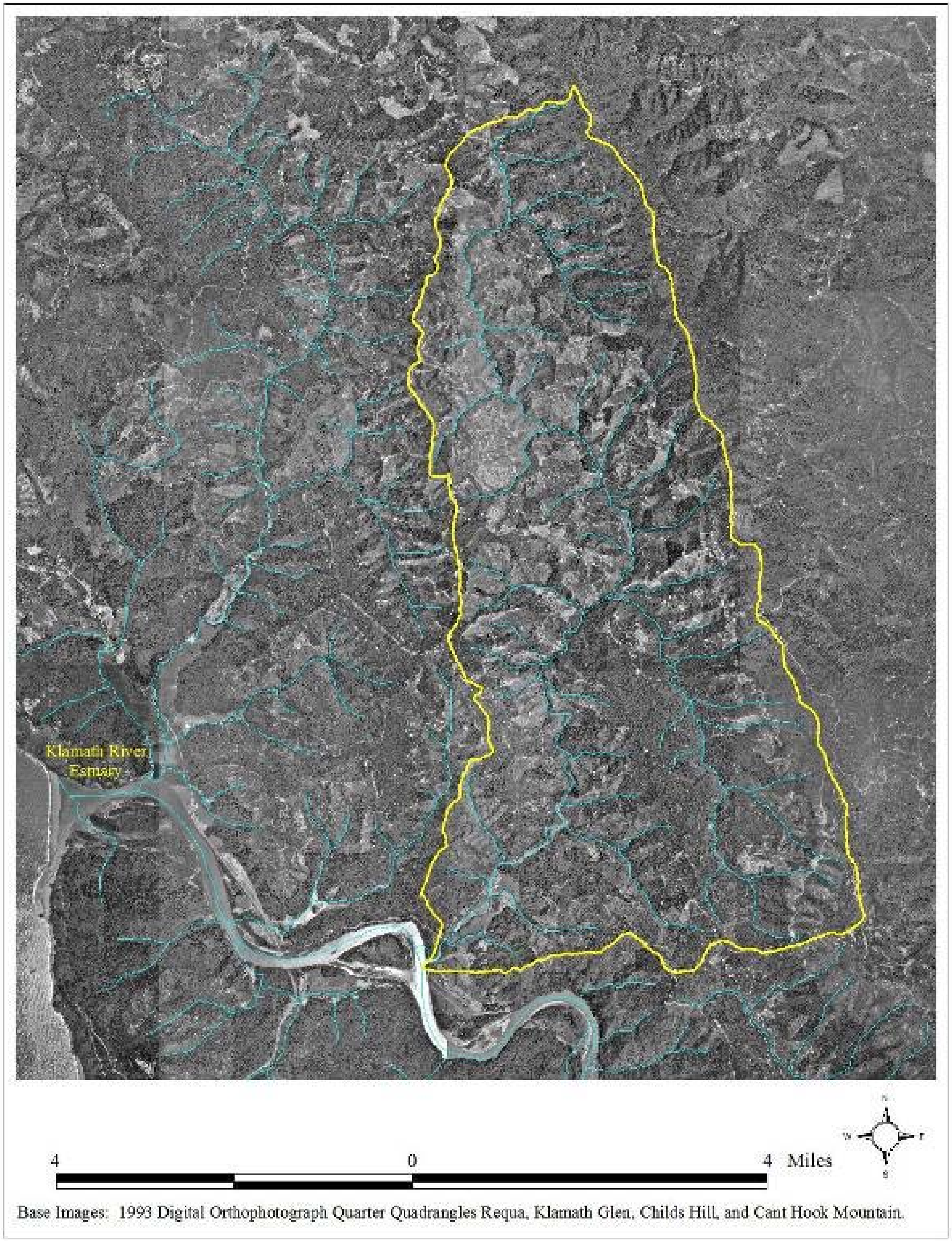


Figure 2. The Terwer Creek watershed, Lower Klamath River Sub-basin, California.

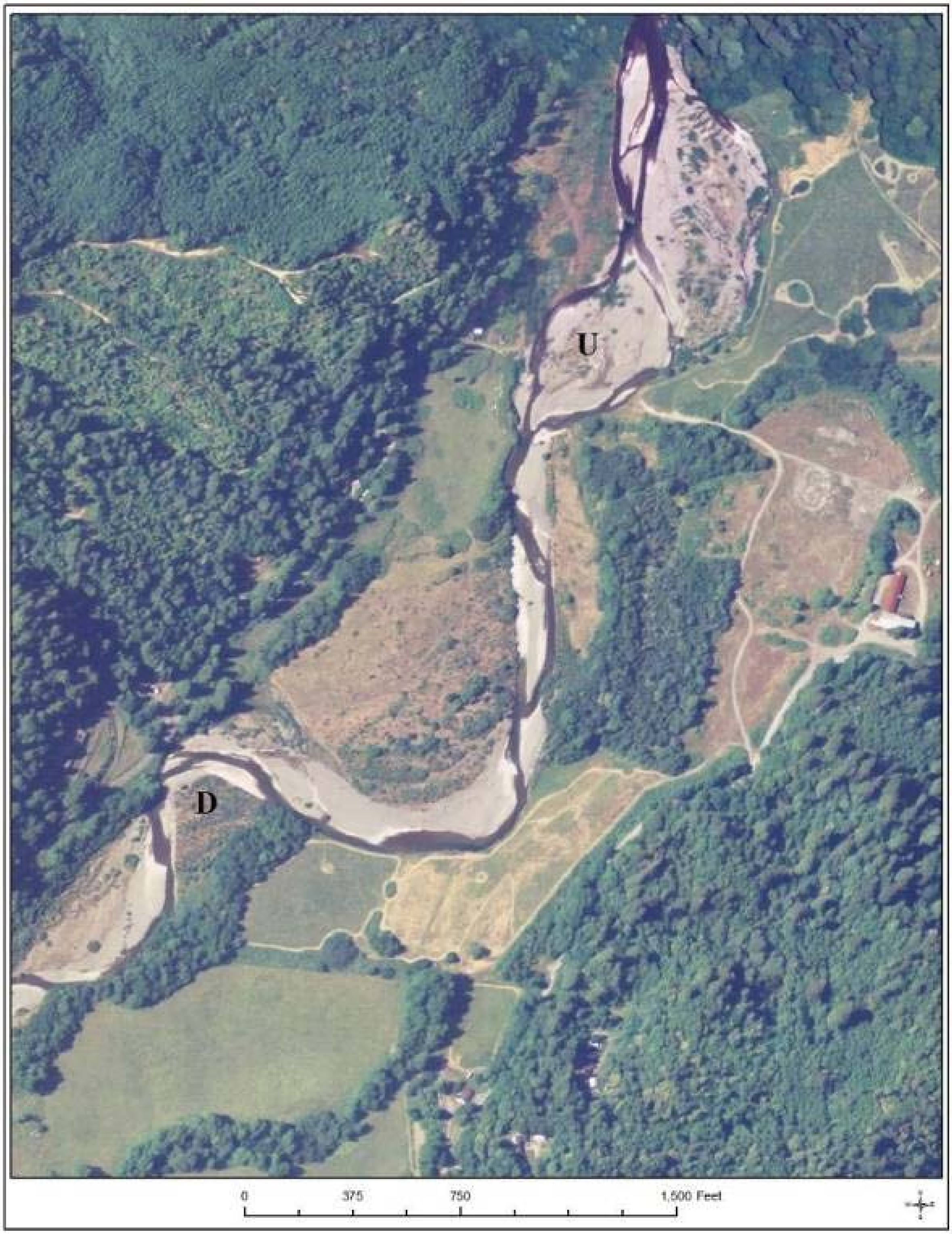


Figure 3. Map of the Terwer Creek valley with the "U" depicting the upper project boundary and the "D" depicting the downstream boundary of the project area (Base image: 2005 NAIP Aerial Imagery).

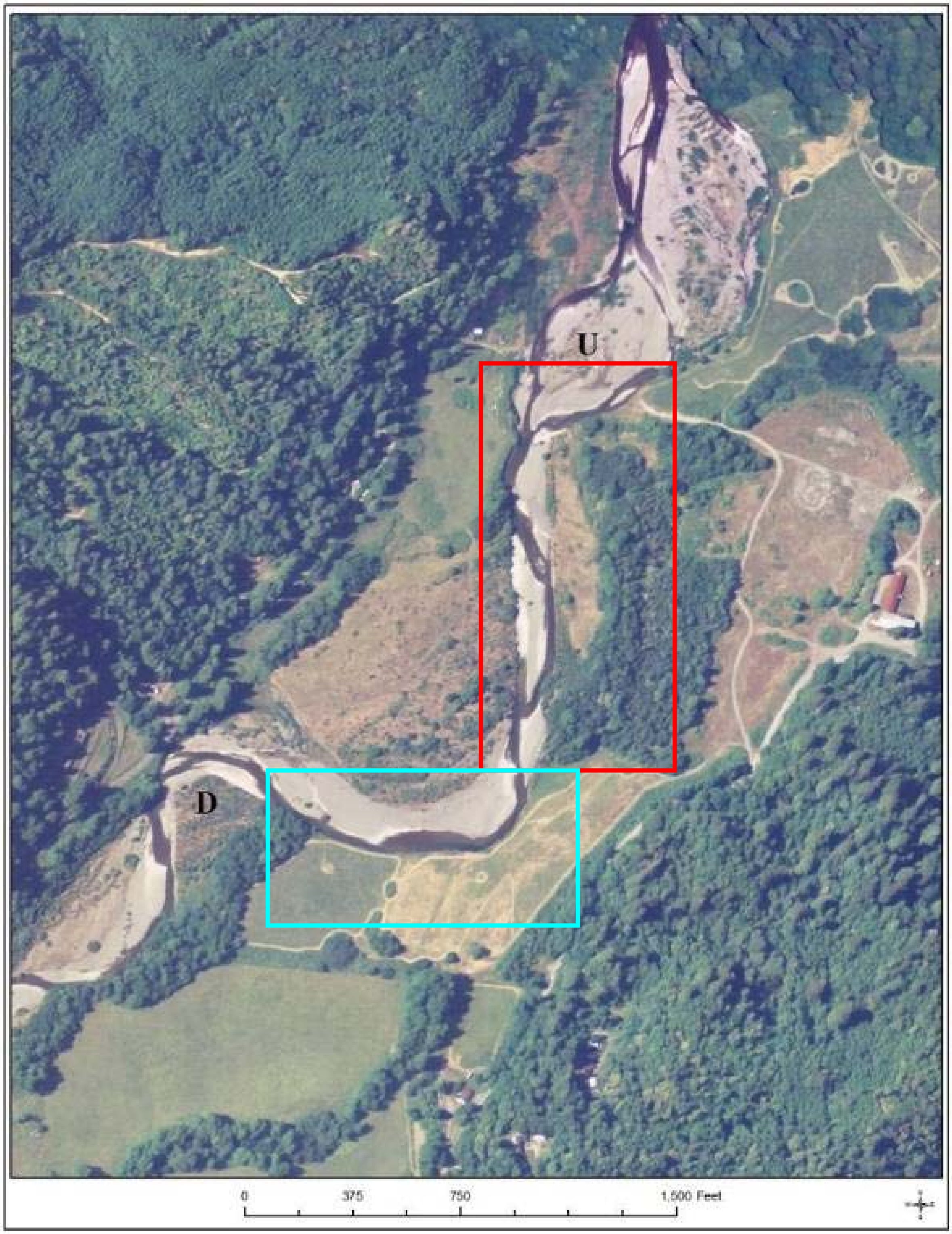


Figure 4. Map depicting the upper (outlined in red) and lower (outlined in light blue) project areas in the Terwer Creek valley (Base image: 2005 NAIP Aerial Imagery).

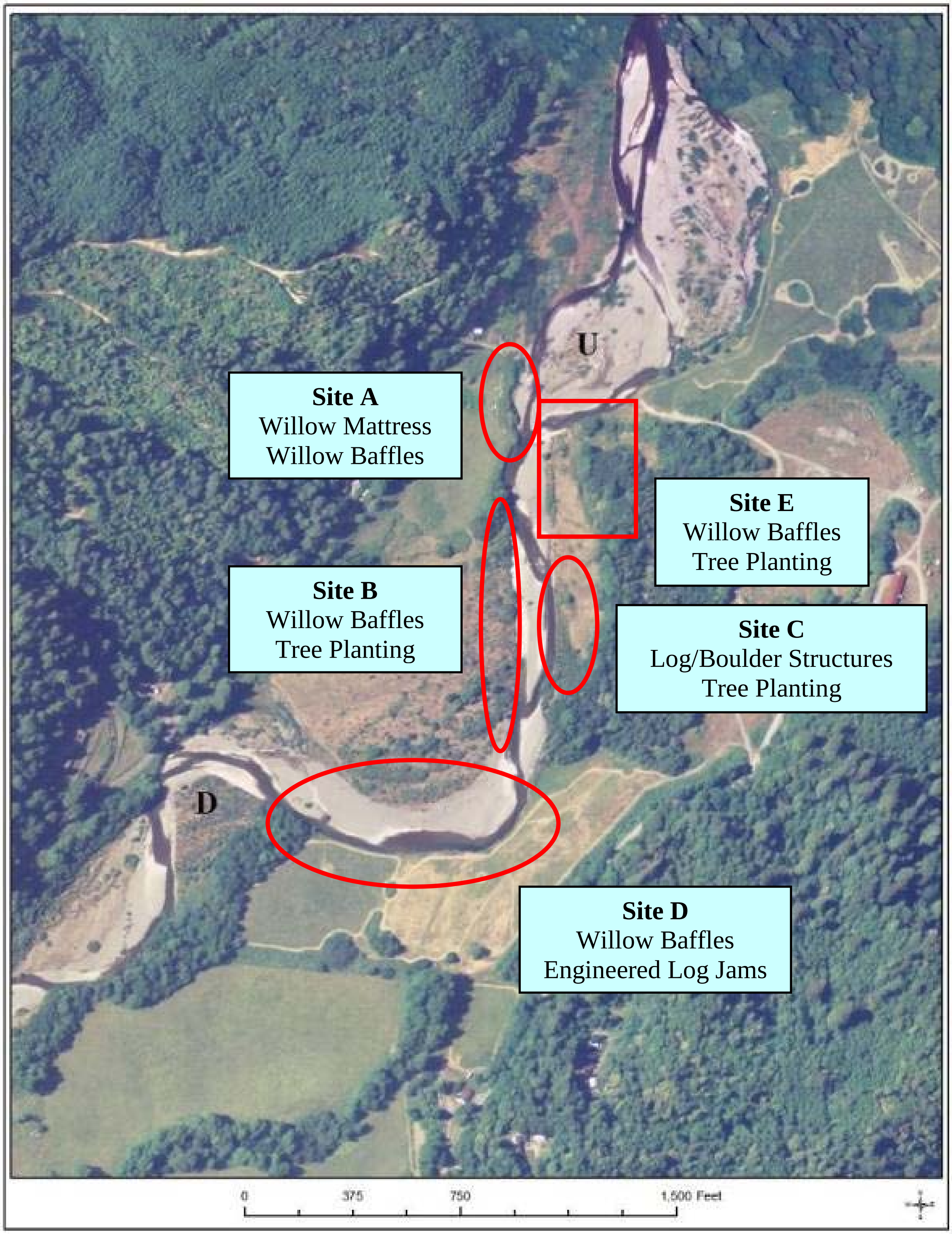


Figure 5. Map depicting several of the individual project sites located in the Terwer Creek valley (Base image: 2005 NAIP Aerial Imagery).

Figure 6. Yurok Fisheries staff constructing willow siltation baffles on a floodprone surface in lower Terwer Creek (Site D) (Top 2008 and Bottom 2009).

Figure 7. Looking upstream at an eroding bank (site A) dominated by Himalayan blackberry, Terwer Creek, Lower Klamath River, California, October 2005.

Figure 8. Looking upstream at an eroding bank (site A) during blackberry removal and outsloping activities, Terwer Creek, Lower Klamath River, California, September 2008.

Figure 9. Willow placed in the toe trench of the willow mattress (site A) prior to backfilling (Left), and Yurok Fisheries staff staking the willow mattress to the bank (Right) Terwer Creek, Lower Klamath River, California, October 2008.

Figure 10. Willow mattress (site A) being staked to bank following backfilling, Terwer Creek, Lower Klamath River, California, October 2008.

Figure 11. Looking upstream at the upper half of the willow mattress (site A) after it was staked and covered with soil, Terwer Creek, Lower Klamath River, California, October 2008.

Figure 12. Willow mattress (site A) following completion and mulching, Terwer Creek, Lower Klamath River, California, November 2008.

Figure 13. Removing Himalayan blackberries behind willow mattress (site A) prior to construction of willow baffles (Top - September 2008), and following removal of Himalayan blackberries (Bottom - December 2008), Terwer Creek, Lower Klamath River, California.

Figure 14. Willow terrace baffles being constructed behind willow mattress (site A), Terwer Creek, Lower Klamath River, California, December 2008.

Figure 15. Looking downstream at the willow mattress and terrace baffles (site A) following construction, Terwer Creek, Lower Klamath River, California, January 2009.

Figure 16. Looking upstream at an eroding bank (site B) prior to constructing willow baffles (Top - June 2006), and during construction (Bottom - October 2007), Terwer Creek, Lower Klamath River, California.

Figure 17. Looking downstream at an eroding bank (site B) prior to constructing willow baffles (Top - September 2007), and following construction (Bottom - October 2007), Terwer Creek, Lower Klamath River, California.

Figure 18. Looking downstream at an eroding bank (site D) prior to enhancement efforts (Top - October 2005), and during initial willow baffle construction (Bottom – March 2008), Terwer Creek, Lower Klamath River, California.

Figure 19. Looking upstream at an eroding bank (site D) prior to enhancement efforts (Top - December 2005), and following initial willow baffle construction on the left bank (Bottom – November 2008), Terwer Creek, Lower Klamath River, California.

Figure 20. Looking upstream at a floodplain surface (site D) following willow baffle construction, Terwer Creek, Lower Klamath River, California, December 2008.

Figure 21. Looking upstream at floodplain surfaces (site D) following willow baffle construction and a high flow event, Terwer Creek, Lower Klamath River, California, (Top - January 2009; Bottom - January 2010).

Figure 22. Looking downstream at the initial willow baffles (site D) (Top – December 2006), and the same area following more willow baffle construction and a high flow event (Middle and Bottom – January 2009), Terwer Creek, Lower Klamath River, California.

Figure 23. Photographs taken from an eroding bank (site D) looking towards Terwer Creek prior to enhancement efforts (Top - October 2005), and during tree planting (Bottom - January 2009), Lower Klamath River, California.

Figure 24. Looking upstream of an eroding bank (site C) prior to constructing log-boulder structures (Top - October 2005; Bottom - May 2006), Terwer Creek, Lower Klamath River, California.

Figure 25. Looking downstream at Yurok Fisheries staff positioning a log in an excavated trench (site C) (Left - October 2008), and following construction (Right - November 2008), Terwer Creek, Lower Klamath River, California.

Figure 26. An engineered log jam during construction (Site D) (Top – Fall 2009), and during a high flow event (Bottom – January 2010), Terwer Creek, Lower Klamath River, California.

Figure 27. An engineered log jam following construction (Site D) (Top – Fall 2009), and during a high flow event (Bottom – January 2010), Terwer Creek, Lower Klamath River, California.

Figure 28. Looking downstream at an engineered crib wall jam during construction (Site D) (Fall 2009), Terwer Creek, Lower Klamath River, California.

Figure 29. Looking downstream at an engineered crib wall jam during construction (Site D) (Top - Fall 2009), and during winter base flows (Bottom – Winter 2009-2010), Terwer Creek, Lower Klamath River, California.

Figure 30. Looking upstream at an engineered crib wall jam during a high flow event (January 2010), Terwer Creek, Lower Klamath River, California.

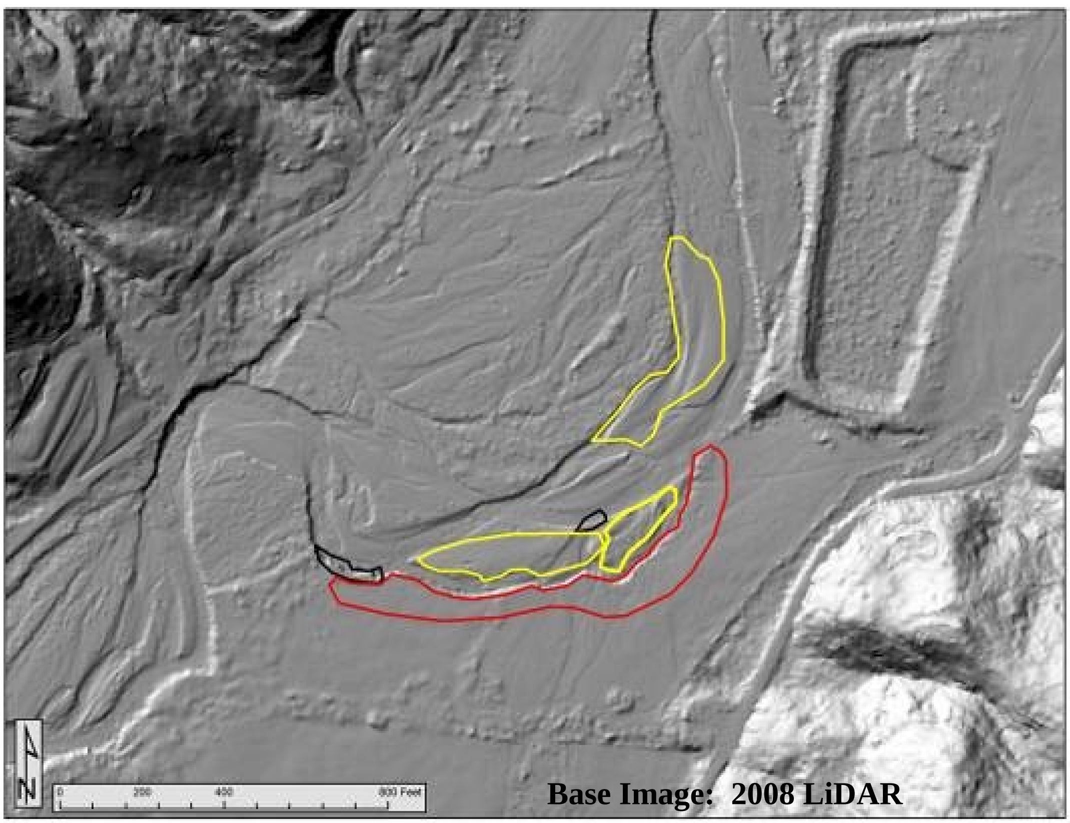


Figure 31. Map depicting enhancement techniques used in the lower portion of the project area (Site D), Terwer Creek, Lower Klamath River, California (Black = engineered log jams; Yellow = willow baffles and coarse wood; and Red = willow baffles and tree planting).

Table 1. Trees planted in riparian areas of lower Terwer Creek as part of the Tribal Landowner Incentive Program project (2007-2009), Lower Klamath River Sub-basin.

Species	Type	Quantity	Date Planted
Douglas Fir	Bareroot	1,350	Winter 2007-2008
Douglas Fir	Bareroot	500	Winter 2008-2009
Sitka Spruce	Bareroot	400	Winter 2007-2008
Sitka Spruce	Bareroot	150	Winter 2008-2009
Big Leaf Maple	2-gallon pots	94	Winter 2007-2008
Big Leaf Maple	2-gallon pots	70	Winter 2008-2009
Black Cottonwood	2-gallon pots	171	Winter 2007-2008
Black Cottonwood	2-gallon pots	72	Winter 2008-2009

Figure 32. Photographs of the Yurok Tribal Native Plant Nursery, and crews loading up native conifer saplings that were grown out at the nursery, Klamath, California.

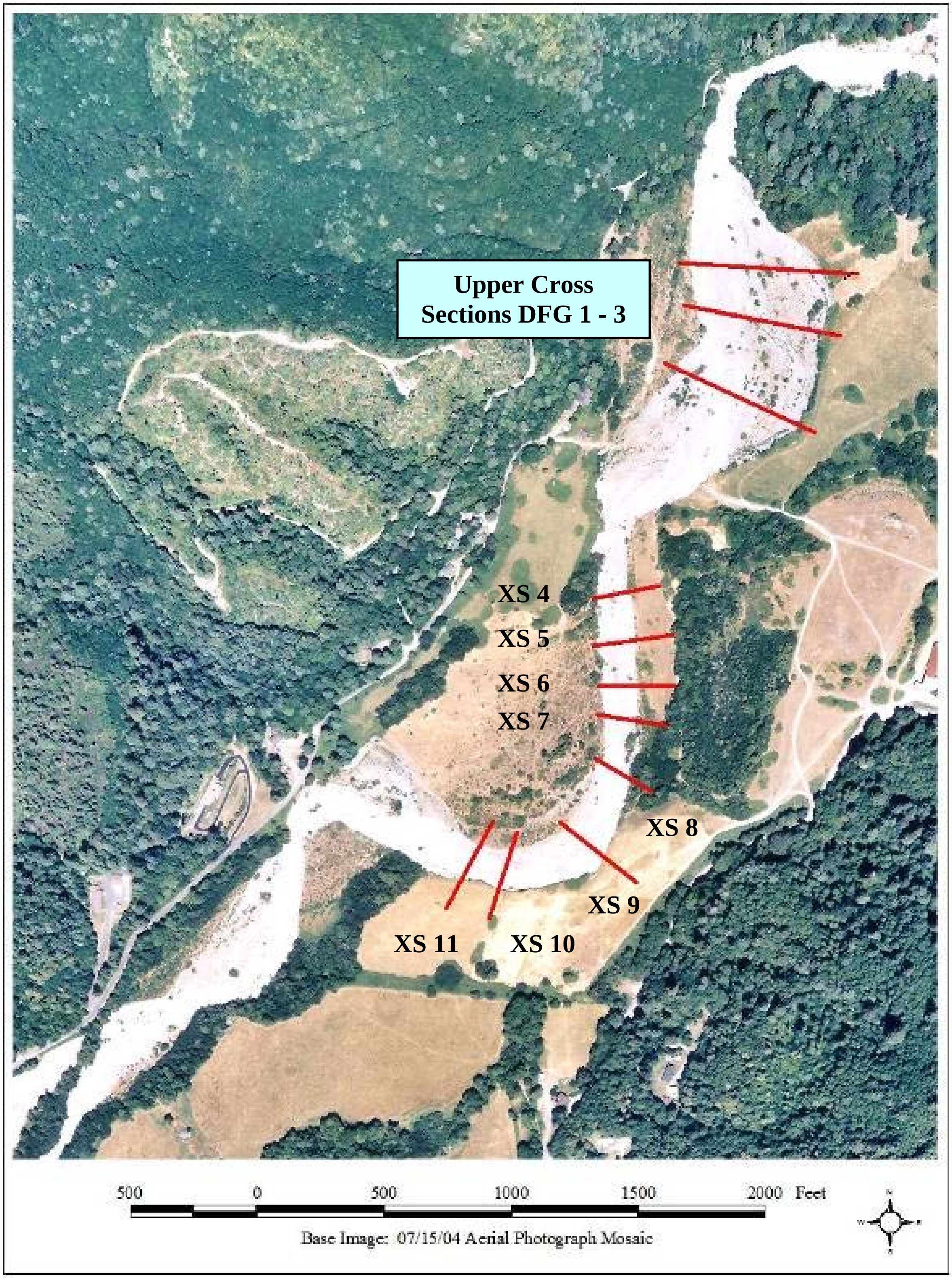


Figure 33. Map depicting permanent cross section locations in lower Terwer Creek.

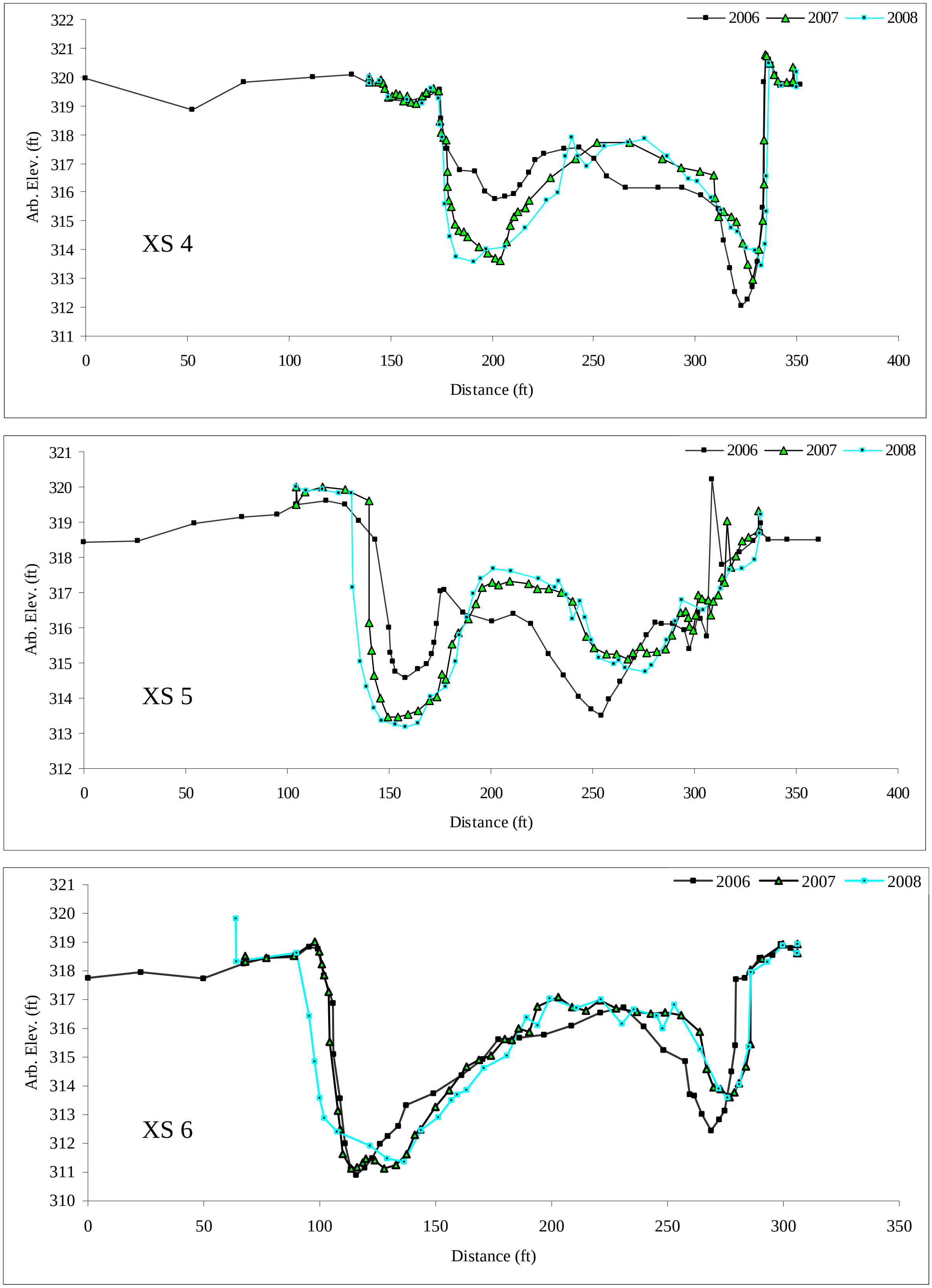
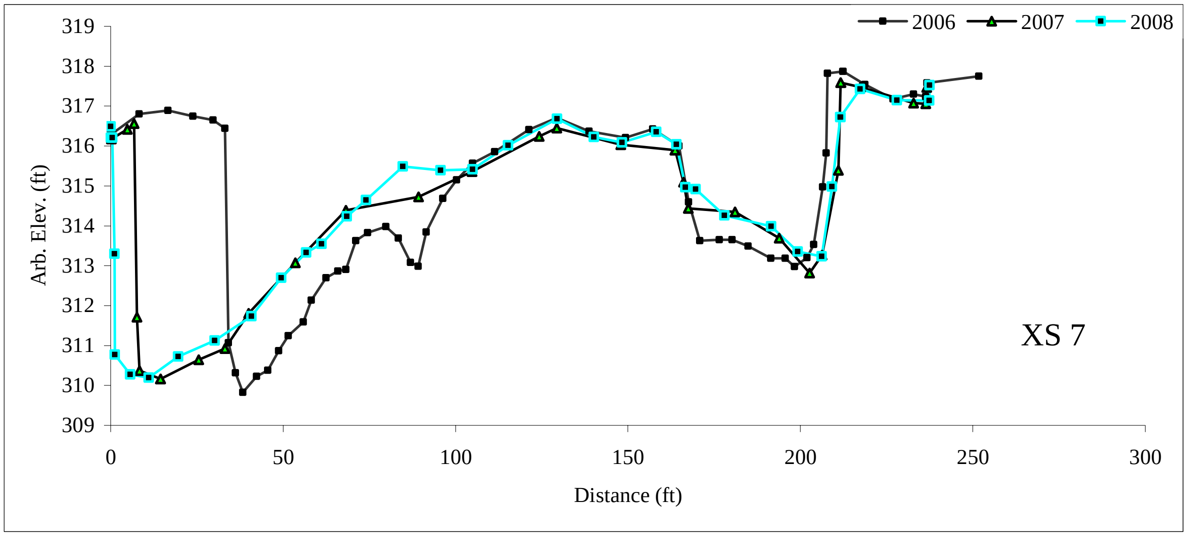
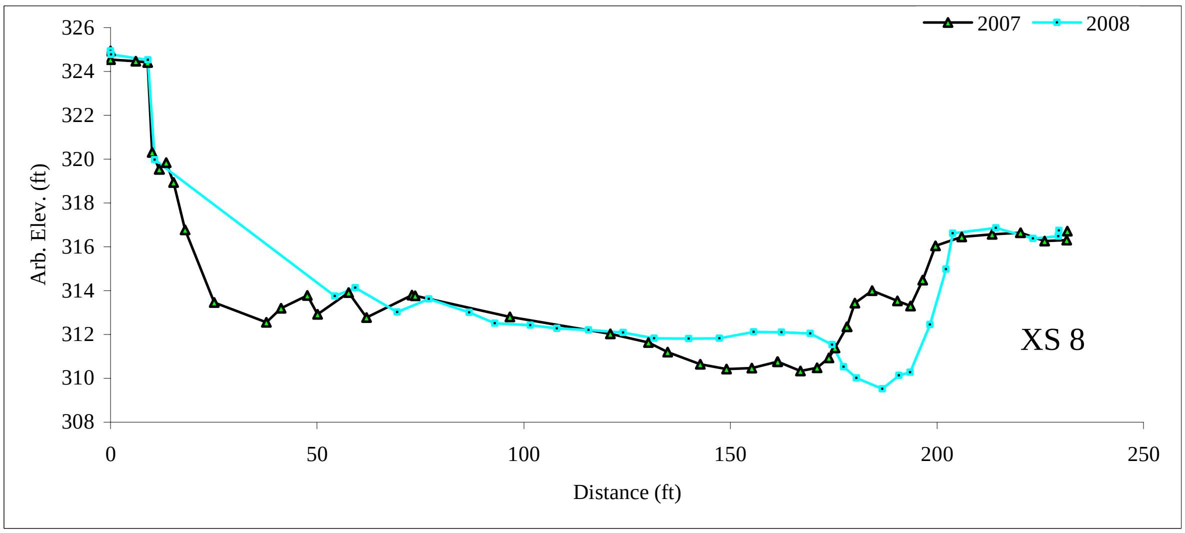


Figure 34. Topographic data collected at eight permanent cross sections located in lower Terwer Creek (2005 – 2008).





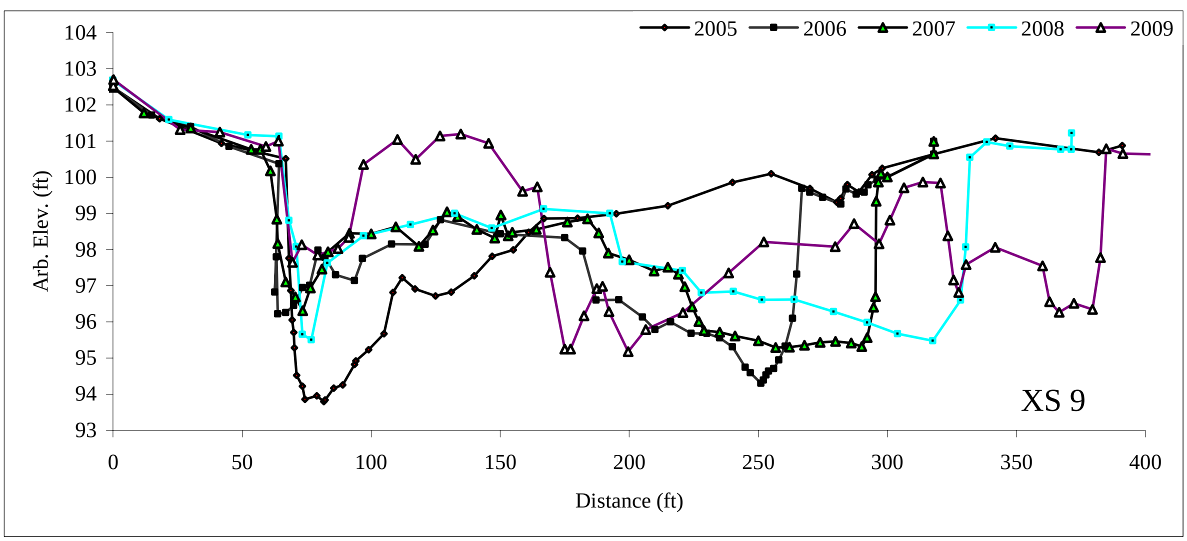
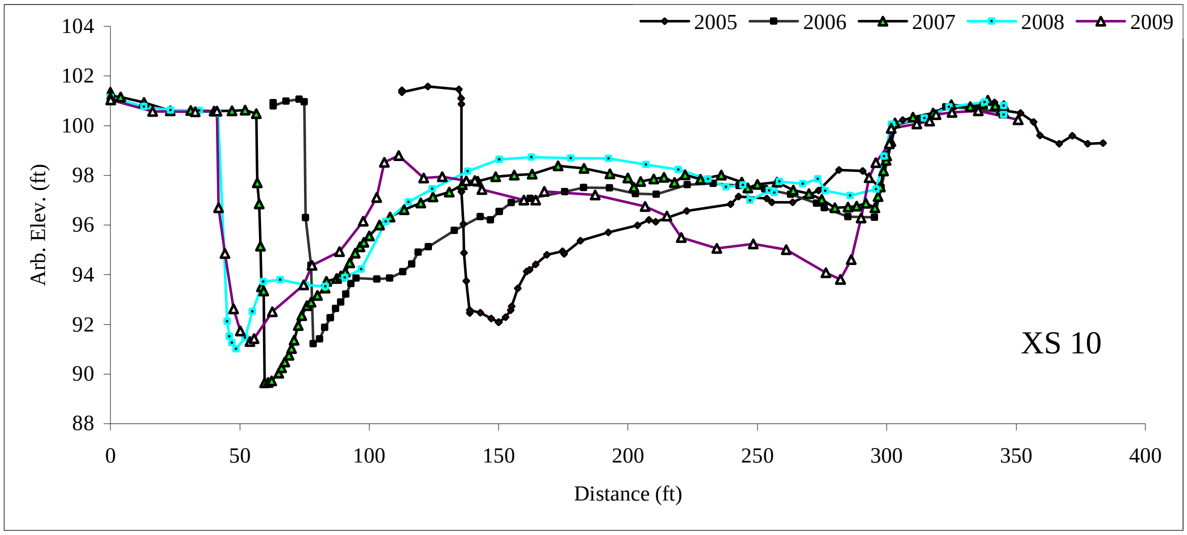


Figure 34. Continued.



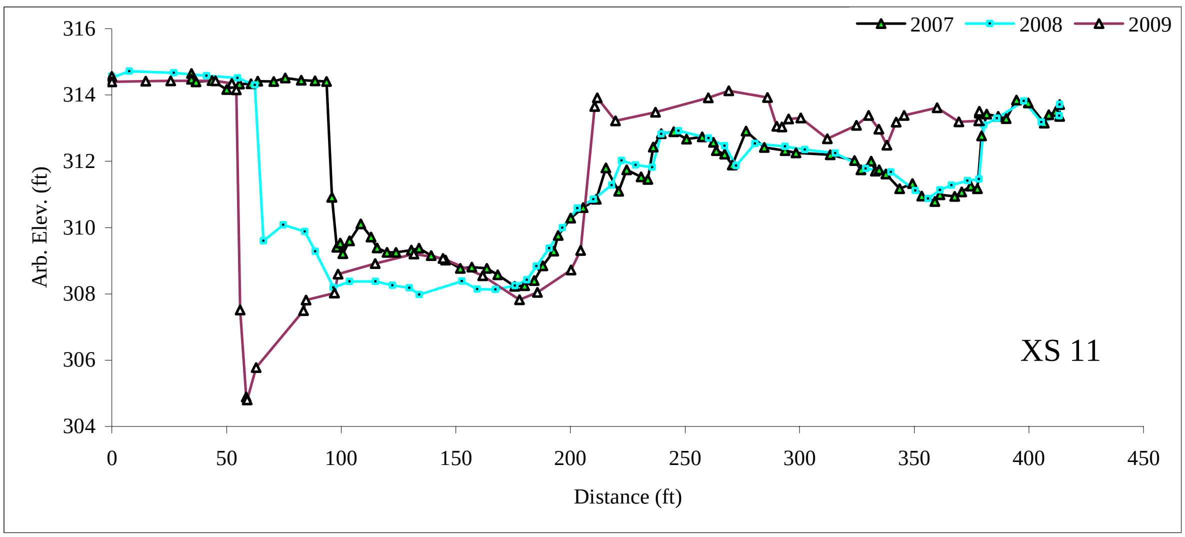


Figure 34. Continued.

Figure 35. Photographs of an eroding bank in the lower portion of the project reach (Site D), Terwer Creek, Lower Klamath River, California (Fall 2009).

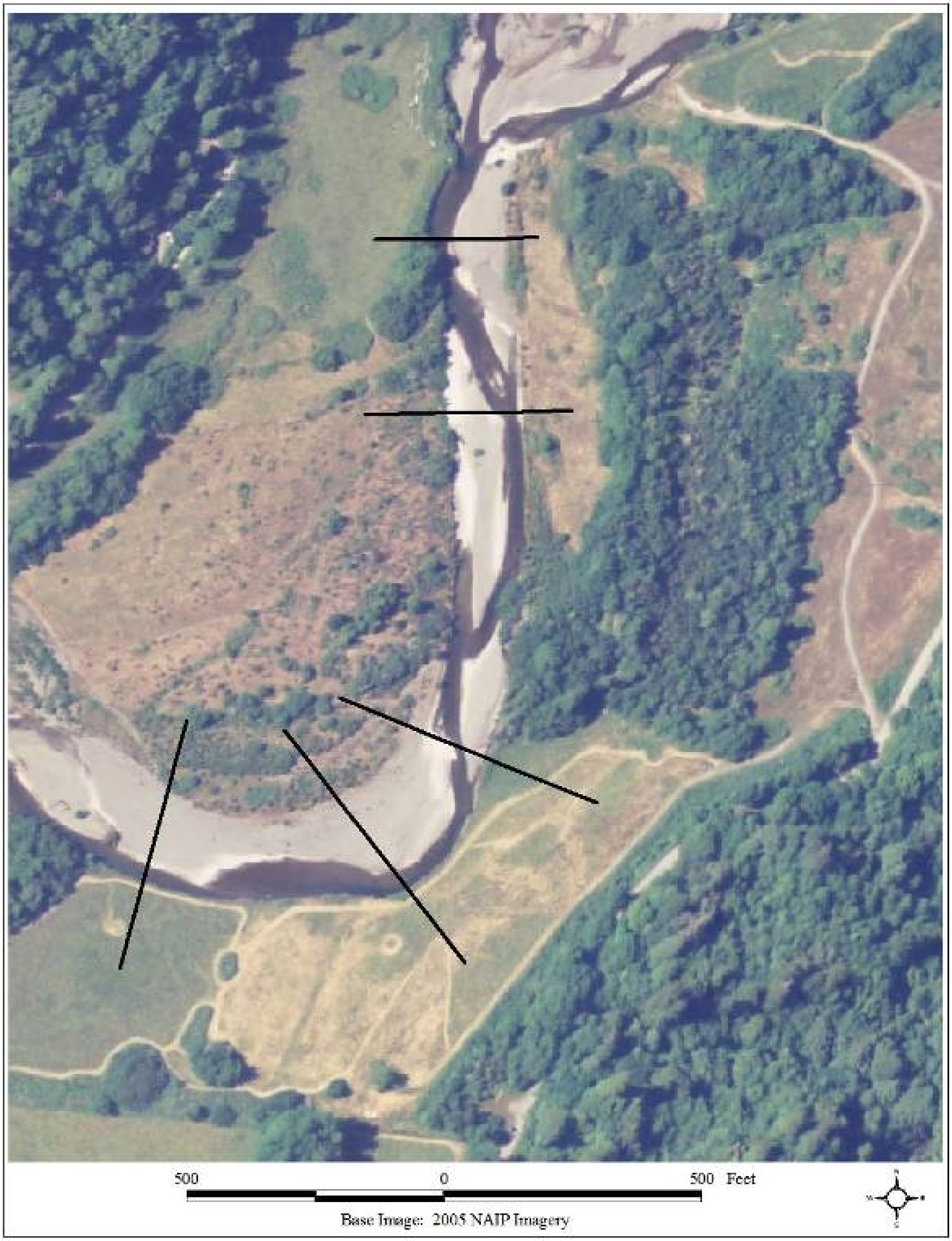


Figure 36. Map depicting permanent vegetation survey transects in lower Terwer Creek.

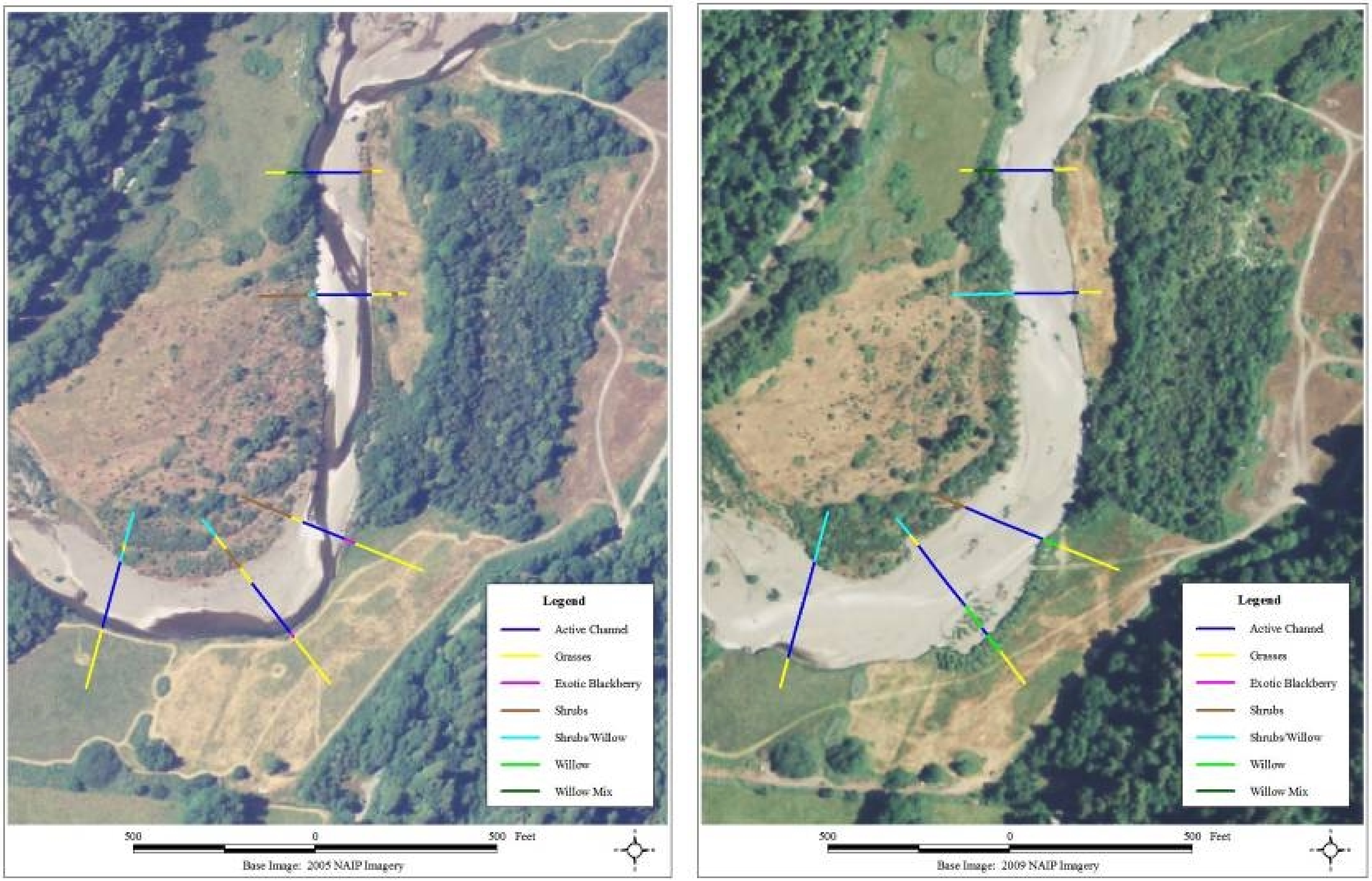


Figure 37. Maps depicting vegetation transect survey data for 2005 (Left) and for 2009 (Right) in lower Terwer Creek.

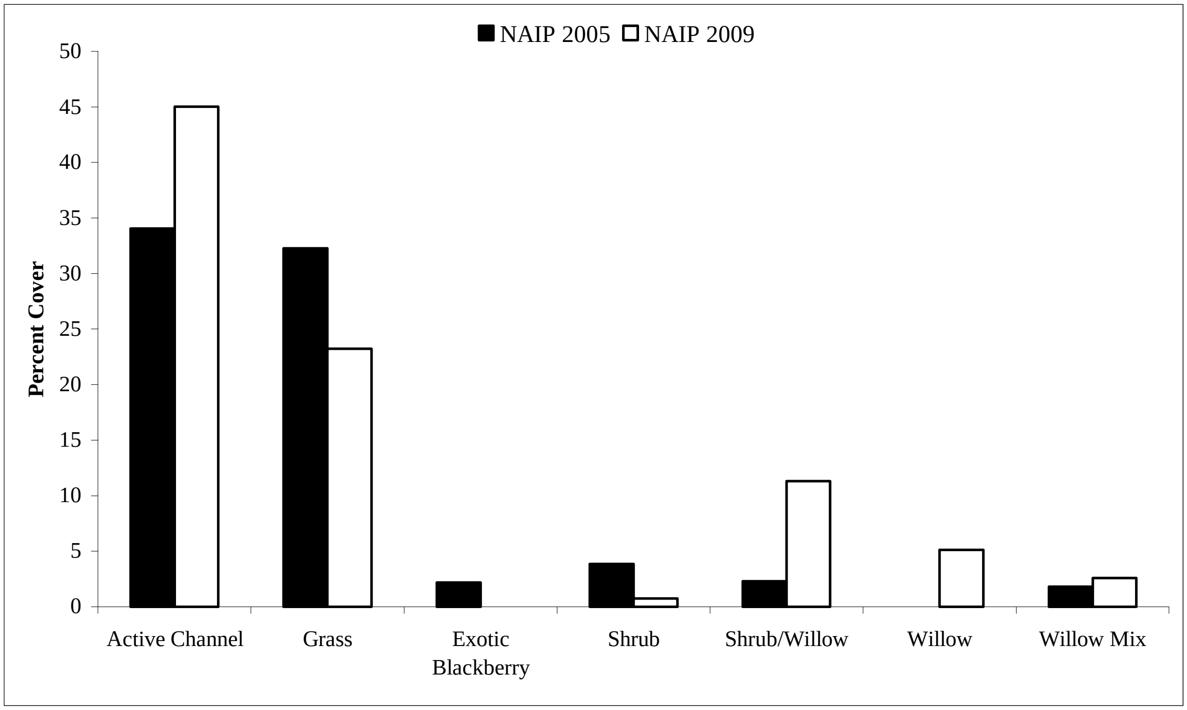


Figure 38. Vegetation cover data collected at five permanent transects located in lower Terwer Creek in 2005 and 2009.

17. Integrating Engineered Log Jam Technology into River Rehabilitation

Tim Abbe, George Pess, David R. Montgomery, and Kevin L. Fetherston

Abstract

Reach-scale river rehabilitation projects using Engineered Log Jams (ELJs) were implemented successfully in four demonstration projects in western Washington from 1995 through 1999. ELJ technology is founded on the premise that river management can be improved by understanding, emulating, and accommodating natural processes using sound science and engineering practices. The ELJ demonstration projects were developed as part of river rehabilitation efforts in which reach analyses were crucial for providing information about historical channel dynamics and revealing opportunities and constraints that helped refine project objectives and improve designs. Each ELJ demonstration project constructed to date improved salmonid habitat and addressed traditional problems constraining habitat rehabilitation, such as bank and bridge protection. The projects described here offer examples of instream structures compatible with rehabilitating and maintaining aquatic and riparian habitat in fluvial corridors throughout the Puget Sound.

Restoration of Forest Rivers

Rivers of the Puget Sound region, as elsewhere across North America, have been severely impacted by land development. In particular, the role of large woody debris as a principal structural component of forest streams has been almost eliminated during the last century throughout the Pacific Northwest (Chapter 4). In the Puget Sound, as in many other regions, the removal of woody debris has reduced the physical and ecological complexity of streams and rivers (e.g., Marzolf 1978; Shields and Nunnally 1984; Harvey and Biedenharn 1988; Smith and Shields 1990; Hartopo 1991; Maser and Sedell 1994). This is of particular concern today as the physical habitat created by woody debris provides important habitat for salmon and other aquatic species (e.g., Tschaplinski and Hartman 1983; Swales 1988; Pearsons et al. 1992; Lonzarich and Quinn 1995).

Despite the widespread recognition of woody debris as a principal physical and biological component of forest streams, and despite extensive wood reintroduction programs aimed at channel restoration, little has been done to develop engineering guidelines for wood placement. Guidelines that have been developed assume that wood must be artificially anchored to remain stable (D'Aoust and Millar 1999). The engineering analysis of such studies is sound, but the underlying assumptions ignore the mechanics that underpins the stability of natural snags, which, of course, do not benefit from artificial anchoring (e.g., Abbe et al. 1997; Brauderick and Grant 2000). Random placement of woody debris without an understanding of the geomorphology (e.g., mechanics of wood stability, hydraulic conditions, sediment transport, natural woody debris supply, channel dynamics) and social context (e.g., local land use, infrastructure, recreational activity in rivers) can significantly increase the potential for unanticipated consequences, including habitat degradation, property loss, and injury.

Initially, stream channels were cleared of stable wood to improve navigation and later because it was assumed that instream woody debris reduced flow conveyance and increased flood risks. Recent studies, however, have shown that instream woody debris can block up to 10% of a channel's cross-sectional area without significantly reducing conveyance (Gippel 1995; Shields and Gippel 1995). Channel clearing was not the only practice in traditional river engineering that degraded fluvial environments. Traditional river engineering focuses on straightening, impounding, and generally simplifying channel conditions. Common bank protection measures do not emulate natural conditions and processes and dramatically reduce the habitat and hydraulic complexity found in natural forest rivers. Traditional measures such as rock revetments provide little beneficial habitat for most salmonids when compared to unprotected banks with vegetation or woody debris. Incorporation of vegetation into bank protection measures, such as bioengineering, has been widely used to reduce environmental impacts, but many of these measures amount to cosmetic treatments on traditional structures (e.g., Thorne 1990; Shields et al. 1995). Restoration efforts have long attempted to create "natural" structures in streams for habitat and to stabilize channels (Tarzwell 1934) but have not been based on accommodating processes and conditions typical of forested systems, and the resulting structures bear little, if any, resemblance to natural structures that accomplish the same effect.

Forested alluvial river valleys undisturbed by humans have high levels of morphological and biological complexity (e.g., Hawk and Zobel 1974; Sedell and Frogatt 1984). The upper Sauk River north of Darrington, Washington, offers an example of a relatively intact channel migration zone of a large forested alluvial river and exhibits a complex anastomosing channel with numerous log jams (Figure 1A). The White River southeast of Auburn, Washington, and east of Lake Tapps has a significantly simpler channel form with fewer secondary channels and lower sinuosity (Figure 1B). Both the Sauk and White Rivers are low-gradient (<0.01) unconfined gravel bedded rivers. Industrial forestry within the depicted portion of the White River valley has reduced the quantity of functional woody debris (i.e., large trees) capable of forming log jams vital to maintaining an anastomosing system and a complex forest structure. Agricultural development has had even greater impacts, as illustrated by the channelization of the Snoqualmie River north of Duvall, Washington (Figure 1C). This portion of the Snoqualmie is a very low gradient river that once had secondary channels, extensive wetlands, and a diverse riparian forest. All of these have been lost as the river has been channelized into a fraction of its original corridor. Ultimately human development can transform a river valley from a dynamic complex mosaic of forest, wetlands, and channels into a static channel with an impermeable floodplain, such as found in urban areas along the Green River in south Tukwila, Washington (Figure 1D). Here, cultural constraints leave little opportunity for restoration other than improving channel-boundary complexity to improve aquatic refugia for migrating fish.

Current river management often precludes a reach-based, scientific approach because much of the funding to maintain infrastructure along rivers comes from state and federal emergency response programs that require rapid response and often involve replacement of the original structure. Such emergency response actions almost always fail to incorporate environmentally sustainable solutions. The cumulative effect of river management actions arising from emergency response can significantly impact aquatic ecosystems through progressive confinement of a channel by successive rock revetments. Throughout much of the Puget Sound, human activity has transformed complex anas-

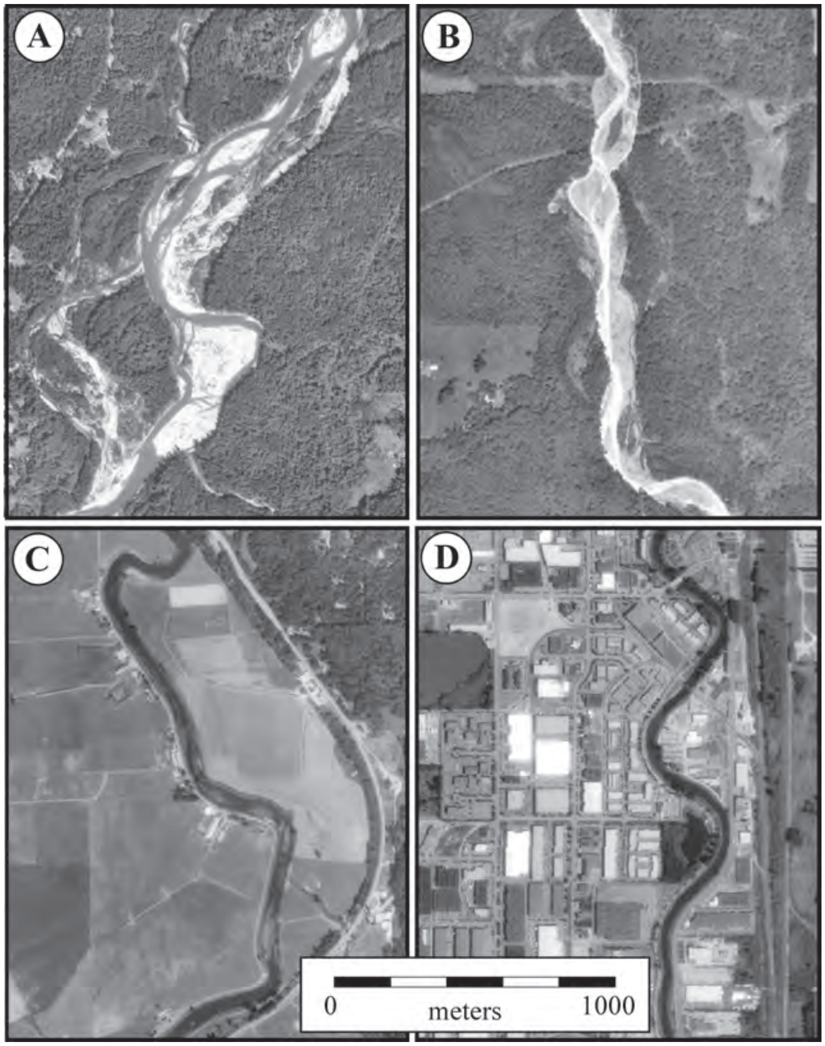


Figure 1. Four Puget Sound river corridors that illustrate reduction of geomorphic complexity and salmonid habitat with loss of woody debris and progressive encroachment on the fluvial corridor. All photos are from the U.S. Geological Survey and are identical in scale. (A) The upper Sauk River north of Darrington (09-07-89). (B) The White River southeast of Auburn and east of Lake Tapps (07-20-98). (C) The Snoqualmie River north of Duvall (08-04-90). (D) The Green River in south Tukwila (07-10-90).

tomosing forest channel systems with abundant woody debris and diverse habitat into simple single-thread channels with little complexity and cover (Figure 2).

Engineered Log Jam (ELJ) Technology

ELJ technology is based on the premise that the manipulation of fluvial environments, whether for traditional problems in river engineering (e.g., flood control, bank protection) or for habitat restoration, is more likely to be sustainable if it is done in a way that emulates natural landscape processes. The concept of ELJs began with the observation that natural log jams can form “hard points” that provide long-term forest refugia (Abbe and Montgomery 1996). Such natural hard points create stable foundations for forest growth within a dynamic alluvial environment subject to frequent disturbance. Log

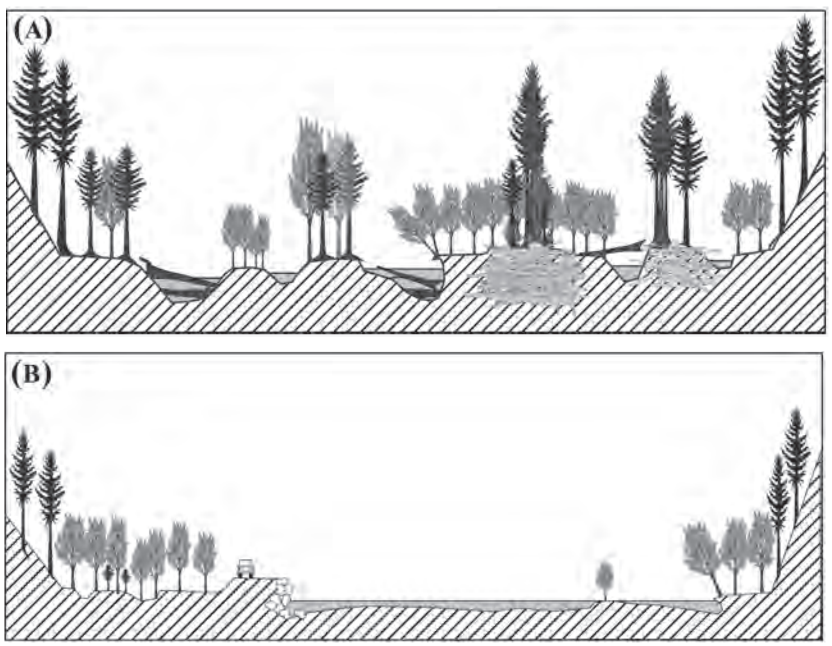


Figure 2. (A) Natural anastomosing forest river valley with abundant instream woody debris, complex mosaic of channels, and forest structure associated with regions such as found in the upper Sauk River (Figure 1A). (B) Degradation of forest rivers due to direct (e.g., channel clearing and confinement) and indirect (e.g., removal of riparian trees, increase in sediment supply or discharge associated with upland disturbance) human disturbance, such as the White River (Figure 1B).

jams thereby enable the development of trees large enough to continue forming stable log jams. Scientific and engineering studies of both woody debris and other types of flow obstructions contributed to the development of ELJ technology, such as the effect of boundary roughness on flow conditions, channel migration, and bed surface grain size (e.g., Raudkivi 1990; Pitlick 1992; Buffington and Montgomery 1999a), the effect of bluff body obstructions on flow deflection and scour (e.g., Garde et al. 1961; Raudkivi and Ettema 1977; Miller et al. 1984; Hoffmans and Verheji 1997), the impacts of debris accumulation at bridge piers (e.g., Melville and Sutherland 1988; Melville and Dongol 1992; Richardson and Lagasse 1999), and the hydraulic and geomorphic effects of natural snags (e.g., Shields and Gippel 1995; Abbe and Montgomery 1996; Gippel et al. 1996; Wallerstein et al. 1997).

Distinct types of log jams, or instream woody debris accumulations, are found in different parts of a channel network (Abbe et al. 1993; Wallerstein et al. 1997). Using observations from the Queets River basin on the Olympic Peninsula in Washington, distinct types of log jams have been classified based on the presence or absence of key members, source and recruitment mechanism of the key members, jam architecture (i.e., log arrangement), a jam's geomorphic effects, and patterns of vegetation on or adjacent to the jam (Abbe et al. 1993). Six jam types (Figure 3) provide naturally occurring templates for ELJs intended for grade control and flow manipulation (Figures 4-9). Jam types primarily applicable to grade control include log steps and valley jams; those types more applicable to flow manipulation include flow deflection, bankfull bench, bar apex, and meander jams.

Channel planform and flow obstructions can result in significant changes in water surface topography, locally raising water elevations enough to inundate secondary channels and portions of the floodplain during flows that otherwise would not engage the floodplain (Miller 1995). ELJs can create the same effect as they obstruct flow and control channel planform, thus serving as one of the principal mechanisms of connecting secondary channels and wetlands within floodplains to the mainstem channel.

The design process recommended for ELJs (Figure 10) begins with analysis of the watershed context within which the project is set, then follows with reach analysis and assessment. If opportunities are identified for potential ELJ applications, then appropriate types of natural log jams are selected based on the project objectives and constraints. After the general reach-scale strategy and ELJ layout are refined, individual structures are designed and specifications for logs and jams are prepared. Finally, the structures are constructed and evaluated over time.

Logs used to construct individual ELJs fall into three basic structural categories. *Key members* are individual logs with rootwads, which are unlikely to

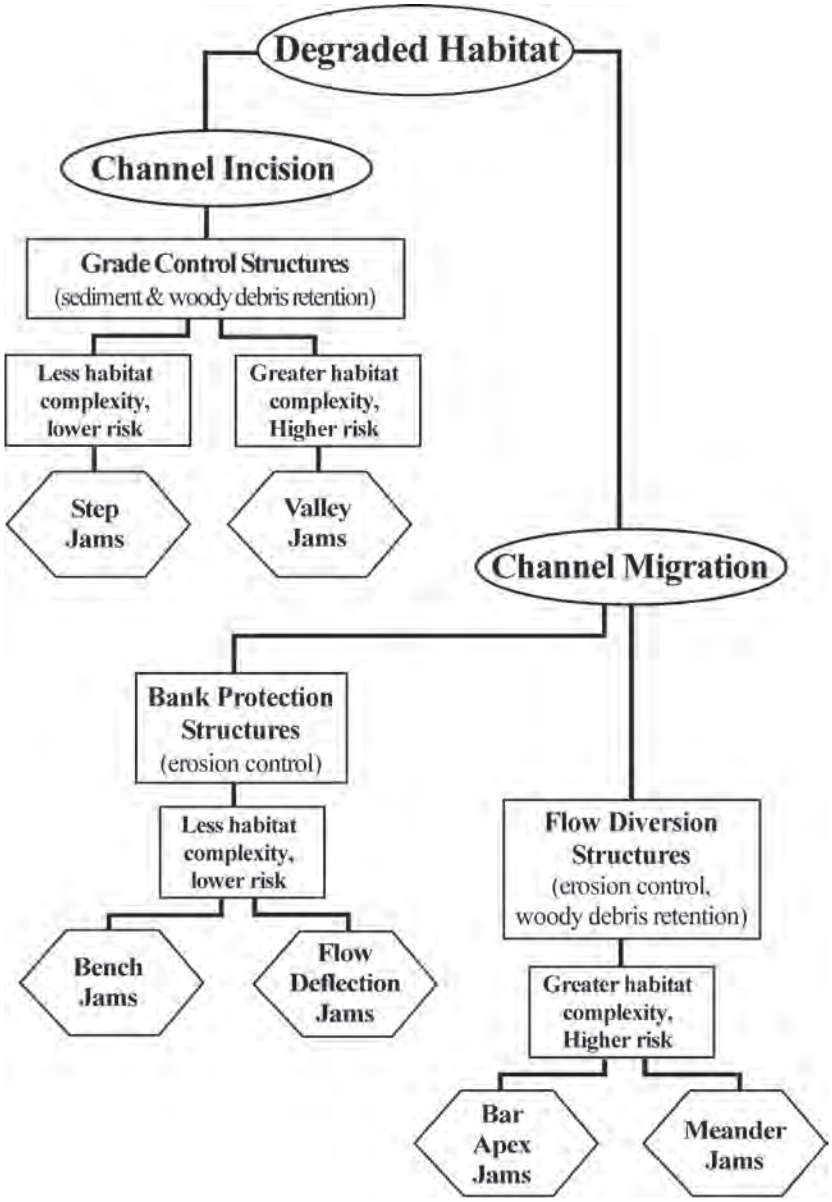


Figure 3. Classification of engineered log jam structures appropriate for treating different problems associated with habitat degradation. Two basic categories of habitat degradation involve vertical (incision) and lateral (migration) changes in channel position.

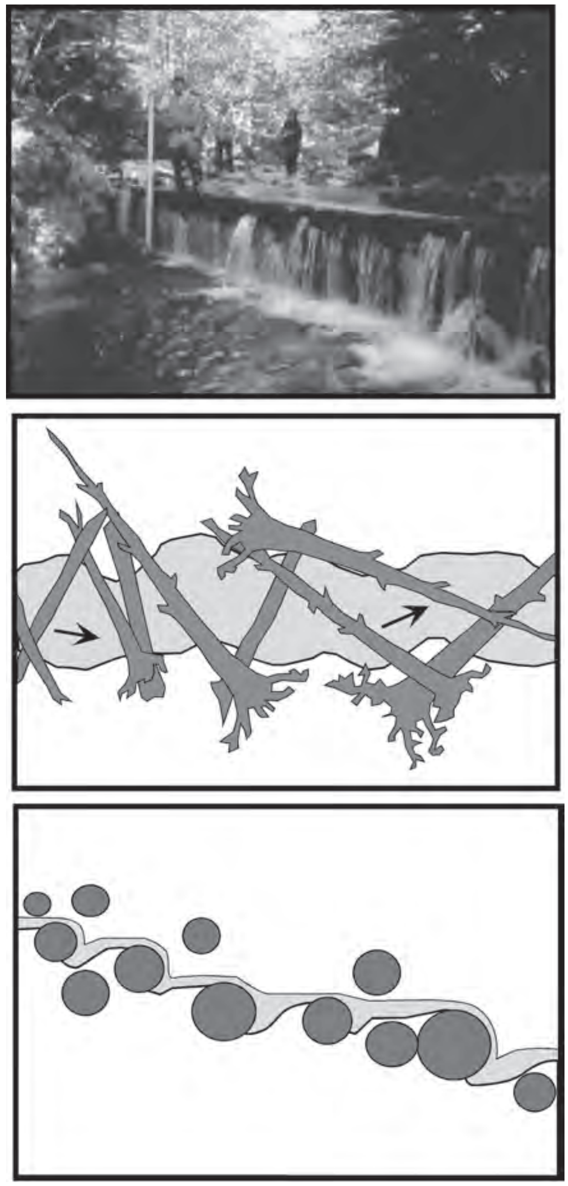


Figure 4. Step jams or multi-log log weirs are found in relatively small channels with a wide range of gradients. These structures can account for more than 80% of the head loss in a channel (Abbe 2000) and almost all of the hydraulic and habitat diversity within the channels where they occur.

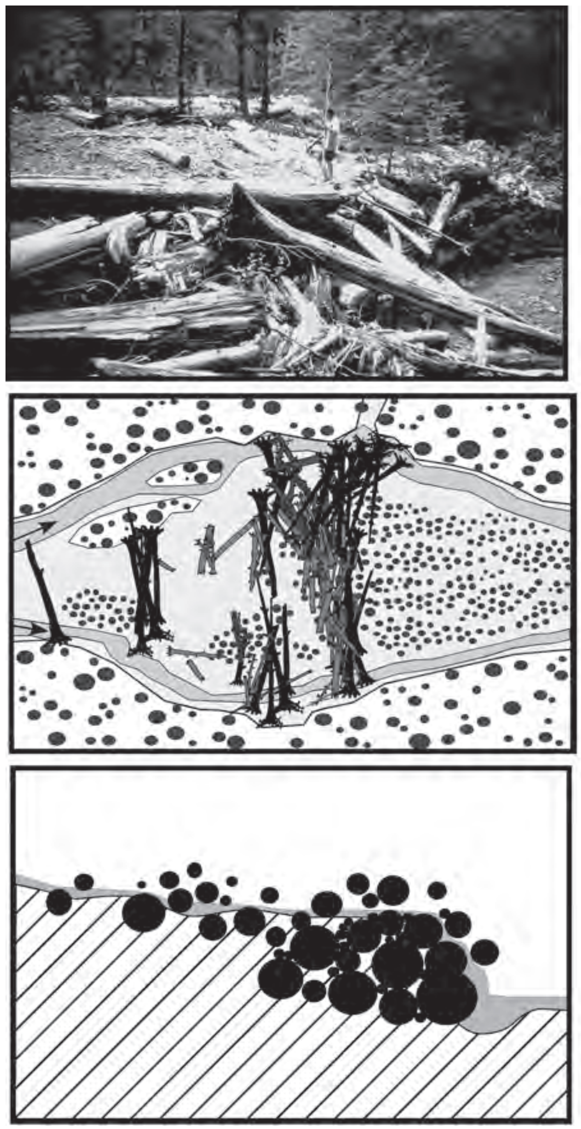


Figure 5. Valley jams are large, complex grade control structures found in channels with gradients ranging from 2 to over 20%. These structures are typically composed of tens or hundreds of trees, can raise the channel bed over 5 m, and transform plane-bed and step-pool channels into pool-riffle channels (Abbe 2000). These structures are also responsible for creating a complex channel network across the valley bottoms in which they occur.

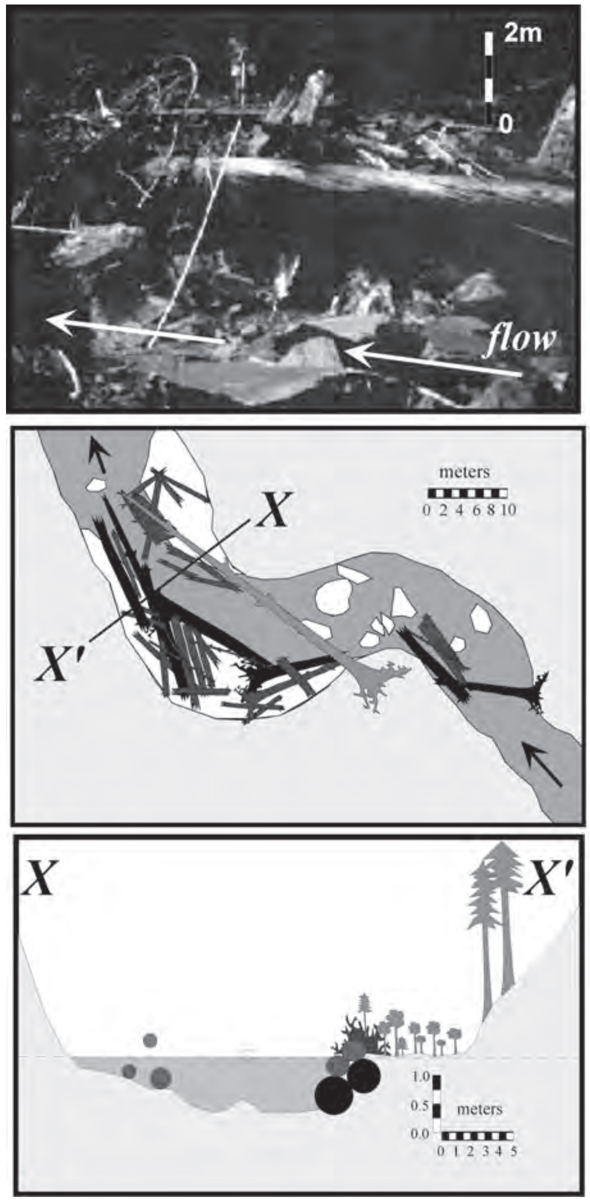


Figure 6. Bench jams are typically found in relatively small, steep channels (slopes >2%) where large logs become wedged into the margins of a channel and create local revetments protecting floodplain deposits and vegetation. Where these structures occur, wood forms the stream bank and prevents erosion of alluvium stored behind them.

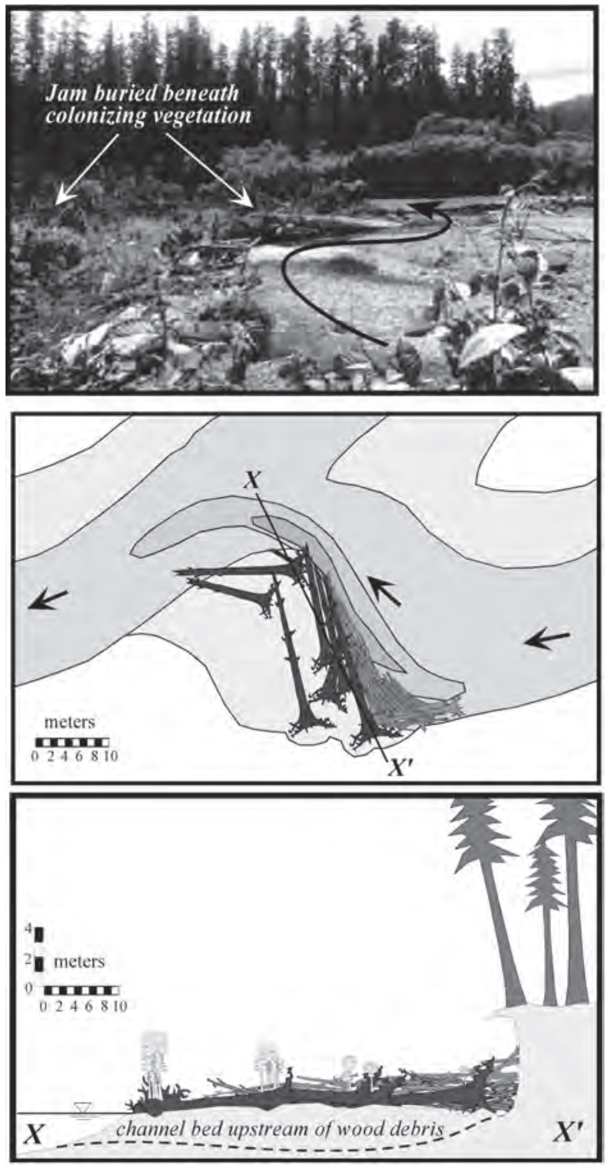


Figure 7. Flow deflection jams are found in relatively large channels with moderate gradients. These structures form initially when large trees (key members) fall into the river and deflect flow. But with time these structures become integrated into a new river bank and are thus classified as bank protection or revetment type structures as opposed to flow diversion structures.

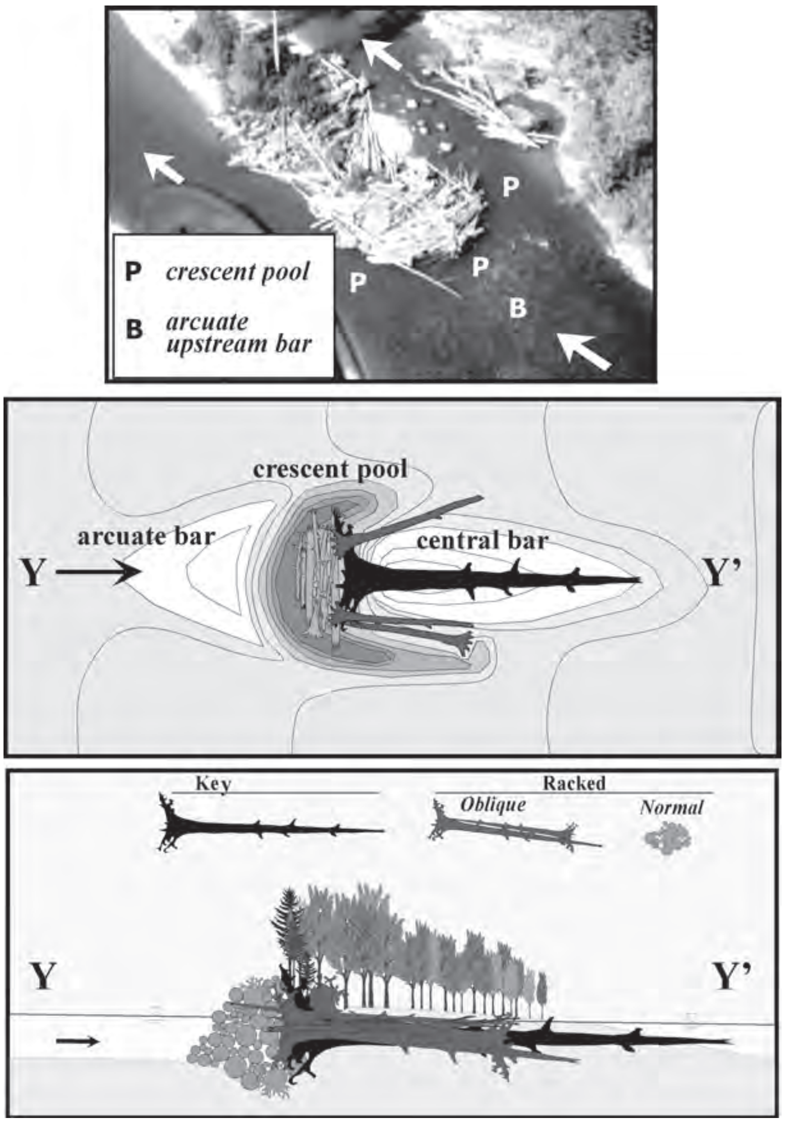


Figure 8. Bar apex jams are bi-directional flow diversion structures found in large channels with low to moderate gradients. These structures create forest refugia in dynamic channel migration zones and are responsible for much of the channel complexity and pool formation in these systems. Bar apex jams are a principal mechanism contributing to the formation of anastomosing channel systems in the Pacific Northwest.

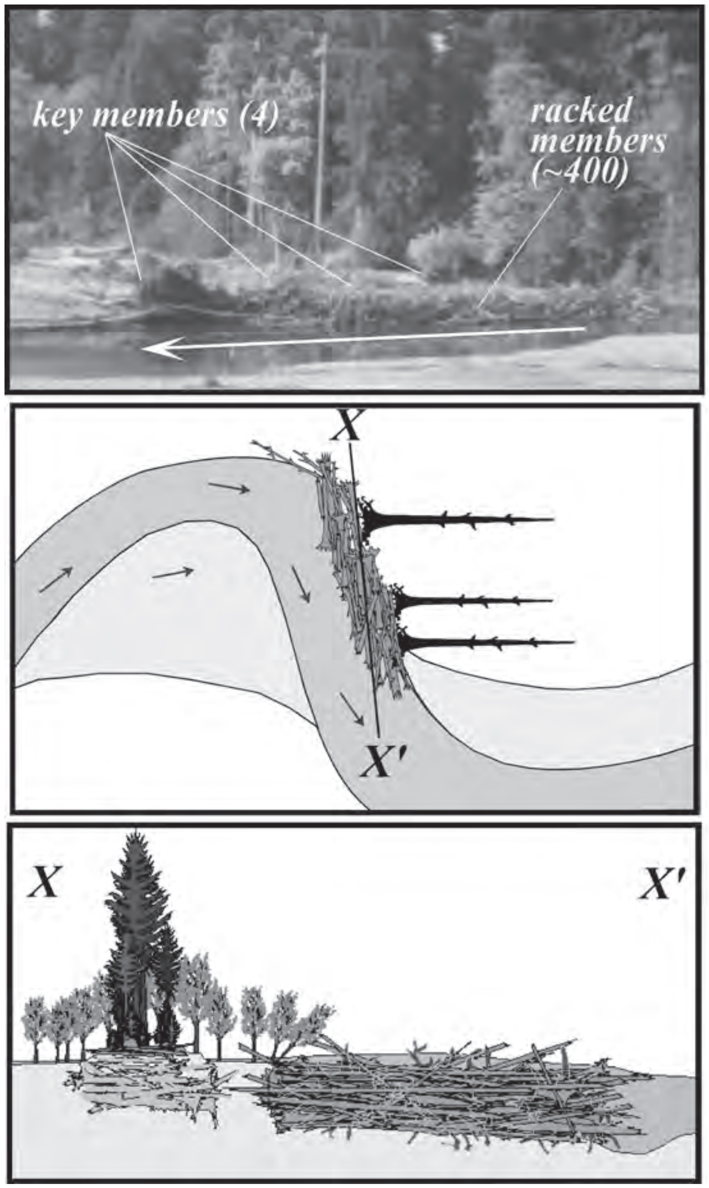


Figure 9. Meander jams are large flow diversion channels found in large alluvial rivers. These structures offer a model that has been successfully emulated to limit channel migration, protect banks, and restore aquatic habitat and riparian forests. Natural meander jams are a principal cause of channel avulsions in Pacific Northwest rivers.

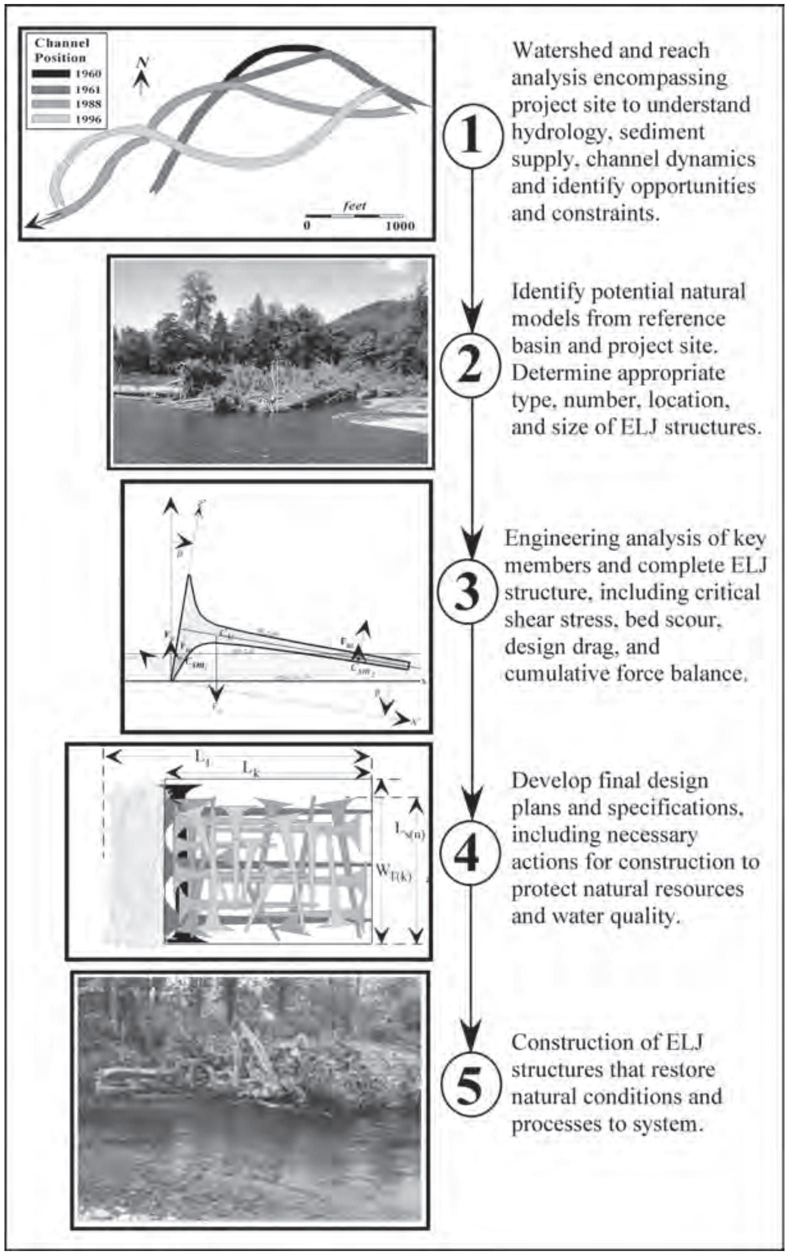


Figure 10. Five basic steps recommended for designing and implementing an ELJ project.

move during a bankfull flow, and are used as the foundation of all ELJs. In alluvial channels, key members are usually set deep into the channel substrate. In bedrock channels, key members are situated on the channel bed between pre-existing roughness elements or opposing banks. Properly situated, key members can transform a bedrock channel into an alluvial channel (Montgomery et al. 1996). *Stacked members* are slightly smaller than key members and are used in some ELJs to supplement key members. Stacked members are laid down in two or more layers that link individual members together and increase the integrity of the structure. Most stacked member logs should retain a substantial rootwad. *Racked members* include the smallest logs, with the largest range in sizes, and are often the only logs visible after construction is completed, depending on the type of ELJ. Racked members form a dense, chaotic pile of debris extending from well below the channel thalweg to above the bankfull elevation. Racked members act to decrease the permeability of and deflect flow around the structure.

No artificial materials are necessary to construct an ELJ. Native trees and alluvium at the site are all that is needed if the trees meet the design specifications for size and shape. Most projects will import trees to the site because it is usually preferable to preserve existing riparian trees, and an adequate local supply of large trees is rare. Trees large enough to act as key members may need to be cut for transport and then glued and bolted together at the site before placement. The stability of ELJs is founded on how snags interact with alluvium and instream flows. The shape and size of individual logs is critical, as are the architecture of the ELJ and its size and position within the river system. Long-term contributions to stability come from trees growing on top of ELJs, due to both root cohesion in alluvium under which the structure is buried and from the weight of the trees themselves.

Most ELJ projects involve a series or array of structures within the channel or extending across the channel migration zone (CMZ). The appropriate type, size, and position of ELJs will depend on a thorough geomorphic, hydrologic, and hydraulic analysis of the project site sufficient to characterize the river's dynamics and predict the likely range of future conditions. Such studies should include historical analysis of the changes the river has undergone and, if possible, what conditions were like prior to human development. These site assessments are referred to as reach studies and are recommended for any project that will manipulate the boundary conditions in and along a river.

Between 1995 and 1999, thirty ELJ structures were constructed in four demonstration projects in western Washington (Figure 11). The objectives of these projects ranged from bank protection to habitat restoration and illustrate a wide range of applications for this technology in Puget Sound rivers and streams.

Reach-Based Design

Before attempting to design ELJs, it is important to understand a river's physical boundary conditions and the relationship of those boundary conditions to fluvial processes and habitat. A reach analysis must be done at spatial and temporal scales adequate for describing these relation ships. With this understanding, ELJs can be designed and placed to achieve the desired goals, accommodate natural processes, and in some cases even diminish risks associated with human infrastructure and property. In a reach analysis, physical and human constraints are identified and demarcated. These areas are then incorporated into design alternatives; for example, differentiating areas within the channel migration zone (CMZ) where the mainstem channel can freely move, areas in the CMZ where only secondary channels are acceptable, areas which can tolerate inundation but no channels, and those areas where no inundation is acceptable.

A reach analysis is linked to changing conditions and disturbance patterns in the watershed. For example, industrial forestry can significantly increase

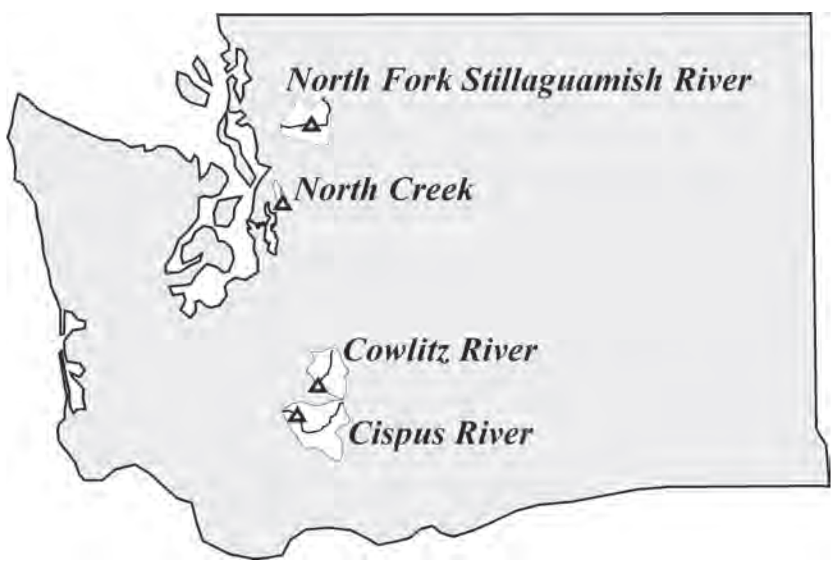


Figure 11. Locations of ELJ demonstration projects constructed in western Washington between 1995 and 1999: North Fork Stillaguamish River (1998), North Creek (1998), Upper Cowlitz River (1995), and Cispus River (1999).

sediment delivery to the river system (e.g., Kelsey 1980), which in turn can result in channel aggradation (Stover and Montgomery 2001) and textural fining (Buffington and Montgomery 1999b). The removal of instream woody debris and riparian forest may also increase the frequency and magnitude of peak flows and lead to significant geomorphic changes such as channel incision (e.g., Brooks and Brierly 1997). The most dramatic increases in the frequency and magnitude of peak flows are associated with rapidly urbanizing watersheds (e.g., Hammer 1972; Graf 1975; Booth and Jackson 1997; Moscrip and Montgomery 1997). Because these types of watershed disturbances will ultimately influence fundamental conditions within a project reach, they should be accounted for in design strategies.

The nature of these reach analyses and subsequent designs are illustrated by four ELJ demonstration projects constructed from 1995 to 1999. The overall goal of each project was to help restore fluvial environments in the contexts of natural processes and existing human constraints. Goals specific to each project are discussed in detail in the following sections.

Case Studies

Upper Cowlitz River

Three unanchored ELJ structures emulating meander jams were installed in December 1995 to halt erosion and reduce property loss from channel migration along 430 m of privately owned land along the upper Cowlitz River, Washington. Cost was a substantial constraint to the landowner, who nonetheless expressed a clear desire to maintain or improve aquatic and riparian habitat. The unvegetated width of the channel at the site is 195 m; the average bank erosion rate from 1990 to 1995 was 15 m/yr. Erosion along the landowner's shoreline from 1992 through 1995 resulted in as much as 50 m of bank retreat and the loss of about one hectare of forest land. After bank erosion associated with a 12-year recurrence interval flow in November 1995, the landowners became concerned they would lose the entire riparian corridor and inquired about erosion control alternatives that could retain as much of the habitat and aesthetic qualities of the site as possible. The high cost of a rock revetment or rock barbs (groins), together with the desire to salvage woody debris along the channel, led the landowners to pursue the experimental use of ELJs.

The floodplain adjacent to the site consists of timberlands that have been selectively harvested since the 1930s. Present forest cover is dominated by a 50–80 year old mixed conifer and deciduous forest with basal stem diameters up to 2.2 m and averaging about 0.4 m. Bank erosion along the Upper Cowlitz is common, and several large, conventional bank revetment projects have been constructed (and reconstructed) since the 1960s. Analysis of historical aerial photographs revealed northward channel migration and progressive widening of the Cowlitz River since 1935.

The three ELJ's built along the Upper Cowlitz River (summer 1996) were based on bar apex and meander jams (Abbe and Montgomery 1996) common in large alluvial channels and naturally occurring in the Cowlitz River. Both jam types consist of large key member logs with rootwads facing upstream and boles aligned with bankfull flow. Bar apex jams are usually relatively narrow structures with 1 or 2 key members that direct flow to either side of the jam. Meander jams usually are considerably wider with 3 to 6 key members, and they are situated such that they force a change in channel direction.

Five weeks after construction, the project experienced a 20-year recurrence interval flow of approximately 850 m^3/s (Abbe et al. 1997). Each ELJ remained intact and transformed an eroding shoreline into a local depositional environment. In addition, approximately 93 tons of woody debris that was in transport during the flood was trapped by the ELJs, which helped to increase the stability of the ELJs and alleviate downstream hazards. Enhancement of physical habitat included creation of deep pools at each ELJ. Because enough trees were found at the site (local landowner) and costs for design and permitting were extremely low, this project cost less than 1% of a traditional rock revetment project along an upstream meander. The cost of the ELJ project for a 430 m long reach was $10,000, or $23 per meter, whereas the cost of rip rap for a 683 m long project was $999,253, or $1464 per meter. This experimental project demonstrates that ELJs can meet local bank erosion control objectives while helping to rehabilitate riverine habitat in a large alluvial river.

Cispus River

In 1998-1999, the United States Forest Service (USFS) and Lower Columbia Fish Recovery Board (LCFRB) collaborated on an ELJ project on two side channels in the Cispus River near Randle, Washington. The project objectives were: (1) to protect a USFS road damaged in 1996, and (2) to create habitat complexity for adult and juvenile anadromous fish in a morphologically simplified stretch of the river. The Cispus River, a tributary to the Cowlitz River, had the potential to support salmonids after a program was begun in 1993 to reintroduce three species of anadromous fish to the upper Cowlitz River Basin and evaluate and improve habitats where possible.

Two sets of ELJ structures (revetments) were constructed along the Cispus River in 1999. Four ELJs were constructed directly adjacent to Forest Road (FR) 23 at Cispus River Mile (RM) 20 (Site B) and another set of three ELJs was constructed upstream at RM 21 (Site C) (Figure 12). All the structures were part of a strategy to protect FR 23 (Figure 13), because the February 9, 1996 flood, reportedly a >100-year recurrence interval event (Brenda Smith, USFS, personal communication), destroyed several hundred feet of the road at Site B and threatened the road at Site C. Pre-existing rock revetments failed at both sites. An emergency rock revetment was constructed along Site B as part of replacing the road washout. Reach analysis commenced in the summer of 1996 and the seven ELJs were constructed in September 1999.

The goal to improve fish habitat focused primarily on the placement of woody debris structures and debris jams into two side channels. Plans for the upstream site (Site C) included the placement of three large structures. The downstream site (Site B) called for the placement of four debris jams (Figure 14). The goal was to place these structures in a manner to protect the road during periods of high runoff while providing habitats for both juvenile and adult anadromous fish. The intent was to provide holding pools for upstream migrating adults and rearing habitats for juveniles during higher flows. It was anticipated that high flows would deposit the scoured materials downstream of the structures, sorting out gravels that may be used for adult spawning. The sites were completed and monitoring began in the fall of 1999.

By the fall of 1999 and the spring of 2000, it was apparent that winter high flows had scoured the base of the structures at Site B but had little effect on Site C. Numerous adult coho salmon were observed holding in the pools at the

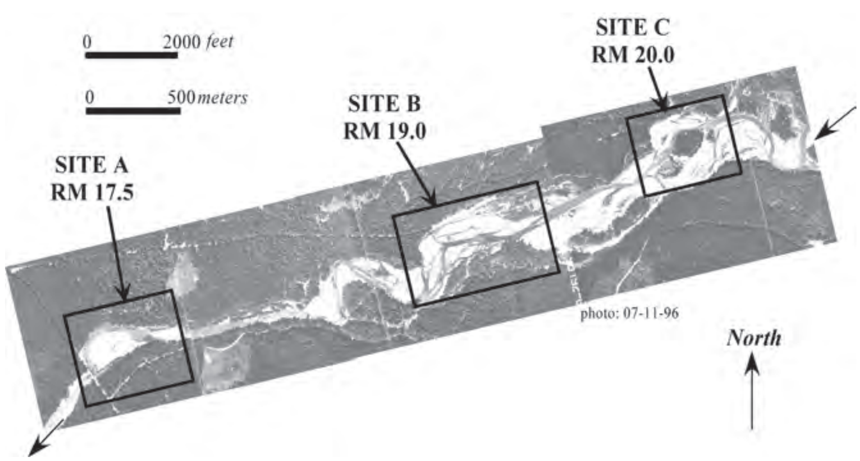


Figure 12. Cispus River sites A, B, and C. River flows from right to left. Forest Road 23 is on the north side of river.

Figure 13. Photographic illustration of the differences between traditional blanket rock revetment (left) and ELJ solution (right) to protecting Forest Road 23 along Cispus River at Site B. A series of 4 ELJs was constructed to protect the road, enhance aquatic habitat, and establish a riparian buffer between the road and river. Each of the structures is approximately 7 m in height with about 4 m exposed above the low water table.

Figure 14. Oblique aerial photograph of the Cispus River ELJ project site B at River Mile 19. Arrows indicate flow direction and B1 through B4 indicate ELJ locations.

structures at both sites. Over 100 redds were counted in the reaches between the jams at Site B. Twelve redds were observed at Site C, but these were located above and below the construction site. One steelhead redd was observed at Site B in 2000. In the spring of 2001 (a period of lower than normal flows), only twelve redds were observed at Site B and none were observed at Site C.

Snorkeling surveys were performed in cooperation with Washington Department of Fish and Wildlife (WDFW) staff in July and August of 2000 to evaluate site utilization by juveniles. Observations indicate extensive use of the structures by young of the year coho. The scouring effects near the structures at Site B provided cover and depth for the juvenile fish. Juvenile coho use was limited in the reach between sites B and C because of local sediment deposition that reduced flow depth. At Site B, 92% of the young of the year coho observed were associated with the structures, and only 8% were found in the area above or below the structures at Site B. Many of the observed fish between the structures were juvenile steelhead. At Site C, 61% of juveniles were located in pools associated with the ELJs, even though these pools account for only a small percentage of the surface area of the stream. The cost of constructing Cispus sites B and C was approximately $300,000.

North Fork Stillaguamish River

The North Fork Stillaguamish River project site is about 8 km east of Oso, north of Washington State Highway 530 and upstream of the C-Post bridge (Figure 15). The project was first conceived in 1996 for enhancement of salmon habitat.

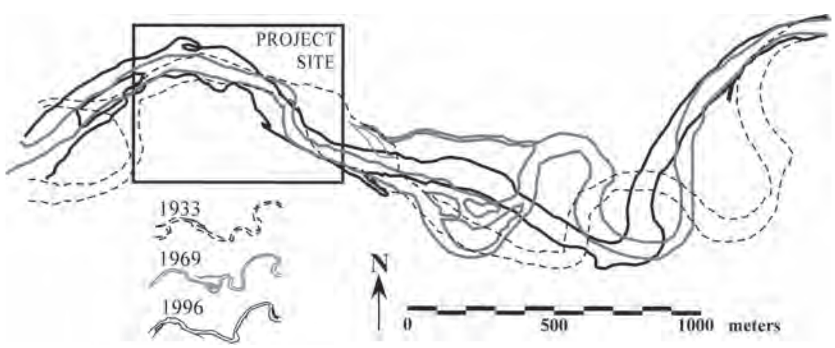


Figure 15. Selected historical planforms of North Fork Stillaguamish River ELJ Project Reach (River Miles 21-23): 1933, 1969, and 1996.

This goal was based on a comprehensive assessment of habitat conditions and historic change that identified a need to develop and maintain pool habitat as a key to recovery efforts for chinook salmon (*Oncorhynchus tshawytscha*) (Pess et al. 1998).

Chinook salmon are large-bodied fish that spend months in deep, cool pools during low flow prior to spawning. A key observation is that chinook spawning location strongly correlates to pool frequency and size; more than 80% of the chinook spawning nests (redds) surveyed in the North Fork Stillaguamish occurred within one channel width of a pool (Pess et al. 1998). Furthermore, twice as many redds were associated with pools formed by log jams versus pools with no wood, which also had three times as much instream cover (Pess et al. 1998). Historically, log jams were abundant and played a significant role in the morphology of the Stillaguamish River (Secretary of War 1931). The combination of these factors led to the proposal to construct engineered log jams in the North Fork Stillaguamish to create and enhance summer chinook holding pools.

The ELJ project reach has a drainage area of approximately 300 km^2 and is a low-gradient (<0.01) meandering gravel-bed channel that has repeatedly migrated across the floodplain during the past century (Figure 15). Natural log jams historically stabilized gravel bars in the North Fork Stillaguamish, allowing vegetation to take hold and create in-channel “islands” that resulted in an anastomosing channel network. Gravel bars and forest encompass most of the floodplain, but some homes and pastures are located along the lower portion of the surveyed reach. Estimates of the one- and five-year recurrence interval peak flows at the USGS gage at Arlington, Washington, are 258 cfs (7.3 cms) and 425 cfs (12 cms), respectively.

The upper North Fork Stillaguamish (above RM 15) has gone through large-scale channel changes over the last 70 years. A four- to five-fold increase in hillslope sediment input (primarily as landslides) between 1978 and 1983 from the upper portion of the North Fork Stillaguamish basin above RM 35 is likely to have contributed to an expansion of the unvegetated channel width and rapid changes in channel position. Many of the landslides were associated with logging and road-building in steep headwaters (Pess et al. 1998). A large increase in the sediment supply of a river can result in channel aggradation and extensive infilling and loss of pools (e.g., Kelsey 1980; Lisle 1995). Channel aggradation and widening, combined with the loss of pool-forming structures such as log jams, is thought to have reduced the quantity and quality of large pool habitat for adult and juvenile salmonids in the North Fork Stillaguamish. The lack of high quality pool habitat has altered migration and spawning timing for steelhead and possibly summer chinook (Curt Kraemer, WDFW, personal communication).

Project Objectives, Constraints, and Opportunities

The primary goal of the project was to increase quality and quantity of holding pool habitat for spawning summer chinook in the project reach. While evaluating the system, a number of additional objectives, constraints, and opportunities were also identified.

Objectives

- Maintain an active channel migration zone
- Increase the quality and diversity of aquatic and riparian habitat
- Increase linkages between channel system and riparian floodplain forest and wetlands by:
  - Maximizing the length of perennial channels
  - Maximizing linkages between channel system and floodplain

Constraints

- Accommodate existing infrastructure encroachment into channel migration zone
- Avoid increasing flood peak water elevations
- Protect property along southern margin of project reach
- Maintain or increase protection to downstream bridge by:
  - Minimizing woody debris accumulation at bridge
  - Minimizing threat of channel avulsion around bridge

Opportunities

- Introduce a multiple channel system for both perennial and ephemeral flow conditions
- Incorporate ELJ structures to:
  - Emulate instream structures representative of a low-gradient Puget Sound river
  - Limit channel migration at sensitive locations
  - Stabilize and help sustain secondary channel system
  - Increase physical and hydraulic complexity within the channel
- Increase bank protection in specific locations using an approach that emulates naturally occurring structures (e.g., log jams) and incorporates natural physical processes (e.g., channel migration, wood accumulation).

Implementation

In the summer of 1998, five ELJs were constructed upstream of the C-Post Bridge (Figure 16). Four of the ELJs were meander type jams designed to deflect flow on only one side. The remaining ELJ was a bar apex type designed to accommodate flow around either side. Each ELJ is completely inundated

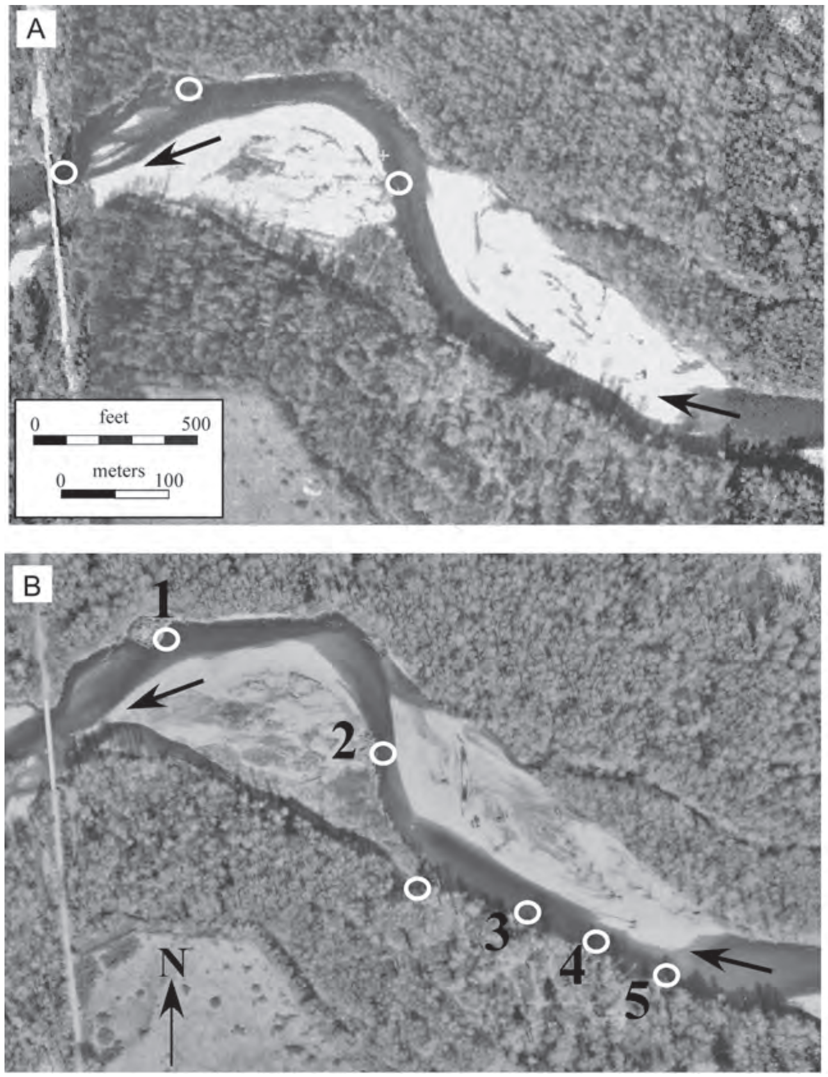


Figure 16. North Fork Stillaguamish River 1998 ELJ project site. March 1998 prior to construction (A) and two years after construction in March 2000 (B). Principal pool locations are noted by circles and ELJ location are numbered. Note the large increase in drift directly upstream of ELJ 2 between 1998 (A) and 2000 (B). ELJs 1, 3, 4, and 5 simulate “meander jams” and ELJ 2 simulates a “bar apex jam.”

during bankfull flow. The North Fork Stillaguamish ELJ project also included the acquisition of 29 hectares of conservation easement within the channel migration zone. This area is set aside to permit natural migration of the channel and migration induced by the installation of the ELJs. The project also included installation of arch culverts at side channels passing beneath the C-Post Bridge road. The total project cost was approximately $400,000.

In 1997 and 1998, we collected information on characteristics of wood naturally occurring within the project reach and of wood for ELJ construction. Post-construction wood surveys conducted in 1999 included a field reconnaissance of approximately 10 km of river downstream of the project site. Natural and imported logs were given identification tags and cataloged with data that included species, location, rootwad dimensions (minimum and maximum diameters), basal trunk diameter (equivalent to diameter at breast height), crown diameter, length, and physical condition (state of decay). Imported logs also included measurements of cut geometry when applicable. These data were used to measure the stability, movement, and recruitment of individual logs, structural integrity of the ELJs, and evaluate ELJ performance relative to the project design and objectives.

Results to Date

Between September 1999 and February 2000, at least fourteen flows equaling or exceeding bankfull stage occurred (Figure 17). All five ELJs remained in place. During the first high flows in November and December of 1998, ELJ 1 was damaged when one of the structure's seven key members was lost. Significant scour occurred beneath the outer upstream corner of the ELJ and undercut the key member in question. With nothing to support the saturated log from beneath, it sank, broke in half, and was carried 10.5 km downstream to where it was found in the summer of 1999. The loss of ELJ 1's outer key member was only confirmed when the structure was inspected from below, since there was almost no change in the structure visible from above (Figure 18). Even with the loss of a key member, ELJ 1 remained in place and continued to perform as predicted. Each of the five ELJs have formed and maintained scour pools ranging from 2–4 m in depth. Sand deposition has occurred downstream of all five ELJs. Designed as a series of flow deflectors, the three upstream ELJs (3, 4, and 5) have prevented further bank erosion along the south bank.

All of the structures except for ELJ 3 experienced a net increase in woody debris or drift, particularly ELJ 2, which collected over 500 pieces of woody debris exceeding 2 m in length. Drift accumulation upstream of ELJ 2 effectively increased the structure's breadth by six-fold and contributed to the development of a perennial secondary channel south of the mainstem channel, thereby

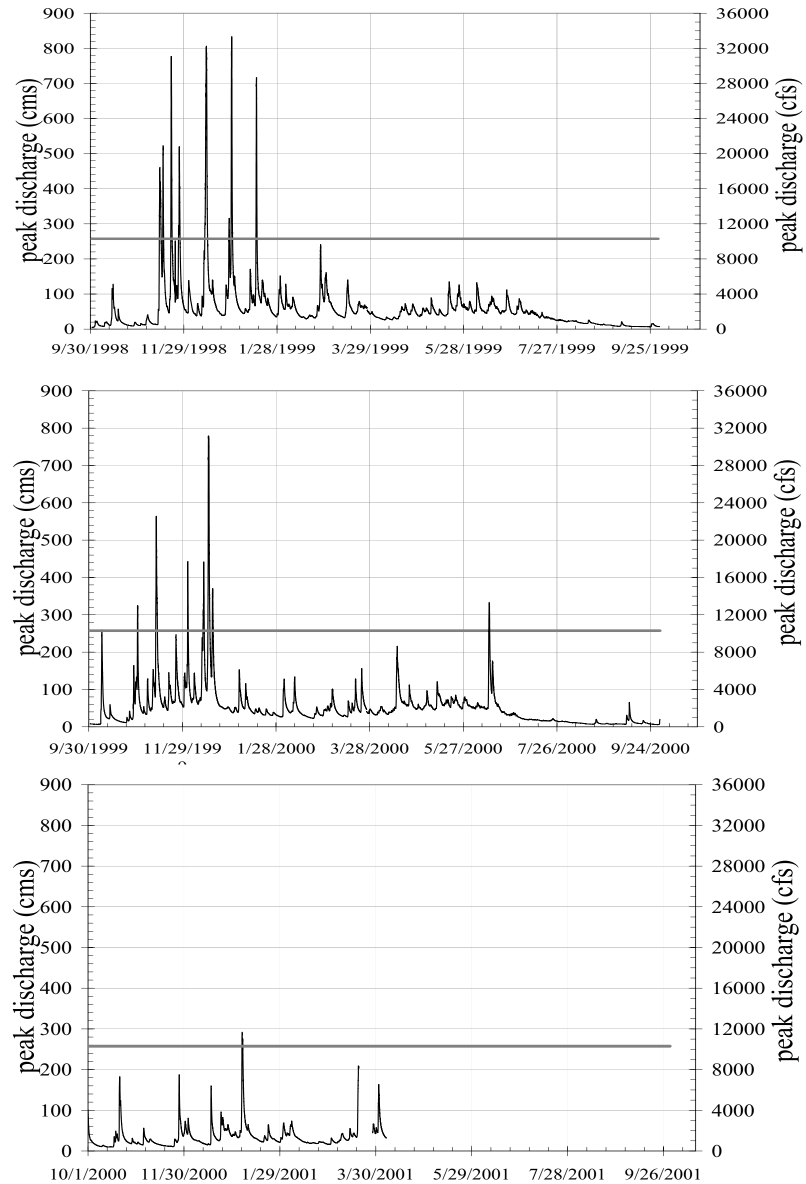


Figure 17. Annual hydrographs for Water Years 1999, 2000, and first half of 2001, North Fork Stillaguamish River, USGS Gage 12157000 near Arlington, Washington. Bankfull stage at the 1998 ELJ site (horizontal line) corresponds to approximately 10,000 cfs at Arlington gage.

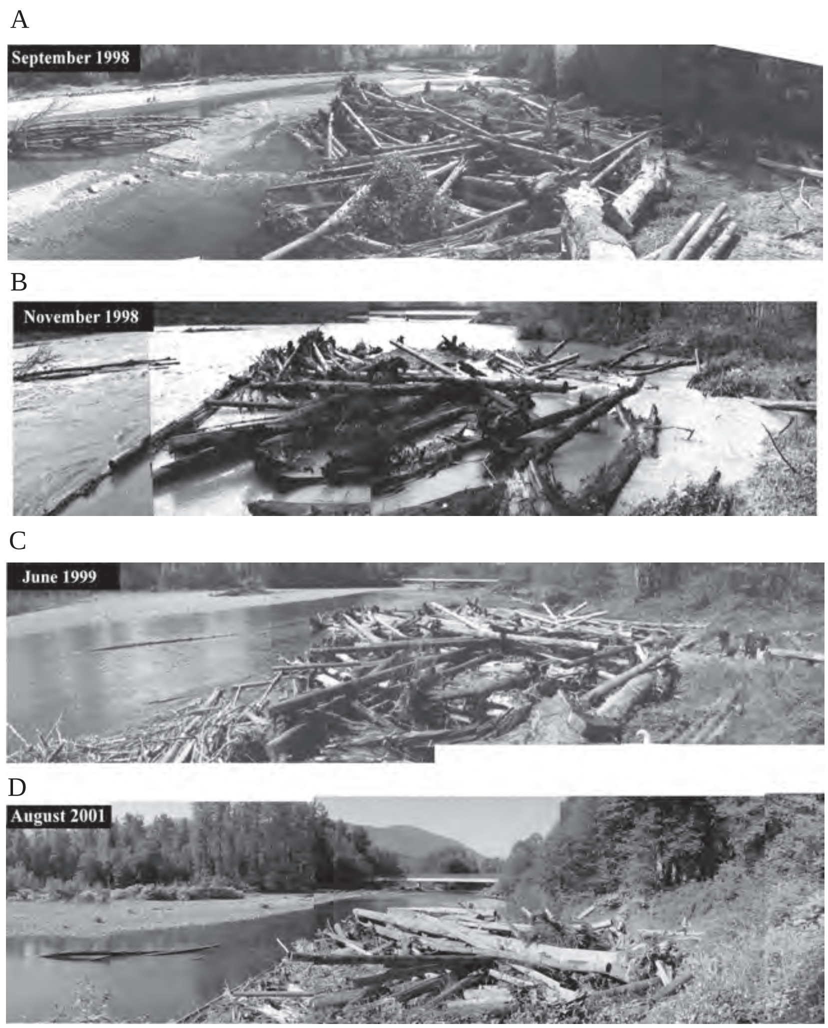


Figure 18. Photographs looking downstream at ELJ 1 (C-Post Bridge is in background). As-built conditions in (A) September 1998; (B) November 1998 during a peak flow cresting bankfull stage and over topping the ELJ; (C) June 1999 after 8 peak flows equal to or exceeding bankfull stage; and (D) in August 2001 after 16 peak flows equal to or exceeding bankfull stage.

creating a forested island. The effectiveness of the North Fork Stillaguamish ELJs in collecting drift is revealed by data collected on log displacement distances during Water Year 1999. Of the logs that moved, those that had to pass at least one ELJ had average displacement distances an order of magnitude less than those logs that passed downstream of the C-Post bridge (Figure 19). The North Fork Stillaguamish downstream of the C-Post bridge is a relatively simple, clear channel lacking stable log jams. From field surveys in September 1999, we estimate that 98% of the approximately 350 logs used in the five ELJs remained in place through eight peak flows equal or exceeding bankfull stage.

Reduction of the drift accumulation at the C-Post bridge was to be accomplished by: (1) trapping drift that might otherwise accumulate at the bridge; and (2) deflecting flow to improve channel alignment nearly orthogonal to the bridge, thereby providing for more efficient conveyance past the bridge. The large drift accumulation formerly lodged on the bridge's center pier was removed during ELJ construction and as of spring of 2001 no drift has yet to lodge on the bridge (Figure 20).

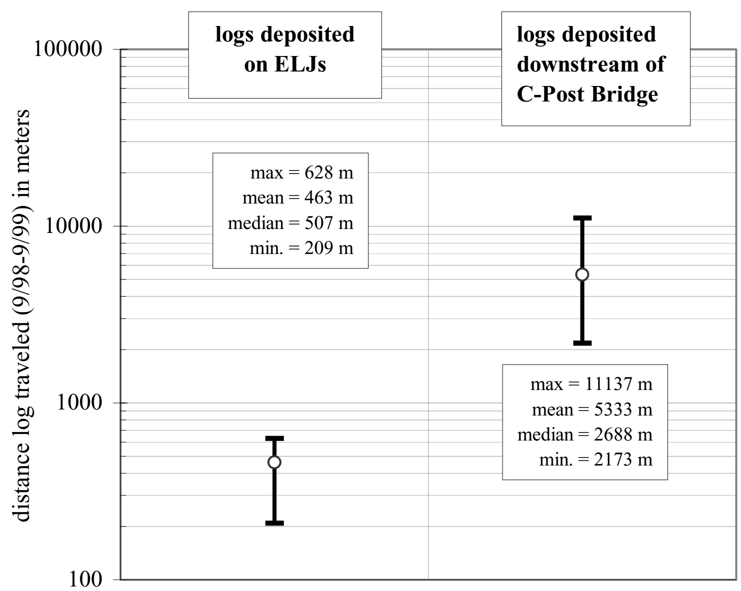


Figure 19. Displacement distances of tagged logs that moved in Water Year 1999: logs which had to travel past at least one ELJ had a significantly lower distance traveled than those logs that moved downstream of the C-Post Bridge, where few major flow obstructions were encountered all the way to Puget Sound.

The biological response to ELJ construction was evaluated by comparing baseline physical habitat and fish population information to post-construction surveys. Baseline data includes adult chinook and other salmonid population estimates through snorkel surveys, quantitative measures of habitat characteristics (e.g., number of pools, residual pool depth), and qualitative measures of habitat quality (e.g., amount of in-channel cover). Preliminary monitoring data suggest that changes in habitat condition have led to redistribution in adult chinook within the treatment reach. ELJs in the North Fork Stillaguamish have increased pool frequency, pool depth, and in-channel wood cover. Pool frequency increased immediately after ELJ construction from 1 pool/km to 5 pools/km and has remained at that level. Residual pool depth in the treatment reach also increased after ELJ construction, increasing from an average of 0.4 m to 1.5 m. The total number of pools in the area shown in Figure 16 increased from 3 to 6 after the project, but residual pool depths increased significantly. Most (80%) of chinook salmon utilization within the project reach was concentrated at the C-Post bridge in the largest, deepest pool within the reach; the remaining 20% was observed in a small pool adjacent to a natural log jam situated where ELJ 2 was constructed (Figure 21). Chinook response was immediate and consistent over the three years following construction. Instead of congregating in one pool (80% found in the C-Post Bridge pool) prior to ELJ construction, chinook redistributed throughout the treatment reach, utilizing the increase in pool availability and quality.

Lower North Creek

North Creek runs through the new University of Washington Bothell-Cascadia Community College (UWB-CCC) Campus in Bothell, Washington. The North Creek catchment is situated at the north end of Lake Washington northeast of Seattle. Restoration of North Creek is the result of a political, environmental, regulatory, and ecological design process that began in 1989 when the Washington State legislature authorized the design and construction of the branch campus. The restoration project was intended to mitigate for impacts to wetlands resulting from construction of the campus buildings and infrastructure. The State of Washington committed to a restoration design of the North Creek channel and floodplain that was significantly greater in scope, complexity, and cost than required by federal regulatory agencies.

The North Creek watershed is approximately 7,300 hectares and extends 20 km north of the Sammamish River. The watershed experienced intensive timber harvest at the turn of the century, which was followed by a long period of agricultural development. Present estimates of percent impervious area within

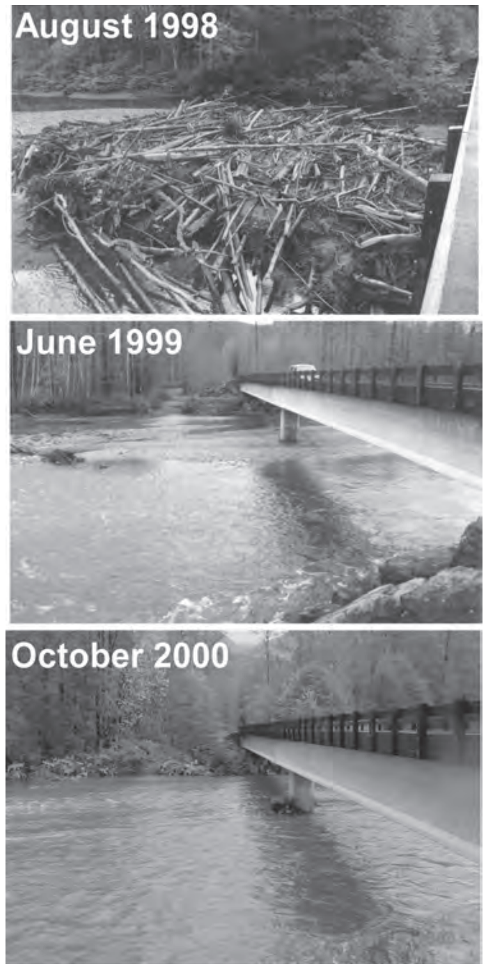


Figure 20. C-Post Bridge directly downstream of the 1998 ELJ project on the North Fork Stillaguamish River. Prior to constructing five ELJs upstream of the bridge, drift (mobile woody debris) accumulation was a chronic problem requiring frequent maintenance (A). Drift was removed in 1998 when the ELJs were built to test the hypothesis that ELJs could reduce drift accumulation by collecting drift upstream and improving channel alignment with the bridge to facilitate drift conveyance beneath the bridge. In the first year, there were eight flow events that equaled or exceeded bankfull stage without any drift accumulation on the bridge (B). The bridge remained clear after two years and 8 more flows equal to or exceeding bankfull stage (C). Only one peak flow equal to or exceeding bankfull stage occurred in the third year (Water Year 2001) and the bridge remains clear of drift.

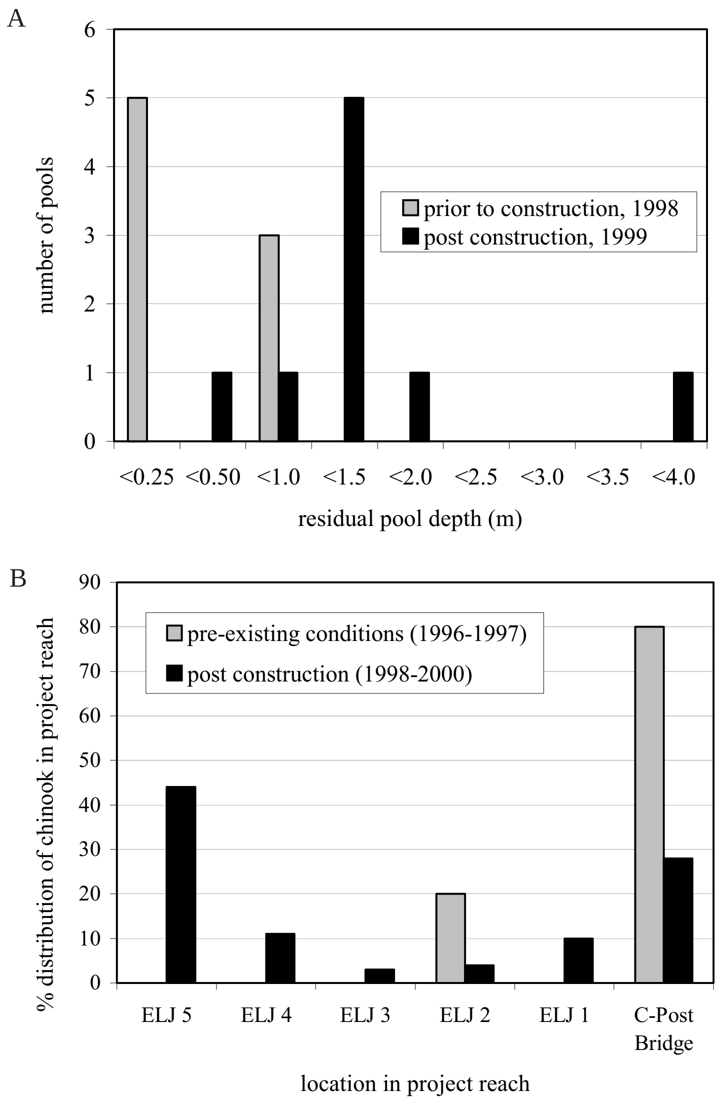


Figure 21. Results of the 1998 ELJ project in the North Fork Stillaguamish River. (A) The total number of pools only increased from 8 to 9 after the project, but residual pool depths increased significantly. (B) 80% of chinook salmon utilization within the project reach was concentrated at the C-Post Bridge in the largest, deepest pool within the reach; the remaining 20% was observed in a small pool adjacent to a natural logjam situated where ELJ 2 was constructed. Chinook distribution dispersed significantly after construction, correlating directly to the presence of ELJs.

the North Creek watershed vary from 14% to 27%. The estimated 100-year flood in lower North Creek is 41 m^3/s based on 16% effective impervious area.

The project site is situated just upstream of North Creek's confluence with the Sammamish River and covers approximately 24 hectares and 1,000 m of the lower creek channel (Figure 22). Historically, the landscape of the North Creek and Sammamish River confluence was a complex mosaic of very low gradient floodplain channels, depressional ponds, and marsh, scrub-shrub, and forested wetlands. The pre-settlement floodplain vegetation reflected the physical diversity of the landscape, with conifer dominated patches, scrub-shrub thickets of small trees and shrubs, and open water ponds fringed by emergent marsh vegetation, all set within a valley bottom deciduous forest matrix comprised of cottonwood and red alder. By the early twentieth century, the site was logged and the North Creek channel was straightened and leveed along the valley margin. An extensive network of ditches was excavated to dewater the forested wetland. These alterations effectively decoupled North Creek from its floodplain, drastically reduced the total channel length, and transformed the native emergent, shrub, and forested wetlands into a pasture. Prior to construction in 1998 the site was covered by Reed Canary Grass (*Phalaris arundinacea*). The net result of this historic land use was to significantly diminish salmonid habitat quality and abundance in North Creek.

Project Objectives, Constraints, and Opportunities

The UWB-CCC reach of North Creek is typical of many urbanized, low-gradient stream and floodplain environments in the Puget Sound region. The rehabilitation design was constrained by single points of channel entry and exit to the campus property and a floodplain limited in extent by the Highway 405 and 522 road corridors. Given the degraded status and inherent physical constraints of the campus site, the goal of the design was to restore as much as possible the site's hydrologic, biogeochemical, and habitat functions. The restoration design was based upon historic site information, hydrologic modeling, and an extensive sampling effort to characterize ecosystem structural characteristics of similar Puget Sound lowland riverine reference sites.

Objectives

- Hydrologically reconnect North Creek with its floodplain
- Reintroduce both in-channel and floodplain large wood
- Restore native floodplain forest plant community
- Increase the quantity, quality and diversity of aquatic and terrestrial habitat
- Provide visual access from both the campus and highway corridors

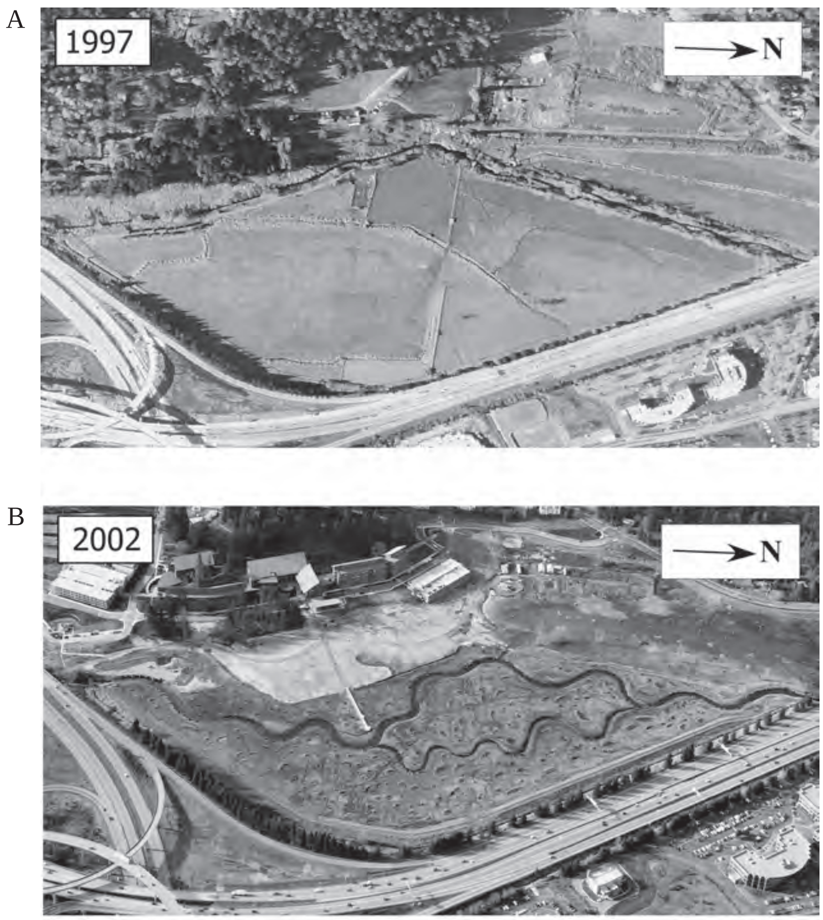


Figure 22. North Creek channel and floodplain restoration site: (A) pre-existing conditions in November 1997 with creek channelized at northern margin of floodplain and (B) after construction of new channel and floodplain system in January 2002. ELJs constructed at the North Creek site include flow deflection jams, a bar apex jam (at inlet to secondary channel) and log crib revetments. Photographs courtesy of Soundview Aerial Photography, Arlington, WA. Flow is from right to left in both images.

- Increase linkages between channel system and riparian floodplain forest and wetlands by:
    - Maximizing length of perennial channel system
    - Maximizing contact time between water and wetlands
    - Maximizing linkages between channel system and floodplain

Constraints

- Limit the area of flood inundation and channel migration on urbanized site
- Accommodate increased peak flows resulting from urbanization of the upstream watershed
- Allow no export of drift downstream of project area
- Protect critical infrastructure beneath and adjacent to the project area (storm sewer pipe and university campus buildings)

Opportunities

- Introduce a multiple channel system for both perennial and ephemeral flow conditions
- Maximize tolerance for channel change (i.e., lateral channel movement)
- Incorporate ELJ structures to:
    - emulate instream structures representative of a low gradient Puget Sound stream
    - limit channel migration at sensitive locations
    - stabilize and help sustain secondary channel system
    - increase physical and hydraulic complexity within the channel

It was decided that a more natural stream channel morphology would be returned to North Creek by constructing a new channel system that provided a greater diversity of habitat such as found in pristine, low-gradient sites in the Puget Lowland. In particular, the new stream channel system was constructed to allow overbank flow to occur on an approximately 1-year return interval. This approach seeks to restore the linkage between channel and floodplain components of the North Creek ecosystem. The new main channel was designed with bed and bank features and a variety of in-channel habitats, including pools, riffles, and large wood. Secondary channels were designed to engage at different flow stages.

Project Design

The North Creek project involved construction of a sinuous new mainstem and a perennial side channel, four types of ELJs incorporating approximately 1200 unanchored logs, and an aggressive revegetation plan. Infrastructure constraints mandated that channel migration be controlled. The overall project goal of improving aquatic habitat with respect to this constraint was achieved by using ELJ structures to limit bank erosion, contain channel migration, and create beneficial instream habitat. Engineered log jams emulating flow deflection jams were used along many of the channel meanders. At the inlet to the secondary channel a bar apex jam was constructed and inside the inlet a set of log steps were placed to prevent incision and dissipate energy. These jams were integrated with flow deflection jams to protect banks of the channel. Toward this end, tree bole revetments and crib structures were used to stabilize the critical banks and meanders; a bar apex type ELJ was built to locally raise water elevations at the secondary channel inlet; and a complex multiple log weir was set beneath the bed of the inlet channel to reduce the probability of the secondary channel becoming the mainstem channel.

The restoration design for the floodplain plant community was based upon quantitative characterization of similar floodplain forests at 58 Puget Sound reference sites. Based on these reference site data, 25 distinct plant communities were designed and planted at North Creek. The goal of the North Creek plant community restoration was to set the stage for the development of a compositionally and structurally representative Puget Lowland floodplain forest. The newly constructed channel reach was not engaged upon initial construction in order to allow riparian vegetation to become established along the channel banks. During the vegetation establishment period from August 1998 to August 2001 the project site was inundated several times due to backwater effects of the Sammamish River during winter high flows. The cost for the entire North Creek restoration project was approximately $6 million.

Results to Date

The new creek channel system was opened to the full discharge of Lower North Creek in August 2001. During the winter of 2001-2002 the creek experienced several peak flows that inundated the floodplain. Students from the Center for Streamside Studies surveyed twenty-five channel cross-sections in October 2001 and re-surveyed them again in January 2002. At the cross-sections, the channel has experienced some net scour and no significant change in width or location. All of the engineered log jams remain intact and are associated with deep pools. The North Creek project shows that a large-scale project involving rehabilitation of a complete channel and floodplain reach is feasible in urbanized areas if sufficient land is available. The project also suggests that unanchored logs can be incorporated into engineered log jams as an integral part of stream restoration, even in an urban stream, although the long-term consequences of increasing channel discharges with progressive watershed urbanization have yet to be evaluated.

Conclusion

River rehabilitation in large portions of fluvial landscapes, including areas within naturally defined channel migration zones, can be severely constrained or even precluded due to agriculture, industry, commercial forestry, residential development, and transportation infrastructure. Because human development affects so much of the fluvial landscape and is likely to continue to do so, meaningful rehabilitation of fluvial ecosystems will require strategies that integrate technology that not only re-establish and sustain natural processes but also maintain infrastructure and protect human life and property. Consequently, strategies are most likely to succeed if based on multi-disciplinary collaboration of physical and biological scientists, civil engineers, planners, and community representatives. Traditional engineering problems can be solved with non-traditional approaches, such as ELJs, that provide specific benefits together with habitat enhancement. In this context, ELJs are versatile in that they can be used for both habitat enhancement as well as general river engineering. However, in the implementation of ELJ projects, it is important to clearly delineate objectives and constraints, establish the spatial and temporal scale of the project, and document what ultimately happens on the ground. The potential risks of applying ELJ technology without adequate scientific assessment and engineering design can threaten not only the success of a single project but also human welfare and future policy decisions regarding the management of instream woody debris. The success to date of ELJ projects in western Washington highlights the potential benefits of this experimental technology for enhancing fluvial ecosystems while protecting infrastructure and property within fluvial corridors.

Acknowledgments

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Response of Juvenile Coho Salmon and Steelhead to Placement of Large Woody Debris in a Coastal Washington Stream

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Abstract.—Many fish habitats have been altered in Pacific Northwest streams and rivers over the past century by a variety of land use practices, including forestry, urbanization, agriculture, and channelization. There are research and management needs for evaluation of the effectiveness of rehabilitation projects intended to enhance stream fish habitat recovery. The response of populations of juvenile coho salmon *Oncorhynchus kisutch* and steelhead *O. mykiss* to addition of large woody debris (LWD) was tested in North Fork Porter Creek (NFPC), a small coastal tributary of the Chehalis River, Washington. The NFPC was divided into three 500-m study sections; two sections were altered with two approaches (engineered and logger's choice) to adding LWD, and the third was kept as a reference site. Immediately after LWD addition, the abundance of LWD pieces was 7.9 times greater than the pretreatment level in the engineered site and 2.7 times greater in the logger's choice site; abundance was unchanged in the reference site. Subsequent winter storms brought additional LWD into all three study sites. In the years that followed, the amount of pool surface area increased significantly in both the engineered and logger's choice sites, while it decreased slightly in the reference site. After LWD addition, winter populations of juvenile coho salmon increased significantly in the engineered and logger's choice sites, while they remained the same in the reference site. There were no significant differences in the coho salmon populations during spring and autumn within the reference, engineered, or logger's choice sites. The coho salmon smolt yield from the engineered and logger's choice sites also increased significantly after LWD addition, while it decreased slightly in the reference site. After LWD addition, the reference site and the engineered site both exhibited increases in age-0 steelhead populations; however, the population in the logger's choice site did not change. There was no difference in age-1 steelhead abundance among sites, or before and after enhancement during any season. Winter populations of juvenile coho salmon and age-0 steelhead were related inversely to maximum and mean winter discharge.

Fish habitat in Pacific Northwest streams and rivers has been altered over the last century by a variety of land use practices, including forestry (Wendler and Deschamps 1955; Salo and Cundy 1987; Hicks et al. 1991), pioneer settlement and subsequent urbanization (Sedell and Luchessa 1982; Sedell et al. 1988; Booth 1991), agriculture (Elmore and Beschta 1987; Platts 1991), and modification of stream channels (Kramer 1953; Cederholm 1972; Salo and Jagielo 1983). These activities have resulted in dramatic reductions in abundance of large woody debris (LWD) in stream channels (Sedell and Luchessa 1982; Grette 1985; Bilby and Ward 1991).

Large woody debris (i.e., organic material longer than 2 m and having a diameter of at least 10 cm) performs a variety of functions in streams. It is often the most important pool-forming agent in smaller systems (Bisson et al. 1987); it stores gravel, fine sediment, and organic matter (Beschta 1979; Bilby and Likens 1980; Cederholm et al. 1989); and it dissipates the energy of flowing water (Heede 1976). These processes have important effects on fishes living in streams, in that they create spawning and rearing habitat, increase nutrient and organic matter retention (which increases food production in the system), and provide refuge from predators and cover during high winter flows (Bustard and Narver 1975; Lestelle 1978; Lestelle and Cederholm 1982; McMahon and Hartman 1989; Hicks et al. 1991). Several studies in the Pacific Northwest have indicated that availability of low-velocity habitat within the main channel, sheltered from the effects of winter flood flows, is often an important factor in retaining juvenile coho salmon within the stream channels over winter, these fish later contribute to stream smolt production (Mason 1976; Reeves et al. 1991). The LWD is important in creating this type of habitat (Bustard and Narver 1975; Bisson et al. 1987).

There is a need for evaluation of the effectiveness of restoration projects intended to enhance stream and fish habitat (Koski 1992). Numerous efforts to increase the abundance of LWD in streams where it is considered deficient have been undertaken over the last decade (Duff and Banks 1988; House et al. 1988; Sheng 1993). However, Frissell and Nawa (1992) found that many large and costly salmon habitat restoration projects have been implemented by federal and state agencies with little or no analysis of the response of the targeted stream biota. In addition, much of the LWD placed in streams during these projects failed to perform as intended or was damaged or removed from the system by high flows. Some projects have shown benefits to salmonid fish populations, but, in many cases, evaluations and monitoring have been noticeably lacking.

Increases in numbers of anadromous (Ward and Slaney 1981; House and Boehne 1995) and nonanadromous (Gowan and Fausch 1995) fishes after addition of LWD to a stream have been demonstrated. These results are cited widely as justification for enhancement projects which involve the introduction of LWD. However, further examination of both published and unpublished information on the effectiveness of various enhancement efforts suggests that numerous projects have had no impact or negative impacts on fish populations (Hall and Baker 1982; Hamilton 1989). The need for careful evaluation of enhancement efforts has become widely recognized (Hall and Baker 1982; Reeves and Roelofs 1982; Everest and Sedell 1984; Hall 1984; Klingeman 1984; Platts and Rinne 1985).

Our study evaluated the changes in habitat and the response of juvenile coho salmon *Oncorhynchus kisutch* and steelhead *O. mykiss* to two approaches of introducing LWD to a stream. One section of stream was treated by placing logs in the channel using heavy equipment and securing the wood in place, a relatively expensive approach which has been applied widely in the Pacific Northwest. The other approach involved simply cutting and felling trees into the stream channel and cabling them to their stumps, an inexpensive technique commonly used.

Methods

Study Area

We evaluated LWD placement in North Fork Porter Creek (NFPC), located west of Olympia, Washington, in the state-owned Capitol Forest 46°59′N, 123°14′W (Figure 1). North Fork Porter Creek is a third-order tributary to the Chehalis River, draining an area of 25 km^2.

The study area was located approximately 0.5 km upstream from the mouth of the NFPC. Average bank-full channel width is about 10 m and channel gradient is 2%. Average annual discharge is approximately 1 m^3/s with summer low flow of 0.05 m^3/s and an estimated 50-year return interval flow of 51 m^3/s (Orsborn 1990).

The climate in the watershed is characterized by warm, dry summers and cool, wet weather the rest of the year. Annual precipitation ranges from 127 to 178 cm, occurring primarily as rain (McMurphy and Anderson 1968). Snow may accumulate and persist for several weeks during winter at higher elevations within the watershed. Air temperatures are moderated by marine influence of the nearby Pacific Ocean. Annual mean temperature is 10.4°C with recorded extremes from −18.3°C to 39.5°C (Phillips 1964).

The NFPC watershed is underlain by bedrock of the Crescent Formation, consisting of basalt

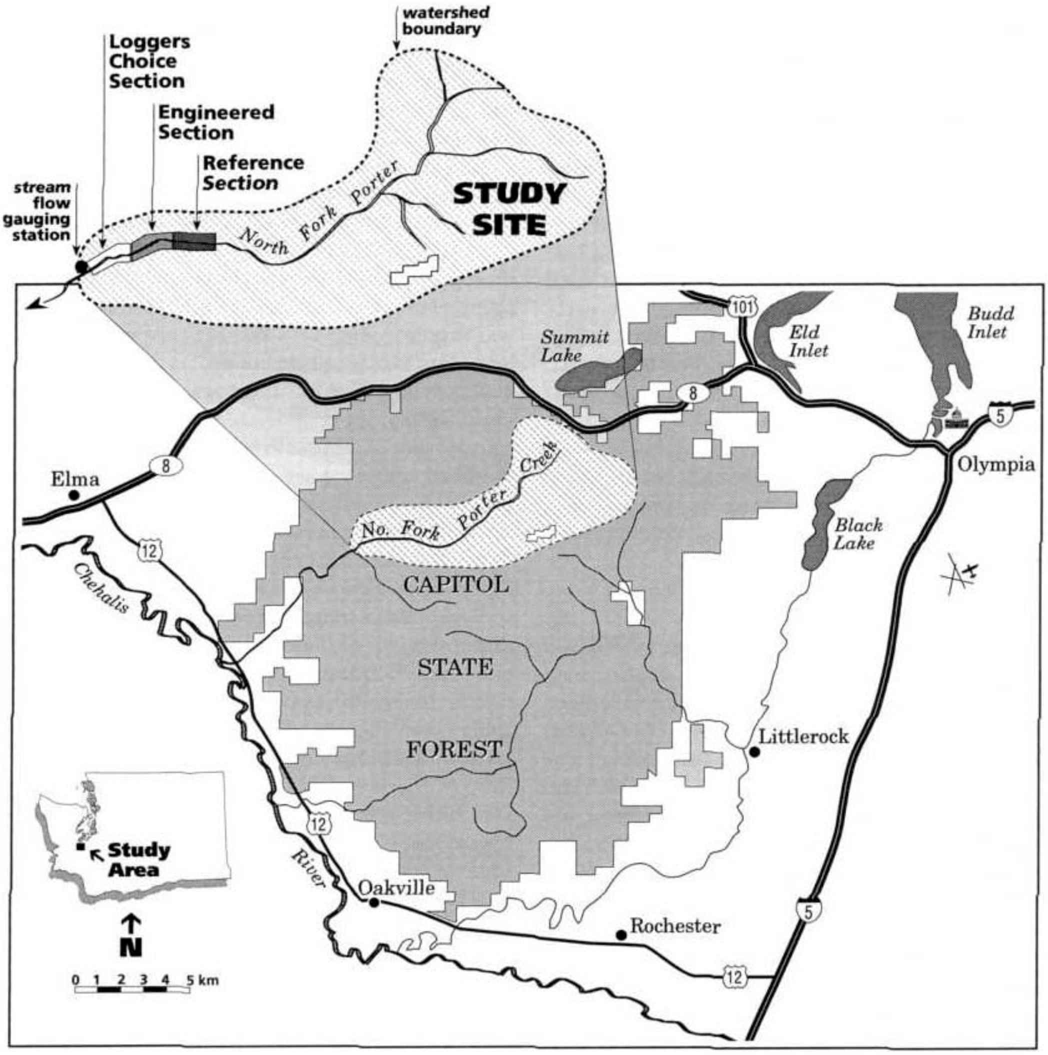

FIGURE 1.—Location of the Porter Creek watershed, Washington, showing the location of the reference and experimental sections.

flows deposited during the early and mid-Eocene and sedimentary deposits from the Oligocene and Miocene. Soils formed from this bedrock in areas of low relief are deep, well-drained silt and clay loams while soils in steeper terrain are shallower and contain more gravel (Pringle 1986).

About 8 km of the stream is accessible to anadromous fishes which include coho salmon, steelhead, coastal cutthroat trout *O. clarki clarki* and Pacific lamprey *Lampetra tridentata*. Resident (nonanadromous) species occupying the study site include several species of sculpin *Cottus* spp. and cutthroat trout.

Land Management History

The Capitol Forest was originally logged between 1920 and 1940 (Carman et al. 1984) and the NFPC watershed was logged during the latter part of this period. Timber harvested at this time was removed from the forest by railroad, as evidenced by abandoned grades and trestles near the study site. No forest practice regulations were in effect at that time, and impacts on the stream and the riparian area were severe.

During the 1970s about 35 km of stream within the Capitol Forest were cleared of nearly all LWD to eliminate possible blockages to anadromous fish migration. The NFPC was included in this treatment.

Logging of second-growth timber in the NFPC watershed has been ongoing since 1975. The primary harvest method is clearcutting of blocks ranging in size from 40 to 100 ha. Streams have received varying levels of protection from logging depending on the size of the stream and the regulations in effect at the time the area was harvested. A buffer of standing trees was retained along the NFPC following logging in the early 1980s. The buffer ranges 8–25 m in width. The predominant overstory species in the buffer is red alder *Alnus rubra*, a common early successional species in forests of western Washington. A few Sitka spruce *Picea sitchensis*, Douglas-fir *Pseudotsuga menziesii*, western hemlock *Tsuga heterophylla*, western redcedar *Thuja plicata*, and bigleaf maple *Acer macrophyllum* also were included in the buffer.

Experimental Design

The study sites for this project were established on one stream to minimize between-stream physical and biological variability. It would have been helpful to have study sites on several streams, but the costs involved proved to be prohibitive. The 1,500-m study area on NFPC was separated into three, 500-m sites—reference, engineered, and logger's choice—to provide enough stream area for physical and biological response to LWD placement (Figure 1). Statistical inferences derived from our treatments would have been much more powerful if replicate treatment sites on the NFPC could have been established; nonetheless, our design permitted us to compare the response of physical habitat features and fish populations to our treatments at these sites and to better understand the processes responsible for the observed changes.

Large woody debris addition to the two treatment sites began in late summer 1990 and was finished in late summer 1991. Two years were required because construction activity in the stream was permitted only during August and September. The goal for the treated sites was to increase the size and frequency of pools and amount of LWD cover during winter, and to positively influence the number of overwintering juvenile salmonids within the two treatment sites.

Reference site.—The reference site was deliberately not altered during this study, and was located upstream of the two treated sites to minimize influences resulting from installation of the enhancement structures at the treated sites. Although no LWD was purposefully added to this site, 48 pieces entered the site between 1991 and 1994 during winter storms and some changes in habitat characteristics did occur over the 6-year study.

Engineered site.—The center site was labeled the engineered site because of the methods used to introduce LWD at this location. A thorough survey of the area and a detailed analysis of the hydrology of NFPC were completed prior to developing plans (Orsborn 1990). Introduction of LWD was accomplished with labor-intensive techniques involving heavy equipment and anchoring of wood added to the channel. Logs and boulders used in the project were transported to the channel with a tractor and placed with a tracked loader with a thumbed bucket. Large woody debris abundance was increased to levels typical of streams in forests where no timber harvest had occurred (Bilby and Ward 1989). In all, 133 structures containing 200 logs were added to the engineered site.

Logs were arranged into five different configurations at the engineered site (Figure 2A). In general, the full-crossing structures were intended primarily to control stream gradient while the partially crossing, parallel, pyramid, and logjam structures were intended to provide cover and habitat for the fish. Most of the logs used for these structures were cut from a stand of large conifers approximately 1 km from the study area. Conifer logs decompose more slowly than hardwood logs of similar size (Harmon et al. 1986), which increases the longevity of the structures. To create access to the area for heavy equipment, some red alder, Douglas-fir, and Sitka spruce had to be removed from the adjacent riparian stand; many of these trees were placed and anchored in the channel.

Several methods were used to anchor the logs in the channel (Figure 2A). Full-crossing logs were placed in narrow trenches excavated in each bank, boulders were placed on the ends of the log and covered with soil. A length of 1.8-m high cyclone fencing was stapled from bank to bank along the upstream side of the full-crossing logs; and covered with black fiberglass fabric to prevent the stream from undercutting the logs. One end of the partial-crossing logs was similarly buried in streambanks; however, the free end was anchored to the streambed using cable and epoxy cement. Parallel structures also were attached to the streambed with cable and epoxy cement. This procedure involved drilling a pair of holes into a buried boulder and wrapping a 14-mm steel cable

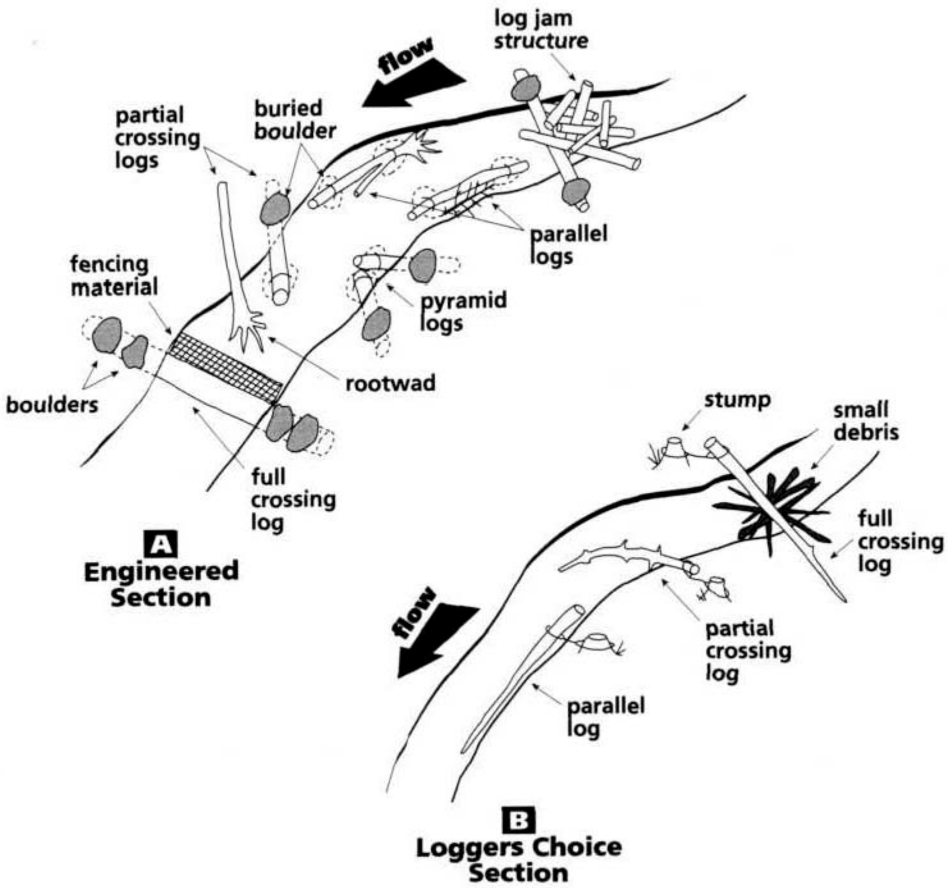

FIGURE 2.—Types of woody debris structures added to the (A) engineered and (B) logger's choice stream sections.

around the log and cementing the cable into the holes. In most cases, the boulder attached to the log was buried purposefully in the streambed. Other partially crossing logs were secured by wedging one end between two live trees on the streambank, and the free end was allowed to move in the current. Wherever two logs came into contact with each other (i.e., in the logjam), they were drilled and pinned together with a length of 13-mm diameter steel reinforcing rod.

TABLE 1.—Expenses incurred in implementation of the two large woody debris addition techniques compared in this study.

Expense	Engineered section	Logger's choice section
Engineering and design	$14,600.00	0.00
Heavy machinery	$33,000.00	0.00
Hand labor	$12,600.00	$2,700.00
Logs and rock	$17,000.00	$3,000.00
Other materials	$3,050.00	$750.00
Pumps	$2,000.00	0.00
Total	$82,250.00	$6,450.00
Cost/m of channel		
	$164.50	$12.90

Additional cover was provided at some of the parallel and partially crossing structures by nailing whole, 3–4 m long conifers (approximate diameter of 10 cm) to the shoreline side of the parallel log structures (Figure 2A). The approximate cost for treating the engineered section was $82,250 (Table 1). Twenty-nine additional pieces of LWD entered the engineered site between 1991 and 1994 during winter storms.

Logger's choice site.—A much less expensive approach, called logger's choice, was used to add LWD to the downstream-most site. Logs added to this site were all red alder cut from the streambank and dropped into the channel. Felling crews were instructed to cut 60 trees larger than 30 cm in diameter and distribute them as evenly as possible along the 500-m stream reach. The trees were tethered to their respective stumps with 14-mm-diameter steel cable to prevent transport downstream and possible damage to bridges, roads or private property (Figure 2B). Approximate cost of this treatment was $6,450 (Table 1). Thirty-two additional pieces of LWD entered the logger's choice site between 1991 and 1994 during winter storms.

Evaluation of Habitat and Fish Populations

Juvenile coho salmon and steelhead populations, coho salmon smolt yield, and physical habitat of the three stream sites were evaluated beginning in June 1988. Measurements were collected seasonally through spring 1994. Coho salmon and steelhead were much more abundant than cutthroat trout at all three sites and, thus, were the focus of our study. The low densities of cutthroat trout prevented us from evaluating the response of this species to habitat enhancement efforts. We did not sample the sculpins and Pacific lampreys, and we assumed they would have a consistent influence on salmonid abundance in all study sections.

Salmonid populations were surveyed by selecting representative habitat units of each type present in a study site, isolating the unit with nets, and collecting the fish with an electroshocker. Approximately 20% of the water surface area of each study site was sampled directly on any given sampling date. Each habitat was fished three times and total population in the unit was estimated using a removal–summation calculation (Carle and Strub 1978). Fishes collected during electrofishing were identified to species, and fork length (FL) was measured for each individual.

The total population of a fish species within a treatment was estimated by multiplying the average fish density for a given habitat type by the total area of that habitat type present in the entire treatment site. Ninety-five percent confidence limits about the whole-site population estimates were determined using a bootstrapping method (Efron and Tibshirani 1993). This technique produces asymmetrical confidence intervals about the population estimate. We considered populations among treatment sites, or before and after enhancement within a treatment site, to be significantly different when overlap of the 95% confidence intervals was less than 10% of the smaller interval.

Large woody debris was added to the treated stream sites in 1990 and 1991. Less than half the wood added was placed in autumn 1990; the remainder of the wood and all the cover structures were added in autumn 1991. Therefore, habitat enhancements from LWD addition were not expressed fully until winter of 1991–1992. Thus, we consider data collected from spring 1988 through smolt migration in 1991 to represent preenhancement conditions, and data collected from spring 1991 through smolt migration in 1994 to represent postenhancement conditions.

Habitat surveys and fish population estimates were conducted in late winter (March), spring (June) and autumn (late September). The sample times were established to provide us with information about changes in population levels over the low-flow summer period and over the winter, when frequent periods of high discharge occurred.

Habitat was assessed three times each year, in conjunction with determination of fish populations, using the method of Bisson et al. (1982). This technique entails the identification of individual habitat units and measurement of width and length of the water surface. Habitat units in the NFPC study sites consisted of four types of pools (scour pools, plunge pools, dam pools, and backwaters), and three types of fast water (riffles, cascades, and glides).

Large woody debris in the channel prior to enhancement was inventoried in 1989. The length and diameter of each piece was measured and each piece was marked with a numbered steel tag. Large woody debris was reinventoried after wood was added to the treated stream sections, both in 1992 and 1994.

In order to ensure that sufficient juvenile coho salmon were present at the study sites to take advantage of any improvement in habitat, fed coho salmon fry (approximately 1 g each) were released at the sites during 3 of the 6 years. An average of 19,000 unmarked fry were stocked throughout the study sites during early April of 1989, 1990, and 1991. The fry were distributed evenly throughout, and for about 100 m upstream of the study sites, to ensure that sufficient fry seeding occurred during the study. In retrospect we believe that, because of the large size of these fry, they may have left the site soon after planting. At the time of seeding, resident fish were much smaller than planted fish. Lack of availability of fry during the final 3 years prevented us from stocking the sites during the latter half of the study. However, population census of the coho salmon juveniles during the spring and late summer of stocked versus unstocked years indicated that stocking had no discernible effect on density of the fish. This suggests that natural reproduction by coho salmon in the NFPC was sufficient to fully seed the sites. Thus, the fact that stocking was not done during all 6 years should not affect our results.

Coho salmon smolts produced in each of the three study sites were collected each year from early April through mid-June. In some years the traps did not begin fishing until mid-April. Because of the variable time of trap installation, an uncounted number of presmolts and smolts may have emigrated from the stream prior to trapping onset. Total counts of smolts were made with traps similar to the one described by Armstrong (1978), consisting of temporary small-mesh screen weirs that direct downstream migrating fish into a live box. Traps were located at the downstream end of each of the study sites, and a fourth trap was placed at the upstream end of the reference site to intercept smolts produced above the study area. Traps were emptied daily. Captured smolts were identified, measured (FL), transported below the lower study site and released. Nonsmolting undersized (<135 mm FL) steelhead and cutthroat were released directly into the next downstream study site.

During occasional periods of high flow the traps became inoperative. These periods were rare, accounting for only 3% (11 days) of the total 370 fishing days over the 6 years of sampling. However, this was a problem when it occurred during the peak smolt migration. The most troublesome period of smolt trap inundation occurred on 8 May 1993, when a high-intensity rain storm caused the NFPC to rise and overflow the smolt traps for a 24-h period. While the traps were inundated, downstream migrating fish were able to move freely between the study sites. In order to correct for this problem, a factor was developed from the average proportion of smolts caught between all four traps during the 1-week period prior to inundation. This average was used to reproportion the total summed trap catches for the week following inundation. Experiments with marked fish indicated that the time needed for a smolt to swim through all three study sites was about a week. For example, on 8 May 1993 an unknown number of smolts probably moved into the reference and engineered study sites, causing a disproportionate number of smolts to be caught in their respective traps. Therefore, during the 7-day period after 8 May, the total catch of all four traps was summed and reapportioned based on the preinundation week's intertrap proportions. This allowed us to reallocate the fish that had moved into the reference and engineered sites, and add them back into their respective traps. The proportions used for this calculation were 84.4% caught in the uppermost trap, 3.5% caught in the reference site trap, 9.1% caught in the engineered site trap, and 3.0% caught in the logger's choice site trap.

Although our electrofishing population surveys indicated that substantial numbers of age-1 steelhead used the NFPC, we captured few steelhead smolts in the traps. It is likely that they left the system earlier than the coho salmon. Because high flows prevented us from installing the traps earlier than about 1 April, data on steelhead smolt yield was judged too incomplete to report.

A discharge recording station was installed on the NFPC about 75 m below the downstream end of the study sites in 1988 (Figure 1). Floods altered the channel at the gauging station in 1989, and the instrument was subsequently relocated about 50 m upstream. Instrumentation at the station operated more than 95% of the time. However, on several occasions malfunctions left gaps in the data. These gaps were filled by correcting flows at our station on the NFPC with simultaneous data collected at a Washington Department of Natural Resources (WDNR) station on lower Porter Creek (Jim Ryan, WDNR, unpublished data). When data from the WDNR recorder were not available, NFPC flows were corrected with data at a U.S. Geological Survey station on nearby Schaefer Creek. Flow data were used to examine the effect of discharge on fish populations before and after enhancement.

Results

Changes in LWD Abundance and Habitat

Large woody debris abundance changed in all three study sites after enhancement (Table 2). Abundance of LWD in the reference site more than doubled after enhancement of the two treated sites. This increase was attributable to input from the riparian area or wood transport from upstream during winter storms. Increases in LWD number and volume in the engineered and logger's choice sites were due to both deliberate addition of wood to the channel and the subsequent accumulation of wood during winter storms. By the end of the study in 1994, the number of pieces of LWD in the engineered site was 8.9 times the pretreatment level, while in the logger's choice site it was 3.6 times the pretreatment level. The number of LWD pieces increased 2.3-fold in the reference site.

Wood added during the enhancement project had little impact on average LWD diameter (Table 2). However, average piece length at both the engi-

TABLE 2.—Woody debris amounts and characteristics in North Fork Porter Creek before treatment (1989), immediately after treatment (1991), and in 1992 and 1994 in the reference, engineered, and logger's choice sites. Two hundred pieces of large woody debris (LWD) were added to the engineered site during enhancement, and 60 pieces to the logger's choice site. Changes in LWD amount over time at the reference site, and changes not accounted for by deliberate additions of wood at the two treated sites were caused by natural inputs of LWD during winter storms.

	Reference				Engineered				Logger's choice			
LWD characteristics	1989	1991	1992	1994	1989	1991	1992	1994	1989	1991	1992	1994
Number of pieces	36	36	84	84	29	229	251	258	35	95	95	127
Median diameter (cm)	29		28	28	35		32	32	26		32	31
Median length (m)	4.0		2.9	3.0	3.0		5.7	5.5	3.4		10.0	8.4
Median volume (m^3)	0.3		0.2	0.2	0.2		0.5	0.4	0.3		0.8	0.6
Total volume (m^3)	30		69	69	15		197	188	25		84	101

neered and logger's choice sites increased significantly following enhancement (t-test, $P < 0.05$). Increased piece length and abundance resulted in a 11.5-fold increase in total wood volume in the engineered site and a 3.0-fold increase in the logger's choice site. The reference site exhibited a 1.3-fold increase of total wood volume as a result of natural input. However, the wood entering the reference site was small- and medium-sized, as piece lengths and volume decreased between 1989 and 1992. This material had little impact on channel morphology, as described below.

TABLE 3.—Habitat characteristics before and after enhancement by treatment. Values represent the average proportion of stream surface area in each habitat category for surveys conducted for three years before and three years after enhancement. Miscellaneous (misc.) habitats include backwaters, secondary channels, and glides. These habitats never accounted for more than 10% of the total surface area at any site during any survey.

	Reference		Engineered		Logger's choice	
Habitat type	Before	After	Before	After	Before	After
Spring						
Riffle	0.33	0.57	0.37	0.34	0.36	0.46
Cascade	0.15	0.04	0.29	0.00	0.17	0.03
Scour pool	0.45	0.35	0.33	0.32	0.40	0.46
Dam pool	0.00	0.02	0.00	0.16	0.00	0.02
Plunge pool	0.00	0.00	0.00	0.11	0.01	0.00
Misc. habitats	0.07	0.02	0.01	0.07	0.06	0.03
Autumn						
Riffle	0.34	0.47	0.45	0.23	0.30	0.29
Cascade	0.11	0.03	0.14	0.00	0.18	0.08
Scour pool	0.47	0.46	0.34	0.40	0.46	0.58
Dam pool	0.00	0.00	0.00	0.23	0.00	0.00
Plunge pool	0.01	0.00	0.04	0.11	0.00	0.00
Misc. habitats	0.07	0.04	0.03	0.03	0.06	0.05
Winter						
Riffle	0.44	0.50	0.44	0.39	0.38	0.43
Cascade	0.06	0.07	0.14	0.00	0.12	0.00
Scour pool	0.41	0.39	0.34	0.39	0.38	0.43
Dam pool	0.00	0.00	0.00	0.01	0.02	0.05
Plunge pool	0.01	0.00	0.04	0.16	0.00	0.01
Misc. habitats	0.08	0.04	0.04	0.06	0.10	0.08

Pool area increased in both the engineered and logger's choice sites following enhancement (Table 3). The engineered site displayed the most dramatic increases in pools, with the proportion of the water surface composed of pools increasing from 33%, 38%, and 38% in spring, autumn, and winter, respectively, to 59%, 74%, and 56%. Most of the increase in the engineered site was due to the creation of dam and plunge pools associated with the full-crossing LWD structures placed in the stream. The logger's choice site exhibited increases of 7% to 12% in proportion of pool areas, due almost entirely to creation of additional scour pools. Very few of the LWD pieces added to this site fully blocked the stream, because pieces floating in the channel were swept to the margins during winter high flows. Because fully blocking pieces of LWD usually are needed to form dam or scour pools, these habitats remained rare in the logger's choice site after enhancement. The reference site displayed slight decreases in proportion of the water surface area composed of pools after enhancement during all seasons.

Fast-water habitats decreased at the two enhanced sites (Table 3). In the engineered site, riffles decreased and cascades were eliminated after completion of enhancement. In the logger's choice site, riffles increased during spring and winter, but stayed relatively constant during autumn before and after enhancement. The proportion of cascades decreased by more than 10% during all three seasons in the treated sites. Fast-water habitats increased at the reference site.

Although we did not quantify changes in substrate characteristics, large amounts of gravel accumulated at the structures added to the two treated sites. We frequently observed coho salmon and steelhead spawning in the treated sites after en-

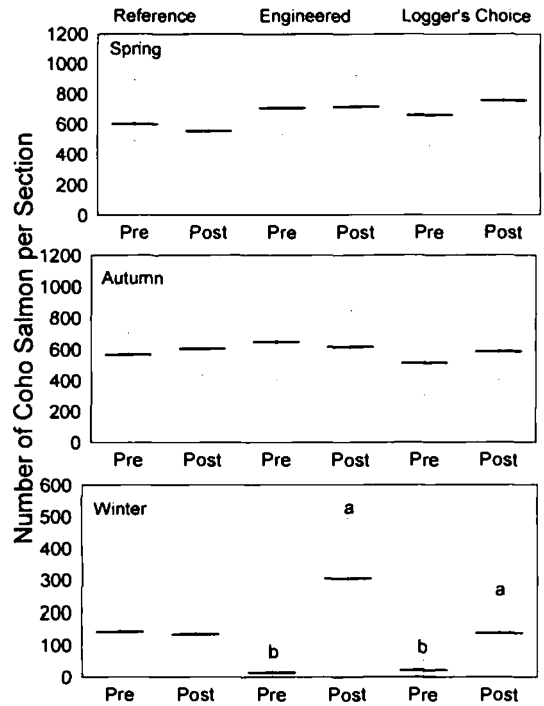

FIGURE 3.—Average juvenile coho salmon abundance seasonally before (Pre) and after (Post) addition of large woody debris to the engineered and logger's choice stream sections. Error bars represent 95% confidence intervals. An "a" above the error bar indicates a significant difference in numbers of coho salmon before and after treatment at a site. A "b" indicates a significant difference in numbers of coho salmon between the reference and treated section.

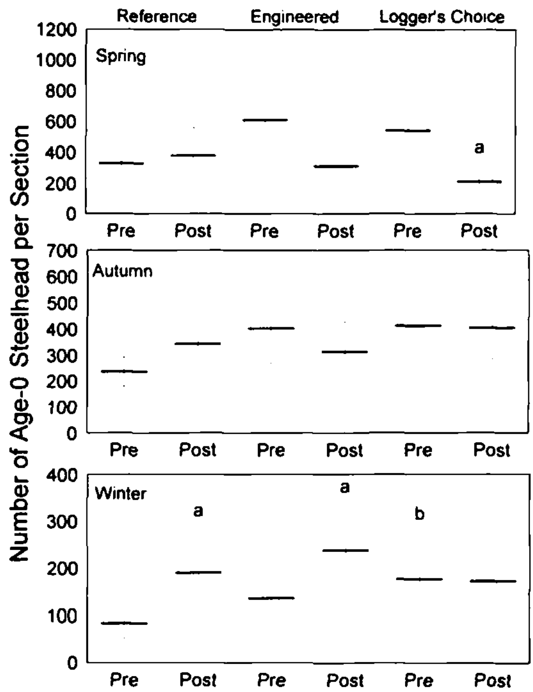

FIGURE 4.—Average age-0 steelhead abundance seasonally before (Pre) and after (Post) addition of large woody debris to the engineered and logger's choice stream sections. Error bars represent 95% confidence intervals. An "a" above the error bar indicates a significant difference in numbers of age-0 steelhead before and after treatment at a site. A "b" indicates a significant difference in numbers of age-0 steelhead between the reference and treated section.

hancement, whereas before enhancement, few coho salmon or steelhead were observed spawning within the entire study area.

Fish Response to Habitat Enhancement

Stocking of fish in 1989, 1990, and 1991 had no apparent effect on spring population densities of coho salmon (Figure 3). Stocking took place in early April. However, population estimates in June did not differ significantly between stocked and unstocked years (stocked = 0.25, SE = 0.065 coho/m^2, not stocked = 0.16, SE = 0.044 coho/m^2; t-test $P = 0.331$). Therefore, stocking coho salmon fry during 3 of the 6 years of this study should have had little impact on the responses exhibited by the fish to the enhancement projects.

Abundance of coho salmon during spring and autumn sampling periods showed no response to enhancement (Figure 3). Average spring populations ranged from 550 to 750 fish/site while autumn population levels varied from 500 to 650 fish/site. There were no significant differences among sites or among years during spring and autumn.

Juvenile coho salmon populations did respond to enhancement during winter (Figure 3). Prior to enhancement, the reference site supported nearly 10 times the number of presmolt coho as the two treatment sites. After enhancement, coho abundance increased 20-fold in the engineered site and 6-fold in the logger's choice site. The reference site exhibited no change in coho abundance after treatment of the other two sites.

There were no significant differences in age-0 steelhead abundance during spring among the sites prior to enhancement (Figure 4). After enhancement, no change was observed in the reference or engineered sites in spring; however, age-0 steelhead abundance declined significantly in the logger's choice site. During autumn, no changes among sites before and after enhancement were noted. During winter before enhancement, the log-

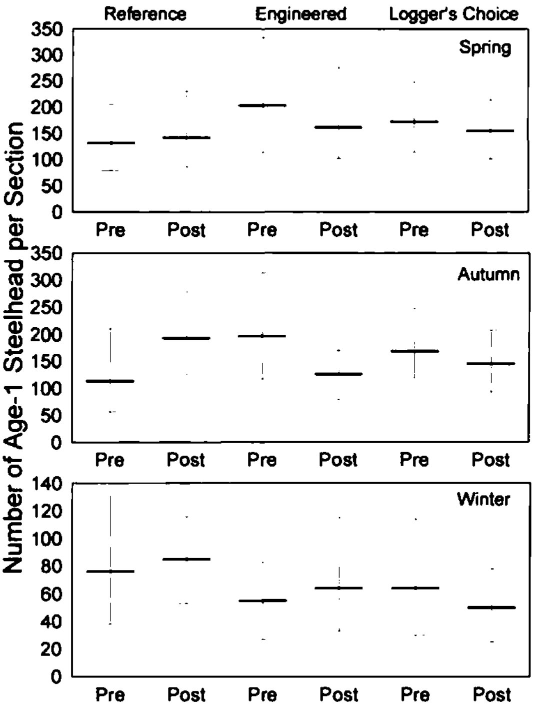

FIGURE 5.—Average age-1 steelhead abundance seasonally before (Pre) and after (Post) addition of large woody debris to the engineered and logger's choice stream sections. Error bars represent 95% confidence intervals.

ger's choice site supported higher populations of age-0 steelhead than the reference site. After enhancement, age-0 steelhead increased during winter in both the reference site and the engineered site; however, the population in the logger's choice site did not change after enhancement.

Age-1 steelhead abundance was similar among sites and before and after enhancement during all seasons (Figure 5).

The number of coho salmon smolts migrating from the engineered and logger's choice sites increased following enhancement (Figure 6). An average of 117 smolts/year emigrated from the engineered site prior to enhancement, and 55 smolts/year emigrated from the logger's choice site, by far the lowest number for the three sites. Following enhancement, average annual yield increased to 370 smolts/year from the engineered site and 142 smolts/year from the logger's choice site. Smolt production at the reference site remained relatively unchanged before and after enhancement of the two other reaches, 134 smolts/year before and 109 smolts/year after enhancement. The number of coho salmon smolts produced upstream from the experimental area averaged 2,534 smolts/year prior to enhancement and 3,016 smolts/year afterwards. Changes in number of emigrating coho salmon smolts from the engineered and logger's choice sites before and after treatment are statistically significant (t-test, $P < 0.005$ and $P = 0.036$, respectively), but no significant changes occurred

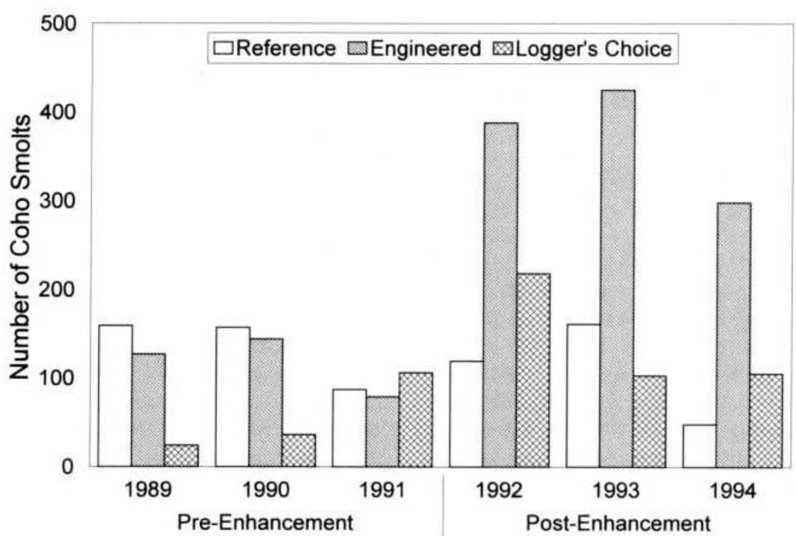

FIGURE 6.—Production of coho salmon smolts in the three study sections before (pre-enhancement) and after (post-enhancement) addition of large woody debris to the engineered and logger's choice sections.

TABLE 4.—Mean lengths of coho salmon smolts captured from 1989 through 1994 on the North Fork Porter Creek.

	Reference			Engineered			Logger's choice		
		Length (mm)			Length (mm)			Length (mm)	
Year	*N*	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
1989	144	114	8.2	113	115	8.0	24	113	6.5
1990	153	119	6.6	144	121	7.0	35	122	7.8
1991	86	121	6.7	77	120	7.5	101	122	7.2
1992	228	117	8.5	564	115	6.4	264	115	3.7
1993	372	117	6.8	436	116	8.1	125	117	6.7
1994	56	118	7.2	294	116	6.6	105	115	6.2

in emigration from the reference site or from the reach upstream of the experimental area.

The estimated number of juvenile coho salmon using the engineered site of the NFPC during winter prior to enhancement was considerably lower than the number of smolts ultimately produced (Figures 3, 6). This discrepancy likely is due to the fact that one pool in the engineered site was too deep to sample. This single pool could have contained enough juvenile coho salmon to account for the difference. After enhancement, many habitats with characteristics similar to the large pool were created. We were able to sample many of these new habitats. Thus, estimates of abundance in the engineered site likely were more accurate after enhancement, as indicated by the closer agreement with the eventual smolt numbers. Winter population and smolt yield estimates at the other two study sites were similar.

The mean lengths of coho salmon smolts were similar among the three sites for any year, but differed among years (ANOVA, $P < 0.05$; Table 4). This information may have been biased due to presmolt movements before the traps were installed, and during the temporary trap inundation of 8 May 1994.

Discharge in the NFPC ranged from less than 0.2 m^3/s during summer to more than 17.0 m^3/s during a storm in late November 1990. Peak winter discharges exceeded 10 m^3/s during the winters of 1989–1990, and 1990–1991, both preenhancement winters. Supplemental discharge data collected during the winter of 1994–1995 indicate an additional storm of magnitude greater than 10 m^3/s. Over the course of this study only three log structures moved, and this occurred during the 1990–1991 storm; four cyclone fence log aprons were scoured out of position during the 1994–1995 storm.

Winter population levels of juvenile coho salmon and age-0 steelhead were related to mean winter discharge and maximum winter discharge (Figure 7). Coho salmon populations decreased more rapidly with increasing mean winter discharge than did age-0 steelhead. However, populations of both species, at all three sites, were very low when mean winter discharges exceeded 1.5 m^3/s and when peak daily discharge exceeded 10 m^3/s. This pattern was evident both before and after enhancement.

Discussion

The proportion of stream surface represented both by pools and by LWD abundance increased following treatment of the engineered and logger's choice sites of the NFPC. The treated sites also exhibited increased coho salmon populations during winter and increased smolt yield. Juvenile coho salmon are found most commonly in deep pools during winter (Hartman 1965; Chapman and Bjornn 1969; Bustard and Narver 1975; McMahon and Hartman 1989), and those pools that contain an abundance of LWD are preferred over habitats with lesser amounts of wood (Tschapliniski and Hartman 1983; Grette 1985; Martin et al. 1986; Murphy et al. 1986). This behavior has a number of potential advantages, including conservation of energy, avoidance of predators, and protection from high current velocity during freshets. Greater availability of the type of habitat preferred by coho during winter, such as pools with abundant LWD, is the most probable cause of the response by the fish in the treated sites. We assumed that the presence of resident nonsalmonids such as sculpins and juvenile Pacific lamprey did not affect the abundance of salmonids among sections differentially.

Large woody debris abundance at our reference site also increased during our study, due to natural input from the red alder–dominated riparian stand. However, the pieces of LWD added to this section of stream were much smaller than those placed in the two treated sites (Table 2). Small pieces of wood are less likely to maintain position and have a lesser effect on channel form than larger pieces

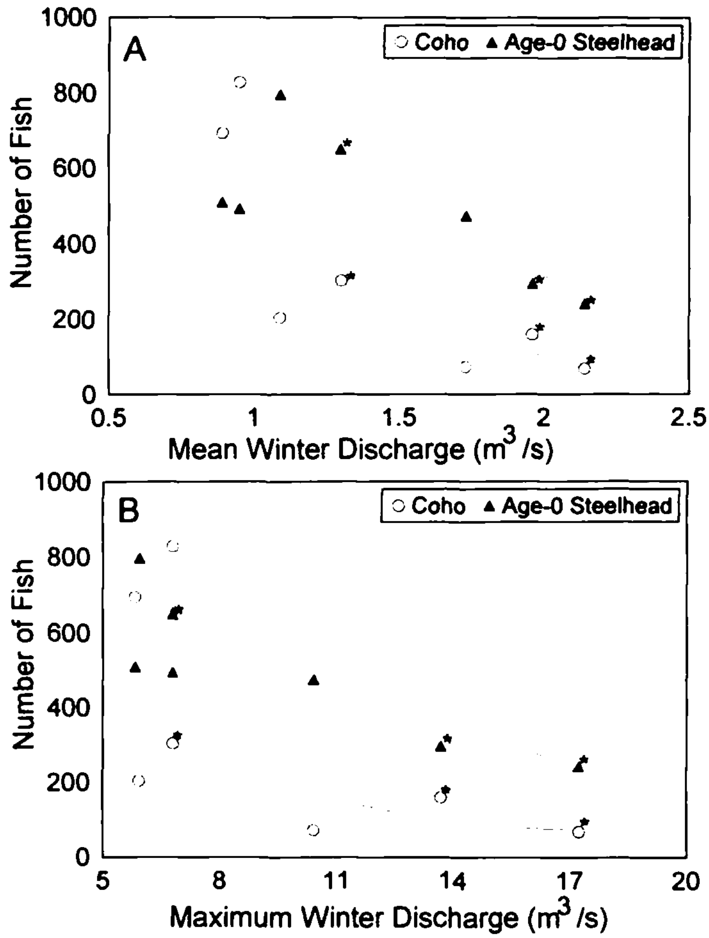

FIGURE 7.—Relationships between winter coho salmon (solid line) and age-0 steelhead (dashed line) abundance and (A) mean annual winter discharge (November–March) and (B) maximum daily winter discharge. Fish abundance values represent totals for all three study sections. Data points marked with an asterisk (*) indicate preenhancement values. Regression equations for mean winter discharge: log(number of coho salmon) = −2.48 log(mean flow) + 2.68 (r^2 = 0.79); log(number of steelhead) = −0.86 log(mean flow) + 2.78 (r^2 = 0.54). Regression equations for maximum winter discharge: log(number of coho salmon) = −1.76 log(max flow) + 4.01 (r^2 = 0.59); log(number of steelhead) = −0.87 log(max flow) + 3.49 (r^2 = 0.83). All regressions are significant ($P < 0.05$).

(Bilby and Ward 1989). Thus, despite the increase in LWD abundance at the reference site, no change in pool frequency or size and no change in fish populations were observed at that site.

The lack of response by the coho salmon population during spring and autumn suggests that availability of pools and LWD during summer were not critical in determining population levels. This same observation was reported by Grette (1985) for several small streams on Washington's Olympic Peninsula. Hartman and Scrivener (1990) found increases in juvenile coho salmon populations both in July and September at Carnation Creek soon after the input of logging debris; however, this benefit was lost after winter storms. Summer population levels, however, may not be an important determinant of smolt production for a given site. If the availability of winter habitat is very low, the capacity of the system to generate coho salmon smolts will be low, regardless of summer populations at the site (Mason 1976). The increased winter populations and smolt production we observed in response to LWD addition, with no corresponding increases in spring or autumn population levels, indicate that the availability of suitable winter habitat likely was a major limiting factor of coho salmon production in our study area.

There is the problem that more smolts were produced from the engineered and logger's choice sections than were estimated by electrofishing during the preconstruction winter period. This may be explained by the fact that the removal–summation method of fish population estimation tends to underestimate the actual size of the population (Peterson and Cederholm 1984; Thompson and Rahel 1996). Also, some atypical deep pools could not be sampled in these sections, and may have held a disproportionate number of juvenile coho salmon.

Although we observed increased coho salmon abundance in winter and increased smolt production at our enhanced sites, we cannot estimate what impact these increases had on overall coho salmon smolt production from the Porter Creek watershed. Improved habitat conditions at our enhanced sites did retain fish over the winter. However, these fish possibly could have found suitable overwinter habitat elsewhere in the watershed. Thus, improved habitat at the treated sites may not have increased smolt output from the whole watershed. However, if suitable conditions were not available elsewhere, or if these habitats were already fully occupied, improved winter habitat conditions at our study site would have added to the smolt production from Porter Creek.

Increased populations of juvenile steelhead in response to habitat enhancement of the type we conducted have been noted in other studies (House and Boehne 1985). However, we saw little response. Age-1 steelhead displayed no change in population levels during any season in any of our study sites. Age-0 steelhead did decrease significantly in spring following LWD addition to the logger's choice site. The cause of this decline could not be determined. A shift in habitat composition may have contributed, because age-0 steelhead prefer riffle habitat (Bisson et al. 1982), and this habitat type decreased in the logger's choice site (Table 3). However, no change in age-0 steelhead abundance was observed in the engineered site, in which riffle habitat was also reduced by the addition of LWD. Another possibility is that the larger number of coho salmon presmolts occupying the logger's choice site following enhancement increased predation on age-0 steelhead. The greater abundance of LWD in the engineered site may have provided adequate cover for steelhead fry to prevent increased predation, despite higher numbers of presmolt coho salmon. Regardless, the population levels of age-0 steelhead in the logger's choice site were not different from the reference or engineered sites later in the summer. Nor did abundance of age-1 steelhead differ in the following year.

Winter flow was an important factor in determining winter population levels of coho salmon and age-0 steelhead. Abundance of both species was low during winters with high average discharge or with high daily maximum discharge, both before and after enhancement. This relationship suggests that habitat enhancement efforts in the NFPC were most effective during winters of low or moderate flow, but were of little benefit during winters with elevated flows. Apparently, the pools created by LWD placement in the two treated sections did not offer sufficient protection from periods of elevated discharge.

Comparing the two approaches to enhancement on a cost-per-smolt basis requires an estimate of the longevity of the two treatments. The logger's choice site exhibited significant signs of deterioration by 1994. Many of the red alder logs added to the logger's choice site were swept to the side of the channel during the high flows in 1991 and 1994. In addition, many of these logs had decayed by 1994 and were broken by high flow and lost from the study area. We estimated that the habitat in the logger's choice site would approach the pretreatment condition within 5 years of treatment. No evidence of decay was observed in coniferous LWD added to the engineered site, and very little damage to structures was experienced by repeated exposures to elevated flows. These structures were designed to persist for 25 years or more. Harmon et al. (1986) estimated that some large pieces of old-growth conifer debris may take hundreds of years to decay. Grette (1985) estimated a longterm average of 0.5% annual loss rate of old-growth conifer debris, but a much faster rate of loss for smaller, less rot-resistant, second-growth debris. This loss is attributed to wood decay, breakage, and displacement during high flow periods. Hartman et al. (1996) wrote of the structural and habitat changes caused by the loss of LWD in streams, which occurs over a long time period, and they found a 59% reduction of LWD volume in a 70-year period.

The cost of the two methods of enhancement evaluated in this study was considerably different (Table 1). However, when considered in terms of cost per additional coho salmon smolt produced, the greater longevity of structures added to the engineered site offsets the higher initial cost (Table 5). In addition, there are insufficient numbers of trees next to the channel to sustain the logger's choice method at 5-year intervals. Therefore, any

TABLE 5.—Cost per additional coho salmon smolt of the logger's choice and engineered approaches to stream habitat enhancement. Additional number of coho smolts produced is based on the average increase observed in the two treatment sections following LWD addition.

Variable	Logger's choice	Engineered
Total cost	$6,450	$82,250
Additional smolts/year	87	253
Longevity of treatment	5 years	25 years
Additional smolts over life of the project	435	6,325
Cost/additional smolt	$14.82	$13.00

long-term benefits to coho salmon smolt production would require transport of wood to the stream, which would increase the cost and further enhance the economic advantage of the engineered approach. The logger's choice approach for adding LWD may be most appropriate where conifer trees can be felled into the channel. The large size and decay-resistance of conifererous LWD would increase longevity of the treatment and enable the added pieces to maintain position better during high flows. The increased longevity of coniferous LWD would substantially reduce the cost per additional coho calculated for our logger's choice treatment (e.g., an increase from 5 years to 10 years would reduce the cost per smolt by half).

The cost per additional coho salmon smolt for both methods of LWD addition at NFPC was relatively high. Survival rate from smolt to adult varies annually. Holtby et al. (1990) reported smolt survival rates ranging from 5% to 22% for Carnation Creek, Vancouver Island, British Columbia. In order to compare our treatments, we assumed a survival rate from smolt to adult of 10%, our engineered treatment would produce an additional 25 adult coho salmon/year and the logger's choice approach would produce 8 additional adult coho salmon/year at costs of $130 and $150/adult, respectively. However, application of these techniques in stream segments with a higher potential for increased coho smolt production than our study sites could generate more dramatic results. Juvenile coho salmon occupy low-gradient, small streams with relatively stable discharge at high densities, especially during winter (Skeesick 1970; Scarlett and Cederholm 1984; Brown 1985). Our study area had a gradient of about 2% and exhibited rapid rises in discharge in response to rainfall. Thus, the potential for increased production of coho salmon smolts at our study sites in response to LWD addition probably was limited by the nature of the system. By implementing enhancement activities where flow, gradient, and other physical characteristics of good winter coho salmon habitat exist, the increase in smolt production could be much greater than was observed in our study.

Deliberately adding LWD to streams which are deficient in this material is one aspect of an overall approach to restoring productive stream habitat in the Pacific Northwest. However, manipulation of instream habitat will not be effective if the factors which initially produced poor habitat are not addressed. We suggest a three-step process to aquatic habitat restoration. First, upslope factors that affect stream habitat should be identified and corrected. Improperly located or constructed roads that are prone to generating mass slope failures, practices which accelerate surface erosion and sediment delivery to streams, or other activities that perpetuate poor habitat conditions, should be corrected before attempting to address habitat deficiencies within stream channels.

Second, riparian areas should be managed to encourage natural maintenance of productive stream habitat. Many riparian areas in the Pacific Northwest are dominated by early successional vegetation, the product of past management actions (Bisson et al. 1997). The large conifers necessary to produce large, decay-resistant LWD are rare (Bilby and Ward 1991). Management in these areas should focus on accelerating the development of desired vegetation. However, development of riparian stands dominated by large conifer trees will take decades or centuries in many areas (Grette 1985; Bisson et al. 1987; Sedell et al. 1988; Murphy and Koski 1989; Bisson et al. 1992). Deliberate addition of LWD to streams can be used as an interim measure until the riparian forest begins to deliver adequate amounts of LWD.

Deliberate manipulation of instream habitat is the third component of our approach. However, in view of the considerable expense involved, addition of wood to channels should be limited to those areas where this material is deficient, and where there is a high probability of generating a positive response from the targeted fish species. To achieve the desired results from this type of project, involvement of both fish biologists and hydraulic engineers is essential. For those streams that still retain riparian forests in near-natural conditions, we recommend that sufficiently large areas adjacent to the channel be preserved to ensure that abundant LWD of the appropriate size and species will continue to fall into the channel.

Finally, we realize that there are some problems with this study design, and would hope future researchers could learn from our findings. First, the study sections were continuous on a single stream with downstream effects and no replication. We believed it was preferable to deal with within-stream variability rather than between-stream variability, and the high cost of additional study streams was prohibitive. Second, windthrow and floatable LWD was inadvertently added to the three study sites during the study. The reference and engineered sites debris loading caught some natural floating debris before it was able to reach the logger's choice site further downstream. The effect of this problem may have been alleviated if we had used shorter sections (e.g., 100–200 m) in a replicated, randomized-block design with buffer segments between each block. When working under field conditions, one runs the risk of many unanticipated problems; in retrospect, there are many tradeoffs between economics, statistical rigor, and other factors. We hope that others can learn and progress from our experience.

Acknowledgments

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RIVER RESEARCH AND APPLICATIONS

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JUVENILE SALMON RESPONSE TO THE PLACEMENT OF ENGINEERED LOG JAMS (ELJS) IN THE ELWHA RIVER, WASHINGTON STATE, USA

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ABSTRACT

Engineered log jams (ELJs) are increasingly being used in large rivers to create fish habitat and as an alternative to riprap for bank stabilization. However, there have been few studies that have systematically examined how juvenile salmonids utilized these structures relative to other available habitat. We examined Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*) and trout (*O. mykiss* and *O. clarki*) response to the placement of engineered log jams (ELJs) in the Elwha River, Washington State, USA. We used summer snorkel surveys and a paired control-treatment design to determine how engineered log jams in a large river system affect the density of juvenile salmon. We hypothesized that densities of juvenile salmonids would be greater in habitats with ELJs than in habitats without ELJs in the Elwha River and that this ELJ effect would vary by species and size class. Juvenile salmonid density was higher in ELJ units for all control-treatment pairs except for one pair in 2002 and one pair in 2003. Positive mean differences in juvenile salmon densities between ELJ and non-ELJ units were observed in two of 4 years for all juvenile salmon, trout greater than 100 mm and juvenile Chinook salmon. Positive mean differences occurred in one of 4 years for juvenile coho salmon and trout less than 100 mm. The results suggest that ELJs are potentially useful for restoring juvenile salmon habitat in the Elwha River, Washington State, USA. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS: stream restoration; wood placement; fish response; Pacific Northwest

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INTRODUCTION

Wood and log jams have been found to play a significant role in the ecology and morphology of streams and rivers in a wide range of climates and physiographic regions including Asia (Rikhari and Singh, 1998), Australia and New Zealand (Webb and Erskine, 2003), Europe (Piegay and Gurnell, 1997), northeastern North America (Warren and Kraft, 2003), southeastern North America (Wallerstein *et al*., 1997), southwestern North America (Haden *et al*., 1999) and northwestern North America (Abbe *et al*., 2003; Montgomery *et al*., 2003). Wood accumulations in large river systems (e.g. bankfull width greater than 30 m), and resulting geomorphic and biological effects, have been greatly reduced throughout the world over the last several thousand years (Montgomery *et al*., 2003). North American Pacific Northwest watersheds have seen wood accumulations decline over the last century since the mid to late 1800s (Collins *et al*., 2002; Montgomery *et al*., 2003). Anthropogenic effects along large rivers typically include removal of wood accumulations within a river, degradation or total removal of riparian vegetation along banks, and 'simplification' of riverbank environments by armouring streambanks with large angular rock (riprap) for the purposes of bank protection and flood control (Schmetterling *et al*., 2001). The simplification of riverbanks is a contributor to the loss of salmonid habitats throughout the Pacific Northwest, in large part due to the loss of preferred habitat characteristics related to in-channel stream cover and habitat complexity (Schmetterling *et al*., 2001; Beechie *et al*., 2005).

Over the last decade, reach-scale rehabilitation projects using ELJs have been used across the Pacific Northwest of the United States to, in part, recover complexity to channel margin habitats in large rivers (Abbe *et al*., 2002). ELJ technology is based on the premise that the manipulation of fluvial environments, whether for traditional problems in river engineering (e.g. flood control, bank protection) or for habitat restoration, is more likely to be sustainable if it is done in a way that emulates natural landscape processes (Abbe *et al*., 2002; Brooks *et al*., 2006). For example, wood accumulation from natural log jams can form 'hard points' that provide long-term forest refugia (Abbe and Montgomery, 1996). Such natural hard points create stable foundations for forest growth within a dynamic alluvial environment subject to frequent disturbance (Abbe *et al*., 2002).

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Initial attempts to construct log jams in larger streams met with mixed success. Slaney *et al*. (1994) found that most wood placed in the Nechako River was mobilized during winter flows, with the exception of log jam structures called 'debris catchers (key pieces)'. Savery (2000) found that log jams placed in the Mashel River in the Puget Sound region of Washington State did not remain over the period of one winter, thus the effects on salmonids was minimal. Thus, while these larger stream wood placement projects provided instream cover and increased juvenile salmonid densities, their lack of long-term residence could not result in any long-term potential benefits.

ELJ projects have incorporated improved engineering and construction techniques (Abbe and Montgomery 1996; Abbe *et al*., 2002; Nagayama and Nakamura, 2009). This has resulted in improved aquatic habitats and addressed traditional problems constraining habitat rehabilitation, such as bank and bridge protection, because they have remained stable despite being subjected to numerous large flow events (Abbe *et al*., 2002; Brooks *et al*., 2006; Coe *et al*., 2006). However, their longer-term biological and physical influence (e.g. greater than 3 years) has not typically been quantified (Brooks *et al*., 2006).

While the long-term biological influence of ELJs in larger river systems have not been addressed, there is ample evidence of a positive response by juvenile salmon to wood placement in the Pacific Northwest and other parts of the world (Cederholm *et al*., 1997; Inoue and Nakano, 1998; Roni and Quinn, 2001; Lehane *et al*., 2001; Miyakoshi *et al*., 2002). Slaney *et al*. (1994) reported that placement of debris catchers in the Nechako River resulted in an increase in salmonid fry densities and adult trout due to the increase in instream cover. Fish densities have been positively correlated with an increase in wood cover and complexity in larger systems, and wood cover has been found to be the most important factor influencing the distribution and abundance of juvenile coho salmon (*O. kisutch*) (Peters, 1996). Inoue and Nakano (1998) found positive correlations at habitat-unit scale between woody-debris cover area and juvenile Masu salmon (*O. masou*) densities. Significant and positive responses to constructed debris dam structures were identified in age 0+, 1+ and 2+ salmonid density and biomass 1–2 years after wood placement in Douglas River, Ireland (Lehane *et al*., 2001). Between 40 and 69% of the total variation in density and biomass was attributed to environmental variables associated with the structures such as an increase in water depth, pool habitats, and instream cover in the form of vegetation and wood (Lehane *et al*., 2001). Abundance and biomass of juvenile brown (*Salmo trutta*) and rainbow trout (*O. mykiss*) increased in the treatment compared to the control in the Muhlebach River, a tributary to the Rhine River in Liechtenstein, and was also attributed to slower velocities and more cover (Zika and Peter, 2002). Densities of juvenile masu salmon during the winter months were significantly correlated to wood cover availability in the Masuhoro River Japan (Miyakoshi *et al*., 2002).

In this study we examined the effects of ELJs on juvenile salmonid fish distribution and abundance over time in mainstem habitats of the Elwha River, a large western Washington river. We asked the general question of how do engineered log jams in a large river system affect the occurrence and density of juvenile salmonids? How do such changes in the occurrence, distribution and density of juvenile salmonids relate to changes in habitat condition? We hypothesize that the likelihood of occurrence and densities of juvenile salmonids will be greater in habitats with ELJs than in habitats without ELJs in the Elwha River. We also hypothesized that there would be differences in salmonid response as a function of species and size class. Specifically, we hypothesized that certain species such as juvenile coho, juvenile Chinook and trout less than 100 mm would respond more favourably to the constructed log jams because they have a greater preference for low velocity areas and cover, relative to trout greater than 100 mm.

STUDY AREA

The Elwha River drains a 700 km^2 watershed in the Olympic mountains of western Washington State, flowing northward into the Straight of Juan de Fuca (Figure 1). The Elwha River ecosystem falls within the Olympic Peninsula Province vegetation classification (Franklin and Dyrness, 1988). The lower Elwha falls within the western hemlock (*Tsuga heterophylla*) zone and are typically dominated by forests composed of Douglas fir (*Pseudotsuga menziesii*), mixed with western hemlock and western red cedar (*Thuja plicata*) above the floodplain. The Lower Elwha floodplain forest community are dominated by red alder (*Alnus rubra*), co-occurring with black cottonwood (*Populus balsamifera ssp. trichocarpa*), grand fir (*Abies grandis*) and bigleaf maple (*Acer macrophyllum*) in varying proportions. Currently the Lower Elwha floodplain is mixed in varying proportions of both these conifer and deciduous species.

Over 85% of the watershed is within the boundaries of Olympic National Park. Construction of two dams in the early 1900s on the Elwha River reduced accessible anadromous habitat by 90% (Pess *et al*., 2008). Downstream of the dams river sinuosity is reduced and river incision has isolated the mainstem channel from its floodplain, mainly due to the lack of sediment and wood recruitment from upstream sources (Pohl, 2004). Floodplain logging, diking and channelization have further reduced habitat complexity in the Lower Elwha below the dams by dramatically reducing wood recruitment and loading (Kloehn *et al*., 2008; Pess *et al*., 2008).

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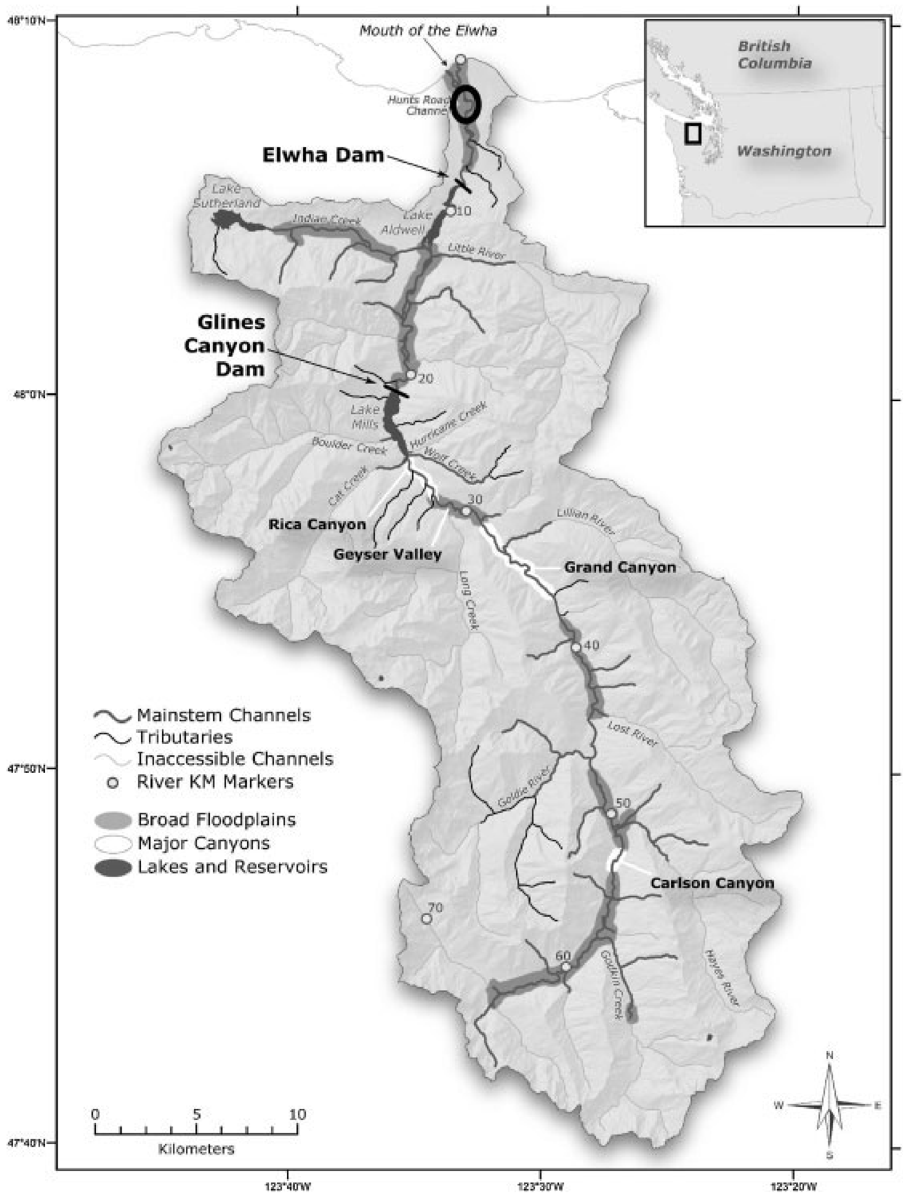

Figure 1. Map of Washington State and the Elwha River watershed. Study area is denoted by solid black circle.

The Elwha dams have altered the biological and physical characteristics of downstream reaches (Pess *et al*., 2008). Implementation of the Elwha River Ecosystem and Fisheries Restoration Act (1992) called for removal of both dams on the Elwha (DOI, 1995). Both dams are expected to be removed starting in 2011. The Elwha Klallam Tribe has initiated a large-scale restoration strategy in the lower Elwha River in order to: (1) improve current habitat conditions and (2) to 'prepare' the lower Elwha River, and its floodplain, for the significant increase in sediment supply resulting from the removal of the Elwha dams. Specifically, their goal is to re-introduce large-scale log jams in a 4.8 km long treatment reach of the lower Elwha floodplain in order to: (1) maintain existing side-channels, (2) activate new and abandoned side-channels and (3) capture wood and sediment recruited from upstream sources (McHenry *et al*., 2000). Below the dams, the Elwha River is, in general, a low gradient (slope of 0.34%), pool-riffle, meandering alluvial channel, with a cobble/gravel channel bed. Between 1999 and 2004, 21 log jams were constructed between river kilometre 2.7 and 4.0 of the lower Elwha (Figure 2). Six were constructed in 1999, two in 2000, three in 2001, five in 2002, three in 2003 and two in 2004. The log jams function by altering flow patterns through diversion, deflection or restriction, and protecting or enhancing eroding banks (McHenry *et al*., 2000).

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Figure 2. Photograph of a typical engineered log jam on the Elwha River, Washington State, USA. This figure is available in colour online at wileyonlinelibrary.com

METHODS

Study design and data collection

We collected data on juvenile fish use and fish habitat to compare habitat units with ('treatment') and without ('control') ELJs in the mainstem Elwha River (Figure 3). Seasonal fish habitat and density surveys were conducted between 2000 and 2003 in four to six habitat units with and without constructed log jams. Each unit was adjacent to a stream bank and averaged 54 m in length (±29 m), 11 m in width (±8 m) and 643 m^2 in total area (±553 m^2). Habitat unit width, length, maximum depth and minimum depth were measured for each unit. Fish habitat surveys were conducted prior to juvenile fish enumeration efforts to identify the distribution of habitat types within each reach.

Daytime summer snorkel surveys were conducted within each of the habitat units in the control (i.e. non-ELJ) and treatment (i.e. ELJ) areas (Table I). A snorkeler in a habitat unit moved upstream and counted and identified each fish seen in the unit. The number of snorkelers in each varied as a function of the size of the unit. Typically there was one snorkeler per unit, however in the larger units two to three snorkelers per unit, thus the unit was portioned equally width wise. Fish species, total count and visually estimated lengths were tallied by each snorkeler and this information was given to an individual along the bank who was watching the snorkel activity and recording the fish counts and lengths for each habitat unit observation. Species identified during the snorkel surveys included Chinook salmon (*O. tshawytscha*), coho salmon, adult pink salmon (*O. gorbuscha*), rainbow trout, cutthroat trout (*O. clarki*), bull trout (*Salvelinus confluentus*) and three-spine stickleback (*Gasterosteus aculetus*). Sculpin (*Cottus* spp.) were identified to genus during snorkel surveys; however, two species dominate in the Lower Elwha—torrent (*Cottus*

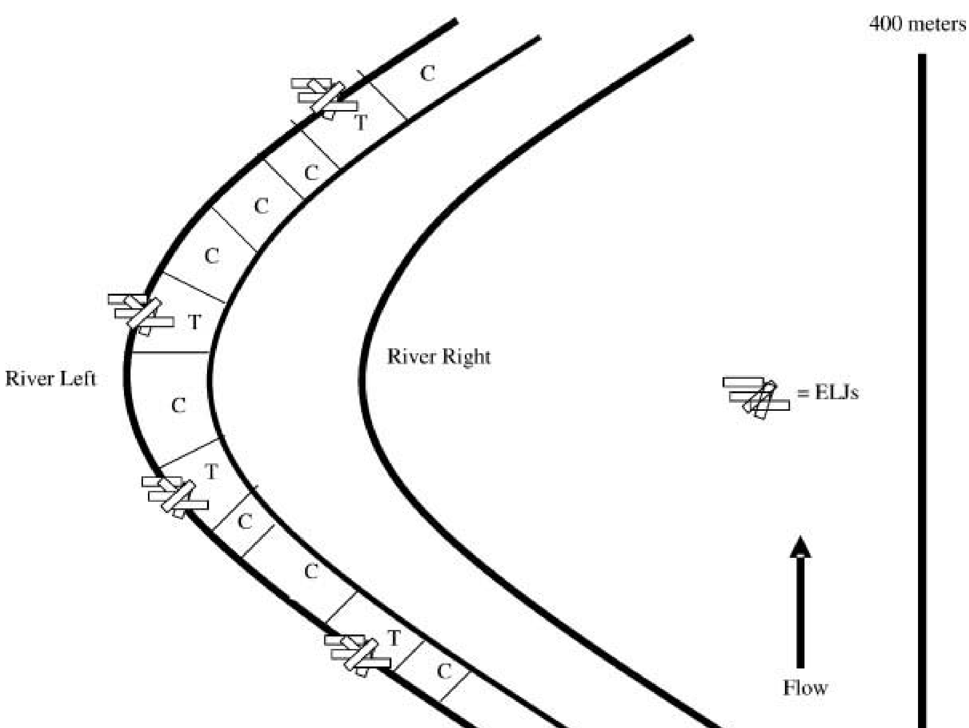

Figure 3. Schematic of ELJ placement and study design. 'T' denotes the treatment units, while 'C' denotes the control habitat units.

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Table I. Environmental conditions associated with habitat and fish surveys in the Elwha River 2000–2003

Year	Discharge during fish surveys (cm^{-3}/s)	Low flow discharge (cm^{-3}/s)	Temperature (°C)	Visibility	Number of snorkelers
2000	17.7	10.8	17	>4 m	4
2001	18.0	8.8	16	>3 m	6
2002	25.5	8.0	15	>2 m	5
2003	11.3	5.9	17	>4 m	6

rhotheus) and reticulate (*C. perlexus*) sculpin. Length categories for juvenile salmon were <50 mm, 50–100 mm, 100–200 mm and greater than 200 mm. Lengths of non-salmon species were not estimated. We calculated fish density by dividing the number of fish observed by species and size class by the area snorkelled.

Constraints related to the study design and data collection

To control unexplained spatial variation in fish densities and avoid confounding treatment effects with location, we selected a control unit for each ELJ unit. Controls were selected such that they were close to the treatment unit and were similar to the pre-treatment conditions of the treatment unit. Some control and treatment units were immediately adjacent to each other introducing the possibility of the units affecting each other through non-localized habitat effects and fish movement. However, this movement would likely decrease differences between the units, thereby producing conservative results. One of the primary goals of the restoration action was to allow juvenile salmonids greater access to what was perceived by the project proponents as higher habitat quality. Thus, the increase in fish density estimates may be a redistribution of juvenile fish. In addition, there are only 8 km of anadromous habitat below the Elwha River dams and finding a 'true' control with a buffer between the treatment and control would have resulted in examining either a slightly steeper, more confined stream reach, or a tidally influenced stream reach. Both were not viable options, because habitat differences would have resulted in larger differences in salmonid density, distribution and abundance than the potential effects of the ELJ treatment.

Engineered log jams have a pre-determined structure consisting of large key pieces anchoring a matrix of smaller wood. There was considerable space within each complex structure that cannot be viewed from the periphery of the log jam. We therefore limited sampling events to periods when flow was sufficiently low to allow snorkelers to safely venture into the log jams and view these spaces.

Snorkel surveys have been shown to be an effective sampling method for both day and night sampling (Roni and Fayram, 2000). However, sampling large river systems to estimate relative use patterns for juvenile salmonids is an inherently difficult task and has numerous limitations regardless of the method used (Beechie *et al*., 2005). In particular deep and turbid water can contribute to increased observation error for snorkel surveys (Thurow *et al*., 2006). To reduce observation error we used the same core group of experienced snorkellers for the duration of the study, limited sampling to periods of good visibility (i.e. >2 m), only focused on the bank units, which were shallower, for the analysis, and averaged counts of multiple snorkelers for units that were especially challenging (e.g. some log jams). To assess variability in counts between snorkelers, we had multiple snorkelers conduct counts in several units. We found that the between snorkeler variability (±15%) was much less that the variability between units (±80%). Large numbers of hatchery origin Chinook salmon were present in the units during our surveys. These fish were generally easy to distinguish from the wild fish based on size (hatchery fish were greater than 100 mm in length, while all wild fish were between 35 and 80 mm in length), and were recorded in a separate category.

Data analysis

The fish density data from all snorkel counts had a non-normal, over-dispersed distribution with no salmonids in over 10% of the habitat units and over 250 salmonids observed in another 10% of the habitat units. We accounted for this in our analysis by locally pairing ELJ and non-ELJ units to reduce variability due to location, applying a cube root transform to stabilize the variance of the densities, and using permutation tests which require fewer assumptions than standard parametric tests. For the permutation test we used the mean difference between treatment and control as the metric and used a one tail hypothesis (see Good, 2005 for a simple introduction to permutation tests).

The permutation test was repeated for the five species groups (Chinook, coho, trout <100 mm, trout >100 mm and juveniles), during each of the four sampling events. While we did not adjust alpha for multiple tests, the results focus only on general patterns, avoiding

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conclusions based on one or two unique results. While larger individual analyses, including more of the data, would have likely increased the power to detect effects and simplified reporting of the results, the small sample sizes, varying unit boundaries across time, and high fish variability imposed on the design by river dynamics and restoration schedules made more complex models unfeasible. Conclusions focused on patterns across multiple sampling events and species/size classes.

RESULTS

Juvenile salmonid density ranged from 0 to 2.7 fish m^{-2} with a median of 0.12 and standard deviation of 0.53 (Table II). The control and treatment medians were 0.05 and 0.25, respectively. There was a large amount of variability in densities between units by annual sampling events (Table II, Figure 4). Densities of juvenile salmonids were on average higher in ELJ units in 18 of the 20 species

Table II. Mean density (fish m^{-2}) of juvenile salmon in habitat units with and without ELJs, Elwha River 2000–2003

Chinook	Coho	Trout <100 mm	Trout >100 mm	Juveniles	Year	Control (C) or Treatment (T)	Pair
0.442	1.19	0.85	0.255	2.738	2000	T	1
0.02	0	0.029	0.003	0.052	2000	C	1
0.039	0.055	0.017	0.006	0.117	2000	T	2
0	0	0.012	0.003	0.015	2000	C	2
0.036	0.024	0.042	0.007	0.102	2000	T	3
0.005	0.02	0	0.008	0.029	2000	C	3
0.091	0.066	0.024	0.054	0.223	2000	T	4
0	0	0.005	0.007	0.013	2000	C	4
0.111	0.486	0.153	0.069	0.792	2001	T	5
0	0.041	0.306	0.001	0.348	2001	C	5
0.071	0.303	0.035	0.007	0.413	2001	T	6
0	0	0.112	0	0.112	2001	C	6
0.128	0.687	0	0	0.815	2001	T	7
0.02	0.085	0.018	0.011	0.134	2001	C	7
0.041	0.183	0.224	0.047	0.484	2001	T	8
0	0	0.083	0	0.083	2001	C	8
0.014	1	0.309	0.014	1.337	2001	T	9
0	0.177	0.052	0	0.23	2001	C	9
0	1.685	0.144	0.016	1.846	2001	T	10
0	0.003	0.252	0	0.255	2001	C	10
0.021	0	0.062	0	0.083	2002	T	11
0	0	0.038	0	0.038	2002	C	11
0.078	0	0.247	0	0.326	2002	T	12
0	0	0	0	0	2002	C	12
0.121	0	0.085	0.013	0.206	2002	T	13
0.192	0.469	0.052	0.002	0.714	2002	C	13
0.018	0	0.092	0.014	0.124	2002	T	14
0	0	0.067	0.074	0.117	2002	C	14
0.019	0.013	0.031	0	0.064	2002	T	15
0	0	0.044	0	0.044	2002	C	15
0.027	0	0.182	0.002	0.211	2002	T	16
0	0	0.052	0	0.052	2002	C	16
0.066	0	0.562	0.075	0.703	2003	T	17
0.002	0	0.007	0	0.009	2003	C	17
0	0.011	0.003	0.015	0.021	2003	T	18
0.007	0	0.064	0.012	0.082	2003	C	18
0.003	0.018	0	0.065	0.061	2003	T	19
0.035	0	0.022	0	0.057	2003	C	19
0.025	0.051	0.106	0.021	0.204	2003	T	20
0.017	0.008	0.008	0.051	0.059	2003	C	20
0	0.072	0.609	0.075	0.756	2003	T	21
0	0.003	0.009	0	0.011	2003	C	21
0.018	0	0.179	0.091	0.272	2003	T	22
0	0	0.008	0	0.009	2003	C	22

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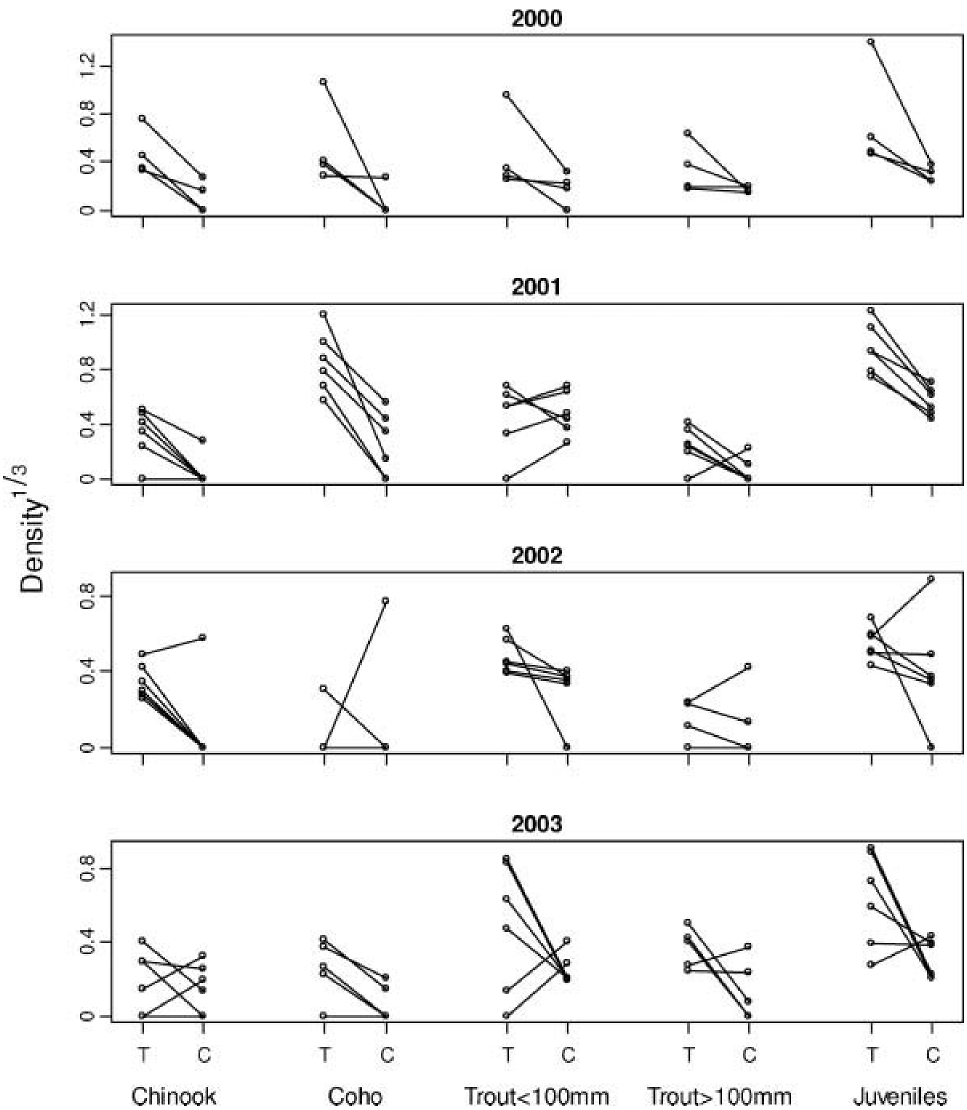

Figure 4. Density$^{1/3}$ of treatment and control habitat units by salmon species and size class (2000–2003) in the Elwha River, Washington State, USA. 'T' denotes the treatment units, while 'C' denotes the control habitat units. Lines connecting circles indicate which habitat units were paired. Multiple lines indicate more than one pairing.

group by year comparisons (Table II). These differences were significant in two of the 4 years for juvenile Chinook, trout greater than 100 mm, and all juvenile salmon, and in one of 4 years for coho salmon and trout less than 100 mm (Table III). Strongest differences by year occurred in 2001, followed by 2002 and 2003 (Table III). Differences between the ELJ and non-ELJ habitat units were also expressed in terms of juvenile salmon density$^{1/3}$ (Figure 4). Overall densities were similar in terms of magnitude; however, densities in ELJ habitat units were consistently higher than in non-ELJ units for all species, with the exception of trout less than 100 mm (Figure 4).

DISCUSSION

Examination of all juvenile salmon suggests significantly higher mean densities in habitat units with ELJs than habitat units without ELJs in the Elwha River, with patterns varying by species and year (Tables II and III, Figure 4). Other studies have shown similar patterns of higher densities of juvenile salmon associated with wood accumulations due to a combination of low-velocity microhabitats and associated overhead cover (Shirvell, 1994; Roni and Quinn, 2001; Beechie *et al*., 2005). ELJs allow for the convergence and divergence of flow in and around the obstructions resulting in an increase in slower water habitats adjacent

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Table III. Mean density (fish m^{-2}) difference between habitat units with (treatment) and without (control) ELJs by salmon species and size class in the Elwha River, Washington State, USA 2000–2003

Year	Sample Size	Chinook	Coho	Trout < 100mm	Trout > 100mm	Juveniles
2000	4	0.146 (0.06)	0.329 (0.06)	0.222 (0.06)	0.075 (0.13)	0.768 (0.06)
2001	6	0.058 (0.03)	0.673 (0.02)	0.007 (0.63)	0.024 (0.05)	0.754 (0.02)
2002	6	0.019 (0.03)	−0.074 (0.75)	0.080 (0.02)	−0.008 (0.50)	0.020 (0.17)
2003	6	0.010 (0.34)	0.023 (0.06)	0.236 (0.11)	0.053 (0.05)	0.317 (0.05)

Permutation test *p*-values are in parentheses.

to faster water habitats, and the potential use of wood as in-channel cover (Brooks *et al*., 2006). As with previous studies, the pattern of use we found varied by species, size class and year.

Juvenile Chinook consistently exhibited significantly higher densities in habitat units with ELJs in two of the 4 years of sampling (Table III). Smaller Chinook juveniles, particularly ocean-type, the majority of Elwha River Chinook, typically occupy low-velocity habitats with a variety of cover types (Healey, 1991; Beechie *et al*., 2005). Juvenile coho salmon also exhibited consistently higher densities and use in habitat units with ELJs (Figure 4). Coho fry also tend to occupy low-velocity habitats in the summer and winter months, and exhibit a greater preference towards complex cover such as wood accumulations (Roni and Quinn, 2001; Giannico, 2000; Beechie *et al*., 2005).

Trout densities and utilization of habitats with ELJs varied by size class in the Elwha River. Trout greater than 100 mm showed greater affinity to habitat units with ELJs, both in significance level and densities than trout less than 100 mm. Previous research also suggests that *O. mykiss* are typically associated with a broader range of velocities and cover types, and are particularly associated with cobble-boulder cover types (Beechie *et al*., 2005). In addition, the combination of low velocity areas with overhead cover adjacent to higher velocity areas can create rearing space next to feeding opportunities for larger trout (Hughes and Dill, 1990; Lima and Dill, 1990).

Cover in general, and complex wood cover in habitat units has been shown to increase juvenile salmonid densities (Gowan and Fausch, 1996; Peters, 1996; Beechie *et al*., 2005). Beechie *et al*. (2005) found age-0 coho, age-0 steelhead and age-1 or older steelhead selecting banks with the most complex wood cover. Peters (1996) found a similar pattern for these and other salmonids including juvenile Chinook. Complex cover also provides visual isolation for salmonids, protects them from visual predators, reduces antagonistic interactions with conspecifics, and can decrease territorial needs (Imre *et al*., 2002). All of these attributes are particularly important during low flow periods such as the summer. The combination of lower velocity areas, deeper habitat units and complex wood cover all contribute to the change in juvenile salmon densities and suggest that ELJs are potentially useful for restoring juvenile salmon habitat in the Elwha River.

One trend that is apparent is the decline in the difference between the control and treatment sites over time (Table III and Figure 4). The decline in mean density difference between the treatment and control habitat units is similar to what other studies have found with respect to smaller streams, where decreases in salmonid density effect size decreased after 2 years (Whiteway *et al*., 2010). One main hypothesis that has been put forth is that in-stream structures eventually fail and do not support the long-term utilization of these habitats (Frissell and Nawa, 1992; Thompson, 2006; Whiteway *et al*., 2010). However, it is important to note that many of these in-stream structures have not been monitored over an adequate time period to report the overall stability of the structures as well as the accompanying fish use associated with them (Whiteway *et al*., 2010).

The ELJs in the Elwha River have been monitored for their physical stability over the same time period as the fish surveys and have proved to be stable with little significant change in position or surface area noted despite frequent inundation from floods including two peak floods that rank within the top 10% of floods recorded for over 100 years of record (McHenry *et al*., 2007, report to Salmon Recovery Funding Board). In addition pool development occurred rapidly around the constructed ELJs, with 95% of the ELJs built since 2000 developing scour pools, the deepest of which has a maximum depth exceeding 5 m, and pool surface area increasing from 15% to 48% (McHenry *et al*., 2007, report to Salmon Recovery Funding Board). The ELJs also had a significant effect on sediment storage within the project reach where a 60% increase in the amount of sediment stored in gravel bars occurred from 2000 to 2004 (McHenry *et al*., 2007, report to Salmon Recovery Funding Board). Associated with these changes we also observed a significant reduction in bed substrate grain size in the vicinity of several ELJs, with the mean particle size changing from large cobble to gravel (McHenry *et al*., 2007, report to Salmon Recovery Funding Board).

So why is the inter-annual variation in mean juvenile salmonid density so great? We hypothesize that there are

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several factors which affect the results including variation in annual adult salmon returns, differences in summer low flows and the increasing number of other ELJs constructed in the Elwha during the study period. The annual number of returning adult Chinook salmon spawning in the Elwha ranged between 655 and 1045 (Washington Department of Fish and Wildlife, unpublished data) and increased each year, which could result in a larger number of juvenile Chinook salmon, and more utilization of 'less preferential' habitats, in this case being the control habitat units. No estimated number of adult steelhead or coho salmon spawners is available to describe trends in their adult population abundance. Low flows could either concentrate juvenile salmonids in areas associated with the ELJs, or result in areas of the ELJs not being watered and thus reduced the use of the treatment habitat units. The number of ELJs in the Elwha increased from a total of 8 in 2000 to 19 by 2003, an increase of almost 3 per year (McHenry *et al.*, 2007, report to Salmon Recovery Funding Board). The increase in the number of ELJs beyond the study reach can also result in a dispersion of juvenile salmonids, which could also have an effect on the juvenile densities of salmonids found over time in the study reach. Our dataset is limited to only 4 years and is ultimately incomplete to quantify the effects of each potential variable but all of the preceding variables have been shown by others to affect the density of juvenile salmonids (Roni and Quinn, 2001; Niemelä *et al.*, 2005).

In conclusion the consistent positive mean differences in juvenile salmon densities between ELJ and non-ELJ units that were observed in two of four years for all juvenile salmon suggest that ELJs are potentially useful for restoring juvenile salmon habitat in the Elwha River, Washington State, USA. These results are consistent with other studies that suggest in-stream restoration projects can improve salmonid density, and is an important 'temporary tool' while larger scale more process-based watershed restoration actions are implemented (Roper *et al.*, 1997; Roni *et al.*, 2002; Whiteway *et al.*, 2010). The large-scale restorative action that will occur in the near-term in the Elwha basin is the removal of two large impassable dams that will open over 70 km of the historically available anadromous salmonid habitat (Pess *et al.*, 2008).

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