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Build it and they will come; a cost-effective analysis of salmon habitat restoration techniques in the Pacific Northwest.

by

Patricia Sun Garcia

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Patricia Sun Garcia

has been approved for
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Tom Rainey, PhD
Member of the Faculty

Date

ABSTRACT

Build it and they will come; a cost-effective analysis of salmon habitat restoration techniques in the Pacific Northwest.

Patricia Sun Garcia

Pacific salmon species are listed under the Endangered Species Act (ESA) in western Oregon and Washington state. Recovery efforts for the five listed species include various restoration techniques such as the input of large woody debris (LWD) into streams and the creation of artificial side channels in old oxbows and river meanders. Millions of dollars are spent annually creating or enhancing habitat for salmonids and other fish species. Much of these projects vary in cost and size. A cost effective analysis of LWD and side channels was conducted to assess which project type is most economical. The analysis revealed LWD as more cost effective than side channels over time. Fish densities were used as a metric of responsiveness to treatment, and plotted over time against annual expenditures. While both restoration types demonstrated increased fish density soon after implementation of treatment, over time, density values decreased considerably as annual expenditures increased over time. No significant relationship was detected in the percent change of fish density for both LWD or side channels. This study recommends that restoration projects take into consideration the measurable variables with future cost effectiveness analysis in mind before implementation, and prioritizing and identifying key actions and measures of restoration effectiveness before allocating precious and limited funding dollars.

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Chapter 1. Overall Introduction

Pacific salmon (*Oncorhynchus spp.*) are an economic mainstay and a cultural icon of the Pacific Northwest. For centuries, the revered fish has sustained the indigenous people and settlers, and the abundant flora and wildlife in the region. In 2001, the National Marine Fisheries Service (NMFS) listed several species of Pacific salmon as threatened and endangered in Washington and Oregon states. The listing of the Pacific salmon falls under the United States Endangered Species Act (ESA). In Washington state alone, there are at least twenty listed stocks including Puget Sound chinook, Hood Canal chum and Coastal coho salmon.

The listing of salmon has not come without its controversies. The populations of Pacific salmon (chinook, chum, and coho to name a few), especially the wild stocks of chinook salmon in Puget Sound, have been diminishing significantly for the last three decades. Federal and state agencies, private, tribal and non-profit groups have tried to address the issue with hatchery supplementation and broodstock programs. The result of the listing is a final acknowledgement that despite much of the efforts to address the low numbers, recovery of the Pacific Northwest's salmon populations are at a point of decline, perhaps facing extinction.

Human activities have destroyed habitat and is one of the main factors causing the decline of Pacific salmon. Floodplains of rivers are important geographic areas for side-channels, which provides critical rearing and overwintering habitat for juvenile salmon

(Peterson 1982a, 1982b; Scarlett and Cederholm 1984; Brown and Hartman 1988; Nickelson et al. 1992a, 1992b). Restoration of stream, riparian, and estuarine habitats is a priority for state, tribal and federal government agencies, and for non-profit groups attempting to recover listed salmon stocks.

Millions of dollars are being spent annually in the PNW in order to create or enhance habitat for salmonids and other fish species. The Salmon Recovery Funding Board (SRFB), an organization in charge of allocation of restoration funding in Washington, has allocated upwards to 477 million dollars to over 1700 projects aimed at habitat restoration and recovery (SRFB 2011)). Large portions of these funds have been distributed to local government agencies and watershed community groups.

While diminished or altered habitat may be one of the major factors for salmonid species decline, other activities have contributed to the decline of the species. Dams, recreational and commercial fisheries, and hatcheries have all been implicated and extensively evaluated. Collectively known as the “4 H’s”, habitat, hydroelectricity, harvest and hatchery are main focal points attributed to the gradual decline in the last century (Nehlsen et al. 1991).

Hydroelectrical power, the by-product of the dams, affect the migration of juvenile and adult salmon. There are over 2000 man made structures in Washington state alone. Four of the most contentious, Ice Harbor, Lower Monumental, Little Goose, and the Lower Granite impede passage on the Snake river a major tributary of the Columbia river, once known as the largest and most productive salmon runs in the world. While the dams provide cheap power and electricity for much of the PNW and California, it has come at a considerable cost economically and environmentally, especially for Indian tribes that once fished areas now flooded by reservoirs.

Management of harvest has almost exclusively been at the state level. Commercial and recreational fisheries are managed yearly based upon forecasting escapement and return of fish runs from each system. Though managed jointly, the relationship of commercial and recreational fishers remains contentious with poor fish returns and numbers. The local tribes address their own fishery and harvest requirements separate from the state as sovereign nations based on their treaty rights.

Hatcheries, which are managed by the tribes and the state, and receive aid from private and local organizations, enhance harvest. Hatchery supplementation programs were once considered the premier technology for producing fish for the rivers. This has fallen out of favor as artificial propagation of a species leads hatchery fish out-competing wild fish for habitat and food. Years of selection bias by hatchery managers have produced stocks with certain phenotypes versus their wild counterparts. This selection provides smolts an advantage for survival during outmigration to the ocean waters. Hatchery fish are larger and more aggressive than their wild cousins.

Focus has been on habitat restoration as a primary means of addressing fish recovery; specifically, the restoration of spawning and rearing habitat on rivers, channels, sloughs and off-channel areas (Cederholm & Scarlett 1988, Cederholm et al. 1991, Lister and Finnigan 1997; Morley et al. 2005, Roni 2001, Roni et al. 2002). Funding for environmental projects are under more scrutiny by the general public and legislature during economically lean years. Budget cuts to state agencies reduce funding sources, which diminish resource dollars to local groups attempting restoration or habitat improvements. Limited resources make it more difficult to protect habitat and lands by purchasing and/or restricting use altogether. Restoration presents more possibilities for forming partnerships with nonprofits, state agencies and local watershed parties involved in improving fish habitat. These improvements include replacing culverts and improving fish passage to key habitat areas. Unlikely allies and cooperation minimize the impact of government oversight and regulation and much perceived infringement on private owners and lands, as well as reduce the potential for lawsuits.

Restoration of fish habitat for stock recovery may be the only acceptable remedy available that is easily applicable as other attempts, i.e. hatcheries, harvest management or dam removal, have produced inadequate results or have been economically unfeasible. While research studies (Beechie et al Cederholm et al. 1991, Morley et al. 2005, Roni et al. 2001, Roni et al. 2006,) demonstrate limited positive trends with habitat restoration, its benefits economically, politically and scientifically are more likely than a controversial removal of a large dam or strict regulation. Restoration of fish habitat is certainly more cost effective when juxtaposed against dam removal, providing a much cheaper alternative for attaining recovery goals. Additionally, restoration measures in an attempt for species recovery, is mandated under the Endangered Species Act (ESA) in addition to federal regulations such as the Clean Water Act (CWA) (Beechie et al 2008).

There is a paucity of data overall on the effectiveness of various habitat restoration techniques or how or where to implement restoration projects (Reeves et al. 1991; Frissell and Nawa 1992; Beschta et al. 1994; Chapman 1996). The effectiveness and success of restoration efforts have been evaluated by research fisheries scientists, (Beechie el al. 2008, Beschta et al. 1994, Chapman 1996, Everest et al. 1991, Frisell and Nawa 1992, Pess et al. 2005, Reeves et al. 1991, Roni et al. 2006, Roni el al. 2010), and follow-up monitoring for fish usage is increasing (SRFB Report 2008). Many researchers dedicated to the study of salmon recovery view this as an opportunity at examining a trend that looks towards recovery of a listed species under the ESA.

Economic analyses for the restoration of salmonid habitats remain limited (Beschta et al. 1994, Cederholm et al. 1988, 1997; Cederholm and Scarlett, 1991; Everest et al. 1991; Roni et al 2006, Roni et al. 2010). Assessing economic efficiency of the options available in habitat restoration is difficult. Placing an economic value on fisheries is problematic as valuation can be very subjective, difficult to quantify and influenced by economic climate and priority (Plummer 2005). Additionally, salmon are not just commodities, but a cultural icon in the PNW. There is great difficulty placing a monetary value on cultural symbols. Most, if not all cost-effective analyses are generally limited to health care, national defense issues, business and economics and education (Boardman et al. 1996; Levin and McEwan 2001). Most economic analyses of salmonids have focused on harvest, fisheries allocation and recreational values of sport fishing such as willingness to pay (WTP) rather than habitat restoration (Changeaux et al. 2010, Haisfield et al 2010, Homelund and Hammer 1999; Plummer 2005, Postel and Carpenter 1997).

Successful restoration projects are difficult to define and the variables used as metrics of success can be a varied depending on the overall goal i.e increased fish numbers, fish usage, and access to critical habitat (Plummer 2005, Roni 2002, Roni et al. 2006, Roni et al. 2010). Successful projects have found increased population counts of trout fry, improved rearing habitat for coho salmon and a more diverse benthic community in stream waters (Morley et al 2005, Roni et al 2006, Pess et al. 2005). For instance, Morley (et al) found increase fish usage and density in side channel areas and ponds after construction of these areas. Total smolt numbers provide the measure for quantifying the success of the project. Roni (et al) measured smolt size in relation to habitat and project types. Both projects found beneficial increases in areas important for salmonid propagation and survival.

Habitat restoration efforts and stream restoration

Restoration efforts up until recently have been limited to a few methods and techniques such as shoreline plantings, large wood placement (also known as large woody debris (LWD)), gravel placement and enhancement, and culvert replacement. Enhancement or restoration in various forms has been occurring for more than 50 years in North America (Roni 2001). For instance, the addition of large wood pieces or boulders and rocks to streambeds has been practiced at least since the 1930s (Roni 2001). Newer methods are now employed; the techniques ranging from a variety of methods including the addition of woody debris to streams, to the creation of artificial channels in areas where old river channel meanders once existed.

Gore (1985); Koski (1992); and the National Research Council (NRC) (1992) define restoration as returning an ecosystem or habitat to its predisturbed state. Restoration can be defined as the reestablishment of the structure, functions, and natural diversity of an area that has been altered from its natural state (Cairns 1988; National Research Council [NRC] 1992). However, the two techniques described in this thesis, commonly referred as restoration, are actually enhancements or improvements and habitat creation. Enhancement usually encompasses placement of boulders, wood or gravel into a given area and creation introduces additional habitat where it no longer exists or has long been removed from the natural regime and process. Both typically are considered enhancement techniques as existing conditions are supplemented rather than restored to its predisturbed or original state. The two terms have caused some confusion and are used interchangeably, but for these purposes, restoration is used as a general term to describe habitat improvements.

There are generally six types of restoration techniques currently employed by restoration groups and government agencies. These are the following: 1) the reconnection of old habitats such as sloughs, ponds and channels with the active stream channel, 2) riparian restoration involving replacing riparian vegetation with conifers, 3) road removal or improvement, 4) instream restoration such as the placement of wood and/or structures, 5) nutrient additions of inorganic materials or salmon carcasses, and 6) habitat creation and excavation of new channels and wetlands (Morley 2005, Roni et al. 2002, Roni et al. 2006). These techniques usually focus on repairing or augmenting specific habitat structural features instead of addressing restoration of whole complete watershed processes. Additionally, restoration is easier to implement and pursue on public lands. Private areas require greater coordination, effort and negotiation.

Most restoration efforts are on a "reach scale", a discontinuous rather than contiguous scale that connects and sustains existing habitats and the ecosystem. The projects overall are interrupted patchworks along select riparian corridors in various watersheds that cross various state and local jurisdictions. Restoration efforts thus are scaled down due to the complications of land ownership, legalities or limited funding and time restraints. Many restoration techniques have varied lifespans and fish response, (Beechie et al. 2005, Polack et al. 2005, Roni et al. 2002). For instance, LWD in waterways remain much longer in the ecosystem if coniferous species such as pine and cedar are utilized versus the deciduous species (big leaf maple, alder). Biological breakdown by microbes is sustained over longer time periods (months versus years), providing a more sustainable nutrient resource for benthic invertebrates, and smolts that rely on these as a food source (Naiman and Bilby 1998). Various restoration projects are species specific such as the creation of new off-channel areas for coho salmon (*O. kisutch*) (Gianico and Hinch 2003, Morley et al 2005, Roni et al 2006b) and benefit only that species at the expense of other fishes such as trout (Plummer 2005, Morley et al. 2005, Roni et al. 2006).

This thesis will focus on the cost effectiveness of two particular restoration methods, notably the addition of large woody debris and the creation of artificial stream channels. Various agencies use these two restoration techniques in regions along the rivers known as off-channel areas or habitats (Cederholm et al 1988, Nichelson et al 1992b, Norman 1998, Peterson et al 1983, Paulin & Associates 1991, Swales et al 1989, Bonnel 1991, Sheny et al 1990, House et al 1988, Cowan et al 1995).

Chapter 2. Detail of Restoration Types and Methods

Off-channel Background

Off channel areas are naturally found within a geological floodplain of a river. These areas can be defined as riparian or forested wetlands (Mitsch and Gosselink, 2000), or interfaces between terrestrial and aquatic systems with distinct environmental and community processes (Naiman and Bilby, 1998 and 2001). Riparian ecosystems have distinct vegetation and soil characteristics and are found whenever streams or rivers occasionally flood beyond their channel confines (Mitsch and Gosselink, 2000).

Three major features distinguish these riparian areas from other ecosystem types. These systems have linear form due to the proximity to the streams and rivers, energy and matter that passes through the system occurs in much larger amounts as a result of being an open system, and they are functionally connected to upstream and downstream ecosystems as well as upland and aquatic systems (Mitsch and Gosselink, 2000). This concept and its complement the River Continuum Concept (Vannote et al. 1980 from Naiman and Bilby 1998 and 2001) regards river systems as continuous gradients of physical conditions and associated processes with recognizable patterns in community structure and organic matter and energy (Naiman and Bilby 1998 and 2001).

Decades of anthropogenic disturbance such as urbanization, timber harvest, stream cleaning, agricultural use and diking, flood control, road building, gravel mining, livestock grazing and ranching has contributed to the degradation of these habitats. Increased pressures from commercial and recreational fisheries too have contributed to the steady decline of many salmon stocks. Prior to European settlement, the Skagit River and many of its tributaries, for example, were allowed to meander across its floodplain creating new side-channels and oxbows (Beechie et al. 1994). The simplification of physical habitat in rivers along with the channelization and diking of the larger streams and rivers for commercial and human interests has contributed to the loss of many of these off-channel habitats (Beechie et al. 1994). Tim Beechie (et al.), a research fish scientist with NOAA Fisheries estimated a loss of greater than 50 percent of these areas in the Skagit basin of Washington, and Thomas Nickelson (et al.), retired Oregon Department of Fish and Wildlife biologist (1992b) demonstrated that less than one percent in area for off-channel habitats exist now in parts of Oregon.

These off-channel areas, such as sloughs, oxbows, alcoves, wall-based channels, ponds, wetlands and other permanently and seasonally flooded areas are recognized as important rearing habitat for juvenile salmonids (Peterson 1982, Cederholm and Scarlett 1984, Swales and Levins 1989) after extensive years of research and observation by fisheries experts. These off-channel areas are some of the most critical anadromous fish production areas in the Pacific Northwest (Doyle 1984). These areas are a focal point of many of the restoration efforts since the listing of several stocks in Washington and Oregon. Current research has concentrated on off-channel habitats as important rearing areas for juvenile coho salmon (*Oncorynchus kisutch*) and coastal cutthroat trout (*O. clarki clarki*). Tim Beechie (et al.) (1994) found that loss of these habitat areas is the largest factor limiting coho smolt production in the Skagit Basin, Washington. Off-channel habitats have been restored or created using various techniques such as blast pools (Cederholm and Scarlett 1991), excavation (Koning and Keeley 1997), reconnecting or connecting isolated wetlands and ponds (Richards et al. 1992), alcoves or small-excavated ponds adjacent to the main channel (Johnson et al. 1994).

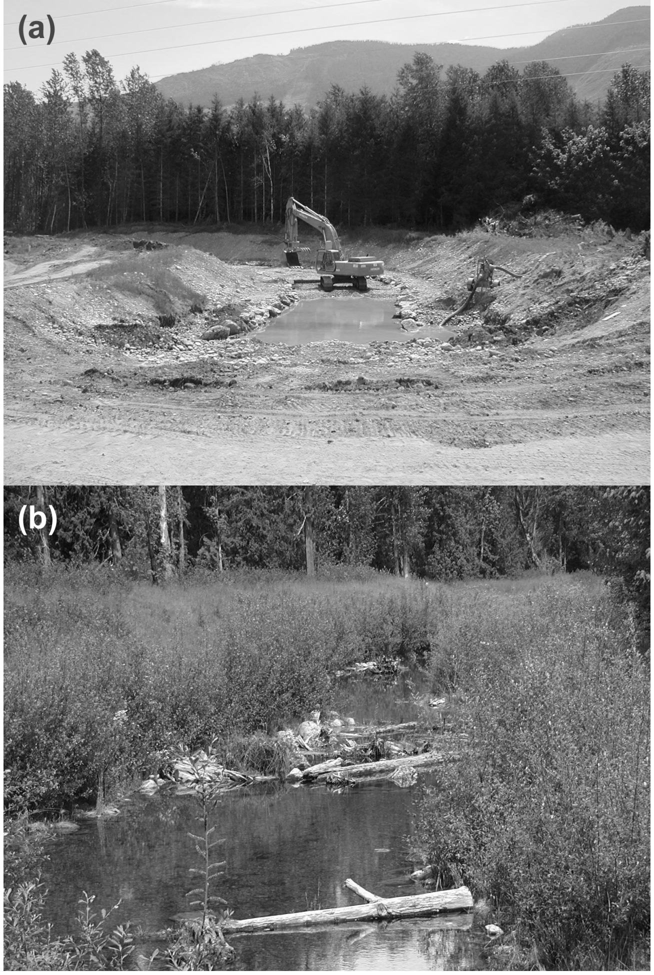
The role of off-channel areas as habitats for juvenile coho salmon has been well documented by fisheries researchers such as D.R. Bustard and D.W. Narver 1975, Phil Peterson 1982, Si Simenstad 1982, S. Swales and C. Levings 1989, B. Ward 1996, Jeff Cederholm and Warren Scarlett 1982, and Phil Peterson and L. Reid 1984. Warren Scarlett and Jeff Cederholm, salmon biologists for the Washington State Department of Natural Resources (1988) reported utilization of off-channel areas during fall and winter along Washington coastal rivers. Juvenile fish migrate into these areas seeking refuge from high waters where they feed and grow until the following spring season for migration to the ocean. This provides optimal opportunity for growth and protection from predation, and moderated hydrologic and temperature regimes increasing the likelihood of survival. Studies have shown that overwintering in the off-channel areas increases smolt survival (Bustard and Narver 1975, Groot and Margolis 1991, Peterson 1982a and 1982b).

While juvenile coho salmon utilize off-channel areas during fall and winter for rearing, adult salmon utilize these areas for reproduction. Salmonids are semelparous, reproducing only once after returning from the ocean. The adults use the mainstem river and the smaller tributaries for spawning, building redds to deposit eggs and then dying after mating (Groot and Margolis 1991). The young alevins hatch in the interstitial spaces of the gravel beds growing until strong enough to rear and feed in larger portions of the river and the off-channel areas (Cederholm et al. 1988) preparing them for migration as smolts to the sea (Groot and Margolis 1991, Holtby et al. 1990, Nickelson et al. 1992, NRC 1996, Peterson 1982, Simenstad et al. 1982, Swales and Levings 1989).

Creation of Side Channels

Creation or excavation of artificial habitats involves building new off-channel areas such as side-channels, connected ponds and sloughs and other wetland areas for fish utilization. The most common technique is the excavation of side-channels with large construction equipment (Figure 1).

Figure 1. Construction of Illabot artificial side channel (a) before (b) after (Morley et al. 2005)



This method is often used by state agencies that have greater resource dollars. The new habitat is constructed adjacent to the mainstem river or stream channel that also serves as the inlet/outlet access. Channels are carved into areas with existing groundwater upwelling and reinforced with large boulder or riprap banks. Gravel substrate and riparian plantings are added along with wood debris structures that have been attached with wire cable to withstand seasonal flood events. These artificial channels act as old oxbows, sloughs and meandering side-channels that would have developed over the natural course of the river. Groundwater presence and old swales are most sought after for design consideration, as they seem to produce thermal and hydraulic regularity. Research by Everest (et al.) indicates that groundwater areas have regular temperature regimes in comparison to the mainstem river and other investigations by researchers support this observation (Morley et al. 2005).

Instream Restoration

Instream restoration, specifically, the placement of large woody debris (LWD) involves the placement of wood debris, log structures or logjams, root wads with short sections of trunk, and root wads within the active stream channel (Figure 2). LWD is sized usually greater than 10 cm in diameter and 2 m in length and coniferous to assure stability and long-term function (Slaney and Zaldokas, 1997). Conifers are preferred over the more readily available deciduous species due to its longevity in water (Naiman and Bilby 1999 and 2000) and greater size. Wood is placed into streams to create habitat and enhance the biota itself or is used in conjunction with other restoration techniques such as the creation of artificial channels or the reconnection of old habitats.

Figure 2. Instream restoration with LWD

In the early part of the century, upland areas with low gradient tributaries provided optimal spawning and rearing habitat for coho salmon (*O. kisutch*) (Beechie et al. 1994). Logging and stream cleaning, in addition to other factors, have contributed to the reduction of important geomorphic components on floodplain areas. Structural elements assist in the creation of microhabitats such as pools and riffles, adding to the complexity of the stream channel (Beechie and Sibley 1997, Sedell et al. 1990 and 1994). The alteration of these natural processes and habitats has had a profound effect on the Pacific Northwest's anadromous salmonid species (Beechie and Sibley 1997).

The addition of deflector logs, weirs, root wads with tree trunks and cover logs are some design features for LWD placement. Key pieces are strategically placed to influence geomorphic changes hydraulically and physically in the stream channel (Cederholm et al. 1997, Roni et al. 2001, Sedell et al. 1984, Slaney and Zaldokas 1997). Artificial wood placement mimics biological processes removed from the naturally occurring regime. These placements are artificial in nature due to the deliberate input of wood pieces into streams. Whereas, naturally wood entered streams from events such as windthrow, decay, beaver, and flood events (Naiman and Bilbly 1998 and 2001, Sedell et al. 1984), the artificial placements attempt to recreate and supplement these lost inputs from the system.

Pacific salmon are endemic to Washington, Oregon, Idaho, Alaska, California and Canada. This thesis is an analysis of fish data collected over several years from Oregon and Washington states. The two geographic areas were chosen for the specific restoration techniques implemented in each project (wood inputs and channel creation). The Washington state data encompasses artificially constructed channels whereas the Oregon data set is of large woody debris placement into various stream channels.

The two restoration methods differ in several aspects, which includes monetary specifics. The construction of large channels is labor intensive and requires large overhead capital such as heavy construction equipment and trained operators. Wood placement is limited to materials cost such as tree stumps and slash lumber, often a by-product of commercial logging. The former requires considerable detailed forethought and planning for creating a waterway that is either nonexistent or isolated from the mainstem. The goal is to mimic a similar habitat that salmonids find suitable for rearing and overwintering. The latter is limited in that additional biological inputs are only the primary goal for habitat restoration. In order to assess the feasibility of the two different techniques, a cost analysis associated with each method is prudent, especially if funding is somehow limited or restricted.

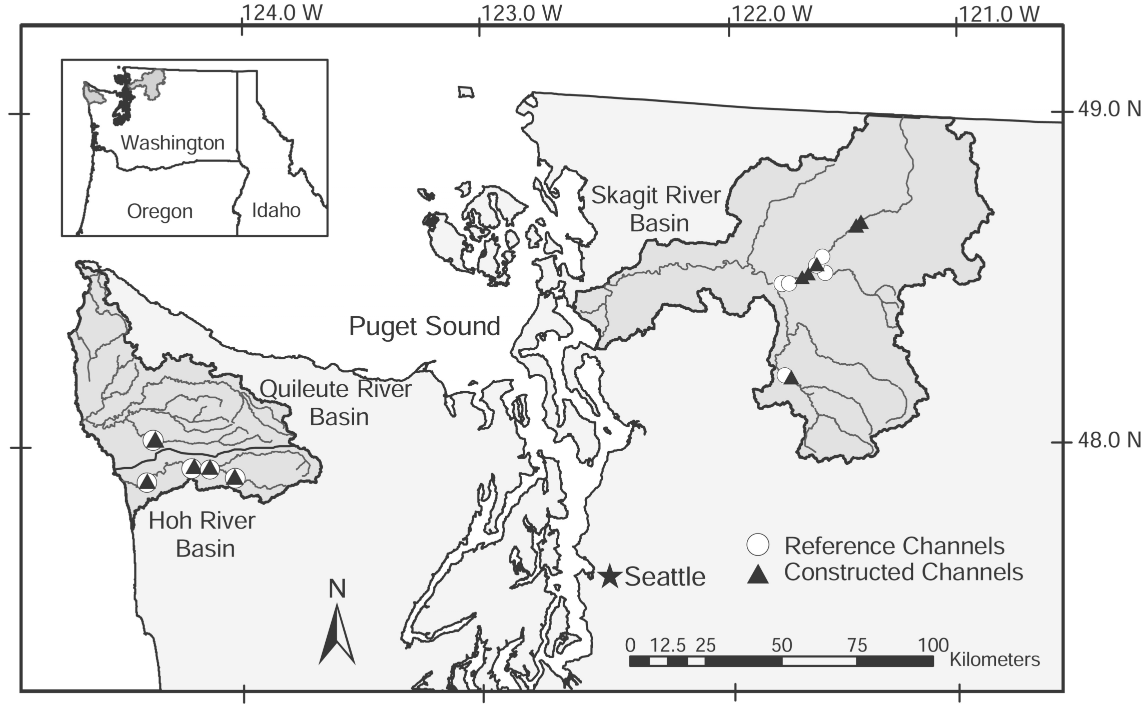
Cost assessments can be problematic and difficult. It is difficult to measure biological or environmental variables under a common metric as each project often measures success or failure differently based on biological response. Project success is often quantified by biological metrics such as fish production or increase of smolts, fish abundance or growth parameters (Plummer 2005).

Chapter 3. Methods

Data and Study Areas

The study areas are located in several watersheds and river basins throughout western Washington and Oregon. I obtained the cost data of the side channels from the Washington Department of Fish and Wildlife (WDFW) biologist Chris Detrick. These sites were constructed over the last two decades in the Skagit, Hoh and Quillayute River basins. I collected the juvenile smolt numbers by snorkeling and electrofishing with Sarah Morley, Research Fisheries Biologist of NOAA Fisheries Watershed Program for our study of fish utilization of the side channel areas during the years 2001 to 2003. The headwaters of these river systems are located in the forested mountain regions of the North Cascades and Olympic mountains. These lands are managed for park wilderness, recreation and commercial logging, while land use in the lowland regions is composed of mixed commercial forestry, hobby farms and rural low-density housing (Morley et al 2005).

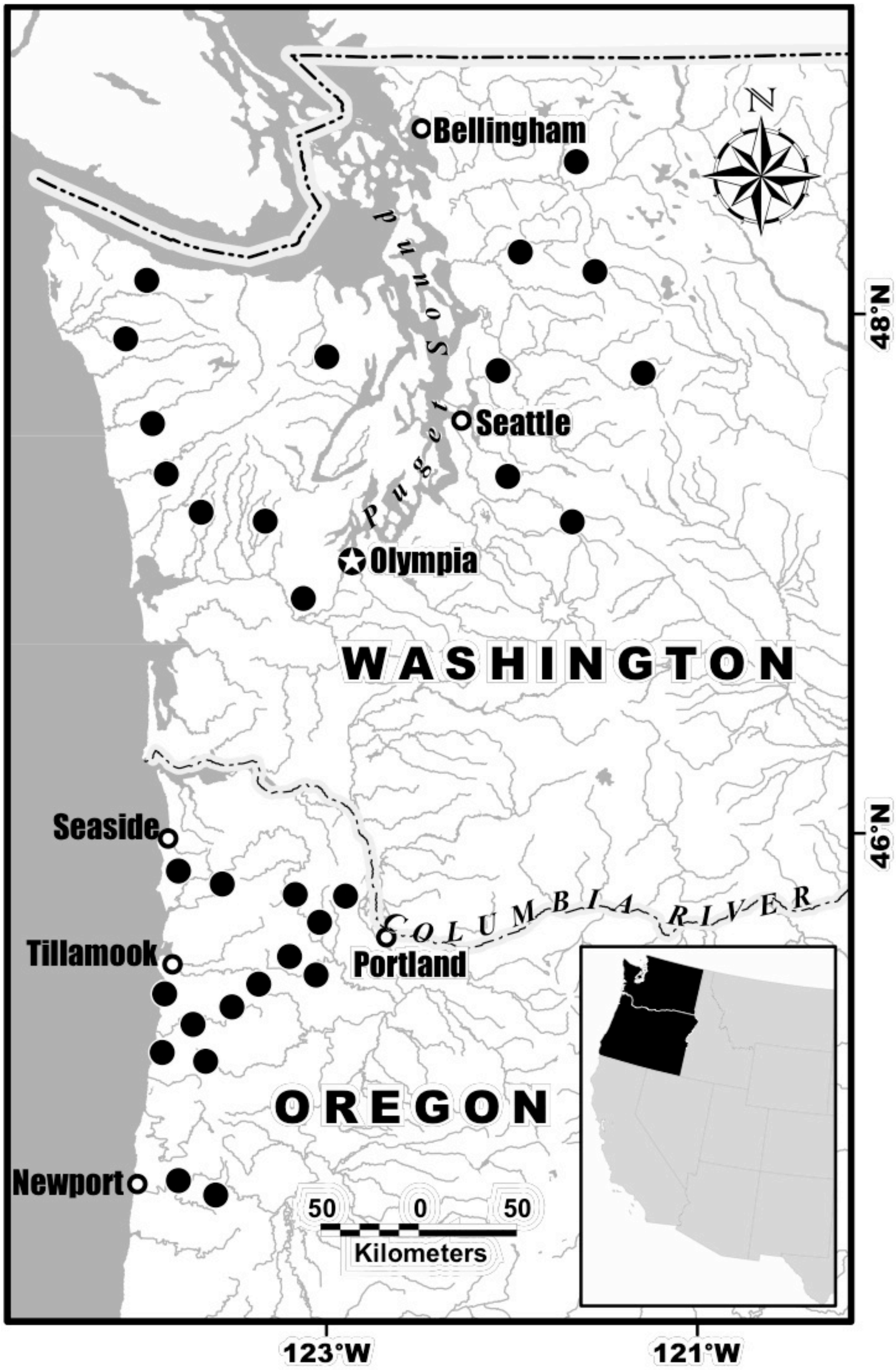
Figure 3. Locations of reference and treatment side channels western Washington (Morley et al. 2005)



Winters are mild and summers cool allowing for a variety of tree species such as Douglas fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*), Western red cedar (*Thuja plicata*), Sitka spruce (*Picea sitchensis*), red alder (*Alnus rubra*), and big leaf maple (*Acer macrophyllum*) to flourish in the wet Pacific Northwest (Pojar and MacKinnon 2004, Franklin and Dyrness 1988). Here, a variety of fish species including the five species of Pacific salmon, Chinook, coho, chum, pink and sockeye, along with a various char (Dolly Varden (*Salvelinus malmo*) and bull trout (*S. confluentus)*), cutthroat (*O. clarki)*, rainbow and steelhead trout (*O. mykiss*), whitefish (*Prosopium williamsoni*), three spine stickleback (*Gasterosteus aculeatus*), sculpin (*Cottus spp.*) and lampreys (genus *Lampetra*) inhabit the waters (Morley et al. 2005, R.S. Wydoski and R.R. Whitney 2003) and the terrain composed of volcanic, sedimentary or glacial alluvial soil deposits (Franklin and Dyrness 1973 and 1988).

The research sites were evaluated for biological responses such as increased fish usage, temperature regimes differences and habitat changes after different restoration techniques were applied to stream channels. In western Washington, eleven artificially constructed side channels were paired with naturally occurring side channels for comparison of fish abundance, density and usage (Figure 3). The eleven artificial channels are located in various river basins along the Puget Sound and coastal regions in Washington whereas the twenty-one LWD streams were almost exclusively along coastal and inland areas of Oregon with the exception of five located in Washington state (Figure 4).

Figure 4. Locations of LWD reference and treatment sites (Roni 2001)



The western Oregon and Washington LWD fish abundance data was compiled from various agencies, which then analyzed for a Northwest Fisheries Science Center

(NWFSC) project completion report (Roni 2001). Thirty streams paired with reference sites were treated with large woody debris placement within the active channel and monitored for fish response. Cost data was available for only twenty of the streams studied and were provided by various agencies. Average stream lengths varied from 200 to 1000 meters for artificial channels whereas the LWD streams were 75 to 120 meters long.

Method

This analysis was conducted with only fiscal measures in mind and serves as a preliminary exploration of providing an additional tool when considering restoration measures. While biological factors are an important component to restoration priorities, this analysis evaluates only the costs of implementing certain restoration techniques and not the biological indices. Analysis of these project costs is possible as each project collected the same biological metric though the treatment methods differed. According to Mark Plummer, economist with NOAA Fisheries, this is allowable as long as the evaluation weighs the project's ability to deliver biological benefits against its economic costs. Projects must use the same technological and biological indicators (Plummer 2005, SRFB 2008). The comparison of physical and biological variables as benefits to actual costs of a project is also known as "bang for the buck" (Plummer 2005, SRFB 2008). This analysis meets this requirement for the LWD input and channel creation projects evaluated. This evaluation is a preliminary effort in determining and identifying the more cost effective technique of the two project types.

The methods for this analysis are modeled from the Salmon Recovery and Funding Board (SRFB) Annual Progress Report for 2008. The total costs of each project were divided by life expectancy calculations to derive an annual expenditure over time (Table 1). Life expectancy of restoration project types was garnered from Roni et al. (2002) where restoration types were evaluated for effectiveness based on estimated response time after implementation and longevity of action. Life expectancy for LWD and Channel Connectivity are averages calculated where longevity was estimated between 5 to 20 years for natural LWD placement and 10 to 50 years for off-channel projects (Table 2).

Table 1. Total costs for projects Oregon and Washington

Project Name	Category	Project Total Cost	Annual Life-Cycle Cost
Bear Cr	Instream Structures (LWD)	$2,000	$133.33
Bergsvik Cr	Instream Structures (LWD)	$4,966	$331.07
Bewley Cr	Instream Structures (LWD)	$4,948	$329.87
Buster Cr	Instream Structures (LWD)	$9,780	$652
Deer Cr	Instream Structures (LWD)	$9,661	$644.07
Elliot Cr	Instream Structures (LWD)	$8,203	$546.87
Farmer Cr	Instream Structures (LWD)	$225	$15.00
Kenusky Cr	Instream Structures (LWD)	$6,063	$404.20

Killam Cr	Instream Structures (LWD)	$1,900	$126.67
Klootchie Cr	Instream Structures (LWD)	$9,588	639.20
Lobster Cr	Instream Structures (LWD)	$6,000	$400
Louisgnot Cr	Instream Structures (LWD)	$11,979	$798.60
N. Fork Rock Cr	Instream Structures (LWD)	$8.761	$584.07
S. Fork Little Nestucca R	Instream Structures (LWD)	$1,924	$128.27
Tobe Cr	Instream Structures (LWD)	$14,000	$933.33
Beaver Cr	Instream Structures (LWD)	$7150	$550.00
French Cr	Instream Structures (LWD)	$33,506	$2,577.38
Hoppers Cr	Instream Structures (LWD)	$42,975	$3,305.77
Porter Cr	Instream Structures (LWD)	$88,700	$6,823.08
Shuwah Cr	Instream Structures (LWD)	$25,000	$1,923.08
Illabot II	Channel Connectivity	$553,753	$18,458.43
Taylor	Channel Connectivity	$500,024	$16,667.47
Illabot I	Channel Connectivity	$160,377	$5,345.90
Park Slough II	Channel Connectivity	$77,072	$2,569.07
Constant	Channel Connectivity	$152,654	$5,088.47

Park Slough I	Channel Connectivity	$86,931	$2,897.70
Rayonier	Channel Connectivity	$136,000	$4,533.33
Nolan	Channel Connectivity	$156,000	$5,200.00
Young Slough	Channel Connectivity	$162,000	$5,400.00
Lewis	Channel Connectivity	$134,600	$4,486.67
Mosley	Channel Connectivity	$41,700	$1,390.00
* Adapted from SRFB 2008			

The instream wood data includes species breakdown and totals of all salmonids sampled. Species differences for the channel projects were not evaluated for this analysis. This was conducted in the original study (Morley et al. 2005) and is published in the Canadian Journal of Fisheries and Aquatic Sciences where primary usage of the off-channel areas was demonstrated to be greater than 90% coho species. This analysis focuses only on total salmonid species for this restoration type.

Table 2. Projected Life Expectancy for each project by Restoration Type

Project Category	Life Expectancy for Project (yrs)	Average Value Used (yrs)
Instream Structures - Large Woody Debris (LWD)	5 – 20	13
Channel Connectivity - Off-Channel Areas	10 – 50 +	30
Adapted from Roni et al. (2002) and SRFB Annual Progress Report (2008).		

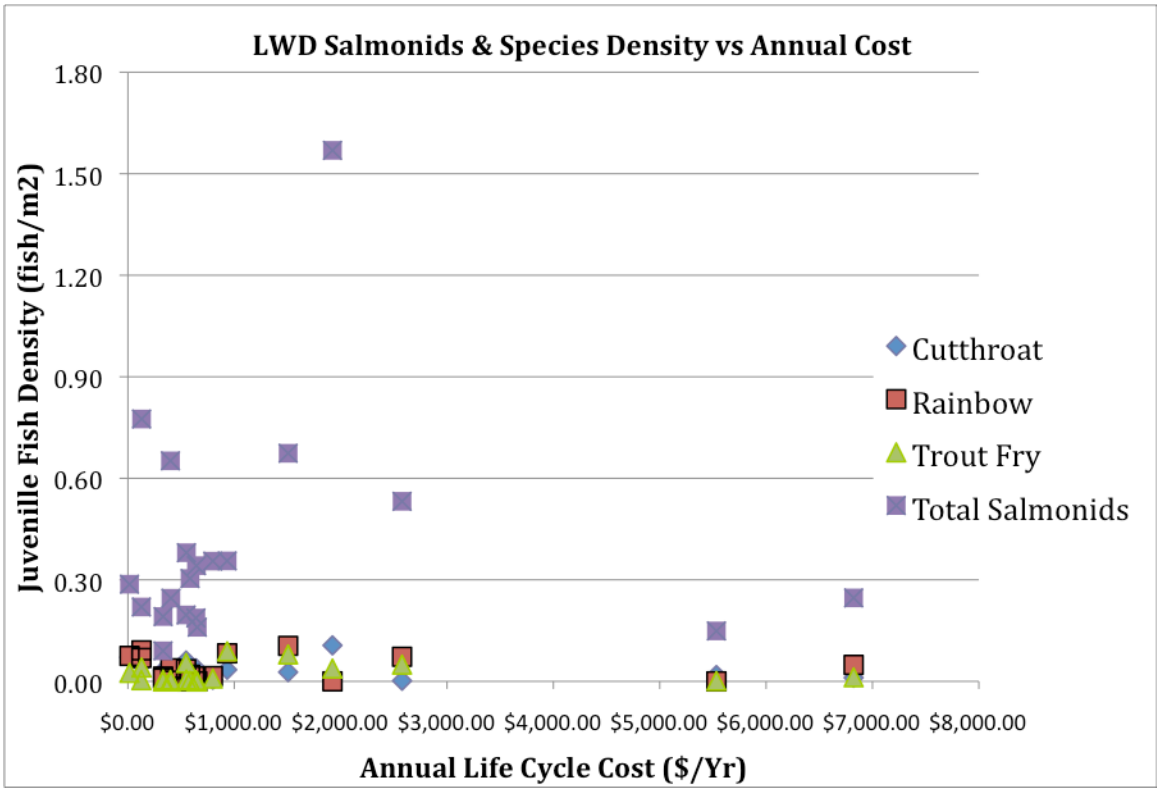
STATA 11.1 was used to determine all statistical calculations and analysis in addition to Microsoft Excel for Mac 2008 for graphic comparisons. Fish counts were calculated for density values (number of fish/area m^2) across all species of salmon in the LWD projects and for all salmonids for LWD and channel projects. These values for the project types were then plotted against the calculated annual life cycle costs for each site. A simple linear regression was used with robust standard errors in order to determine a difference in values for both project types.

The linear regressions were used to examine the relationship(s) between percent fish densities change (percent change fish treatment density/reference density) and annual expenditure per year. The data was log transformed to improve linearity, sample distribution and variances. The percent change of fish densities was calculated as a geometric mean. Two sites were excluded in the calculations for LWD and two sites for the simple linear regression of the percent change of fish density of channels due to low or negative values. The results were graphed to demonstrate trends and relationship(s).

Chapter 4. Results

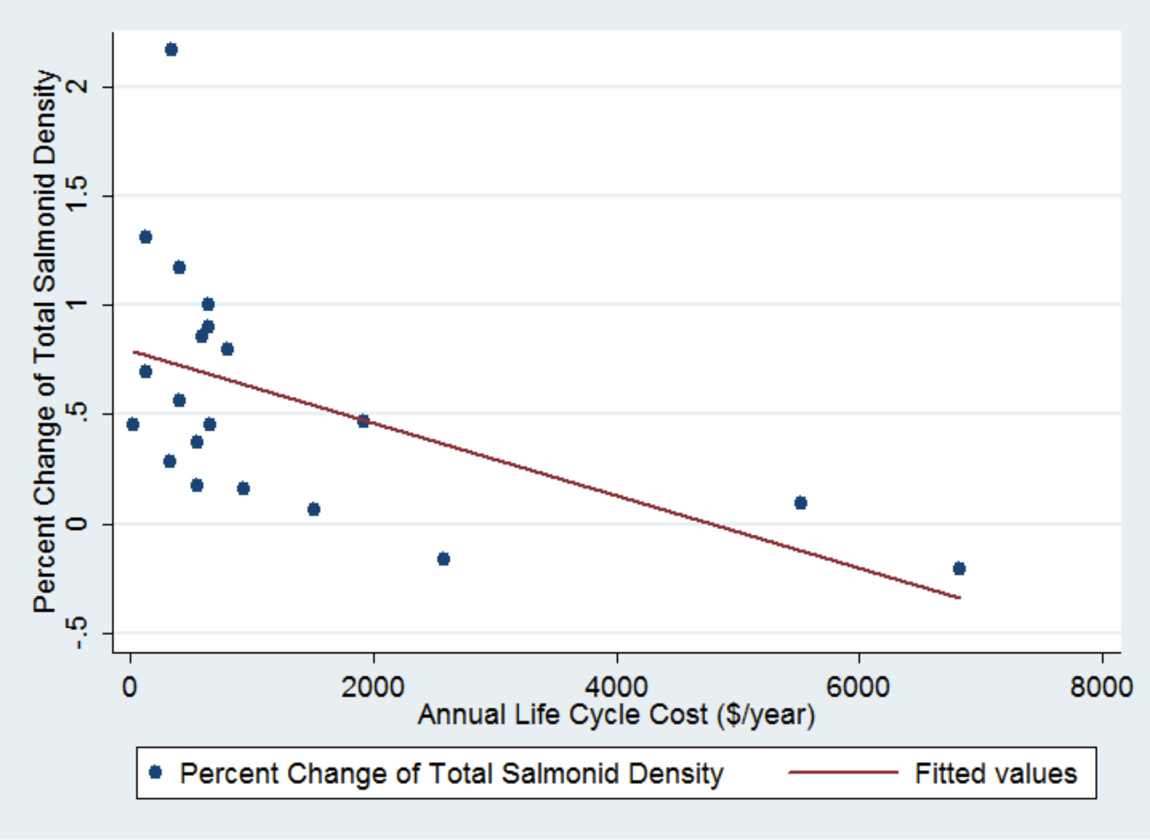
Analysis of the data revealed a consistent trend for both project types. The LWD projects plotted against annual expenditure revealed density values demonstrating positive responses to the project effort. However, over time, the fish density (fish/m$^{2)}$ values diminished against annual life cycle cost (dollars/year) and revealed a negative trend (Graph 1). Projects were beneficial for increasing the fish densities at each site, but overall were expensive and not cost effective. Salmonids as a group benefited from wood input, but individual species response revealed minimal change and response as opposed to the total salmonids density. Individual species density values resembled the salmonids densities for wood projects. Values increased initially in the early years and then diminished significantly over time demonstrating a negative trend as annual expenditure increased.

Figure 5. LWD cost effectiveness for salmonids and species breakdown



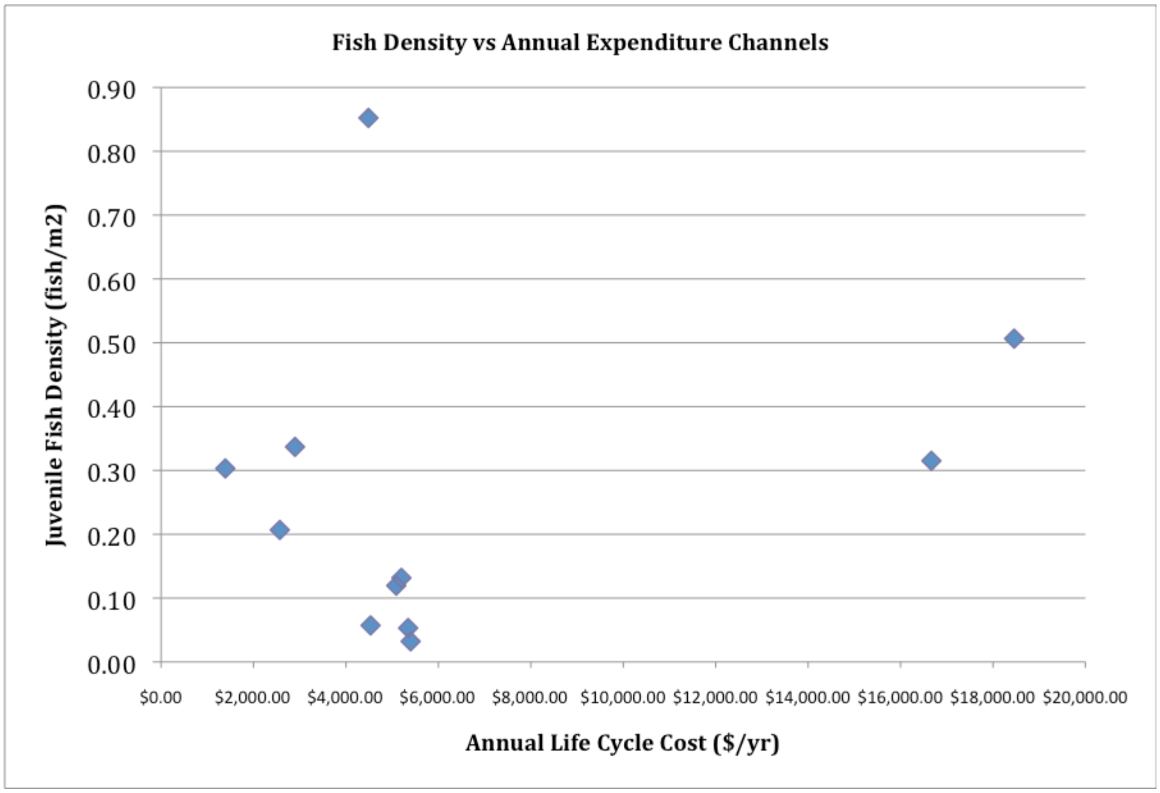
A regression analysis of the percentage change in fish density values revealed a negative trend supporting the diminished return of fish densities observed against the annual expenditures, but no significant relationship could be attributed to the changes (p > 0.51) (Figure 6). There was no remarkable significance in relationships with or without the inclusion of two LWD sites.

Figure 6. Percent Change of Total Salmonid Density (LWD)



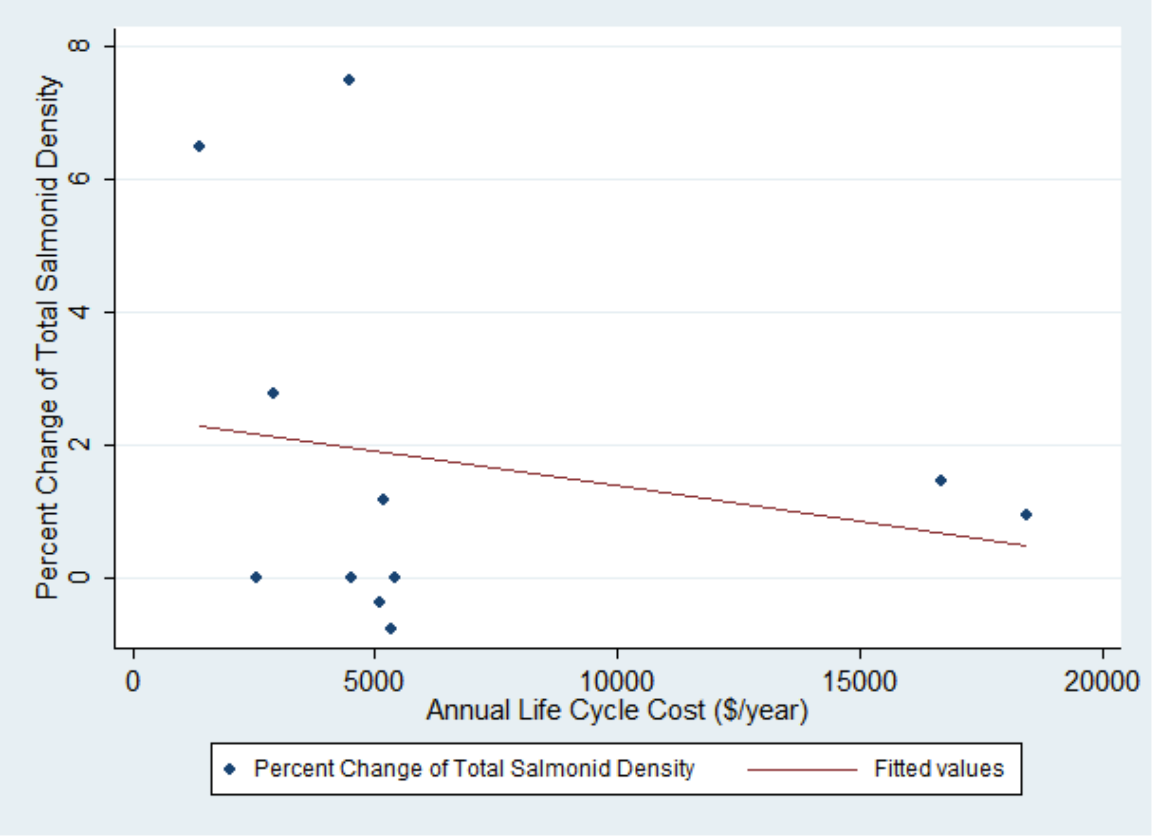
Fish density values demonstrated a positive response immediately after completion of the channels. However, when evaluated over time, density decreased as costs increased or annual expenditures rose (Figure 7). The values of the channels resemble that of the LWD projects analysis.

Figure 7. Channel fish density versus annual life cycle cost



No significant relationship was detected in the percent change of fish density (Figure 8) as costs increased yearly ($p > 0.145$). No changes were detected with the exclusion of two sites. An analysis without exclusions made no significant changes in the relationship of the percent change for channel projects though exclusion did improve linearity and normality thus improving p-values as a whole.

Figure 8. Percent Change of Total Salmonid Density Channels



The two project types directly compared supported the findings of a positive response to treatment application. However, analysis of the two side by side provided decreased fish density overall as annual life cycle cost increased. Overall, all salmonids benefited as a whole to both treatment types, but the comparison did show LWD to be more cost effective than the channels (Figure 9 & 10).

Figure 9. Channels versus LWD with salmonids and salmonid species annual cost

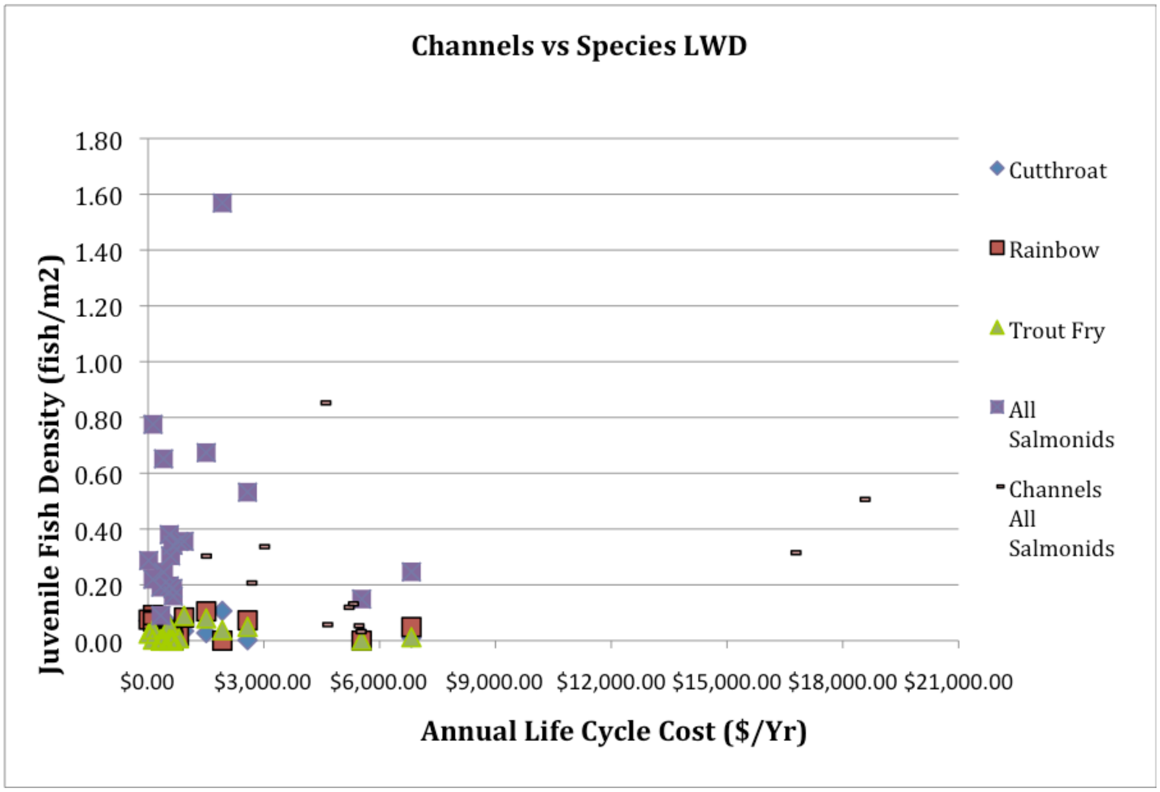
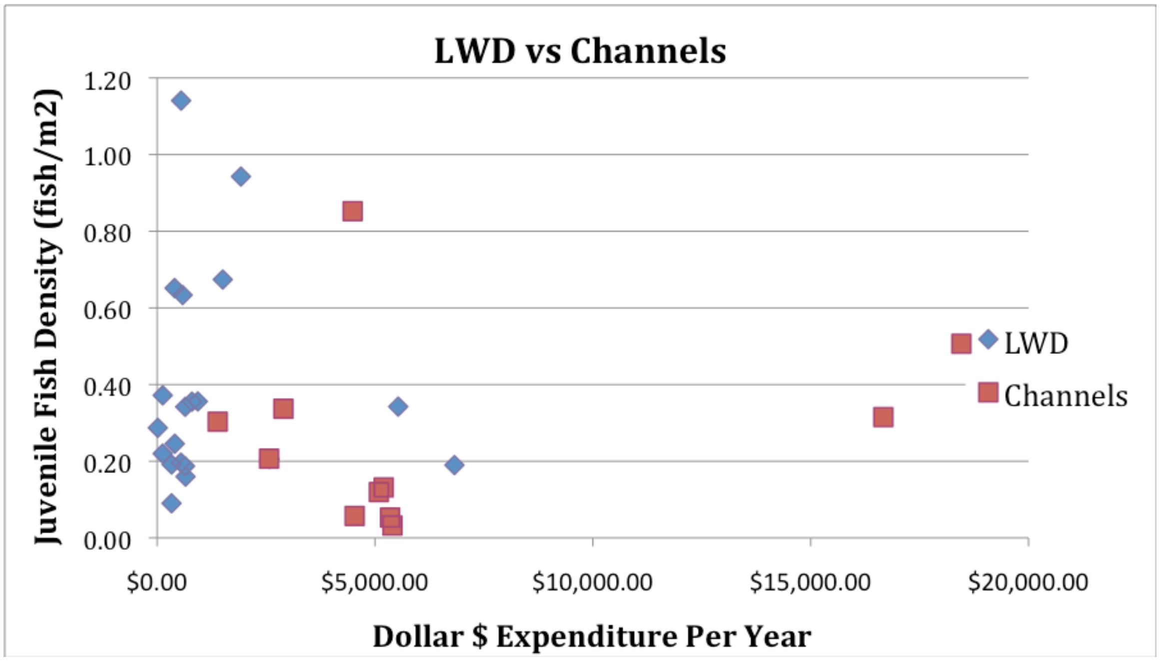


Figure 10. LWD versus channels and annual costs



Conclusion & Discussion

Instream restoration and channel creation is beneficial for juvenile salmonids. Research demonstrates that restoration can increase fish density and response to treatments such as LWD and artificial channel creation (Roni 2001, Roni 2002, Roni et al. 2006, Morley el al. 2005). The study results of this analysis revealed a demonstrated fish response immediately after implementation of restoration measures for both projects types. This is consistent with other studies conducted in the Pacific Northwest (Beechie et al. 1994, Burgess 1980, Morley et al. 2005, Nickelson et al. 1992, Pess et al. 2005, SRFB 2008, Roni et al. 2006). However, the cost effectiveness of restoration for juvenile salmonds is still virtually unexplored.

The most recent research suggests that certain restoration types benefit specific species of salmon such as coho (Gianico and Hinch 2003, Morley et al. 2005, Plummer 2005, Roni 2001, Roni et al. 2002, Roni et al. 2006, SRFB 2008). Restoration in conjunction with harvest management is a primary measure to address the loss of habitat and listing of the species. This analysis found that LWD is more cost effective over time than the channel projects. Salmonids benefited best with LWD input and over time, LWD was more cost effective than channel restoration projects. Individual species demonstrated no significant benefit overall with wood input though annual costs over time were less than the compared channel projects. As a whole, both LWD and channel projects are expensive to implement and demonstrated decrease fish density values as annual expenditure increased. This is consistent with the available research of cost effectiveness studies (SRFB 2008).

Many of these projects require significant capital and multiple sources to fully fund a project. Addressing funding limitations while implementing restoration has become a priority during lean economic years. Past studies by J. Cederholm and W. Scarlett (1988) and J. Cederholm et al. (1991) factored into consideration limited funding in their restoration efforts. More recently, researchers are considering and implementing cost effectiveness analyses in their studies for a host of projects in various parts of the world (Changeaux et al. 2001, Haisfield et al. 2010, SRFB 2008, Thomas & Blakemore 2010) and now the PNW (SRFB 2008). Research scientists are scrutinizing efforts and creating protocols to prioritize measures that integrate cost effectiveness in watershed and restoration actions (Beechie et al. 2003, Beechie et al. 2008, Pess et al. 2005, Roni et al. 2002, Roni et al. 2010, SRFB 2008) to maximize restoration effectiveness.

Limitations and Recommendations

Small sample sizes of each project type did limit the analysis and inclusion or exclusion of outliers revealed no significant changes or effect on the relationship outcome. Additional sample sites for a larger pool may provide better results statistically and reveal a more powerful relationship in the final evaluation. This can be accomplished with additional monitoring data and by increasing efforts to monitor projects after completion (Beechie et al. 2003, SRFB 2008). Calculating percentage changes for fish densities proved limiting with the minimal data points available. Utilizing ratios in lieu of percent change may have provided a stronger outcome without having to manipulate the data extensively. The end result would reduce the need to log transform the data to minimize error and normalization.

These projects were monitored for only two years. Limited monitoring data reduces the likelihood of finding stronger statistical trends among the study sites. New research suggests monitoring restoration projects for a minimum of 5 years for fish response and habitat improvement. This is considered the minimum expected response time to restoration treatment measures for LWD and artificially created channels (Beechie et al. 2003, Roni 2002). Morley (el al) found a positive correlation of fish density with project age where physical habitat may have been a key factor as sites with more mature canopy cover or fewer disturbances provides optimal conditions for rearing juvenile salmonids. Additional years of monitoring are suggested for sampling sites, as this will increase the robustness of the collected data (SRFB 2008, Roni et al. 2010). Continued monitoring will provide opportunity to detect changes in an intact continuum and providing an opportunity of a better financial return on the initial restoration investment as projects mature.

The data utilized for this analysis was designed by pairing treatment and reference streams. Baseline fish data was not collected prior to restoration. This particular design collects data only after treatment has been initiated and the baseline for the treatment site is a reference stream chosen elsewhere based on similar morphology and habitat characteristics, usually in the same watershed. This method does not take into account the variability that may be present in the two different sites and is often difficult to control for variability thus providing for challenges statistically. It is recommended that study project designs take into consideration the measurable variables with future cost effectiveness analysis in mind before implementation, and by prioritizing and identifying key actions and measures of restoration effectiveness (Beechie el al. 2008, Roni et al. 2010). Pre and post project analysis of study designs, watershed assessments, and conforming protocols and parameters from many different projects allows for evaluation of commonalities and cost analyses (Beechie et al. 2008, SRFB 2008)). An increased sample size with improved monitoring may reduce project costs especially if agencies increase collaboration with the pooling of their efforts (personal communication Jennifer O'Neal, research ecologist Tetra Tech). The SRFB currently utilizes these methods to evaluate and monitor project effectiveness in the PNW.

Both LWD and channel restoration projects can vary in size and cost. Typically, creations of side channels tend to be larger and more expensive. The larger costs tend to result in a diminished return on the investment. Densities of fish usage need to be quite large to actualize a modest return in the investment. This was evident in the overall analysis. For restoration projects in off channel areas, research substantiates a relationship of area and size to decreased productivity of juvenile smolts (Morley 2005, Roni et al. 2006) and other researchers have suggested limitations on project size in order to maximize coho smolt production. Given the considerable costs associated with restoration efforts, it is suggested that smaller and more numerous site selections may prove more cost effective when considering restoration and/or habitat improvement. This analysis indicates that channels are the least cost effective for increasing juvenile salmonid density versus LWD projects. The costs of the LWD efforts are considerably less with some projects at a minimal investment at $250 dollars. It may prove that smaller and more numerous site selections as more efficient and productive for increasing fish production in greater numbers than few or one large and more costly project such as a side channel. Protection of intact or pristine environs or reconnecting existing habitat areas, is a strategy available that is a less costly alternative for restoration (Roni et al. 2002). Funding sources could then be applied more selectively and judiciously after taking into consideration habitat and watershed factors (Roni et al. 2002).

While these findings do not suggest a positive relationship of fish densities to annual cost expenditure, nor does it indicate restoration as a whole as cost effective, it does demonstrate trends that could be useful for future study. The importance of cost analyses as a vital component of restoration priorities cannot be overstated especially during fiscally austere years. Evaluating cost effectiveness in restoration efforts is key to setting priorities and identifying actions and final goals. Monitoring efforts of projects are often too inadequate reducing the likelihood of measuring the long term effectiveness of restoration projects. We as biologists and environmentalists need to consider cost analyses as an additional tool in justifying the recovery of species.

Table 3. Definitions of different off-channel habitat restoration techniques modified from references in the literature.

HABITAT TYPE	DEFINITION	CITATION
Constructed Alcove	Slack water area excavated along the channel margin and separated from the main current by the streambank or large channel obstruction; similar to backwater pool.	Nickelson et al. 1992a,b Solazzi et al. 2000
Blast Pool	Holes blasted in mud substrate by explosives and subsequently flooded by a small low-head dam; often arranged in series to create a "beaded-channel".	Cedarholm & Scarlett 1988, 1991 Poulin et al. 1991
Constructed Groundwater Channel	Groundwater-fed side channel excavated on old river swale; often includes log weirs for gradient control, rip-rap for bank armoring, and gravel placement for spawning.	Sheng et al. 1990 Cowan 1991
Constructed Groundwater Pond	Similar to groundwater channel described above but with pond morphology (no gradient, greater depth, etc.); connected to river by short access channel.	Henderson 1997
Constructed Dammed Pond	A pond created by the placement of structures (gabions, logs, boulders, or concrete) across the full width of a channel; rootwads and small trees often added.	Nickelson et al. 1992b Solazzi et al. 2000
Gravel Pit Reclamation	Abandoned sand and gravel mining sites enhanced via connection to river channel, addition of cover (such as LWD and aquatic vegetation), and bank revegetation.	Richards et al. 1992 Norman 1998a,b
Mill Pond Reclamation	Similar to gravel pit reclamation but with ponds abandoned from old mill operations.	C. Detrick, WDFW, pers. comm. 2000

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