Study Plan for the Intensively Monitored Watershed Program:

Strait of Juan de Fuca Complex

Funded by:
Salmon Recovery Funding Board

Prepared by:
Intensively Monitored Watersheds
Scientific Oversight Committee*
and IMW Partners

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INTRODUCTION

The Intensively Monitored Watershed program is a basin-scale validation monitoring effort to evaluate the effectiveness of salmon habitat restoration activities in increasing the production of salmon as recommended in the Washington State Comprehensive Monitoring Strategy (Crawford, et al 2002). The base program is funded by the Salmon Recovery Funding Board (SFRB), administered through the Washington Department of Ecology, and implemented by the IMW collaborators.

The basic premise of the Intensively Monitored Watersheds (IMW) program is that the complex relationships controlling salmon response to habitat conditions can best be understood by concentrating monitoring and research efforts at a few locations. The data required to evaluate the response of fish populations to management actions that affect habitat quality or quantity are difficult and expensive to collect. Focusing efforts on a relatively few locations enables enough data on physical and biological attributes of a system to be collected to develop a comprehensive understanding of the factors affecting salmon production in freshwater.

The ultimate objective of nearly all efforts intended to improve salmon habitat is to increase the abundance of the fish. Therefore, the most meaningful measurements of the effectiveness of a restoration program are those related to the performance of the fish during their period of freshwater residency; from adult spawning through smolting of their offspring. Because salmon use multiple habitat types during freshwater rearing and may move throughout the watershed to locate these habitats, the spatial scale at which an evaluation is conducted should be large enough to encompass all the habitats required for the salmon to complete this phase of their life history. The size of the area required to capture the full range of habitats needed to complete freshwater rearing will vary by species.

The IMW Program consists of three elements:

- Studies at three complexes of three or four watersheds each focusing on coho salmon and steelhead trout (Figure 1),
- Evaluation of the effects of estuary restoration on juvenile chinook salmon growth and survival on the Skagit River Estuary.
- A Pacific Northwest-wide landscape classification intended to guide the application of IMW results to other watersheds. The classification is based on similarity of physical and biological characteristics to the watersheds included in the IMW project. Watersheds which have biophysical characteristics and patterns of human activities comparable to IMW sites will be locations where IMW results can be extended with the greatest degree of certainty.

The three IMW complexes that focus on coho salmon and steelhead trout: Strait of Juan de Fuca, Hood Canal, and Lower Columbia, include a total of ten watersheds. The IMW Complex areas range from 78 km$^2$ to 206 km$^2$ (Table 1) with individual watershed areas ranging from 13 km$^2$ to 75 km$^2$. Watersheds of this size are sufficiently large to provide all the habitat conditions required for the target species to complete freshwater rearing. We have focused on coho and steelhead in smaller watersheds for four reasons:

1) These species spend more time in freshwater (1-3 years) than most other species of anadromous salmonids. Thus, they should be more responsive to changes in the quality and quantity of
freshwater habitat than species which only reside in streams and rivers for a short period of time (e.g. ocean-type chinook, chum, pink).

2) Only large changes in fish population metrics will be detectable within the life of this project, given the inherent variability in these populations. In order to cause a detectable change in the fish populations, it is likely that a fairly substantial change in freshwater habitat conditions will need to occur. The relatively small size of the study watersheds will make practicable the application of restoration treatments to a large proportion of the impaired freshwater habitat, increasing the probability of generating a detectable response from the fish.

3) Many of the restoration projects and land use regulations that have been implemented in the region have been based on the habitat requirements of coho salmon. Therefore, this species should be the most likely to respond to many of the restoration actions that are being funded.

4) Because these three species complete freshwater rearing in a small watershed, fish responses to management actions can be assessed using a before-after/control impact design. Use of this type of design should make the responses by the fish easier to detect. Such a design would not be logistically feasible with species requiring a much more extensive area to complete rearing.

This document describes the IMW monitoring efforts in the Strait of Juan de Fuca (Straits) complex. The other three complexes are described elsewhere (refs for other IMW docs). The study plan for the entire IMW program may be viewed at http://www.iac.wa.gov/Documents/Monitoring/IMW_StudyPlan.pdf.

Table 1. Characteristics of the three watershed complexes in western Washington.

<table>
<thead>
<tr>
<th></th>
<th>Strait of Juan De Fuca</th>
<th>Hood Canal</th>
<th>Lower Columbia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Watersheds</strong></td>
<td>West Twin</td>
<td>Stavis</td>
<td>Germany</td>
</tr>
<tr>
<td></td>
<td>East Twin</td>
<td>Little Anderson</td>
<td>Abernathy</td>
</tr>
<tr>
<td></td>
<td>Deep</td>
<td>Big Beef</td>
<td>Mill</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seabeck</td>
<td></td>
</tr>
<tr>
<td><strong>Focal Species</strong></td>
<td>coho</td>
<td>coho</td>
<td>coho</td>
</tr>
<tr>
<td></td>
<td>steelhead</td>
<td>steelhead</td>
<td>steelhead</td>
</tr>
<tr>
<td><strong>Land Use</strong></td>
<td>forestry – private, state, and federal</td>
<td>urban, rural residential, forestry – private and state</td>
<td>forestry - private and state agriculture in lower valleys</td>
</tr>
<tr>
<td><strong>Complex Area (watershed)</strong></td>
<td>113 km² (33, 35, 45 km²)</td>
<td>78 km² (15, 13, 36, 14 km²)</td>
<td>206 km² (57, 73, 75 km²)</td>
</tr>
<tr>
<td><strong>Geology</strong></td>
<td>mixed sedimentary and metamorphic</td>
<td>glacial till</td>
<td>flow basalt w/ interbedded sandstone</td>
</tr>
<tr>
<td><strong>Precipitation</strong></td>
<td>190 cm/yr</td>
<td>105 cm/yr</td>
<td>160 cm/yr</td>
</tr>
</tbody>
</table>
Figure 1. Locations of the four IMW study sites: Strait Juan de Fuca, Hood Canal, Lower Columbia, and the Skagit River Estuary.

Goals and Hypotheses
The goals of the IMW program’s coho / steelhead complexes are to determine:

1) Whether freshwater habitat restoration can effect a change in production of outmigrant coho salmon and steelhead trout;

2) What features or processes influenced by the habitat improvements caused the increased production or lack thereof; and

3) Whether the beneficial effects of habitat improvement are maintained over time.

The first goal is addressed by measuring smolt/outmigrant production in each treatment basin relative to the reference basin in that complex. However, addressing the first goal may not provide information about the cause of any increase in outmigrant production. Thus, the second and third goals are critical if the results of the IMW effort are to be useful to local restoration advocates to prioritize restoration
projects within and among watersheds. However, the data required to answer questions two and three are more complicated to measure, requiring assessment of the fish populations at various stages during freshwater rearing over a period of years. The basic set of monitoring variables described below will provide basin-wide estimates of spawner abundance, egg-to-parr survival, parr-to-smolt survival, smolt production, and habitat. These data are the foundation of the monitoring efforts and will be supplemented with additional research to better identify causal mechanisms.

The hypotheses to be tested are listed below. Hypotheses 1-5 apply to all three IMW Coho/Steelhead complexes. Hypotheses 6 and 7 are unique to the Straits Complex.

1. The increase in outmigrant production following habitat treatments is greater in treatment watersheds than in reference watersheds.
2. The increase in mean parr population, growth, and density is greater in treated watersheds than in control watersheds.
3. The increase in mean egg to parr survival is greater in treated watersheds than in control watersheds.
4. The increase in mean parr to smolt survival is greater in treated watersheds than in control watersheds.
5. Restoration results in a measurable increase in habitat, basin wide.
6. The relative proportion of fall outmigrants in East Twin River does not change over time relative to West Twin River.
7. Marine survival rates of fall and spring migrants from East Twin and West Twin Rivers are equal.

Experimental Design

Long-term monitoring using before-after studies have been recommended to determine biological response to habitat alteration (e.g., Stewart-Oaten et al. 1986; Reeves et al. 1991; Smith et al. 1993). The addition of a control (or controls) to the BA design, commonly called a before-after control-impact (BACI) design, is meant to account for environmental variability and temporal trends found in both the control and treatment areas and, thus, increase the ability to differentiate treatment effects from natural variability (Smith et al. 1993). A before-after/control (referred to here as reference) -impact (BACI) design, implemented at different spatial scales is the basic design being applied in the IMW studies. However, the Strait of Juan de Fuca complex has too little pre-restoration smolt production data to use a BACI design at the basin scale. Instead we will compare production as well as the rate of change over time in treatment vs. control basins after restoration. Monitoring of individual projects with pre-implementation data will allow for a BACI analysis.

The West Twin River will not receive any restoration projects and will serve as a statistical reference basin. The BACI design will be implemented at multiple spatial scales, the scale dependent on the question being addressed. Some questions are best addressed at a reach scale. Questions that can be addressed at this finer scale include life-history specific biological responses or physical habitat responses to management actions. Reference sites for some reach-level projects are within the basin designated for treatment. These reference sites consist of a reach in close proximity and comparable in initial habitat condition to the treated section of channel. No habitat manipulation would occur during the period of evaluation in the reference stream reach. For evaluations of effects at the scale of the
entire basin, a comparison with the reference watershed in a complex is required. The IMW approach does require sufficient influence over management decisions to ensure that reference sites, at all spatial scales, remain untreated through the duration of the study. The IMW project is coordinating restoration plans with the Lower Elwha Klallam Tribe in order to ensure the integrity of the reference sites. We expect human activities will occur in some of the reference watersheds (e.g., logging in those reference watersheds with commercial forest lands). The IMW partners have no ability to control these activities. However, we do not believe these actions will compromise the integrity of the study provided that any effects associated with these activities can be measured and segregated from responses related to restoration actions.

**Strait of Juan de Fuca Description**

The Deep Creek, West Twin River, and East Twin River watersheds are located on the northwestern Olympic Peninsula and cover a combined area of approximately 113 km$^2$ (Figure 2). Individual basin areas are 45 km$^2$, 33 km$^2$, and 35 km$^2$, respectively. These watersheds drain directly into the Strait of Juan de Fuca. The headwaters of the stream systems initiate in the Olympic Mountains and flow into gradually broadening river valleys. Stream channels generally flow in a northeasterly direction in the upper watershed areas and then turn northerly to the Strait of Juan de Fuca. Elevations in the watershed range from sea level to 1,142 meters atop Mt. Mueller in the headwaters of the East Twin and West Twin rivers.

These watersheds are underlain by volcanic rocks of the Crescent Formation, marine sedimentary rocks, and glacial deposits. The oldest rocks (the Crescent Formation) are at higher elevations, while the youngest, the marine sedimentary rocks, are at the lower end of the watershed. Glacial deposits occupy lower valley margins and valley floors toward the upper part of the watershed, and throughout broad terrace areas in the lower parts of the watershed. Recent alluvium is found locally adjacent to higher-order channels, especially at the lower end of the watershed. The area of the watershed underlain by the Crescent Formation is steep and dissected with generally shallow soils. Landslides and resulting debris torrents are most common in this area of the three watersheds. The marine sedimentary rocks include a mixture of siltstones, sandstones, mudstones and conglomerates. Most mass wasting on this geology is associated with steep converging topography and over-steepened channel margin slopes. The low strength, fine-grained nature of these rocks contributes to the generation of fine sediment in these watersheds. Glacial deposits occupy valley bottoms, toe slope areas, and terraces in the lower part of the watershed. Typically they are relatively thick deposits on gentle slopes and not particularly susceptible to erosion. Exceptions are where streams have incised deeply into these deposits, leaving high banks (of relatively weak materials) and may form small inner gorge structures that are susceptible to, and in part created through, erosion and/or mass wasting. Glaciolacustrine clay overlying dense glacial till is found in some areas along the lower Deep Creek inner gorge and the upper part of the East Fork of the East Twin River, a condition susceptible to deep-seated mass wasting. (Neal and Buss 1992).
Early-succession forest stages occupy 27.3 percent of the watershed, mostly on private land while mid-succession stages cover 60.8 percent of the watershed. Late-succession stands cover 11.0 percent of the watershed, mostly on National Forest land. Only 0.8 percent of the watershed is not forested, primarily wetlands and waterbodies. There are few residences in the three watersheds with no agricultural or urban development.

There is a total of 230 km of stream channels in the Deep Creek (36.8%), West Twin River (32.4%), and East Twin River (30.7%) watersheds (Table 2). Drainage density within the watersheds averages around 2.8 km/km². Nearly 80% of the total channel length is relatively steep (>8%). Moderate-gradient (2-4%) and low-gradient (<2%) channel segments accounted for 6.6 percent and 8.6 percent of the channel length, respectively.

Fall chum (*Oncorhynchus keta*), coho salmon (*Oncorhynchus kisutch*), winter steelhead (*Oncorhynchus mykiss*), and resident and anadromous cutthroat trout (*Oncorhynchus clarki*) utilize the Deep Creek and Twin Rivers watersheds. Historical accounts mention Chinook salmon (*Oncorhynchus tshawytscha*) in these watersheds but it is unclear whether these were the results of WDFW hatchery outplants that occurred in the 1970’s or a natural population. Chinook salmon have not been observed in recent years.
Table 2. Length of channel segments by gradient and confinement categories.

<table>
<thead>
<tr>
<th>Gradient Category (percent)</th>
<th>Length by Confinement Category (m)</th>
<th>Total Length (m)</th>
<th>Percent of Watershed Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Confined</td>
<td>Unconfined</td>
<td></td>
</tr>
<tr>
<td>&lt; 1</td>
<td>0</td>
<td>5440</td>
<td>5400</td>
</tr>
<tr>
<td>1 – 2</td>
<td>1620</td>
<td>13,160</td>
<td>14,780</td>
</tr>
<tr>
<td>2 – 4</td>
<td>12,140</td>
<td>3320</td>
<td>15,460</td>
</tr>
<tr>
<td>4 – 8</td>
<td>13,820</td>
<td>0</td>
<td>13,820</td>
</tr>
<tr>
<td>8 – 20</td>
<td>47,030</td>
<td>0</td>
<td>47,030</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>136,370</td>
<td>0</td>
<td>136,370</td>
</tr>
<tr>
<td>All</td>
<td>210,980</td>
<td>21,920</td>
<td>232,900</td>
</tr>
</tbody>
</table>

Due to chronically low escapements, no terminal salmon fisheries are currently conducted in the watersheds. Tribal fisheries for winter steelhead have been closed in Deep/Twins since 1990. The East Twin River is currently closed to sport steelhead fishing, and all wild steelhead must be released by anglers on Deep Creek and the West Twin River. The status of salmon and steelhead stocks based upon the most two recent stock reviews is summarized below (Table 3).

Table 3. Status of salmonid stocks in the Deep/Twins Watershed.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chum</td>
<td>Fall</td>
<td>Wild</td>
<td>Native</td>
<td>Healthy</td>
<td>Critical</td>
</tr>
<tr>
<td>Coho</td>
<td>Fall</td>
<td>Wild</td>
<td>Mixed</td>
<td>Depressed</td>
<td>Stable</td>
</tr>
<tr>
<td>Steelhead</td>
<td>Winter</td>
<td>Wild</td>
<td>Unresolved</td>
<td>Healthy</td>
<td>Depressed</td>
</tr>
</tbody>
</table>

The Pacific Fisheries Management Council reviewed the status of coho populations in the Strait of Juan de Fuca region and concluded that none of the 48 independent drainages in this region supported healthy coho stocks (PFMC 1997). The study concluded that SJF coho populations as a whole are negatively impacted by low freshwater survival, low marine survival rates and high marine interception rates.

Historic monitoring

Sporadic spawning ground surveys by WDFW in Deep Creek between 1950-1970 reported counts as high as 206 fish/mile (330 fish/km). Repeatable surveys of index areas have been conducted in Deep Creek and Sadie Creek (East Twin tributary) since 1984 by WDFW (Figure 3). These index areas may provide an indication of temporal trends, but cannot be reliably expanded into an estimate of
watershed-level spawner abundance. The Deep Creek index reach (river mile 0.0-1.3/km 0.0-2.1), was established primarily to assess chum salmon and its utility in evaluating coho salmon trends in Deep Creek is unclear.

Significant efforts have been made since 1997 to improve estimates of spawning salmon abundance in Deep Creek and East and West Twin rivers. A stratified random sampling system of available habitat types was initiated in 1997. This new system enables estimation of individual watershed escapement. Estimates of coho escapement using this system to the Deep/Twins watersheds are depicted in Figure 4. Escapement to each individual watershed has been consistent with Deep Creek supporting the highest number of spawning coho followed by West Twin then the East Twin River.

The status of Winter Steelhead was considered healthy in the early 1990’s (as a result of higher escapement to the Pysht River). Formal steelhead escapement surveys were only initiated in 1995, limiting the ability to determine long-term trends in watershed escapement (Figure 5). Winter steelhead adults enter the watershed beginning in December and continue through May. Spawning occurs in February through early June. The stock is currently managed for wild production and no hatchery outplants have been released in the Deep/Twin complex since the early 1980’s.

Monitoring of outmigrating steelhead and coho began in Deep Creek in 1998 and in West Twin and East Twin Rivers in 2001 with Deep Creek typically more coho and steelhead smolts (Figures 6 and 7).

Figure 3. Coho salmon escapement (redds/km) to WDFW index area on Sadie Creek (1984-2004).
Figure 4. Coho salmon escapement to Deep Creek and East Twin and West Twin Rivers, 1998-2002.

Figure 5. Steelhead escapement to Deep Creek and West Twin and East Twin Rivers, 1995-2005.
Figure 6. Steelhead smolt production from Deep Creek and West Twin and East Twin Rivers, 1998-2005.

Figure 7. Coho smolt outmigration from Deep/Twin Rivers, 1998-2005.
**Methods**

The specific parameters measured in each watershed will vary depending on the questions being addressed and the types of treatments being applied. However, a basic set of data will be collected at all of the watersheds (Table 4). These common measures are intended to capture the effect restoration actions are having at a watershed scale and to provide context for interpretation of changes observed following application of treatments. The common parameters include measures of water quantity and quality, habitat characteristics and characteristics of the fish populations.

*Water Quantity and Quality*

Continuous stage height recorders have been installed near the mouth of each watershed. Discharge is estimated using a relationship between stage height and flow that is being developed for each flow monitoring station. Water samples are collected monthly at the gauge site and analyzed for temperature, dissolved oxygen, pH, specific conductivity, total nitrogen, nitrate+nitrite-N, ammonia-N, total phosphorus, soluble reactive phosphorus, suspended sediment, and dissolved organic carbon. Continuous turbidity monitors have been deployed at each flow gauging site. These instruments collect turbidity data at 15 minute intervals. The turbidity sensor triggers a pump water sampler at high turbidity levels to estimate suspended sediment loads, a method termed Turbidity Threshold Sampling-TTS (Lewis 2003, 1996). The use of *in situ* continuous turbidity monitoring provides a real-time, quantitative estimate of the duration and intensity of suspended sediment exposure to the fish. *In situ* water temperature loggers have been deployed throughout each basin to characterize changes in water temperature from headwaters to the mouth.

*Habitat Conditions*

An EMAP (Environmental Monitoring and Assessment Program) based approach, developed by EPA, is being used to provide annual, basin-wide estimates of habitat condition. EMAP uses precise measurements and/or visual estimates of habitat attributes using transects and variable-length samples (Simonson et al. 1994, Angermeier and Smogor 1995) based on stream size (Kaufmann et al. 1999, Peck et al. 2001). These methods have been selected to ensure precise, repeatable measurements because low measurement precision substantially limits the ability to detect spatial differences and temporal trends in habitat attributes (Peterson and Wollrab 1999, Larsen et al. 2004). The EMAP sampling approach attempts to allocate sampling effort in a manner that balances the objectives of describing spatial variability in environmental conditions and detecting trends over time. Spatial variation is best captured by maximizing the number of sites sampled while evaluating temporal trends requires re-sampling of sites (Larsen et al. 2001). We have chosen to select new sites each year in order to better describe the current status of habitat prior to restoration rather than revisiting sites (Urquhart et al. 1998, Roper et al. 2003). The duration of the study and temporal periodicity of sampling are the primary determinants of the ability to detect trends in habitat conditions (Larsen et al. 2004), and therefore to assess correlations between changes in habitat conditions and salmon abundance, distribution and production. Field methods will closely follow those developed in the Western EMAP Pilot Study (see Peck et al. 2001). Twenty sites per watershed per year are being measured. The measurements and the metrics calculated in the EMAP sampling are listed in Table 5.

In addition to the habitat measurements collected on all the IMW watershed complexes (described above) several evaluations specific to the SFJ complex also are being implemented. Prior to beginning the restoration efforts, channels in areas where restoration might be implemented (virtually all areas accessible to anadromous fishes) were mapped. In addition, extensive habitat measurements were made using the TFW Ambient Monitoring methodology (Schuett-Hames et al. 1994). Repeat surveys
of habitat conditions have been conducted at intervals (1992, 1995, 1997, and 2003) as restoration has progressed. Thirty-six permanent cross-section stations have been established throughout the areas where treatments have been applied and at nearby reference sites to measure changes in channel bed elevation and substrate size. The cross-sections have been periodically re-surveyed (1998, 1999, 2002, 2005) to assess restoration effects.

**Table 4. Variables measured in all coho, steelhead, and cutthroat IMW complexes.**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Frequency</th>
<th>Data available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Continuous</td>
<td><a href="https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp">https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp</a></td>
</tr>
<tr>
<td>Water temperature</td>
<td>Continuous</td>
<td><a href="https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp">https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp</a></td>
</tr>
<tr>
<td>Probabilistic sampling</td>
<td>Annual</td>
<td><a href="http://wdfw.wa.gov/hab/imw/index.htm">http://wdfw.wa.gov/hab/imw/index.htm</a></td>
</tr>
<tr>
<td>Smolt production</td>
<td>Annual</td>
<td>By request: <a href="mailto:wehi461@ecy.wa.gov">wehi461@ecy.wa.gov</a></td>
</tr>
<tr>
<td>Juvenile abundance</td>
<td>Annual</td>
<td><a href="http://wdfw.wa.gov/hab/imw/index.htm">http://wdfw.wa.gov/hab/imw/index.htm</a></td>
</tr>
<tr>
<td>Spawners</td>
<td>Annual</td>
<td><a href="http://wdfw.wa.gov/hab/imw/index.htm">http://wdfw.wa.gov/hab/imw/index.htm</a></td>
</tr>
</tbody>
</table>

**Table 5. Measurements procured using the EMAP sampling protocol.**

<table>
<thead>
<tr>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>width-depth ratio</td>
</tr>
<tr>
<td>channel confinement</td>
</tr>
<tr>
<td>average pool depth</td>
</tr>
<tr>
<td>residual pool depths</td>
</tr>
<tr>
<td>Substrate size distribution</td>
</tr>
<tr>
<td>Shading</td>
</tr>
<tr>
<td>LWD size and distribution</td>
</tr>
<tr>
<td>Off channel slope</td>
</tr>
<tr>
<td>channel sinuosity</td>
</tr>
</tbody>
</table>

**Fish Populations**

The Lower Elwha Klallam Tribe installed smolt traps in Deep Creek in 1998, in the West Twin and East Twin Rivers in 2001, and in Sadie Creek in 2005. Traps, consisting of a fence weir and live box, capture the entire population of emigrating smolts. Trapping begins in late April and continues through mid-June. Peak outmigration occurs in late May. Since 2004, coho and steelhead parr have been captured in late summer and PIT tagged in East Twin and West Twin Rivers. Permanent antennae have been installed near the mouth of each stream to record the outmigration of individual tagged fish from each basin and the return of tagged spawners. The PIT tagging studies are described in detail below.
In all watersheds adult abundance and distribution surveys are conducted throughout the spawning season. The traditional WDFW index reaches have been supplemented with surveys of randomly selected reaches, stratified by habitat unit. All spawning fish (coho) or redds (steelhead) encountered during the stream surveys are counted and location is noted for later entry into a GIS database. The purpose of the surveys is to generate abundance estimates of spawning fish for each watershed and to assess spawner distribution.

Parr abundance is determined each summer. Fish are collected at 10 randomly selected reaches (site selection based on EMAP protocols) in each complex by one-pass electroshocking surveys. Catch per unit effort (time) is used to provide an indication of parr distribution and relative abundance of age 0 trout. Total watershed abundance of coho and age 1 steelhead parr is estimated using a mark-recapture method. The adipose fin is removed from all coho and age 1 steelhead parr captured in the Deep Creek and PIT tags are implanted into fish in East Twin and West Twin Rivers. Marks are noted during smolt trapping the following spring in Deep Creek, enabling an estimate of the survival of marked fish from summer through smolting. Total parr abundance in each watershed the previous summer is then estimated from the survival rate and the proportion of marked to unmarked fish captured in the smolt trap or PIT-tag reader.

**PIT-tag studies**

The standard juvenile, smolt, and adult monitoring (described above) in the Straits IMW complex provides some information on the effects of restoration on fish abundance. This information is being augmented through the use of passive integrated transponder (PIT) tags. Prior to the development of PIT tag technology and the more recent development of remote detectors, collecting accurate survival, movement and migration information was difficult. The recent improvements in this technology have enabled us to compare fish abundance, survival, movement and migration timing (life history) among watersheds, reaches, and habitats before and after completion of restoration treatments. Specifically, we are focusing on the following questions:

1. What is the effect of habitat restoration activities throughout the watersheds on survival, growth and migration timing of fish?
2. Do survival, growth and movement differ among tributaries and reach types within the watersheds? Will the application of restoration projects cause differential responses in these variables among locations and reach types?
3. What is the effect of reach-level restoration efforts on local movements and growth of fish?
4. Does survival, growth, or movement differ among habitat types (e.g., pools, riffles, glides) and can we improve survival by creating more pool habitats?

Initially, we set out to answer the third question by examining differences in survival and movement between restored (complex habitat with high levels of LWD) and unrestored reaches (simple no LWD placement) in East Twin river. This effort served as a pilot study to assess the capabilities of new PIT tag technologies and provided us with the methodologies required to address the remaining questions.

Stationary multiplex PIT tag readers were installed in East Twin and West Twin Rivers in the summer/fall of 2004 allowing for the detection of PIT tagged fish passing the readers. These were located approximately 1000 m and 500 m from saltwater in East and West Twin, respectively.
To address these questions we examined fish movement in two simple and two complex (LWD enhanced) 100-meter-long reaches in East Twin River in 2003 and 2004. During late summer (August and September), about 800 trout and coho were collected by electrofishing, anesthetized, measured, weighed, PIT tagged, and released into their habitat of origin. Movement of the tagged fish was monitored with a hand-held reader used to interrogate fish encountered during periodic snorkel surveys. This work is part of a University of Washington masters thesis (T. Bennett).

Continuous PIT tag detectors were not in place in spring 2004. Surprisingly, only about 5% of the fish PIT tagged in late summer 2003 were captured in smolt traps in spring 2004. The low tag recovery rate in 2003 also suggested that large numbers of fish (>1,500) needed to be tagged. The reason for this low recovery rate could have been high mortality rates or migration of tagged fish from East Twin River prior to the installation of the smolt trap. A stationary PIT tag reader, located near the site of the smolt trap, was installed in 2004 to determine if early emigration of the fish was the cause of the low, spring recovery rate.

In 2004 nearly 3000 fish were tagged in East Twin River and West Twin River (Table 6). The stationary PIT tag reader indicted that large numbers of coho and trout parr emigrated from the study watersheds in the autumn (See preliminary analyses).

Table 6. Number of trout and coho PIT tagged in 2004, 2005, and 2006. Overwinter survival is being calculated by dividing the number of tagged spring migrants by the total number of tagged fish minus the fall emigrants (survival = spring migrants/ (total tagged – fall migrants)).

<table>
<thead>
<tr>
<th></th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E. Twin</td>
<td>E. Twin</td>
<td>E. Twin</td>
</tr>
<tr>
<td></td>
<td>W. Twin</td>
<td>W. Twin</td>
<td>W. Twin</td>
</tr>
<tr>
<td>Coho</td>
<td>2,208</td>
<td>3,200</td>
<td>2,500</td>
</tr>
<tr>
<td>Trout</td>
<td>475</td>
<td>1477</td>
<td>1,325</td>
</tr>
<tr>
<td>Total</td>
<td>2,964</td>
<td>9,300</td>
<td>7,650</td>
</tr>
</tbody>
</table>

The number of PIT tags deployed in the study streams was further increased in 2005 and a permanent tag reader was installed on West Twin. We PIT tagged 9,300 juvenile coho and trout in East and West Twin in August and September 2005. About one third of these fish were tagged at randomly selected reaches and the remainder was tagged in the lower few kilometers of the East and West Twin where most of the anadromous fishes are concentrated and we could efficiently collect large numbers of fish. This broad-scale spatial tagging effort in 2005 will not only allow us to compare fish survival, growth, and migration between the treatment (East Twin) and control (West Twin) (question 1), but also allow us to answer questions 2 and 3 as fish were tagged throughout the watersheds and we have information on reach types and habitat types where fish were tagged. We will continue tagging approximately 3,500 juvenile coho and trout per year in each watershed.

Data management

Database management has been largely centralized and integrated into existing databases at WDFW and Ecology (Table 4). This is more efficient and enables easier dissemination of the data. The exceptions to this are special studies where the data require extensive, ongoing manipulation to be meaningful to scientists (e.g. data collected in the PIT-tagging studies of juvenile movement and survival described below in the Straits of Juan de Fuca IMW complex). In these cases the study results will be released and posted in technical reports to the IMW websites at WDFW and Ecology.
Restoration Treatments

Compromised habitat conditions varied among reaches but were very similar among the three basins. These include:

- Excess sediment delivery due to elevated rates of mass wasting
- Streambed scour from dam-break floods
- Lack of wood in channels
- Loss of off-channel, floodplain habitats due to channel incision
- High stream temperature due to loss of riparian cover.

A restoration strategy was developed with the goal of reestablishing the dominant physical processes that controlled the identified limiting factors. This strategy includes the following:

- Reduction in the rate of mass wasting to historical background rates
- Reestablishment of late-succession, conifer-dominated, riparian forests.
- Reintroduction of large pieces of wood (LWD) to channels.
- Re-creation of off-channel habitats.

Increased rate of mass wasting in was caused by poorly constructed roads. In 1999-2001, road maintenance and abandonment were conducted on some hazardous road segments within the watershed. A recently completed NEPA analysis of the entire 3040 road system, which has generated dozens of landslides in Deep Creek, East Twin River, and West Twin River, concluded that significant (~30 miles) portions of this mid-slope road system should be decommissioned. The U.S. Forest Service has funding to achieve approximately half of the proposed decommissioning and the North Olympic Peninsula Lead Entity was awarded SRFB funding in January 2006 to complete remaining treatments. Because this corrective action will be taken simultaneously in all three watersheds in the complex (including the reference watershed) evaluating responses to this treatment is not part of the study.

Channel restoration activities on Deep Creek began in 1997 and focus on using LWD to accomplish specific goals, depending upon the dominant impact at the reach level (Figure 8). For example, above RM 1.3, the 1990 dam-break flood resulted in severe scour of the bed and the almost complete loss of in-channel LWD. Conversely, below RM 1.3, the impacts were primarily associated with sediment deposition (pool filling, channel widening). Because of the inherent channel instability observed below RM 1.3, restoration activities were initiated above this point (RM 1.0 to 4.0). Between 1997-2002 LWD and rock was placed in an attempt to convert this plane-bed reach into a forced pool-riffle reach. Over 1,500 individual pieces of LWD have been used to form log revetments, engineered log jams, constructed log jams, deflectors, log weirs, and rock/log structures. Additionally rock weirs were used in some locations to build channel bed features. In 2004-05 restoration activities focused on the lower reaches of Deep Creek (RM 0 to 1.3) and large, complex logjams (including channel spanning) were constructed at 23 locations. To date, 4.0 miles of Deep Creek, 0.5 miles of Sampson Creek, and 0.4 miles of Gibson Creek (Deep tributaries) have received in-stream restoration treatments, while riparian vegetation improvements have been conducted on 2.5 miles of riparian forest. The riparian vegetation projects included manipulation of existing stands to promote the growth of conifer-dominated riparian stands. Four off-channel, winter rearing habitat projects have been implemented.
A watershed analysis (USFS 2002) conducted in the 1990s identified the same suite of factors affecting habitat condition in East and West Twin rivers as Deep Creek. However, logging related disturbances have been less severe in the Twin Rivers than Deep Creek. Restoration efforts in the East Twin River were initiated in 1998, when an off-channel rearing pond was constructed on private property near river mile 1.0 (km 1.6). Large scale LWD reintroductions were initiated in 2002 by the Elwha Klallam Tribe when a Salmon Funding Recovery Board awarded a restoration grant to fund these efforts. In the summer of 2002 over 450 metric tons of LWD was placed with a helicopter into Sadie Creek at forty sites in river mile 0-2.0 (km 0.0-3.2) and at 30 sites in the East Twin River in river mile 2.0-3.0 (km 3.2-4.8). These efforts were followed in 2003-04 with ground-based placement at an additional 35 sites in the East Twin at river mile 1.2-2.0 (km 2.0 and 3.2). An estimated 50 year flood occurred in October of 2003, resulting in substantial habitat response to restoration. Additional ground based treatments were completed by the Tribe in 2005 between river mile 0.3-1.0, with the addition of complex LWD structures at 16 sites.

Based on the effects of habitat restoration shown in Table 5 of the 2006 IMW Study Plan (http://www.iac.wa.gov/Documents/Monitoring/IMW_StudyPlan.pdf) and the restoration completed to date, the expected increases in smolt production were calculated for Deep Creek and East Twin River (Table 7). Restoration in Deep Creek is expected to result in an increase of 2684 coho smolts, a 24% increase in mean annual production. The increase in East Twin River coho smolt production was calculated at 1855, an increase of 22% over the mean.

### Table 7. Calculated effects of habitat restoration on coho smolt production in Deep Creek and East Twin River were based on the literature review summarized in Table 5 of the 2006 IMW Study Plan.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Wood placement</th>
<th>Off channel habitat</th>
<th>Total smolts/yr</th>
<th>% of mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>meters restored</td>
<td>parr produced</td>
<td>smolts produced (estimated)</td>
<td>m² habitat restored</td>
</tr>
<tr>
<td>Deep Creek</td>
<td>5632</td>
<td>3147</td>
<td>1187</td>
<td>4046</td>
</tr>
<tr>
<td>East Twin R.</td>
<td>6437</td>
<td>3597</td>
<td>1357</td>
<td>1347</td>
</tr>
</tbody>
</table>

It is clear that habitat restoration projects, properly selected and implemented, can increase fish density (see reviews in Roni et al. 2002, 2005). In order for the IMW to test the effects on smolt production, we must ensure that:

1) enough projects are implemented to cause an increase in smolt production and

2) the monitoring program is able to detect the anticipated response within a reasonable time frame.

The first will be addressed basin by basin as restoration plans are developed. The second, the ability of the monitoring program to detect a change in smolt production, was addressed through a series of power analyses in the 2006 study plan with key results presented in the following section (http://www.iac.wa.gov/Documents/Monitoring/IMW_StudyPlan.pdf).
Figure 8. Restoration projects in Deep Creek and East Twin River.
Analysis

Fish

Because fish monitoring and habitat restoration began at about the same time a comparison of the fish metrics in the treated watershed vs. the reference watershed over time will be done using two designs (Table 8) Assuming that the fish response is proportional to the amount of habitat restoration, then fish production should increase, relative to the reference, gradually over time and may be evaluated using regression analysis. If fish production responds only after a critical amount of restoration has occurred, then the increase should be evident after that level of restoration has occurred and can be tested using a paired t-test. Although multiple years of pretreatment data would enhance our ability to detect differences, these methods, along with an examination of the causal mechanisms of changes in production, should be sufficient to detect changes in mean production of 22-60% at an 80% confidence level with approximately ten years of monitoring. This estimate is based on a power analysis using long-term Hood Canal coho smolt production data.

The detailed resolution of fish outmigration and better survival estimates obtained using the PIT tag readers will likely enhance our ability to detect differences in summer parr population, overwinter and marine survival rates, and outmigration timing. However, because collection of these data was only recently initiated, existing data are insufficient to estimate a minimum detectable change in these metrics.

Habitat

Habitat is sampled for two purposes using two designs. First, we employ a Before-After study design to estimate the reach-scale effects of a suite of restoration projects on physical habitat in order to evaluate the effects measured fish metrics. The anadromous length of each stream was divided into segments, based on when the habitat restoration projects were scheduled for completion. Each segment was monitored at least one year prior to restoration and following restoration at three to five year intervals. Second, we employ the EMAP random site selection method to estimate habitat conditions across the entire watershed. This estimate will be used as a covariate in the analysis of outmigrant production.

PIT tagging data analysis

Differences in survival, growth, and migration among tributaries, reaches and habitats are being compared using an ANOVA or t-tests (survival, growth), graphical analysis (migration timing), and chi-square test or Kolmogorov-Smirnov goodness of fit tests (movement, migration timing). As we collect multiple years of data for each watershed, we will utilize specific metrics such as median migration date and proportion of fall migrants etc. to compare among treatment and control watersheds and among years. These will be compared using parametric statistics such as ANOVA or ANCOVA assuming data are normally distributed. If not, we will apply graphical or nonparametric statistics to examine differences among watersheds and years.
Table 8. Statistical tests and criteria proposed in the data analysis.

<table>
<thead>
<tr>
<th>Component</th>
<th>Indicator</th>
<th>Metric</th>
<th>Statistical test</th>
<th>Statistical criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish</td>
<td>Outmigrant production</td>
<td>Numbers</td>
<td>Regression or paired t-test</td>
<td>$\alpha = 0.20$</td>
</tr>
<tr>
<td></td>
<td>Summer parr population and growth</td>
<td>#, length</td>
<td>Paired t-test</td>
<td>$\alpha = 0.10$</td>
</tr>
<tr>
<td></td>
<td>Egg-to-parr survival</td>
<td>%</td>
<td>Paired t-test</td>
<td>$\alpha = 0.10$</td>
</tr>
<tr>
<td></td>
<td>Parr-to-smolt survival</td>
<td>%</td>
<td>Paired t-test</td>
<td>$\alpha = 0.10$</td>
</tr>
<tr>
<td></td>
<td>Outmigration timing</td>
<td>%</td>
<td>Graphic analysis and $\chi^2$ test</td>
<td>$\alpha = 0.10$</td>
</tr>
<tr>
<td>Habitat</td>
<td>Marine survival</td>
<td>%</td>
<td>Paired t-test</td>
<td>$\alpha = 0.10$</td>
</tr>
<tr>
<td></td>
<td>Pool area</td>
<td>$m^2$</td>
<td>Paired t-test</td>
<td>$\alpha = 0.10$</td>
</tr>
<tr>
<td></td>
<td>Width-depth ratio</td>
<td>Ratio</td>
<td>Paired t-test</td>
<td>$\alpha = 0.10$</td>
</tr>
<tr>
<td></td>
<td>LWD</td>
<td>#, Volume</td>
<td>Paired t-test</td>
<td>$\alpha = 0.10$</td>
</tr>
</tbody>
</table>

**PIT tagging preliminary results**

Data from the PIT tag readers and marked fish indicated that unexpectedly large numbers of parr (primarily coho) migrated to sea during fall months (Figure 9). Relatively few parr migrated during winter (January through March) and the largest numbers emigrated as smolts in the spring. A t-test indicated that fall-migrating coho were significantly smaller at tagging than spring coho migrants (64.1 and 74 mm, respectively) (Figure 10). This suggests that smaller, less fit fish are forced out in the fall or seek other foraging opportunities outside the watershed. The relative contribution of fall and spring-migrating coho to adult returns will be assessed as returning tagged adults are detected at the permanent PIT tag readers in the fall 2007 and by examining carcasses for tags in fall/winter 2007-08.

Total numbers of tagged smolts captured in the East Twin smolt trap in spring 2005 was 228 coho, 2 cutthroat trout, 32 steelhead, and 7 age 1+ trout, a total of 269 tagged fish. However, 388 passed the PIT reader located a short distance upstream from the smolt trap. Possible explanations for this discrepancy include trap avoidance, predation on tagged fish, and smolts moving to past the trap location during a period when trap panels were pulled for high water between May 23 and May 25, nearly at the height of migration.

After the installation of the West Twin reader in 2004, we recorded four PIT tagged fish moving between East Twin River and West Twin River during the summer. Although this represents a very small proportion of tagged fish, it was surprising that 500 m of saltwater between the two river mouths did not present a barrier to movement of these fish.

As indicated earlier, 9,300 and 7650 juvenile salmonids were tagged in the summers of 2005 and 2006, respectively. The 2006 data will be analyzed and summarized following the completion of spring 2007 migration period.
The percentage of fall migrants was not significantly different between treatment and control reaches (t-test, p > 0.10; Table 9). Similarly, survival estimates from the complex and simple reaches did not differ (t-test, p > 0.10), but complex reaches had higher densities of fish. This suggests that habitat enhancement through LWD placement leads to more smolts not through higher survival, but increased densities.

Table 9. A comparison of the proportion of early migrants and overwinter survival for coho tagged in simple and complex reaches and East Twin versus Sadie Creek (major tributary) in 2004. Fall migrants are the number of tagged fish detected passing the PIT readers before January 1. Overwinter survival was calculated as the # spring migrants/ (total tagged fish - # fall migrants). Number in parenthesis is number of outmigrating fish detected in fall or spring.

<table>
<thead>
<tr>
<th></th>
<th>Simple</th>
<th>Complex</th>
<th>East Twin</th>
<th>Sadie Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall migrants</td>
<td>20.9</td>
<td>20.1</td>
<td>21.6</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>(151)</td>
<td>(148)</td>
<td>(351)</td>
<td>(15)</td>
</tr>
<tr>
<td>Overwinter Survival</td>
<td>9.3</td>
<td>10.2</td>
<td>10.2</td>
<td>22.4</td>
</tr>
<tr>
<td></td>
<td>(53)</td>
<td>(60)</td>
<td>(130)</td>
<td>(127)</td>
</tr>
</tbody>
</table>

Figure 9. Fall 2004 to spring 2005 migration of East Twin River juvenile coho and trout tagged in summer 2004. A total of 459 trout and coho were detected by the PIT tag reader leaving the system between September 24 and December 31, 2004, while 356 fish were detected leaving the system between January 1 and June 20, 2005.
Figure 10. Length at tagging of juvenile coho salmon tagged in 2004 moving past the East Twin Creek PIT tag reader in fall 2004 and spring 2005. Fall migrants were significantly smaller at time of tagging (late summer) than spring migrants.

Other observations
Maintaining the permanent PIT tag readers presents some challenges. The readers require a substantial amount of continuous power. Power was initially supplied by eight, 12-volt, car batteries that needed to be replaced/recharged on a weekly basis. The battery system on the East Twin River reader was replaced in June 2004 with a thermoelectric generator powered by liquid propane stored in a 100-gallon propane tank. This power supply is much more reliable and can power the system for 60 days without service. This option is being assessed for the reader on West Twin. The West Twin reader suffered serious damage when it was inundated in a large flood. It was subsequently replaced and the electronics moved to higher ground.

Schedule and Budget
Table 10 shows monitoring timeline and projected schedule for results. This schedule assumes that up to 10 years will be required for a significant change in production to be detectable.

The Budget for FY08 (Table 11) shows direct Salmon Recovery Funding Board funding as well as in-kind support from the IMW partners, and existing monitoring done outside of the IMW program, but critical to it.
Table 10. Timeline for monitoring and expected results in the Strait of Juan de Fuca complex.

<table>
<thead>
<tr>
<th>Year</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998-2001</td>
<td>Outmigrant monitoring by Lower Klallam Tribe begins</td>
</tr>
<tr>
<td>1997-2005</td>
<td>Habitat restoration implemented</td>
</tr>
<tr>
<td>2004</td>
<td>IMW monitoring begins</td>
</tr>
<tr>
<td>2005</td>
<td>Permanent PIT tag antennae installed</td>
</tr>
<tr>
<td>2007</td>
<td>First estimates of summer parr population, survival, and outmigration timing</td>
</tr>
<tr>
<td>2008</td>
<td>First estimates of marine survival for East and West Twin Rivers</td>
</tr>
<tr>
<td>2008</td>
<td>Analysis of habitat metrics</td>
</tr>
<tr>
<td>2010</td>
<td>Interim analysis of data collected to date</td>
</tr>
<tr>
<td>2015</td>
<td>Analysis of fish metrics</td>
</tr>
</tbody>
</table>

Table 11. FY08 budget for the Strait of Juan de Fuca complex. In-kind support is that provided by the IMW partners and includes monitoring and scientific oversight. Existing monitoring includes monitoring not funded by the IMW but that is an integral part of and critical to the study.

<table>
<thead>
<tr>
<th></th>
<th>SRFB</th>
<th>In-kind</th>
<th>Existing</th>
</tr>
</thead>
<tbody>
<tr>
<td>WDFW</td>
<td>$ 61,740</td>
<td>$13,250</td>
<td></td>
</tr>
<tr>
<td>NOAA-NWFSC</td>
<td>$168,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Elwha Klallam Tribe</td>
<td>$ 84,000</td>
<td>$24,500</td>
<td>$90,000</td>
</tr>
<tr>
<td>Ecology</td>
<td>$ 55,200</td>
<td>$13,250</td>
<td></td>
</tr>
<tr>
<td>Weyerhaeuser</td>
<td></td>
<td>$26,300</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$368,940</td>
<td>$77,300</td>
<td>$90,000</td>
</tr>
</tbody>
</table>
References


editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, Maryland.


