Study Plan for the Intensively Monitored Watershed Program: Hood Canal 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 Hood Canal 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>Watersheds</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>Focal Species</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>Land Use</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>Complex Area</td>
<td>113 km²</td>
<td>78 km²</td>
<td>206 km²</td>
</tr>
<tr>
<td>(watershed)</td>
<td>(33, 35, 45 km²)</td>
<td>(15, 13, 36, 14 km²)</td>
<td>(57, 73, 75 km²)</td>
</tr>
<tr>
<td>Geology</td>
<td>mixed sedimentary and metamorphic</td>
<td>glacial till</td>
<td>flow basalt w/ interbedded sandstone</td>
</tr>
<tr>
<td>Precipitation</td>
<td>190 cm/yr</td>
<td>105 cm/yr</td>
<td>160 cm/yr</td>
</tr>
</tbody>
</table>
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 are common to all three Coho/Steelhead complexes. Hypotheses 6 and 7 are unique to the Hood Canal complex.

1. The increase in outmigrant production following habitat restoration 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 geographic distribution of spawners is correlated with maximum November flow, with escapement, and with smolt production.
7. Summer low flows are correlated with habitat quantity and quality and with parr-smolt survival.

**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). Recent examples of aquatic restoration monitoring using a BACI design include Cederholm et al. (1997) and Solazzi et al. (2000).

Downes et al. (2002), in a thorough review of BACI study designs, identified several types, including one with replication (multiple treatment and controls) that they referred to as the multiple BACI or MBACI. Hicks et al. (1991) referred to this design as an extensive BA study but assumed that sampling intensity would be reduced because of the increased number of treatment and control sites. A replicated BACI design potentially is the most powerful of all study designs because it includes replication in both space and time (monitoring of multiple treatments and controls before and after restoration) but also potentially is more challenging and costly to implement than other designs (Downes et al. 2002). Spatially replicating BA and BACI such as the IMW project addresses many of
the problems inherent in these designs and would increase the applicability of our results to other areas. Roni et al. (2005) indicated that while no ideal study design exists to answer all questions, the most powerful design is a BA or BACI design that includes many paired treatments and controls across the landscape that are monitored for many years. Furthermore, they indicated this is the type of monitoring needed to quantify population- and watershed-level responses.

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, other approaches may be used depending upon the question addressed, the scale of the assessment, and the data available.

The Hood Canal IMW complex includes three treatment basins and one watershed, Stavis Creek, serving as a reference site, where no restoration projects will be implemented during the study. There is extensive pre-treatment smolt production data available to assess the relationship between reference and treatment watersheds but little habitat or water quantity/quality data. However, there will be three to four years of habitat data available prior to the initiation of restoration.

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 can be 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. Therefore, 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 local salmon recovery lead entities for each complex in order to ensure the integrity of the reference sites. We expect human activities will occur in some of the reference watersheds (e.g., continued residential development). 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.

Experimental treatments (restoration actions) will begin in Summer 2007 in Little Anderson Creek and scoping of additional projects in Little Anderson and Big Beef Creek are underway. However, these basins, in contrast to the Strait of Juan de Fuca and Lower Columbia, are comprised of numerous landowners adjacent to the streams. Coordination and communication with landowners will be critical to the implementation of sufficient restoration projects to elicit a response in fish production.

It is clear that habitat restoration projects, properly selected and implemented, can increase fish density (see reviews by 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 as restoration plans are developed. The second, the ability of the monitoring program to detect a change in smolt production, is addressed below through a series of power analyses.

Power Analyses

The purpose of these power analyses is to quantify the IMW program’s ability to detect a change (e.g. magnitude of change and number of years needed). The detectable change in smolt production should create clear expectations for the IMW program when viewed in the context of the anticipated effects of habitat restoration.

The advantage of the BACI design is that the effect of external drivers of productivity (e.g. weather events and related stream flow) that affect all study streams can be statistically removed, thereby making changes due to habitat restoration easier to detect. The degree to which the ability to detect treatment is improved is a function of the strength of the correlation between the treatment and control basins. The lower regression line in Figure 2 shows the pre-restoration relationship between coho smolt production in Big Beef Creek and Stavis Creek, the reference stream. The assumption is that after restoration smolt production will increase, i.e. the regression line will be displaced upward so that for a given level of production in Stavis Creek, production in Seabeck Creek will be higher. An advantage of the regression model is that additional explanatory variables may be included in the model, further reducing the unexplained for variability, thereby increasing the power of the test to detect a change in production. However, if there is no significant relationship between the reference stream and a treatment stream, we will use a before-after comparison of smolt production.
Figure 2. Hypothesized increase in smolt production is shown as a translation of the regression line upward (i.e. higher production in Seabeck Creek as a given level of production in Stavis Creek).

The minimum detectable change (assuming a one-tailed, two-sample t-test) is a function of the confidence level ($\alpha$), power ($\beta$), the variance of the data, and the sample size (Equation 1). We have set $\alpha=\beta=0.10$ for all analyses.

$$\Delta P = \sqrt{\frac{2s^2 (t_{1-\alpha} + t_{1-\beta})^2}{n}}$$  \hspace{1cm} (1)$$

where $\Delta P$ = the detectable change in smolt production,
$s^2$ = variance of the pre-restoration data (for the Before-After case) or the residuals of the treatment vs. reference stream regression (for the BACI design),
$t_{1-\alpha}$ = $t_{(0.90, n)}$ ($\alpha=0.10$, one-tailed test)
$t_{1-\beta}$ = $t_{(0.90, n)}$ ($\beta=0.10$)
$n$ = number of years of pre and post-restoration monitoring (sample size).

We have conducted a series of power analyses using data from the Hood Canal IMW complex. Data from Stavis Creek, Big Beef Creek, and Seabeck Creek in the Hood Canal IMW complex were used because only this complex has sufficient data at this time.
to estimate the statistical relationship between the treatment and reference basins. Smolt production has been measured concurrently at all Hood Canal streams since 1993, except that no data were collected in 1996 at Seabeck, Stavis, or Little Anderson Creeks and no estimate is available for Little Anderson Creek in 1998. Flow data, used as a covariate in the analyses, was available all years except 1996. Little Anderson Creek smolt data are not significantly correlated with Stavis Creek (reference stream) data and so only a Before-After analysis was examined in the power analysis.

The power analyses conducted assumed:

1) a Before-After design, applicable where the relationship between Reference and Treatment was not significant;
2) a BACI design, applicable where there is a statistically significant relationship between the Reference and Treatment basins; and
3) a BACI design using environmental covariates, applicable where there is a statistically significant relationship between the Reference and Treatment basins and explanatory environmental data are available (i.e. habitat, flow, # spawners, etc.).

The variance of annual, pre-restoration smolt production in the treatment stream (Big Beef or Seabeck) was used in Equation 1 for the Before-After comparison. A simple linear regression model of treatment stream vs. Stavis Creek, the reference stream, was used for the second analysis, (BACI design with no covariates). Maximum November flow and spawner escapement were added to the regression model to estimate the impact of covariates on the detectable change. The results of the analyses are shown in Table 2 and in Figures 3 and 4.

Assuming an equal number of years of monitoring pre and post-restoration, the analysis shows that we could detect an increase in smolt production on Big Beef Creek equal to 65% of mean production (mean production was approximately 26,000 smolts/year) after six years using a Before-After analysis. At 12 years the detectable difference is reduced to 43%. Use of the BACI design results in a detectable increase in production of 51% and 34% at six and 12 years, respectively. The addition of November flow as a covariate in the BACI model resulted in a detectable increase of 33% and 22% of the mean at six and 12 years respectively.

The results using Seabeck Creek data were similar. Detectable changes of 49% and 33% at six and 12 years, respectively, were calculated using a Before-After design. Use of the BACI design reduced this to 35% and 23% at six and 12 years. The addition of significant covariates to the BACI analysis reduced this further to 27% and 18%.

Little Anderson Creek smolt production data were not correlated with the reference basin, so only the Before-After analysis was considered. Detectable changes calculated using the Before-After analysis were 288% (818 smolts) and 192% (545 smolts) at six and 12 years, respectively.
Table 2. Comparison of detectable change with six and 12 years of post-restoration data based on long-term smolt monitoring data collected in Hood Canal IMW complex. Data indicate that increases in production of approximately 20% and 30% of the mean will be detectable with 12 and six years, respectively, of post-restoration monitoring.

<table>
<thead>
<tr>
<th>Design</th>
<th>Covariates</th>
<th>(R^2)</th>
<th>Variance</th>
<th>Detectable change (% mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 years</td>
</tr>
<tr>
<td>Big Beef Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before-After</td>
<td>NA</td>
<td>NA</td>
<td>9.83 \times 10^7</td>
<td>65%</td>
</tr>
<tr>
<td>BACI</td>
<td>None</td>
<td>0.31</td>
<td>6.76 \times 10^7</td>
<td>61%</td>
</tr>
<tr>
<td>BACI</td>
<td>November flow</td>
<td>0.66</td>
<td>2.71 \times 10^7</td>
<td>33%</td>
</tr>
<tr>
<td>Seabeck Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before-After</td>
<td>NA</td>
<td>NA</td>
<td>227,998</td>
<td>49%</td>
</tr>
<tr>
<td>BACI</td>
<td>None</td>
<td>0.42</td>
<td>111,998</td>
<td>35%</td>
</tr>
<tr>
<td>BACI</td>
<td>November flow, escapement</td>
<td>0.57</td>
<td>68,590</td>
<td>27%</td>
</tr>
<tr>
<td>Little Anderson Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before-After</td>
<td>NA</td>
<td>NA</td>
<td>45,138</td>
<td>288%</td>
</tr>
</tbody>
</table>
Figure 3. Detectable change in smolt production, presented as a percentage of the mean production, vs. number of years needed to monitor for Seabeck Creek. The upper line assumes a Before-After analysis (no significant relationship to the reference stream). The middle line assumes a BACI design with Stavis Creek as the reference. Further improvements are seen in the lower line using a BACI design with flow and escapement as covariates. See Table 6.
Figure 4. Detectable change in smolt production, presented as a percentage of the mean production, vs number of years needed to monitor for Big Beef Creek. The upper line assumes a Before-After analysis (no significant relationship to the reference stream). The middle line assumes a BACI design with Stavis Creek as the reference. Further improvements are seen in the lower line using a BACI design with flow and escapement as covariates (Table 2).

These results indicate there is a high probability that the proposed monitoring will be able to detect response in coho smolt production to restoration in the Hood Canal complex. As the restoration plans for Hood Canal watershed are developed, we will ensure that the anticipated cumulative effect of all restoration projects on smolt production will be large enough that we have a reasonable probability of detecting it.

**Hood Canal Complex-Description**

The Hood Canal complex has the longest smolt production record of the three IMW complexes allowing a more extensive analysis of correlates with smolt production and a longer calibration period of pre-treatment smolt production in treatment vs. the reference watershed. Landuse is more diverse in this complex than the other two, including commercial forestry, expanding rural residential development, and even some urban growth from the Silverdale area into the Little Anderson basin. Although the diverse land use patterns complicate our efforts to determine the effects of restoration on fish production, the basins’ small size provide the potential to treat a substantial portion of the stream network, thereby producing a large change in habitat condition over a short period.
Description

These four basins (Figure 5), on the west side of the Kitsap Peninsula, comprise a large proportion of the West Kitsap WAU. This WAU is within the Puget Sound trough which as a result of glacial activity, generally has a gently rolling upland of glacial till with steep-sided ravines leading down to the river floodplains. The glacial till of the uplands is fairly resistant to erosion but the loose sandy soil and layers of fine textured material comprising the ravine sideslopes are very erodible. In addition, layers of clay in the ravine walls can transport water laterally and where this intersects a road cut, ground water often flows onto the road.

Commercial logging of lowland areas was underway by 1870 with the establishment of large sawmills. Extensive logging of the uplands began in the 1920s when a railroad network was built to transport the timber and continued into the 1940s until few merchantable trees were left. Although forest practices have improved markedly, legacy effects may exist. Based on early 1990’s satellite imagery, over 80% of each basin is forested and the proportion developed is low (Table 3). However, rural residential development has increased continuously since the 1970’s and may be degrading habitat through riparian vegetation removal, stormwater runoff, fish passage barriers, and high sediment loads (WA DNR 1995; Seiler et al. 2002).

Naturally produced salmonids from the Hood Canal Complex include coho salmon, fall chum salmon, cutthroat trout, and a small population of steelhead. The University of Washington maintains an artificial production facility on Big Beef Creek, where summer chum and chinook are reared. All chinook returning to the creek are sorted at a weir located at the mouth and precluded from migrating upstream to spawn in the wild. All of the releases from this facility occur downstream of the weir and, therefore, do not effect the wild juvenile downstream migrant counts at Big Beef Creek. Hatchery fish are not released in any of the other Hood Canal Complex streams.

Smolt counts began in Big Beef Creek in 1978. Smolt counts in the other three streams date from 1992 or 93 (Table 4). Wild coho salmon from Big Beef Creek have been coded wire tagged since 1976. Historically, a substantial portion of the harvest occurred in outside fisheries (i.e., Vancouver Island Troll Fishery, Washington Troll & Sport Fisheries). As these fisheries became increasingly constrained by weak-stock management and ESA, terminal harvests in the Hood Canal Net Fishery have made up the bulk of the fishing impact on this stock. The terminal Area 12 fishery is centered around Big Beef Creek and extends as far north as Lone Rock and as far south as Stavis Bay. Recent data indicate catch rates can be highly variable. In 2002, we estimated a 68% total exploitation rate on tagged, wild Big Beef coho with 98% of the impact occurring in the Area 12 beach seine fishery. Yet in 2003, very few fish were harvested in this fishery as the bulk of the effort was centered in the Areas to the south.
Figure 4. Hood Canal IMW Complex. Washington Department of Natural Resources land is green. Lakes and wetlands are blue. Contour intervals are 100m.

We have drawn upon the following data sources in developing our hypotheses of freshwater production constraints in these basins:

- smolt and adult escapement counts at the Big Beef Creek weir since the late 1970s (WDFW);
- Stream discharge has been measured near the mouth of Big Beef Creek by the USGS since 1969 ([http://nwis.waterdata.usgs.gov/wa/nwis/discharge/?site_no=12069550](http://nwis.waterdata.usgs.gov/wa/nwis/discharge/?site_no=12069550)) and above Lake Symington by the Department of Ecology since 2000 ([http://www.ecy.wa.gov/apps/watersheds/flows/station.asp?sta=15F150](http://www.ecy.wa.gov/apps/watersheds/flows/station.asp?sta=15F150)) ;
- smolt counts in the other three streams since 1992 or 1993 (WDFW);
- Sporadic coho and chum spawning ground surveys in all four basins (WDFW);
- Habitat surveys in all four streams conducted by Point No Point Treaty Council and US Fish & Wildlife Service in 1993 (USFWS, 1993);
- 1998 Ecosystem Diagnosis and Treatment analysis of Big Beef Creek;
- West Kitsap Watershed Analysis (WA DNR 1995);
- Habitat surveys conducted on all four streams by WDFW in 2000-2002;
- The West Kitsap Limiting Factors Analysis (Kuttel 2003);
• Salmon Index Watershed Monitoring (Seiler et al. 2002); and
• The Kitsap Salmon Refugia Report (May and Peterson 2003).

These data sources were used to develop descriptions for each watershed and analyzed to formulate hypotheses regarding factors constraining salmonid production in each basin. Most of the discussion on production constraints will focus on coho salmon. Cutthroat trout utilize habitats similar to those preferred by coho. Steelhead typically utilize larger, higher gradient channels. Steelhead production in these basins is very low, likely due primarily to the small size and low gradient of most channels in these watersheds.

Table 3. Land cover, land management, and ownership percentages for each trap basin are shown below. Land cover is based on satellite imagery from the early 1990s. Public ownership was based on the Major Public Lands map.

<table>
<thead>
<tr>
<th>Smolt trap</th>
<th>Basin area (km²)</th>
<th>Land cover (%)</th>
<th>Ownership (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Forested</td>
<td>Developed</td>
</tr>
<tr>
<td>L. Anderson Cr</td>
<td>13</td>
<td>87</td>
<td>8</td>
</tr>
<tr>
<td>Big Beef Cr</td>
<td>36</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>Seabeck Cr</td>
<td>14</td>
<td>91</td>
<td>2</td>
</tr>
<tr>
<td>Stavis Cr</td>
<td>13</td>
<td>83</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 4. Period of record and data collected at each smolt trap.

<table>
<thead>
<tr>
<th>Smolt trap</th>
<th>Juveniles</th>
<th>Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Since</td>
<td>Species</td>
</tr>
<tr>
<td>Anderson Cr</td>
<td>1992</td>
<td>coho</td>
</tr>
<tr>
<td>Big Beef Cr</td>
<td>1978</td>
<td>coho, cutthroat, steelhead</td>
</tr>
<tr>
<td>Seabeck Cr</td>
<td>1993</td>
<td>coho</td>
</tr>
<tr>
<td>Stavis Cr</td>
<td>1993</td>
<td>coho</td>
</tr>
</tbody>
</table>

Little Anderson Creek

Little Anderson Creek is an independent tributary to Hood Canal located east of Big Beef Creek. The Little Anderson Creek watershed is approximately 13-km² and the smallest of the Hood Canal IMWs (Figure 6). It is bordered on the east by the City of Silverdale and a part of the watershed is within the urban growth boundary of the city. Little Anderson Creek is used by coho and chum salmon, and cutthroat trout. A few steelhead also spawn in the stream each year. Hypothesized constraints to coho production include:

- Preferred habitat is limited to the lowest 2.0-km of the mainstem. (High gradient tributaries with little or no summer flow provide little habitat.)
- Main channel lacks LWD to control bed movement and create rearing habitat
- Steep hillslopes, high channel gradients, and altered hydrology may degrade stream channels upstream of river kilometer (RK) 2.0 and scour and/or bury redds below this point
- Fisheries may exert a higher-than-sustainable impact on Little Anderson Creek coho given its current low productivity

Most of Little Anderson Creek and its tributaries are incised. Stream gradient within the fish-bearing portions of Little Anderson Creek averages 3.1% (WDFW unpublished data). Most suitable habitat is found in the lower 2.0 km of the mainstem, where channel gradient is less than 2%. Upstream of this point, flow is evenly divided between the main channel and the right-bank tributary and the channel steepens to 3-5%. The increased gradient and decreased flow likely limits the use of the stream above this point by anadromous fishes.

Although stream banks are largely intact within the Little Anderson Creek watershed, averaging less than 0.3-m$^2$ of exposed bank per meter of stream length, bed scour has resulted in the transport of large amounts of sediment downstream. Large quantities of sediment were deposited in the lower reaches of Little Anderson Creek following a 1994 storm when a road fill with an undersized culvert on Anderson Hill Road failed. This incident released large amounts of sediment accumulated above the culvert and resulted in a braided channel below the culvert. Although the culvert was removed and a bridge was installed in its place in 2002, damage to the channel as a result of the 1994 storm were still evident in 2002. Low to moderate levels of LWD were available to retain gravel and create pools resulting in little spawning and rearing habitat (WDFW unpublished data). Recently, beavers have constructed several dams in this reach and the channel has shifted widely across the valley floor in response the dams and high flows.

Little Anderson Creek produces the fewest coho smolts of the four Hood Canal watersheds. Annual coho production through 2004 ranged from 45 to 833 smolts while cutthroat production has been much higher than coho in all but two of the ten years of record (Figure 7). In low gradient stream systems, coho smolt production is typically one or more orders of magnitude higher than cutthroat (Seiler et al. 2003b). Coho may be sensitive to peak winter stream flows as their eggs are in the gravel through the winter and thus subject to redd scour and sediment deposition (Figure 8. Cutthroat trout do not spawn until spring and avoid negative impacts associated with winter high flows. Summer low flow, an indicator of the amount of summer rearing habitat available is not correlated to coho production. Figure 8 was made using Big Beef Creek flow data, the nearest stream gauge.
Figure 6. Orthophoto of the Little Anderson Creek watershed; the horizontal line indicates the upstream extent of preferred coho and steelhead spawning and rearing habitat.

Figure 7. Annual production of coho, steelhead, and cutthroat smolts from Little Anderson Creek.
Figure 8. Little Anderson Creek coho production as a function of peak December to March discharge in Big Beef Creek.

A potential impact is the terminal Area 12 fishery. It is likely that Little Anderson coho, which are not tagged, experience exploitation rates similar to Big Beef coho. Given their low productivity, high harvest rates on Little Anderson Creek coho may cause very low spawner returns. Therefore, the low coho production observed in Little Anderson Creek may, in part, be due to low escapements. Weekly spawner and redd counts were initiated in 2004 during the coho spawning season to estimate escapement and spawner distribution.

**Big Beef Creek**

Of the four Hood Canal complex streams, Big Beef Creek is the largest, draining a 36-km$^2$ basin. The watershed may be divided into four sections. The upper watershed flows through an extensive network of wetlands (Figure 9). Channels in the upper watershed are low gradient and unconfined. Although similar wetlands are also found in the headwaters of Seabeck and Stavis Creeks, they are less extensive. Below the wetland section, Big Beef Creek flows into Lake Symington, a shallow, man-made impoundment surrounded by a housing development. A fishway provides passage for adult and juvenile coho, steelhead, and cutthroat above the dam. Downstream of the reservoir, Big Beef Creek flows through a canyon to Hood Canal. The stream is highly confined through much of this reach. Within three kilometers of Hood Canal the channel becomes
less constrained as the canyon floor widens and the channel is bordered by a floodplain.

Figure 9. Primary features in the Big Beef Creek watershed.

Upon entering Hood Canal, Big Beef Creek forms a small estuary. The estuary connects to Hood Canal through a narrow opening in a causeway carrying the Seabeck Highway. The estuary was spanned by a 200-m wide bridge prior to the 1970s when the old bridge was replaced with the causeway and a 12-m wide bridge. Since then much of the estuary has filled with sediment. Formerly abundant salt marsh habitat that was inundated through all phases of the tidal cycle has largely been replaced by an incised channel meandering across a mudflat at low tide.

The distribution of spawning salmonids varies among these stream segments. Chum salmon spawn almost exclusively downstream of the Lake Symington dam. Coho steelhead and cutthroat access habitat further upstream in the watershed with the majority of coho and steelhead spawning above Lake Symington.

The University of Washington Big Beef Creek Research Station, located at the mouth of the stream, includes a fish counting weir. WDFW built and currently operates this upstream/downstream trapping facility. Both adult salmon entering the watershed and downstream-migrating juveniles are captured at the weir. The trapping facility has been operating since 1976.

Big Beef Creek produces the most smolts of the Hood Canal complex watersheds. Coho smolt production has ranged from 11,500 to 47,000, and averages over 25,000. Since trapping began in 1978, coho salmon production has exhibited three short-term trends. Production between 1978 and 1986 showed a lot of inter-annual variation, but little trend, with an average production of 29,000 smolts (Figure 10). Coho production decreased between 1987 and 1996, averaging just over 19,000 smolts. Since 1997, production has
returned to the pre-1987 level, averaging 30,000 smolts, and again exhibits considerable interannual variation. Steelhead and cutthroat production are an order of magnitude lower than coho production in Big Beef Creek. Hypothesized constraints to coho production include:

- Extremely low summer base-flow limits the availability of summer rearing habitat in the lower and unconfined valley
- Predation by largemouth bass and other exotics on coho salmon over-wintering in or migrating through Lake Symington reduces the survival of offspring produced above the lake
- Low fall flows limit access to spawning habitat in the upper watershed
- High summer water temperatures reduce available rearing habitat in Lake Symington and a portion of the canyon below the lake
- Land use actions have greatly increased coarse sediment inputs from adjacent hill slopes and tributaries in the lower canyon filling pools and widening channels in the lower canyon and unconfined valley sections, thereby reducing rearing habitat and channel stability
- Removal of large cedar debris in the lower canyon and unconfined valley in the 1980s has destabilized the channel and reduced rearing habitat

Coho smolt production is positively correlated with peak November streamflows (Figure 11). Flow data for Big Beef Creek are not available for the entire period of coho smolt production record. However, a similar relationship was found using the maximum 3-day November precipitation measured at Bremerton as a surrogate for flow (Figure 12). The relationship between smolt production and high flow during the spawning period suggests that higher fall flows may enable spawners to reach areas of the watershed.

Figure 10. Big Beef Creek coho, steelhead, and cutthroat smolt production.
inaccessible during years of lower flow, thereby increasing the amount of spawning and rearing habitat.

A similar relationship between smolt production and summer base flow (60 day average flow) is suggested (Figure 13). The outlier in the plot coincided with very low November spawning flows, suggesting that limitation on access to spawning habitat may have limited production for this year. Many stream reaches in the Hood Canal complex watersheds are dewatered during late summer. As a result, rearing habitat during low flow years may be greatly reduced compared to higher flow years. Given that some of these watersheds are undergoing fairly rapid development, there is the potential for this situation to be exacerbated as impervious area and water use increases.

A study has been initiated as part of the IMW effort in this complex to better understand the mechanisms causing the observed relationships between flow parameters and smolt production. The specifics of this effort are described later in this plan.

Figure 11. Big Beef Creek coho production as a function of peak November spawner flows ($r^2=0.57$).
Figure 12. Big Beef Creek coho production as a function of peak November 72-hr precipitation during the parent spawner migration ($r^2=0.24$).

Figure 13. Big Beef Creek coho smolt production presented as a function of the lowest 60-day mean flow during the period of freshwater rearing for each cohort.

Coho smolt production can also vary with the size of the parent brood escapement and number of eggs deposited in the gravel, particularly when escapements (egg deposition)
are low (Figure 14). Line “A” is fitted to data from years where the peak three-day November rainfall totals and minimum 60-day mean summer flows were above their respective median values (diamonds). Line “C” is fitted to data from years when both were below their respective median values (triangles) and “B” is fitted to data from years when one was above and the other was below the medians (circles). These relationships indicate that survival rates to smolting at any given level of egg deposition may be influenced by flow.

Lake Symington presents a challenge not present in other watersheds of this complex. Smolts produced above Lake Symington must pass through the lake to reach saltwater. Largemouth bass predation was estimated to have caused a loss of between 4 and 8% of the total coho smolt production from the watershed (Bonar et al. 2004). Predation rate likely varies with the abundance of juvenile salmonids and abundance of piscivorous fishes in the lake. However, the available data suggest that substantial predation is occurring in the reservoir.

Lake Symington also affects summer stream temperatures below the lake. When the lake stratifies in early summer, warm surface water flowing over the dam increases stream temperature substantially immediately below the lake. Maximum daily stream temperatures just below Lake Symington exceeded 16°C continuously from May to September 2001 (Seiler et al. 2002). Temperatures exceeded the lethal limit for coho and chum salmon of 25.5°C for brief periods and were well above the preferred range of approximately 12.5° to 14.5° C throughout the summer. Measurement stations above the lake and near the mouth rarely exceeded 16°C, and then only for brief periods. Temperature impacts from Lake Symington extend only a short distance downstream, but still negatively affect summer rearing for coho, steelhead and cutthroat within that reach.

![Figure 14. Beverton-Holt coho production functions expressing changes in capacity with changing November and summer flow conditions in Big Beef Creek](image_url)
Below the lake Big Beef Creek flows through an incised gorge whose walls are comprised of a mixture of glacially deposited sediments some of which are very erodible. A number of small tributaries enter Big Beef Creek in this section. Erosion of the valley walls by Big Beef Creek and its tributaries has contributed a tremendous amount of coarse and fine sediments to Big Beef Creek. Land-use activities have intensified sediment contribution rates. The most striking example is along Kid Haven Road. The road was constructed along a small tributary of Big Beef Creek. Material from the road cut was pushed into the stream channel causing the stream to erode the toe of a steep bank on the side opposite the road. Although precise measurements of the sediment generated by this channel realignment were not made, it appears that thousands of cubic meters of material have entered Big Beef Creek as a result. Similar problems exist on other tributaries in this area. As a result, Big Beef Creek moves a large amount of sediment each year and the bed is relatively unstable below the canyon reach, which may influence egg-to-fry survival in this section of the stream. The sediment has also filled pools and reduced rearing habitat, resulting in simplified plane-bed channel morphology in the upper half of the lower canyon section.

Many large cedar logs were removed from the stream in the early 1980s, primarily to produce shakes and shingles. Following their removal, much of the remaining, smaller wood was flushed from the system within a few years. The loss of LWD has contributed to the degradation of habitat in the lower canyon and unconfined valley reach. These large logs were responsible for stabilizing accumulations of wood in the channel, providing pool habitat and cover, and retaining spawning gravel. Loss of wood may partially explain the reduction in coho smolt production observed from 1987 to 1996. More recently, habitat complexity has been increasing in lower Big Beef Creek with the formation of many log jams below Kid Haven Road. Currently, over 30 jams, composed mainly of alder, have been counted downstream of this point. These are trapping sediment and creating pool habitat. These jams may be short-lived given the rapid decay rate for alder. Fewer jams exist between the Kid Haven Road crossing and Lake Symington.

Seabeck Creek

Seabeck Creek is a 14-km² watershed located west of Big Beef Creek. The fish-bearing portion of the mainstem is approximately 6.2-km long with the lower 3 km flowing through an unconfined or moderately confined valley (Figure 15). In the upper 3 km, the channel is more confined and is incised within the steep surrounding hills. Seabeck Creek has two right-bank fish bearing tributaries (WDFW unpublished data). The smaller of these, Trib 1, enters Seabeck Creek approximately 150-m upstream of the mouth and the larger, Trib 5, enters the creek approximately 1,600-m upstream of the mouth.
Figure 15. Anadromous fish reaches within the Seabeck Creek watershed

Of the four Hood Canal IMWs, Seabeck Creek has the second lowest smolt production. Since trapping began in 1993, production has averaged approximately 1,400 coho, 300 cutthroat, and fewer than 30 steelhead smolts per year (Figure 27). No trends in production are evident for any species over this eleven-year period. Hypothesized constraints to coho production include:

- Extremely low summer flows combined with sediment deposition cause much of the accessible habitat to become dry, greatly reducing available summer rearing habitat and fragments much of what remains.

- Bed erosion and channel incision Tributary 5 has disconnected the stream and floodplain and degraded habitat downstream in the mainstem.

- LWD is scarce in the lower mainstem and Tributary 5 reducing rearing habitat.

Spawning ground surveys have indicated that approximately 9.6 kilometers of stream habitat are accessible to adult coho salmon. However, about a half of the area accessible to adult salmon exhibits discontinuous flow or is dry during summer. Only 2.4 kilometers at the mouth of the watershed and another 2.3 kilometers upstream, but separated from the wetted reach at the mouth by a long, dewatered reach, flow continuously through the year. The dry reach previously flowed year around (Neuhauser pers. comm.).

Dry and discontinuous portions of the channel occur at low-gradient reaches downstream of obvious sediment sources, suggesting that coarse sediment deposition may cause sub-surface flow. One such reach occurs upstream of a culvert under the Seabeck-Holly Road where the channel gradient decreases downstream from two eroding banks. Downstream of this point, the stream gradient increases and surface flow returns. The culvert appears to be a major contributor to the condition at this site as large amounts of coarse sediment have accumulated above the road.
Figure 16. Wild coho, steelhead, and cutthroat smolt production from Seabeck Creek.

The lack of summer rearing habitat resulting from spatially intermittent flow likely influences coho and steelhead production in Seabeck Creek. The fish trapped in isolated pools in areas of discontinuous surface flow are more susceptible to predation. Factors causing the extreme low flow conditions observed in Seabeck Creek and Big Beef Creek will be a principal area of investigation in the FY2008. The results of these investigations will determine whether or not restoration actions are feasible.

Tributary 5 exhibits severe bed erosion, with an average of over 4 m$^2$ of eroded bank per meter of stream in one 100 m stretch. The stream has incised 2 m or more along this section and banks are eroding in response to the change in bed elevation. Bed and bank erosion continues downstream from this point for approximately 1.7 kilometers, becoming less severe farther downstream. As a result, the channel is highly entrenched and disconnected from its floodplain. An undersized culvert on a forest road may have contributed to the erosion at this site.

Coarse sediment from the bed erosion in Trib 5 has deposited in the mainstem of Seabeck Creek, contributing to the dewatering problem described above. The deposition is especially evident above the Misery Point Road. The bed is currently approximately 0.6 meters below the bottom of the road bridge. Anecdotal reports have indicated that the bed used to be much lower historically (Neuhauser pers. comm.). These reports are supported by the presence of many live cedars along this reach with the base of their trunks buried in sediments. The bridge abutments may constrict flow, encouraging deposition upstream of the bridge. As a result of the sediment generated by bank erosion in Trib 5, areas in the lower mainstem and lower Trib 5 may be more susceptible to scour and sediment deposition than in other portions of the watershed.
Habitat surveys have found functioning LWD to be at very low levels in lower Seabeck Creek and in Trib 5. Consequently, simplified pool-riffle and plane-bed channel morphologies exists in the lower mainstem and Trib 5, respectively; and provide less habitat than would more LWD-rich, complex channel forms. The lack of wood also contributes to bed instability which exacerbates the potential for redd scour and burial, described previously.

Stavis Creek

Stavis Creek is a 15-km² watershed adjacent to Seabeck Creek watershed on the west (Figure 17). During summer, fish occupy nearly 8 km on the mainstem, 2 km of South Fork Stavis Creek, and 0.4 km on an unnamed left bank tributary to the mainstem (WDFW unpublished data).

![Stavis Creek Legend](image)

Figure 17. Anadromous fish streams within the Stavis Watershed.

Stavis Creek was selected as the reference watershed for the Hood Canal complex. Of the four watersheds Stavis Creek is the least developed and will likely be subjected to less development pressure during the study than the other three basins. Most of the land within the watershed basin is managed for timber production by the private land owners or by DNR Lands Division. Some rural residential development has occurred along the ridge south of SF Stavis Creek.

Stavis Creek is the second most productive stream in the Hood Canal complex. Production averages approximately 6,000 coho, 1,400 cutthroat, and 70 steelhead smolts (Figure 18). As with Big Beef Creek, coho and cutthroat smolt production in Stavis
Creek have been increasing since the late 1990s.

![Figure 18. Stavis Creek wild coho, steelhead, and cutthroat production.](image)

Periodic input of large amounts of sediment also may impact smolt production in this system. A large, deep-seated, slope failure, located approximately 600-m upstream of the confluence of SF Stavis Creek, occurred during the winter of 1999 on a steep slope that had been logged about 10-15 years earlier (Neuhauser pers. comm.). The erosion scar from this slide was estimated at 550 m² (WDFW unpublished data). A large amount of fine and coarse sediment was delivered to the channel by this slide impacting habitat down to the mouth of the stream. Coho smolt production during the spring of 1999 was much reduced, possibly due to impacts from the slide on fish that were over-wintering in the lower watershed below the sediment source (Figure 18). Unlike Big Beef Creek, summer flow is not correlated with the number of coho smolts produced.

**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 5) and will be used to test hypotheses 1-5. 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. Methods used to test hypotheses 6 and 7 are described at the end of the Methods section.
**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 6.
Table 5. Variables measured in all coho, steelhead, and cutthroat IMW complexes.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Data available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Continuous</td>
</tr>
<tr>
<td>Water temperature</td>
<td>Continuous</td>
</tr>
<tr>
<td>Probabilistic sampling</td>
<td>Annual</td>
</tr>
<tr>
<td>Smolt production</td>
<td>Annual</td>
</tr>
<tr>
<td>Juvenile abundance</td>
<td>Annual</td>
</tr>
<tr>
<td>Spawners</td>
<td>Annual</td>
</tr>
</tbody>
</table>

Table 6. 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**

WDFW has operated a smolt trap and adult weir on Big Beef Creek since 1978. The upstream trap is operated from mid-August through December. Smolt trapping began in 1992 in Little Anderson Creek and 1993 in Stavis Creek and Seabeck Creek.

Upstream migrants are enumerated by species, age, sex, mark status, and condition before being released upstream. To minimize stress, fish are processed within 12 hours of entering the trap or immediately, during peak migration periods. In all watersheds adult abundance and distribution surveys of the entire anadromous stream network are conducted weekly throughout the spawning season. All spawning fish and redds 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. Marks are noted during smolt trapping the following spring, 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.

Hypotheses 6 and 7

Current analyses suggest that November high flow (spawning flows-$Q_{sp}$) affect the geographic distribution of spawning salmon and that greater distribution results in higher production (hypothesis 6). However, the relationship between geographic distribution and $Q_{sp}$ has not been quantified and alternative mechanisms are possible. For example, $Q_{sp}$ may simply allow access to a few locations of high production (source areas) rather than increasing the overall area accessible to spawners. High $Q_{sp}$ may also reduce redd competition or predation. Quantifying the relationship between $Q_{sp}$ and distribution strengthens mechanistic inferences and promotes better restoration selection and better detection of restoration effects.

Hypothesis 6 will be tested by installing approximately 35 water level loggers at strategically selected (to allow calculation of cumulative sub-watershed flows) EMAP habitat monitoring sites in the Little Anderson, Stavis and Seabeck watersheds. Water level data are recorded every 15 or 30 minutes and collected after winter high flows. The streams are walked at weekly intervals during November and December to record the number and location of spawners, carcasses, and redds. Local water level data and transect-based habitat data (i.e., EMAP-based sample data) are used to estimate accessibility (thalweg depth) across a range of $Q_{sp}$. Local water level data can be correlated with watershed flow records to estimate probability of access to specific locations at a given flow.

Hypothesis 6 will be assessed by testing for a significant difference in the length of stream occupied at different $Q_{sp}$ after accounting for differences in escapement using ANCOVA and comparing the prediction accuracy and information content of alternative models that predict spawner distribution and subsequent production using $Q_{sp}$ and escapement as predictors. Other hypotheses to be tested include:

1) Spawner distribution will be positively correlated with $Q_{sp}$.
2) Spawner distribution will be positively correlated with smolt production.
3) Spawner distribution will be positively correlated with smolt production after accounting for the effect of escapement.
4) $Q_{sp}$ at individual water level loggers will be predict thalweg depth, and reach and sub-watershed spawner distributions.

To evaluate Hypothesis 7, that summer low flows are correlated with habitat quantity and quality and with parr-smolt survival; water level from the water level loggers at 35 EMAP sites in each watershed is being recorded across a range of flows from May
through September. The distribution of summer habitat and juvenile salmon are recorded from extensive surveys that map the location of water in a GIS in July through September. The stage height and the habitat data collected for EMAP sites and extensive surveys will be used to estimate available habitat as a function of stream flows (stage height). Juvenile abundance and survival are estimated at the EMAP study reaches as described earlier. More specific hypotheses to be tested include:

1) \(Q_{sl}\) and habitat quantity are positively correlated.

2) \(Q_{sl}\) is correlated with the length of wetted stream.

3) Length of wetted stream is positively correlated with egg-to-parr and parr-to-smolt survival

**Restoration Treatments**

All Hood Canal complex streams lack LWD and are impacted by current or past sediment inputs (Table 18). These systems also exhibit strong relationships between flow characteristics and smolt production. The impact of low summer flows on rearing habitat and high fall flows on spawner access to upstream habitat are likely the mechanisms responsible for these relationships. Big Beef Creek has the added issue of high water temperature and predation related to Lake Symington.

**Table 7. Primary constraints on production are listed by IMW basin.**

<table>
<thead>
<tr>
<th>Constraint</th>
<th>L Anderson</th>
<th>Big Beef</th>
<th>Seabeck</th>
<th>Stavis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low summer flow</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Fall spawner flows</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Predation by exotics</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High water temp</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment input</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Lack of LWD</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

The restoration objectives for Big Beef, Seabeck, and Little Anderson creeks will attempt to address the deficiencies that have been identified within these watersheds. Restoration actions implemented as part of this study will closely follow the recommendations of the Hood Canal/Eastern Strait of Juan de Fuca Summer Chum Salmon Recovery Plan (HCCC in prep). The HCCC plan is focused on the recovery of summer chum salmon. Although the plan focuses on a single species, the active restoration actions suggested in the plan are likely to benefit multiple species and to address some of the problems.
identified above. This plan is not yet complete. Restoration actions implemented by the IMW Study prior to the completion of the plan are described below and are based on the information presented above and discussions among WDFW, WDOE, and HCCC staff.

Restoration actions will be implemented sequentially across the Hood Canal complex watersheds, starting with Little Anderson Creek. The physical habitat problems in this watershed are relatively straightforward and there are willing landowners to partner on the restoration projects, including Kitsap County Parks Dept, which owns the lower 0.7 km of the stream.

Large wood is largely absent in the lower Little Anderson Creek watershed. An extensive LWD placement project is being planned for 1600m of Little Anderson Creek above Anderson Hill Road by the HCCC. No action is proposed for the lower 0.7 km located on county property. The channel in this lower reach is actively moving across the valley floor in response to recent beaver dam construction. We are monitoring habitat changes caused by the beaver activity and do not plan to conduct projects in this reach until changes caused by these natural processes are complete.

A suitable control reach for the LWD placement project on Little Anderson Creek is not available. Therefore, we have designated a reach with comparable physical characteristics on Stavis Creek as the project reference for this BACI-design evaluation. The reference reach was selected based on comparability in watershed area, aspect, and reach gradient to the project reach on Little Anderson Creek (Figure 19). Pre-project monitoring of large wood placement was initiated in 2004 and continued in 2005. Two of the EMAP habitat sampling sites described earlier fell within project reach on Little Anderson Creek and one within the control reach on Stavis Creek. These sites, spanning 900 meters cumulatively, were sampled in 2004 and 2005 and will be the basis for the project monitoring. The EMAP data have been supplemented with measurements of all channel units throughout the treatment reach. Pools, riffles and glides were classified and measured to obtain channel unit area (Thurow 1994). Additionally, extensive LWD
surveys also were conducted using Trimble GPS units.

Figure 19. Restoration and control reaches for Little Anderson Creek LWD project.

Biological data at the treatment and reference reaches for this project also have been collected. Fish are being sampled by electrofishing at each of the sampled EMAP sites to provide an index of abundance of fish by species and age class. This sampling will be repeated in each year post-treatment. In addition, we snorkeled all pools and glides, and one sixth of the riffles to obtain salmonid abundance, standardized by channel unit area, throughout the treatment reach (Hankin and Reeves 1988). Sampling will continue for at least two years post-treatment.

We used juvenile Coho density estimates to calculate the likely effect of this project on Coho density and summer juvenile population size. Pre-treatment density estimates were collected by snorkeling 84 randomly selected mesohabitat units in 1.44 km of degraded habitat in Little Anderson Creek in 2005. Approximately 660 m (2033 m$^2$) of stream was sampled and 851 Coho were counted. We estimated the effect of LWD placement by multiplying the observed density by the multiplier (1.81) developed by Roni and Quinn (2001) to predict the effect of LWD placement. We then multiplied the new density estimate by the area of stream we can treat (1260 m$^2$). We estimate that LWD placement will increase Coho density in the treatment section from 0.42 to 0.76 Coho/m$^2$ and increase the number of Coho in the treatment section from 529 to 958. It is as yet unclear whether and how the treatment will affect parr to smolt survival, however if we assume a survival of 10-20%, as estimated in the Strait of Juan de Fuca complex, this translates into 43-86 additional smolts. This is a 16-32% increase in mean annual production, a change detectable with the existing monitoring program.
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.

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.

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>α =0.20</td>
</tr>
<tr>
<td></td>
<td>Summer parr population and growth</td>
<td>#, length</td>
<td>Paired t-test</td>
<td>α =0.10</td>
</tr>
<tr>
<td></td>
<td>Egg-to-parr survival</td>
<td>%</td>
<td>Paired t-test</td>
<td>α =0.10</td>
</tr>
<tr>
<td></td>
<td>Parr-to-smolt survival</td>
<td>%</td>
<td>Paired t-test</td>
<td>α =0.10</td>
</tr>
<tr>
<td></td>
<td>Outmigration timing</td>
<td>%</td>
<td>Graphic analysis and χ² test</td>
<td>α =0.10</td>
</tr>
<tr>
<td></td>
<td>Marine survival</td>
<td>%</td>
<td>Paired t-test</td>
<td>α =0.10</td>
</tr>
<tr>
<td>Habitat</td>
<td>Pool area</td>
<td>m²</td>
<td>Paired t-test</td>
<td>α =0.10</td>
</tr>
<tr>
<td></td>
<td>Width-depth ratio</td>
<td>Ratio</td>
<td>Paired t-test</td>
<td>α =0.10</td>
</tr>
<tr>
<td></td>
<td>LWD</td>
<td>#, Volume</td>
<td>Paired t-test</td>
<td>α =0.10</td>
</tr>
<tr>
<td></td>
<td>Spawner distribution vs Fall streamflow</td>
<td>%</td>
<td>Correlation, ANCOVA</td>
<td>α =0.10</td>
</tr>
<tr>
<td></td>
<td>Habitat vs summer flow</td>
<td></td>
<td>Regression analysis</td>
<td>α =0.10</td>
</tr>
</tbody>
</table>

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Simple correlative analyses are being used to assess the relationship between flow statistics and spawner and redd distribution. Analysis of covariance is used to assess the relationship between flow statistics and geographic distribution while accounting for the possible effects of escapement on geographic distribution. Spatially attributed thalweg and habitat data are correlated with local stage height and watershed flow to assess the effect of local depth on the geographic distribution of spawning salmon.

Regression analysis will be used to assess the relationship between water level, habitat quantity, life stage survival, and production. Analysis of the relationship between water level and egg-to-parr or parr-to-smolt survival will require a number of years of data. Hypotheses include:

**Schedule and Budget**

Table 9 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 10) 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 9. Timeline for monitoring and expected results in the Hood Canal complex.

<table>
<thead>
<tr>
<th>Year</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978, 1992, 1993</td>
<td>Outmigrant monitoring began in Big Beef, Stavis, Seabeck, and L Anderson, respectively</td>
</tr>
<tr>
<td>2007-09</td>
<td>Habitat restoration implemented</td>
</tr>
<tr>
<td>2004</td>
<td>IMW monitoring begins</td>
</tr>
<tr>
<td>2007</td>
<td>First estimates of summer parr population, survival, and outmigration timing</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 10. FY08 budget for the Hood Canal 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-Fish</td>
<td>$176,964</td>
<td></td>
<td>$25,000</td>
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<tr>
<td>WDFW-Habitat</td>
<td>$208,800</td>
<td>$24,900</td>
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</tr>
<tr>
<td>Ecology</td>
<td>$ 73,600</td>
<td>$13,250</td>
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<tr>
<td>Weyerhaeuser</td>
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<td>$26,300</td>
<td></td>
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<tr>
<td>Total</td>
<td>$459,364</td>
<td>$64,450</td>
<td>$25,000</td>
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</tbody>
</table>
References


