Responses to questions asked by the ISRP for BPA project #30005

Questions and Responses:

1. *What happens after the geomorphology and hydrology of the watershed are evaluated? Are there reasonable actions that can be taken to stabilize the riparian zone or is instability a basic feature of the riparian zone along the Grays River?*

We know that the underlying geology of the Grays River watershed is generally unstable. We also know that there has been extensive logging activity and road construction that have contributed to the instability in the watershed. Yet, most of the logging and road construction occurred in the 1970's and the upland areas and riparian corridors have had 25 years or more to recover from these activities. What we need to understand now is if the instability in the system is increasing, decreasing, or in a somewhat steady state, and where might be the best place to focus our restoration and protection efforts.

With the vast majority of land (over 96%) in the Grays River subbasin in either private industrial forest or state lands, we expect that the overall trajectory towards riparian and watershed recovery will likely continue with the additional level of protections provided by the new Forests and Fish regulations. Under these regulations, industrial forestland owners will be required to survey their roads and culverts and then identify and repair those that have the potential to contribute excessive sediment to stream channels. These landowners will also be required to repair passage problems, starting with priority blockages within 5 years. We will coordinate our assessment and restoration efforts with the major industrial forest owners to identify critical areas to focus these significant protection and restoration efforts.

While we believe that overall watershed conditions may be improving, we know that significant problems remain to be resolved in the watershed. We fully expect that we will be able to use the existing data from stream surveys, coupled with the hydrologic and geomorphic assessments, to identify priority areas where restoration actions can make a difference. The hydrologic model we will develop for the Grays, along with the geomorphological assessment, will give us the ability to answer questions on how various land uses would affect stream flow and sediment transport in the watershed. We will be able to run simulations for various scenarios that will provide the data we need to prioritize road abandonment and culvert repairs in critical areas, identify areas with unstable slopes that need protection and stabilization, and evaluate the potential for surface soil erosion in each grid cell of the model. This information will allow us to focus on the highest priority areas to protect and/or restore, and will direct restoration in the critical areas. We can then work with the major landowners in the basin on setting priorities and implementing critical restoration activities.

If, through these assessments, we find that there is little we can do to reduce the instability in the short-term, information gathered as part of this project will be invaluable to help various agencies make decisions on fish management and restoration actions that are appropriate considering the trajectory of the system.

2. *The assessment should focus on the upstream processes that would indicate whether the channel movement is much more dynamic than in the past: e.g. is habitat alteration from logging causing downstream instability? Are there fixable damages?*

We will integrate information from a number of different sources in conducting the assessment of the watershed and developing our protection and restoration recommendations. The Washington Conservation Commission recently published a Limiting Factors Analysis for the Grays River watershed (Wade 2002). This document includes data from fairly comprehensive stream surveys that date from 1996 on overall riparian and instream conditions, culverts, bank erosion, fish distribution, road crossings and densities, land cover, and overall watershed conditions affecting salmonids in the Grays River. A number of professionals, familiar with the Grays system also added their knowledge to existing information on watershed conditions.

The information in this document suggests that road construction and logging have had, and continue to have, significant impacts on overall watershed processes and instream habitat conditions. Overall, riparian conditions in the Grays watershed rated generally either in “fair” or “poor” shape according to Conservation Commission’s standards. Yet, the analysis also notes that overall watershed and riparian conditions in the Grays River appear to be improving, especially in reaches upstream of the spawning areas on industrial forestlands. For example, in the three Watershed Administrative Units above the main spawning reaches, the percentage of surveyed 1000-foot reaches with riparian conditions that fell in the “good” or “fair” category were 12.5% for the West Fork, 75% for the South Fork, and 78% for the Upper Grays (Wade 2002). Under the new Forest and Fish regulations governing these industrial forests these conditions should continue to improve.

Overall, land cover also improves in the upper reaches, likely alleviating some of the past impacts from elevated peak flows to downstream reaches. However, the analysis notes that data are lacking to understand how past alterations and existing land cover and riparian conditions relate to the habitat conditions within the stream channels that fish encounter, and to identify specific actions that we could take to best address these issues.

The hydrologic model we will develop for the Grays, along with the geomorphological assessment, will give us the ability to answer questions on how existing conditions and various land uses affect stream flow and sediment transport in the watershed. We will be able to run simulations for various scenarios that will provide the data we need to prioritize road abandonment and culvert repair in specific areas, to evaluate slope stability in mass wasting assessments and identify areas to avoid, and to evaluate the potential for surface soil erosion in each grid cell of the model. This information should identify both the types of land use activities that contribute to the problems in downstream reaches, and the locations that would be most sensitive to those activities or benefit from protection and restoration.

3. *What are the proposed sequence of the watershed assessments and the prioritization of habitat restoration projects?*

The Lower Columbia Fish Recovery Board (LCFRB) is working with a number of local, state, and federal agencies including NMFS, NWPPC, USFWS, WDFW, WDOE, five counties, and 13 cities to develop a Recovery Plan for all listed anadromous salmonids in the lower Columbia. As part of this recovery planning effort, the LCFRB is also working with the NWPPC to develop Subbasin Plans for the region that are consistent with recovery plans for the Washington tributaries.

Initial work on these and other plans has determined that few, if any, watersheds in the lower Columbia have sufficient data to make explicit connections between land use, habitat conditions, and fish abundance and productivity. To gather this information in a coordinated manner the LCFRB is conducting a number of subbasin/watershed assessments across the region including the Grays River.

After reviewing a number of watershed assessment guidance documents from around the region, the LCFRB proposes to use the NWPPC's Watershed Assessment Template (NWPPC 2000) to direct subbasin and watershed assessment work in the lower Columbia that will then be incorporated into the recovery and subbasin plans. This template includes most, if not all, of the elements and analysis needed for developing management and recovery plans for lower Columbia tributaries for anadromous salmonids.

The Template also provides guidance for prioritization of collection and analysis of data at finer scales. While the information necessary to cover all the elements in this assessment template does not exist for most streams, the overall goal is to eventually fill in all elements of the assessment template at a sufficient level of detail to understand and describe the habitat conditions in the watershed necessary to maintain viable populations of anadromous salmonids.

Linked to this Assessment Template is the LCFRB's Watershed Assessment Approaches document. This document outlines a process for conducting watershed assessments that will provide consistency both within watersheds and across the lower Columbia region. The assessment approach is based on Washington State's Guidance for Watershed Assessment Document (JNRC 2001). The Watershed Assessment Approach takes a stepped approach that includes:

- Step 1 (region-wide data collection and prioritization) of the assessment approach gathers all existing data on watershed conditions and stock status, and then uses this information, products from NMFS's Technical Review Team (TRT), and EDT to help prioritize subbasins for additional assessment work.
- Step 2 (Subbasin Characterization and Additional Assessment Needs) uses existing information to develop a landscape/watershed analysis that identifies and describes habitat-forming processes and the causes of change within each

  subbasin, additional assessment needs in the subbasin, and priority areas for protection and restoration in the subbasin (this may be accomplished using a comprehensive EDT analysis, linked with land use data).
- Step 3 (Detailed subbasin assessment plan) is the development of a detailed watershed/subbasin assessment plan that identifies prioritized assessment needs and specific approaches for gathering data within prioritized streams/reaches. This document becomes the scope of work for what types of additional assessment work are needed within a subbasin, where this assessment work is needed, and the protocols that will be used to collect the data and monitor conditions over time.
- Step 4 (Complete Subbasin Assessment Template) will gather the data necessary to fill critical data gaps and then complete the subbasin assessment template. This document will include strategies and action plans for protection and restoration efforts in the subbasin and across the lower Columbia for each species of interest.

The LCFRB, with the help of WDFW, WDOE, and various federal agencies, plans on completing Steps 1-3 by the end of 2002 for all Washington subbasins within the lower Columbia, including the Grays River Subbasin. We already have a considerable amount of the data collected that will help direct many of the decisions regarding overall restoration and protection priorities. We have databases and GIS coverages on hydrography, transportation, land use, fish distribution, migration barriers, riparian conditions, bank erosion, some recent water quality data, and various in-stream channel conditions for a majority of the watershed. This data points to specific areas within the watershed that require protection, restoration, and additional assessment. The Grays River Watershed and Biological Assessment (i.e., this project) will fill many of the assessment needs that have been already identified.

Some of the identified data gaps that the Grays River Assessment will fill include the location and quantity of excessive sediment inputs, sediment transport and water routing, data on fish distribution and utilization by life-history stages, connections between existing habitat conditions and fish productivity, priority habitat locations, and a better understanding of the trajectory of watershed recovery.

Significant monitoring efforts are also underway in the lower river that will help characterize habitat conditions, and juvenile fish distribution, abundance, and survival within the restored floodplain and estuarine habitats. With this assortment of data we will be able to complete Step 4 of the Assessment Approach and identify specific actions that we can to take to protect, restore and enhance fish habitat throughout the subbasin.

4. *Better describe the efforts to protect chum across the region.*

As noted by the ISRP, this proposal fits well into regional programs and is well connected to other projects. The prioritized list of actions will be available to be integrated into other projects.

The following response summarizes past, proposed, and future efforts on the Grays River. The results from the proposed Grays River assessment will play an important role in the recovery and re-introduction efforts in other areas of the lower Columbia River.

Past efforts (through FY 2002)

As the ISRP noted, Grays River stock are an important, unique genetic group of threatened salmon. However, due to the unstable nature of chum habitat in the Grays River and the loss of the only protected spawning habitat within the basin (Gorley Springs) in December 1999, the Grays River chum stock is even more vulnerable to future catastrophic disturbances. Therefore, actions have been taken to maintain this population while the effects of the loss of the protected spawning habitat and potential for habitat improvements within the watershed are being assessed. These actions include the following steps:

Step # 1 Help maintain, and if possible increase, the Grays River chum population through brood stock collection;

Step # 2 Release Grays River stock in the Chinook River to increase distribution and abundance;

Step # 3 Acquire conservation easements and land acquisitions to protect potential spawning and rearing habitat in the Grays and Chinook rivers.

The plan to increase the Grays River chum population, which had remained chronically low but stable for many years, was to collect brood stock from the Grays River and release the progeny back into the river for up to three complete cycles (12 years). In the event the stock showed signs of increased abundance before the three complete cycles, the brood stock collection for the Grays River would be terminated. If the population did not increase at the end of three complete cycles, it would be terminated as it was assumed that some other limiting factor was affecting abundance. The Hatchery Genetic Management Plan (HGMP) for the Grays River describes the brood stock collection plans. A copy of the HGMP is attached.

Another objective of the original brood stock collection in the Grays River was to re-introduce a Columbia River stock into the Chinook River basin. It replaced Willapa Bay stock that had been successfully released at Sea Resources Hatchery for many years. Now, Grays River origin chum are released into the Chinook River to increase geographic distribution and abundance of the Grays River stock.

Efforts have begun to protect potential rearing and spawning habitat in the Chinook and Grays River watersheds. To date, over $7 million of non-BPA funds have been spent on conservation easements and land acquisitions in the two watersheds.

Proposed efforts (FY 2003-2005)

Proposed efforts within the region for FY 2003-2005 build and expand on the past efforts. The actions could include:

> Step # 1 Continue brood stock collection on the Grays River for release in the Grays and Chinook rivers to maintain or increase the population size;
>
> Step # 2 Conduct spawning ground surveys and sample the returns to determine whether brood stock efforts have been successful to maintain or increase the population size of Grays River chum stock;
>
> Step # 3 Sample returns from outside the Grays and Chinook rivers to determine whether straying is occurring from the brood stock program;
>
> Step # 4 Map the spawning distribution and habitat use to qualify and quantify existing habitat in the Grays River;
>
> Step # 5 Estimate the carrying capacity for chum salmon on the Grays River based on spawning ground counts and the amount of area in which they spawn;
>
> Step # 6 Conduct a full geomorphic assessment of the Grays River watershed to better understand current habitat conditions and predict future conditions that might impact chum production;
>
> Step # 7 Continue pursuing conservation easements and land acquisitions in the Grays and Chinook rivers to protect the rearing and spawning habitat.

Depending upon availability of state funding, brood stock collection efforts are expected to continue on the Grays River. Progeny are expected to be released into the Grays and Chinook rivers.

Adults will begin returning to the Grays and Chinook rivers from the brood stock collection efforts at Grays River during this period. The contribution of the hatchery fish at the hatcheries and on the spawning grounds will be measured by the collection of thermally marked otoliths. From spawning ground surveys and recovery of the marked otoliths, egg-to-adult survival rates from these artificially produced fish will be generated. Our Grays River Assessment proposal will collect the data necessary to determine these survival rates.

Stray rates of the artificially produced fish will also be estimated. Otoliths will be collected from spawning ground surveys outside the Grays River basin. This work will be conducted under another BPA project.

A major objective of the Grays River Assessment proposal is to map the distribution of the Grays River natural-spawning chum population and collect habitat use information. The proposal will track the Grays River chum natural spawning distribution under existing conditions over the course of three years, likely under different water flows. This information will be valuable in comparing population size, distribution, and estimating the amount of spawning area utilized before and after any habitat improvements.

Habitat use information on the Grays River will be focused on the spawning areas identified during the spawning ground surveys. The habitat use data collection would be expanded to include areas of non-use in the surrounding area. A comparison between the two areas could be used to determine whether similar spawning habitat conditions are located in the non-use area.

By combining the spawning ground counts and mapping of the known spawning area, it may be possible to estimate the spawning capacity for the Grays River. Population estimates using the Area Under the Curve Method could be generated from the spawning ground counts. The mapping of the spawning area would quantify the amount of habitat being utilized. Preferred spawning densities for non-Columbia areas of ½ female per meter-square could be applied to the amount of spawning habitat being utilized to determine the carrying capacity.

The grays River Assessment proposal would also conduct a full geomorphic assessment of the Grays River watershed from the headwaters to the mouth. It will identify current habitat conditions and provide insight into potential future conditions. It will provide recommendations for improvements, both short and long term. At the end of FY 2005, a prioritized list a habitat improvements in the Grays River basin will provide better direction for chum restoration and protection efforts.

Future efforts (beyond FY 2005)

The ultimate goal is to restore and protect the habitat in the Chinook and Grays rivers so the Grays River stock becomes self-sustaining through natural production. If returns continue to be below the carrying capacity of the available spawning habitat, brood stock collection and habitat improvements could be continued, or other production areas could be enhanced.

In the event chum fully seed the spawning habitat in the Grays or Chinook river systems, efforts could begin to re-introduce Grays River stock into suitable areas between Grays River and Bonneville. The steps for recovery efforts in those areas would be essentially the same as those for the proposed for the Grays River.

The amount of supplementation into the areas between Grays River and Bonneville would depend on abundance and genetic makeup of chum salmon found in the historical spawning grounds from Grays River to Bonneville. This work is being accomplished under BPA Project titled “Evaluate Spawning of Fall Chinook and Chum Just Below the Four Lowermost Mainstem Columbia Dams”, Project # 199900301.

Evaluation and monitoring of habitat restoration, brood stock supplementation, and resulting juvenile production will also play a major role in determining the success of recovery efforts for Columbia River chum. Egg-to-fry and egg-to-adult survival rates are critical components of the evaluation. The Monitoring and Evaluation Plan for the Duncan Creek Chum Salmon Re-Introduction Program provides detailed instructions to evaluate the success of the lower Columbia River chum recovery efforts. A copy is attached.

5. *What are the prospects for sedimentation in the lower river at the confluence of the Grays River with the Columbia? Is this a limiting factor?*

What data there is suggests that sedimentation and aggrading stream channels are likely problems throughout the lower river. Local landowners in the lower river have experienced significant and frequent flooding events. Certainly, the extensive diking along most of the lower river has contributed to the problems, as has road construction and logging in the generally unstable upper watershed.

The Lower Columbia Fish Recovery Board has prioritized protection and restoration of floodplain habitats in the lower Grays River. Subsequently, a number of floodplain acquisition and restoration projects in the lower Grays River have been forwarded to Washington State's Salmon Recovery Funding Board for funding over the last three years. There is now a significant refuge of some 1,500 acres of connected floodplain and estuarine projects developing in the lower Grays that should help mitigate some of the sediment problems in the lower river. Removal of tidegates, and dike breaching is underway or planned for most of this area, creating significant additional flood storage capacity and areas for sediment deposition, and restoring floodplain and estuarine functions in the lower river.

The Limiting Factors Analysis for the Grays River (Wade 2002) and the Subbasin Summary for the Grays identified potential problems with sedimentation in the lower Grays River and Grays Bay. Some of the problems noted were potential passage problems across the Grays River bar during low flow periods, loss of pool habitat and channel complexity in the lower river, and possibly excessive predation in the shallow water near the mouth. Diking and tide gates have confined sediment loads to the main river channel along most of the lower river. The ongoing program to acquire and restore floodplain habitat in the lower Grays should promote sediment deposition outside the main channel, increase channel complexity, and provide critical off-channel rearing and feeding habitat for multiple salmonid species.

The Grays River assessment proposal focuses on the major spawning grounds for chum and chinook and the watershed upstream of the spawning grounds. The major reasons for this focus included:

1. That the lack of stable spawning habitat is considered the primary physical limitation on Grays River chum production today (Subbasin Summary 2001, Washington Conservation Commission 2002; NWPPC 1990). Therefore, we focused our assessments efforts on determining the most appropriate actions to address this problem.
2. The data and models from this assessment will support at the least a qualitative assessment of hydrologic inputs and sediment transport through the lower river. This data can likely be used to determine appropriate actions to address sediment deposition in the lower river, and provide guidance for any additional assessments that may be needed.

3. The assessment was focused to meet needs identified in the Subbasin Summary, the Biological Opinion for the operation of the Federal power system, and the Limiting Factors Analysis, all of which focused on the need to understand what is limiting chum salmon production in Columbia River tributaries.
4. There is a significant protection and restoration program already underway that should address most of the limiting factors for salmonid production in the lower river.
5. The lower Grays River and Grays Bay is tidally influenced with multiple additional inputs to the system. Modeling this area would significantly complicate any hydrologic analysis, and significantly increase the cost of the analysis.

Works Cited:

Grays River Subbasin Summary (Draft). 2001. Prepared for the Northwest Power Planning Council. October 26, 2001. 108 pages

Joint Natural Resources Council. 2001. Guidance on watershed assessment for salmon. State of Washington. May, 2001. Olympia, Washington. 54 pages.

Northwest Power Planning Council. 2000. Final draft subbasin assessment template for the Northwest Power Planning Council's Fish and Wildlife Program. June 6, 2000. 15 pages.

Wade, G. 2002. WRIA 25 Habitat Limiting Factors Analysis. Washington Conservation Commission. Olympia, Washington. 269 pages.

Attachment 1.

MONITORING AND EVALUATION PLAN FOR THE DUNCAN CREEK CHUM SALMON REINTRODUCTION PROGRAM

INTRODUCTION

In March 1999, NMFS listed Lower Columbia River chum salmon as a threatened species under the auspices of the Endangered Species Act (ESA). Currently, two genetic enclaves of Lower Columbia River chum salmon are recognized, a population that returns to the Grays River and a constellation of stocks that spawn just below the Bonneville Dam, e.g. in Hardy and Hamilton Creeks and also adjacent to Ives Island. This latter group, or the Bonneville Population, is felt to be panmictic since chum produced from this part of the Columbia are sometimes prevented from using natal spawning sites because of variations in water flow. When this occurs, fish will spawn in new locations and may reproduce with individuals that had originated from other nearby spawning sites. In the early twentieth century hundreds of thousands of chum salmon returned to Lower Columbia River tributaries and mainstem spawning sites. Since then habitat alterations leading to dynamic flow regimes, riverbed movement and heavy siltation have been largely responsible for the decline of this species in the Columbia. The few stable spawning areas that still exist are often in danger of being destroyed by flood events, development, or dewatering due to hydropower demands or climatic variation.

Both state and federal agencies have responded to the decline of Lower Columbia chum salmon by instituting direct recovery actions. The USFWS for instance, just finished building a controlled-flow spawning area for chum salmon on Hardy Creek. Moreover, in 1998, WDFW started a chum salmon recovery effort in Grays River. Here, random samples of adult chum salmon returning to the Grays River were captured, artificially spawned and had their offspring incubated and reared at the Grays River Hatchery prior to being liberated back into their natal stream. All of these fry received thermal marks so that their fry-to-adult survival rates and spawning ground distribution patterns could be evaluated. Beginning in 1999 this effort was expanded. Some Grays River fry were transplanted to the Chinook River where Sea Resources reared them before releasing the fry at the mouth of the Chinook River. This effort to re-establish a native Lower Columbia River chum stock in the Chinook River was continued in 2000.

The Hatchery Genetic Management Plan for the Grays River project presents a generic recovery strategy for Lower Columbia River chum salmon that has four main components. First, to conduct comprehensive stream surveys throughout the Lower Columbia to identify the presence and size of extant chum populations. Second, during these surveys to locate springs and identify areas in streams where controlled-flow spawning areas for chum salmon could potentially be sited. Third, to maintain existing chum populations by direct intervention (e.g. the Grays River program) and carefully evaluate the consequences of such efforts by monitoring survival rates, migration timing, spawning ground distribution patterns and inadvertent domestication effects precipitated by fish cultural practices. And fourth, to reintroduce Lower Columbia chum salmon into vacant habitat areas if such sites appear to possess adequate spawning and incubation conditions.

Since the fall of 1998, portions of the recovery plan described above have been carried out. Stream surveys were made in 1998 and again in 2000 and showed that remnant populations of chum exist in numerous Lower Columbia River tributaries, e.g. the Skamokawa, Elokomin, Abernathy, Germany, Washougal, Lewis, Cowlitz, and St. Cloud Creek. In addition, a new mainstem population was discovered spawning slightly upstream of the I-205 Bridge. Spring sites and areas where chum salmon were observed spawning have been identified, and as previously mentioned the introduction of Grays River chum into the Chinook River was started in 1999. The work so far completed suggests that the potential to rebuild, maintain, and re-establish chum salmon in the Lower Columbia is high.

Background Information On The Duncan Creek Project

Duncan Creek, located approximately five miles below the Bonneville Dam on the Washington side of the Columbia was identified as the first upriver location where chum salmon should be re-introduced. For almost forty years chum have been prevented from entering Duncan Creek because of a man-made dyke and culvert. Fish-passage work completed in 2000 and recent landowner agreements, however, will allow chum salmon to once again enter the stream. Duncan Creek is an ideal location for a re-introduction effort because of its environmental characteristics (low gradient, numerous springs), high likelihood of remaining undeveloped, and close proximity to an appropriate donor population of Lower Columbia River chum salmon.

As presented in our BPA High Priority Proposal, the Duncan Creek Project has two goals: 1) to reintroduce chum salmon back into Duncan Creek by providing them with a protected spawning and incubation environment, and 2) to simultaneously evaluate the effectiveness of natural re-colonization and a "jump start" introduction strategy as recovery options for Lower Columbia River chum salmon. The high priority proposal for Duncan Creek presents the tasks that must be accomplished to achieve these goals. Briefly, the renovation of Duncan Creek requires that: 1) existing gravel in four branches of the steam (approximately 18,725 square feet of spawning area) that contain mud, sand, and organics be removed and replaced with gravels that are expected to maximize egg-to-fry survival rates (see Tables 1 and 2 below). The new gravel layer will be at least two-feet deep throughout each channel. In addition, no impervious liners will be added to channel bottoms or sidewalls thus enabling ground water to percolate unimpeded through the gravel. 2) The banks of the renovated channel areas will be armored with "quarry small" (6 to 8 inch in diameter broken rock). Such protection will reduce the importation of fines from the banks into the spawning gravels by shielding them from the digging activities of spawning fish. As further protection, the channel banks will possess moderate slope values (e.g. three linear feet of slope for every one foot of drop). And, 3) uplands immediately adjacent to the channels will be planted with indigenous vegetation, e.g. *Salix* spp. Such plantings will provide shade, further stabilize the banks of the channel, reduce variation in water temperature and also help capture fines or sediments derived from upland areas.

Table 1. The length and width of spawning areas A, B, C, and D in Duncan Creek and the volume of new gravel needed to fill each of these renovated channels. Measurements are in feet or cubic yards.

Channel	Length Of Channel	Mean Channel Width	Drop In Feet From Head of Channel To Its Mouth	Mean Slope (%)	Spawning Area (Ft^2)	Volume Of New Gravel Needed
A	657	10.5	8.27	1.26	6,899	511
B	706	12.3	7.37	1.04	8,663	642

C	162	7.0	4.75	2.93	1,134	84
D	108	18.8	2.16	2.00	2,030	150
Totals	1633	11.6	NA	NA	18,726	1,387

Table 2. The size frequency of the spawning gravels that will be added to channels A, B, C, and D in Duncan Creek.

Diameter of Gravel	Percent by Volume
4 – 6 Inch Rock	2
2.5 – 4 Inch Rock	13
1 – 2.5 Inch Rock	35%
¾ -1 Inch Rock	35%
3/8 –3/4 Inch Rock	10%
No. 4 – 3/8 Inch Rock	5%
No 10 – No 4 Material	0%

Current thoughts about the best way to introduce salmonids into renovated habitats, like channels A, B, C, and D can be divided into two general methods. One approach is to create new habitat and allow natural straying to colonize it over a period of years. WDFW's SHEAR program, for instance, has consistently used this method to seed stream areas that they have re-opened via culvert repairs or other improvements. Alternatively, such areas may be immediately planted with salmonids (i.e. "Jump Started") from adjacent populations in an effort to expedite habitat use.

The second goal of the Duncan Creek project is to objectively compare the merits of these two protocols on chum salmon recovery. This will be accomplished by measuring the rate of colonization of the newly created Duncan spawning areas by chum salmon from up to three sources. One source would be natural strays, another would be adults originating from fry that were created by artificial crosses and then incubated and reared in Duncan Creek water, and a third possible source would be individuals derived from parents that had been allowed to spawn naturally in portions of the Duncan Creek spawning channels. Because of a significant monitoring need (see below) we will be creating artificial crosses on chum salmon collected from the Bonneville population. Our intent is to incubate, thermally mark, and rear these fish in Duncan Creek water. Hence, in a perhaps serendipitous manner we will have an opportunity to evaluate how rapidly the renovated habitat in Duncan Creek is colonized by chum salmon derived from at least two different sources, natural strays and fish originating from an artificial rearing program. Ancillary information about the survival and straying proclivities of the offspring produced from fish representing each of these sources can also be obtained if efforts to collect otoliths on Bonneville chum salmon are carried out as planned.

MONITORING AND EVALUATION PLAN FOR THE DUNCAN CREEK PROJECT

Every salmon recovery or supplementation effort is accompanied by a need to evaluate its biological consequences on the targeted population. Moreover, depending upon the species and size of the program, extracurricular monitoring on the status of local, non-targeted species may also be necessary because of potential competition, predation, and possibly disease transference effects. Without such long-term efforts the ability to customize recovery programs to local idiosyncrasies disappears and the capacity to examine genetic effects and to refine future recovery efforts is impossible. In essence we must know what we did in order to anticipate what we should do in the future.

The monitoring and evaluation needs of the Duncan Creek project will be directed toward answering a series of basic questions. These are: 1) what egg-to-fry survival rates are being achieved in the renovated spawning channels, 2) what is the survival of the eggs and fry used in the artificial rearing program that will take place at Duncan Creek, 3) what is the survival and spawning ground distribution of adult chum salmon produced from the spawning channels and from the artificial rearing program, and 4) what is the straying rate of non-project chum salmon into Duncan Creek. To answer these questions a considerable amount of subsidiary information will be needed. What follows is a description of the tasks and methods that will be used to address each of the monitoring questions.

Evaluating The Egg-To-Fry Survival Rates Of Chum Salmon In The Renovated Duncan Creek Channels

Estimating Potential Egg Deposition

To evaluate egg-to-fry survival in naturally spawning fish, two egg deposition estimates must be made. First, a potential egg deposition value (PED) is calculated. This estimate relies on linkages between phenotypic traits such as body weight or length to estimate the fecundity of each spawning female. Numerous body size/fecundity relationships have been calculated for a wide array of salmonid species (see e.g. Pritchard 1937; Rounsefell 1957; Allen 1958; Donaldson and Menasveta 1961; Gray 1965; Smolei 1966; Kato 1978; Gall and Gross 1978; Schroder 1981). Typically, female size (weight or length) can explain anywhere from 10 to 70% of the variation associated with fecundity. For chum salmon returning to Big Beef during the years 1974 – 1976 for instance, analyses between body weight (log10) and fecundity produced r^2 values that ranged from .248 - .625 (Schroder 1981). Similar fecundity relationships were generated for chum salmon returning to the Grays River in 1998 and 1999 (Schroder unpublished data). Once again, both log values of weight or length were used to predict fecundity. These traits were found to explain 30 to 39% of the variation associated with fecundity in Grays River chum. In an effort to reduce some of this variation, multiple regression analyses were performed that used either length or weight values and also egg size (weight in mg), condition (i.e. Fulton's K) or reproductive effort (total egg mass weight/total body weight) data. Twenty-five such regressions were completed. They indicated that when log body weight, egg weight and transformed reproductive effort values were used over 95% of the variation associated with fecundity could be explained. Egg size and body weight values can be collected from live fish. However, reproductive effort cannot be determined unless the fish are artificially spawned. When reproductive effort values were removed from the regression analyses smaller amounts of variation were explained. In an attempt to produce a surrogate for reproductive effort, a K (weight/length cubed) value for each female was calculated. The addition of this variable to the regression models produced formulas that could explain 67 to 94% of the variation associated with fecundity.

Approximately 30 to 50 females should be spawned to develop regression formulas that can be used to predict fecundity. The length (Fork and mid-eye-to-hypural plate to the nearest mm), weight (nearest gram), egg size (mg), condition (K), egg mass weight (0.1 gram), age, and fecundity of each female spawned will need to be recorded to provide the information required to produce such regressions. These collections will need to be made several times on Bonneville chum until we can see how great yearly variation in fecundity may be. Rounsefell (1957) for example, reported that within salmonid populations, different body size fecundity relationships may occur each brood year and that females in the same population maturing at different ages may also have dissimilar body size fecundity relationships. If year-to-year and age effects are high, then annual collections may be necessary to produce reliable fecundity estimations on the females allowed to spawn in the Duncan Creek channels or in other controlled flow areas (e.g. the Hardy Creek Channel) located near the Bonneville Dam.

The effort to collect data that can be used to produce fecundity estimates brings with it the opportunity to use those eggs in an artificial rearing program designed to jump start the Duncan Creek population. How the fish should be mated and the protocols that should be followed to obtain biological information on each male and female spawned are presented in Appendix 1. The fertilized eggs collected from these fish will be incubated, marked, reared and released from Duncan Creek as fed fingerlings.

The actual estimation of the PED of each female placed into the Duncan channels is relatively straightforward. In some cases, body weight, egg size and K will be known for a female. When this occurs her fecundity will be predicted by using a multiple regression formula that uses those variables. Ninety-five percent confidence intervals will be developed around this estimation so that maximum, minimum, and expected egg number values can be produced for each fish. In some cases, egg size values will not be obtained because many females will deposit all of their eggs, when that occurs a formula that uses body weight and K or just body weight (whichever explains the greatest amount of variation in fecundity) will be employed. Again 95% confidence intervals for this formula will be used to predict a maximal, minimal, and expected fecundity value. These three estimates will be summed for the fish placed into the channels to produce a maximal, minimal, and expected PED value for each Duncan Creek channel.

Estimating Actual Egg Deposition

The second egg deposition estimate is referred to as actual egg deposition or AED. It equals PED minus any potentially viable eggs that a female retains at death. Egg retention values will be obtained from each female placed into the Duncan channels by simply retrieving the fish soon after death (< 24 hr) and counting the number of eggs still remaining in the coelomic cavity. As mentioned above, many females will have successfully deposited all of their eggs, and in this instance AED will equal PED. In other cases a variable number of eggs may be retained, only those that are not deformed or firmly attached to the ovarian membrane will be counted as these represent eggs that could have potentially been deposited.

The channels will be checked at least once a day for spawner mortalities. To maintain DO levels and constrain pathogens, all dead fish will be removed and their carcasses will be placed back into Duncan Creek or the Columbia River. At death, however, each female will have a mid-eye-to-hypural plate measurement taken and be examined for egg retention before disposal. In those instances where egg retention has occurred, a random sample of up to ten eggs will be collected to provide an estimate of egg size. Previous work has shown that there is very little variation in egg size within a female (e.g. the modal coefficient of variation value in egg size for Grays River females equaled 2.5%). Hence, even if a female retains only one or two eggs an accurate estimate of her egg size can still be made. Such samples will be placed in water, refrigerated for twenty-four hours, blotted dry and individually weighed to the nearest milligram. These egg size data will be used to help generate the fecundity estimates described above.

Estimating Fry Abundance From The Duncan Channels

At the end of each of the four Duncan Creek channels a cross weir will be built to hold two modified fyke nets. In part A of Fig 1. an example of the type of cross weir needed is shown. The cross weir depicted is twenty-six feet wide and has two six-foot wide by four-foot high bays that were designed to hold adult pickets and fry traps. The Duncan Creek channels are not as wide so smaller cross weirs with a similar design will be used. Other materials besides concrete can be employed to build cross weirs. The need to monitor fry production and survival from the Duncan channels will continue for a number of years and consequently concrete weirs are recommended because of their durability. Each bay in the cross weir is lined with channel iron to ensure that pickets and fry traps can be tightly fitted to prevent fry loss. In part B of Fig. 1. two fyke nets and their live boxes are shown. The fyke nets are made with 1/8 inch knotless nylon webbing that has received a coating to protect the net from UV damage. The attached live boxes were constructed using marine grade plywood and supplied with Styrofoam logs for floatation. The interior of each box has been painted white to make it easier to detect and capture fry. Fry trap installation will occur several weeks before emergence is expected and all the live boxes

.

A B

Fig. 1. Examples of the cross weir design (A) and modified fyke nets (B) that will be installed at the end of each Duncan Creek channel to monitor fry production and survival. Photographs were taken at the Cle Elum spring chinook observational stream.

will be checked daily until fry emergence has been completed.

Fry will be removed from each live box once a day by capturing them with a dip net. The captured fish will be placed in five gallon buckets and taken to a site adjacent to the channels where the fish will be counted, marked, and released (see below). To ensure that the fry are not stressed, the counting and marking location will have a gravity-fed source of water, at least four, six-foot in diameter circular tanks with exterior standpipes, a shelter (e.g. a ten by twenty foot Tarp World shelter or small trailer), a source of electricity, and an electric air compressor with air stones. Upon reaching the shelter each bucket of fry will receive its own air stone and then will be counted by using one of two methods. When less than three thousand fry have been captured the fish will be hand-counted. On those days when large numbers of fish have been obtained the following gravimetric method will be employed. Groups of 100 fry, approximately one group per thousand fish, will be hand counted and weighed on an electronic balance to the nearest 0.1 of a gram. After a group has been counted out, the fry will be poured into a fine wire mesh screen colander and gently blotted on a damp sponge to wick off most of the water adhering to the screen and fry. They will then be poured into a beaker containing water that had previously been tared to zero and weighed on an electronic balance. At least three such groups of fry will be processed each day gravimetric counting occurs. These data will be used to generate a mean fry weight and also to produce 95% confidence intervals around this mean value. The remaining fish will be processed as follows, buckets of water will be tared to zero on an electronic balance and groups of non-counted fry will by be poured into the colander, blotted and weighed. The weights of these groups will be recorded and summed and the following simple algebraic equation will be used to estimate the number of fry captured:

Number of non-counted fry = (100)(Total Wt. Of Non-counted Fry)/(Mean Wt. Of 100 fry)(x)

To demonstrate, assume that the mean fry weight for a given day equaled 0.410 or that 100 fry weighed 41 grams and that 3,425 grams of non-counted fry had been weighted out, the number of non-counted fry would then equal:

Number of non-counted fry = (100)(3425)/(41.0)(x)

Number of non-counted fry = 342,500/41x

Number of non-counted fry = 8,354

To obtain the total number of fry just add the number of fry hand counted, or for example assume that in the above case six groups of 100 fry were weighed to obtain the mean weight value, then the total number of fry for that day would equal 8, 354 + (6)(100) or 8,954. Ninety-five percent confidence around this estimate can be obtained by using the lowest and highest mean weights to estimate the number of non-counted fry and then add the number of counted fish to those values.

Estimating Egg-to-Fry Survival Rates And Assessing Fry Condition at Emergence

The total trapping or emergence period will last anywhere from 30 to 90 days, perhaps longer depending upon weather conditions. At the end of that period the total number of fry captured in each channel will be determined and this number will be divided by that channel's AED value to compute an egg-to-fry survival for each of the channel arms. The expectation is that egg-to-fry survival should approach or exceed 40% if the channels are operating in an appropriate fashion. Although chum salmon are expected to immediately emigrate downstream after emergence a small proportion ($< 1\%$) will remain in freshwater, rearing for short periods of time before beginning their downstream migration. Therefore, to obtain accurate survival estimates each channel should be seined soon after emergence has been completed to capture and enumerate these fish.

Periodic assessments of fry condition will be made throughout the emigration period to document any environmental or stock-specific effects on fry produced from each channel. To make such assessments, individual length (fork length) and weight (0.01g) measurements will be made on 30 randomly chosen fry collected from each channel every Monday, Wednesday, and Friday throughout the emergence period. The length and weight data will be used to calculate individual K_D values (Bams 1970) for each fish using the following formula:

$$K_D = \frac{10\sqrt[3]{\text{Wt in mg}}}{\text{Fork Length in mm}}$$

Typically K_D values in chum salmon fry range from 2.0 to 1.8, the higher the K_D value the more yolk material the fry possesses, emaciated fry will have K_Ds that are less than 1.7. Both intra-gravel conditions and stock effects can influence K_D values. For example, poor intra-gravel conditions may prompt pre-mature emergence and this would be disclosed by fry having higher than expected values. Such fish are particularly susceptible to predation because of their conspicuous yolk sacs and non-hydrodynamic form. Emaciated fish are also at risk because they have no or little endogenous food (yolk materials) to draw on as they begin to forage and migrate. Hence their ability to avoid starvation and engage in evasive swimming behavior will be reduced (Fresh and Schroder 1987). Consequently, the routine monitoring of K_D values over the course of each out-migration season will provide a direct measure of one aspect of fry quality. It will also help ascertain whether the intra-gravel environment in each channel is appropriate for chum salmon.

Assessing Environmental Parameters in the Duncan Creek Spawning Channels

Before committing resources towards the construction of spawning channels and an artificial rearing complex at Duncan Creek or anywhere else in the Lower Columbia River, comprehensive water chemistry surveys should be conducted. The elements and compounds that need to be examined and their acceptable standards are presented in Alderdice and McLean (1982), and Bell (1984) and are summarized in Appendix 2. Because Duncan Creek was a chum salmon spawning area in the past and is currently utilized by other salmonid species, it is unlikely that water chemistry problems exist. However, a comprehensive scan will help expose any potential problems and allow corrective actions to take place prior to fish introduction.

Besides water chemistry, other environmental or abiotic conditions are known to affect the performance and survival of salmonid fishes during spawning, incubation, and downstream migration. Consequently, to evaluate the success of the Duncan Creek project the environmental conditions it operates under need to be continuously monitored. This type of documentation will identify factors that are responsible for any unexpectedly high mortality rates. It may also offer insights into conditions that need to be improved or simply help explain why mortalities occurred. Water temperature for example, may delay spawning and increase egg retention rates in chum populations if it falls below 36^{o} F (Schroder 1973; Koski 1975). In addition, relatively low or high temperatures can be lethal to salmonid embryos prior to blastopore closure (Brannon 1987; Tang et al. 1987; McNeil and Bailey 1975). Thus, if extremely low temperatures occur soon after spawning, and fry survival is low, the probable explanation is thermal disruption of normal ontological events rather than some other factor.

Measurement of Environmental Parameters in Surface Waters

Chum salmon utilize two interconnected zones in streams, a surface water area where spawning and juvenile life takes place and the hyporheic zone or intra-gravel area where incubation proceeds. The types of environmental parameters that will be measured in each of these zones are somewhat similar; however, the sampling methods used in each area are often different. In the surface water zone, velocity, depth, flow, temperature, suspended sediments, and dissolved oxygen levels will be routinely observed.

A digital current meter will be used to take velocity and water depth readings at each cross weir. At this location, all the water leaving a channel goes across the weir and it is relatively easy to obtain depth and velocity data. Each channel should have a velocity that ranges from 0.75 to 1.25 feet per second (fps) and be approximately 12 to 18 inches deep. A stream gauge (water height) will be established on the upstream side of each cross weir and water height values will be recorded once a day for each channel. A relationship between water height values and cubic feet per second (cfs) will be established and used to estimate daily cfs values for the channels during the spawning and incubation period. The water velocity measurements will be made just prior to fish introduction, immediately after all the adult fish in a channel section have perished, and once a month thereafter until fry emergence has been completed.

Surface water temperatures will be recorded by using Onset © Tidbit recorders. These small (1.125 ”) in diameter devices will be placed inside perforated PVC pipe containers and suspended in mid-water at the beginning and end of each channel section. They will be programmed to record water temperatures once every two hours throughout the spawning and incubation period. The amount of settleable solids in the waters flowing through each channel will be measured by using Imhoff Cones. In this case, a three liter sample of water will be removed from each channel at the cross weir and used to fill three Imhoff cones that will be allowed to sit undisturbed for one hour. The quantity of sediment that has settled out of each sample will then be recorded in ml of sediment per liter of sample [see Standard Methods For The Examination Of Water And Wastewater

(1989) or later editions for further details). Such samples will be collected once a week in each channel. Dissolved oxygen concentrations in the surface water will be taken once every two weeks. Three, locations will be sampled, one at the head end of a channel, another at the middle, and a final one close to the cross weir at the terminus of the channel. Three independent readings will be made at each location by using a portable oxygen meter and probe. The probe will be calibrated prior to each use and standard methods will be followed.

Measurement of Environmental Parameters in the Hyporheic Zone.

The majority of the mortality experienced by salmonids typically occurs from fertilization through emergence. For example, Wicket (1952 cited in McNeil 1962) estimated that 75 to 95% of the chum salmon eggs deposited in a controlled stream died prior to emergence. Other investigators have documented similar mortality rates. Hunter (1948 as cited by McNeil 1962) found that 86% of the chum salmon embryos he excavated from natural redds were dead and Neave and Foerster (1955) found 86 to 99% mortality rates in chum and pink salmon redds in British Columbian and Southeastern Alaska streams. Numerous studies have attempted to determine the factors responsible for mortality during the incubation period (e.g. see Wicket 1954; Wicket 1958; Alderdice et al. 1958; McNeil 1962; McNeil and Ahnell 1964; Cooper 1965; McNeil 1966; Koski 1966; Koski 1975; Witzel and MacCrimmon 1981, 1983; Loptspeich and Everest 1981; Sowden and Power 1985; Alexander and Hansen 1986; Chapman 1988; Kondolf et al. 1991; Marten 1992; Geist and Dauble 1998; Argent and Flebbe 1999; Baxter and McPhail 1999 and others). A variety of causes have been identified, chief among them are redd superimposition by other spawners, scouring and gravel fill induced by dynamic water flows, dewatering and subsequent dehydration and desiccation, sedimentation or the incidence of sand and silt in spawning gravels which simultaneously reduces intra-gravel flow and entombs salmonid alevins, low seepage velocity of interstitial waters, low dissolved oxygen levels, high or low water temperatures during early development, and the occurrence of intra-gravel predators.

Several of these factors will be controlled in the Duncan Creek channels. For instance, the effects of redd superimposition and high egg retention rates induced by female competition for space can be ameliorated by: 1) providing each female with three- or more square meters of space, and 2) placing the fish into a channel over a two to three day period (Schroder 1973). Moreover, because the channels are protected from the Columbia River and are fed by upwelling springs, incubation mortalities caused by dynamic water flows and dewatering should not occur. However, factors such as gravel composition, water temperature, vertical hydraulic gradients, and oxygen levels in the hyporheic zone will need to be monitored. Such data will help characterize the general environmental circumstances that eggs and larvae experienced during incubation and also ascertain if sub-optimal conditions occurred at any point during the incubation cycle. Additionally, these data will indicate whether the channels need to be cleaned or altered to maintain optimal incubation conditions.

Assessing gravel composition in the channels. The survival of embryonic salmonids is affected by the composition of the gravels that surround them during their incubation period (Chapman 1988). Materials < to 3.3 mm (sand and silt) appear to have the greatest impact. For instance, relationships between the abundance of fine sediments and smaller gravel sizes in spawning gravels and decreased survival rates have been documented in a number of salmonid species (McNeil and Ahnell 1964; Koski 1966, 1975; Witzel and MacCrimmon 1983). Sand and silt particles can reduce permeability in the hyporheic zone and subsequently affect the rate of oxygen delivery and metabolic waste removal from eggs and alevins. Such particles also reduce interstitial pore volumes and can physically impair alevin movements, injure respiratory surfaces, and physically stop fry emergence.

A number of studies have tried to develop an index of gravel composition that reflects its ability to incubate salmonids. The geometric mean (D_g) of spawning substrate particle size and its associated standard deviation (S_g) indirectly characterize the pore size and permeability of substrates (Lotspeich and Everest 1981; Tappel and Bjornn 1983; Sowden and Power 1985). Lotspeich and Everest (1981) and Beschta (1982) proposed that D_g be divided by S_g to produce the "fredle index" or f_i (Sowden and Power 1985). When fredle index values were plotted against egg-to-fry survival data obtained from four independent studies it was found that survival increased as fredle values rose from 1 to 4 (Chapman 1988). This suggests that the fredle index does provide a reified measure of gravel quality and that gravel substrates with relatively high fredle values (> 4) have the capacity to foster high intra-gravel survival rates in salmonids. The gravel mixture presented in Table 1 of this document has a fredle index value of 5.2 and was created to maximize egg and alevin survivals in the Duncan Creek channels.

It is expected that the Duncan Creek channels will be filled with a consistent mixture of gravels. The gravel-monitoring program presented here has two goals. The first is to simply document the gravel composition added to the channels, i.e. does it approximate the requested specified mixture. The second goal is to monitor annual changes in the composition of these gravels with an emphasis on whether the fraction of fines (here defined as materials < 3 mm in diameter) in the gravel increases over time. Two basic *in situ* techniques can be used to sample stream gravels. One of these relies on obtaining a grab sample of material from the surface of the stream to a specified depth. Certainly the most widely used and best-known grab sampler is the so-called McNeil Sampler that was described in McNeil and Ahnell (1964) and shown in Fig 2. The sampler is inserted into the streambed approximately 6 inches or 15 cm. Gravel is then removed by hand from the 6-inch by 4-inch (15 x 10 cm) collection cylinder and placed into the larger cylinder. During this process, fines will be suspended in the water column and they are contained within the larger cylinder. Once a sample has been collected, a waterproof cap is placed over the top of the collection cylinder and the sampler is removed from the streambed. The second type of sampler relies on creating frozen cores of water and gravel and is thus able to collect sands and fines without disturbance. Walkotten (1973) developed the first device of this type which consisted of a three to four foot long by ½ to ¾ inch in diameter rigid copper pipe equipped with a pointed brass point. Liquid CO_2 is introduced into the pipe via a smaller diameter (3/8 inch) copper pipe that runs down to the brass point. Carbon dioxide is metered into the pipe via a flexible reinforced hose. Typically, gas is run through the sampler for about two to three minutes at a rate that induces a cloud of "snow" to pour out of the top of the sampling tube. The pipe and frozen core are then removed from the substrate for later analysis. A core sampler that uses three interconnected copper pipes and liquid carbon dioxide was subsequently developed and it provides a larger sample of material than the Walkotten "Wand" (5 kilo samples vs. 0.5 to 2 kilos).

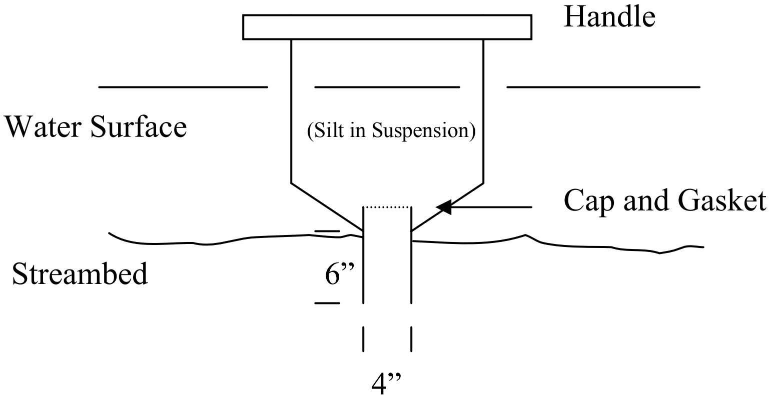


Fig 2. A diagram of the McNeil Gravel Sampler (taken from McNeil and Ahnell 1964).

Frozen core sampling has several advantages over the McNeil grab system. The cores can be placed over boxes that have been subdivided into bins. As the core melts, sediments and gravel originating from different vertical zones are segregated into separate bins and these samples can be analyzed separately from one another. Next, these samples require less time and are not as labor intensive to collect. The McNeil sampler, on the other hand, provides slightly more consistent samples, larger sample sizes (~ 10 kilos) (NCASI 1986), and is very reliable. Nonetheless, the gravel composition in the Duncan channels will be tracked by using frozen core samplers because of their ease of use and capacity to indicate the vertical distribution of sand and fine sediments.

In natural streams, gravel composition can vary widely depending upon local current patterns. Hence, when investigators have attempted to characterize gravel in such situations large sample sizes have proven to be necessary. In the Duncan channels, gravel composition should be rather uniform and sample sizes correspondingly low. Rood (1998) presents a method that will be used to determine how many samples should be removed from the Duncan channels to adequately characterize their gravel composition. He reports that the number of samples (N) required to obtain a given rate of precision equals:

$$N = [(t_{\alpha,N})*(C_v/I)]^2$$

Where $t_{\alpha,N}$ is Students t at 1-α, C_v is the coefficient of variation of the sample, and I equals the desired precision. N is found through iteration. Rood (1998) calculated some expected sample sizes using this formula on gravel data collected by Wolcott and Church (1991). He assumed that the gravel fraction of interest would be sediment < 1 mm in diameter, that α would equal 0.05, and that the C_v associated with this fraction was 28.9%. To achieve a precision level of 1%, Rood found that over two thousand samples would have to be analyzed; conversely a precision level of 10% required only twenty-four samples. Since the Duncan channels should be less variable than natural streams, twenty gravel samples will initially be removed from each stream channel. The samples will be collected in the following fashion. Every channel will be divided into fourths, from top to bottom. Five samples will be collected from each of these strata. Each fourth will be divided in turn, into ten equal segments and samples would be removed from five of these. Suppose, for example, that we were sampling Duncan Channel A, which is 657 feet long. In this case, the four larger segments would be approximately 164 feet long and the ten smaller subsections within them would be 16.4 feet in length. A random number generator would be used to determine which five would be sampled. For consistency, gravel samples will be removed from the center of each subsection.

To calculate the precision at which a particular fraction of gravel has been collected Rood (1998) provides the following formula:

$$I = DF/F^*$$

Where, F* is, for example the mean percentage of fines and DF is a confidence interval constructed around that statistic (Rood 1998). The gravel samples collected in the channels will be analyzed by drying and weighing the fraction of gravel retained on a series of Tyler sieves. This method will allow us to determine a fredle index, calculate precision estimates for particular gravel fractions and also help determine if enough samples are being collected to meet our desired rate of precision (i.e. $I < 10\%$). A first set of gravel samples will be collected prior to fish introduction. Thereafter gravel samples will be obtained on an annual basis after fry emergence has been completed. New sampling points will be determined each year.

Another method of assessing the quantity and types of fines imported into spawning gravels is to use sediment traps. Mahoney and Erman (1984) developed some simple traps that can be quickly used to sample fines in streams. I believe, however, that the gravel sampling approach described above will provide us with a more consistent and precise assessment of how the presence of fines may change over time. During the monitoring period, sediment traps may be evaluated and compared with standard gravel sampling to see if they can be a useful alternative to traditional gravel sampling procedures in the Duncan channels and elsewhere.

Plainly, the major objective of the gravel-monitoring program is to determine whether individual channels should be cleaned. The original gravel composition is designed to create a substrate that females can use to produce nest and redd architectures that promote high egg-to-fry survival rates. The literature review by Chapman (1988) suggests that gravels with fredle values > 4 promote high incubation survival rates. If the gravel samples in the Duncan channels indicate they have fredle values that are < 3 then efforts to purge the channels of sand and fines will have to occur. Such cleaning can be done with trash pumps and hoses that will be used to drive water and air mixtures into the substrate. This process will dislodge sediments so that they can be worked downstream and out of the channels. Such an effort will be very labor intensive but will provide significant survival benefits. It is unlikely that such cleaning will have to occur very often because the channels are largely protected from the importation of sand and sediments. As the project becomes more mature, and surrounding vegetation develops, the likelihood of wholesale cleaning will decrease even more because of the sediment trapping ability of the adjacent plant life.

Monitoring Oxygen Levels, Vertical Hydraulic Gradients, and Water Temperatures in the Hyporheic Zone. The affect of differing levels of dissolved oxygen and intra-gravel water flows on salmonid survival has also been extensively studied. In general, this work shows that survival is positively related to dissolved oxygen levels and apparent intra-gravel velocities (Chapman 1988). Of the two parameters, dissolved oxygen appears to the most important. For example, Shumway et al. (1964) and Coble (1961) discovered that very low intra-gravel water velocities could meet the oxygen requirements of developing embryos if oxygen concentrations in these waters remain high (Chapman 1988). In most streams there is a positive relationship between gravel porosity, intra-gravel flow and oxygen levels.

The intrusion of groundwater into intra-gravel areas may alter these relationships. Depending upon their origin, such waters may have depleted levels of oxygen or contain other deleterious materials. For instance, ground water seepage occurred in a number of areas in the Big Beef Creek spawning channels. Chemical analyses showed this water had relatively high levels of hydrogen sulfide and carbon dioxide (Koski 1975). These areas were visibly detectable because of the orange "flowers" of bacterial growth that occurred on the gravel substrate and banks where the seepage occurred. Such chemical characteristics may cause death, induce early hatching (Alderdice et al. 1958) or impact developing embryos in other ways (Koski 1975). Conversely ground waters may be rich in oxygen, accentuate intra-gravel flows and promote survival.

Sowden and Power (1985) examined the effects of groundwater seepage, gravel composition and oxygen concentration on the survival of rainbow trout embryos. They found that when mean dissolved oxygen (DO) levels fell below 4.3 mg/L (4.3 ppm) survival was negligible (< 1%). It improved when mean oxygen levels exceeded 5.2 mg/L, in fact a linearized model that examined the relationship between survival and mean oxygen concentration developed by these authors showed that 61% of the variation in survival could be explained by mean DO levels. When they added intra-gravel flow rates into a multiple regression formula an additional 9% of the variation could be accounted for. Other investigators have found similar effects (Chapman 1988). Koski (1975), for example, found that chum salmon incubating in sections of the Big Beef Creek channels that had DO levels less than 3 mg/L had about one-third the survival rate as those emerging from sections with higher DO levels. He also observed that low DO levels delayed emergence.

Chapman (1988) summarized much of the available literature on the importance of DO levels and concluded that any deprivation of dissolved oxygen from saturation can lead to biological problems. The Duncan Creek channels will have areas where significant seepage or ground water inputs are expected to occur. This is one of the attributes that have made this area attractive to naturally spawning chum salmon in the past. From the above, however, it is important that intra-gravel DO levels in these and adjacent areas of the channels be monitored on a routine basis to see if areas with low DO exist. The detection of DO in intra-gravel locations will be accomplished by using piezometers (Fig. 3) or standpipes that will be driven into the substrate. Again a stratified scheme will be used to place the piezometers into each channel. In this case, they will be installed at 50 foot intervals from the top of a channel to its cross weir. Each piezometer will be inserted into the approximate center of a channel and will be driven twelve inches into the substrate so it can sample intra-gravel water that is located where eggs are expected to be buried. Dissolved oxygen levels and water temperatures will be determined by using portable oxygen meters with sensors that can be inserted into the piezometer. Prior to taking any measurements the instrument will be calibrated using approved methods and three consecutive readings will be made in each piezometer. DO levels will be determined on a once every two week basis from egg deposition through emergence. A portable painter's plank will be placed across the channel to get access to each piezometer to prevent any inadvertent mortality caused by walking in the channels.

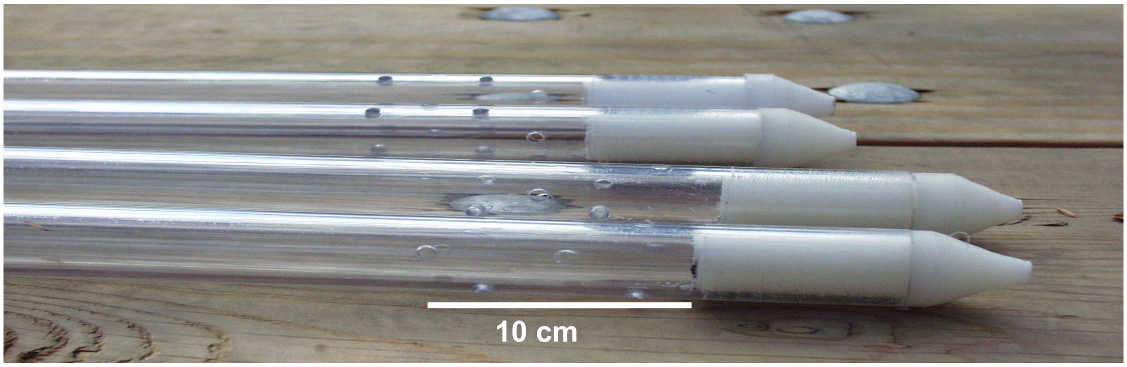


Fig. 3. A photograph showing the lower portion of four, 1x ¾ x 48 inch (2.5 x 1.9 x 122 cm) clear polycarbonate piezometers equipped with polyethylene nosepieces. A set number of one-eight inch in diameter (0.32 cm) holes have been drilled into the lower 4 inches (10 cm) of each piezometer to accommodate the collection of intra-gravel water.

If we discover that DO levels are consistently below saturation values in certain portions of the channels then an assortment of remedial strategies will be tried and evaluated. First such areas could simply be excluded from fish use by pickets or other barriers (e.g. just placing large stones over these areas should stop their use by spawners). Or conversely, logs or other natural barriers could be placed adjacent to these sites to promote surface water exchanges. In addition, these sites could be slightly excavated to create resting pools and riffles, again in an effort to induce surface water exchange and simultaneously to provide adult fish with some sheltered spots to rest in. Adult fish may simply avoid these areas and it will be of interest to see if they start to exploit such spots after some habitat alterations have occurred.

Piezometers can also be used to determine vertical hydraulic gradients (VHG), substrate permeability, and vertical intra-gravel flow rates (Q)(Freeze and Cherry 1979). In the Duncan Creek channels VHG values at each piezometer will be determined three times each year, once immediately after spawning has been completed, in December when typical winter flows are occurring and in the Spring after fry emergence has been completed. VHG values are determined by using the following formula:

$$\text{VHG} = \triangle h / L$$

Where $\triangle h$ equals water elevation difference between the inside of the piezometer and the stream surface. It is calculated as $h_s - h_1$, where h_s is the distance from the top of the piezometer to the stream surface and h_1 is the distance from the top of the piezometer to the water surface inside the piezometer. Three measurements of h_s and h_1 will be made at each piezometer every time VHG values are being assessed. This replication will provide an assessment of variability and also allow a mean VHG with confidence intervals to be established for each piezometer. To reduce variation, an electrical interface measuring tape will be used. In the above formula, L equals the distance below the streambed to the top of the first row of piezometer holes (Finn and Maclean personal communication; Barnard and McBain 1994; Dahm and Valett 1998). Positive VHG values indicate that upwelling is occurring and negative ones disclose areas where down-welling is occurring (Freeze and Cherry 1979). Tracking these values overtime will provide us an opportunity to document the prevalence of ground water inputs into each channel and see if they change seasonally.

Normal spawning activities may dislodge some of the piezometers. Consequently, the position and status of each piezometer will be determined after spawning has been completed. Those that have been uprooted or knocked out of alignment will be reinserted at the proper depth in a nearby location. When replacement occurs it will be noted, then data collection will take place as described above.

Intra-gravel permeability and vertical intra-gravel flow rates will not be determined. The measurements taken on gravel composition, DO, and VHG should adequately characterize the general intra-gravel environmental conditions present in each channel. Intra-gravel water temperatures, however, will be continuously recorded from the time fish are placed into the channel until fry emergence has been completed. To accomplish this, Onset © Tidbit recorders will be placed into perforated 1 x 2 inch (2.5 x 5 cm) PVC containers and buried 12 inches (30 cm) into the substrate. Each container will be attached to the shoreline by a light metal cable. Four intra-gravel tidbit recorders will be evenly placed into every channel. The recorders will be labeled to indicate what channel they were monitoring and where they were buried. They will be set to record water temperatures once every two hours. Data will be downloaded from the recorders at the end of the incubation season.

General Objectives of the Environmental Monitoring Program in the Duncan Creek Channels

Chapman (1988) has chided past investigators on linking general conditions in streams to egg-to-fry survival in salmonids. He rightfully states that female salmon, through their digging activities, create incubation areas that have different environmental conditions than those found in adjacent non-disturbed stream areas (see also de Gaudemar et al. 2000). Plainly the direct affects of various factors on early survival must be measured within nests to fully appreciate their impacts (Chapman 1988). The monitoring effort described above is not designed to examine the influence of various parameters on fry survival. Instead it will be used to obtain a generalized picture of the conditions in each channel. And as mentioned above, when certain parameters like gravel composition or dissolved oxygen appear to have characteristics that are known to reduce survival then actions designed to alleviate this circumstance will occur. Perhaps the best measure of the incubation characteristics of each channel will be its egg-to-fry survival rate. These rates should be around 40% or higher. If survival falls below this level the environmental monitoring effort should help indicate why that may be occurring and consequently what things might be done to increase a channel's capacity to produce more fry.

Evaluating Egg-To-Fry Survival Rates In the Artificial Rearing Program

Eggs collected from the females used to establish the body trait fecundity relationships for the Bonneville chum salmon population will be artificially fertilized and incubated at Duncan Creek. How these matings will occur, and how survival from fertilization to ponding will be estimated, is described in Appendix 1. A brief summary of the protocols presented in the appendix for tracking egg survival is presented below. First, it is anticipated that Remote Site Incubators (RSIs) (Fig. 4) will be used to incubate the eggs from fertilization through emergence. In many of our salmon recovery projects, the egg complements of single females are incubated separately and therefore it is possible to develop egg-to-fry survival data for each female. This type of accounting is not possible in RSIs; instead eggs are placed on screened trays that over lie a rugose incubation substrate (usually plastic biorings or bio saddles). At hatching, alevins fall through the screens and penetrate into the substrate matrix where they remain until emigration. Thus, in RSIs, eggs from multiple females are placed onto an egg tray and up to five trays can be inserted into an RSI. The RSI shown in part B of Fig. 4, for example, can successfully incubate up to 100,000 eggs if it is supplied with five egg trays and 10 to 15 gallons (38 to 57 L) per minute of incubation water.

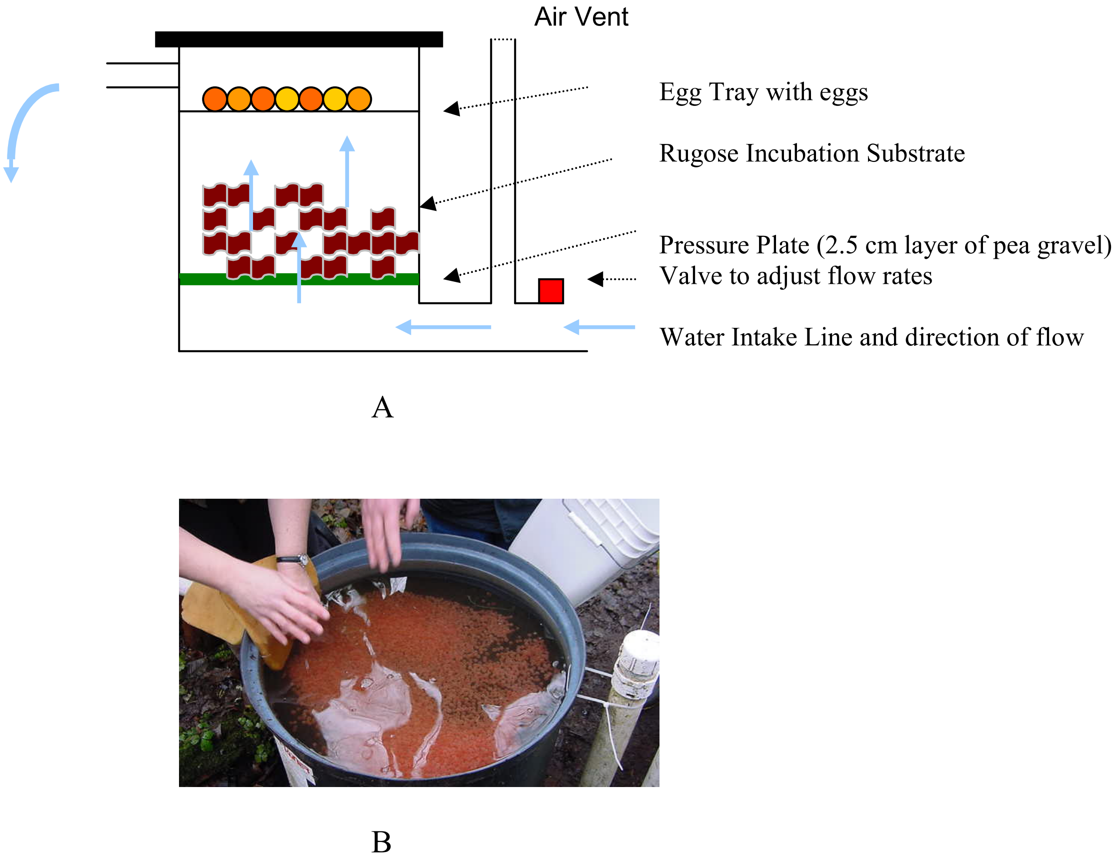


Fig. 4. Part (A) is a schematic view of a typical RSI showing that water enters the bottom of the structure and up-wells past a pressure plate, into the incubation chamber and continues through the egg trays and out an exit opening. When fry emerge they swim out through the exit pipe. Part (B) is a photograph showing eggs recently placed into a 55 gallon (208 L) RSI. During incubation an opaque lid is placed over the device to protect the eggs and developing alevins from light.

To monitor egg mortality we have to know how many eggs are added to each RSI. As Appendix 1 indicates, estimates of the number of eggs collected from each female will be made at spawning. Immediately after fertilization these eggs will be placed into a RSI. The total number of eggs introduced into an RSI then equals the sum of these estimates for the females used to supply it with eggs. At eyeing the eggs in each tray are shocked using standard methods and any dead eggs are then removed and counted. The total number of dead eggs can be divided by the total number placed into the RSI to obtain an egg to eyed-egg survival value. Most of the incubation mortality that occurs will usually transpire during this period. After the fish have hatched, the egg trays should be removed and inspected for any dead alevins. On a few occasions, fish may die at hatching and these mortalities will also be recorded. Once emergence from a RSI has been completed it needs to be inspected for any mortalities or monstrosities that may remain in the incubation substrate. This task should be performed by pouring the substrate into a fine mesh net placed over a plastic tub filled with water. Each piece of substrate can then be inspected by hand for dead alevins. Invariably there will also be a small portion of deformed fish, such monstrosities range from Siamese twins to fry with severe cases of scoliosis or other maladies. A tally of the incidence of such fish will be made. Once these data have been collected the following four estimates will be calculated:

1) Egg to Eyed-Egg Survival = Total Mortalities Up to The Eyed Egg Stage/ Total Eggs Placed into a RSI
2) Eyed-Egg to Fry Survival = Total Eyed Egg and Alevin Mortalities/Total Number of Eyed-Eggs
3) Overall Survival = Total of all Mortalities (excluding live monstrosities)/Total Number of Eggs Placed into a RSI
4) Incidence of Monstrosities = Total Number of Monstrosities/Total Number of Eggs Added to a RSI

In general, overall egg-to-fry survival should equal 90% if the fertilization and incubation environments are functioning properly. Some monstrosities are caused by physical stress or shock, e.g. Siamese twinning. If large numbers (hundreds) of these fish are found then a review of egg handling procedures, from collection through emergence, should occur to determine how to reduce any inadvertent stresses. Moreover, by examining mortality at different stages it will be possible to isolate when it is occurring and possibly why. Gamete viability, for instance, can be variable and appears to be mostly linked with egg quality. If high mortalities occurred from fertilization to eyeing it is possible to collect samples of the dead eggs and clear their chorions to see if they were fertilized, and if so at what stage of development they died. Environmental conditions such as low oxygen levels or smothering due to fine silt can cause significant mortalities as well. These events will be detectable not only because of periodic mortality assessments but also because environmental parameters within each RSI will be monitored and recorded.

Monitoring Environmental Conditions In The RSIs

A few key environmental factors, water flow, dissolved oxygen, temperature, and sediments in the incubation water, will be monitored in each RSI. Because of their relatively remote location it is important that an automated alarm system designed to detect low flows be installed at the Duncan Creek incubation site. This system will be identical to one that is currently being used in a summer chum salmon recovery project that is taking place in Jimmycomelately Creek, a Strait of Juan de Fuca stream. The alarm system is activated when water flows fall below a certain level. When this happens, it automatically dials the phone numbers of a number of local people and notifies them that the site is experiencing low flows. It continues to send this message until the alarm is shut off at the site. The Jimmycomelately Creek project is located in a valley and does not have electricity so portable batteries power the alarm system. In spite of its location and power source, the system has proven to work very well, notifying volunteers several times during last year's incubation and fish rearing seasons that flows needed to be adjusted. Response time to the alarm was rapid and no egg or fish losses due to low flows occurred. The alarm for the Duncan Creek RSIs will be established in a head box that will deliver water to the RSIs.

Besides this automated monitoring, routine water flow measurements through each RSI will be made on a weekly basis. As described above, each RSI will receive 10 to 15 gallons of water per minute. These flow rates will be checked by filling a 5 gallon bucket (19 L) with outflow water for 10 seconds and then ascertaining the quantity of water captured by pouring it into a 5000 ml graduated cylinder. Three measurements will be made on each RSI at every observation period. Flows per minute will be determined by multiplying the mean volume of water collected in ten seconds by six. Flow rates will be adjusted by using the valve in the water intake line if they are lower or higher than desired (see Fig. 4. Part A). Some of the water used to make these assessments will also be poured into three Imhoff Cones to determine the quantity of settleable solids that may be in the incubation water. These measurements will occur once every two weeks.

Dissolved oxygen levels are expected to be at or near saturation in each RSI because the incubation water will be thoroughly aerated at the time it enters the head box. Moreover, the amount of water moving through each RSI should provide the eggs and alevins with an adequate and continuous supply of oxygen. Dissolved oxygen levels will however, be checked three times during the incubation period. Once just before eggs are added but after flows have been adjusted, again at the time when the egg trays are inspected for mortalities, and a final time after emergence has started. A portable oxygen meter will be used to collect these data. Additionally, each RSI will be equipped with an Onset © tidbit temperature recorder set to record temperatures every two hours. They will be buried in the substrate at the time eggs are being added to a RSI. Data will be downloaded at the end of the emergence period.

Monitoring Fry Performance In the Artificial Rearing Program

The rearing protocols that are currently being used in WDFW's chum salmon recovery projects will be followed during the rearing phase of the Duncan Creek project. These are presented in Part II of Appendix 1. A brief overview of these procedures is provided below.

To rear all the fry produced by the artificial rearing program, eight fiberglass raceways, 3 feet wide x 3 feet deep and 16 feet long, will be established at Duncan Creek. Each will be supplied with up to 30 gallons per minute of water. A maximum of 20 thousand fry will be placed into a raceway giving the project a total rearing capacity of 160 thousand fry. The interior of the raceways will be colored a dark gray or brown to match the substrate colors found in the adjacent Columbia River.

As fry emerge from their RSI they will be retained in a tote box lined with 1/8 inch-mesh nylon net. Hand or gravimetric counts of the fry leaving each RSI will occur on a daily or as needed basis. After being counted, up to twenty thousand fish will be placed into each raceway. Whenever possible the raceways should be completely loaded over a seven day period so that all the fish are approximately the same size and therefore can receive the same size food. The fish will be fed eight times a day, five days a week at 3% of their body weight. Ration size will increase periodically throughout the rearing period, but food diameter will not exceed one-fortieth the length of the fish (approximately the diameter of their esophagus). Mortalities in each raceway will be counted and removed each day. Mean fry weight will be determined on a weekly basis by randomly removing and weighing three groups of twenty-five fish from each raceway. This weight plus the estimated number of fry in a raceway will be used to calculate the daily ration of food that should be delivered to the fish during a given rearing week. Rearing will continue until the fry weigh between 1 to 1.5 grams and are 50 to 57 mm fork length. At that time the fish are ready to be released. The mortality and growth data collected during the rearing phase will be used to calculate rearing mortality and overall growth rates for each raceway. Mortality rates should not exceed 5% and are typically less than 1 %. If at any time mortalities start to increase over time a trained pathologist should be brought in to inspect the fry and recommend treatment. If chum are provided with adequate flows and are not over fed disease epizootics should not occur.

All feeding will stop forty-eight hours before a release. Just prior to being released, fifty fry will be individually weighed to the nearest 0.01 g and have their fork lengths determined to the nearest mm to obtain a mean size at release value. To make a release, the fish will be gently crowded to one end of their raceway with a block seine and dipped netted into one of two tote boxes strapped onto a flat bed truck. Each tote will be lined with a fine mesh net and have its own aeration system. Approximately, one half of the fish in a raceway will be placed into each tote. At transfer, the totes will be covered with tight fitting lids to prevent water and fish losses and driven a short distance to the Columbia River for release. A dip net will be used to remove the fish from each tote. After being captured they will be poured into five gallon buckets, hand-carried to the river's edge and then liberated. All releases will occur at night.

Assessing the Survival and Spawning Ground Distribution of Adult Chum Salmon Produced From the Spawning Channels and Artificial Rearing Program

Three types of information are needed in order to produce survival estimates and make assessments about where adult chum salmon produced from the Duncan Creek project spawn. First, we must know how many fry are being released from the project on an annual basis. Many of the procedures presented above are designed to provide that information and thus we should have good estimates of the numbers of juveniles produced by the channels and the numbers released from the rearing program. Second all the fish produced from the project have to be identifiable at the adult stage. Consequently each individual generated by the project needs to receive a permanent mark that can be used to recognize it when it reaches maturation. Finally, adult chum salmon returning to spawn in different sites in the Bonneville area will need to be sampled to estimate the proportion that originated from the Duncan Creek project. In addition, the abundance of chum spawning in each location will have to be ascertained. Overall survival by treatment can then be calculated by summing the estimated number of project chum spawning in each area and dividing that amount by the total number of fry released from each of the project's treatments (e.g. the channels or rearing program). A simple example of how this procedure will work is shown in Table 3.

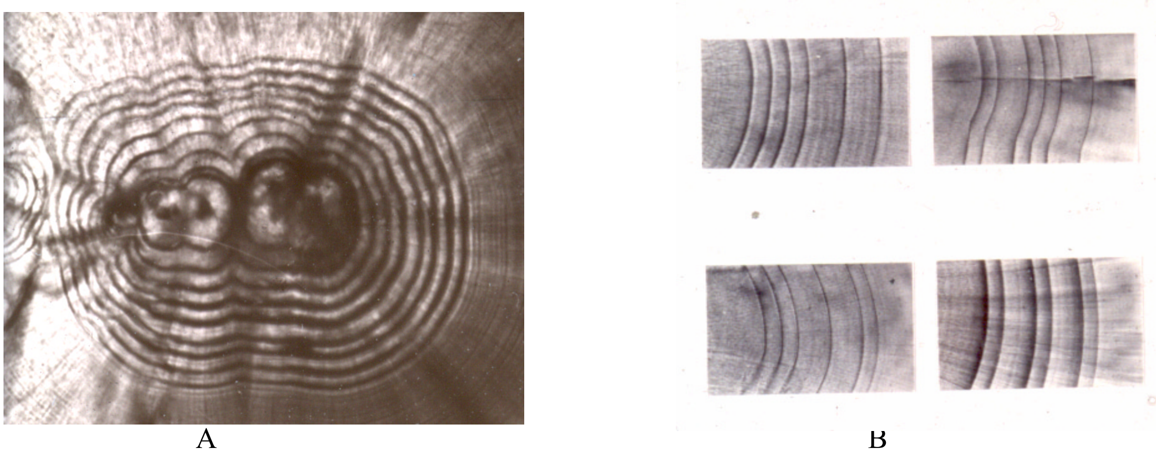
Table 3. An example of the types of data needed to estimate the survival and distribution patterns of chum salmon adults produced by the Duncan Creek project.

Sampling Site	Estimated Pop. Size	Number Sampled	% Channel Fish	% Reared Fish	Estimated No. Of Channel Fish	Estimated No. Of Reared Fish
Duncan Creek	300	200	50%	50%	150	150
Ives Island	250	100	5%	2.5%	12.5	6.25
Hardy Creek	125	75	5%	5%	6.25	6.25
Hamilton Creek	100	50	2%	4%	2	4
I-205	100	50	0%	0%	0	0
TOTALS	875	475	19.51%	19.03%	170.75	166.5

The data shown in Table 3 depict a hypothetical abundance and distribution pattern for the adult chum produced by the project. Estimated population sizes will be determined by using the area under the curve or other standard methods. Real recovery data will need to be sorted by brood year origin in order for survival estimates to be made. This is necessary because Columbia River chum salmon mature at three, four, and five years of age. Hence, to know how many adults were produced from a given release, it will be necessary to add the number of three-, four- and five-year olds produced by that release of fry. A survival estimate for a release is then obtained by dividing the total number of adults produced, by the number of fry they originated from. For example, suppose that 200,000 channel fry were released and that a total of 200 adults were produced from that group over the course of three years. Survival would then equal 200/200,000 or 1%.

Placing Marks On The Chum Salmon That Will Be Reared At Duncan Creek

To obtain data like that shown in Table 3 requires that chum fry originating from the project be permanently marked and that these marks can be reliably read after sampling. A long-standing challenge faced by fisheries researchers and managers has been how to tag or mark small salmonids without injuring them. Numerous methods have been developed. Some like fin clipping and half-length Coded Wire Tags (CWTs) (Thrower and Smoker 1984) demand that each fish be individually handled. Others, like fluorescent spray marking can be applied simultaneously to many fish but will leave some unmarked, are inherently stressful, and become more difficult to detect over time. Thermal marking of otoliths (Volk et al. 1994; Schroder et al. 1996; Volk et al. 1999) on the other hand is a benign and universal way to mark embryonic salmonids. This method will be used to mark all the fry generated by the artificial rearing program. A comprehensive review of the method can be found in Volk et al. (1999). Briefly, shifts in water temperature experienced from the eyed-stage through yolk absorption are used to induce recognizable bands on the microstructure of otoliths. The bands and spaces between them are organized to produce bar codes on otoliths by following a series of simple rules (Volk et al 1994) that create relatively wide and narrow spaces between the bands. Marks can be induced into otoliths both before and after hatching. The technique was first applied to pacific salmon in 1985 (Volk et al. 1990) and since then over three billion salmonids have been marked using this procedure. Fig. 5. provides a microscopic view of salmonid otoliths that have been thermally marked. In Part (A) a simple repetitive pattern was induced into the specimen prior to hatching, in Part (B), examples of four bar code patterns relying on the placement of relatively wide and narrow spaces between thermally induced bands are shown.


A

B

Fig. 5. Photomicrographs that show the general appearance of thermally marked salmonid otoliths. In Part (A) a pre-hatched embryo received a simple repetitive mark while in Part (B) the interleaved two-of-five rule was used to create four distinct bar codes. To create these marks six thermal events were used to produce five spaces, two of which are twice as wide as the remaining three.

Six portable, 10,000 BTU water chillers and two insulated water chilling boxes will be set up and used at Duncan Creek to thermally mark the chum that will be reared at the site. Three chillers will be placed into each chilling box and approximately 4 to 5 gallons (15 to 19 L) per minute of water will be pumped into the box and chilled 7 to 9°F (4 to 5°C). One additional water chiller will be kept on site and used as a backup chiller in case one of the other units has any mechanical problems. The chilled water from both boxes will be combined and delivered to each RSI at predetermined times to produce desired bar codes in the incubating fish. Generally, the duration of exposure to chilled water ranges from 8 to 24 hrs depending upon how variable the temperatures are in the ambient water supply; longer exposures are needed when ambient temperatures vary by several degrees over a 24 hr period. It typically takes about 30 or more days to induce both pre- and post hatch codes. At the conclusion of the marking period twenty fry from each RSI will be collected and preserved in 100% ethanol. The otoliths from these specimens will be processed and used as vouchers that can be referred to when adult specimens are being decoded.

<u>Placing Marks On The Chum Salmon That Will Be Produced From the Duncan Creek Spawning Channels</u>

To induce thermal marks fish must be incubated or held in temperature controlled environments for several days of longer. In some instances, like the Duncan Creek channels it impossible to produce such marks. Instead, another method that quickly and benignly marks fish is needed. About forty years ago, Trefethen and Novotny (1963) recommended that stable isotopes be introduced into fishes to create recognizable marks.

Since then investigators have introduced bone-seeking cations into fishes by feeding, injections and immersion baths. Behrens Yamada and Mulligan (1982, 1987) exposed salmonids to strontium (Sr) chloride by holding them in dilute baths (1 ppm) or using strontium enriched diets. Their methods produced recognizable marks but took weeks to complete. Schroder et al. (1995) modified their protocols by exposing salmonid fry to strontium baths containing up to 9000 ppm for 24 hrs. Calcified tissues collected from the fish they exposed were analyzed by several techniques; one was Wave-Length Dispersive Spectrometry (WDS). This method bombards a specimen with primary electrons from an artificial source. They interact with the specimen surface to produce backscattered electrons, secondary electrons, and x-rays. The machine has an x-ray detector that is used to identify the elemental composition of the specimen and backscattered electrons may be used to create Backscattered Electron Images or BEIs. When BEIs were taken from otoliths collected from fish that Schroder et al. marked strontium bands were easily seen. In Fig. 6. A BEI of an otolith collected from a brown trout alevin exposed to four 1000 ppm strontium baths is shown. Exposure duration was for 24 hours and five day intervals occurred between immersion events. Four or eight hour exposures will create equally vivid marks. Multiple strontium marks are also possible by using varying the concentration and holding time of just one immersion bath. In the Duncan Creek situation, newly emerged fry collected from the channels will be marked by holding them in 1000 ppm solutions for eight hours. As mentioned earlier, six foot in diameter (1.8 m) circular tanks will be established at the site, they will be lined with 1/8 inch nylon mesh netting, supplied with a source of running water, and air stones powered by an electric air compressor. Each tank can accommodate up to 20,000 or more fry. Once loaded with fish, the air stones would be turned on and the pass through water supply shut off. A pump that re-circulates tank water would be used to help aerate the holding water. An appropriate amount of strontium chloride would be then be added to the tank and the fish would be held in their marking solution for eight hours. At the end of the immersion period, the tank water would be turned back on again and all affluent water would pass through a bed of activated charcoal to bind up the strontium and chloride in the exit

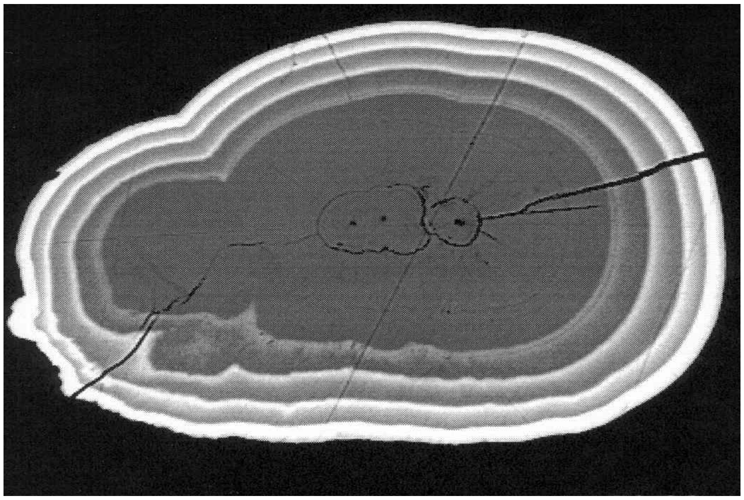


Fig. 6. A Backscattered Electron Image of an otolith collected from a brown trout alevin exposed to four, 1000 ppm strontium immersion baths.

water. At nightfall, the recently marked fish would be gently dip netted from their tanks and liberated into Duncan Creek. If the lower portion of Duncan Creek harbors predators the fry will be liberated directly into the Columbia River using methods similar to those described for releasing the reared fish. Mark clarity will be periodically checked by holding several fish from each marking episode and rearing them for up to two weeks. Otoliths would be extracted from the fish and examined using WDS.

Methods similar to this are being used by the Alaska Department of Fish and Game to mark 26 million sockeye fry. Researchers there have obtained an INAD from the FDA. We will have to do the same thing to use this method. We believe that this should readily occur because we are marking the fish at a very small size and none should be eaten by humans because of their rarity and ESA protected status.

Assessing the Colonization Rate of Wild Chum Salmon Into Duncan Creek

One of the objectives of this project is to determine how rapidly Bonneville chum salmon will colonize the newly opened Duncan Creek system. Any chum salmon entering the Duncan Creek drainage from 2001 through 2003 will be strays or colonizers and annual counts of their abundance will be made. To facilitate these counts a “V” trap and live box will be built just upstream of the newly built fish passage structure at the mouth of Duncan Creek. The trap will capture all adult salmon entering the stream. These fish will either be placed into the Duncan Channels or used in the artificial rearing program. In 2004, the first three-year old fish produced from the project should return. From this point on, a mixture of project fish and strays will be entering the basin. The origin of these fish will be ascertained by inspecting their otoliths. As indicated above, all the fish produced from the artificial rearing program will receive thermal marks that will indicate their brood year, and that they originated from this program. Fish originating from the channel will receive strontium marks. Unlike thermal marks, strontium deposits are not readily seen under normal light microscopy. Consequently to differentiate between channel fish and strays it will be necessary to examine otoliths that do not have thermal codes with WDS (Wave Dispersive Spectrometry). This analytical technique will indicate, via BEI images or microprobe transects, whether a fish has received a strontium mark or not.

Hence, beginning in Fall 2004, otoliths from every chum salmon entering Duncan Creek will to be collected, either after they have spawned naturally in the channels or been used in the artificial rearing program. These specimens will be analyzed by WDFW using methods described by Volk et al. (1999). Briefly, hemi-sections will be made on one sagitta (the largest of the three different otoliths found in salmonids) and visually inspected for thermal marks. If no mark is evident, the section will be coated with a thin layer of carbon and examined by WDS for a strontium mark. Peak strontium counts will be made on any mark detected. In this fashion, the number of adult chum salmon originating from the rearing program, from the channels, and straying into Duncan Creek will be determined on an annual basis.

Colonization or straying rates in chum salmon may be affected by both environmental and social conditions (abundance). The data collected from the chum entering Duncan Creek could be examined using statistical procedures such as multiple regression techniques to see if water flows or other environmental conditions (e.g. rain fall, water temperature, tidal cycles) and the abundance of project fish influenced the incidence of straying into the basin.

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Attachment 2

HATCHERY AND GENETIC MANAGEMENT PLAN (HGMP)

Washington Department Fish and Wildlife

SECTION 1. GENERAL PROGRAM DESCRIPTION

1.1) Name of Program

Lower Columbia River Chum Salmon Recovery Project

1.2) Population (or stock) and species

Lower Columbia River ESU chum salmon (*Oncorhynchus keta*); fall run component.

Grays River stock

1.3) Responsible organization and individual:

Name (and title): Washington Department of Fish and Wildlife
Organization: Washington Department of Fish and Wildlife
Address: 600 Capitol Way North, Olympia WA 98501-1091
Telephone: (Dan Rawding, Lead Biologist) 360.906-6747
Fax: Dan Rawding, 360.906-6776 and 360.906-6777
E-mail: rawdidr@dfw.wa.gov

Other organizations involved, and extent of involvement in the program:

The attempts to recover and restore Lower Columbia chum salmon have been predominately supported by Washington State. In 1998, for example, monies from State Senate Bill 6324 were used by WDFW (Washington Department of Fish and Wildlife) to begin a chum salmon recovery program in Grays River. In this instance, brood stock were captured from Gorley Springs, a Grays River tributary, artificially spawned, thermally marked, and reared at the Grays River Hatchery. Over one hundred thousand reared fry were released from the hatchery in March and April of 1999. In addition to this work, SSB 6324 dollars were used to conduct extensive stream surveys by WDFW to determine if remnant populations of chum salmon existed in tributaries entering the Lower Columbia on the Washington side of the river. In 1999 monies from a legislative appropriation to WDFW for hatchery recovery efforts on ESA listed salmon stocks will be used to support the recovery efforts outlined in this document. One aspect of our recovery plan calls for re-introducing Lower Columbia River chum salmon back into streams where they had previously existed. The first attempt at making such a re-introduction will rely on the assistance of Sea Resources, a non-profit educational organization headquartered in the Chinook River basin. Sea Resources will provide rearing vessels, water, and labor so that chum salmon native to Grays River can be re-introduced into the Chinook River, one of the lowest tributaries to the Columbia River on the Washington side. They will be responsible for rearing the fish and will assist in their liberation into the lower part of the Chinook River. In addition, Sea Resources staff will actively work with WDFW to develop high quality chum salmon spawning areas in the Chinook basin so that a self-sustaining, naturally-reproducing population of chum salmon can be re-established in the basin. The

Lower Columbia River Fish Recovery Board, Lower Columbia River Fish Enhancement Group, local sport fishing clubs, and citizens and landowners in Wahkiakum, Cowlitz, Clark, and Skamania counties will assist us in our efforts to collect brood stock, rear and liberate fed-fry, determine whether genetic enclaves of chum salmon exist in tributaries of the Lower Columbia River, and develop natural spawning refugias for this species.

USF&WS (United States Fish and Wildlife Service) in cooperation with Burlington Northern Railroad and Washington Trout are developing a controlled-flow spawning channel for Lower Columbia River chum salmon in the Hardy Creek drainage. The physical parameters of this channel plus its monitoring and evaluation components will serve as an important archetype for any additional chum salmon spawning channel development in the ESU. USF&WS also has traps in Hardy Creek and the spring channel of Hamilton Creek to estimate adult and juvenile abundance.

Efforts are also underway to modify an existing dam near the mouth of Duncan Creek to allow free passage of adult and juvenile chum. Funding for modification of the dam is expected to be provided by The Skamania Landowners Association, Washington State Department of Natural Resources Aquatic Lands Enhancement Account, Washington State Salmon Recovery Funding Board, and the Bonneville Power Administration.

In the mainstem Columbia just below Bonneville Dam, several agencies under Bonneville Power Administration funding are evaluating the spawning success of chum salmon found there. Oregon and Washington departments of fish and Wildlife, USF&WS, U.S Geological Survey, and Pacific Northwest Nation Laboratory have joined together to collect life history and habitat use data for fall chinook and chum salmon below the four lowermost Columbia River mainstem dams so the hydrosystem can be managed in a manner to protect and/or enhance these spawning populations.

1.4) Location(s) of hatchery and associated facilities:

Brood stock Capture: A temporary weir and adult trap will be installed at the mouth of Gorley Springs (WRIA 25-0129), a tributary that enters the Grays River, Washington, at Rkm 20.0. It will be in operation from early November through mid-December, or until adult chum salmon cease entering Gorley Springs. When Grays River chum salmon released into the Chinook River return to that basin to spawn they will be captured, as needed, at the Sea Resources Hatchery weir (WRIA 25-0001) Rkm 6.6. The goal of the Chinook River program is to develop a self-reproducing population.

Brood stock Holding to Maturity: Grays River Hatchery-located on the West Fork of the Grays River, Washington (WRIA 25-0131) at Rkm 23.3. After Grays River chum salmon released into the Chinook River return to that basin they will be held at the Sea Resources Hatchery (WRIA 25-0001) Rkm 6.6 on a as needed basis. The goal of the Chinook River program is to develop a self-reproducing population.

Fish Spawning, Incubation, Rearing: Spawning: Grays River Hatchery-located on the West Fork of the Grays River, Washington (WRIA 25-0131) at Rkm 23.3. Sea Resources Hatchery-located (WRIA 25-0001, Rkm 6.6) in the Chinook River (WRIA 25-0001) Columbia Rkm 10.0. Incubation: Grays River Hatchery-located on the West Fork of the Grays River, Washington (WRIA 25-0131) at Rkm 23.3. Sea Resources Hatchery-located (WRIA 25-0001, Rkm 6.6) in the Chinook River (WRIA 25-0001) Columbia Rkm 10.0. Rearing: Grays River Hatchery-located on the West Fork of the Grays River, Washington (WRIA 25-0131) at Rkm 23.3. Sea Resources Hatchery-located (WRIA 25-0001, Rkm 6.6) in the Chinook River (WRIA 25-0001) Columbia Rkm 10.0.

Rearing to Release: Grays River Hatchery- concrete raceways, located on the West Fork of the Grays River, Washington (WRIA 25-0131) at Rkm 23.3. Sea Resources Hatchery-fiberglass raceways (WRIA 25-0001, Rkm 6.6) located in the Chinook River (WRIA 25-0001) Columbia Rkm 10.0.

1.5) Type of Program:

Integrated recovery program that utilizes supplementation and re-introduction strategies.

1.6) Purpose (Goal) of Program:

The goals of the Lower Columbia River chum salmon recovery project are to: 1) determine if remnant populations of Lower Columbia River chum salmon exist in Lower Columbia River tributaries; 2) If such populations exist, develop stock-specific recovery plans that would involve habitat restoration or the creation of spawning refugias, the capture of native brood stock, factorial mating of adult fish, incubation, thermal marking, and post-emergent rearing of fry and subsequent release of those fish into their native streams followed by an evaluation of fry-to-adult survival. If chum have been extirpated from previously utilized streams, develop re-introduction plans that utilize appropriate genetic donor stock(s) of Lower Columbia River chum salmon and integrate habitat improvement and fry-to-adult survival evaluations; 3) stabilize the Grays River chum salmon population by randomly capturing adults entering Gorley Springs, factorially mating them and subsequently incubating and rearing them in the Grays River Hatchery. All these fry will be thermally marked and released when wild cohorts emigrate out of the Grays River; 4) re-introduce Lower Columbia River chum salmon into the Chinook River basin. A portion of each family produced by the Grays River mating program will be transferred at the fry stage to Sea Resource's hatchery. Once there, the fish will be reared until they reach 1 to 1.5 g in size and at that time they will be liberated into the lower part of the Chinook River, at night, on a falling tide. All of these fry will also be thermally marked.

1.7) Specific performance objectives of Program:

1) Conduct systematic stream surveys in Lower Columbia River tributaries and use GPS technology and maps to indicate where chum salmon spawn in each surveyed basin. Quantify the occurrence of chum salmon in those systems where they are found.
2) Identify ground water sources and possible spawning channel locations that could be developed in each surveyed watershed.
3) Develop site-specific recovery initiatives for Lower Columbia River chum salmon on a tributary-by-tributary basis, working closely with local citizens, regional salmon enhancement groups, local, federal and state entities.
4) Collect one hundred and fifty to three hundred thousand eggs from chum salmon returning to Gorley Springs. Artificially mate these fish in a factorial fashion, collect biological information on each spawner, evaluate egg-to-fry survival rates, thermally mark each individual, and release fed fry (1 to 1.5 g in size) into the Grays River during March and April.
5) Import approximately fifty to one hundred thousand Grays River origin fry to the Sea Resources Hatchery located in the Chinook basin. Thermally mark all such fish, rear them in raceways and liberate the reared fish in March and April into the lower portion of the Chinook River.
6) Work with Sea Resources staff and other interested parties and identify portions of the Chinook basin where chum spawning areas can be produced in an effort to establish suitable spawning areas for this species in the watershed. Annually repeat the importation of Grays River stock into the Chinook River for up to twelve years or until a stable, self-sustaining population of naturally reproducing chum salmon has been established in the watershed.

1.8) List of Performance Indicators designated by "benefits" and "risks"

Benefits:

1) The discovery of genetic enclaves of chum salmon in Lower Columbia River tributaries with the development and implementation of site-specific recovery efforts for these populations will significantly reduce the likelihood of extinction of this species in the Lower Columbia River. Currently, there are only two known, stable populations of Lower Columbia River chum salmon, the Grays River stock and the Hardy/Hamilton Creek population. Chum have been observed in other tributaries, e.g. the Elochoman, Lewis, Cowlitz, and Washougal rivers and Skamokawa,

Abernathy, Germany, St. Cloud, Duncan, and Tanner (an Oregon stream) creeks, but their numbers are low (often less than 10 live individuals). In addition, annual counts of chum salmon at Bonneville and The Dalles Dam show low numbers of fish. Fewer than 100 chum were counted annually at Bonneville Dam from 1970-1997 (except 1987 when 147 fish were counted). Chum were counted at The Dalles Dam only 5 times during this same 18 year period. Those counts totaled 7 fish.

This program is designed to support comprehensive, multiple year stream surveys so that the size and stability of these and other possible chum salmon populations in the ESU can be determined.

2) Stabilization of the Grays River chum population. Currently most of the natural production from this population occurs in Gorley Springs, a man-made channel, located at Rkm 20. Flow in the Grays River is dramatically affected by rainfall and the river commonly moves across its flood plain. Consequently, the Gorley Springs channel is at risk of being destroyed by natural river meanderings and flood events. By importing chum into the Grays River hatchery it provides this population with a new source of recruits that is largely protected from the vagaries of high stream flows and major flooding events.

3) Egg-to-fry and smolt-to-adult survival rates of the fish incubated and reared at the Grays River and Sea Resources hatcheries will be significantly greater than those achieved by fish naturally spawning in the Grays River basin. Thus the judicious use of hatchery cultural procedures will help accomplish point two above. In addition, the factorial mating scheme employed at the time of spawning and the number of fish utilized as brood stock will ensure that the effective population size of these fish is maintained at a level where the effects of genetic drift and inbreeding depression are minimized.

4) The introduction of Grays River chum salmon into the Chinook Basin also helps preserve this stock and allows it to colonize a watershed where Lower Columbia chum have been absent for many years.

5) Each cultured fish released will be marked (either by thermal manipulation or other means at the eyed-, alevin- or fry-stage of development) so that its origin and rearing treatment can be deciphered at any later stage in its life cycle. These data will allow objective evaluation, monitoring, survival, distribution-straying, and production assessments to be linked to every recovery effort.

6) Escapement estimates for Gorley Creek will be generated.

7) Fecundity estimates by age will be generated which could be used to estimate number of eggs deposited by the natural spawning population.

Risks

1) Brood stock trapping via weirs may inadvertently delay the arrival of fish to their spawning grounds and decrease their reproductive success.

2) Flooding, high currents, overcrowding in a weir trap may kill some of the fish held in a weir trap or holding box.

3) Some brood stock fish may also perish prior to spawning either through natural causes or by being stressed by the capture process or because of poor holding conditions after capture.

4) Poor incubation conditions or improper handling of newly fertilized eggs can also cause mortalities to occur while the fish are being incubated in a hatchery setting.

6) Overcrowding, inappropriate feeding rates and food size, poor water quality, and inadequate water exchange during the rearing period can promote the outbreak of diseases in cultured chum salmon and cause some of the reared fish to perish during the rearing period or produce low quality smolts.

1.9) Expected size of program:

Expected releases:

In 1999 our goal is to collect and spawn sixty-four pairs of chum salmon from the Gorley Springs trap. These fish will provide us with approximately one-hundred and sixty-six thousand eggs (based on fecundity data collected from Gorley Springs chum salmon spawned in 1998) that will produce one-hundred and fifty-six thousand fry (based on an anticipated 94% egg-to-fry survival). One hundred and six thousand of these fish will be reared and released from the Grays River Hatchery. The remaining fifty thousand will be transferred to the Sea Resources Hatchery located in the Chinook River Basin and reared and released at that location. We expect to collect and culture chum salmon at Gorley Springs into the foreseeable future until habitat improvements in the Grays River basin moderate the river's dramatic and destructive flow regimes. When that occurs the river will provide good incubation conditions for naturally spawning fish. In the meantime, the numbers of reared chum liberated from the Grays River Hatchery will vary from 100 to 200 thousand fry per year depending upon the strength of the returning brood stock. In no instance will more than 50% of the fish returning to Gorley Springs be used as brood stock.

The introduction of Grays River chum will occur in the Chinook basin for a maximum of twelve years or three generations. If abundant chum salmon adults ($\geq$ 50 pairs) return to the Chinook River before this twelve year period has ended then some of these returning fish will be used as brood stock and importation of Grays River chum will cease. This strategy is being employed to expedite the development of basin-specific adaptations in the re-introduced chum and therefore to foster the development of another unique Lower Columbia River chum salmon population.

Expected release numbers in other tributaries will obviously vary and are difficult to predict. However, the following general rules will be used: 1) in those cases where less than 100 total fish return to a tributary, efforts will be made to capture and utilize all of these fish as brood stock during a recovery program. 2) when more than 100 fish return to a system, no more than 50% of the fish will be used for brood stocking purposes. 3) In those cases where controlled- flow streams or spawning channels have been created for the fish, instantaneous densities for females will be regulated so that they do not exceed 1.7 m^2/female. Additionally, redd superimposition in spawning channels will be controlled by the use of cross weirs and pickets.

Chum salmon from other Lower Columbia River populations will not be introduced into another stream system unless the population native to that system is known be extirpated. When re-introduction efforts take place a minimum of fifty thousand eggs or fry originating from at least 25 females (preferably more than 50) will be transplanted on a yearly basis for up to twelve years. In all of these situations, simultaneous habitat improvements will occur with the goal of creating high quality spawning refugias for the re-introduced fish. When more than fifty pairs return to a site three years in a row, these fish, rather than individuals from the original donor population(s) will be used for brood stock in an effort to create a locally adapted population.

Adult fish produced/harvested:

The number of adult fish produced will obviously be affected by the number and size of the fry released and the post-release environmental conditions the fish encounter. Initially, the Grays River supplementation effort calls for the release of one hundred to two hundred thousand fry reared to about 1 to 1.5 grams. The Sea Resources Hatchery effort is designed to release approximately fifty to one hundred thousand fed fry. Unfed fry-to-adult survival rates in this species typically range from 0.3 to 3% (Salo 1991). Rearing the fish until they reach a gram or slightly larger can significantly increase their survival by one percent or more (Fresh et al. 1980; Kaeriyama 1989; Salo 1991; Fuss and Hopley 1991).

We are unaware of any data that estimates the fry-to-adult survival rates of reared Lower Columbia River chum salmon but speculate that it should average about 1%. This value is one to two percent lower than the survival rates of reared chum originating from more northern populations. We assume that fry-to-adult survival of reared Lower Columbia chum salmon will be lower than that observed in other locations because these fish represent some of the southern-most stocks of this species in North America. Consequently, they may commonly experience challenging environmental circumstances during early life history stages that deleteriously affect their survival rates (WDF sub basin plan 1990). Consequently, the Grays River releases of chum salmon fry are expected to produce five hundred to fifteen hundred adults. These fish mature at ages three, four, and five so for any given return year between 200 to 750 adults from the program are expected to return to the Grays River. The fish liberated from the Sea Resources Hatchery will produce 250 to 750 adults per release, with seventy-five to three hundred returning during the same year.

In the Lower Columbia, chum salmon are only caught incidently (Keller 1999). For example, in 1998 only thirteen chum were harvested and Keller (1999) reported that 1998 was the sixth consecutive year when less than 100 chum were harvested in the Columbia River. By-catches of chum are low because the fish typically enter the Columbia River after the commercial gill net seasons have closed (Keller 1999).

Escapement goal:

The Grays River was once known for its large chum salmon population. Bryant (1949) stated that 7,674 chum salmon were counted in the lower twenty one kilometers of Grays River (including the West Fork) in 1936. Since then the watershed has been extensively logged and subsequent landslides, erosion, and channel changes have seriously damaged salmon spawning areas in the basin. In 1985, the Washington Department of Fisheries built a spawning area on Gorley Springs at Rkm 19 and since that time approximately 38% of the chum spawning in the Grays River have used it as a spawning site (Keller 1996). Escapements into the basin over the past twenty-three years have ranged from one hundred and seven in 1980 to over three thousand two hundred in 1992 and has averaged twelve hundred during the past decade (WDF 1990--sub basin plan; Keller 1999). Currently, no formal escapement value has been established for Grays River. Instead, the management goal has been to allow as many adult chum salmon as possible to enter the system and spawn. In 1999, a study designed to estimate the duration of freshwater life in adult Grays River chum salmon is being conducted. The results of this study will be used to refine previous population estimates and help determine biologically meaningful escapement levels for the basin.

1.10) Date program started or is expected to start:

This program began in October of 1998. At that time we began conducting stream surveys for native chum salmon returning to Lower Columbia River tributaries and also started collecting brood stock from the Grays River.

1.11) Expected duration of program:

The collection of chum salmon brood stock from the Grays River will continue until significant habitat improvements have stabilized the dynamic river-flow patterns currently extant in the basin. Until that can be accomplished, the population will be vulnerable to catastrophic flood events. Stream surveys for adult chum salmon in the Lower Columbia River will continue into the indefinite future. The re-introduction of Lower Columbia River chum salmon (Grays River stock) into the Chinook River, on the other hand, is expected to last for a maximum of twelve years. If a self-sustaining population is established earlier, then the importation of Grays River fish will cease.

1.12) Watersheds targeted by program:

Initially two watersheds, the Grays River, the Chinook River basins will be the sites for our recovery efforts. Additional, Lower Columbia River tributaries will be targeted for recovery efforts in the future once enough stream survey data have been collected to indicate which systems possess native chum salmon or contain habitat that can be utilized by this species.

SECTION 2. RELATIONSHIP OF PROGRAM TO OTHER MANAGEMENT OBJECTIVES

2.1) List all existing cooperative agreements, memoranda of understanding, memoranda of agreement, or other management plans or court orders under which program operates. Indicate whether this HGMP is consistent with these plans and commitments, and explain any discrepancies.

The recovery and supplementation program described in this HGMP is consistent with the following agreements and plans:

-The Columbia River Fish Management Plan
-U.S. vs Oregon court decision
- Production Advisory Committee (PAC)
- Technical Advisory Committee (TAC)
- Integrated Hatchery Operations Team (IHOT)
- Pacific Northwest Fish Health Protection Committee (PNFHPC)
- In-River Agreements: State, Federal, and Tribal representatives
-Northwest Power Planning Council Subbasin Plans
-Washington Department of Fish and Wildlife Wild Salmonid Policy

The now expired CRFMP called for the continued existence and rebuilding of indigenous populations of salmon in the Columbia River. The recovery program described in this HGMP is designed to accomplish these objectives.

2.2) Status of natural populations in target area

Chum salmon (target populations) -

The natural population targeted for recovery and supplementation is the Grays River chum salmon stock. As mentioned previously, chum salmon production in the Lower Columbia River has drastically declined over the past fifty years (WDF 1951; WDF et al. 1993). Many lower Columbia tributaries once produced chum, however, at present, significant natural production appears to be limited to three areas: Grays River, Hardy Creek, and Hamilton Creek. The latter two streams are located just below the Bonneville Dam (Rkm 229 and 230 respectively) on the Washington-side of the river. Spawning ground counts made in these drainages since the late 1950's indicate that both streams possess stable populations of chum salmon (WDF et al. 1993). The Grays River population, on the other hand, is considered depressed due to a long-term negative trend in spawning ground escapements (WDF et al. 1993). Because of the generally low abundance of this species throughout the Columbia the NMFS listed Lower Columbia River chum salmon as a threatened species under the auspices of the ESA in early 1999.

The recovery and supplementation plan described in Part 1 calls for the re-introduction of Lower Columbia River chum (Grays River stock) into the Chinook basin. The Chinook River used to contain a native chum salmon population that was apparently extirpated several decades ago (WDF 1951). In the late 1980's, chum salmon from Bear Creek, a Willapa Bay population were transplanted into the Chinook River via a hatchery program run by Sea Resources. Initially adult returns back to the Chinook from this transplant were close to a thousand fish per year, however, recent returns have been low. For example, in 1997 and 1998 twenty or less adults returned (Garth Gale pers. comm.) to the Sea Resources Hatchery. In 1998, it was decided that these non-native chum should be removed to accommodate our effort to re-introduce native Lower Columbia River chum salmon back into the basin. Consequently, in 1999 all adult chum salmon returning to the Sea Resources Hatchery have been destroyed.

Other salmonid species-

Two other salmonid species in the target area, chinook and steelhead have been listed as threatened under the ESA. The latest status report on salmonid fishes in this area is presented in WDF et al. 1993. Table 1, distills this information for each salmonid species by lower tributary. The watersheds shown here are all on the Washington-side of the river. Comparable data for Oregon tributaries are not currently available. Open squares represent areas where status is unknown or the species is not present. Data for cutthroat trout were not included and remain to be determined.

Table 1. Stock status of salmonid fishes in Washington State Lower Columbia River tributaries as of 1992 (From WDF et al. 1993)

Watershed	Chum	Spring Chinook	Fall Chinook	Coho	Summer Steelhead	Winter Steelhead
Chinook River						
Grays	Depressed		Healthy	Depressed		Depressed

Table 1. Stock status of salmonid fishes in Washington State Lower Columbia River tributaries as of 1992 (From WDF et al. 1993) continued . . .

Watershed	Chum	Spring Chinook	Fall Chinook	Coho	Summer Steelhead	Winter Steelhead
Skamokawa			Healthy	Depressed		Unknown
Elochoman			Healthy	Depressed		Depressed
Mill Creek			Healthy	Depressed		Depressed
Abernathy Creek			Healthy	Depressed		Depressed
Germany Creek			Healthy	Depressed		Depressed
Cowlitz River		Healthy	Healthy	Depressed		Depressed
Coweeman			Healthy	Depressed		Depressed
Toutle				Depressed		Depressed
South Fork Toutle			Depressed	Depressed		Healthy
Green (Toutle)			Depressed	Depressed		Depressed
Kalama		Healthy	Healthy	Depressed	Depressed	Healthy
Lewis		Healthy	Healthy	Depressed		Depressed
East Fork Lewis			Healthy	Depressed	Unknown	Depressed
North Fork Lewis					Depressed	
Salmon Creek				Depressed		Depressed
Washougal			Healthy	Depressed	Unknown	Unknown
West Fork Washougal					Unknown	Unknown
Hardy Creek	Healthy			Depressed		
Hamilton Creek	Depressed			Depressed		Unknown

2.2.1) Geographic and temporal spawning distribution.

The Grays River is approximately 26 kilometers long and can be divided into three distinct sections. The lower section is 9 Km long and is diked and subject to tidal influence. This part of the river possesses numerous sloughs but no well formed gravel bars are present for spawning (Busack and Shaklee 1995). The next 10 Km of the river, or the middle section, flows through a wide, flat valley before entering the last or upper section which contains steep foothills. Before 1952, a two-and-a-half meter high falls occurred in a narrow canyon at Rkm 21 and prevented most salmon, including chum, from using the uppermost reaches of the river. In 1951, steps were blasted in the falls and the upper watershed was then made accessible to anadromous salmonids (Busack and Shaklee 1995). Typically chum salmon spawn in middle section, using a six kilometer stretch that runs approximately one kilometer above the West Fork downstream to the Covered Bridge. Tributary spawning occurs in the West Fork (Rkm 21), and in Crazy Johnson (Rkm 21.4) and Gorley Springs (Rkm 19) creeks (WDF et al. 1993; Busack and Shaklee 1995). Spawning begins in late October and runs through the middle of December (WDF et al. 1993).

2.2.2) Annual spawning abundance for as many years as available.

The Grays River was once noted for its large runs of chum salmon. In 1936, a total of 6,286 chum were counted below the falls at river mile 13 and an additional 1,388 chum were counted in the West Fork of the Grays River (Bryant, 1949). Washington Department of Fisheries (WDF) estimated 7,500 chum returned to the Grays River system in 1951. Today, the Grays River chum run is a fraction of the historic run size.

Washington Department of Fisheries records indicate chum spawned in the West Fork and mainstem Grays River, Seal River, and Malone, Fossil, Hull, Klints, and Crazy Johnson creeks (WDF, 1973). No spawning ground counts could be found for Seal River and Malone Creek. Chum are no longer consistently observed in Fossil, Hull, and Klints creeks and those streams are usually not surveyed. The West Fork of the Grays River peak index area counts are usually minor but are part of the annual spawning ground counts. Crazy Johnson and Gorley creeks plus the mainstem Grays comprise the remaining annual spawning ground counts.

Spawning ground surveys on the mainstem Grays began in 1944, 1959 for the West Fork, 1984 for Gorley Creek and sporadically since 1953 for Fossil, Hull, and Klints creeks. Spawning ground counts in Crazy Johnson Creek did not begin until 1965 even though fish may have been present. Originally, Crazy Johnson Creek spawning ground counts were a replacement for Duncan Creek where chum runs had diminished for several reasons including a dam with poor fish passage design (Fiscus, 1971).

In 1985, WDF Habitat Division constructed a pilot channel at Gorley Creek. Subsequent spawning ground counts revealed a substantial number of chum spawned in the improved channel. Over 400 chum were counted in Gorley Creek the following year (Fiscus, 1987).

Listed below are the peak live and dead chum counts for the Grays River system. The table should be used with caution. Stream survey counts have been made on different stream sections and by a variety of methods. Historic mainstem Grays, Fossil, Hull, and Klints creeks surveys have focused on the primary spawning areas. In addition, the mainstem Grays stream surveys have changed since 1962 (Hymer, 1993).

Grays River chum peak live and dead fish counts 1938-1999.

Year	Mainstem	West Fork	Crazy Johnson	Gorley	Fossil	Hull	Klints
1999 (prelim)	69	100	927	496	0	6	No Count
1998	154	214	145	430	0	0	0
1997	79	55	485	185	No Count	No Count	No Count
1996	415	160	396	348	0	0	No Count
1995	66	0	413	293	No Count	No Count	No Count
1994	41	18	90	75	0	No Count	No Count
1993	704	39	78	256	1	No Count	No Count
1992	1,269	289	320	611	1	No Count	No Count
1991	93	13	204	219	No Count	No Count	No Count
1990	166	0	100	405	2	No Count	No Count
1989	176	16	120	21	No Count	No Count	No Count
1988	342	27	289	712	No Count	No Count	No Count
1987	711	42	2	3	0	No Count	No Count
1986	245	79	193	403	0	No Count	No Count
1985	449	3	0	0	0	0	No Count
1984	325	12	35	0	0	1	No Count
1983	89	3	34		No Count	No Count	No Count
1982	663	6	87		0	8	No Count
1981	No Count	3	11		0	No Count	No Count
1980	52	7	52		1	No Count	No Count
1979	108	0	18		0	0	No Count
1978	227	0	65		No Count	No Count	No Count
1977	199	37	164		0	0	No Count
1976	215	0	14		1	No Count	No Count
1975	22	16	126		72	6	No Count
1974	3	11	40		26	No Count	15
1973	11	19	181		20	No Count	No Count
1972	491	33	69		46	No Count	No Count
1971	25	15	266		26	No Count	0
1970	19	37	95		No Count	No Count	
1969	194	104	61		8	6	
1968	No Count	31	125		33	No Count	
1967	216	218	91		1	No Count	
1966	450	244	87		6	No Count	
1965	66	21	76		0	No Count	

Year	Mainstem	West Fork	Crazy Johnson	Gorley	Fossil	Hull	Klints
1964	No Count	34			2	No Count	
1963	211	247			No Count	No Count	
1962	115	70			No Count	No Count	
1961	317	290			No Count	25	
1960	356	144			1	15	
1959	546	261			2	96	
1958	17				101	No Count	
1957	239				191	No Count	
1956	No Count				130	No Count	
1955	39				43	No Count	
1954	No Count					No Count	
1953	492					0	
1952	1,218						
1951	1,520						
1950	No Count						
1949	No Count						
1948	No Count						
1947	595						
1946	884						
1945	1,332						
1944	2,263						
1938	6,286	1,388					

Efforts have been made to estimate the total spawning populations. In 1978, WDF conducted a carcass tagging experiment to determine the Grays River chum natural spawning population. For the purpose of that population estimate, Grays River chum were treated as one homogenous population. Grays River total spawning ground population estimates were calculated for 196-1978 using this information (Dammers, 1979).

However, peak count expansion factors for each individual stream may be more accurate. During low flow years, chum spawn primarily in the larger mainstem Grays River; during higher flows they can be found in larger number in the smaller tributaries. In addition, individual stream peak count expansion factors were assumed to be different based on stream size, length, and flows.

In 1991, chum carcasses were tagged to determine individual peak count and visibility expansion factors. In addition, WDF attempted to conduct a carcass tagging study to estimate the total chum natural spawning population in Gorley Creek (Hymer, 1993).

In other parts of the state, WDFW uses Area Under the Curve (AUC) to estimate the total spawning population. This method is used in southern Puget Sound, Willapa Bay and for Hood Canal (summer chum) (NMFS Status Review, 1996). For consistency and possible increased accuracy, this method is being explored for the Columbia River populations. However, it is uncertain whether stream life information for non-Columbia stocks is applicable to Columbia chum. To determine stream-life information specific to Columbia River chum, fish collected and then released upstream from Gorley trap will be uniquely marked each day. Recovered carcasses will be examined for marks and approximate time of death (in days) will be noted.

2.2.3) Progeny-to-parent ratios, survival data by life-stage, or other measured of productivity for as many brood years as possible.

Progeny-to-parent survival rates:

Smolt-to-adult survival rates have not been calculated for Grays River chum salmon. As indicated in Part I, however, this stock is at the southern end of the North American distribution for this species and hence survival rates are expected to be strongly affected by phenomena occurring during incubation and early ocean residence. In more northern areas, chum salmon often achieve ten percent egg-to-fry survival rates and one to five percent fry-to-adult survivals. We have thermally marked all of the fry released from our Grays River chum recovery effort and will continue to do so. A research project taking place in Gorley Springs is designed to determine the average stream life of male and female chum salmon in Grays River. That information will be used in conjunction with adult count data to derive a population estimate of chum using the system. In 2001 we will begin sampling adult chum salmon returning to Grays River and examine their otoliths to determine how many originated from our releases of fed fry. These mark and recovery statistics will be used to ascertain what the fry-to-adult survival rates were for each brood year of cultured fish released into the Grays River. In addition, it will be possible to make survival estimates for the progeny produced from wild spawners, in this case it will be an egg-to-adult survival value. These values will be derived from our population estimates which will indicate the approximate number of wild females spawning in the Grays River. Fecundity data collected during brood stocking will be used to determine the potential number of eggs wild females deposited in the Grays River during a given brood year. Once that value has been approximated and we know the proportion of wild origin and hatchery origin adult chum returning to the Grays it will be possible to produce an egg-to-adult survival value for naturally produced fish.

The survival rates of the fish that were cultured in the Grays River Hatchery during 1998/99 at various life-history stages are presented in Table 3.

Table 3. The survival of chum salmon brood stock, eggs, alevins, and reared fry held at the Grays River Hatchery in 1998/99.

Percent Survival By Life Stage	1998 Brood Year	1999 Brood Year
Adult Holding (Survival of adults until spawning)	97%; 3 males perished prior to spawning, all females survived, A total of 100 fish were held.	100% (120 adults have been held as of 28 Nov 1999)
Fertilized Egg to Eyed Egg	94 %	Not yet determined
Eyed Egg to Fry	98%	Not yet determined
From Fry to Smolt	99%	Not yet determined
Overall (Egg-to-Smolt)	91.2%	Not yet determined

2.2.4) Annual proportions of hatchery and natural fish on natural spawning grounds for as many years as possible.

Chum salmon found on the Grays River spawning grounds are assumed to be entirely from natural production. This is particularly true since the mid 1980s when egg box programs and hatchery fry releases ceased. Even then, the hatchery fish were only planted to supplement fisheries in areas without native chum salmon and where spawning areas were poor or non-existent (WDF et al., 1993).

Introduced and local chum stocks were used for experimental egg box and fry release programs on the Grays River during 1972-1980. Based on subsequent spawning ground surveys, success of those programs seemed to be minor. Fingerling releases of Hokkaido (Japanese) chum stocks into the Grays River system in 1976 contributed little if any to the natural spawning population based on the 1978 escapement (Fiscus, 1978).

The few chum observed naturally spawning in Hull Creek in 1982 and 1984 may have been returns from fry releases from an egg box site on that stream. Between 30,000-90,000 chum fry were released annually into Hull Creek from 1978-1980 (Allen, 1983).

No coded-wire tagged chum from have been recovered in the Grays River system though few hatcheries tag juvenile chum salmon.

2.2.5) Status of natural population relative to critical and viable population thresholds.

In March 1998, Columbia River chum salmon were listed as “threatened” under the Endangered Species Act. Currently, significant chum natural production is limited to three areas: Grays River, Hardy Creek, and Hamilton Creek. Grays River chum stock status was considered depressed due to long-term negative trend in spawning ground escapement counts (WDF et al., 1993).

2.3) Relationship to harvest objectives:

The Columbia River historically contained large runs of chum salmon that supported a substantial commercial fishery in the first half of this century. These landings represented a harvest of half a million chum salmon in the Columbia River in some years (NMFS Status Review, 1996). By 1955, landings had diminished to 10,000 fish. Since 1965, landings have averaged less than 2,000 fish annually. Presently, no Columbia River commercial fisheries target chum. Chum landings occur incidentally to targeted coho seasons in the late fall gill net fishery (WDFW, 1993).

Current commercial fisheries are expected to end prior to the primary migration time or were area/gear specific to minimize chum handling. Commercial landings from 1993-1998 averaged 29 fish. Commercial harvest rates from 1993-1997 averaged less than 2% based on the minimum chum run size (WDFW/ODFW 1999).

The Columbia River system is closed to recreational harvest of chum salmon. Chum angling has been closed on the Oregon side of the Columbia River since 1992 and on the Washington side since 1995. Additionally, a salmon angling closure was adopted for the Grays River in 1994. (WDFW/OFDW, 1998).

2.4) Relationship to habitat protection and recovery strategies

Grays River Basin

The lack of stable spawning habitat is considered the primary physical limitation on chum production today (NWPPC, 1990). Natural limiters for the Grays River chum stock include gravel quality and stability and availability of good quality near shore mainstem freshwater and marine habitat. This watershed has been ravaged by logging road construction and subsequent timber harvest since the 1960s, only recently has the rate of road building and harvest subsided. This had led to numerous road and harvest unit slope failures creating tremendous sedimentation and instability of spawning riffles (WDF, 1993).

Formal recovery plans for Columbia River chum have not been made. However, the Columbia Basin System Planning Production Plan addresses habitat protect and recovery for Grays River chum. The recommended strategy emphasizes habitat protection through continuation and expansion of state regulatory programs including the Fisheries Code, the Shorelines Management Act, and the Forest Practices Act. In addition, a habitat risk assessment map for the watershed should be developed to be used by state and local agencies when reviewing and permitting forest practices. It also calls for identifying and remedies for man-caused sources of sediment.

The Plan also suggests developing spring fed natural spawning and incubation channels. For supplementation it recommends introducing chum fry to selected tributaries of the Grays River through the use of on-site streamside incubators or off-site incubation and short-term, on-site rearing for imprinting size advantage.

Chinook Basin

In 1996, Sea Resources, a nonprofit educational organization, developed a comprehensive watershed recovery plan for the Chinook River basin (Dewsberry 1997). The plan has six parts: 1) to protect critical upland habitat from landslides and thereby protect the lower river from debris torrents in an effort to re-establish a more natural regime of sediment and organic matter movement through the watershed; 2) to reduce sediment inputs by repairing and stabilizing existing roads in the watershed and when possible to decommission unnecessary roads; 3) to protect and restore the valley floor by re-establishing a mature conifer dominated forest; 4) to restore the lower estuary by (a) removing or redesigning the tide gate located at the mouth of the Chinook River, (b) by limiting development in the lower portions of the watershed, (c) by re-establishing woody debris accumulations in the Chinook estuary and in Baker Bay, and (d) by encouraging beaver dam development in the lower river; 5) to use an existing hatchery to help supplement salmonid populations in the basin, and 6) to evaluate the effects of habitat improvements in upland, valley floor, stream channel, an estuarine areas on habitat characteristics and salmonid abundance (Dewsberry 1997).

Since the completion of their basin recovery plan, Sea Resources has received funds from a variety of sources and has begun implementing many of the habitat changes delineated in their plan. For example, they have established a green house next to their hatchery facility and are currently growing native plants which will later be transplanted throughout the basin. Moreover, they have planted native evergreens in riparian zones and are presently working on stabilizing upland areas by planting native shrubs and trees. They are placing large woody debris in the basin, removing and repairing roads and performing evaluation studies through their environmental education program (for further details on habitat restoration in the basin go to: www.searesources.org). In addition, the hatchery operated by Sea Resources has the infrastructure needed to rear and release chum salmon fry until suitable spawning areas are either artificially created or manifest themselves through natural recovery processes.

The habitat restoration and evaluation work mentioned above and orchestrated by Sea Resources will continue into the foreseeable future. Hence, the basin has the potential to provide a stable and high quality spawning, incubation, and early rearing refuge to Lower River Columbia River chum salmon. Consequently, it was chosen as our initial site to try re-introducing native Columbia chum salmon back into a stream where this species once existed. Finally, the close proximity of the Chinook River to the Columbia River estuary and ocean pastures also made it an attractive site for re-introduction.

2.5) Ecological interactions

Salmonid and non-salmonid fishes or other species that could:

1) negatively impact program:

Chum salmon (smolts) emigrate from the Columbia River in March and April. Not much is known about their early estuarine life. In Puget Sound, however, newly emerged chum salmon tend to feed on epibenthic prey in shallow nearshore areas until they reach approximately 55 mm in fork length. After reaching this size they become pelagic, feed predominately on zooplankton, and begin moving northward into oceanic pastures. A similar offshore and northward migration strategy may be used by Lower Columbia River chum salmon.

Because of their relatively small size, newly emerged and migrating chum fry are vulnerable to a large array of potential predators. For the Grays River stock, that would include juvenile steelhead, cutthroat trout, northern pike minnow, cottids, and wild and hatchery origin coho and chinook salmon. In the Chinook River basin, a population of warm water fishes (small mouth bass, yellow perch, crappie, blue gills, pumpkin seeds, cat fishes) have established themselves and these fishes along with resident salmonids could act as significant predators. In addition, The U.S. Army Corps of Engineers is attempting to trans-locate a large colony of Caspian Terns to Sand Island, an islet located in Baker Bay close to the mouth of the Chinook River. These birds could significantly impact juvenile chum salmon if they reside for prolonged periods of time in the bay.

The rearing and release strategies developed for our chum recovery program, however, are designed to dampen predation. First, the fish will be reared until they reach about 55 to 60 mm in length (fork) or 1 to 1.5 g in weight. This will make them large enough to escape some of their potential predators and shorten their dependence on shallow estuarine feeding areas thus reducing their exposure to aerial and bottom dwelling predators. Second, the fish will be liberated during darkness on a falling tide in an effort to expedite emigration out of the Columbia River and reduce their visibility. In the Chinook basin, reared chum will be transported about three kilometers downstream and released to avoid a concentration of warm water fishes. Third, even though the fish are reared they will be liberated in March and April, the same time that natural migrants are leaving the system. This should minimize interactions with Caspian Terns and also maximize the likelihood that they will encounter favorable nearshore conditions.

2) be negatively impacted by program:

No negative species interactions are expected to be produced by this program. Because of the size of the released fish and their food habits they are unlikely to directly compete with wild chum salmon fry or with other salmonid fishes using the Columbia estuary. Also the total number of fry that will be liberated is relatively small (approximately 100 to 200 K from Grays River and 50 to 100 K from the Chinook River) and early enough in the Spring to limit any behavioral effects on wild salmonids (e.g. the inducement of premature out-migration) or ancillary predation (e.g. by the creation of a numerical response in predators).

3) positively impact program:

No significant positive interactions caused by other species are expected. The presence of adult chinook, coho, and other salmonid species may increase the amount of micro-nutrients present in the Grays and Chinook rivers. However, only a small proportion (< 1%) of chum fry remain in freshwater to rear for short periods of time and hence they are unlikely to derive much benefit from the carcasses of other salmonids.

4) be positively impacted by program:

Many species, including cutthroat, steelhead and rainbow, coho, and chinook are known to prey on chum fry and consequently juveniles of these species may benefit from increased numbers of chum fry. Besides direct fry consumption, increased numbers of adult chum salmon carcasses into the Grays and Chinook rivers will add micro-nutrients into these streams which by direct or indirect routes would be available to salmonids and other species in the basin. In addition, released fed fry may buffer the effects of predation on wild chum salmon fry.

SECTION 3. WATER SOURCE

Adult chum salmon captured as brood stock are collected at the mouth of Gorley Springs, a man-made channel fed by numerous ground water springs. Once captured, the fish are transported to the Grays River hatchery where they are held in Grays River water until spawning. Fertilized eggs are incubated in 10-12°C well water at the hatchery until yolk absorption. At that time, fish selected for transfer to the Sea Resources Hatchery will be transported to that facility and placed into raceways supplied with surface water from the Chinook River. Fry that are destined to be released into the Grays River, on the other hand, will be placed into 6 m wide x 24.7 m long x 1.2 deep concrete raceways that are supplied with 946 to 1,325 liters/min (0.56 - 0.78 cfs) of 100% well water. Three weeks prior to release, Grays River water will be gradually added to each raceway so that at the end of the rearing period, the fish have been exposed to 100% Grays River water for at least ten days.

At the Sea Resources Hatchery, six or more portable fiberglass raceways (0.9m wide x 0.9m deep x 4.8 m long) will each be provided with 38 to 75 liters/min of surface water.

SECTION 4. FACILITIES

Descriptions of the physical plants listed in this section -

Grays River Hatchery

The Grays River Hatchery is located at Rkm 3.2 on the West Fork of the Grays River. It was opened in 1961 and was built on land acquired by WDF from the C.J. Schmond family. Operating funds for the hatchery are provided by the NMFS as part of its Mitchell Act program.

The facility has ten (6 m wide x 24.7 m long x 1.2 deep) concrete raceways, one (18 m wide x 61 m long) earthen pond and two, 12 m wide x 18 m long, concrete ponds that are used for adult holding or juvenile rearing. A 14.5 m wide x 30.2 long building holds the incubation room, offices, and cold storage locker. Seven years ago, most of the concrete deep troughs originally placed in the hatchery for egg incubation were removed and replaced with “Heath” style upright incubator trays. The hatchery now possesses sixty stacks of Heath trays and each stack is equipped with 16 trays. Aluminum head boxes suspended above the incubators supply each stack with a regulated amount of water. In 1998, six, 10,000 BTU portable water chillers were added to the hatchery to facilitate thermal marking. The hatchery has three sources of water for rearing and incubation. Water from a 3,800 liter/min capacity well is mainly used for incubation and must be pumped into the hatchery. Gravity-fed water can also be obtained from “Auxiliary Creek” and from the Grays River. The hatchery is staffed with 3.5 FTEs and has three residences, one or more staff members are present on station, seven-days-a-week to respond to any operational emergencies (Ashbrook and Fuss 1996).

Sea Resources Hatchery

In 1890, Alfred Houchen established a salmon hatchery in the Chinook Basin at Rkm 4.8. Brood stock was initially provided to the hatchery by fishers who operated salmon traps located at the mouth of the Chinook River. In 1927, the U.S. Army Corps of Engineers constructed a tide gate and dike at the mouth of the Chinook River in an attempt to control floods in the lower river. The dike and tide gate significantly altered lower river habitat and the flow dynamics of the stream. In addition, logging, mining and agricultural activities in basin caused substantial habitat degradation which further reduced natural salmon production. Fish traps were banned in 1933 by the State Legislature and two years later the State closed the original Chinook hatchery. Almost thirty years later in 1967, a group of Long Beach Peninsula citizens organized Sea Resources Inc., to educate local students and re-vitalize salmon runs into the Chinook River. The original hatchery site was provided to the group by Martin Wirkkala, and coho, fall chinook, and chum salmon were cultured at the site (Brent Davies and Garth Gale pers comm.; www.searesources.org).

Currently the hatchery possesses seven concrete Burrows ponds that are 2.4 m wide and 24.4 m long. There is also a 14 m wide x 37 m long building that houses an incubation room, offices, a lecture hall, wet laboratory, and a shop. In 1998, a 6 m x 24 m green house was built next to the office/hatchery building. The incubation room contains 35 full stacks of "Heath" style salmon incubators. The incubation room and raceways are supplied with gravity-fed Chinook River water which is delivered to the hatchery by a .9 km long by 38 cm in diameter pipeline. A drop of 3 m occurs from the intake of the pipeline to the hatchery to provide the hatchery with almost 3 meters of head. Depending upon stream flows, and amount of in-water debris, the line can deliver up to 1,900 liters of water/min to the hatchery. The hatchery originally had eight Burrows ponds, however, this past year, one of the ponds was filled with earth so that it could be used as a platform for portable fiberglass raceways. Six to eight of these 0.9m wide x 0.9m deep x 4.8 m long raceways will be installed at this site and supplied with Chinook River water. Space also exists in the incubation room to establish two to three additional raceways and this may occur in the future. Raceway installation is expected to begin late in 1999 or early in 2000. The hatchery manager has a residence on site and the facility is manned 24 hrs a day seven days a week (Garth Gale and Brent Davies, pers. comm.)

For the programs that directly listed fish for use as brood stock, provide detailed information on catastrophic management, including safeguards against equipment failure, water loss, flooding, disease transmission, or other events that could lead to a high mortality of listed fish -

Grays River Hatchery-Catastrophic management against equipment failure, water loss, and flooding

Adult Holding: Prior to spawning, brood stock are held at the Grays River Hatchery in the concrete holding ponds mentioned above. When adult chum salmon are collected at Gorley Springs each selected fish is placed into its own 25 cm in diameter x 122 cm long PVC holding tube and held in its tube until spawned. The holding ponds are supplied by gravity-fed Grays River water, if the water supply to the ponds was ruptured that event would be detected by an alarm system. If that occurred the hatchery staff has at least three rescue options. First, depending upon stream conditions, the tubes could be quickly removed from the pond and placed in the nearby Grays River until the water supply to the pond is restored, second the tubes could be moved to nearby raceways or to the earthen pond and supplied with water at those sites, or if none of those locations are suitable, the fish could be liberated into the river or transported back to Gorley Springs and either held there or liberated into Gorley Springs.

Spawning and Incubation to the fry stage: Ripe fish are killed and then brought into the hatchery incubation room for factorial mating. The resulting embryos are incubated in well water until yolk absorption. If a power failure disrupts the delivery of well water, a backup 80 Kilowatt diesel generator can be used to produce power to run the well pump and water distribution to the developing fish will not be disrupted. If the water line containing well water is ruptured or the pumps delivering well water are destroyed, two options exist. First, if none of the eggs have hatched, each Heath tray can be de-watered and the eggs can be kept moist for up to 24 hrs or longer, until replacement pumps can be installed or the line repaired. If that is not possible, gravity-fed water from Auxiliary Creek or Grays River can be used for incubation. If all water lines are ruptured, egg trays can be carried out to the rearing raceways or earthen pond and supplied with gently moving water at those locations

Rearing: As mentioned above, fry will be initially reared in well water and eventually acclimated to Grays River water. If well water for whatever reason is not available, the fish can be converted to gravity-fed water originating either from Auxiliary Creek or Grays River. If all water supplies are disrupted, fry can be maintained by supplying each raceway with air stones that are fed by cylinders of compressed air or depending upon conditions in the river and time of year the fish could be released into the Grays River.

Grays River Hatchery-Catastrophic management for disease transmission

Adult Holding and Spawning: At spawning, kidney, spleen, and ovarian fluid samples are collected from each female, and kidney and spleen samples are taken from each adult male. These samples are screened by WDFW's virology lab. Any gametes that originate from parental fish infected with viral pathogens will not be transplanted out of basin. At fertilization, all gametes are soaked in an iodophor solution for one hour. During early ontogeny (prior to hatching), dilute formalin is routinely dripped into the incubation water to control *Saprolegia* and other pathogens. Moreover, at eyeing, eggs are shocked and any mortalities are removed. All embryos are incubated in trays supplied with rugose substrate to prevent inefficient yolk utilization and the occurrence of physical abnormalities. And finally, at ponding, any remaining mortalities and monstrosities are removed. These measures are designed to limit and control any disease outbreaks from spawning to ponding.

Rearing and release: During the rearing phase, routine checks of fish health will be made by WDFW pathologists. Gill disease will be controlled by rearing the fish at relatively low densities and by providing them with whole food pellets as opposed to mash. If disease outbreaks occur the fish will be immediately treated using accepted fish health protocols.

Sea Resources Hatchery-Catastrophic management against equipment failure, water loss, flooding, and disease transmission

For the first three years of this project, no adult holding, spawning, or incubation will occur in the Sea Resources Hatchery. As mentioned above, the water supply to the hatchery is gravity fed and consequently unless the water line is breached no breakage in flow to the facility should occur. If the line is ruptured, portable gas pumps will be used to bring Chinook River water into several of the Burrows ponds. The ponds will be used as settling basins and incubation and rearing water will then be pumped from the ponds by gasoline powered pumps to the incubation room and rearing raceways. Disease control will follow the steps outlined for the Grays River Hatchery.

Describe any instance where the construction or operation of the physical plant results in destruction or adverse modification of critical habitat designated for the listed species -

The operation and any construction activities associated with the Grays River and Sea Resources hatcheries are not expected to cause any adverse impacts on listed fish or on critical habitat. The programs comply with NPDES permit effluent discharge requirements, which serve to protect the receiving waters adjacent to these hatcheries.

Describe any inconsistencies with standards and guidelines provided in any ESU-wide hatchery plan approved by the co-managers and NMFS-

This chum salmon plan does not violate any extant standards or guidelines for salmon recovery.

4.1 Brood stock collection

Grays River Hatchery

To capture brood stock, a weir and live box are installed in late October in Gorley Springs a man-made, spring fed tributary to Grays River. Trap placement is in a quite pool approximately 30 m from the mouth of Gorley Springs. The 1.2 m wide by 3 m long live box has aluminum pickets supported by 1.9 cm in diameter steel piping. The front end of the trap has a V shaped entrance and the back end has a "Dutch Door" to facilitate fish movement through the live box. The live box also has a screened bottom made from perforated aluminum plate and two plywood lids that can be locked. The weir fence stretches completely across Gorley Springs (approximately 9 m) and has metal pickets set on 3.8 cm centers.

The trap is removed at the end of the chum run into Gorley Springs which usually occurs in early December. While in operation, the trap is manned on a 24 hr a day basis. When flooding occurs, the live box is opened to allow fish passage. Furthermore, sand bags placed around the live box produce quite water zones in the box so that any adults held in the box are not stressed by high water velocities. Captured adults are inspected and brood stock is collected by using a pre-established random number process that will be described later. Selected fish are placed into perforated, 25 cm in diameter x 122 cm long PVC holding tubes and placed into a 760 liter tank mounted on a flat bed truck. The fish are then hauled about 5 Km to the Grays River Hatchery where the tubes are placed into one of the concrete adult holding ponds described above. Each tube holds only one fish, and the date of capture and sex of the fish are written on the outside of the tube. Sexual maturity is checked on a regular basis and ripe fish are spawned twice a week when available.

Sea Resources Hatchery

Brood stock will not be collected at the Sea Resources Hatchery for at least an additional three years. If our re-introduction project is successful, brood stock will be collected at the hatchery's rack and selected adults will be stored in PVC tubes placed in one of the Burrows ponds until spawning occurs.

4.2) Spawning

Grays River Hatchery

At the adult holding pond, mature fish are removed from their tubes, killed with a sharp blow to the head, and females are bled by severing a gill arch. The fish are then transported to the hatchery building where biological information on each adult is collected and gamete extraction takes place. All adult carcasses are returned to the Grays River.

Sea Resources Hatchery

Adult fish will be killed and bled and then brought into the incubation room so that biological data can be collected on each fish and factorial matings and egg disinfection will occur in the incubation room.

4.3) Incubation

Grays River Hatchery

As mentioned earlier, the Grays River Hatchery uses vertical stack incubators. The eggs collected from each female are usually fertilized by two or three males. Several minutes after fertilization, or after micropyle closure, the eggs from a single female are recombined and placed into a single tray. A rugose substrate, folded vexar plastic screening, is added to each tray after the eggs have been shocked and picked. Each tray is supplied with 19 liters of water/min and loading densities are well within acceptable ranges.

Sea Resources Hatchery

The Sea Resources Hatchery also uses vertical stack incubators, spawning and incubation identical to those at the Grays River Hatchery will be followed.

4.4) Rearing

Grays River Hatchery

Fry produced from one or two egg take dates are placed into a separate, screened off rearing areas established in one or two of the station's, 6 m wide x 24.7 m long x 1.2 deep, concrete raceways. The fish be reared for approximately one to two months before being released into the Grays River

Sea Resources Hatchery

Fry produced from one to two egg take dates will be placed into 0.9m wide x 0.9m deep x 4.8 m portable fiberglass raceways. The fish will be reared for approximately one to two months before being trucked 3 Km to a release site in the lower Chinook River.

4.5) Acclimation/release

Grays River Hatchery

Initially the fry will be reared in well water, however, during the last three weeks of the rearing period water from the Grays River will be added to the raceways. During the last ten days of rearing the fish will be reared entirely in Grays River water. All releases will be made during darkness an will coincide with a falling tide.

Sea Resources Hatchery

At this location the fish will be reared entirely in surface water collected from the Chinook River. Releases will also occur during darkness and with falling tides.

4.6) Other

No other physical facilities are associated with this effort to supplement/re-introduce Lower Columbia River chum salmon.

SECTION 5. ORIGIN AND IDENTITY OF BROOD STOCK

5.1) Source

Native Grays River stock trapped from Gorley Creek will be used for this program.

5.2) Supporting information

5.2.1) History

Broodstock used for this program since 1998 originated from adults trapped at Gorley Creek. No other broodstock has been used.

5.2.2) Annual size

Brood Year	Males	Females	Total
1998	50	50	100
1999	64	64	128

5.2.3) Past and proposed level of natural fish in the brood stock

It is assumed only naturally produced fish have been for broodstock.

5.2.4) Genetic or ecological differences

There are no known genotypic, phenotypic, or behavioral differences between the natural spawning and fish collected for brood stock.

5.2.5) Reasons for choosing

Chum salmon propagated through this program represent indigenous Grays River stock which is the target of the supplementation. Grays River chum are one of three remaining viable populations in the lower Columbia River. Grays River stock is the closest donor stock for the Chinook River.

5.3) Unknowns

There are no known circumstances where a lack of data leads to uncertainties about the choice of the broodstock for this program.

SECTION 6. BROOD STOCK COLLECTION

6.1) Prioritized goals

Current brood stock goals for the project call for the collection of at least forty and up to a maximum of 100 pairs of Grays River origin chum salmon. The primary objective of the project is to provide a stable, annual source of chum salmon fry back into the Grays River (100 to 200 K fry), a secondary objective is to re-introduce 50 to 150 K Grays River fry into the Chinook basin on an annual basis for up to twelve consecutive years.

If Grays River chum salmon are successfully introduced into the Chinook basin, all adults up to a maximum of 100 pairs returning to the Sea Resources Hatchery will be collected and spawned. Transplants of chum salmon from the Grays River into the Chinook will be reduced according to the number of eggs collected from adults returning to the Sea Resources Hatchery. The goal in the Chinook basin is to allow the fish to naturally spawn and not rely on hatchery production to maintain the population. Hence, releases of cultured fry from the Sea Resources facility will take place for a maximum of twelve years.

6.2) Supporting information

6.2.1) Proposed number of each sex

Grays River and Chinook River (Sea Resources)

Equal numbers of males and females will be collected.

6.2.2) Life-history stage to be collected (e.g., eggs, adults, etc.)

Grays River and Chinook River (Sea Resources)

Adult chum salmon returning to the Grays and Chinook rivers will be collected.

6.2.3) Collection or sampling design

Grays River

The brood stock collection process developed for this recovery effort has two objectives; first, to randomly collect representative fish, and second to proportionately collect them throughout the duration of the run. We have attempted to meet these goals by using the following approach. First, a population estimate is made on the expected abundance of chum salmon returning to Grays River. That estimate coupled with our need for adults (40 to 100 pairs) establishes an anticipated sampling rate that will be used to obtain the quantity of adults needed for the program. For example, suppose that it is estimated that 1,000 adult chum salmon are expected to return to the Grays River. Previously gathered field data indicate that approximately 30 to 40% of these fish are destined to enter Gorley Springs, the tributary where our adult trap is located. Consequently, we would expect to see 300 to 400 adult fish go into this tributary. We also assume that the sex ratio of these expected migrants will be equal, and therefore 150 to 200 individuals of each sex should be available for sampling. Because Gorley Springs is such an important spawning area, we decided that not more than 50% of the fish entering this tributary could be used as brood stock. This rule was instituted in an effort to reduce the biological impacts of brood stock removal. As stated above, our goal is to collect anywhere from 40 to 100 pairs of fish. The 50% rule indicates that a maximum of 75 (0.5 x 150) fish of each sex should be collected. In this particular situation our sampling rate would equal 50% and our goal for this return year would be 75 pairs. In those cases where more fish are expected to use Gorley Springs our sampling rate would be reduced. For clarity, assume that an estimated 2000 adults are expected to enter this tributary. Based on this number we would estimate that 1000 fish of each sex would be available to sample for brood stocking. Our maximum goal is 100 fish of each sex and so in this instance our sampling rate would be 10% which would provide us with 100 pairs. Second, after having established a sampling rate based on expected returns we needed to determine how to use this rate to obtain a random sample of fish. In many chum populations, males tend to arrive on the spawning grounds several days in advance of females and they also tend to stop arriving sooner than females. Consequently, to help ensure that we collect equal numbers of males and females it is important to sample them independently. This could be done in a number of ways. For instance, at a 10% sampling rate, every tenth male and every tenth female could be saved. However, we wanted to avoid any bias in the collection of brood stock, e.g. the purposeful collection of large individuals, and so generated two sets of random numbers, one for each sex. Each random number is assigned to a fish based on its sex and when it was processed. Table 4 shows an example of such a set of random numbers that was developed for females.

Table 4. Set of random numbers used to determine which captured female chum salmon should be retained for brood stocking purposes. In this table, a 10% sampling rate was employed and thus if a fish was associated with random numbers 1 -100 it was used as brood stock and conversely if it was linked to random numbers 101-1000 it was passed upstream. " Fish Number" refers to the order in which females are processed out of the live box. "Female-1", for example would be the first female removed from the trap during a trapping season and so on.

Fish Number	Random Number	Decision
Female - 1	314	Release Upstream
Female - 2	522	Release Upstream
Female - 3	401	Release Upstream
Female - 4	74	**BROOD STOCK**
Female - 5	422	Release Upstream
Female - 6	995	Release Upstream
Female - 7	847	Release Upstream
Female - 8	953	Release Upstream
Female - 9	932	Release Upstream
Female - 10	540	Release Upstream

At the 10% sampling level, 10% of these values would indicate that an individual of a given sex should be saved for brood stock. By using this approach, no predictable pattern of collection occurs and fish are removed at the right frequency in an unbiased fashion. A constant sampling rate also allows us to proportionately sample the run in a consistent fashion. That is, when adult abundance is low the number of adults collected for brood stock is low and vice-a-versa.

On a few occasions we have collected more males than needed (our 50% sex ratio assumption was invalid). Surplus males are returned to Gorley Springs to resume their spawning migration after a two to three day delay. Because spawning occurs shortly above the location of our trap these males are able to resume their reproductive activities soon after liberation. No other salmonids have been captured in the Gorley Springs trap, if any are collected they will be immediately released so that can resume their upstream migration.

Chinook River (Sea Resources)

In the Chinook River, all chum returning to the hatchery (up to 100 pairs/year) will be spawned. If adult abundance is predicted to exceed this amount then a random selection process similar to that described for the Grays River population will be employed.

6.2.4) Identity

Grays River

Only Grays River chum salmon are expected to return to the Grays River, no other chum populations apparently exist in this part of the Lower Columbia.

Chinook River (Sea Resources)

All chum salmon released into the Chinook River will be thermally marked to identify them as transplants from the Grays River. Some fish released from Sea Resources in the spring of 2000 are expected to return as three-year olds in 2002. Prior to that, any adult chum returning to the basin can be considered a stray or descendant of the Bear Creek chum that were planted into the basin. All adult chum returning to the Chinook River prior to 2002 will be destroyed. In 2002, scales will be removed and read to determine the age of the fish, all four-year olds in 2002 will be considered strays and destroyed. Three year-olds will initially be considered as fish returning from the Grays River fry plants. Otoliths will be collected from these fish and decoded to confirm that they originated from our re-introduction effort.

6.2.5) Holding

Grays River and Chinook River (Sea Resources)

Adult chum salmon will be held in adult holding ponds at the Grays River and Sea Resources hatcheries until spawning.

6.2.6) Disposition of carcasses

Grays River and Chinook River (Sea Resources)

Carcasses of chum salmon spawned at the Grays River and Sea Resources hatcheries will be returned to their respective watersheds for nutrient enrichment and productivity enhancement purposes.

6.3) Unknowns

The effects of the Grays River brood stocking effort on the population abundance and demographics of chum salmon native to this river are presently unknown but will be monitored by the use of thermal marks and routine in-river sampling of adult carcasses. Clearly, too, whether the Chinook River basin has received enough habitat restoration to support a naturally reproducing population of chum is uncertain. And perhaps just as importantly, whether Grays River chum can adapt to the conditions in the Chinook basin is currently unknown. Again, the use of thermal marks on these fish should help us evaluate how successful the fish are and routine biological sampling should also indicate if any traits such as egg size, fecundity x size relationships, and reproductive effort values change because of the new suite of environmental conditions/challenges present in the Chinook watershed.

SECTION 7. MATING

7.1) Selection method

As mentioned above fish, used for brood stocking are collected at the trap sites in a random fashion throughout the duration of the spawning run. Obviously, the number of fish spawned per day and who they are mated with depends upon which fish are ripe on a given spawning date. No effort is being made to cross fish with particular phenotypic attributes (e.g. size- and age-at-maturity) in any systematic fashion.

7.2) Males

A factorial mating scheme, either a 2 x 2 or 3 x 3 is followed whenever possible. To make these matings, the total egg mass of each female is weighed and then divided into the number of aliquots necessary to make the cross, either two or three. Each aliquot is then fertilized by a different male. In a 3 x 3 mating, for example, every female has one third of her eggs fertilized by a different male and every male fertilizes one third of the eggs obtained from three different females. This approach is used to ensure that each fish has an opportunity to contribute genetic material to the next generation. If simple one x one crosses are used exclusively there is a risk that individual males and females may be crossed with infertile partners and thus have their potential fitness reduced or eliminated. A factorial mating scheme tends to protect the effective population size of the cultured fish by buffering them from having all of their gametes affected by a single infertile partner (Busack pers. comm.) In 1998, 47 females and 45 males were spawned at Grays River, and as of 29 Nov 1999, 68 females and 68 males have been spawned. Table 5 shows the number of females that were involved with various types of crosses, from simple one-to-one crosses to the more complicated three-by-three factorials.

Table 5. The number of females used in various types of factorial crosses during 1998 and 1999 at the Grays River Hatchery.

Brood Year	Type of Factorial Cross			
	1♀ x 1♂	2♀♀ x 2♂♂	3♀♀ x 3♂♂	2♀♀ x 3♂♂
1998	6	30	9	2
1999	4	22	42	0

7.3) Fertilization

Prior to gamete extraction, each female is bled by severing a gill arch and is wiped clean of water, mucus and blood in an attempt to minimize contamination and gamete activation. Eggs from each female are collected separately in dry plastic pails. Each lot of eggs is then poured into a plastic colander that sits on top of another colander that has been lined with a plastic bag. The eggs are gently rotated around the colander to remove excess ovarian fluid which is retained by the lower colander. The eggs are then weighed to the nearest tenth of a gram on a top loading electronic balance. Depending upon the type of factorial cross being used, two to three aliquots of eggs are then weighed out and placed into new dry plastic pails. A label with the female's number is placed into each of these pails. A small sub sample of eggs (30 to 100) is then removed from one of the aliquots and weighed to the nearest hundred of a gram. The eggs in the sub sample are then hand counted two times. The data from this sample provides an estimate of the green egg weight of each female (sample weight/egg number = mean green egg weight) and is used to calculate a fecundity estimate (egg mass weight/mean green egg weight = fecundity) for that fish. Ten of the eggs from the sub sample are retained and placed in water and allowed to water harden for 24 hours. These eggs are then individually weighed to the nearest mg to provide an estimate of the water-hardened egg weight for each female. The ovarian fluid captured by the lower colander is then poured back into each egg lot and the pails are stored in a cooler supplied with a 10 cm layer of crushed ice that is covered with some light insulating material. Once all the females that are going to be used in a factorial cross have been processed, milt is extracted from the males that will be used to make the cross. Like the females, each of these fish is wiped dry of water, mucus, and blood before milt is collected in dry, 1 liter plastic containers. Each milt sample is labeled and placed into a cooler until all the milt samples have been collected. The cross is made by laying out the pails containing the eggs of the same female into a row. For a three by three cross, nine pails would be laid out, with each row having eggs from the same female and each column having eggs from three different females. Milt from each male is added to one column of pails. At least 5 cc's of milt is added to each pail. Incubation water is poured over the combined gametes and they are gently swirled for 30 to 45 seconds and allowed to stand for another minute or more. By this time the micropyles in the eggs have closed and the eggs from each female are placed into a single incubation tray and immersed in an iodophor bath for one hour before being placed into normal incubation water.

A considerable amount of ancillary biological data are collected either before or immediately after spawning. For example, prior to gamete removal each fish is measured (Fork Length) to the nearest mm and weighed on an electronic balance to the nearest 0.5 gram. Eye, liver, heart, muscle, and sometimes fin material is removed for electrophoretic processing and DNA samples are removed from the opercle. Three to six scales are collected for later age determination and kidney and spleen samples are removed from each fish for viral screening. Ovarian fluid is also collected from each female and used in the viral screening process which relies on the enzyme-linked immunosorbent assay (ELISA). Because we intend to transfer some of the eggs from each female to the Chinook River it is important that each fish be screened for viral pathogens. Those individual that test positive for viral infestation will not be transferred.

7.4) Cryopreserved gametes

No cryopreserved gametes will be used in this recovery/re-introduction program

7.5) Unknowns

The effects of the supplementation program on within population diversity and whether domestication effects will manifest themselves because of our cultural practices are unknown. Biological data, however, will be collected on each adult used as brood stock throughout this program. Because all the hatchery fish will be thermally marked it will be possible to compare a number of phenotypic traits between hatchery-origin and natural-origin adults to see if any noticeable domestication has taken place.

SECTION 8. REARING AND INCUBATION

INCUBATION:

8.1) Number of eggs taken and survival objective to ponding

Grays River Hatchery

The current annual egg taking goal for Grays River ranges between 100 and 300 K eggs. In 1998 we were able to achieve a 92% survival rate from green egg to ponded fry. The project goal is to consistently maintain a 90% egg-to-fry survival rate at the Grays River Hatchery.

Sea Resources Hatchery

The Sea Resources Hatchery is not supplied with well water but instead must rely on surface water from the Chinook River. Storm events can significantly increase the sediment load in the water supply and care must be taken to ensure that incubating eggs are not suffocated by excess siltation. For that reason, we are not incubating any chum eggs at the hatchery for the first three years of the project. When eggs are incubated at the hatchery a 90% egg-to-fry survival rate will be the goal. The number of eggs incubated at this site will be dependent upon the number of fish returning to the river but will not exceed 300 K.

8.2) Loading density

Grays River Hatchery and the Sea Resources Hatchery

A single female will be placed into each incubation tray, or in those instances where eggs from several females are placed into a single tray their combined density will not exceed that recommended by Piper et al. (1982).

8.3) Influent and effluent gas concentration

Grays River Hatchery and the Sea Resources Hatchery

Influent and effluent gas concentrations, including dissolved oxygen concentrations are and will be within parameters optimal for salmonid egg and juvenile survival

8.4) Ponding

Grays River chum salmon are transferred into their rearing ponds after yolk absorption is almost complete. Fry produced from chum spawned in 1998 were transferred to rearing ponds at the Grays River Hatchery on Jan 25, Feb 1, 11, 16, 22, and March 9, 1999. Fish length at ponding ranged from 34 to 42 mm and the average weight of the fry was 370 mg. A similar ponding strategy will be used in the future for both the Grays River and Sea Resources hatcheries.

8.5) Fish health monitoring

No fish disease outbreaks occurred during the incubation to ponding period at the Grays River Hatchery in 1998 and the mortality levels experienced were lower than the program standards. Fish health is continuously monitored in compliance with Co-manager Fish Health Policy standards (WDFW and WWTIT 1998).

REARING

8.6) Number of fish ponded and survival objective to release

The objective of the Grays River program is to pond from 100 to 200 K fry and for the Sea Resources Hatchery, the objective is to pond 50 to 300 K fry. In 1998, 92% of the eggs collected, produced fry that were ponded at the Grays River Hatchery. During the rearing period, which ranged from 32 to 50 days, mortalities were extremely low, less than 1%. Our program objective is to achieve a 95% survival rate during the rearing period.

8.7) Density and loading

The fish are reared using the loading densities recommended by Piper et al. 1982. The rearing water at Grays River is approximately 10°C (50°F) and the fish at release average between 58 to 54 mm (2.3 to 2.1 inches) in length. Flow into each raceway can vary between 946 to 1,325 liters/min (250 to 350 gallons/min). Given these parameters, each raceway can hold a maximum of 73,000 fry at the end of the rearing period. This maximum value was calculated by multiplying the Piper constant at fifty degrees Fahrenheit by the number of gallons entering a raceway and dividing that product by the length of the reared fish or (1.8 Piper constant at 50° F)(350 gpm)/(2.3 fish length in inches = 274 lbs of fish per raceway); since there are 266 fish per pound (1.7 g) at the end of the rearing period that means that the maximal carrying capacity in a Grays River raceway at the end of the rearing period is (266)(274) or 73,000 fish. In 1998 this loading density was never reached. Our loading density goal for both the Grays River and Sea Resources hatcheries is to try to rear the fish at less than one-half a pound of fish per gallon per minute for the majority of their rearing period and thus never exceed the loading value recommended by Piper et al. (1982).

8.8) Influent and effluent gas concentrations

Influent and effluent gas concentrations at both hatcheries, including dissolved oxygen concentrations will and are within parameters optimal for juvenile salmon production and survival.

8.9) Length, weight, and condition factor

Table 6 presents length (fork length), weight, and Fulton condition factor data collected on the chum released from the Grays River Hatchery in 1998. This information was collected on the day the fish were liberated into the West Fork of the Grays River.

Table 6. The length, weight, and condition factors of chum salmon juveniles liberated from the Grays River Hatchery in 1998. Data for each release were obtained by sampling 100 individuals just prior to release.

Biological Parameter	Release One March 16, 1999	Release Two March 16, 1999	Release Three March 25, 1999	Release Four April 15, 1999
Mean Length	58.8 mm	56.2 mm	55.2 mm	54.6 mm
SD for Length	2.8	2.8	3.4	2.7
95% +	59.4 mm	56.7 mm	56.0 mm	55.1 mm
95% -	58.2 mm	55.6 mm	54.6 mm	54.0 mm
CV for Length	4.8%	4.9%	6.2%	4.9%
Mean Weight	1.73 g	1.54 g	1.4 g	1.4 g
SD for Weight	0.23	0.24	0.25	0.21
95% +	1.77 g	1.59 g	1.45 g	1.44 g
95% -	1.69 g	1.50 g	1.35 g	1.35 g
CV for Weight	13.4%	15.5%	17.62%	15.33%
Mean Condition	0.84	0.87	0.82	0.85
SD for Condition	0.06	0.05	0.05	0.06
95% +	0.86	0.87	0.83	0.87
95% -	0.84	0.86	0.81	0.84
CV for Condition	6.9%	5.3%	5.88%	6.74%

8.10) Growth rate, energy reserves

Fish health and condition are monitored by fish health professionals throughout the rearing period. Growth samples were taken from each rearing area on a once-a-week basis to estimate mean body weight values for each group of reared fish. These values were used to adjust the daily ration of food provided to the fish. Growth rates (changes in length or body weight/day) for each group fish averaged around 0.4 mm and 27 mg per day. No formal assessments were made of the energy reserves the fish possessed at the time of their release. However, unfed fry have a Fulton Condition Factor of approximately 0.68 $[((wt)/(length)^3)(100{,}000)]$ as can be seen in Table 6, the fish released from the Grays River Hatchery in 1998 had condition factors that were slightly higher than this, indicating that they were a little more robust than unfed fry. Consequently, we feel these fish had adequate reserves to migrate to their estuarine feeding grounds. One of cultural goals in this project is to release fry that have condition factors that range from 0.68 to 1.0. Fish with condition factors greater than one may be obese and not as able to migrate or escape predation as those in a slightly slimmer condition.

8.11) Food type and amount fed, and estimates of feed conversion efficiency.

Unfed fry will be started on a BioDiet semi-moist starter food (BioDiet # 3). As soon as possible they will be converted to a dry BioDiet diet consisting of 1 mm in diameter pellets which they will be fed until liberation. Fish will generally be fed at a 2 to 3% body weight/day rate. The expected fed conversion rate will be $\geq$1.2.

8.12) Health and disease monitoring

Fish health and disease condition will be continuously monitored in compliance with Co-manager Fish Health Policy standards (WDFW and WWTIT 1998).

8.13) Smolt development indices, if applicable

At emergence, chum salmon fry are physiologically able to move directly into sea water. No formal measurements on degree of smoltification are conducted.

8.14) Use of "natural rearing methods"

Some "NATURES" (natural rearing systems) approaches may be employed and evaluated. In particular, some raceways at both hatcheries may be provided with underwater feeders and floating cover. Since chum fry are initially epibenthic feeders we feel that presenting them with food in mid-water may be beneficial. In addition, the use of floating "lily pad covers" will also help the fish retain their fear responses to overhead shadows. At the Sea Resources hatchery we may also provide some of the raceways with dark bottoms and grey to green-blue side walls in an effort to provide the fish with a hetero-chromatic environment that mimics the color conditions found in Baker Bay and in the Columbia River. If these types of environments are implemented they will be carefully evaluated and compared against conventional methods. This will be accomplished in two ways, first be assessing any in-culture costs of these treatments (growth and mortality measurements) and second by comparing the fry-to-adult survival rates of fish produced from the two treatments via thermal marks recovered from returning adults.

8.15) Unknowns

The Sea Resources Hatchery relies on gravity-fed surface water to supply its raceways and incubation room. After heavy rains significant amounts of very fine sediments are transported downstream and they will be delivered into our rearing raceways. The effects of this sediment on growth, survival, and juvenile quality are not known. Chum salmon have been successfully reared at the site in the past and raceway maintenance will occur during and after heavy sedimentation in an attempt to minimize any deleterious effects.

SECTION 9. RELEASE

9.1) Life history stage, size, and age at release

Table 6 presented the mean weight, length, and condition of the reared chum salmon juveniles released from the Grays River Hatchery in 1999. Future releases from this site and from the Sea Resources Hatchery will liberate fish with comparable age and size characteristics. Release timing coincides with when unfed chum salmon fry emigrate from the Grays River.

9.2) Life history stage, size and age of natural fish of the same species in release area at time of release

Lack of data (time of emergence, age, and size at migration) was evident in the "Stock Assessment of Columbia River Anadromous Salmonids" Final Report 1984, and the Columbia River Subbasin Plan. Limited seining on the mainstem Grays River in 1979 gained little information on juvenile chum. More in-depth seining on Gorley and Crazy Johnson creeks in 1992 and 1993 shed some light oh the data gaps. Further efforts were made in 1995

From seining results in 1995, it was determined that chum emergence in Gorley Creek begins in early March, peaks in mid March and is completed by mid-April. The timing was consistent with results from the 1992 and 1993 seining efforts. In 1995, the juvenile chum captured in Gorely Creek averaged 40 mm and ranged from 36-46 mm (Keller, 1996).

9.3) Dates of release and release protocols

Fed fry will be released from both hatcheries from mid March to mid April. All releases will occur after darkness has fallen and when possible on a falling tide in an effort to protect the fish from in-stream predation and expedite their movement toward the Columbia estuary. The fish are not fed for at least 24 hrs prior to a release to minimize handling stress. At Grays River a stick seine is used to gently concentrate the fish into a relatively small portion of their raceway. Then dip nets are employed to capture the fish and place them in a tote box filled with 750 liters of Grays River water. The tote is lined with a fine mesh (3.125 mm), knotless nylon net and supplied with air stones to keep the water well oxygenated. After the tote has been loaded, a lid is placed on the box and the fish are hauled about 100 meters to the West Fork of the Grays River. Personnel then carefully load the fish into 19 liter capacity plastic buckets which are then hand-carried to the river so that the fish can be gently released. A similar release strategy will be used at the Sea Resources site except the fish will be hauled for 1.6 to 4.8 Km to a lower river location before being carefully released into the Chinook River.

9.4) Location(s) of release

As mentioned above the release location for the fish reared at the Grays River Hatchery is on the West Fork of the Grays River right at the hatchery location. In the Chinook basin the fish will be trucked downstream approximately 3 Km from the Sea Resources Hatchery to reduce predation losses and expedite their movement into Baker Bay and toward the Pacific Ocean.

9.5) Acclimation procedures

At Grays River the fry will be converted from well water to Grays River water about two weeks prior to being released. Such a conversion will not be necessary at the Sea Resources facility since the fish will have been reared entirely in Chinook River water. As mentioned above, the fish will not be fed for at least 24 hrs prior to being released. Loading densities in the transfer tanks will be kept at low levels and all the fish will be released by hand from 19 liter buckets in an effort to reduce stress and disorientation.

9.6) Number of fish released

In 1998, one-hundred and ten thousand fed chum salmon juveniles were released into the West Fork of the Grays River. We plan to release anywhere from one-hundred to three-hundred thousand fed chum salmon into the West Fork on an annual basis. Initial fry releases into the Chinook basin will range between fifty and one-hundred thousand individuals. If the re-introduction effort is successful, and adults returning to the Chinook can be used as brood stock then fry releases will increase slightly and range between one-hundred to a maximum of three-hundred thousand individuals.

9.7) Marks used to identify hatchery adults

All the hatchery fish will have their otoliths thermally marked using methods described by (Volk et al. 1990; Volk et al. 1994; Schroder et al. 1996; Volk et al. 1999). Initially two thermal marks will be used, one to indicate that the fish were reared and released at the Grays River Hatchery and another that identifies the fish as having been reared and released into the Chinook River. If NATURES style raceways are tried, additional thermal codes will be used to aid statistical evaluations of the effectiveness of conventional and NATURES rearing methods.

9.8) Unknowns

How the release timing and strategies outlined above may effect demographic characteristics in the Grays River population (age at maturation, return timing, size at maturity) will remain unknown until hatchery adults begin to return and comparisons between them and natural origin chum can be made.

SECTION 10. MONITORING AND EVALUATION OF PERFORMANCE INDICATORS

Monetary support for the work described here is mainly coming from funds provided to WDFW from the State Legislature. Significant contributions will also come from Sea Resources. Additional funds are needed, however, to carry out the stream survey work, and to help improve the infra-structure at the Sea Resources Hatchery. At present it is uncertain where these dollars will come from.

10.1) Marking

As mentioned previously every chum salmon produced by our recovery program will be thermally marked to make it possible for us to determine their origin and what type of cultural treatment they experienced.

10.2) Genetic data

Busack and Shaklee (1995) state “Based solely on the distribution of spawning grounds, Columbia River chum can be aggregated into two groups, Grays River and Below-Bonneville Tributaries. The spawning grounds of these two groups are separated by more than one hundred river miles and although information on straying based on coded-wire tags is not available, we do not believe that significant spawner exchange occurs between Grays River and the area just below Bonneville Dam”. Extensive collections of eye, muscle, heart, and liver tissues have been collected from a substantial number of chum salmon populations located in Puget Sound, the Straits of Juan de Fuca, coastal Washington and Oregon, the Columbia River, and coastal British Columbia. Electrophoretic evaluations of these samples revealed that . . . “Columbia River chum populations [are] genetically distinct from each other and from all [the] other populations assayed. . .The Grays River and Hamilton Creek populations have a localized allele, *LDH-B1*160,* that [is] only found in the Columbia River. In addition, these collections share alleles with other Washington and Oregon coastal populations that have not been observed in Puget Sound” (Busack and Shaklee 1995). To add to this base line, we are collecting similar tissue samples from each adult used for brood stock. Moreover, punches of material removed from the opercle are being archived for later DNA analyses. These collections will continue into the foreseeable future.

10.3) Survival and fecundity

The fecundity of each female used as brood stock will be determined gravimetrically (see SECTION 7, part 7.3 Fertilization for a description of how fecundity is calculated at spawning. The eggs from each female are incubated separately from one another and so it is possible to calculate another fecundity estimate at eyeing after the eggs have been shocked. First, all unfertilized or aborted eggs are removed and counted. Then the entire remaining egg mass is weighed to the nearest tenth of a gram after excess water has been removed by placing the eggs in a plastic colander. Prior to placing the eggs in the colander the balance is tared to zero, after the egg mass has been weighed the colander is re-weighed, if the balance registers more than zero, this extra weight, caused by water residue, is subtracted from the egg mass weight. Next, four samples of approximately 20 to 30 eggs are weighed to the nearest one-hundredth of a gram. The number of eggs in each sample is hand counted twice to ensure that an accurate count has been made. Moreover, the weighing boat used for each sample is re-weighed and the weight of any water residue adhering to it is subtracted from the sample weight. These small egg samples provide estimates of a mean eyed egg weight for each female. The total egg mass weight is divided by these estimates and four independent fecundity values are then calculated for each female. A mean fecundity value with a 95% confidence interval calculated for each female and this mean value then becomes the final fecundity estimate for each female.

Relationships between female size (length and weight) and fecundity for individuals maturing at the same age (3, 4, and 5) have not yet been developed for Grays River chum salmon. However, an overall mean fecundity value for females maturing at each of these ages has been calculated from information gathered on the females spawned in 1998 (Table 7). Note that seven females were excluded from this data set. Their reproductive effort ((egg mass weight/total body weight))(100) values indicated that they had spawned at least once prior to being captured. Additional fecundity and reproductive data will be collected on each female used as brood stock throughout the duration of this program.

Table 7. Mean fecundity, reproductive effort, and egg weights of three-, four- and five-year-old chum salmon captured at Gorley Springs (Grays River) in 1998.

Age at Maturation	Fecundity		Reproductive Effort		Egg Weight (mg)	
	No. Sampled	Value	No. Sampled	Value	No. Sampled	Value
3-Years	13	3,023	13	20.7%	15	269.5
4-Years	26	2,714	26	19.2%	31	303.2
5-Years	1	2,097	1	16.4%	1	408.3

10.3.2) Survival

a) Collection to spawning

Any losses of brood stock collected at Gorley springs and later at the Sea Resources Hatchery will be recorded. Our goal is to achieve at least a 95% survival rate in the collected brood stock. To reach that goal, each adult is held in its own individual holding tube to protect it from repeated handling and to reduce holding stress.

b) Green eggs to eyed eggs

Survival to the eyed-stage of development is calculated for each female. This is accomplished by dividing the number of dead or aborted eggs found after shocking at the eyed stage by the female's estimated fecundity. A goal of 92% is the survival standard for this stage in the life cycle.

c) Eyed eggs to release

A survival estimate from eyeing to yolk absorption is calculated in a manner similar to that for green eggs to eyed eggs. At yolk absorption or ponding, the number of dead eggs, alevins and monstrosities produced by each female is counted. This value is then divided by the number of viable eggs each female had at the eyed stage of development to produce an eyed-egg to fry survival rate. The incidence of different types of monstrosities, e.g. scoliosis, twins, bent spines, albinos, mosaics, abnormal fins, and so on, in each female is recorded. In-culture mortality is not calculated for each female. However, each raceway is checked and mortalities are removed and counted on a daily basis. Since we have an estimate of the number of fry placed into each raceway it is possible to determine the mortality of these fish by dividing the number of mortalities observed during the rearing period by the number of fry that were introduced into a raceway. During the 1999 rearing season at Grays River, less than a 1% mortality rate occurred throughout the rearing period.

d) Release to adult, to include contribution to:

(i) harvest

Few chum salmon are expected to be harvested even incidentally. As mentioned earlier, the commercial catch of chum salmon in the Columbia River continues to remain low. Nineteen ninety-eight marked the sixth consecutive year when less than one hundred chum were harvested in the river. Generally, chum salmon enter the river in late October, after the commercial gill net seasons have ended (Keller 1999).

(ii) hatchery brood stock

See SECTION 2, part 2.2.3 for a description of how thermal marks will be used to estimate the fry-to-adult survival rates of cultured chum salmon juveniles.

(iii) natural spawning

As part of our effort to evaluate the survival of hatchery-origin chum salmon in the Grays River, stream surveys and collection of otoliths from chum carcasses will occur. These will be decoded and the distribution and abundance of naturally spawning hatchery-origin chum salmon will be calculated on a yearly basis.

10.4) Monitoring of performance indicators in Section 1.8

Monitoring and Evaluation Objectives

Objective 1:	Determine if other genetic enclaves of chum salmon exist in Lower Columbia River tributaries and if so, implement site-specific recovery efforts for these populations.
Objective 2:	Stabilize the Grays River chum salmon population by using the Grays River Hatchery as a protected location for incubation and fry production. Collect enough adults to maintain an appropriate effective population size (40 or more pairs)
Objective 3:	Ensure that the survival of brood stock prior to spawning is at least 95% and that their offspring experience expected survival benefits from being sequestered in a hatchery environment. In addition, transplant a portion of each produced family to the Chinook basin in order to establish native Lower Columbia River chum salmon into another river basin. Evaluate the fry-to-adult survival of released fish and compare biological characteristics of hatchery-origin adults to natural-origin cohorts to evaluate domestication effects.
Objective 4:	Place distinctive marks on the otoliths of every cultured fish released into the Grays and Chinook River. Ensure that these marks are linked to particular release locations and strategies so that their effects on adult survival can be evaluated.

Monitoring and evaluation tasks that should be completed to meet the above objectives:

Objective 1:	Determine if other genetic enclaves of chum salmon exist in Lower Columbia River tributaries and if so to implement site-specific recovery efforts for these populations.
Task 1.1	Conduct annual in-stream surveys of Lower Columbia tributaries beginning in mid-October and continuing through December
Task 1.2	When chum salmon are located use GPS units and local maps to locate and document their spatial and temporal distribution

Task 1.3 Perform a habitat evaluation of each surveyed watershed, determine if ground water sources are available and also document any side channels or other areas where controlled spawning areas could be developed and monitored.

Task 1.4 Collect biological data (scales, GSI and DNA samples) on all available chum salmon carcasses

Task 1.5 Produce annual reports that describe the results of the above surveys and prioritize those populations and areas that should receive supplementation, recovery, or re-introduction efforts.

Task 1.6 Identify which existing populations of chum salmon would be the best potential donor populations for streams which have extirpated populations of chum salmon

Task 1.7 Develop site-specific habitat restoration plans for each location where chum salmon recovery is planned.

Objective 2: Stabilize the Grays River chum salmon population by using the Grays River Hatchery as a protected location for incubation and fry production. Collect enough adults to maintain an appropriate effective population size (40 or more pairs)

Task 2.1 Install on an annual basis an adult collection trap and weir at the mouth of Gorley Springs or on another appropriate Grays River tributary.

Task 2.2 Maintain the adult trap and randomly collect brood stock from the returning adults

Task 2.3 Collect at least 40 pairs but not more than 100 pairs for brood stocking purposes

Task 2.4 Spawn, incubate and rear some of the offspring produced from each artificially produced family at the Grays River Hatchery and release the subsequent juveniles into the Grays River during mid March through mid April during darkness.

Objective 3: Ensure that the survival of brood stock prior to spawning is at least 95% and that their offspring experience expected survival benefits from being sequestered in a hatchery environment. In addition, transplant a portion of each produced family to the Chinook basin in order to establish native Lower Columbia River chum salmon into another river basin. Evaluate the fry-to-adult survival of released fish and compare biological characteristics of hatchery-origin adults to natural-origin cohorts to evaluate domestication effects.

Task 3.1 Place all collected brood stock fish into their own holding tube, provide them with optimal water exchange and saturated oxygen levels, routinely check for maturity, return surplus fish within two to three days of capture, spawn the fish when ripe. Evaluate the survival of collected adults and make necessary changes to holding protocols if mortalities occur.

Task 3.2 Monitor the survival of collected gametes from the green egg-to-eyed egg, eyed egg-to-fry, and fry-to-release stages. Ensure that the program's survival standards have been met, modify operational procedures if mortality exceeds standards.

Task 3.3	At the eyed stage of development remove a portion of eggs from each family and place them in a separate incubation tray so that they can be transported to the Sea Resources Hatchery
Task 3.4	Establish portable fiberglass rearing raceways at the Sea Resources Hatchery and develop an operations plan designed to improve the infra-structure of the hatchery
Task 3.5	Via stream survey work in the Grays and Chinook River basins, collect otoliths from adult chum salmon and decode these specimens to determine if they originated from our recovery/re-introduction program.
Task 3.6	When chum salmon return to the Chinook River basin, capture and spawn up to 100 pairs and rear and release their offspring back into the Chinook River in an effort to expedite the development of a locally adapted population.
Task 3.7	Compare biological data (e.g. egg size, reproductive effort, fecundity relationships, occurrence of various monstrosities, gamete viability, etc.) collected from hatchery-origin and natural-origin adult chum salmon and their offspring to evaluate any domestication effects.
Objective 4:	Place distinctive marks on the otoliths of every cultured fish released into the Grays and Chinook River. Ensure that these marks are linked to particular release locations and strategies so that the effects of each on adult survival can be evaluated.
Task 4.1	Install, calibrate, and monitor portable water chilling equipment at the Grays River Hatchery. When appropriate, install similar equipment at the Sea Resources Hatchery so that eggs and alevins incubated at that location can be thermally marked.

Task 4.2	Develop thermal mark codes using the 2 of 5 rule to produce distinctive thermal marks on the distinct groups of chum salmon being incubated at the Grays River Hatchery
Task 4.3	Begin marking one to two days after picking eyed eggs and continue the marking process until yolk absorption is almost complete.
Task 4.4	At the end of the marking period, collect ten specimens from each marking group and examine their otoliths to verify the code that was established for that group (voucher samples)

10.5) Unknowns or uncertainties identified in sections 5 through 9
Unknowns and uncertainties identified in previous sections will be addressed through the monitoring and evaluation measures proposed above.

10.6) Other relevant monitoring projects
WDFW is currently evaluating the average stream life of chum salmon spawning in Gorley Springs. This information will be critical when we attempt to determine the abundance of chum salmon spawning in the Grays River. Moreover, plans are being developed to evaluate the egg-to-fry survival of fish spawning the Gorley Springs area. Such an evaluation will help us determine how successful such groundwater side channels are for recovering chum salmon. Finally, an extensive amount of habitat evaluation work will be taking place in the Chinook basin. The effect of these changes on chum salmon survival and productivity will provide us with information about how useful this type of restoration may be in chum salmon recovery.

SECTION 11. RESEARCH

Research programs associated with this HGMP are described in the monitoring and evaluation sections above. Research will be directed at determining whether this recovery/re-introduction program is successfully maintaining or increasing chum salmon abundance in the Grays River and introducing a new self-sustaining population of chum salmon into the Chinook basin.

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Attachment 3

APPENDIX 2: WATER CHARACTERISTICS THAT SHOULD BE EVALUATED PRIOR TO SITING SALMON RECOVERY PROJECTS

Characteristic	Standard	Source of Standard
Aluminum	< 0.01 mg/L Not > 0.005 mg/L when pH < 6.5 and $Ca^{2+} < 4.0$ mg/L Not > 0.1 mg/L when pH > 6.5 and $Ca^{2+} > 4.0$ mg/L	WDFW Alderdice[1] Alderdice[1]
Ammonia (un-ionized)	< 0.0125 mg/L	WDFW
Arsenic	< 0.05 mg/L	WDFW Bell
Barium	< 5.0 mg/L	WDFW Bell
Cadmium	Not > 0.0002 mg/L 0.001 mg/L < 0.0005 mg/L when alkalinity ≥ 100 mg/L < 0.005 mg/L when alkalinity < 100 mg/L	Alderdice[1] Bell WDFW WDFW
Calcium	Not < 10.0 mg/L for eggs	Alderdice[1]
Carbon Dioxide	< 1.0 mg/L	WDFW
Chloride	< 4.0 mg/L	WDFW
Chromium	< 0.03 mg/L 0.01 mg/L	WDFW Bell
Copper	< 0.006 mg/L when alkalinity < 100 mg/L < 0.03 mg/L when alkalinity > 100 mg/L	WDFW
Dissolved Oxygen	> 7 mg/L	WDFW
Fluoride	< 0.5 mg/L	Bell
Hardness	< 20 mg/L as $CaCO_3$	WDFW
Iron	< 0.1 mg/L	Bell
Lead	< 0.02 mg/L	Bell
Magnesium	< 15 mg/L	WDFW
Manganese	< 0.01 mg/L	Bell
Mercury	< 0.0002 mg/L 0.05 mg/L	WDFW Bell
Nickel	< 0.01 mg/L	WDFW
Nitrate (NO_3)	< 1.0 mg/L	WDFW
NO_2	< 0.1 mg/L	Bell
Nitrogen (N_2)	<110% Total Gas Pressure (TGP) 100 – 104% TGP no problem	WDFW Alderdice[1]
Nitrogen (N_2) continued	104 –109% Chronic problems, 4 – 5% mortalities >110% TGP Acute problem, complete mortality < 103% Nitrogen gas	Alderdice[1] Alderdice[1] Bell

Petroleum (oil)	<0.001 mg/L	WDFW
pH	6.5 – 8.0 6.5 –6.6 Threshold for eggs	WDFW Alderdice[1]
Potassium	< 5.0 mg/L	Bell
Salinity	< 5.0 parts per thousand	WDFW
Selenium	< 0.01 mg/L	WDFW
Silver	<0.0003 mg/L	WDFW
Sodium	< 75.0 mg/L Not < 1.0 mg/L for eggs	WDFW Alderdice[1]
Sulfate	< 50.0 mg/L	WDFW
Zinc	< 0.005 mg/L	WDFW

Alderdice and McLean (1982) point out that heavy metal concentrations can be determined in a variety of ways, e.g. via total, dissolved or extractable analyses. They recommend that dissolved analyses be used since heavy metal toxicity is closely correlated with dissolved metal concentrations. In this same report they indicate that some water characteristics can increase or decrease the toxicity of metals. For instance, the resistance of fishes to metals generally increases as hardness (mg/L $CaCO_3$) and pH increase. Furthermore, some metals can have additive deleterious effects and therefore even though individually their concentrations may be acceptable once combined with other metals they can become harmful. Finally, exposure duration obviously plays a role in the impact of various water borne components on the well being of fish. In some instances pre-exposure to heavy metals during incubation or early stream life may give fish greater resistance to metals in solution. On the other hand, prolonged exposure to seemingly low levels may be more harmful than short exposures to higher ones. For these and other considerations the interpretation of water quality information can be complex. Therefore it is recommended that a water quality expert review and comment on the chemical analyses that will be performed during a site determination process.

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WDFW—internal water quality standards