Rearing of Juvenile Salmon in Recovering Wetlands of the Salmon River Estuary: Functional Development with Marsh Age

Daniel L. Bottom, National Marine Fisheries Service
Kim K. Jones, Oregon Department of Fish and Wildlife
Trevan Cornwell, Oregon Department of Fish and Wildlife
Charles A. Simenstad, University of Washington

Background

Widespread decline of salmon stocks throughout the Pacific Northwest has stimulated interest in the restoration of freshwater and estuarine habitats. Because many salmon stocks rear in estuaries for an extended period before migrating to sea (Reimers 1973; Simenstad et al. 1982), and estuarine marsh channels are used by some salmonids as nursery habitats (Levy and Northcote 1982; Simenstad et al. 1982), the salmon crisis has lent new urgency to ongoing efforts to restore estuarine wetlands lost to decades of filling and diking of intertidal lands. Removal of tidegates and dikes has been a primary focus of recovery efforts because such "passive" restoration methods offer the most cost-effective means for returning significant quantities of wetland habitat to estuaries. Ongoing research in the Salmon River estuary (Oregon) is providing much-needed information about the responses of estuarine-rearing salmonids and prey resources to wetland restoration.

The effectiveness of estuarine restoration for salmon has rarely been investigated. Although use of tidal wetlands as salmonid rearing habitat has been documented in some estuaries (e.g., Levy and Northcote 1982), little is known about the specific wetland attributes favored by salmon, the relative rates of recovery of various types of diked wetlands, or the ultimate benefits of wetland restoration to salmon survival (Shreffler et al. 1990, 1992; Simenstad and Thom 1996).

Salmon River estuary on the central Oregon coast offers a unique opportunity to evaluate the response of fish and invertebrate prey to wetland recovery because the U.S. Forest Service has initiated a long-term estuarine restoration program as part of their management of the Cascade Head Scenic Research Area. Since 1978, the USFS has completed three major dike removal projects in the Salmon River estuary, returning almost 70% of the historic wetland to tidal influence. Because a new project was initiated every nine years, the Forest Service restoration program has created a series of marsh recovery "experiments" at various stages of succession providing a one-of-a-kind natural laboratory for evaluating estuarine fish and prey community responses to restored wetland habitats. This information is needed to determine relative rates of salmon habitat recovery and to develop appropriate designs for future restoration projects.

To benefit from the unique monitoring opportunity at Salmon River, the Oregon Department of Fish and Wildlife initiated fish surveys in the estuary in 1997 with a small grant provided by the Environmental Protection Agency (Region X). With new funding from Oregon and Washington Sea Grant Programs, the monitoring project was expanded for the period 1998-

2000 to incorporate studies of prey resources, salmonid food habits, and physical habitat features through a collaboration of Oregon Department of Fish and Wildlife, National Marine Fisheries Service, and University of Washington biologists. Oregon Sea Grant has awarded funds to continue a second phase of the Salmon River research program for the period 2001-2003. This report briefly describes the approach and findings of Phase I activities (through 2000), including pilot research initiated in 2000 to develop methods and test the feasibility of (1) salmon mark and recapture studies, and (2) otolith microchemical analyses proposed for Phase II. A detailed summary of fish survey data for Phase I studies (1997-1999 only) is presented in Cornwell et al. (2001) [http://osu.orst.edu/Dept/ODFW/inforeports/index.html]. Additional Phase I results, including the response of prey resources and salmonid food habits are provided by Gray et al. (In Press).

Phase I Objectives and Results to Date

Use of Marsh Habitats by Juvenile Salmon

The goal of Phase I monitoring at Salmon River (1998-2000) was to determine the use of recovering and natural marshes by salmon and other fishes and to evaluate whether marshes provide interim benefits as fish habitat. During this first phase of monitoring we compared species composition and abundance of fish and prey species and salmonid food habits among the recovering marshes and an undiked reference marsh. We also monitored channel geomorphology to evaluate the physical habitat attributes of recovering and undiked marshes that affect rearing opportunities for salmon.

Results of Phase I indicate that juvenile chinook, chum, and coho salmon from Salmon River make use of recovering marsh channels as rearing habitats. Salmon fry enter the estuarine marshes as early as February followed by larger size classes later in the spring and summer. Chinook salmon were most abundant in the control and (during 1999) in the youngest (96) site and least abundant in the oldest (78) site (Figure 1). By July most salmonids had vacated the Salmon River marshes, although some chinook salmon may remain in the estuary as late as October or November. The degree of use and potential benefits of restored wetlands to salmon appear to vary with the recovery age, accessibility, and location of each site along the tidal gradient. Preliminary results of prey resource studies suggestthat differences in prey production and composition and physical habitat conditions among the recovering and reference marshes may affect the growth potential of salmon at each site. For example, a possible tradeoff may exist during early successional stages of marsh recovery as high organic levels boost production of insect prey while relatively poor physical habitat and warm temperatures could limit the growth potential of juvenile salmon (Gray et al. In Press). We plan to develop a bioenergetic model during Phase II studies to investigate differences in growth potential of recovering marshes associated with their developmental stage and position along the tidal gradient.

2000 Feasibility Studies for Phase II Research

The goal of Phase II (2001-2003) of the Salmon River project is to evaluate the benefits of estuarine marsh restoration to salmon as indicated by life-history diversity, growth, and survival to adult. This goal recognizes that the performance of salmon and the benefits they derive from the marshes are not just a function of conditions within the estuary, but are also influenced by the structure of populations and associated juvenile life histories in the Salmon River basin that determine whether salmon can fully realize the productive potential of restored estuarine wetlands. Phase II studies therefore will incorporate additional objectives to evaluate effects of salmon life histories on habitat use and salmonid performance in the estuary: (1) describe the patterns of migration by juvenile chinook salmon into and through Salmon River estuary and marshes, (2) evaluate estuarine and marsh residency of salmon and the contributions of estuarine marshes of different recovery ages and the estuary overall to salmonid growth, and (3) evaluate the long-term success of freshwater and estuarine rearing patterns based on the relative proportions of different life-history types in the returning spawner population.

Mark-Recapture Techniques

A key component of the Phase II monitoring is a trapping and marking program to determine the upriver origins of juvenile salmon sampled in the estuary. The marking program also will allow us to determine the time of estuarine entry and residence periods of individuals and to describe the diversity of juvenile life history patterns in the system. During 2000 we initiated a feasibility study to test whether we could successfully mark various sizes of salmonid juveniles from key production areas upriver and recapture them in the estuary. We established three upriver trapping sites for collecting and marking juvenile salmonids, particularly chinook salmon (Figure 2): an upper Salmon River site at the lower end of the major mainstem spawning area for chinook salmon; a lower Bear Creek site located near the mouth of a primary spawning tributary for chinook salmon; and a lower Salmon River site located near the Salmon River Hatchery just above the head of tide. Fish were collected and marked at each trap site 4 days/week from March through June. Results showed that downstream migration timing differed among species and spawning areas (trap location) (Figure 3).

We used beach seines and trap nets to recover marked fish in the Salmon River estuary and marshes. We recaptured a total of 41 marked juvenile chinook in the estuary. Estuarine recovery rates of marked fish were 1.8 % for the lower Salmon River trap, 0.5% for the Bear Cr. trap, and 0.3% for the upper Salmon River trap. Our results for fish marked near the head of tide indicate that individuals remain in the estuary for days to months and utilize the marshes and tidal channels extensively. However, we saw no obvious trend in duration of estuarine rearing based on the time of outmigration from the upper river (Figure 4).

Otolith Analyses

In 2000 we initiated pilot studies at the 96 and reference marshes to assess whether otolith microchemical techniques could be used effectively to assess variations in life history among juvenile salmon in estuarine habitats. Using microprobe analysis across otoliths of individual fish, we documented a dramatic increase in Sr/Ca values in all specimens collected from the 96 and the reference marsh sites (Figure 5). In combination with water chemistry analyses from various freshwater and estuarine habitats, we conclude that this sudden increase corresponds with the period of transition as salmon leave fresh water and enter estuarine habitats. Increment counts from the point on each otolith corresponding to emergence of fry and/or yolk sac absorption indicated that total age of marsh-captured fish was not widely variable. However, similar counts from the obvious strontium spike corresponding to estuarine entry showed that residence periods in the marshes varied by more than two-fold among individuals.

Preliminary determinations of relative growth rates based on mean otolith increment width indicated that "average" growth was very similar among all specimens from the control and the 96 marshes. However, results also showed significantly lower freshwater growth for specimens collected in the 96 marsh than those from the control marsh. At present, we have no clear explanation for these growth differences.

Implications and Plans for Phase II Studies

From the feasibility studies completed in 2000, we conclude that our proposed marking and recapture methods can be used to monitor salmonid residence times and growth in the estuary and in the restored marshes. However, estuarine recovery rates are relatively low and will need to be increased to better interpret estuarine migration patterns and residence times in the estuary. Moreover, understanding of the effects of marsh restoration would be greatly improved if marking and recapture efforts were expanded sufficiently to estimate the relative proportions of downstream migrants that use restored marsh habitats. This will require an expanded marking and recapture effort to represent the entire spring migration of juveniles into the estuary and to account for any added contribution of fish to the estuary from one or more lowland tributaries downstream of the lower Salmon River smolt trap.

Accordingly, two major subobjectives of our continuing (Phase II) research are: (1) improve recapture rates in the estuary and estimate the proportion of chinook migrants that utilize marsh habitats, and (2) evaluate whether juvenile chinook from lowland estuarine tributaries exhibit patterns of estuarine rearing and habitat use similar to those of fish sampled at the established trap locations upriver. To meet these objectives, we will expand our preliminary trapping and marking effort at the lower Salmon River and Bear Creek traps from 4 to 7 days per week. The additional marking activity at the lower Salmon River trap, which is located near the head of tide, is particularly important because it provides a marker for the time of estuary entry of all upriver subpopulations. The additional person needed to expand sampling at the lower Salmon River trap to seven days per week can also be used to expand sampling at Bear Creek, which is located just a few miles upstream. However, we do not propose to increase our sampling effort at the upper Salmon River site because this would require additional manpower, and we do not expect that estuarine recoveries of marked fish would increase substantially due to the low trap efficiencies at this site.

We also will establish a new sampling site to document outmigration timing and to mark additional fish leaving Salmon Creek, a tributary stream that was formerly connected to the 1996 marsh restoration site until Highway 101 was constructed in the early 1960s. Because Salmon Creek enters the estuary below our lowermost trap site, chinook from this tributary were not represented in the population of marked fish we recaptured in the estuary in 2000. We will establish a regular seining program at Salmon Creek to monitor abundance patterns and timing of peak migrations and to uniquely mark a representative sample of fish for recapture in the estuary. This additional sampling will also help us to interpret whether or not dike removal at the 1996 marsh directly benefits Salmon Creek outmigrants that can no longer access the marsh directly from their upstream spawning and rearing areas due to the rerouting of the creek during highway construction.

Our 2000 studies demonstrated that Sr/Ca levels in otoliths provide a valid marker for identifying the time of salmon entry into the estuary that can be used to assess differences in juvenile life history among individuals collected from various estuarine habitats. Another objective of Phase II studies will be to increase the spatial resolution of the chemical analyses across each otolith, which is currently 15 µm or approximately 3-6 days of time in the growing otolith. In future analyses, we will attempt to alter beam conditions of the microprobe to allow a smaller diameter analysis spot in the region of the dramatic Sr/Ca rise to improve residence time estimates. During Phase II we will also validate the periodicity of otolith-increment formation so that we can interpret the duration of freshwater and estuarine residency of individual fish. For this validation, we will artificially mark the otoliths of experimental groups of salmon using strontium chloride prior to enclosing individuals in one or more of the Salmon River marshes for ten days or more. This will give us a dated reference point on the otolith to compare a known time interval for the enclosed fish with the enumerated increments. Growth measurements for fish enclosed in various Salmon River marshes will also provide an independent measurement of relative growth to compare with predictions from our bioenergetic model. Preliminary marsh enclosure experiments in 2000 indicated that a ten-day enclosure period of juvenile chinook should be effective for determining the frequency of increment formation and individual growth rates based on enumeration of increments after marking otoliths with strontium chloride.

During Phase II studies, we will also conduct trial analyses of chinook salmon otoliths using a more sensitive chemical technique—Inductively Coupled Plasma Mass Spectrometry (ICPMS). This will provide a second analytical method to compare with results from the microprobe technique. Longer-term objectives of the ICPMS method are to evaluate whether less-dramatic strontium gradients within the estuary can be detected and a larger suite of elements in the otoliths can be used to distinguish specific chemical signatures among different stream, marsh, and estuarine habitats.

References

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Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: An unappreciated function. Pages 343-364 *In* V.S. Kennedy, editor. Estuarine Comparisons. Academic Press, New York.

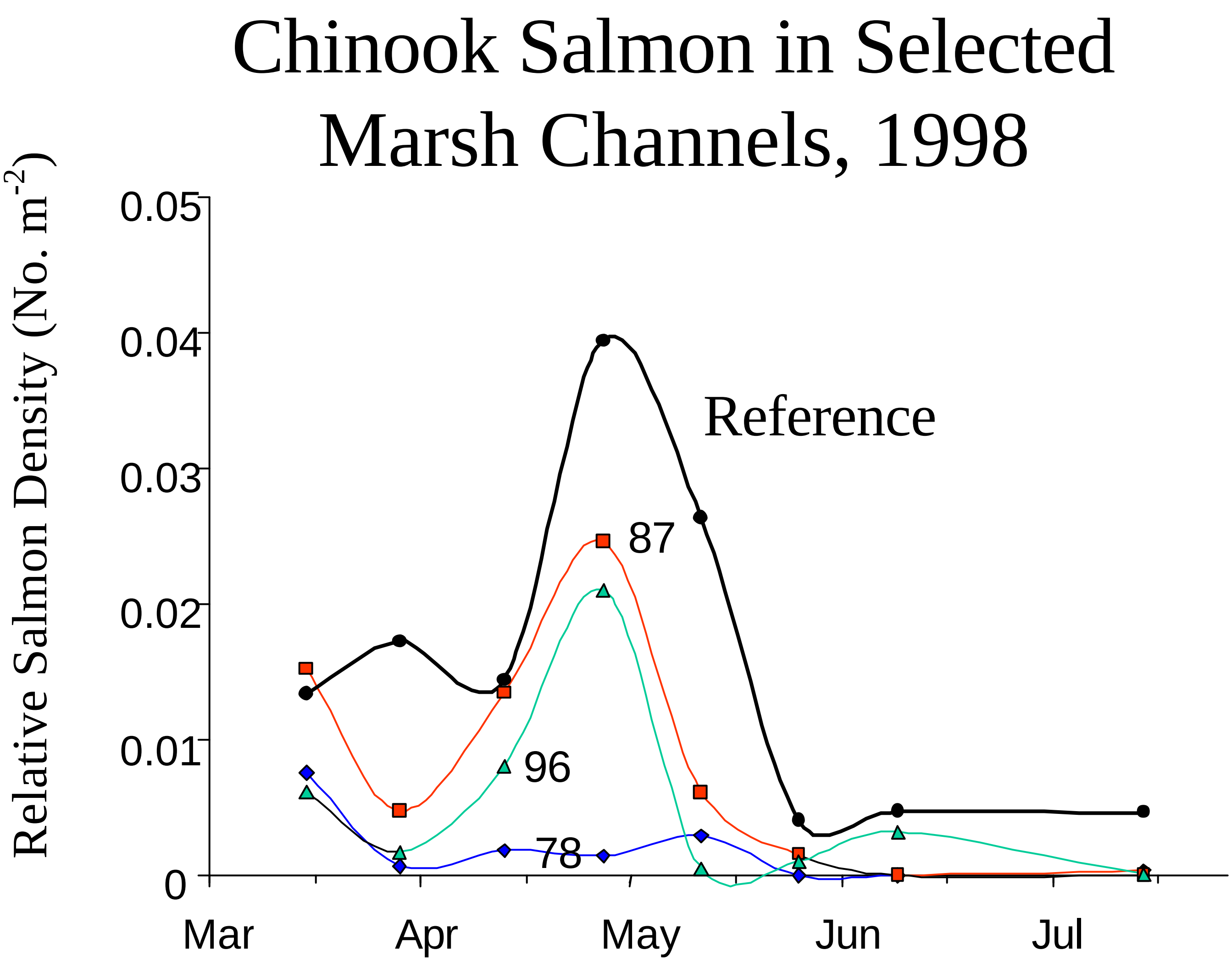

Figure 1. Relative densities (unadjusted for trap efficiencies) of chinook salmon in reference and restored marshes of Salmon River estuary during 1998. Marshes are designated by year of restoration: 1978 (78), 1987 (87), and 1996 (96).

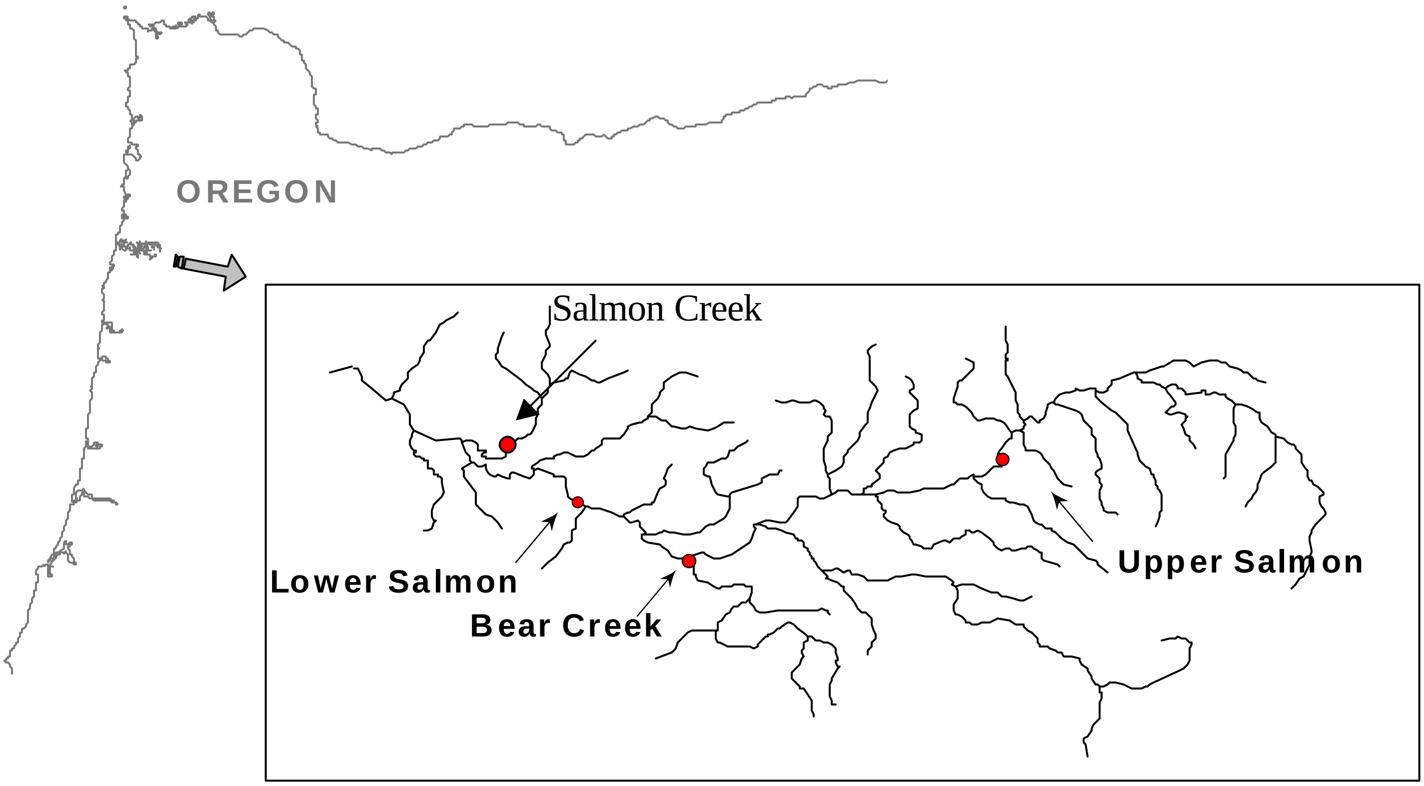

Figure 2. Trap locations in the Salmon River watershed for collecting and marking salmon, including a beach seining site in Salmon Creek, a tidal tributary located downstream of our lower Salmon River trap site.

Salmon River Trap Catch

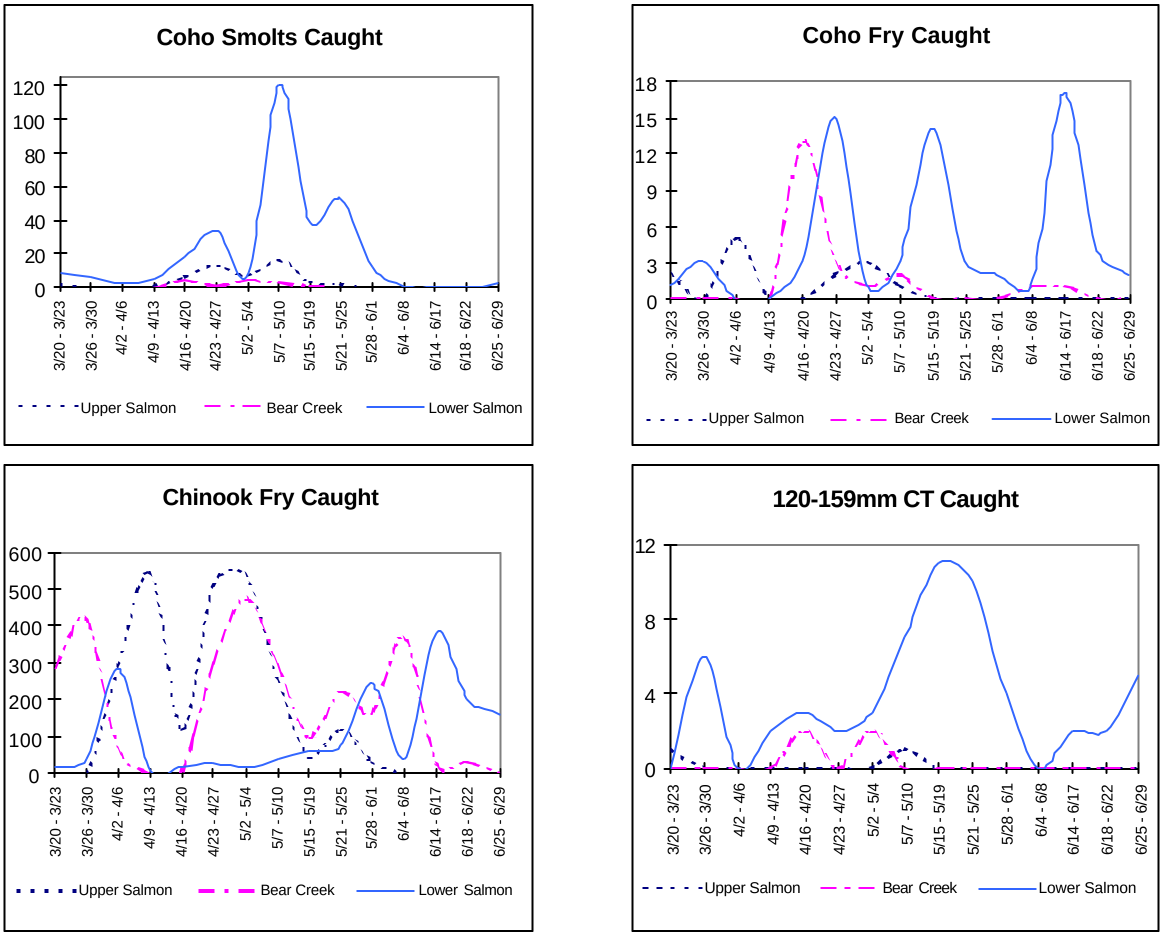

Figure 3. Trends in abundance of outmigrating chinook salmon fry, coho salmon fry and smolts, and 120 to 159 mm cutthroat trout (CT) at the Upper Salmon, Bear Creek, and Lower Salmon trap sites in 2000.

Juvenile Chinook Salmon Mark/recapture Intervals

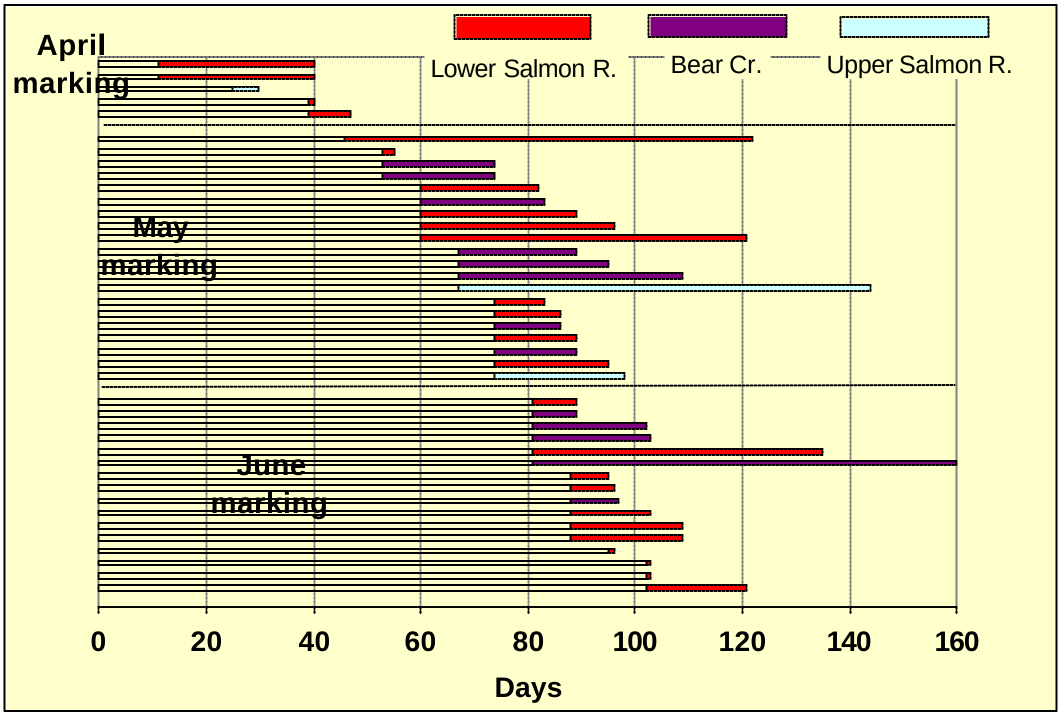

Figure 4. Time intervals between marking of chinook salmon fry at each of three trap sites upriver and their recapture date in the Salmon River estuary. Day 0 (the first day of marking upriver) is March 20. Because the lower Salmon River trap is located just above the head of tide, results for fish marked at this site represent duration of residence in the estuary at the time of recapture.

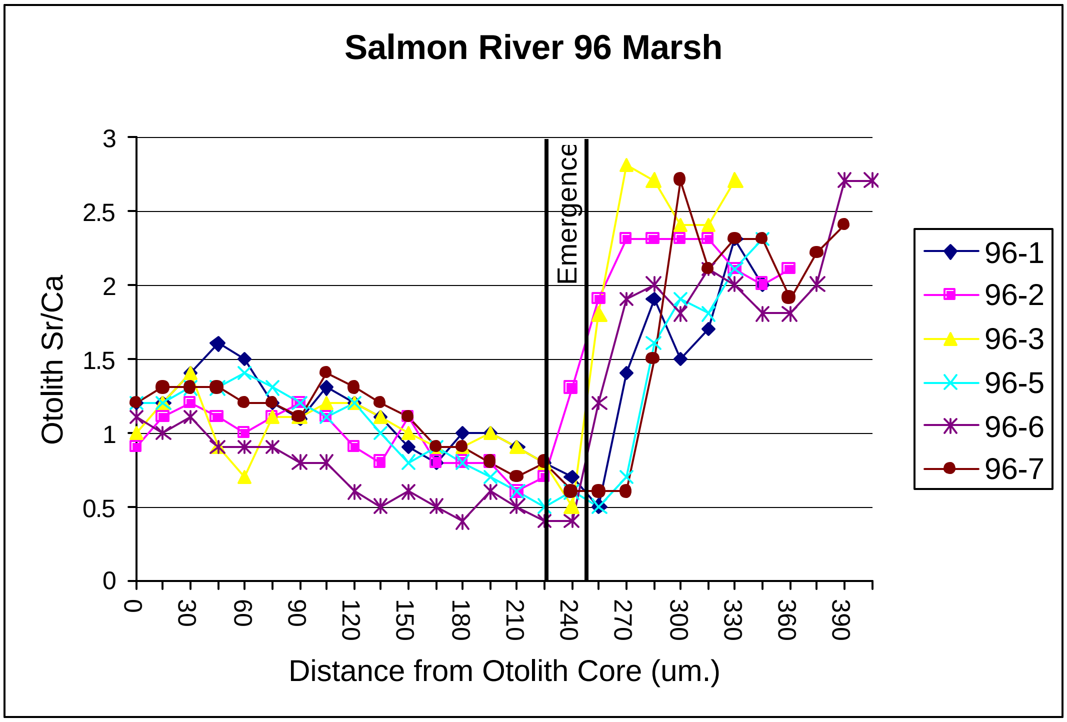

Figure 5. Sr/Ca ratios from microprobe analysis transects across the otoliths of chinook salmon from the reference (control) marsh and most recently restored (96) marsh of Salmon River estuary, June 2000. Analyses were begun at the otolith core and progressed to the mid-dorsal edge of the otoliths at 15um. intervals. Sr/Ca ratios of most fish captured show a dramatic increase in Sr/Ca values to very high levels at or beyond the time of emergence, corresponding to saltwater entry.

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Publications, Presentation, and Outreach

Kim Jones
Oregon Department of Fish and Wildlife
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Publications:

Bottom, D. L., C. A. Simenstad, A. M. Baptista, D. A. Jay, J. Burke, K. K. Jones, E. Casillas, and M. H. Schiewe. In Review. Salmon at River's End: The role of the estuary in the decline and recovery of Columbia River salmon. U. S. National Marine Fisheries Service, Seattle. [Although this concerns the Columbia River estuary, the conceptual foundation for this work applies ideas and results developed in part from the Salmon River Study]

Gray, A.., C.A. Simenstad, D.L. Bottom, and T. Cornwell. In Press. Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River Estuary, Oregon, USA. Restoration Ecology.

Bottom, D.L. and C.A. Simenstad. 2001. Bottlenecks, Barges, and Super Fish: Rethinking Conservation of Estuaries and Salmon. Pages_87-95*In* Oregon Salmon: Essays on the State of the Fish at the Turn of the Millennium. Oregon Trout, Portland, Oregon.

Cornwell, T. J., Bottom, D. L., and K. K. Jones. 2001. Rearing of juvenile salmon in recovering wetlands of the Salmon River estuary. Oregon Department of Fish and Wildlife. Information Reports 2001-05, Portland.

Simenstad, C.A., W.G. Hood, R.M. Thom, D. A. Levy, and D.L. Bottom. 2000. Landscape structure and scale constraints on restoring estuarine wetlands for Pacific coast juvenile fishes. Pages 597-630 *In* M.P. Weinstein and D. A. Kreeger, editors. Concepts and Controversies in Tidal Marsh Ecology, Kluwer Academic Publications, Dordrecht. 864 p.

Presentations:

Bottom, D.L., T. Cornwell, B. Thom, and S. Van de Wetering. "Restoring Salt Marshes in Oregon Estuaries: If We Rebuild Them, Will Salmon Come?" 1998 Annual Meeting, Oregon Chapter American Fisheries Society.

C. Simenstad, D. Bottom, A. Gray, and T. Cornwell. "(Re)Build It and They Will Come? Juvenile Salmon Rearing in Restoring Tidal Marshes of the Salmon River Estuary, Oregon." Invited Presentation, 1999 Annual Meeting, Cal Neva Chapter, American Fisheries Society.

C. Simenstad, A. Gray, and R. Wissmar. "Development of Juvenile Salmon Habitat in the Recovering Wetlands of the Salmon River Estuary." Sept. 1999, Annual Meeting, Estuarine Research Federation.

D. Bottom and C. Simenstad, co-convenors. "The Role of Estuarine Wetlands to Salmon Recovery." Technical panel for PNW Chapter Annual Meeting, Society of Wetland Scientists, May 1999.

D. Bottom, T. Cornwell, P. Jacobsen, and K. Jones. "Use of Restored Estuarine Marshes by Juvenile Chinook and Coho Salmon in the Salmon River Estuary." 2000 Annual Meeting, Oregon Chapter American Fisheries Society.

C. Simenstad, A. Gray, and D. Bottom. "Capacity, Opportunity, and Realized Function of Restoring Marshes to Support Juvenile Salmon in the Salmon River Estuary, Oregon." 2000 Annual Meeting, Oregon Chapter American Fisheries Society.

D. Bottom. "Bottlenecks, Barges, and Super Fish: Rethinking Conservation of Estuaries and Salmon." Invited speaker, seminar series, May 2000, Oregon State University, Hatfield Marine Science Center, Newport, OR .

T. Cornwell, K. K. Jones, D. L. Bottom, A. Gray, and C. A. Simenstad. 2001. The Salmon River estuary study: lessons in restoring wetlands for the sake of salmon. Poster presented at the 2001 Annual Meeting, Oregon Chapter American Fisheries Society.

Outreach:

* A three-part series run each of three consecutive weeks highlighting research at Salmon River estuary on ABCNEWS.com:

- Laura Carsten. July 9, 2001. Salmon like it wet and briny: Scientists wading in to understand why salmon need estuaries (A Salmon River Journal Part I)

http://abcnews.go.com/sections/scitech/DailyNews/salmon_series010709.html

- Laura Carsten. July 16, 2001. Salmon tracking: Monitoring tiny salmon in muddy waters requires a few tricks. (A Salmon River Journal Part II)

http://abcnews.go.com/sections/scitech/DailyNews/salmon_series010716.html

- Laura Carsten. July 23, 2001. Nature takes over: for salmon, a little recovery goes a long way. (A Salmon River Journal Part III).

http://abcnews.go.com/sections/scitech/DailyNews/salmon_series010723.html

* Convenors of a “Sea Grant Juvenile Salmon Estuarine Habitat Restoration Workshop,” February 7-9, 2001 at Oregon Institute of Marine Biology, Charleston, Oregon. Workshop brought together 50 scientists, agency representatives, and restoration practitioners to discuss the status of information about the estuarine ecology of juvenile Pacific salmon and the restoration of habitat for salmon. Workshop co-sponsored by California, Oregon, and Washington Sea Grant programs with additional support by the South Slough National Estuarine Research Reserve. A proceedings of the workshop is in progress.

* Annual meetings with local landowners, Cascade Head Ranch homeowners, resource agencies, and Sitka Center for Art and Ecology to describe sampling results and next year's sampling plans

* Summary of project results in Oregon Sea Grant Restoration newsletter, Spring 1998: "Restoring Salt Marshes in Oregon Estuaries: If we Rebuild Them, Will Salmon Come?"

* Sea Grant Communications video of Salmon River project.

* Co-participant (D. Bottom) in field course on the "Ecology of the Salmon River estuary and the Cascade Head Forest" for the general public through the Sitka Center for Art and Ecology, Otis, Oregon, July 22-23, 2000.