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**GROWTH OF JUVENILE COHO SALMON IN
NATURAL AND CREATED ESTUARINE HABITATS: A
COMPARATIVE STUDY USING OTOLITH
MICROSTRUCTURE ANALYSIS**

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KEY WORDS

comparative study, created estuarine slough, reference site, growth and foraging, juvenile salmon, otolith microstructure analysis.

INTRODUCTION

The continual loss of fish habitat due to development, pollution, and other human activities has been identified as one of the largest long-term threats to the future viability of marine fisheries in the United States (Thayer 1992). In order to counter those losses, the number of compensatory mitigation projects has increased dramatically over the past decade (Kentula 1986, Zedler 1988, Rylko and Storm 1991). Compensatory mitigation is the creation, restoration, or enhancement of resources and habitats in order to compensate for the loss or destruction of those same or other fish and wildlife resources and habitats (Blomberg 1987).

Compensatory mitigation projects, as well as many restoration projects, often attempt to provide wetland habitat for certain commercially important fish and wildlife species. Estuarine wetlands in the Pacific Northwest are known to provide valuable rearing habitat that enhances subsequent ocean survival of migrating juvenile salmon (*Oncorhynchus* spp.) (Reimers 1973, Healey 1982, Levy and Northcote 1982, Simenstad et al. 1982, Simenstad and Wissmar 1983, MacDonald et al. 1988, Levings et al. 1989, Solazzi et al. 1991). The extensive foraging opportunities, optimal growth, refuge from predation, and an opportunity for salinity acclimation in estuarine wetlands are factors attributed to enhanced smolt survival (Reimers 1973, Healey 1982, Simenstad et al. 1982).

Estuarine wetland mitigation in the Pacific Northwest is often designed to construct rearing habitat for juvenile salmon. However, current reviews of existing mitigation studies indicate that a general lack of adequate planning, long-term ecological monitoring, documentation of scientific results, and policy enforcement often inhibits thorough evaluation of such projects (Zedler 1988, Rylko and Storm 1991). Furthermore, the use of natural sites in the vicinity of a mitigation project as reference sites for project design and monitoring criteria has rarely been a component of mitigation plans. Without such information, it is difficult to quantitatively evaluate the ecological functions of a mitigation site.

Even with information from a valid reference site, simple documentation of juvenile salmon presence/absence or abundance/standing stock does not necessarily constitute assessment of the habitat's function in supporting fish growth and survival; most juveniles are highly motile and may only be occupying the habitat for a brief time during their migration through the estuary. Only through detailed evaluation of specific habitat functions (i.e., juvenile salmon growth, diet composition, or residence times) can a habitat's potential to provide biotic support be evaluated. A variety of habitat attributes, such as slough length and width and average water temperature and salinity, can provide general comparative information but offer no direct information on the biota associated with that habitat. Therefore, the overall objective of this study was to determine if juvenile salmon exhibit similar patterns of short-term growth, as inferred from otolith microstructure, in created and natural habitats. Information on individual fish growth can provide a framework for assessing the capacity of a created slough to provide rearing habitat for juvenile salmon.

The creation of an estuarine slough on the Chehalis River, Grays Harbor, Washington (Fig. 1), provided an opportunity to test the function of a compensatory mitigation site to provide

juvenile salmon rearing habitat. A natural slough, Ann's Slough, located ~500 m upstream from the mitigation site, provided the local reference site. Direct comparisons of sub-yearling coho salmon, *O. kisutch*, growth were made between the created and natural habitats.

In order to test the hypothesis that the created estuarine slough offers juvenile salmon rearing habitat not significantly different than a natural estuarine slough, we made comparisons between (1) daily growth rates of juvenile salmon interpreted from otolith microstructure analysis, (2) prey composition and stomach fullness indices of juvenile salmon, and (3) residence times of juvenile salmon in the sloughs. Such data aid in evaluating the functional performance of the created slough to provide juvenile salmon rearing habitat. The primary objective of this report is to present the methodology and results associated with using otolith microstructure analysis as a tool to compare the relative growth of juvenile salmon in natural and created estuarine habitats; therefore, only the information associated with the growth studies is presented here. For further information on the remaining studies, see Miller (1993).

BACKGROUND

Mitigation efforts that create or restore estuarine habitats to enhance rearing areas for juvenile salmon must include the evaluation of fish use of these sites. The presence or absence of a species at a site is only a vague indicator that the area is important habitat for that fish population. As growth is a primary indicator of habitat function during estuarine residence, a quantitative evaluation of daily growth can provide a more precise assessment of the efficacy of these created habitats. The use of otolith microstructure analysis of juvenile salmon residing in a created estuarine slough offers detailed information on the functional success of a mitigation.

Growth rates of juvenile Pacific salmon in estuaries and coastal waters have been determined for a number of species in various areas (Reimers 1973, Healey 1980, Neilson et al. 1985, Tschaplinski 1987, Shreffler et al. 1990). Growth rates vary among species and estuaries. Growth rates for chinook juveniles range between 0.27–3.00 mm day⁻¹ while coho rates range between 0.11–0.13 mm day⁻¹. Because sub-yearling chinook salmon, *O. tshawytscha*, show the most extensive temporal use of estuaries, they are the principal source of growth information (Reimers 1973, Healey 1980, Neilson et al. 1985, Levings et al. 1986, Shreffler et al. 1990) (Table 1).

Mean change over time in individual fish size in a population has commonly been used to estimate estuarine growth rates. Less common has been the determination of instantaneous growth rates of marked fish that are not vulnerable to the effects of emigration and immigration and can provide more detailed information such as variability estimates (Healey 1980; Levy and Northcote 1982; Tschaplinski 1982, 1987; Ryall and Levings 1987; Shreffler et al. 1990). The relationship between daily otolith increment deposition and daily somatic growth can also offer detailed information on fishes' short-term response to feeding conditions or other factors affecting bioenergetics (e.g., temperature)

Since Pannella (1971) discovered the daily deposition of increments within the microstructure of teleost otoliths, a relationship between otolith growth and somatic growth has been shown in various species of salmon (Wilson and Larkin 1980, 1982; Campana 1983; Neilson and Geen 1982, 1985; Volk et al. 1984; Neilson et al. 1985; Bradford and Geen 1987, 1992). Otoliths function as sensory devices to aid fish equilibrium and are known to form daily, bipartite rings of calcium carbonate and protein (Campana and Neilson 1985). Although otoliths are often used to determine age more precisely than previous methods, their accuracy in determining daily growth rates of younger fishes is still being examined (Marshall and Parker 1982, Wilson and Larkin 1982, Volk et al. 1984, Campana 1990, Maillet and Checkley 1990, Hales and Hurley 1991, Bradford and Geen 1992). The deposition of these materials is believed to be regulated by circadian rhythm and therefore produces a diel marker (Campana and Neilson 1985, Gauldie 1990, Gauldie and Nelson 1990). However, the diel periodicity of otolith increment formation in salmon can be altered by periods of stress, such as an abrupt change in temperature. Such a stress alters calcium deposition and results in a discontinuous zone within the otolith that can be used as a time reference marker (Brothers 1990, Volk et al. 1990, Campana 1992).

Several studies have found otolith growth in juvenile salmon to be positively correlated with somatic growth (Marshall and Parker 1982, Wilson and Larkin 1982, Volk et al. 1984, Neilson et al. 1985). However, studies using other fish species in which continuous otolith growth was observed during periods of reduced somatic growth, starvation, or severe changes in ambient temperatures suggest that an uncoupling, or separation, can occur between otolith and somatic growth (Bradford and Geen 1987, 1992; Mosegaard et al. 1988; Secor et al. 1989). While increment deposition may be affected by factors influencing metabolic processes, such as ambient temperature or oxygen consumption, rather than being directly linked with somatic growth, the greatest discrepancies between otolith and somatic growth often occur under extremely stressful conditions and between, not within, size-classes. The use of otolith microstructure analysis to detect relative differences in habitats is supported by Neilson et al. (1985). They examined juvenile chinook growth in the Sixes River and estuary, Oregon, and estimated growth from daily otolith increments. Although otolith increment data resulted in an underestimation of actual somatic growth, relative differences in individual growth were still apparent between years and habitats.

STUDY SITE

The sloughs used for these experiments are located at the interface between tidal oligohaline and tidal fresh waters in the Chehalis River, Washington. The Chehalis River is responsible for 80% of the total freshwater flow into Grays Harbor estuary, Washington State's second largest estuary (Figs. 1 and 2). The estuary comprises six watersheds with a total drainage area of 6,204 km² (Simenstad et al. 1982). Coho, chum (*O. keta*), chinook, and steelhead (*O. mykiss*) comprise the majority of commercially caught salmonids in the Grays Harbor coastal area, with coho

comprising 54% of the total catch between 1984 and 1989 (US Army Corps of Engineers [USACE] 1989).

As part of the Grays Harbor Navigational Improvement Plan (GHNIP), the US Army Corps of Engineers (USACE) created ~1.6 ha of intertidal and shallow subtidal habitat as compensation for the loss of ~0.73 ha of shallow subtidal channel known to be used by juvenile salmon during their ocean migration. The created estuarine slough is located ~500 m downstream from Ann's Slough, which is being used as a reference site for general monitoring procedures and experimentation (Fig. 2).

Both sloughs are located in scrub/shrub, forested wetland near the city of Cosmopolis, Washington. The surrounding overstory vegetation is dominated by Sitka spruce (*Picea sitchensis*), black cottonwood (*Populus balsamifera*), and red alder (*Alnus rubra*). Willow (*Salix* spp.), salmonberry (*Rubus spectabilis*), black twinberry (*Lonicera involucrata*), currants (*Ribes* spp.), wild roses (*Rosa* spp.), and red-osier dogwood (*Cornus stolonifera*) comprise the dominant shrub vegetation. Slough sedge, *Carex obnupta*, dominates the understory. However, water parsley (*Oenanthe sarmentosa*) and skunk cabbage (*Lysichitum americanum*) are also common (Simenstad et al. 1992).

Some structural differences exist between Ann's and the created slough. The created slough is ~366 m long, 3–4 m in depth, and averages 30–50 m in width. As constructed, the habitat design includes a shallow subtidal channel, fringing marsh, unvegetated mud flat, and a riparian buffer zone. In order to provide habitat complexity for juvenile salmon, the USACE placed tree trunks in the slough during construction and transplanted *Carex lyngbyei* into the slough during spring 1991. An intertidal area of 11,026 m² includes a moderately sloping intertidal mudflat. The subtidal channel covers ~4,554 m² and does not dewater during spring tides. Ann's Slough, the natural habitat, has a shallower, longer, and narrower channel that does dewater during spring tides. It has an intertidal area of 14,489 m², is at least 1,250 m long, and *Carex* sedge covers at least 4,546 m² (Simenstad et al. 1992).

MATERIALS AND METHODS

In order to examine short-term growth of juvenile salmon using the created and natural slough, we conducted mark-recapture experiments concurrently at each site. We induced a stress check mark on the otoliths of wild sub-yearling coho salmon via short-term depression of water temperatures. This marked the fish internally while fin-clipping provided an external mark. Experimental fish could then be re-released to each slough and maintained on site for 8–10 d. Otolith microstructure analysis was then completed on recaptured fish and compared between sites.

GROWTH STUDIES

We captured juvenile coho for otolith growth studies in either the created slough or Ann's Slough during 22–25 April 1992. Approximately 500 juveniles between 30 and 60 mm in fork

length were captured with fyke net traps designed specifically for each slough (Fig. 3). The wings of the fyke (13-mm mesh) blocked passage across the entire mouth of the slough. In order to collect and hold fish for marking, a live box with 6-mm mesh was attached to an elongated, narrow opening at the center of the fyke. Captured fish were held in rectangular, plastic totes prior to marking. Each tote held ~225 fish in 0.75 m³ of river water. The water was aerated and cooled to maintain an oxygenated environment at ambient river temperatures (12 to 15°C).

Fish were anesthetized with tricane methyl sulfonate, MS-222, before being weighed (nearest 10 mg), measured (0.1 mm), and adipose fin-clipped. A pilot study completed during spring 1991 determined a sufficient reference mark could be created within the otolith microstructure by immersing chinook juveniles, 40 to 60 mm in length, in water ~5°C lower than ambient conditions for 8 h. Therefore, coho were exposed to water 5°C cooler than ambient water. Blocks of ice were added to the totes to drop and maintain the temperature at an average of 9°C. Fish were held at this temperature for 12 h to ensure stress adequate to produce a mark on the otolith occurred.

After 12 h, fish were split into two groups of 235 and 215 fish; these groups of fish were then released into the created and Ann's sloughs, respectively. Twenty fish were held in tethered live boxes in each of the sloughs throughout the experiment to assess long-term marking mortality. Marking mortalities of 3% occurred because of an aeration problem, and one fish was lost during the post-marking recovery phase.

The fyke nets were modified to prevent experimental fish from exiting the sloughs by removing live boxes and sewing shut the funnel in the centerpiece of the fyke. The nets were placed at the mouth of each slough, and fish were released at the beginning of a neap tidal cycle with a range of low tides between -0.03 and 3.6 ft to ensure a low tide refuge during the experimental period. Water temperature and salinity measurements were recorded daily throughout the experiment.

Attempts to recapture experimental fish began on 2 May 1992 when the spring tidal series produced a low tide of -1.0 feet. Live boxes were replaced and checked every 2 h. Captured fish were anesthetized, weighed, and measured before being preserved in 95% ethanol.

LABORATORY OTOLITH PREPARATION

In the laboratory, the recovered fish were measured (nearest 0.5 mm), weighed (10 mg), and the otoliths were removed by dissection. Both sagittae were removed, excess tissue rinsed off in 95% ethanol, and fixed in circular plastic molds with clear casting resin. Only left otoliths were used for increment analysis because they have been found to be larger than right otoliths (Neilson and Geen 1981). When left otoliths were cracked or damaged, right otoliths were included in analyses except in the generation of the overall otolith length and fish length regression. The otoliths were set with the sulcus acusticus, a depression on the proximal surface, facing the bottom of the mold in a method similar to Neilson and Geen (1982). The samples were then secured to a microscope slide with a thin layer of wax to facilitate later removal. The otoliths were ground and polished on a Struer's Pedemat grinder using a 1200 grit sandpaper followed by an alumina micro-

polish with grit sizes ranging from 0.3-1.0 μm . Final polishing with a silicate polish completed the preparation of the distal side of the otolith. Because otolith specimens were to be examined using transmitted light microscopy, grinding of both sides of the otolith was necessary. After initial grinding, samples were removed from the slides and re-affixed with Duro® Superglue with the sulcus side facing upwards. A similar grinding and polishing method was then completed on the proximal side of the otolith to improve specimen quality.

Otolith microstructure was delineated using Optimas® imaging analysis software and a magnified image of the otolith from an Olympus light microscope displayed on a 14-in color monitor. The microscope was outfitted with either a 2.5X or a 6.7X photo eyepiece to achieve the necessary magnification. Otoliths were examined at magnification levels between 10 and 750X. Readings at all magnifications were calibrated to millimeters with the Optimas® imaging system. Total otolith length (mm) and increment number and widths (μm) were recorded. All length measurements were taken along the long axis of the otolith (Fig. 4). The axis for increment measurements, as described by Bradford and Geen (1987), was 90° from the long axis of the otolith. Occasionally, measurements had to be extended beyond the 90° radius to reach the clearest region of the otolith edge. All measurements remained within an 80° to 90° angle from the long axis (Figs. 4 and 5). Three independent measurements were averaged. Standard deviations were small, usually <1% of the average measurement.

Daily otolith growth was determined for each experimental fish by plotting individual daily increment widths against experimental days (Neilson and Geen 1982, Wilson and Larkin 1982, Bradford and Geen 1987, Francis 1990). Slopes of daily otolith growth were then compared between sloughs with a Mann-Whitney nonparametric comparison test (Zar 1984).

A significant linear relationship between fish fork length and otolith length was established to provide a basis for daily growth analysis (Neilson and Geen 1982, Francis 1990, Bradford and Geen 1992) (Fig. 6). Log transformations of fish length were necessary to normalize the data and stabilize the variance (Zar 1984). The relationship between otolith length and fish length was significant ($p < 0.001$) but weak ($r^2 = 0.40$), probably because the number of recaptured fish with readable otoliths was small ($n = 38$) and the range of individual lengths narrow (42 to 50 mm). Therefore, the regression analysis was expanded to include yearling smolts from the Chehalis River captured in 1992 and University of Washington hatchery coho sub-yearlings from the 1993 brood stock (Fig. 7). A regression model with a log transformation of fish weight for the expanded data set also generated a significant ($p = 0.0001$) linear relationship with otolith length (Fig. 8).

Although linear regression equations that include fish from separate cohorts can bias back-calculated lengths of individuals (Campana 1990), estimated lengths for experimental fish were closer to actual lengths using the expanded model. An average error of $0.15 \pm 5.6\%$ in back-calculated lengths was observed. As total otolith length was assumed proportional to body length and the fish length to otolith length relationship was log-linear, the following regression equation was used in the back-calculation method (Francis 1990).

$$L_f = 0.945(L_o) - 1.372 \quad (1)$$

where L_f = log fish length (mm)
 L_o = otolith length (mm).

Average population growth rates were also estimated for juvenile chinook and coho from fyke net catch data (Healey 1980, Miller 1993). Fish fork lengths (0.5 mm) and weights (0.1 g) were measured throughout monthly sampling from spring 1990 through 1992 (Simenstad et al. 1992, 1993). Average monthly changes in population length and weight data were then compared over time. Although these estimates had some bias because immigration and emigration of individuals through the slough habitats were not considered, they offered an average increase over time for the population rearing in the sloughs.

RESULTS

Cracked or damaged otoliths excluded 11% of the fish while vaterite depositions (irregular formations of calcium carbonate) excluded 15% of the experimental fish from analysis. Therefore, the otolith sample size was 38 fish: 26 from Ann's Slough and 12 from the created slough. The average number of increments observed after the stress-induced check on individual otoliths validated daily increment deposition. The 27 fish captured after 7 d had an average of 7.3 ± 1.8 increments. The four and seven fish captured after 8 and 9 d, averaged 9.0 ± 1.2 and 8.9 ± 1.7 increments, respectively. In all cases, the number of increments were not significantly different than the number of experimental days (paired t-tests, day 7, 8, and 9, $p = 0.448, 0.18, 0.83$, respectively).

The individual otolith growth trajectories for juvenile coho were not significantly different between sloughs (Mann-Whitney nonparametric comparison test, $p = 0.101$; Fig. 9). Therefore, results for all 38 experimental fish were pooled to estimate an average daily growth rate. An average otolith growth rate of $2 \mu\text{m d}^{-1}$ translated to an average somatic growth rate of 0.11 mm or 0.01 g d^{-1} (Eq. 1).

Water temperatures and dissolved oxygen levels were similar throughout the water column in both sloughs, but salinities varied at bottom depths. Average daily temperatures during growth experiments ranged between 12 and 14°C in both sloughs (Fig. 10). Although upper water column salinities were similar in the sloughs, bottom salinities remained below 5‰ in Ann's Slough and reached 9‰ in the created slough (Fig. 11). Previous profiles of dissolved oxygen concentration also demonstrate a similar pattern in both sloughs with no values dropping below 7 mg L^{-1} (Fig. 12) (Simenstad et al. 1992, 1993).

DISCUSSION

Information on the functional response of fish and wildlife is critically important in evaluating the effectiveness of habitat mitigation. This study evaluated rearing habitat in a created estuarine slough by examining daily growth of migrating coho salmon. Growth rates of coho sub-yearlings

in both the created and natural slough were not found to be significantly different within the power of these tests. Although past studies have documented the presence and growth of juvenile salmon in restored wetlands, no natural areas were used for reference (Levy and Northcote 1982, Shreffler et al. 1990). However, the high level of natural variability in salmon usage of estuaries necessitates the use of local reference sites for adequate project evaluation.

The lack of a detectable difference in daily growth between the two sloughs could be due to various factors: (1) no significant difference occurred in the daily growth of coho sub-yearlings in the two sloughs, (2) experiment duration was insufficient to detect such differences in the otolith microstructure, (3) somatic growth and otolith growth are uncoupled, or (4) an inadequate number of fish were recaptured. Replication of the experiment with larger numbers of marked fish would address some of these concerns. However, with regard to the length of the experiment, a longer experimental period could have created a confounding situation. Most juvenile salmon emigrate from an individual slough after a relatively short time period, ~24–48 h (Shreffler et al. 1990, Miller 1993). Although some individuals may re-enter a different tidal slough on later flood tides (Levy and Northcote 1982), restricting fish longer than 7–10 d may have generated an unrealistic environment.

The question of an uncoupling between otolith growth and somatic growth is more difficult to address. Tschapinski (1987) determined mean instantaneous growth rates of coho sub-yearlings in the Carnation Creek river and estuary in British Columbia. In 1979 and 1980, daily growth rates of $0.13 \text{ mm} \pm 0.03 \text{ d}^{-1}$ and $0.12 \pm 0.01 \text{ mm d}^{-1}$, respectively, were determined for estuary-rearing juvenile coho. The similarity between Tschapinski's results (1987; Table 1) and the otolith-determined growth rates from this study suggests that a notable separation between somatic and otolith growth did not occur in this experiment. Most observations of significant separations in growth rates occurred during extremes in temperature or ration in laboratory settings (Mosegaard et al. 1988, Molony and Choat 1990, Bradford and Geen 1992). In this experiment, fish were re-released to the same environment from which they were captured with similar environmental characteristics (i.e., water temperature, dissolved oxygen concentration, surface and water column salinity) and allowed to move freely within each slough. Therefore, we do not consider differential uncoupling between somatic and otolith growth to be a primary factor.

Studies have indicated short-term, 2–20 d, variation in growth detectable within the otolith microstructure, especially with younger fishes (Neilson et al. 1985, Maillet and Checkley 1990, Molony and Choat 1990). Although Bradford and Geen (1992) determined that otolith growth underestimated actual somatic growth of fish fed a reduced ration, significant trends in otolith growth were still apparent. The authors suggested that a prolonged (>30 d) reduction may be necessary to precisely detect differences in somatic growth through otolith analysis. Such evidence suggests that, in experimental situations where similar abiotic parameters occur at all sites, relative differences in growth should be detectable. Although fish size, metabolic rate, temperature, and growth rate all appear to influence otolith deposition, the relative importance of each is unknown and may be species-specific.

An important finding in related research was that sub-yearling coho and chinook foraged on similar prey items in the two sloughs (Miller 1993). However, some differences in the level of importance of those prey were detected between habitats. Indices of stomach fullness were also determined throughout spring 1991 and 1992. The range of fullness indices was similar between habitats, indicating salmon in both areas were actively foraging. Fullness indices were significantly higher in the natural slough in both years. Apparently, any resultant decline in somatic growth as a result of reduced consumption in the created habitat during the 1992 experiments was either insignificant or not detected with otolith microstructure analysis. Additionally, several fish predators known to forage on juvenile salmonids, including northern squawfish (*Ptychocheilus oregonensis*), yearling coho, and steelhead, were found in the sloughs during both 1991 and 1992. Significantly greater densities per unit area of these predators were collected from the created slough than the natural habitat in both years (Miller 1993). Any effect of predator avoidance on diet and consumption rate was also not reflected in otolith microstructure.

SUMMARY AND RECOMMENDATIONS

In summary, the results of this study suggest the created slough is providing juvenile salmon rearing habitat with short-term (7-d) growth potential comparable with Ann's Slough, a natural reference site. Daily growth rates determined through otolith analysis show similar patterns within both sloughs. Related research found juvenile salmon consuming similar prey items in both sloughs, although significantly higher stomach fullness indices were observed in the natural habitat (Miller 1993). These data offer the first comparative analysis of juvenile salmon foraging and growth in both a natural and created estuarine habitat.

The use of otolith microstructure analysis can potentially provide a rigorous, quantitative indicator of the quality of juvenile fish rearing habitat in created or restored wetlands. Patterns of daily otolith increment deposition can serve as surrogates of fish growth when primary abiotic parameters (i.e., temperature, salinity, dissolved oxygen, etc.) are similar in the habitats under consideration. Although numerous studies have examined the variability observed in otolith increment deposition, few studies have explored the processes regulating that deposition. Therefore, the relationship between otolith and somatic growth needs to be clarified prior to widespread application of the otolith technique for assessing habitat restorations or creations. Otherwise, the validity of further field studies exploring daily growth may be compromised by the lack of understanding regarding the processes regulating daily otolith increment formation in juvenile fishes. Accordingly, we recommend laboratory experiments to (1) determine the robustness and precision of any relationships between daily ration, otolith growth and somatic growth; and (2) evaluate the effect of temperature, salinity, fish size, and prey type (taxa, size) on these relationships.

Related research on various parameters of both the created and natural habitat (i.e., fish and invertebrate assemblages, sedimentation rates, and water quality analyses; Simenstad et al. 1992, 1993), in conjunction with the present study, provides an extensive functional assessment of the created habitat. Such information is integral in understanding and evaluating the development of

created estuarine wetlands. However, the continuation of such research and monitoring is necessary to obtain temporal data on the structural development of the slough and changes in species assemblages. Without such information, the contribution of created systems to ecosystem function will be impossible to evaluate. We suggest the following additional research to provide more information on the role estuarine sloughs play in the supporting migrating juvenile salmon:

- explore further the use of otolith microstructure analysis and chemical composition to determine juvenile salmon migration patterns as well as general and site-specific estuarine residence times;
- examine the effects of potential predators, i.e., northern squawfish (*Ptychocheilus oregonensis*), yearling coho, steelhead, present in the created slough on juvenile salmon residing in sloughs.
- investigate the role of vegetation and large organic debris (LOD) in estuaries as microhabitat for juvenile fishes; and
- document the temporal co-development of vegetative and invertebrate communities within the natural and created sloughs as an indication of the role vegetative structure has in structuring invertebrate communities.

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FIGURES

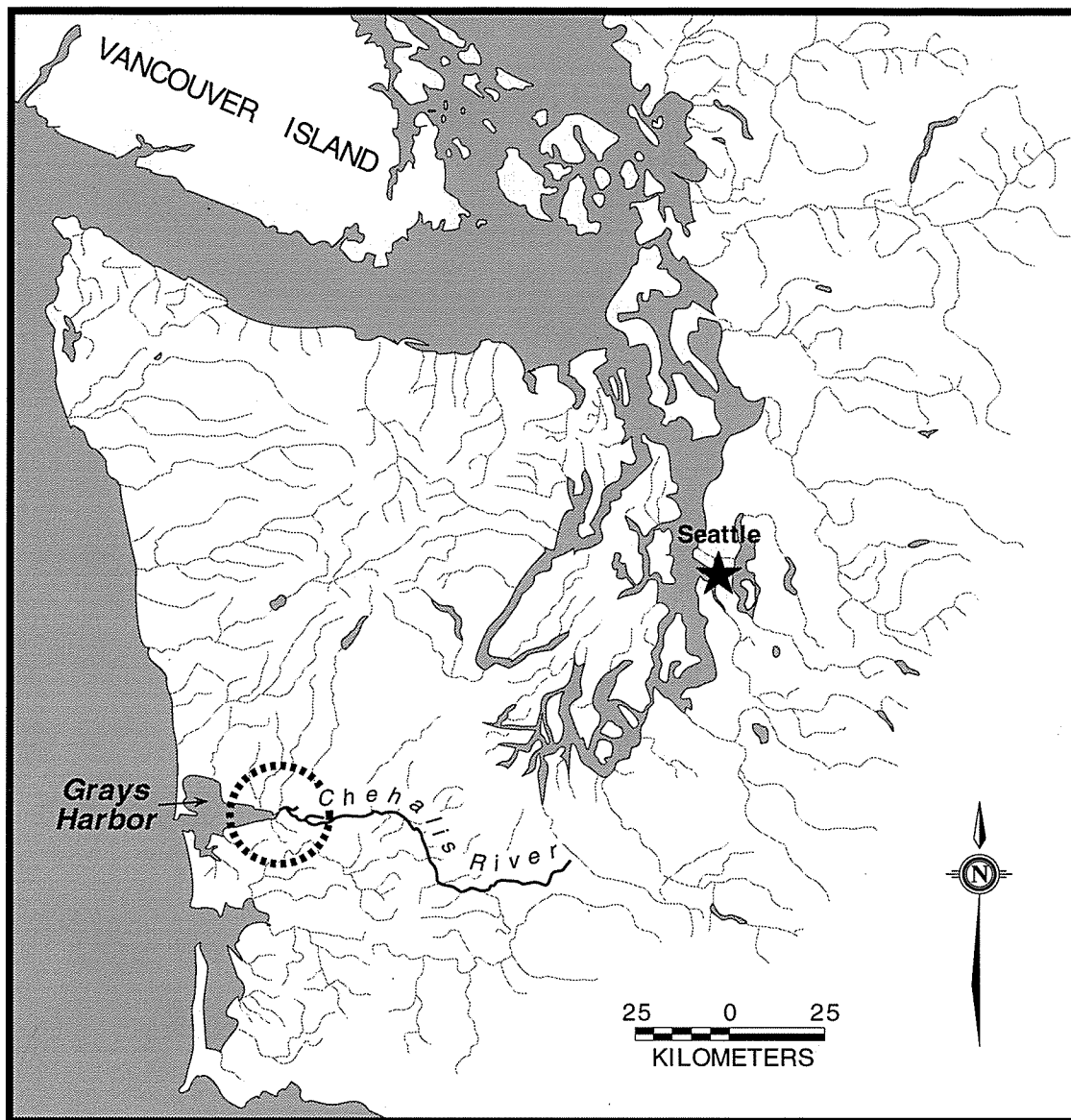


Figure 1. General location of studies evaluating juvenile salmon habitat in created and natural sloughs in the Chehalis River estuary, Grays Harbor, Washington.

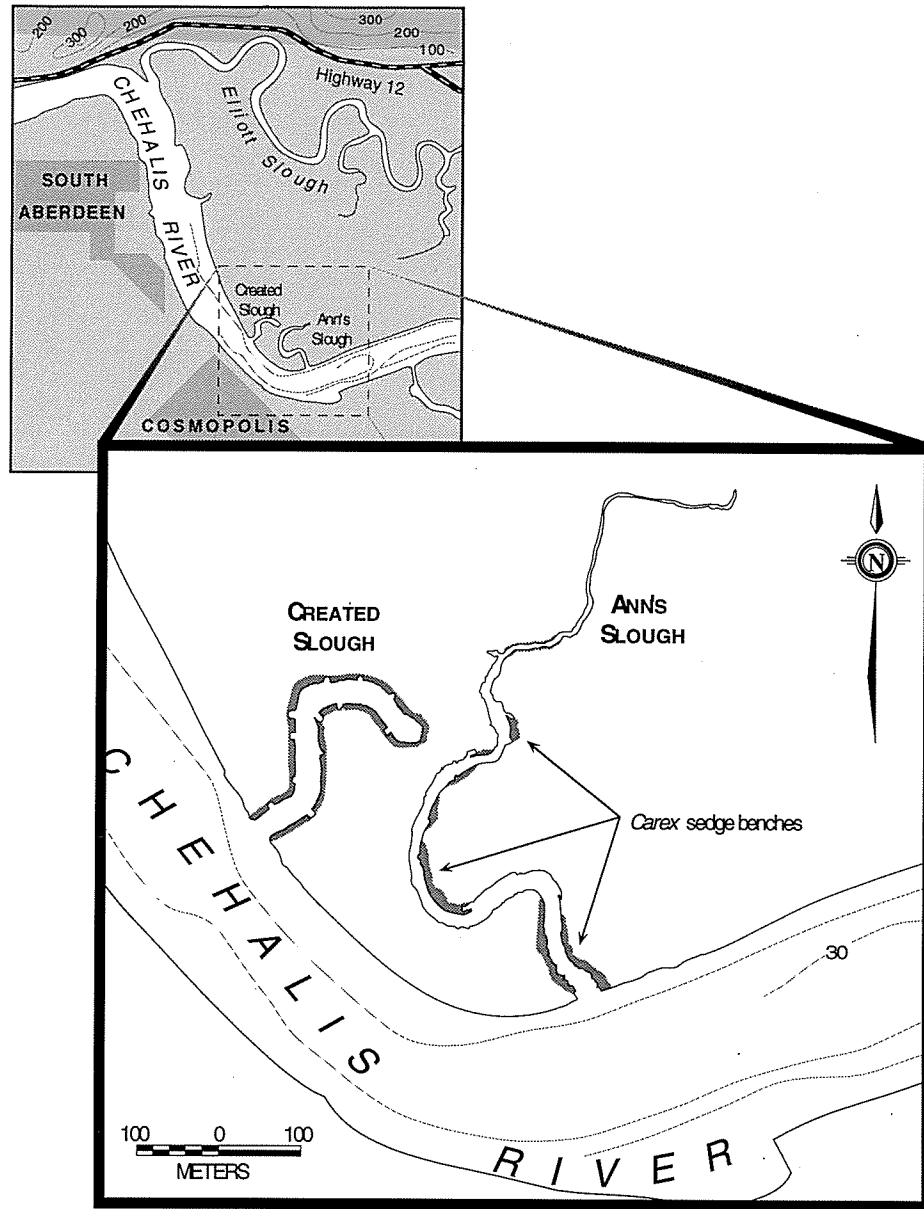


Figure 2. Location of the created slough and a natural slough (Ann's Slough) in the brackish region of the Chehalis River, Grays Harbor, Washington. Five sampling transects along *Carex lyngbyei* sedge benches are shown.

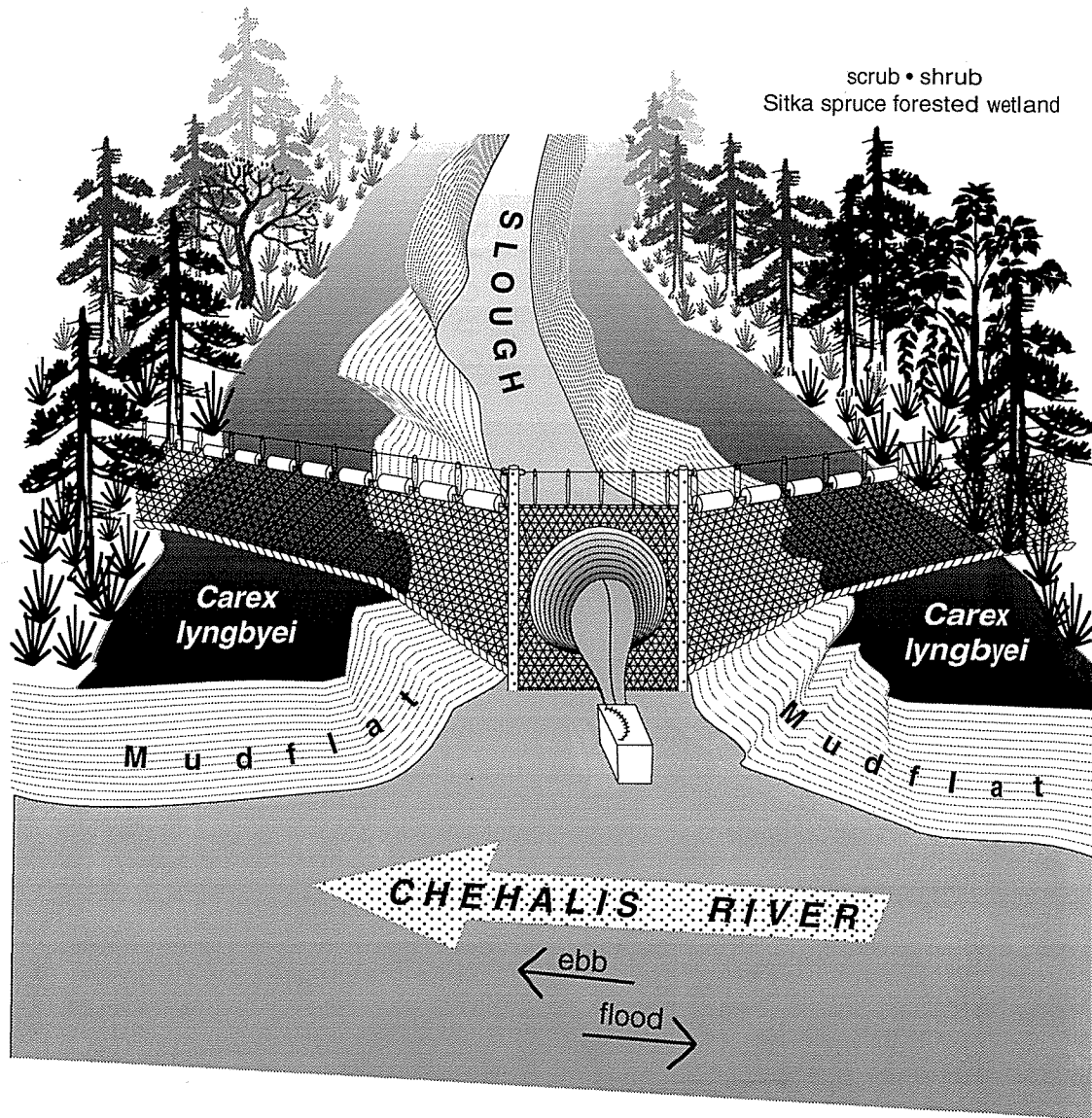


Figure 3. Diagram of outlet fyke net used to sample juvenile salmon and other fishes using slough habitats in brackish region of the lower Chehalis River, Grays Harbor, Washington.



Figure 4. Photograph depicting measurement axes on the sagittal otolith of juvenile coho salmon from the Chehalis River, Washington. "A" delineated the section used for daily growth analysis. "B" represents transect used for total otolith length measurements.

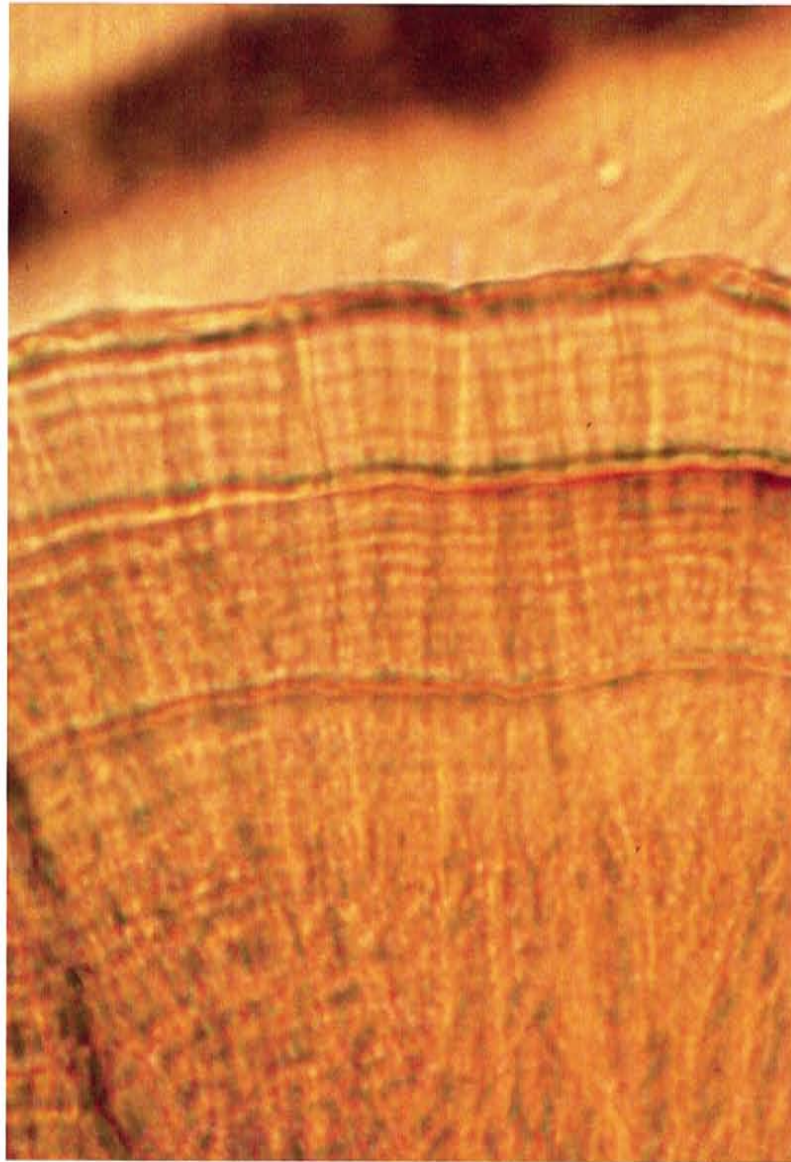


Figure 5. Photograph of region "A" from Figure 4 depicting outer section of the sagittal otolith of juvenile coho salmon from the Chehalis River, Washington. The temperature induced stress mark and five increments representing daily growth are evident.

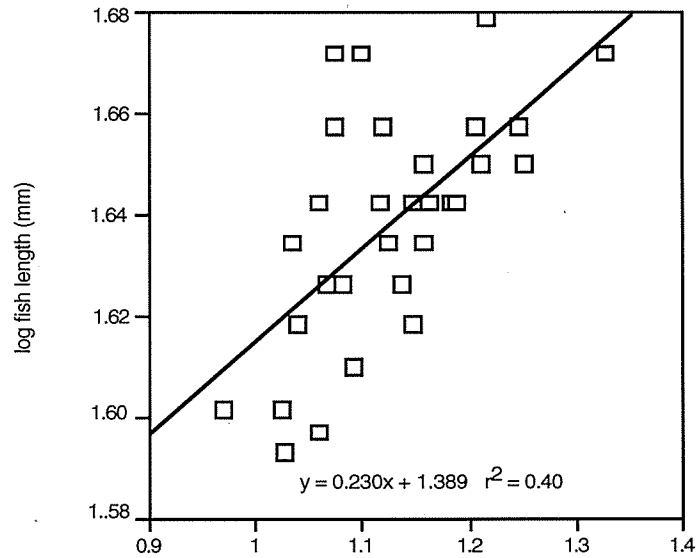


Figure 6. Linear relationship between log of coho fork length (mm) and otolith length (mm) for marked juveniles from the Chehalis River, Washington, 1991 brood year, $p < 0.001$.

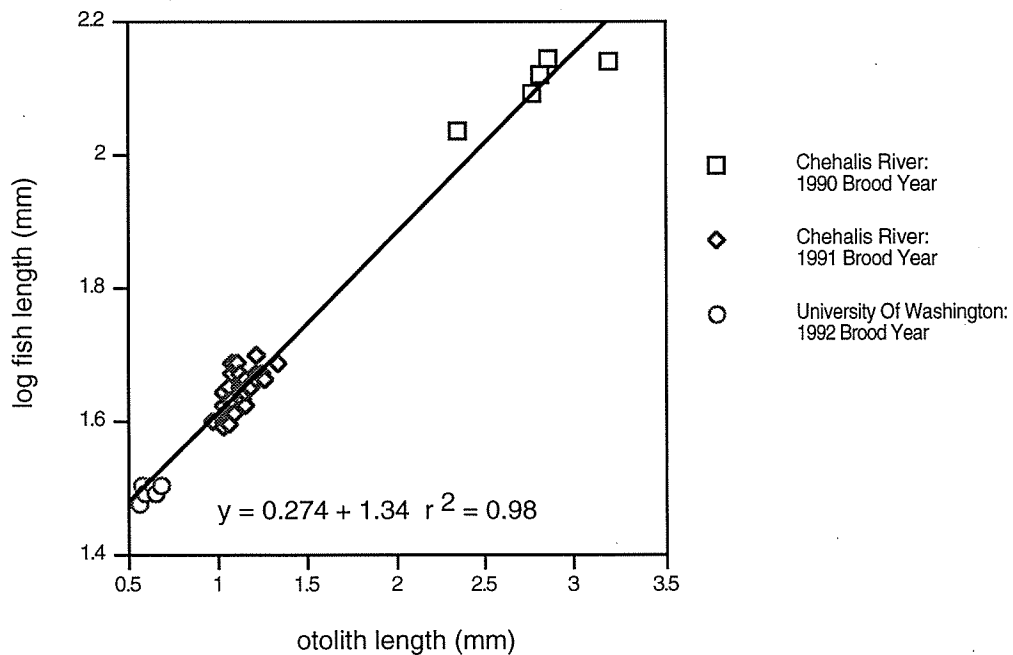


Figure 7. Linear relationship between log coho fork length (mm) and otolith length (mm), $p < 0.001$.

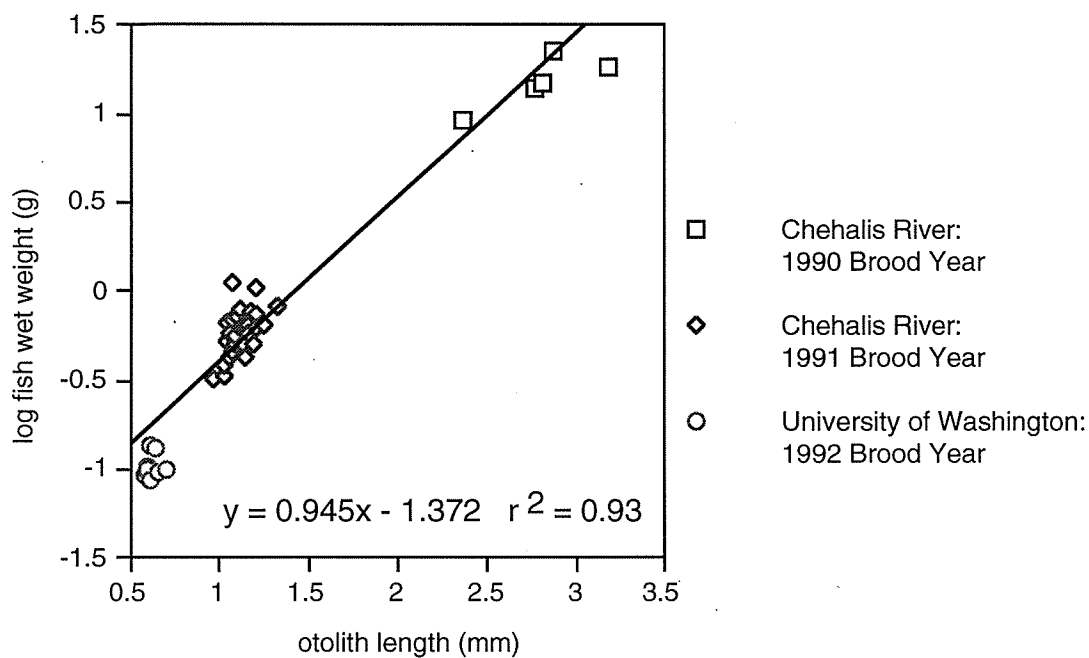


Figure 8. Linear relationship between log coho wet weight (g) and otolith length (mm), $p < 0.001$.

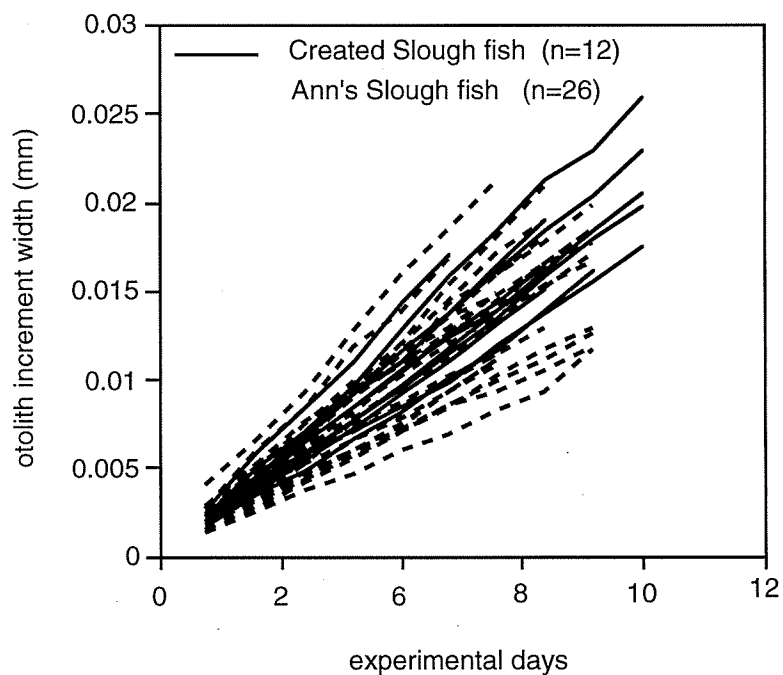


Figure 9. Individual otolith growth trajectories for juvenile coho salmon from the Chehalis River, Washington, during May 1992 experiments. Solid lines represent fish from the created slough. Dashed lines represent fish from the natural slough.

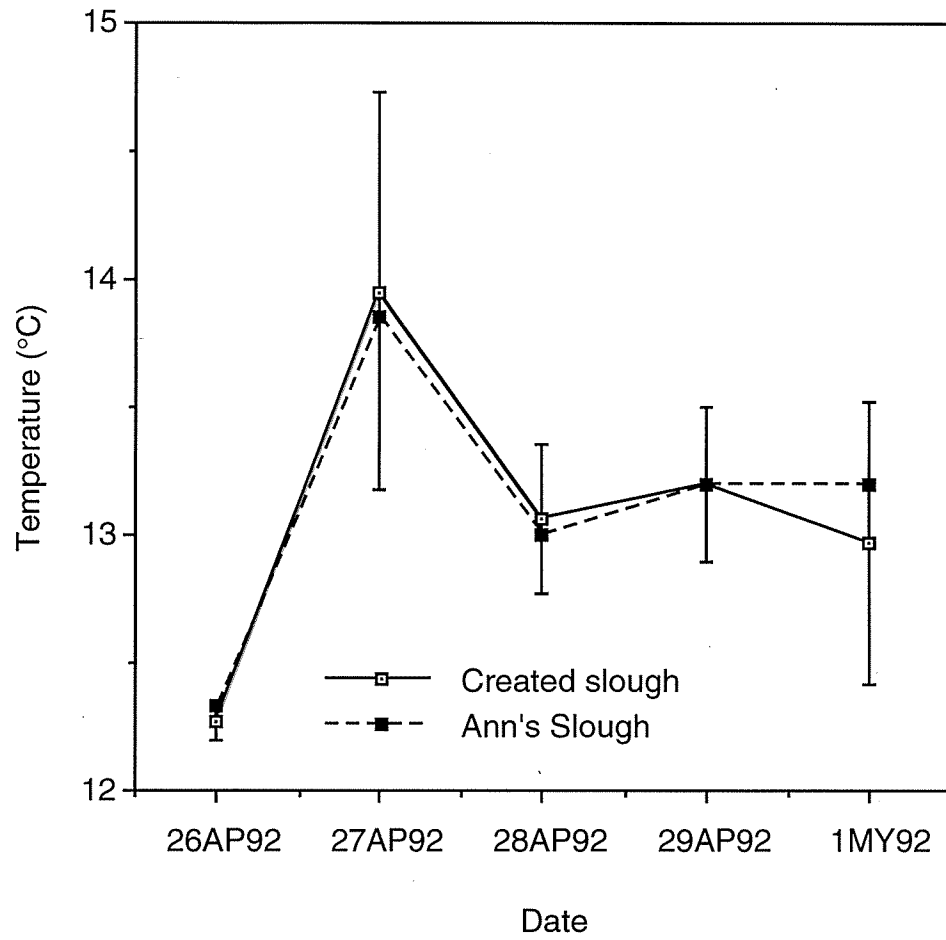


Figure 10. Average temperatures (°C) (± 1 SD) from the natural (Ann's) and created slough during 1992 coho growth experiments.

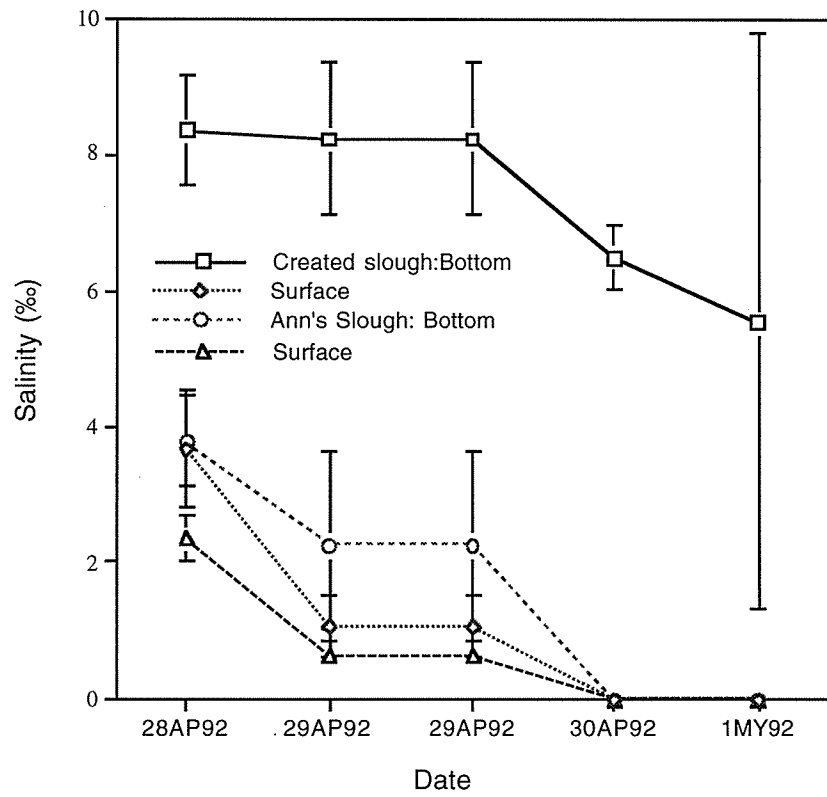


Figure 11. Average salinity (‰) measurements in the natural (Ann's) and created slough during 1992 coho growth experiments.

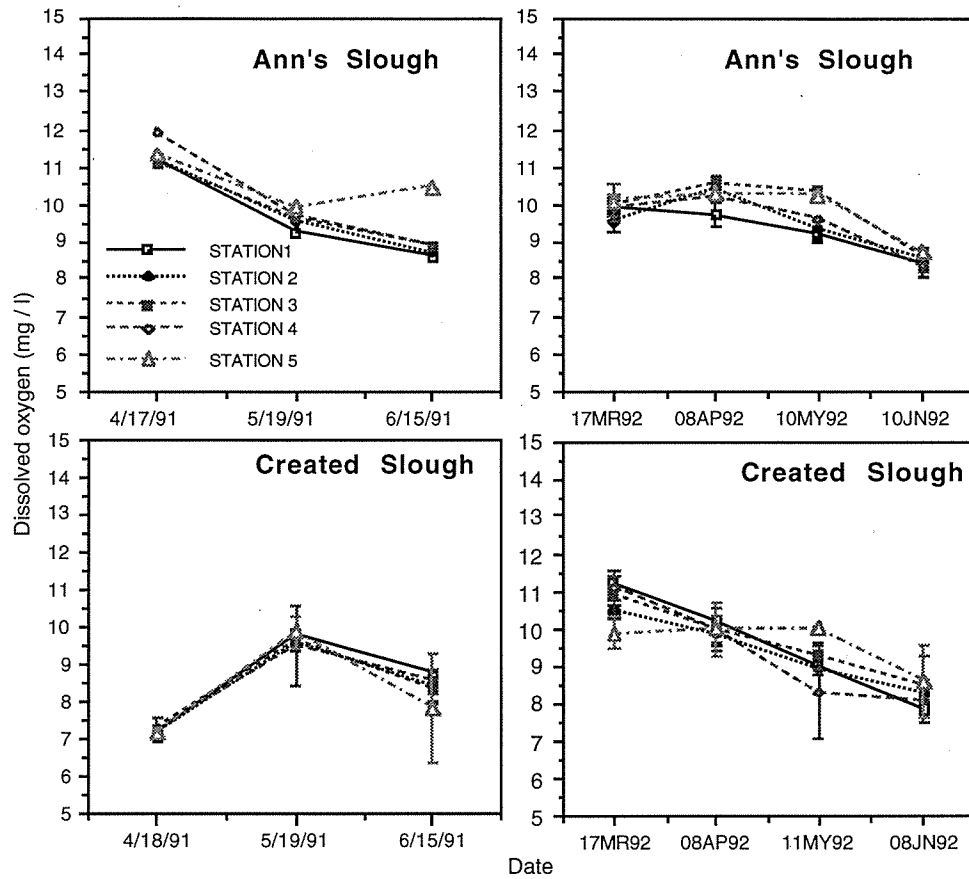


Figure 12. Average dissolved oxygen levels (mg L^{-1}) for the natural (Ann's) and created slough, Chehalis River, Washington, spring 1991 and 1992. Average measurements were calculated from bottom, middle, and surface readings. Vertical lines represent ± 1 standard deviation.

TABLES

Table 1. Individual growth rates (mm d^{-1}) and residence times (days) for juvenile chinook and coho sub-yearlings residing in Pacific Northwest estuaries.

Location	Residence (days)	Growth (mm d^{-1})	Reference
<i>Oncorhynchus tshawytscha</i>			
Sixes River, OR	~90	~0.27–0.77 mm day^{-1}	Reimers (1973)
		~2.4–3 mm day^{-1}	Neilson et al. (1985)
Nanaimo River, BC	~25	~1.32 mm day^{-1}	Healey (1980)
Skagit River, WA	3–6		Congleton (1981)
Fraser River, BC	~30		Levy and Northcote (1982)
Campbell River, BC	40–60	~0.46–0.55 mm day^{-1}	Levings et al. (1986)
Puyallup River, WA	1–43	~0.37 mm day^{-1}	Shreffler et al. (1990)
Coos Bay, OR	6–83		Fisher and Percy (1990)
Chehalis River, WA	1–7		Miller (1993)
<i>O. kisutch</i>			
Carnation Creek, BC		~0.12–0.133 mm day^{-1}	Tschaplinski (1987)
Chehalis River, WA		~0.11 mm day^{-1}	Miller (1993)

Table 2. Two methods for estimating average daily growth of Chehalis River sub-yearling chinook and coho salmon. Population average daily growth rates were calculated using length at capture data at $t = 0$ and $t = 1$. Otolith determined rates are for recaptured juvenile coho salmon from 1992 growth experiments in natural and created estuarine sloughs in the Chehalis River. All fish were collected with fyke nets in 1990-1992. Standard deviations are in parentheses.

	Initial capture group $n_{t=0}$	Second capture group $n_{t=1}$	Growth (mm) avg. mm d^{-1}	Growth (g) avg g d^{-1}
Population average				
1990				
<i>Oncorhynchus kisutch</i>				
1 May–17 May	74	68	0.48 (± 0.52)	0.05 (± 0.06)
17 May–1 June	68	18	0.68 (± 0.85)	0.09 (± 0.12)
1991				
<i>O. tshawytscha</i>				
16 April–20 May	26	53	0.19 (± 0.16)	0.02 (± 0.014)
<i>O. tshawytscha</i>				
20 May–16 June	55	20	0.45 (± 0.53)	0.06 (± 0.09)
1992				
<i>O. kisutch</i>				
26 April–21 May	253	49	0.41 (± 0.47)	0.04 (± 0.05)
<i>O. tshawytscha</i>				
2 May–21 May	37	308	0.47 (± 0.47)	0.04 (± 0.04)
Otolith determined				
1992				
<i>O. kisutch</i>	36	36	0.11 (± 0.02)	0.01 (± 0.002)