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A Comparative Assessment of a Natural and Created Estuarine Slough as Rearing Habitat for Juvenile Chinook and Coho Salmon

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ABSTRACT: Short-term otolith growth rates, residence times, and forage of two species of juvenile salmon (*Oncorhynchus* spp.) were compared in a created and natural estuarine slough on the Chehalis River in Washington to assess the functional equivalency of the created slough in providing suitable rearing habitat. Otolith microstructure, mark-recapture data, and forage of sub-yearling chinook, *O. tshawytscha*, and coho, *O. kisutch*, residing in both sloughs during the spring of 1991 and 1992 served as indicators of rearing habitat quality. No significant differences in the number or width of coho daily otolith increments were detected between the sloughs. Juvenile chinook residence and emigration times were also comparable. Aquatic and terrestrial insects composed the majority of all chinook and coho diets; however, the order of importance of main prey items did differ between sloughs, and salmon in the created slough had emptier stomachs, possibly because of reduced prey availability and/or foraging efficiency.

Introduction

Estuarine wetlands in the Pacific Northwest provide rearing habitat for migrating juvenile salmon (*Oncorhynchus* spp.) that can enhance subsequent ocean survival (Reimers 1973; Macdonald et al. 1988; Levings et al. 1989; Solazzi et al. 1991). Estuarine residence provides juveniles with extensive forage opportunities, refuge from predation, and time for physiological adaptation to increasing salinities during transition from fresh to salt water (Healey 1982; Iwata and Komatsu 1984; Table 1). Rapid growth rates can also occur during estuarine residence; therefore, wetland productivity may be directly related to subsequent early ocean survival (Parker 1962, 1968; Peterman 1978; Table 2).

The loss of coastal wetlands due to urban and residential development, pollution, and other human activities is threatening the future of marine fisheries, such as Pacific salmon, in the United States (Thayer 1992). Since European settlement along the Pacific Northwest coast, 42% of the region's coastal wetlands has been lost (Boule and Bierly 1986; Simenstad and Thom 1992). Such losses prompt efforts to create, restore, and enhance coastal wetland areas to offset the loss of fish and wildlife habitat and resources, often through the process of compensatory mitigation. Despite the regulatory mandate and intent of mitigation efforts, determination of the success of such projects is inhibited by a lack of long-term ecological monitoring, insufficient documentation of scientific methods and results, and limited use of local natural sites as reference areas (Kentula 1986; Zedler 1988; Rylko and Storm 1991).

Creation of a tidal channel, or slough, in the oligohaline region of the Chehalis River, the main tributary of Grays Harbor, Washington, provided an opportunity to evaluate created and natural salmon rearing habitat (Fig. 1). We measured short-term otolith growth rates, residence times, and forage of two species of juvenile salmon in the created and an adjacent natural slough as indicators of rearing habitat quality. The null hypothesis that rearing habitat in the two areas was not significantly different was evaluated using: comparisons of otolith increment widths in sub-yearling coho (*O. kisutch* (Walbaum)); residence times of recaptured sub-yearling chinook (*O. tshawytscha* (Walbaum)); and prey compositions and stomach fullness indices of sub-yearling coho and chinook. Few studies have examined juvenile salmon short-term growth, residence, and diet composition in natural and created estuarine habitats and none have used otolith microstructure analysis to compare growth within those habitats.

We based our growth tests on measurements of otolith microstructure. Previous research suggests that otolith microstructure may be a promising tool in comparative growth studies. Since Pannella (1971) discovered daily growth increments within

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TABLE 1. Residence times (d) for juvenile chinook salmon rearing in Pacific Northwest estuaries. The study reference, species, and location are listed.

Reference	Residence (d)	Location
Reimers 1973	90	Sixes River, Oregon
Healey 1980	25	Nanaimo River, British Columbia
Congleton et al. 1981	3–6	Skagit River, Washington
Levy and Northcote 1982	30	Fraser River, British Columbia
Levings et al. 1986	40–60	Campbell River, British Columbia
Fisher and Pearcy 1990	6–83	Coos Bay, Oregon
Shreffler et al. 1990	1–43	Puyallup River, Washington
Miller and Simenstad, this study	1–7	Chehalis River, Washington

otoliths of teleost fishes, the accuracy and precision of otolith microstructure analysis in determining daily growth rates of younger fishes have been debated (Campana 1990, 1992, for reviews; Hare and Cowen 1995). Otolith growth has been found to be positively correlated with somatic growth in several species of salmonids (Wilson and Larkin 1980; Marshall and Parker 1982; Volk et al. 1984; Neilson and Geen 1985; Neilson et al. 1985). However, observations of continuous otolith growth during periods of reduced somatic growth or starvation suggest that an uncoupling, or separation, between otolith and somatic growth can occur under certain conditions (Bradford and Geen 1987, 1992; Mosegaard et al. 1988; Secor et al. 1989; Maillet and Checkley 1990; Molony and Choat 1990; Secor and Dean 1992; Francis et al. 1993).

The assumption inherent in back-calculation of growth based on otolith microstructure is that otolith and somatic growth are in constant proportion. This assumption has led some researchers to examine otolith microstructure for evidence of relative differences in somatic growth (Neilson et al. 1985; Bradford and Geen 1992). Neilson et al. (1985) examined juvenile chinook growth in the Sixes River and estuary using otolith microstructure analysis and found that otolith increment widths underestimated overall somatic growth rates; however, relative differences in growth between habitats were still apparent. Bradford and Geen (1992) detected significant differences in otolith increment widths of hatchery-reared chinook sub-yearlings fed variable diets; although slower growth rates were calculated using otolith microstructure analysis than with fish length information, otoliths provided a relative indicator of growth between years and habitat types. We examined daily otolith growth to assess juvenile salmon use of a created estuarine slough in comparison with a natural, reference slough.

Study Area

Grays Harbor, Washington State's second largest coastal estuary, drains six rivers with a total drainage area of 6204 km^2 (Simenstad et al. 1982). The Chehalis River is responsible for 80% of the total freshwater flow into Grays Harbor. Commercial stocks of coho, chinook, chum (*O. keta*), and steelhead (*O. mykiss*) occur in the Grays Harbor coastal area (United States Army Corps of Engineers 1989).

In 1990, the United States Army Corps of Engineers (COE) created approximately 1.6 ha of shallow subtidal habitat out of forested shrub-scrub wetland to compensate for the downriver dredging of approximately 0.73 ha of shallow subtidal channel which impacted habitat for juvenile chum, chinook, and coho salmon. The created estuarine slough is located approximately 500 m downstream from a natural slough, Ann's Slough, which was used as a reference site (Fig. 2). The created slough is approximately 366 m long, 3–4 m in depth, and averages 30–50 m in width. The created habitat design included a shallow subtidal channel, fringing marsh, unvegetated mud flat, and riparian zones. The slough has an intertidal area of 11,026

TABLE 2. Growth rates (mm d^{-1}) for juvenile chinook and coho salmon rearing in Pacific Northwest estuaries.

Reference	Growth (mm d^{-1})	Location
Chinook, *Oncorhynchus tshawytscha*		
Reimers 1973	0.27–0.77	Sixes River, Oregon
Healey 1980	1.32	Nanaimo River, British Columbia
Neilson et al. 1985	1.40–3.00	Sixes River, Oregon
Levings et al. 1986	0.46–0.55	Campbell River, British Columbia
Shreffler et al. 1990	0.37	Puyallup River, Washington
Coho, *Oncorhynchus kisutch*		
Tschaplinski 1987	0.12–0.13	Carnation Creek, British Columbia

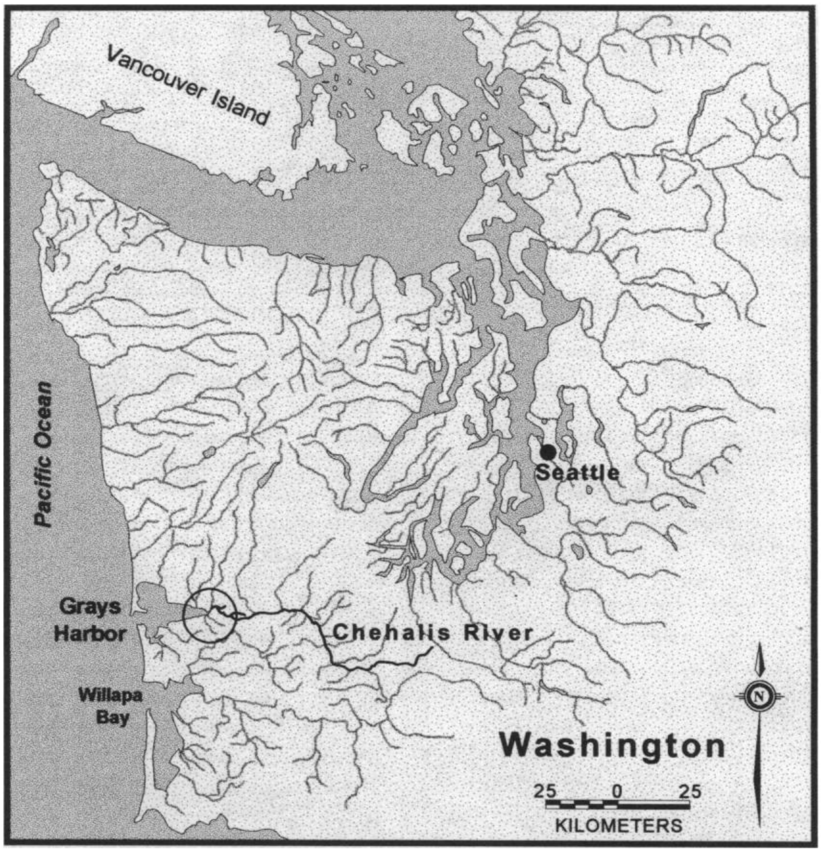

Fig. 1. General location of studies evaluating juvenile salmon use of a natural (Ann's) and created slough on the Chehalis River, Grays Harbor, Washington.

m^2. The subtidal channel covers approximately 4,554 m^2 and did not completely dewater during spring low tides during our study. In order to provide habitat complexity for juvenile salmon, large organic debris (LOD) was either left in place or brought into the slough during construction and a slough sedge, *Carex lyngbyei*, was transplanted during spring of 1991. The developing *C. lyngbyei* sedge covered approximately 4920 m^2, or 45%, of the available intertidal area, as of August 1992. Ann's Slough, the reference site, has a shallower, longer, and narrower channel that does dewater during spring low tides. It has an intertidal area of 14,489 m^2, is at least 1250 m long, and *C. lyngbyei* sedge covers at least 4546 m^2, or 31%, of the total intertidal area (Simenstad et al. 1992, 1993).

Materials and Methods

Wild sub-yearling chinook and coho salmon were collected for growth, residence, and forage analyses from April to June in 1991 and 1992. All fish were captured with fyke nets designed specifically for each slough (Fig. 3). The wings of the fyke net were constructed of 13-mm stretch mesh and blocked passage across the entire mouth of the sloughs. A live box with 6-mm mesh was attached to an elongated, narrow opening at the center of the fyke to collect fish. Fyke nets were set during spring tidal cycles at high slack tide at both the natural and created sloughs, usually within the same hour. Fish residing in the sloughs were then captured exiting the sloughs during the ebbing tide. All fish species collected with fyke nets were either preserved or identified, counted, and released.

GROWTH EXPERIMENTS

Growth experiments included capturing, marking through both an internal otolith check and external adipose fin-clip, releasing, and recapturing sub-yearling coho residing in the natural and created sloughs. We conducted growth studies during late April and May 1992 when sub-yearling coho were the most abundant juvenile salmonid migrating through the system. At least 500 coho sub-yearlings between 30 mm and 60 mm in fork length were captured with the fyke nets during April 22–25, 1992. Prior to marking, captured fish were held

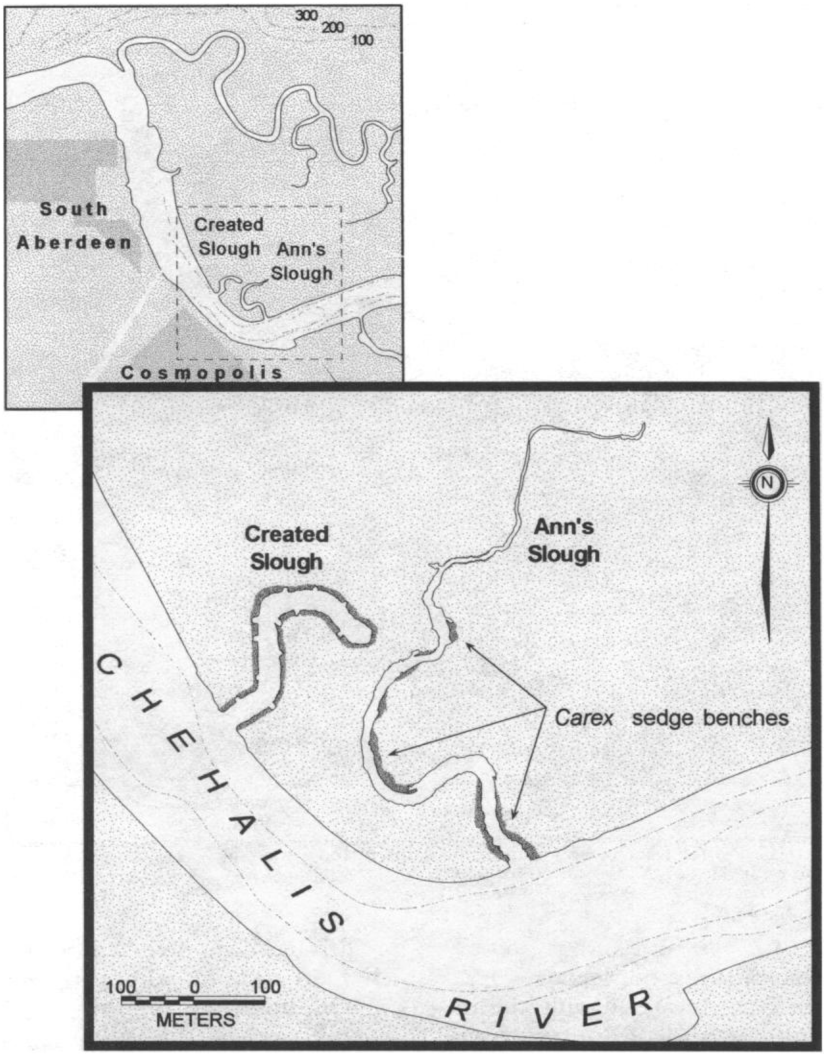

Fig. 2. Location of a natural (Ann's) and a created slough in the brackish region of the Chehalis River, Grays Harbor, Washington.

in rectangular, plastic containers filled with 0.75 m^3 of river water. Each container held approximately 225 fish and the water was aerated and cooled to maintain ambient river temperatures of 12°C to 15°C. Fish were anesthetized with MS-222 (tricane methyl sulfonate) before being weighed (±10 mg), measured (±0.5 mm), and adipose fin-clipped.

Short-term changes in water temperatures have been shown to result in the formation of an optically dense zone within a fish's otoliths which can be used as an internal time reference marker (Brothers 1990; Volk et al. 1990). In a 1991 pilot study, we collected juvenile chinook and coho salmon by the same method described above and held them at 9°C for 12 h to determine if a visible mark was produced in the otolith. The water temperature in containers holding captured fish was reduced and maintained at 9°C by the addition of three blocks of ice every to 4 h to 6 h, producing a discernible stress mark within the otoliths. In this study, fish were held by the same method at 9°C for 12 h to ensure the development of a discernible stress mark within the otolith (Fig. 4). Marking mortalities of 3% (15 fish) occurred because of an aeration problem, and one fish was lost during the post-tagging, chilling phase. After 12 h of chilling, fish were divided into two groups of 215 and 235; these groups were then released into the natural and created sloughs, respectively. Twenty fish were held in tethered live boxes in each of the sloughs throughout the experiment to assess additional marking mortality.

To prevent experimental fish from exiting the sloughs, live boxes were removed and the funnel in the centerpiece of the fyke was sewn shut. The nets were placed at the mouth of each slough and

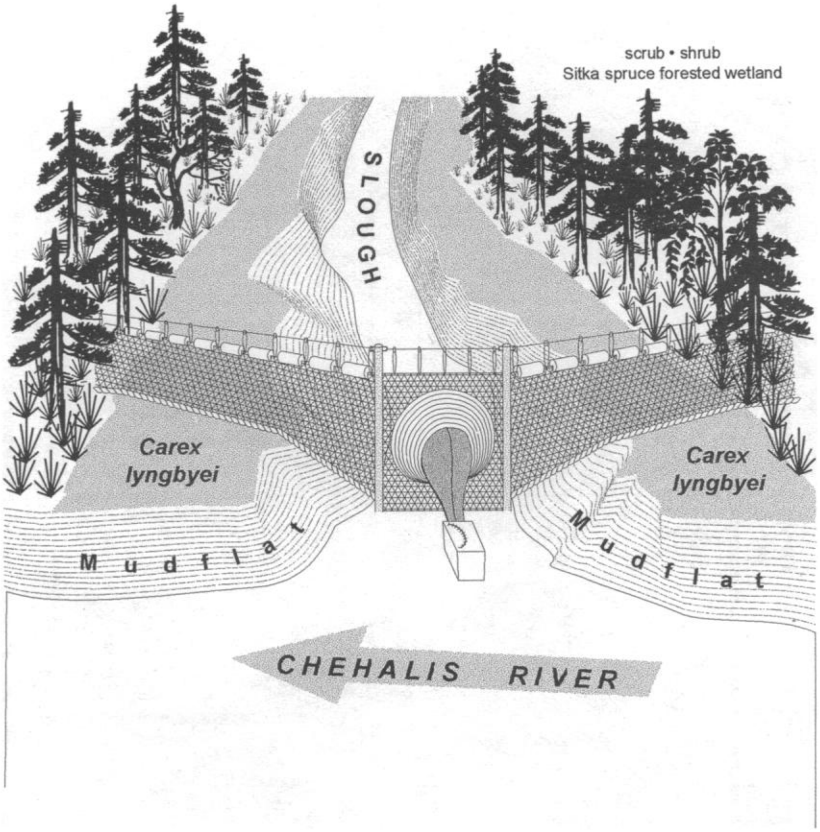

Fig. 3. Diagram of outlet fyke net used to collect juvenile salmon and other fishes residing in brackish sloughs on the lower Chehalis River, Washington.

fish were released at the beginning of a neap tidal cycle when a range of low tides between −0.01 m and 1.1 m ensured sufficient water during the experimental period. Attempts to recapture experimental fish began on May 2, 1992, 8 d after release, when the spring tidal series produced a low tide of −0.01 m. At that time, live boxes were replaced and checked every 2 h. Recaptured fish were anesthetized, weighed, and measured before preservation in 95% ethanol. Water temperature and salinity measurements were recorded daily with a YSI meter throughout the growth experiment.

In the laboratory, recaptured fish were reweighed, measured, and otoliths removed. Both sagittae were removed and excess tissue rinsed in 95% ethanol. Left sagittae were preferentially analyzed unless otolith increments were indiscernible on the left sagitta, in which case we substituted the right sagitta. (When the calcium carbonate in an otolith occurs in the form of vaterite instead of the more common form, aragonite, a lack of uniformity can occur during crystallization and can obscure the increment pattern [Campana and Neilson 1985].) This approach was chosen because no significant difference in increment number or width has been detected between left and right sagittae of chinook salmon (Neilson and Geen 1982).

Otoliths were set with the sulcus acousticus, a depression on the proximal surface, facing down into a plastic mold and fixed in clear casting resin (Secor et al. 1992). The samples were then secured to a microscope slide using a thin layer of removable adhesion wax and with the sulcus acousticus facing upward. Otoliths were then ground and polished with a Struer's® Rotopol-V grinding machine using 1200 grit sandpaper, followed by an alumina micropolish with grit sizes ranging from 0.3 μm to 1.0 μm. Otoliths were ground to a plane in which the primordia were clearly visible with transmitted light microscopy. We completed preparation with a final silicate polish developed by Struer's®.

Grinding of both sides of the otolith was necessary because otolith specimens were examined using transmitted light microscopy. After initial grinding, samples were removed from the slides, turned over, and reaffixed with Duro™ Quick-Gel™. A similar grinding and polishing method was then completed on the distal side of the otolith to improve specimen quality.

Otolith increment number and widths were

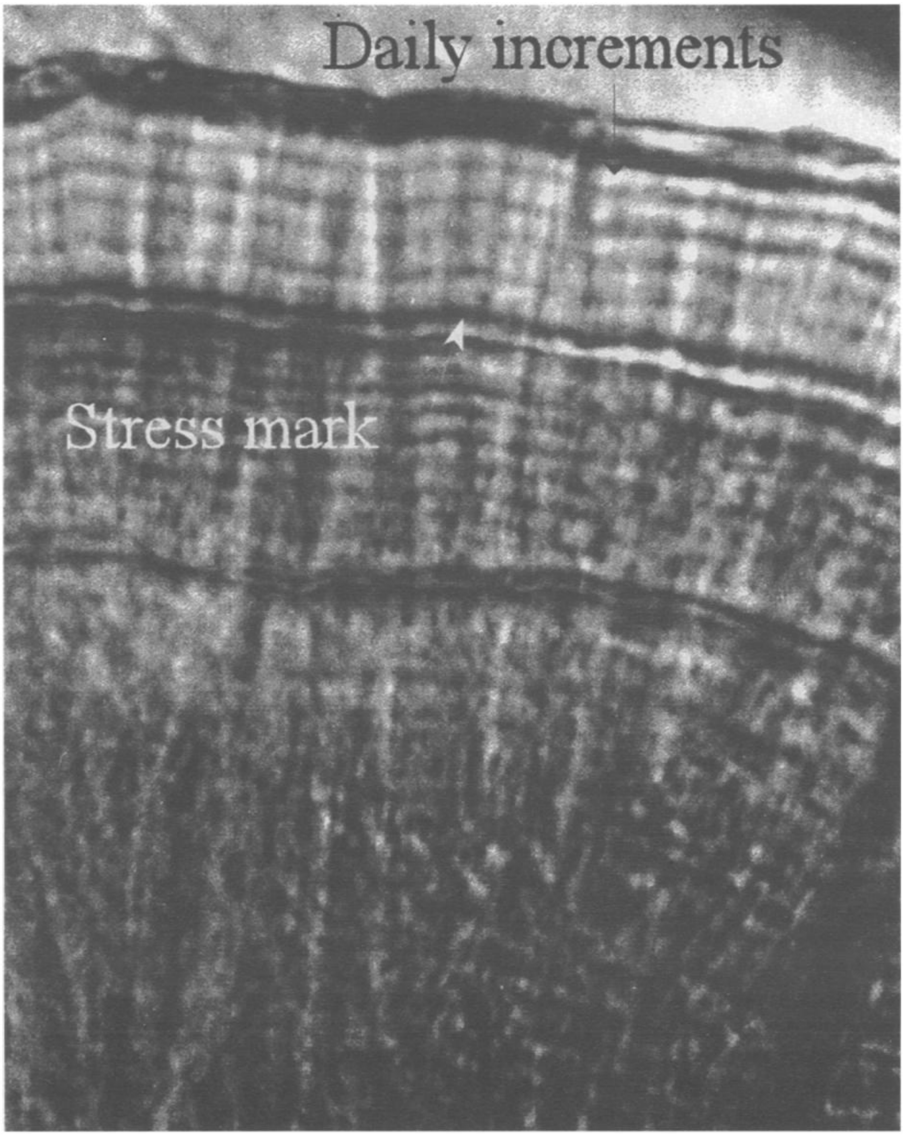

Fig. 4. Digital image of outer section of the sagittal otolith of juvenile coho salmon from the Chehalis River, Washington, identifying a temperature-induced stress mark and six increments representing daily growth.

measured using Optimas® imaging analysis software and a compound microscope at a magnification range of 100× to 750×. An increment is defined as a bipartite concentric ring composed of alternating zones of a predominantly calcium carbonate accretion zone and an organic discontinuous zone. Individual increments are one accretion and one discontinuous zone (Mugiya 1987). Each increment formed after the stress-induced check mark was counted and its width measured. The axis for increment width (μm) measurements was usually 90° from the longitudinal axis of the otolith. Occasionally, measurement radii diverged slightly from 90° to include the clearest region of the otolith (Fig 5). All measurements remained within an 80° to 90° angle from the long axis. Increment widths and standard deviations were calculated from three separate measurements. Although the same reader completed all measurements, repeat measurements of individual otoliths were made approximately 2 wk apart without reference to previous readings in order to minimize bias.

An otolith growth trajectory for each experimental fish was determined by plotting individual daily increment widths for each fish against the number of days fish were held in the sloughs (Wilson and Larkin 1980; Neilson and Geen 1982; Bradford

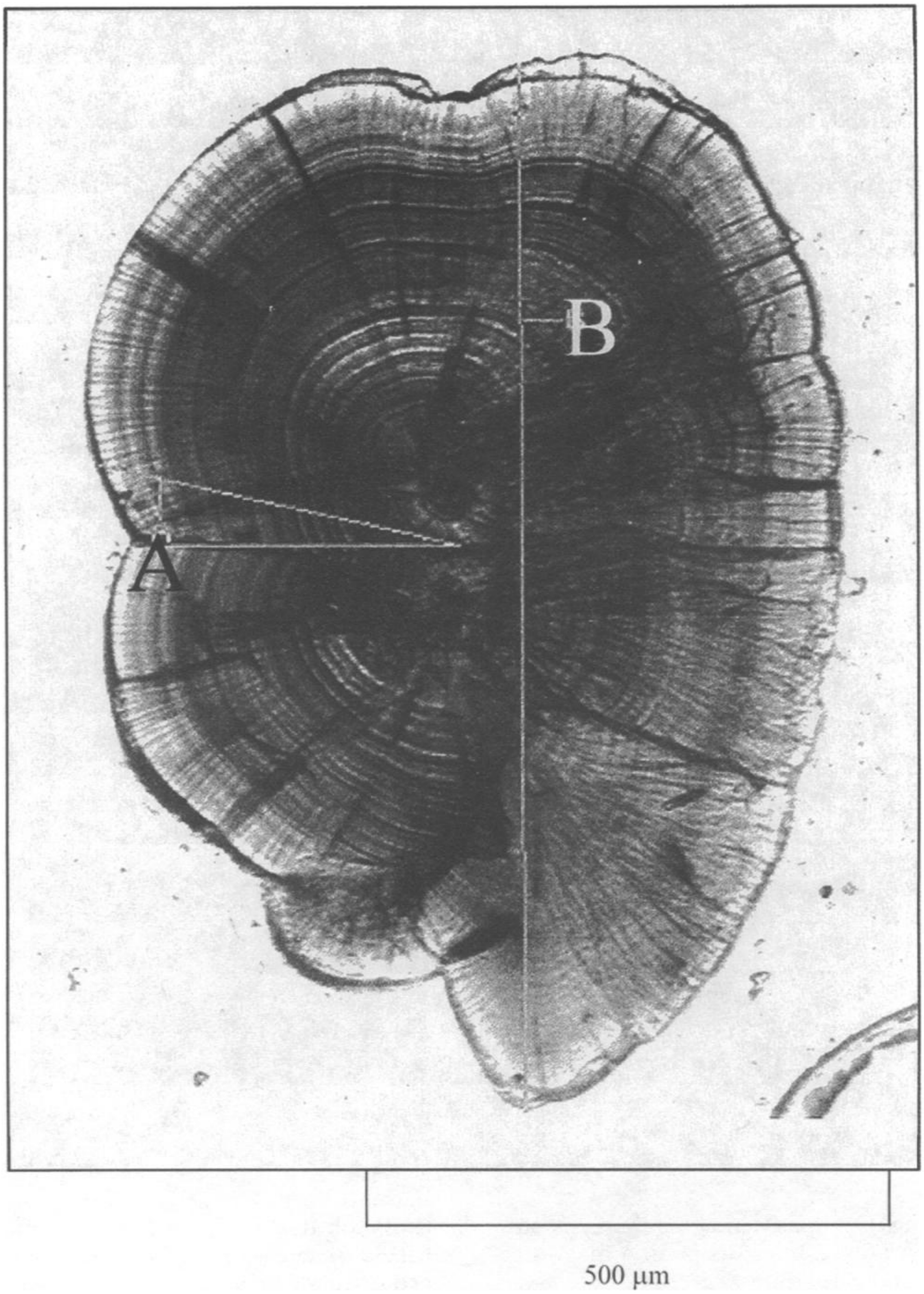

Fig 5. Digital image of measurement axes on the sagittal otolith of juvenile coho salmon from the Chehalis River, Washington. "A" delineates the axis used for increment width measurements and "B" represents the longitudinal axis of the otolith. Scale bar represents 500 μm.

and Geen 1987; Francis 1990). The slopes of the individual otolith growth trajectories represent the rate of otolith growth during the experiment. Rates of otolith growth for fish in the two sloughs were compared with the Mann-Whitney nonparametric comparison test (Zar 1984).

RESIDENCE EXPERIMENTS

We conducted residence time experiments during the neap tidal series immediately following the growth studies in late May-early June 1992 when sub-yearling chinook salmon were migrating through this region of the estuary. Chinook were captured and handled as previously described for coho. Fyke nets were maintained to allow continuous fish capture. Release of 188 and 162 adipose fin-clipped chinook into Ann's and the created slough, respectively, occurred on May 22, 1992. Monitoring of the fyke nets began immediately in order to determine times of volitional emigration from the sloughs. Monitoring continued every 2 h for 48 h and then occurred approximately every 4 h for 6 d. The size of all fishes from both sloughs and times of capture were recorded. Fish were preserved in 95% ethanol or buffered 10% formalin.

DIET ANALYSES

Juvenile salmon were collected for diet analyses three times each month from April to June 1991 and April to June 1992, except for May 1991 and June 1992, when the created slough was sampled twice instead of three times. All diet analyses presented here are for chinook and coho sub-yearlings collected during May 1991 and May 1992. During collection periods, live boxes were checked every 2 h throughout the ebbing tide. To minimize regurgitation, captured fish were anesthetized with MS-222 (tricane methane sulfonate) immediately before preservation in 10% buffered formalin.

Fish were grouped by slough, species, size class (41–50 mm and 51–60 mm in fork length), and capture date. In the laboratory, preserved fish were weighed (± 10 mg), measured (± 0.5 mm), and the stomach removed (to the pylorus). Total stomach contents were then removed, blotted dry, and weighed (± 1 mg). Contents were identified, counted, sorted to the lowest possible taxa, and each taxonomic category weighed (± 1 mg).

Prey items were ranked using an Index of Relative Importance (IRI) that incorporates information regarding the frequency of occurrence, number, and biomass of each type of prey consumed (Pinkas et al. 1971). IRI is expressed as

$$\mathrm{IRI} = \mathrm{F}(\mathrm{N} + \mathrm{G}) \qquad (1)$$

where

F = frequency of occurrence (%) of total contents,

N = numerical composition (%) of total contents,

and

G = gravimetric composition (%) of total contents.

Diet analyses were standardized by comparing contents based on the percentages of the total IRI for each prey category. Overlap in diet composition was assessed using the Percent Similarity Index (PSI) (Hurlbert 1978). PSI is given as

$$\mathrm{PSI} = 100 - (1/2(\Sigma|X_i - Y_i|)) \qquad (2)$$

where

X_i = percent total IRI for prey category i from the natural slough,

and

Y_i = percent total IRI for prey category i from the created slough.

A PSI value of 100 indicates complete overlap while a value of 0 indicates no overlap.

A stomach Fullness Index (FI) was also calculated for each fish examined. The total wet weight of the stomach contents of each fish was divided by the total wet weight of that fish including stomach contents:

$$\mathrm{FI} = \mathrm{WW}_{sc}/\mathrm{WW}_{x} \qquad (3)$$

where

WW = wet weight, sc = stomach contents,

and

x = juvenile salmon.

Differences in fullness indices for similar species and size classes captured within the sloughs were tested statistically using the Mann-Whitney nonparametric comparison test ($P \leq 0.01$).

Results

GROWTH EXPERIMENTS

There were no statistically significant differences in daily otolith growth rates between the created and natural sloughs (Mann-Whitney nonparametric comparison test, P = 0.91) (Fig. 6). Rates of recapture at the end of the growth experiments were 15.3% (33 fish) and 8.1% (19 fish) for the natural and created slough, respectively. Cracked or damaged otoliths excluded 11.0% (6 fish) of the total number of recaptured fish from analysis and vaterite deposits excluded an additional 15.0% (8 fish). Therefore, otoliths from 38 fish were examined; 26 from Ann's Slough and 12 from the created slough. Mortality of control fish maintained in live boxes was minimal, 2.5% (1 fish). The average number of increments formed following release, 7.8, was not significantly different than 8.0, the number of experimental days (Wilcoxon paired-sample test, P = 0.70). Water temperatures in both sloughs ranged between 12°C and 14°C during the experiment. Surface and bottom salinities in Ann's Slough and surface salinities in the

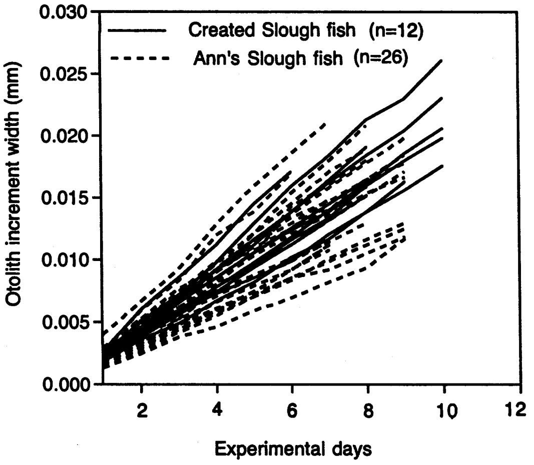

Fig 6. Individual otolith growth trajectories for sub-yearling coho salmon residing in a natural (Ann's) and created slough, Chehalis River, Washington. Daily otolith growth (mm) is plotted against experimental days.

created slough ranged between 0‰ and 4‰ throughout the experiment. Bottom salinities in the created slough ranged between 6‰ and 9‰.

Residence Experiments

Fish residence and emigration times were similar for the two sloughs (Fig. 7). Total recapture rates were 10% and 9% for Ann's Slough and the created slough, respectively. Residence times ranged from 1 d to 7 d with the majority (88%) of all recaptured fish emigrating from the sloughs within 48 h. No marked fish were captured during the first 24 h after release. Within an hour of the first lower low tide on the day after release, 8 fish were captured emigrating from each slough. All fish exited during the lower low tide, with 20 and 17 marked chinook captured from Ann's and the created slough, respectively. The timing of emigration from the two sloughs was similar with 31 fish (83% of those recaptured) collected during the same three sampling periods.

Diet Composition

Overall, taxonomic composition of stomach contents from juvenile chinook and coho salmon in the natural and created sloughs were similar. Both species consumed prey from 16 different orders. However, dipterans, homopterans, gammarid amphipods, coleopterans, and mysids alone accounted for 81% to 94% of the total Index of Relative Importance (IRI) for both salmon species (Figs. 8 and 9). Dipterans (predominantly Chironomidae) and homopterans (predominantly Aphidoidea) composed the majority, 77.8% ± 23.8%, of the total IRI for all salmon diets.

Despite the commonality of prey taxa, there were differences in the ranked order of importance of major prey groups between sloughs. In 1991 coho diets (51–60 mm), dipterans, predominantly chironomids, and aphids composed a greater portion of the IRI from Ann's Slough than the created slough, composing 88.7% and 24.9%, respectively (Fig. 8). In 1992 coho diets (41–50 mm), chironomids were the main prey item in both sloughs, composing 62.4% and 49.9% in Ann's and the created slough, respectively. In the created slough, the mysid *Neomysis mercedis* composed 71.9% and 21.7% of the total IRI in 1991 and 1992, respectively. In Ann's Slough, mysids composed less than 1% of the total IRI of coho diets in both years.

Aphids and chironomids also composed the ma-

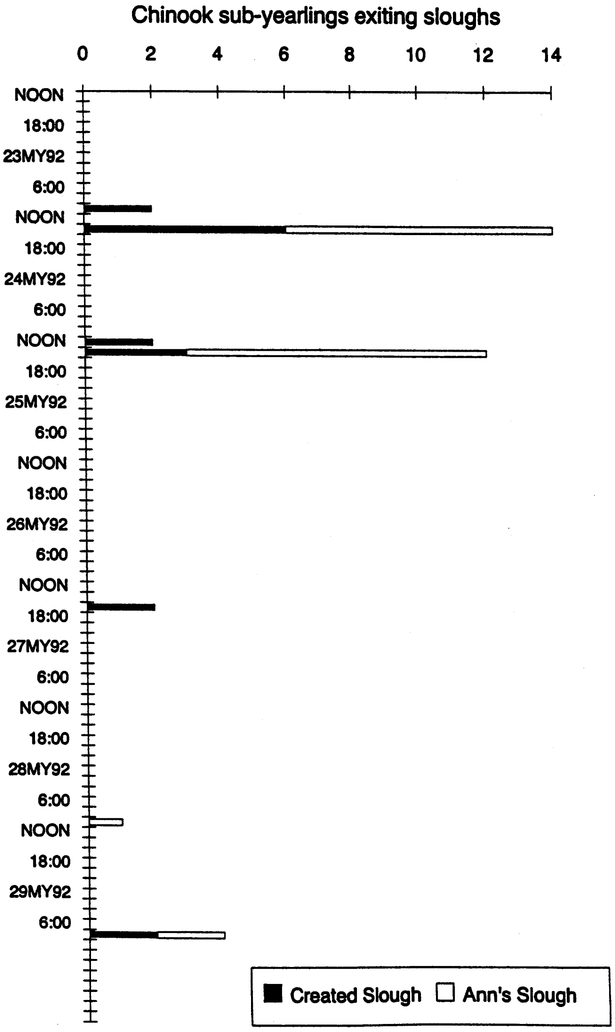

Fig 7. Residence and emigration times of marked juvenile chinook salmon from a natural (Ann's) and created slough, Chehalis River, Washington. Solid bars represent the created slough, white bars Ann's Slough. Fish were released into the sloughs at noon on May 22, 1992.

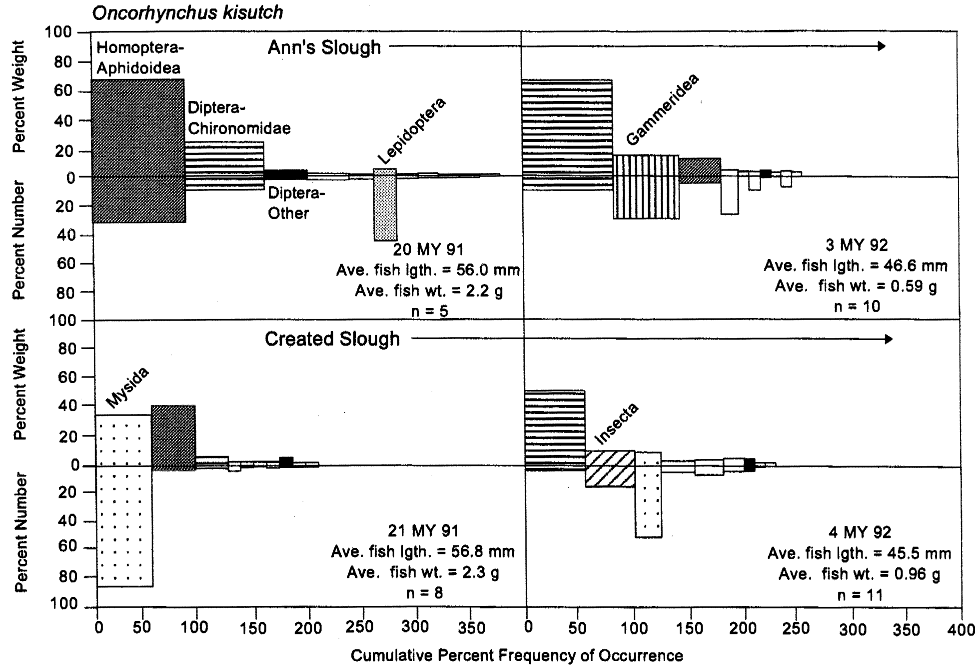

Fig 8. Indices of Relative Importance (IRI) for juvenile coho (*Oncorhynchus kisutch*) salmon captured in a natural (Ann's) and created slough on the Chehalis River, Grays Harbor, Washington. Boxes with grey denote Homoptera-Aphidoidea, horizontal stripes denote Diptera-Chironomidae, black denote Diptera-other, small dots denote Lepidoptera, vertical stripes denote Gammeridea, large dots denote Mysida, and oblique stripes denote Insecta. Taxonomic groups composing less than 5% of the total IRI are denoted by white boxes.

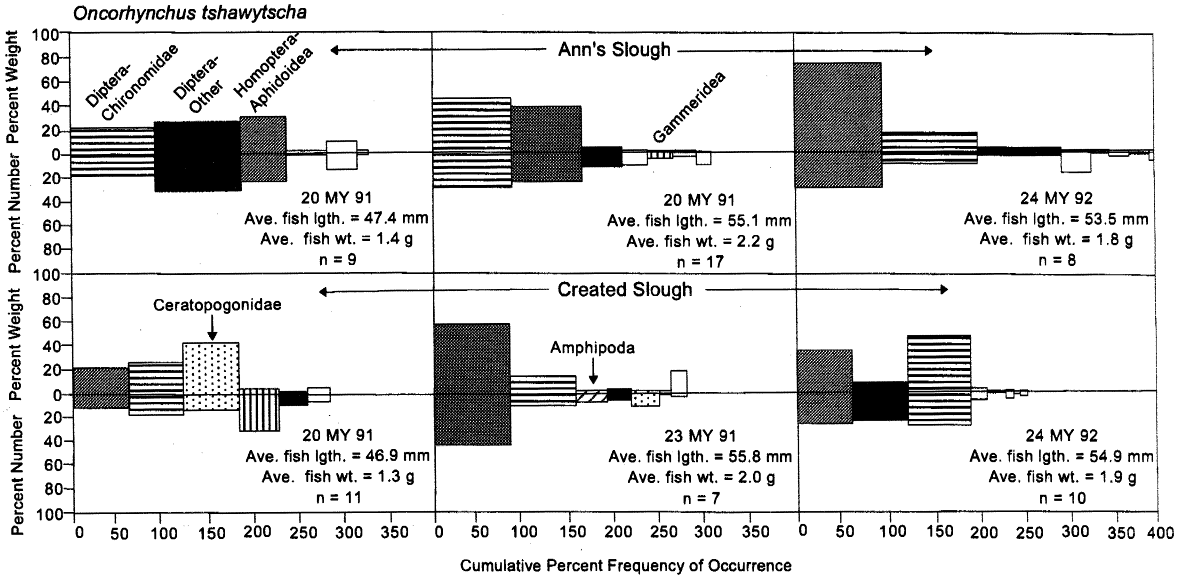

Fig 9. Indices of Relative Importance (IRI) for juvenile chinook (*Oncorhynchus tshawytscha*) salmon captured in a natural (Ann's) and created slough on the Chehalis River, Grays Harbor, Washington. Boxes with horizontal stripes denote Diptera-Chironomidae, black denote Diptera-other, grey denote Homoptera-Aphidoidea, vertical stripes denote Gammeridea, dots denote Ceratopogonidae, and oblique stripes denote Amphipoda. Taxonomic groups composing less than 5% of the total IRI are denoted by white boxes.

TABLE 3. Stomach Fullness Index (FI) and Percent Similarity Index (PSI) for juvenile salmon diet studies in a natural (Ann's) and created estuarine slough on the Chehalis River, Washington. Location, date of capture, sample size, size class, FI, and PSI are listed. FI = WW_{sc}/WW_{x}, where WW = wet weight, sc = stomach contents, and x = whole juvenile salmon. Significant differences in FI between sloughs were determined using the Mann-Whitney nonparametric comparison test ($P < 0.01$) and are indicated by *. PSI = $100 - (1/2\ (\Sigma|X_i - Y_i|))$, where X_i = percent total IRI for prey category i from the natural slough and Y_i = percent total IRI for prey category i from the created slough.

Site	Date Captured	n	Size (mm)	Fullness Index (%)	Percent Similarity Index (%)
Chinook, *Oncorhynchus tshawytscha*					
Ann's Slough	May 20, 1991	9	41–50	1.4	49.2
Created Slough	May 20, 1991	11	41–50	1.3	
Ann's Slough	May 20, 1991	17	51–60	1.4*	60.6
Created Slough	May 23, 1991	7	51–60	0.4	
Ann's Slough	May 24, 1992	8	51–60	2.4*	58.5
Created Slough	May 24, 1992	10	51–60	0.8	
Coho, *Oncorhynchus kisutch*					
Ann's Slough	May 20,1991	5	51–60	1.7	27.3
Created Slough	May 21, 1991	8	51–60	1.3	
Ann's Slough	May 3, 1992	10	41–50	1.9*	57.5
Created Slough	May 4, 1992	11	41–50	0.6	

jority of the chinook diet in 1991 and 1992, ranging from 76.5% to 94.7% of the total IRI (Fig. 9). In both 1991 and 1992, chinook collected from the created habitat consumed a greater proportion of *N. mercedis* and gammarid amphipods than those from the natural slough. Mysids and gammarid amphipods consistently composed a greater portion of both chinook and coho diets in the created slough than the natural slough. These two epibenthic crustaceans composed a 1991 and 1992 average of 20.0% (± 24.0%) of the total IRI for fish from the created slough while contributing 5.0% (± 8.0%) to the diets of fishes in Ann's Slough.

Percent similarity indices (PSI) between diets of fish from Ann's Slough and the created slough ranged between 27% and 61% during the 1991 and 1992 sampling periods (Table 3). Differences were primarily due to the greater relative importance of aphids in the diet of fish in the natural slough, and mysids and amphipods in the diet of fish in the created slough. The ranges of stomach fullness indices, 0.1–5.0% for coho and 0.2–6.0% for chinook, were similar for both species in both sloughs (Table 3). However, significantly higher indices occurred in Ann's Slough in three of the five comparisons (Mann-Whitney nonparametric comparison test) (Table 3).

Discussion

Previous studies have examined short-term growth rates, residence times, and diet composition for populations of juvenile salmon migrating through an entire estuary (Reimers 1973; Healey 1980; Levy and Northcote 1982; Tschaplinski 1982, 1987; Neilson et al. 1985; Murphy et al. 1988). Fewer studies have examined these variables within a specific habitat and even fewer have examined them in constructed estuarine environments (Ryall and Levings 1987; Shreffler et al. 1990, 1992). This study is the first to quantitatively compare created and natural rearing habitat through examination of individual otolith growth trajectories, residence times, diet composition, and stomach fullness indices.

By most criteria, these data indicate that the created estuarine slough on the Chehalis River provided rearing habitat for migrating juvenile salmon comparable to the adjacent natural slough. Although relative differences in the ranked order of importance of major prey items were observed in juvenile salmon diets, overall diet compositions were similar in both habitats. Individual otolith growth rates were not significantly different. Furthermore, we did not detect differences in individual residence or emigration times between the natural slough and the created slough.

Significantly lower stomach fullness indices were detected, however, for both species of juvenile salmon in the created slough, possibly indicating decreased foraging efficiency due to reduced prey availability or a real or perceived predation risk. An assessment was made of prey availability in these two sloughs during spring 1991 and 1992 by collecting infaunal, epibenthic, and neustonic invertebrates (Simenstad et al. 1993). Direct comparisons of relative prey availability were precluded because some of the dominant prey consumed by the juveniles - mysids and gammarid amphipods - were not well represented in our samples. This could have been caused by the rare occurrence and/or patchy distribution of these invertebrates. Average densities of both emergent and neustonic invertebrates were greater in the natural slough while taxonomic compositions were similar between the two sloughs (Simenstad et al. 1993). The reduced average densities of potential prey in the created slough could have contributed to the reduced stomach fullness indices observed in this study.

The increased depth and width of the created slough in relation to Ann's Slough results in longer retention of water and an increase in the range of salinity in the created habitat. The created habitat supports a more diverse assemblage of fishes; in 1992, 22 fish species were collected from the created slough and 16 species from Ann's Slough (Simenstad et al. 1992, 1993; Miller 1993). Higher densities of yearling coho, northern squawfish (*Ptychocheilus oregonensis*), and steelhead were found in the created slough and may alter sub-yearling salmon foraging behavior due to perceived or real predation risk (Miller 1993). Direct evidence of predation on juvenile salmon was documented in yearling coho but not in squawfish (Miller 1993). However, predation on juvenile salmon by squawfish in freshwater habitats is well documented (Wydoski and Whitney 1979).

The geomorphology, hydrodynamics, and location of the created slough may, in part, be responsible for the presence of fish predators and a reduction in refuge area for juvenile salmon, thus altering juvenile salmon foraging behavior. The presence of predators can alter a juvenile salmon's choice of foraging patch and intensity; the distance between a foraging patch and a predator-free refuge can affect a fish's willingness to forage (Dill and Fraser 1984; Abrahams and Dill 1989). Johnsson and Abrahams (1991) demonstrated that wild steelhead were less willing to risk predation to forage than were domesticated hybrid steelhead. In the presence of yearling coho and northern squawfish, the wild sub-yearling chinook and coho rearing in the created slough may have been less willing to forage. Additionally, the presence of predators in the created slough may have forced juvenile salmon to reside in regions of the slough with reduced densities of prey or suboptimal temperature regimes, thereby increasing their metabolic costs. The greater physical variability in the created slough and the presence of predators are possible explanations for lowered juvenile salmon foraging efficiencies. The question associated with lower fullness indices is whether or not such differences are represented in reduced growth efficiencies for salmon rearing in the created slough.

There are two possible explanations for the similar daily otolith growth rates observed in the two sloughs: there was no significant difference in the daily growth of coho sub-yearlings in the two sloughs; or the length of the experiment was not long enough to detect differences in otolith growth. Although some studies have observed a time-lag of approximately 15 d between a reduction in somatic growth and a corresponding reduction in otolith increment width (Bradford and Geen 1987, 1992; Molony and Choat 1990), other studies have observed 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; Mugiya and Oka 1991). In our study, a longer rearing period within the sloughs was not possible due to the lack of low tide refuge during the spring tidal cycle. However, extension of the experiment to include a holding period during which recaptured fish are maintained under identical circumstances for 15–20 d before preservation would address the question of a potential time-lag between otolith and somatic growth.

Although we did not link somatic and otolith growth, we did attempt to examine individual somatic growth of fish (40–70 mm) through the use of external tags. During a pilot study in 1991, different types of external tags (i.e., Floy® disc tags and plastic colored beads secured at the base of the dorsal fin with monofilament line), were tested on approximately 250 chinook and coho juveniles. Recapture rates of tagged fish were low, less than 5%. This was probably a result of reduced swimming efficiency and/or increased predation of tagged individuals because fish maintained on-site after tagging experienced minimal mortality, less than 2%. Therefore, we used only adipose fin-chipping to identify experimental fish from wild fish in our 1992 experiments which limited our ability to address individual changes in somatic growth.

The presence of sub-yearling coho in our experiment is of particular interest since their occurrence in estuaries has only been documented on a few occasions (Tschaplinski 1982, 1987; Ryall and Levings 1987). Although earlier studies suggest the downstream migration of sub-yearling coho to be density-dependent (Chapman 1962; Mason and Chapman 1965), portions of sub-yearling coho populations in British Columbia not only migrated downstream during periods of low coho densities and resided in estuaries but contributed substantial numbers of adult spawners to the population (Tschaplinski 1982, 1987; Thedinga and Koski 1984). Although Mason and Chapman (1965) contend that sub-yearling coho migrants may not survive migration to the ocean, such behavior may indicate an alternative life-history pattern similar to "ocean-type" chinook salmon which rear in brackish-water environments 3 mo or longer prior to ocean entrance (Johnson et al. 1992).

Evidence from previous studies supports the premise that estuaries provide favorable environmental conditions that enhance the survival of juvenile marine organisms, particularly systems with extensive brackish marsh. Indicators of wetland function that directly measure the effects of environmental factors on the survival of individual organisms, or at least indirectly on their fitness, provide useful information for evaluating the ecological role of natural, created, or restored habitats. The results of this study suggest quantitative measurements of organismic responses to environmental conditions that affect survival rates can serve as indicators of a habitat's potential to enhance secondary production, even for transitory, anadromous species such as salmon. This type of assessment also provides valuable baseline information for documenting changes and variability in habitat conditions in brackish slough environments.

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