

**Outmigration Timing and Distribution of Larval Eulachon, *Thaleichthys pacificus*,
in the Lower Columbia River, Spring 2001.**

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INTRODUCTION

The eulachon *Thaleichthys pacificus*, an anadromous member of the smelt family, spawns along the Pacific coast of North America, from the Pribilof Islands (Bering Sea) to the Klamath River in California (Wydoski and Whitney 1979). The Lower Columbia Basin supports one of the largest spawning runs of eulachon, with the majority of spawning activity occurring in the main stem of the Columbia River and the Cowlitz River. Smaller, periodic runs occur in the Grays, Skamokawa, Elochoman, Kalama, Lewis, and Sandy tributaries. Adult migration in the Columbia River system usually begins in December, peaks in February and continues through May (WDFW 2001).

Spawning eulachon females generally deposit eggs in areas where the substrate consists of coarse sand/fine gravel, and where water flows are “moderate” in velocity (Hart and McHugh 1944; Smith and Saalfeld 1955). Eggs adhere to the surface of the substrate and incubate over a period of about 30-40 days, depending on temperature. Upon hatching the larvae become part of the drift as (presumably) passive plankters and are rapidly transported out to sea (Hart and McHugh 1944; Hart 1973) where they rear in near-shore marine areas at moderate to shallow depths (Barraclough 1964).

Historically, the commercial catch of eulachon in the Columbia River system has been strong, yet variable. Annual returns, based on commercial landings, were relatively stable until 1994 when a sharp decline occurred - a trend that continued through 1999. Although the 2000 and 2001 spawning runs were apparently stronger in the Lower Columbia, the relative magnitude is difficult to quantify as restrictive fishery

management strategies imposed in response to the recent decline in returns severely reduced commercial effort.

Mechanisms controlling eulachon recruitment and survival are poorly understood. Conditions in the freshwater environment, where eulachon spawn, may influence productivity. Of particular concern are the potential effects of dredging associated with the U.S. Army Corps of Engineers (USACE) proposed channel-deepening operations on the Columbia River (USACE 1999). Dredging activity has the potential to impact eulachon through entrainment of spawning adults (Larson and Moehl 1990, McGraw and Armstrong 1990) and possible smothering of developing eggs by increased turbidity and suspended sediment in the vicinity of operations (Morton 1977, Prussian et al. 1999). Entrainment of developing eggs and out-migrating larvae has not been documented but remains a concern. In response to these concerns the USACE contracted the Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Fish and Wildlife (WDFW) to identify eulachon spawning sites within proposed channel-deepening areas and to characterize the spatial and temporal distribution of eulachon larvae in the mainstem Columbia River during the out-migration period.

Results from the first year of the study (Spring 2000) showed that smelt larvae were widely distributed throughout the river during the out-migration period; however, sampling limitations precluded us from determining the relative importance of the shipping channel as a migration corridor relative to the remainder of the river. Our objectives in 2001 were to quantify the timing of larval outmigration, to determine cross-

channel larval distribution and to identify the depth distribution of larvae within the shipping channel.

METHODS

Study area

Results from field sampling in the spring of 2000 showed that the majority of out-migrating larvae in the Columbia River mainstem were found downstream of the confluence of the Cowlitz River at Columbia River kilometer (RK) 110 (Figure 1). This year we elected to concentrate sampling effort downstream of the Cowlitz River to maximize larval catch rates.

Sampling Design

To characterize the cross-river distribution of larvae in the study area we conducted sampling at seven transect sites (Figure 1). Transect locations were not chosen randomly. Transect 1 (RK 55), is an historical larval index site (Price Island Index) that has been monitored by the Washington Department of Fish and Wildlife (WDFW) since 1994 (WDFW 2001). Transect 6 (RK 106) was chosen to characterize the cross-river distribution of larvae in close proximity to a known major larval source (the Cowlitz River). Transects 2, 3, 4 and 5 (RK's 64, 75, 82 and 97 respectively) were chosen in an attempt to reflect the heterogeneity in river morphology and relative position of the shipping channel within the study area. During the season it became apparent that substantial numbers of adults had migrated upstream of the Cowlitz River as far as Bonneville Dam (RK 234) and so we elected to expand our sampling further upstream.

Transect 7 was added mid-season at RK 160, a location situated upstream of the Kalama River (RK 117) and Lewis River (RK 139) but downstream of the Sandy River (RK 194). Our objective was to assess larval dispersion from a point source (the Sandy River) in an area where contributions from main-stem spawning were likely to be minimal (no major main-stem spawning areas have previously been documented above Martin Bluff, RK 128).

We established five sampling stations positioned at intervals across the river along each transect. At least one of the stations at each transect was located within the shipping channel. Stations were numbered 1 through 5 across the river from the Washington shore to the Oregon shore. The number of samples collected at a station varied depending on depth. At shallow depths (< 3 m) samples were taken from the bottom of the water column only. At intermediate depths (≥ 3 m and ≤ 8 m) samples were taken from near the bottom and surface of the water column. At the deepest depths (> 8 m) samples were taken from near the bottom, middle and surface of the water column. For each of these depth strata (bottom, mid-water, surface) three replicate samples were taken in succession to account for short-term variability in larval density.

Field Methods

Eight passes of transects 1 - 6 were completed during the period January 28 to June 01, 2001 (Table 1). Transect 7 was sampled four times on April 24 and 27, and May 07 and 10. We used plankton nets deployed from anchored vessels to capture eulachon larvae. The net was a typical ring net design comprising a tapered nylon sock (3.35 m length, 300 μ m mesh) lashed to a stainless steel circular frame (0.61 m inside

diameter). Samples were collected in an 8.9-cm, two-piece polyvinyl chloride (PVC) bucket attached to the end of the sock. Spherical lead weights (2.54 kg, 9.07 kg or both) were attached to the frame base. The net was closeable via a row of choke rings placed around the sock approximately 1.3 m behind the mouth. Water flow was measured with a Swoffer® digital flowmeter consisting of a propeller/sensor mounted in the mouth of the net and connected to an onboard head unit via a cable (Illustrations of net configuration are given in Appendix B).

Sampling was conducted during daylight hours on ebb tides. Vessels were anchored at each station and Differential Global Positioning System (DGPS) coordinates, water temperature, depth and turbidity readings were recorded. Plankton nets were lowered to the desired depth, and allowed to fish for approximately 60 s, closed, and immediately retrieved. The flowmeter was activated when the net reached the desired sampling depth and stopped upon net closure. Contents of the collection bucket were rinsed into storage jars and fixed with dilute (approximately 70%) ethyl alcohol. Rose Bengal stain was added to this solution to aid in subsequent laboratory examination.

Laboratory Methods

Given the large number of samples taken and limited time available, we decided to employ a representative sub sampling methodology for estimating total larval counts. Samples were emptied into an Erlenmeyer flask and total sample volume was recorded. The flask was swirled to produce a random mixing of its contents and approximately 20% of the total sample volume was poured off in to a graduated cylinder. The sub sample

was in turn poured in to a Petrie dish and counts of all larvae present were made with the aid of a dissecting microscope. Total sample count estimates were then extrapolated based on sub sample volumes.

Data Analysis

Larval eulachon density estimates were calculated for each sample based on laboratory count and the estimated volume of water filtered through the plankton net tow using the following digital flow-meter formula:

$$V = R \left(\frac{1}{61} m / \text{revolution} \right) A$$

Where

V = volume sampled (m³)

R = revolution count from flow meter

A = area of net opening (m²)

Catch rate for larvae was estimated as catch per cubic meter in each sample.

The net was open during deployment and it is likely that mid-water and bottom samples were contaminated with larvae on the descent. However we considered the effects minimal since deployment was relatively rapid and made no corrections in the data analysis.

We examined the catch frequencies of larvae to describe the form of the catch distribution and found that the data possessed a strong negative binomial distribution, with several outliers (Figure 2). Attempts to normalize the error terms by transforming data as $\log(\text{catch rate} + 1)$ failed. Consequently we elected to test for significant differences in larval catch rate between sampling strata using non-parametric methods. We employed the Mann-Whitney rank sum test for paired comparisons and Kruskal-Wallis Analysis of Variance (ANOVA) for multiple comparisons. Following a significant result from the ANOVA further testing was performed to isolate differences amongst groups (Dunn's Test when group sample size was not equal; Student-Newman-Keuls test when group sample size was equal). All tests were performed at the $\alpha = 0.05$ level of significance. All statistical procedures were carried out using SigmaStat 2.0 software.

We compared: 1) larval densities from stations located within the shipping channel against combined densities from stations outside the channel for a) all transects combined, b) by individual transect, and c) using outside stations with depth profiles similar to in-channel sites (depths 12.2 m or greater) only; 2) individual station densities by transect and for all transects combined; and 3) depth strata densities for stations located inside the shipping channel by individual transect and with transects combined. Data from transects 1 – 6 were used in the primary analysis. Transect 7 was analyzed separately since sampling at this site was not synchronous with the other sites. To minimize the effects of temporal variation in larval population abundance during the out-

migration we chose to perform the remainder of our statistical comparisons on data from sampling passes 4, 5, and 6 only.

RESULTS

Larval density in the study area varied throughout the season (Figure 3). Larval catches peaked between April 02 and April 18 (corresponding to passes 4, 5 and 6). There was a significant difference in larval density among the eight sampling passes (Kruskal-Wallis ANOVA, $P < 0.001$). Larval densities in the study area during passes 4, 5, and 6 were significantly greater than all other sampling passes but were not significantly different among themselves. (Dunn's Test: between passes 4 and 5, $Q=1.318$, $P>0.05$; between passes 5 and 6, $Q=0.825$, $P>0.05$; between passes 4 and 6, $Q=2.140$, $P>0.05$).

There was a significant difference in larval density between individual transects (Kruskal-Wallis ANOVA, $P < 0.001$) although only transect 6 differed significantly (lower larval density) from the others ($P < 0.05$; Figure 4). Statistical comparisons where data from all transects were grouped were repeated with and without data from transect 6 with no significant changes in test results. Therefore, results are presented with transect 6 included.

Cross-Channel Larval Distribution

Larval densities outside the shipping channel were significantly greater than inside the channel (Rank Sum test, $t=46892.5$, $P<0.001$) when data from all transects were combined.

There were no significant differences between larval densities within and outside the shipping channel at transects 1, 2, and 4 (Rank Sum test: $t=1343.5$, $P=0.524$; $t=1585.0$, $P=0.961$; $t=1491.0$, $P=0.969$ respectively; Figure 5) when these transects were analyzed individually. However, larval densities were significantly greater outside the shipping channel for transects 3, 5 and 6 (Rank Sum test: $t=1260.0$, $P=0.031$; $t=899.0$, $P<0.001$; $t=899.0$, $P<0.001$ respectively; Figure 5) when these transect were analyzed individually.

For stations ≥ 12.2 m in depth (the minimum depth of the shipping channel) larval densities outside the shipping channel were significantly greater than at stations within the shipping channel. (Rank Sum test, $t=899.0$, $P<0.001$).

With data from all transects combined, larval densities decreased across the river from the Washington shore to the Oregon shore (Figure 6). Station 1 larval densities were significantly greater than all other stations, station 2 densities were significantly greater than station 3, 4, and 5 and station 3 densities were significantly greater than those at station 4 (Dunn's test, $P < 0.05$ in all cases). This trend is reflected in individual transects though the effect is reduced progressively downstream (Figure 7).

Vertical Distribution Within the Shipping Channel

Larval densities were significantly different between depth strata for sampling stations located within the shipping channel (Kruskal-Wallis ANOVA, $P < 0.001$; Figure 8). Larval densities were not significantly different between bottom and mid-water strata

(Student-Newman-Keuls, $q=1.508$, $P>0.05$). However, both bottom and mid-water larval densities were significantly greater (Student-Newman-Keuls: $q=7.601$, $P<0.05$; $q=9.876$, $P<0.05$ respectively) than surface larval density.

There were no significant differences in larval density between depth strata for the shipping channel stations of transect 1, 4 and 5 when these were analyzed separately (Kruskal-Wallis ANOVA: $P=0.076$; $P=0.067$; $P=0.093$ respectively). There were, however, significant differences in larval densities between depth strata for the shipping channel stations of transect 2, 3 and 6 (Kruskal-Wallis ANOVA: $P=0.006$; $P<0.001$; $P=0.018$; respectively). Larval densities were significantly greater in bottom samples than surface samples (Dunn's Test: $q=2.910$, $P<0.05$; $q=3.653$, $P<0.05$; $q=2.525$, $P<0.05$ respectively), but not significantly different than mid-water samples (Dunn's Test: $q=0.297$, $P>0.05$; $q=1.158$, $P>0.05$; $q=0.556$, $P>0.05$ respectively). Mid-water larval densities were greater than the surface catches for transects 2 and 3 (Dunn's Test: $q=2.613$, $P<0.05$; $q=2.494$, $P<0.05$ respectively) but not for transect 6 (Dunn's Test: $q=2.376$, $P>0.05$).

Transect 7

Larval densities were significantly greater at stations located outside the shipping channel than stations located within the channel (Rank Sum test: $t=4959.0$; $P=0.033$; Figure 7). Station 1 catches were significantly greater than all other stations. There were no significant differences in larval densities between stations 2, 3, 4 and 5 (Figure 7).

Larval densities were significantly different between depth strata at sampling stations located within the shipping channel (Kruskal-Wallis ANOVA, $P < 0.001$). Larval densities in bottom samples were significantly greater than in mid-water samples (Dunn's Test, $q = 4.928$, $P < 0.05$), and in surface samples (Dunn's Test, $q = 9.549$, $P < 0.05$).

DISCUSSION

The eulachon spawning migration of 2001 was the largest in several years (WDFW 2001). Substantial numbers of adults migrated as far upstream as Bonneville Dam (RK 233) and into all the major Lower Columbia tributaries (Grays, Elochoman, Kalama, Lewis and Sandy Rivers). Commercial landings in the main-stem of the Columbia River were slightly higher than recent years but were still low in historical terms due to continued conservative management that restricted effort during the season (WDFW 2001). However, catch per unit effort (pounds per delivery) was the highest since 1993.

The timing of adult and larval migrations was later this year than last year. Peak larval densities were recorded in early/mid April this year compared with mid March in 2000. The late arrival of adults this year may have been influenced by water temperature of the river. Generally, temperatures below 4 °C inhibit eulachon spawning migrations into the Columbia River (Smith and Saalfeld 1955). This year the bulk of the adult entry into the river occurred after mid February, when temperature of the Columbia River exceeded 4 °C.

Within the study area, migrating larval eulachon were more abundant in the combined area outside of the shipping channel than within the shipping channel itself. Larval densities were generally greater toward to the Washington shore and decreased across the river to the Oregon shore (Figure 6). This trend is pronounced in transects 5 and 6 but becomes progressively less so in successive downstream transects (Figure 7). Transect 6 is located approximately 3 km downstream from the mouth of the Cowlitz River - a well documented spawning area for eulachon (Smith and Saalfeld 1955, Hymer 1994, WDFW 2001). Transect 5 is located < 2 km downstream from Barlow Point (Washington shore) – a location where we recorded high catches of eulachon eggs on artificial substrates during work related to this study this year (Romano et al., in prep.).

It is interesting to note that the cross channel distribution of larvae at transect 3 does not reflect the trend seen at transects 5 and 6 despite its location downstream of, and in close proximity to, Eagle Cliff (RK 82) - a site on the Washington shore historically recognized as a major mainstem eulachon spawning area (Loeffel 1954, Smith and Saalfeld 1955). We found no significant difference in the density of eulachon larvae between stations 1, 2, 3, and 4 of transect 3 (Figure 7). In our study of mainstem eulachon spawning distribution we collected eulachon eggs on artificial substrates in the vicinity of Eagle Cliff (Romano et al. in prep.), however, the number of eggs caught at this location was low despite substantial sampling effort. These observations suggest that the majority of spawning in the study area occurred in the Cowlitz River and the Columbia River in the vicinity of transect 5, and that the trends seen in successive downstream transects are the result of gradual cross channel dispersion of the larval population. Although we documented spawning in several main-stem locations (such as

at Eagle Cliff) with artificial substrates, it appears their input was relatively minor in magnitude since significant cumulative increases in overall larval abundance were not observed at successive downstream transects.

Larval densities at transect 7 were not significantly different between stations 2, 3, 4 and 5. However, station 1 densities were significantly greater than at all other stations. Transect 7 (RK 161) is located upstream of all Columbia River tributaries in which eulachon are known to spawn, with the exception of the Sandy River (RK 194; Figure 1). Large numbers of eulachon were observed to enter the Sandy River this year (personal observation) where they presumably spawned. Spawning in the main-stem of the Columbia River has never been recorded upstream of Martin's Bluff (RK 128; Loeffel 1954) and we collected no eggs above the mouth of the Kalama River (RK 117) during our study of eulachon spawning distribution with artificial substrates this year (Romano et al. in prep.). However, the cross channel distribution of larvae at transect 7 suggests that some mainstem spawning did occur on the Washington shore upstream of station 1. The even distribution of larvae across the river through stations 2 – 5 suggests cross-river dispersal from a major upstream source – probably the Sandy River.

Larval densities in the shipping channel were significantly greater in the lower portion of the water column when data from all in-channel stations were combined. This is consistent with observations made by Loeffel (1954) and Smith and Saalfeld (1955) who reported catching larger numbers of larval eulachon deeper in the water column. When observed individually, however, only shipping channel stations at transects 2, 3, 6

and 7 show this distribution. No significant differences in larval density between depth strata were observed at transects 1, 4 and 5.

It is unclear what mechanisms might affect the distribution of larvae in the water column. Anecdotal laboratory observations suggest larval eulachon exhibit pelagic swim up behavior (Howell, in prep., Wendler 1937) and positive phototropism (Howell in prep.) – adaptive behavior documented in other ichthyoplankton species to facilitate in feeding, lateral transport and predator avoidance (Fortier and Leggett 1983, Manuel and O’Dor 1997). Eulachon larvae subsist on yolk sac contents on their journey to the estuary and ocean where exogenous feeding is assumed to initiate (Smith and Saalfeld 1955) and it is apparent that rapid flushing to the ocean is crucial for survival. Vertical migration up in to the water column on ebb tides where velocities are greater would expedite the journey. However, evidence of this behavior it is not apparent in our data - in fact it appears the opposite is true. The Lower Columbia is subject to strong tidal influences that produce complex, turbulent flow conditions and since larval eulachon are relatively weak swimmers, depth distributions are perhaps dictated by local hydraulic conditions.

The observed larval distributions this year were derived from sampling that occurred only during daylight hours on ebb tides. It is possible that diel and tidal cycles may incur changes in larval distribution. In addition, inter-annual variation in spawning site locations and run size is also likely to influence distribution. In a year of high abundance, such as this year, where larval abundance was not significantly greater in

proposed dredging areas than in other areas of the river channel, dredging related mortality (through entrainment) might be considered insignificant relative to the population as a whole. However, mechanisms controlling eulachon recruitment and survival are poorly understood, and there is little understanding as to how variation in habitat conditions in the freshwater environment affects the survival of larvae.

If dredging activities are to be scheduled to reduce impacts to outmigrating larvae, then planning will be necessarily confined to the short term due to inter-annual variation in run timing, magnitude and spawning locations. Unlike most of the major salmonid runs, where estimates of stock size provide the basis for development of reliable forecasts, there is no developed forecasting or assessment model for eulachon. Currently only in-season commercial monitoring exists to evaluate run size and timing.

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Table 1. Summary of sampling during 2001 USACE larval out-migration study.

Pass	Duration	Comments
1	Jan. 30, Feb 1, 2, 7, 13, 14	Gear Testing
2	Feb. 28, Mar. 1, 2	
3	Mar. 14, 15, 16	
4	Apr 2, 3, 4, 5	
5	Apr 11, 12, 13	
6	Apr 16, 17, 18	
7	May 01, 02, 03	Transect 1 not sampled
8	May 11, 15, 16	Transects 2, 3, 4 not sampled

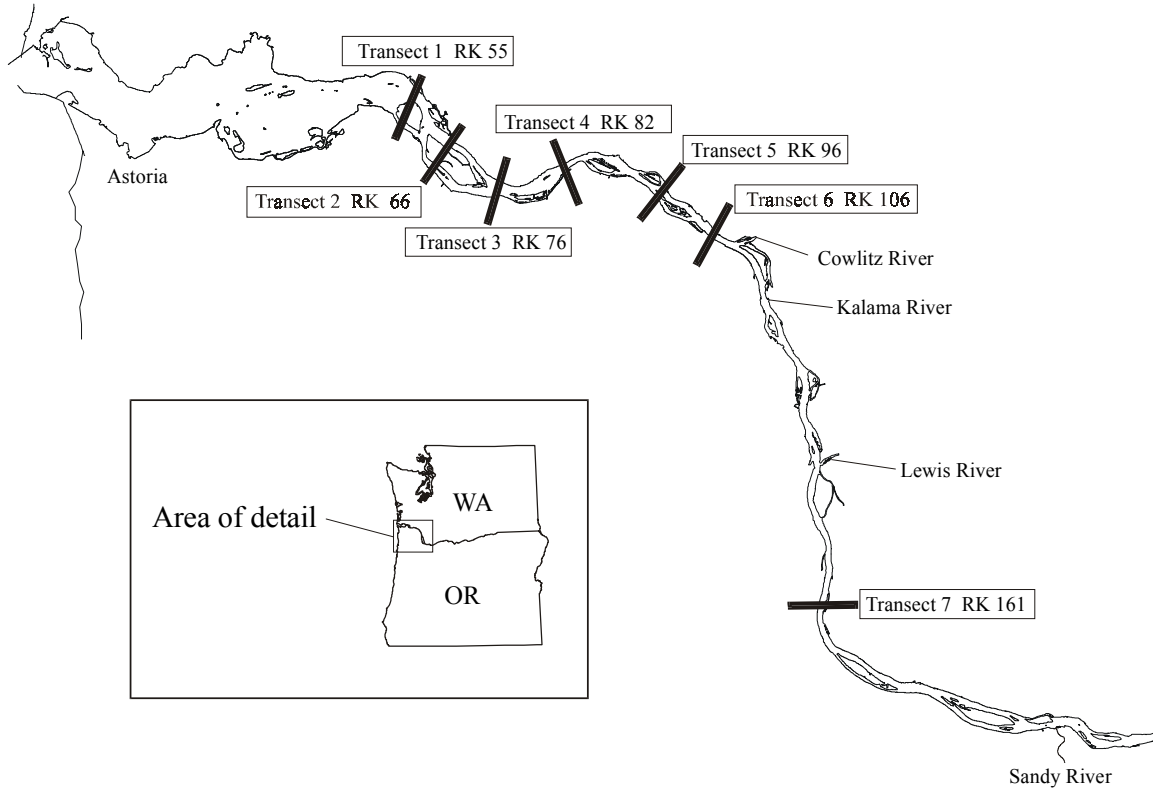


Figure 1. 2001 lower Columbia River, larval eulachon migration study site, showing location of larval eulachon sampling transects, listed by transect name and Columbia River kilometer (RK).

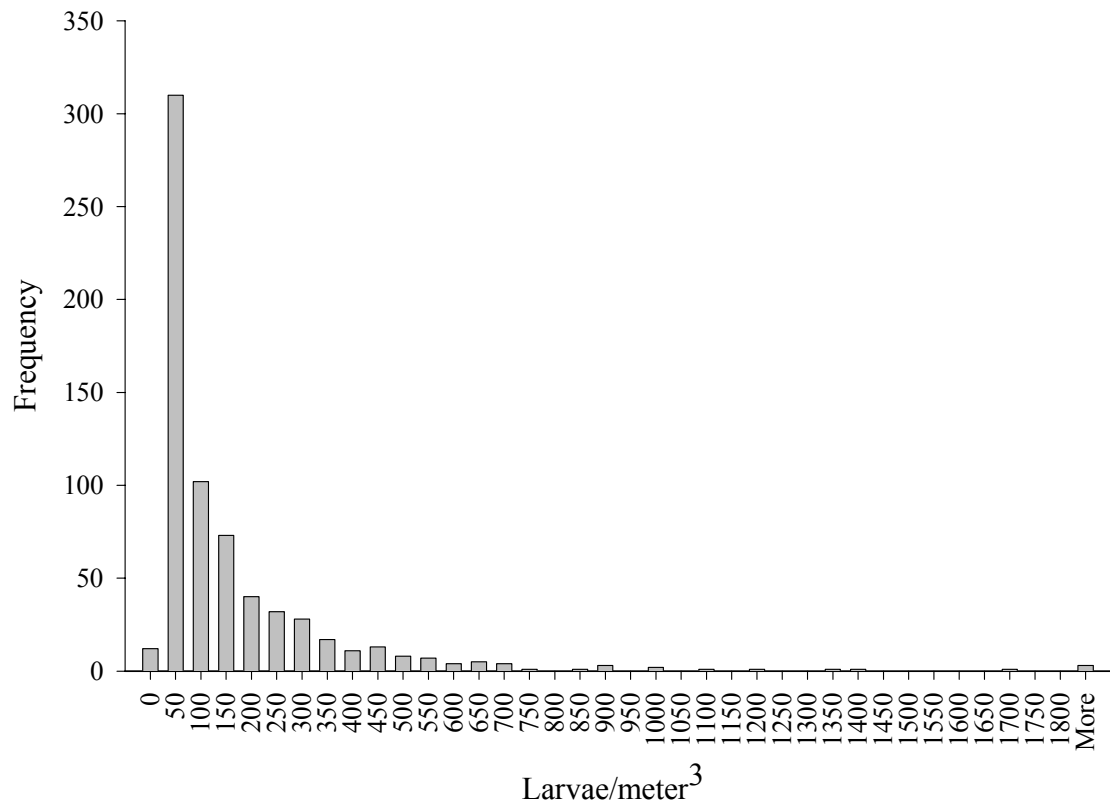


Figure 2. Density frequencies of larval eulachon collected in the Lower Columbia River during the peak of outmigration, spring 2001. Note negative binomial distribution.

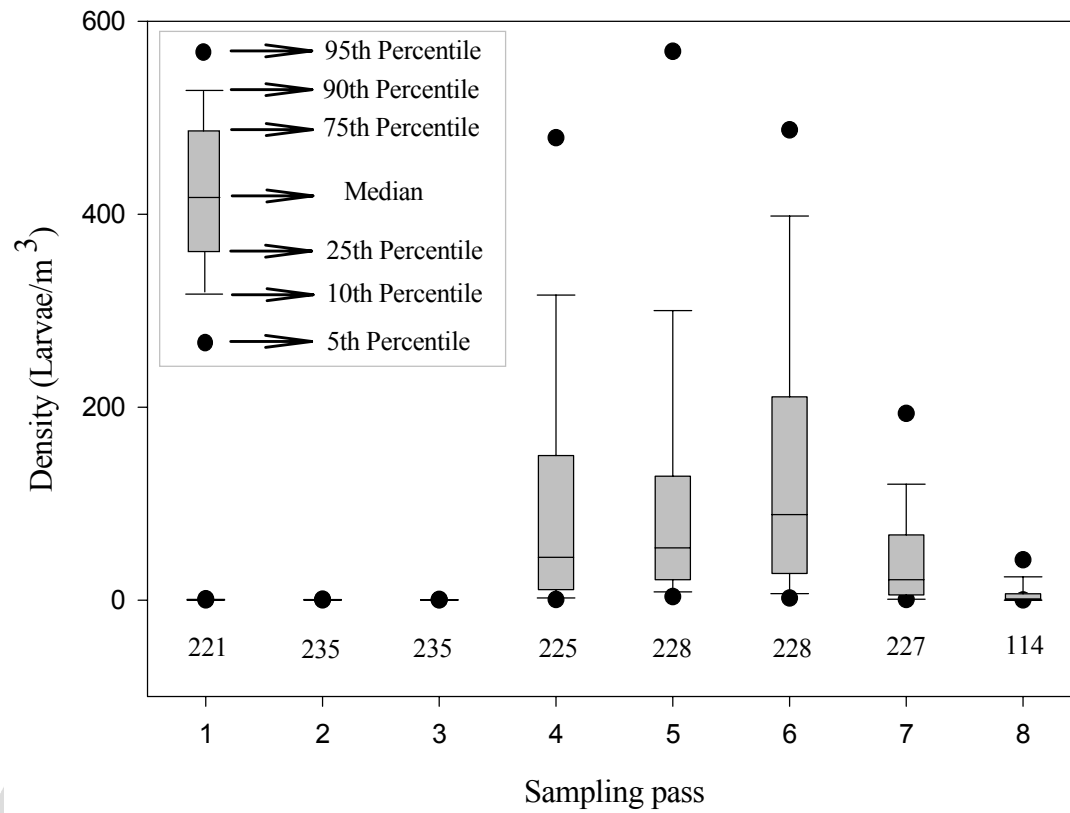


Figure 3. Larval eulachon densities in the Lower Columbia River during spring, 2000. Numbers below plots indicate sample size.

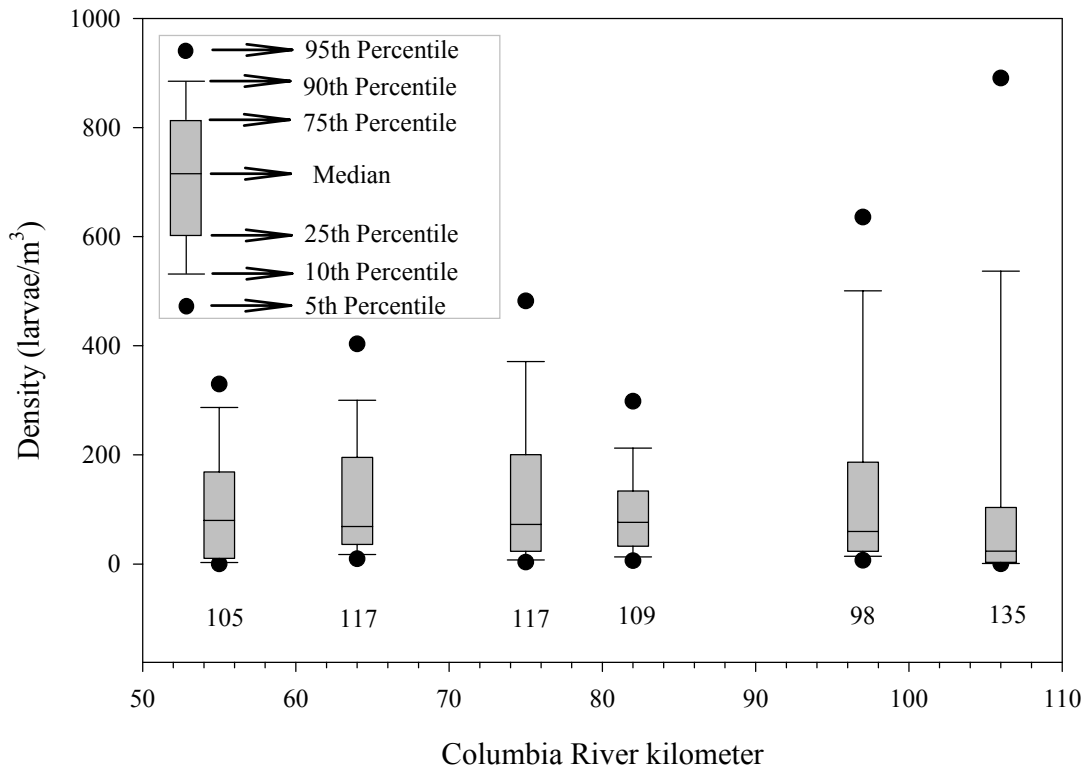


Figure 4. Larval eulachon densities at various sites in the Lower Columbia River during peak outmigration, spring 2001. Numbers below plots indicate sample size.

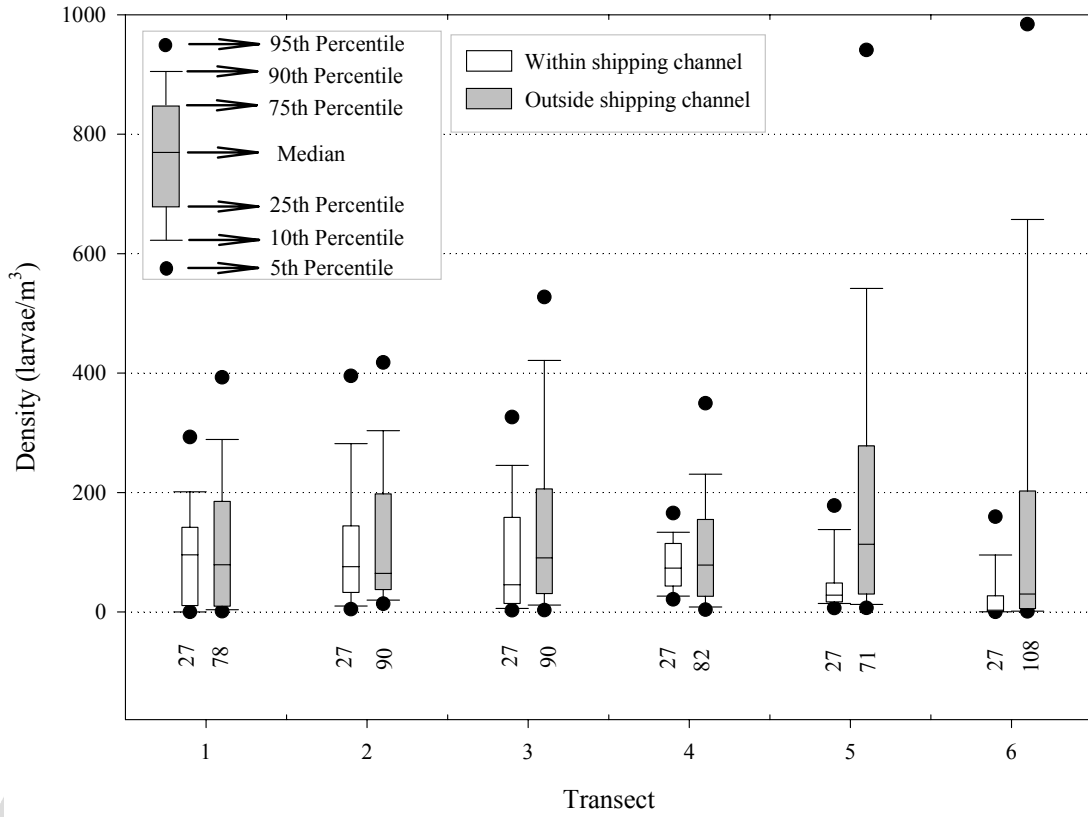


Figure 5. Larval eulachon densities inside and outside the Lower Columbia River shipping channel during the peak of outmigration, spring 2001. Numbers below plots indicate sample size.

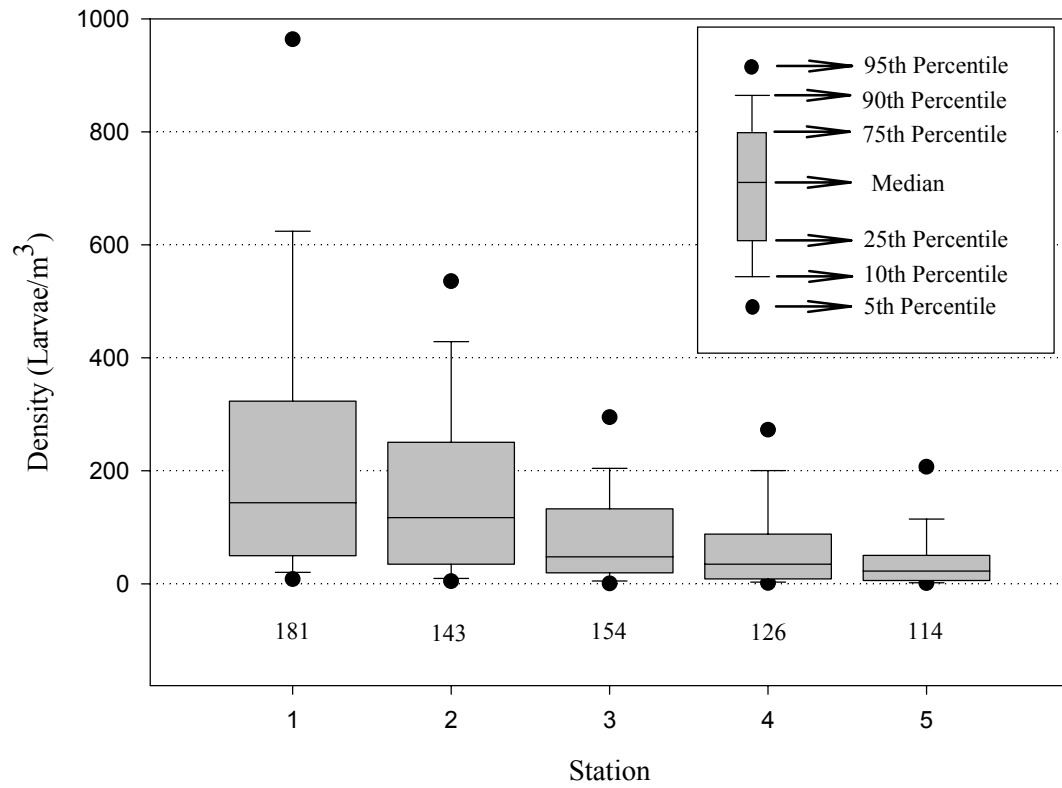


Figure 6. Cross channel distribution of larval eulachon in the Lower Columbia River during the peak of outmigration, spring 2001. Numbers below plots indicate sample size.

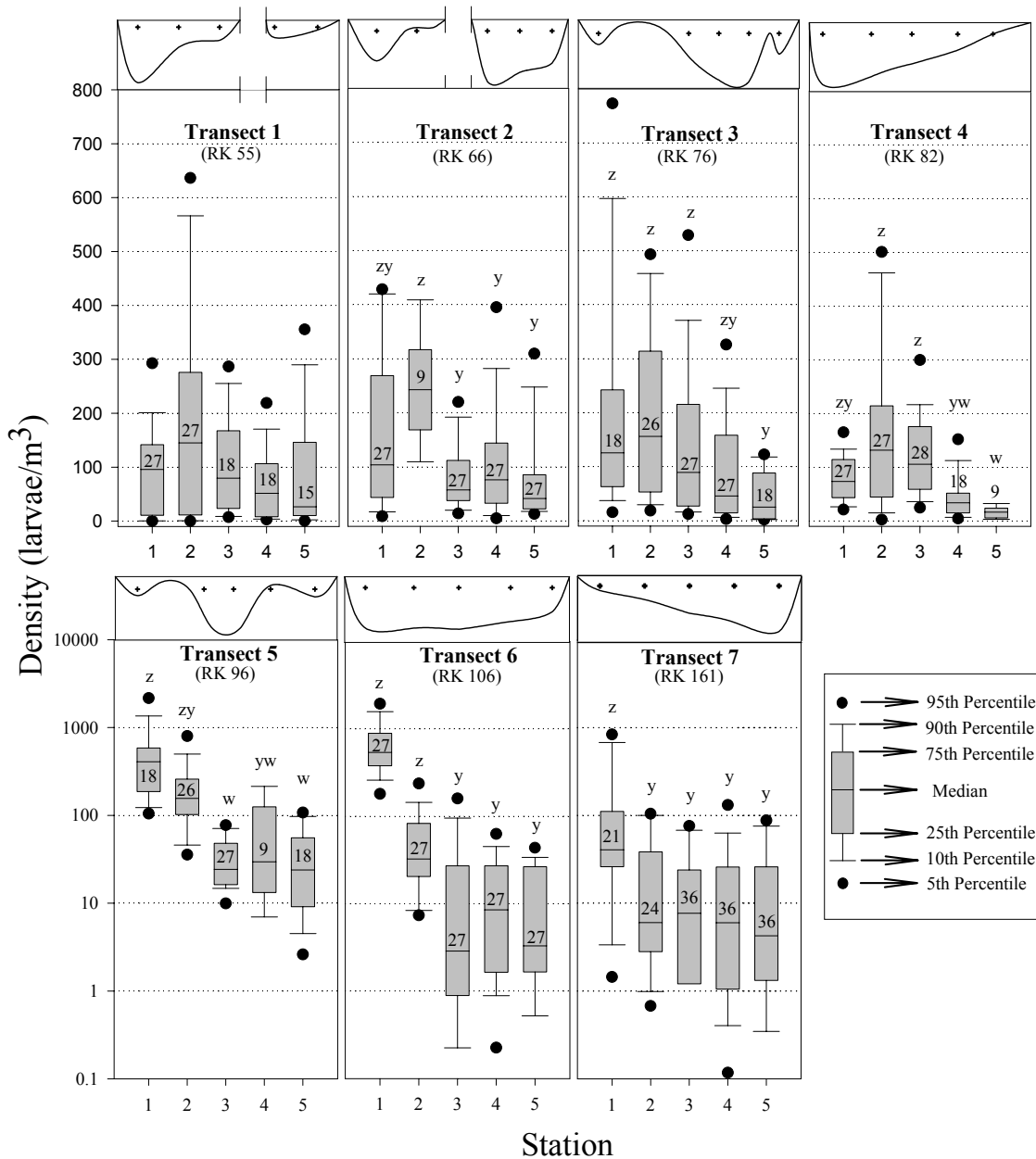


Figure 7. Cross river eulachon larval distribution at seven transects in the Lower Columbia River during the peak of outmigration, spring 2001. Data groups with letters contain significant differences in larval density among stations (Kruskal-Wallis ANOVA; $P \leq 0.05$); within these groups, catches without a letter in common differ ($P < 0.05$). Note logarithmic scale for transects 5-7. Schematics of channel morphology at each transect are shown above each data group. Scaling is not consistent between plots.

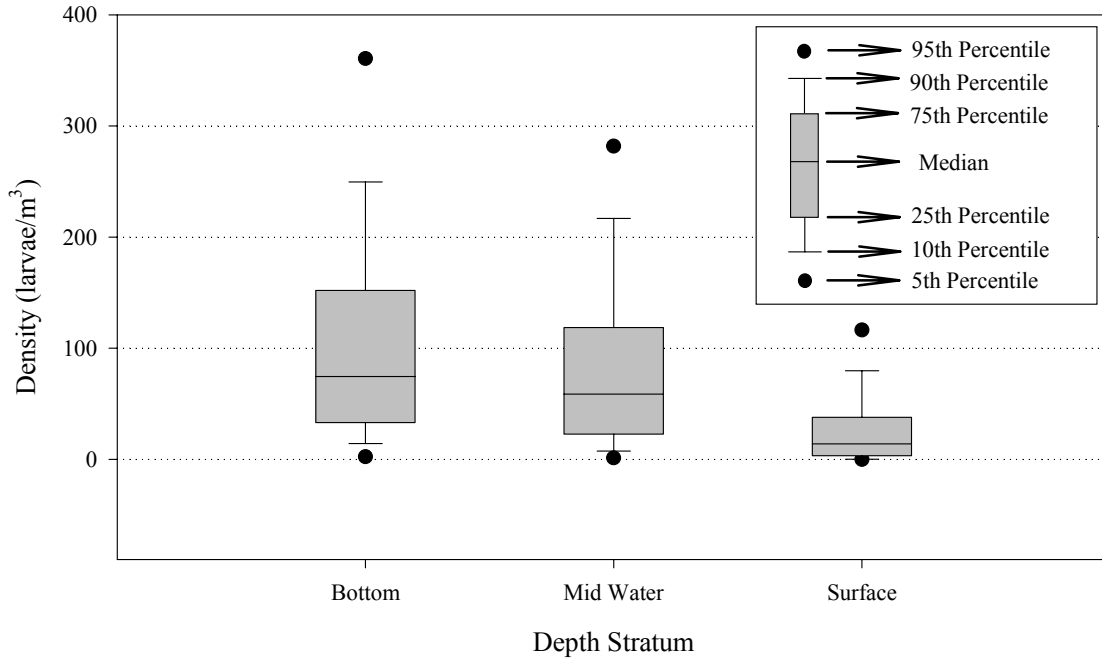
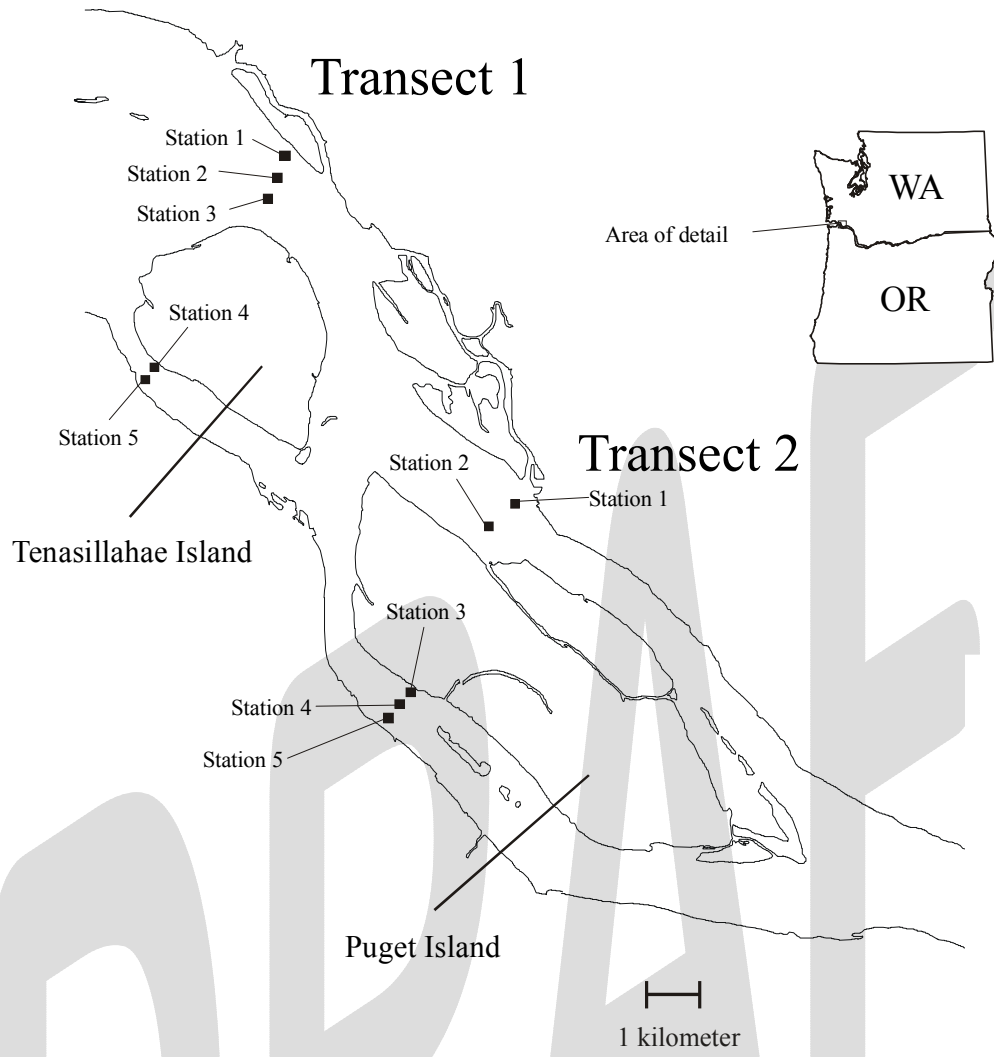
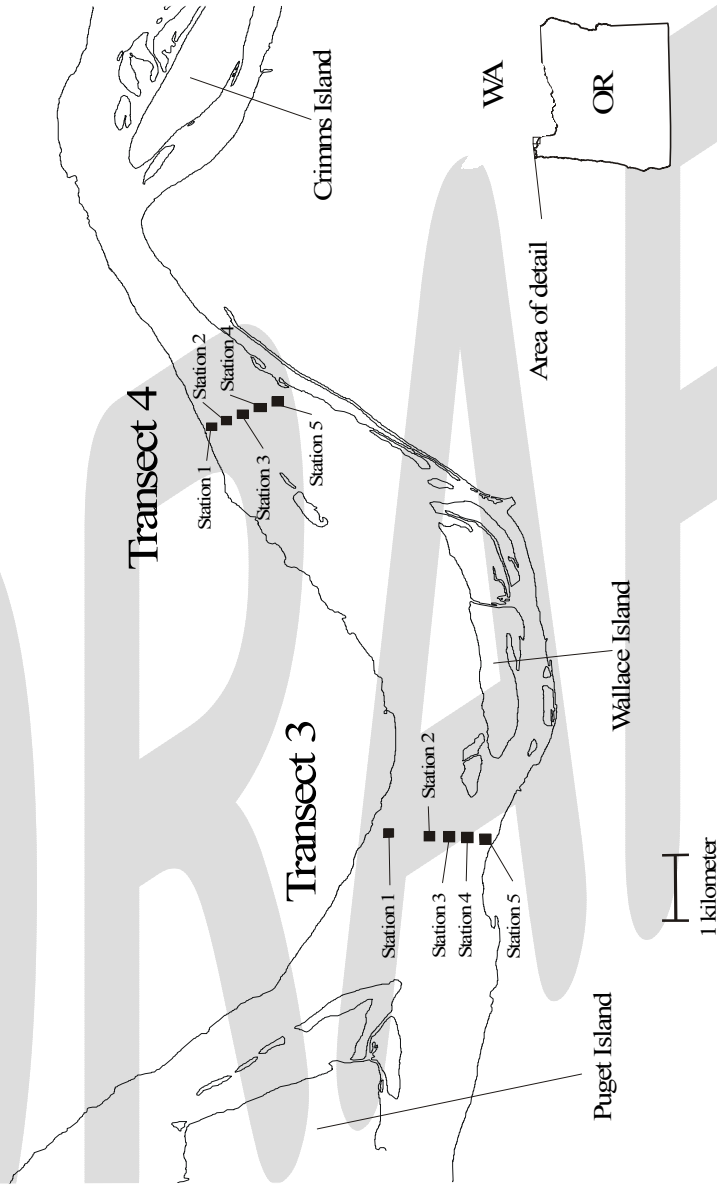


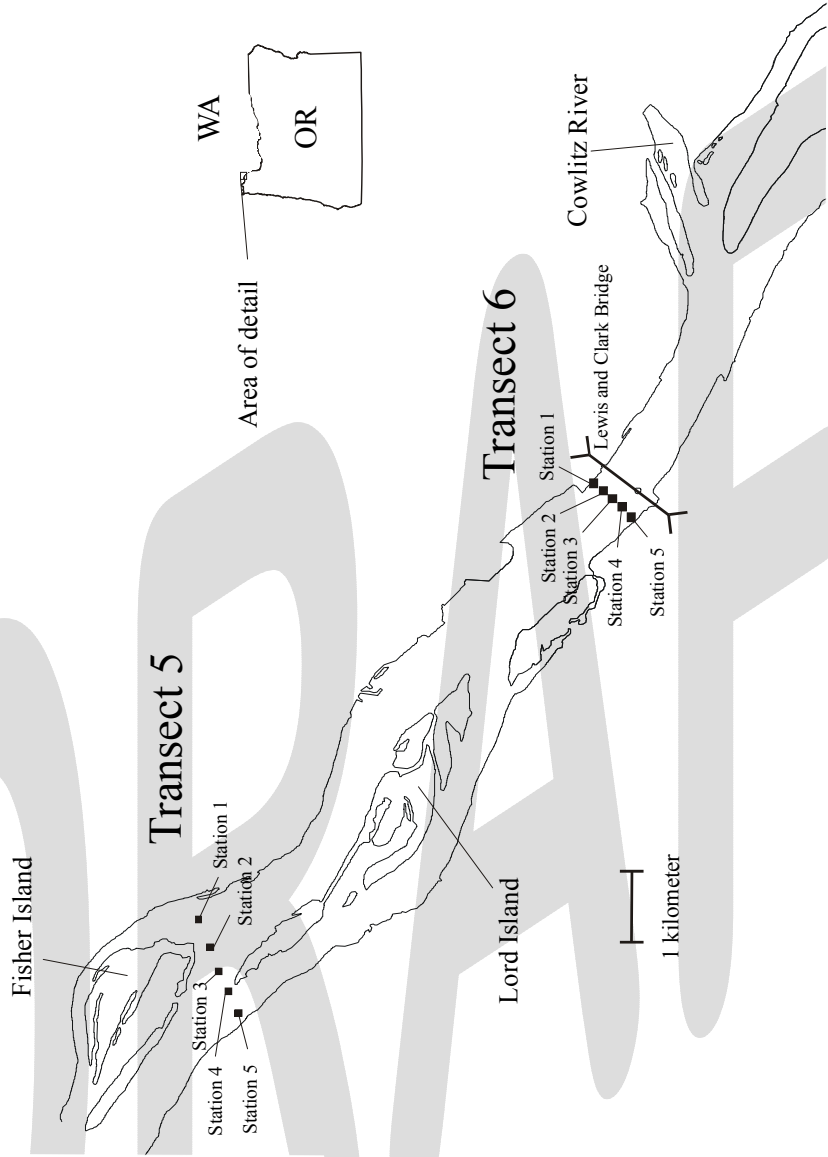
Figure 8. Vertical distribution of larval eulachon in the shipping channel of the Lower Columbia River during peak outmigration, spring 2001. Each plot represents 54 samples.



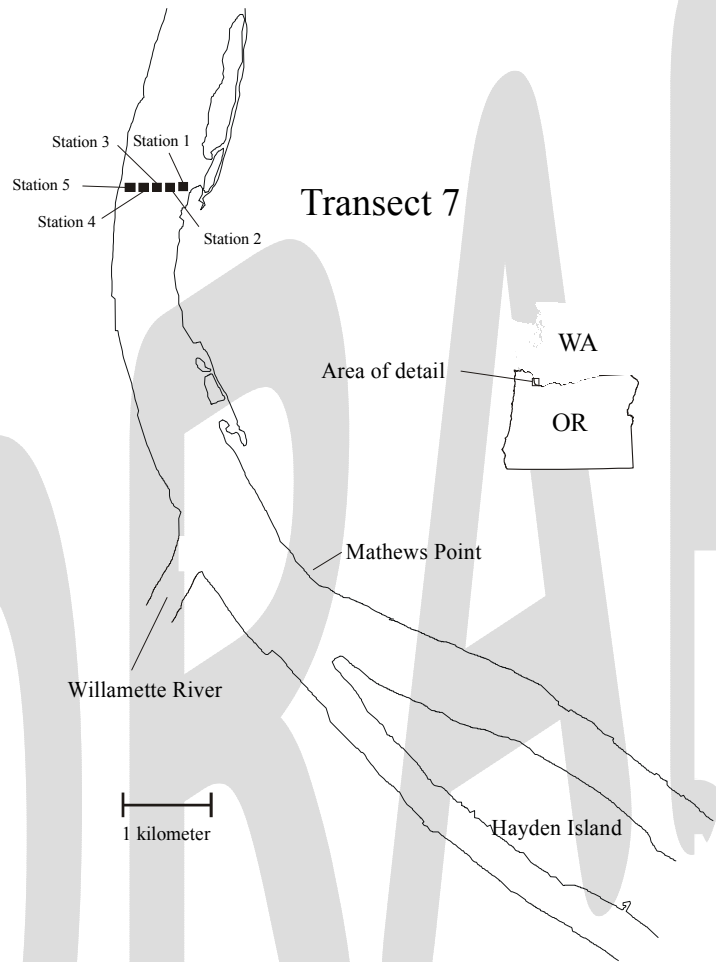
Appendix A. 2001 USACE larval smelt sampling sites, Transect 1 (RK 55) and Transect 2 (RK 66), lower Columbia River.



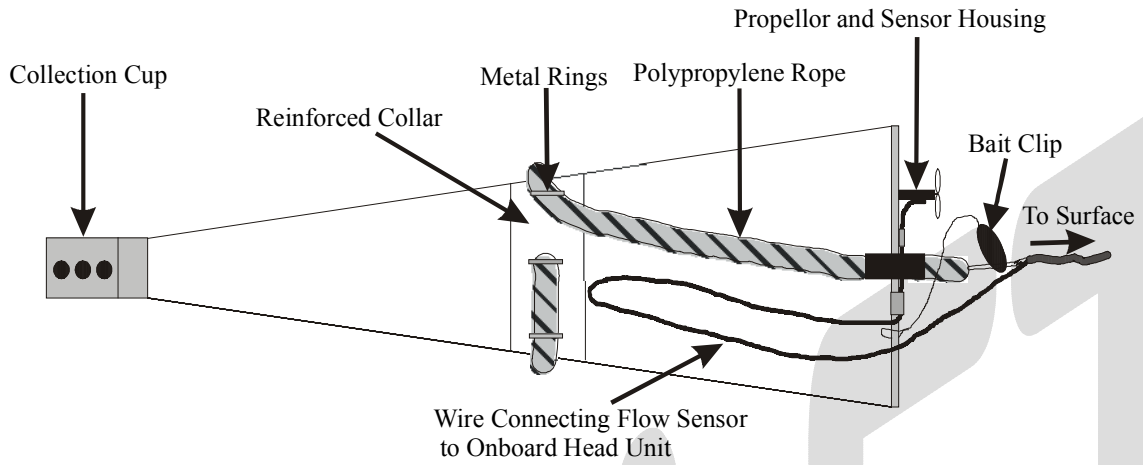
Appendix A. 2001 USACE, lower Columbia River larval smelt sampling sites, Transect 3 (RK 76) and Transect 4 (RK 82).



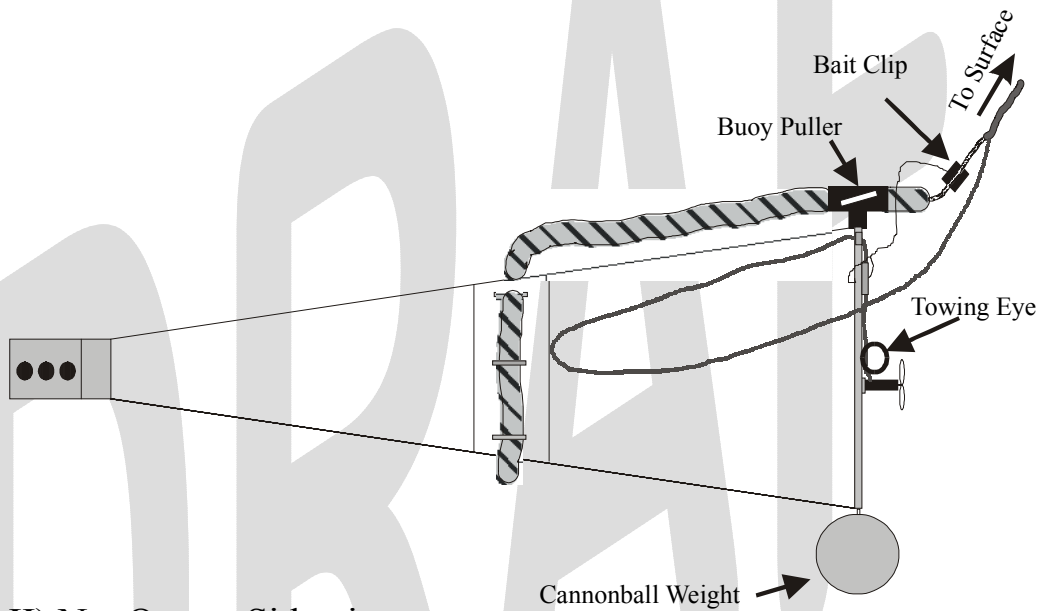
Appendix A. 2001 USACE larval smelt sampling sites, Transect 5 (RK 96) and Transect 6 (RK 106), lower Columbia River.



Appendix A. 2001 USACE larval smelt sampling site, Transect 7 (RK 161), lower Columbia River.

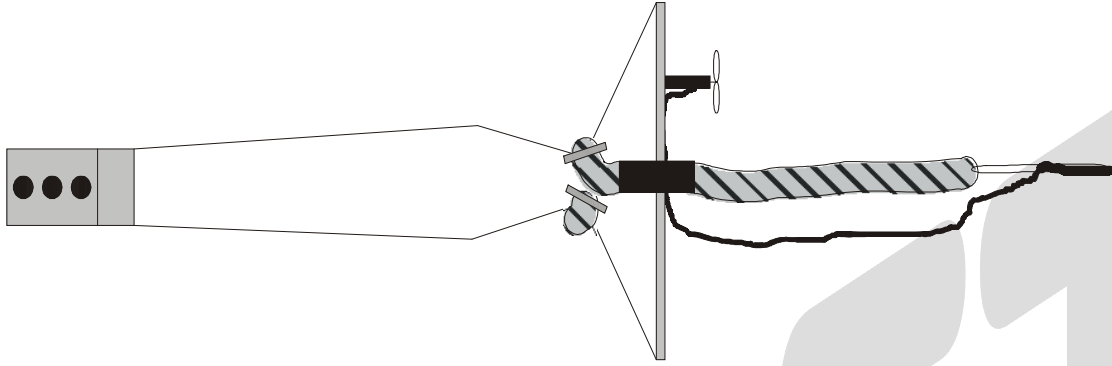


I) Net Open - Plan View

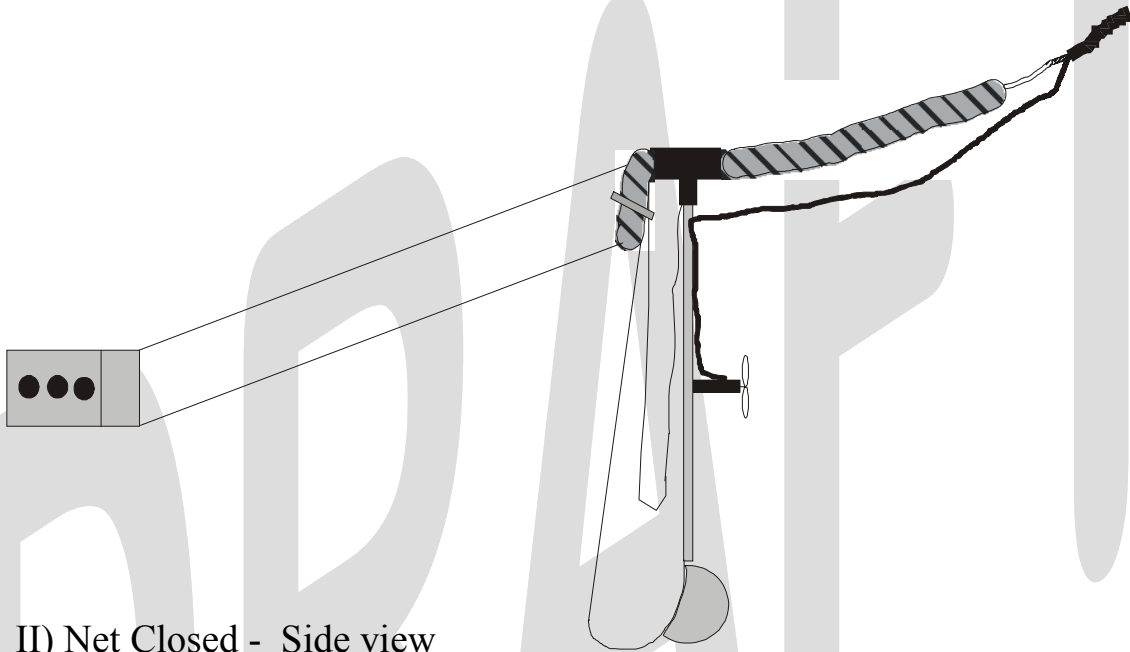


II) Net Open - Side view

Appendix B. Schematic diagrams of modified plankton net gear used in 2001 USACE larval smelt sampling.

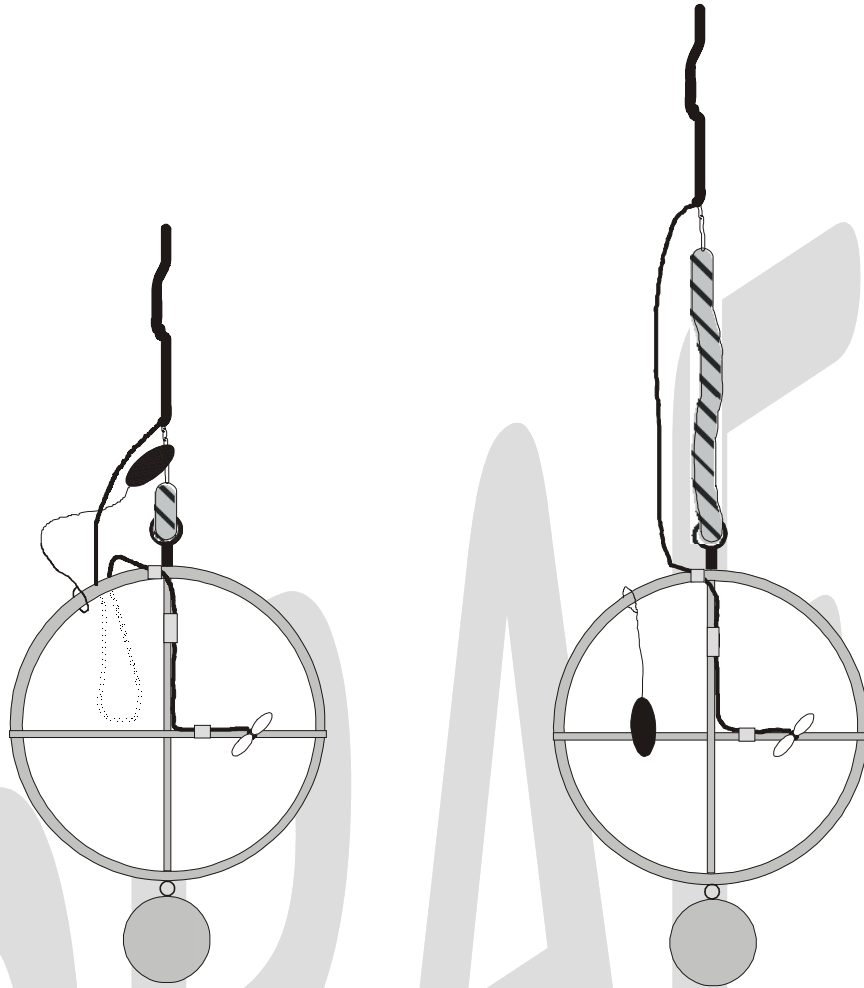


I) Net Closed - Plan View



II) Net Closed - Side view

Appendix B. Schematic diagrams of modified plankton net gear used in 2001 USACE larval smelt sampling.



I) Net Open - Forward View

II) Net Closed - Forward View

Appendix B. Schematic diagrams of modified plankton net gear used in 2001 USACE larval smelt sampling.