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RESIDENCE OF JUVENILE CHINOOK SALMON, *Oncorhynchus tshawytscha*, IN THE SMITH RIVER ESTUARY, CALIFORNIA, 1998-2000.

by

David Zajanc

A Thesis

Presented to

The Faculty of Humboldt State University

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Of the Requirements for the Degree

Master of Science

In Natural Resources: Fisheries

May, 2003

RESIDENCE OF JUVENILE CHINOOK SALMON, *ONCORHYNCHUS TSHAWYTSCHA*, IN THE SMITH RIVER ESTUARY, CALIFORNIA, 1998-2000

By

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ABSTRACT

Master of Science in Natural Resources: Fisheries. Residence of Juvenile Chinook Salmon, *Oncorhynchus tshawytscha*, in the Smith River Estuary, California, 1998-2000.

David Zajanc

Wild juvenile chinook salmon appear to spend an extended period of time in the estuary of the Smith River, California. Based on recovery patterns of freeze-branded juveniles released from June through August, 2000, mean estuarine residence time ranged from 8.3-13.8 d during June and July, and increased to an estimated 38.3 d for fish marked and released in August. Based on computer simulations of the process of estuarine entrance and exit, and on evidence of estuarine growth of juvenile chinook salmon, it appears that these estimates of mean residence times were negatively biased. True mean residence times calculated in other studies may also be considerably longer than those estimated using existing published methods.

Rowdy Creek Hatchery rears large numbers of chinook salmon and many are released as fingerlings into the Smith River estuary during May-June. In 1999, about 13% of Rowdy Creek fingerlings were marked with a left maxillary clip, whereas in 2000 about 22% of fingerlings were marked with an adipose fin clip and coded wire tag. Based on collection and examination of juvenile chinook salmon in the Smith River estuary, following release of these hatchery fish, it appears that the majority of chinook salmon juveniles are still produced by wild spawning fish rather than by Rowdy Creek Hatchery. Maximum estimated daily percentages of hatchery juveniles were 33% in 1999 and 31% during 2000. Within 30 days following releases in 1999 and 2000, the estimated

percentages of hatchery fish present in the estuary had dropped to 15% and 9%, respectively. Together, these estimates of estuarine residence time and percentages of hatchery fish suggest that the Smith River estuary may be an important habitat for wild juvenile chinook salmon.

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INTRODUCTION

Of the Pacific salmon species, the chinook salmon (*Oncorhynchus tshawytscha*) probably exhibits the greatest diversity in life history patterns. Juveniles may enter an estuary immediately following emergence or after spending more than a year rearing in freshwater (Healey 1991). Thereafter chinook salmon juveniles spend from 6 days to 6 months in estuaries prior to moving to the ocean for further growth (Simenstad et al. 1982). Ocean residence may range from 1 to 6 years, and ocean migration patterns are highly variable across populations. Age at maturity ranges from age 2 (almost exclusively males) to age 7 (males and females). Adult fish may enter freshwater throughout the year and time of spawning ranges from 1 to 7 months following freshwater entry (Nicholas and Hankin 1988). Relative to other species of salmon, the chinook salmon appears to take greater advantage of estuaries (Healey 1991). Size and age at estuary entrance, utilization of estuarine habitats, and length of residence may vary among different life history types, but all chinook salmon must spend some time feeding and growing in the estuary (Healey 1982).

One way to gauge the importance of estuaries to chinook salmon would be to determine the duration of time that this species generally spends in estuaries prior to entering the ocean. In published studies, individual fish have been documented to remain in estuaries for up to 2 months in California (Kjelson et al. 1982, Wallace 2000), up to 5 months in Oregon (Nicholas and Hankin 1988), and up to 6 months in Washington (Simenstad et al. 1982). Such documented observations do not, however, suggest what the *average* duration of estuarine residence might be. In the relatively few

published studies that have attempted to quantitatively assess the importance of estuaries to chinook salmon, a mark-recapture approach has typically been used to characterize estuary dependence (Reimers 1973, Healey 1980, Congleton et al. 1981, Kjelson et al. 1982, Levy and Northcote 1982, Levings et al. 1986, Macdonald et al. 1988, Fisher and Pearcy 1990, Shreffler et al. 1990, Wallace 2000). In the majority of these studies, both marking and recapture efforts have both been carried out within the estuary. Given an initial mark and release of a known number of fish, the pattern of decline in standardized catch-per-unit-effort (CPUE) has been used to estimate a "disappearance rate" which must, to some degree, reflect duration of estuarine residence. That is, a high disappearance rate would indicate that fish move rapidly out of an estuary, whereas a low disappearance rate would suggest that, on average, fish remain in an estuary for a substantial period of time.

Many researchers (e.g., Healey 1980, Myers and Horton 1982, Levings et al. 1986, MacDonald et al. 1988) have assumed that the pattern of decline in CPUE of recaptured marked fish should be of an exponential form. Disappearance rate could then be estimated as the slope of a regression of the natural logarithm of CPUE against days following marking. Once disappearance rates have been estimated using this approach, they have been used to calculate values that have been called "residency half-life" and "mean residence time". "Residency half-life" is intended to measure the number of days by which time 50% of the individuals from a marked group have left an area (Myers and Horton 1982). "Mean residence time" is either not clearly defined (e.g., Healey 1980, Levings et al. 1986), or is defined inconsistently by different authors (e.g., Congleton et

al. 1981, Macdonald et al. 1988). Without precise explanations, Healey (1980) estimated an "average residence time" of 60 d based on a daily disappearance rate of 11 – 12% for chinook in the Nanaimo River estuary, British Columbia. Levings et al. (1986) reported "apparent mean residence times" of 65 d for wild fish and 31 d for hatchery fish in the Campbell River estuary, British Columbia (no disappearance rates given). When methods of estimation are explored in detail, researchers have tended to vary in their interpretation of mean residence time. Congleton et al. (1981) described a "weighted mean residence time" as the average of the mean time to disappearance for each 10% portion of a marked group, from the first 10% to the last 10% to leave the estuary. They reported estimates ranging from 2.4 to 3.8 d for chinook in the Skagit River estuary, Washington. For fish in the Campbell River estuary, British Columbia, Macdonald et al. (1988) utilized the mean CPUE of marked fish within their fitted regression equation to estimate a "mean residence time" of 33.8 d. Although published estimates may not be unbiased or fully consistent with one another, they do support a contention that juvenile chinook salmon may sometimes spend considerable time in estuaries.

An important population of fall chinook salmon exists in northern California's Smith River. The Smith River is the only remaining undammed river in California and has received special attention at both state and national levels. Under the "Northwest Forest Plan", the Smith River has been designated as a key watershed (Forest Ecosystem Management Assessment Team 1993), and the Smith River is a part of both federal and California Wild and Scenic River systems. Although freshwater habitat in this system is

relatively pristine, estuary habitat has been severely altered by agricultural activities (diking and drainage) associated with cattle grazing and ranching. As part of a California Sea Grant project devoted to assessment of the ecological importance and restoration potential of the Smith River estuary, we conducted a three year mark-recapture experiment designed to evaluate the use of the Smith River estuary by juvenile chinook salmon. The primary objectives of this mark-recapture study were to determine the average number of days that juvenile chinook salmon spent in the estuary prior to moving to the ocean environment, and to describe seasonal changes in the sizes of juvenile chinook salmon that were present in the estuary. A secondary objective was to estimate the proportion of the juvenile chinook salmon population in the estuary that was contributed from Rowdy Creek Hatchery, a facility operated immediately above the Smith River estuary.

STUDY AREA

The Smith River has a 7.2 km long estuary that enters the Pacific Ocean 5.6 km south of the border between California and Oregon. The estuary typically remains open to the ocean throughout the year (Figure 1). The Smith River drainage basin covers 1,878 km^2, mostly in northwest California, but with 13% of the area in southern Oregon (EDAW 1980). Tides have a mean range of 5.1 ft and a diurnal range of 6.9 ft (Mizuno 1998).

Due to variations in habitat features throughout the estuary, the estuary was classified into three distinct reaches (Figure 2): 1) an "upper reach", typified by salinities from 0-5 ppt, and by diked banks recolonized with blackberries (*Rubus fruticosus*), salmonberries *(Rubus spectabilis*), willows (*Salix sp.*), and red alders (*Alnus rubra*) under 25 years of age; 2) a "middle reach", characterized by salinities from 5-20 ppt, and flanked on the west side by farmland transitioning into blackberries and salmonberries, and on the east side by a diked bank recolonized by willows and alders under 10 years of age; and 3) a "lower reach", that has salinities ranging from 20-30 ppt, and is bordered by an unstable sand berm on the west side, and by agricultural land and resort areas on the east side.

Fall chinook salmon, steelhead (*O. mykiss*), and coastal cutthroat trout (*O. clarki clarki*) are the most abundant anadromous salmonid species that utilize the Smith River estuary. Other common fish species thus far identified in the Smith River estuary are threespine stickleback *(Gasterosteus aculeatus*), prickly sculpin (*Cottus asper*), staghorn sculpin (*Leptocottus armatus*), surf smelt (*Hypomesus pretiosus*), Klamath smallscale

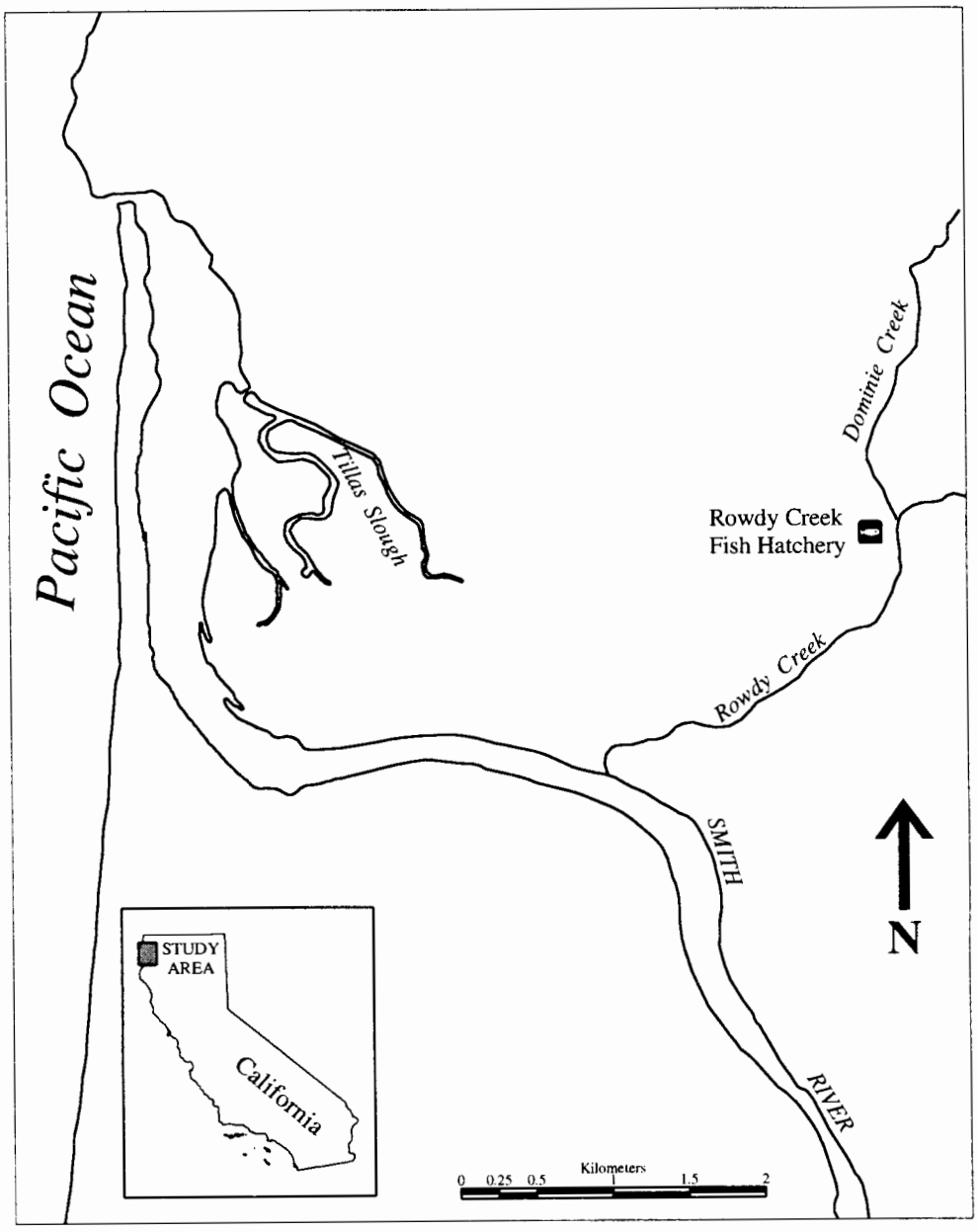


Figure 1. Smith River estuary, California, 1998-2000.

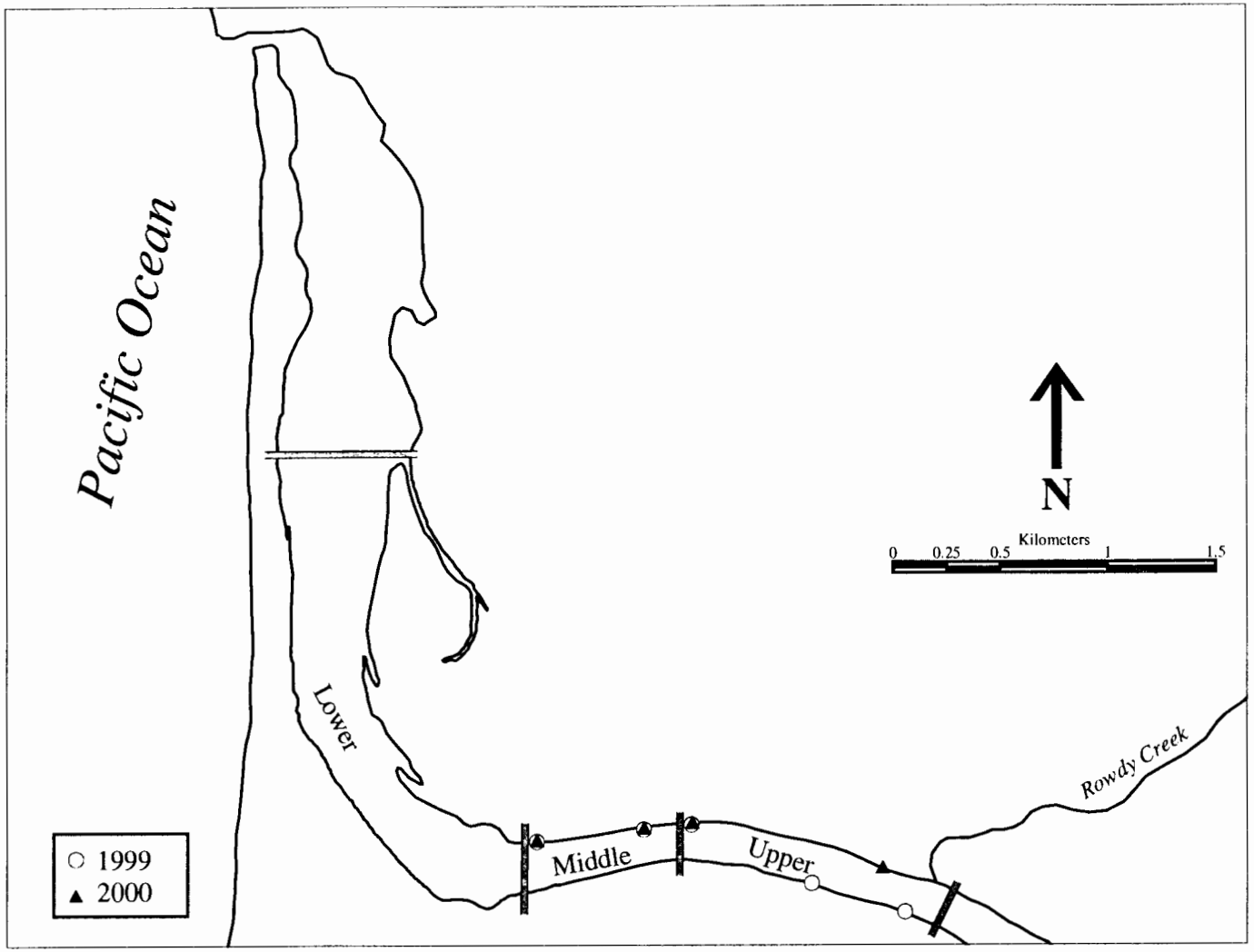


Figure 2. Reaches (upper = upper reach, middle = middle reach, lower = lower reach) and seining site locations (1999, 2000) of the Smith River estuary, California.

sucker (*Catostomus rimiculus*), starry flounder (*Platichthys stellatus*), Pacific sardine (*Sardinops sagax*), American shad (*Alosa sapidissima*), Pacific herring (*Clupea harangus pallasi*), shiner surfperch (*Cymatogaster aggregata*), saddleback gunnel (*Pholis ornata*), Pacific lamprey (*Lampetra tridentata*), jacksmelt (*Atherinops californiensis*), and northern anchovy (*Engraulis mordax*) (Mizuno 1998).

Rowdy Creek Hatchery is a privately owned hatchery located on Rowdy Creek, a tributary entering the Smith River at the upstream end of the study area (Figure 1). Rowdy Creek Hatchery released from 235,084 to 485,012 fingerling chinook salmon (approximately 5.7 g each) annually during May and June of 1998-2000 (Table 1). Fish were released at one of three locations: 1) at hatchery ponds feeding into Rowdy Creek proper, 2) into Dominie Creek, a tributary to Rowdy Creek, or 3) at a public boat ramp located approximately 2 km upstream of Rowdy Creek. Choice of release location was based on flow conditions and water temperatures in Rowdy Creek, Dominie Creek, and the mainstem Smith River.

During 1998 and 1999, Rowdy Creek Hatchery administered left maxillary clips to a small percentage of juvenile chinook salmon stocked into the system. In 1998, less than 3% of the May-June release were marked (Table 1). These marked fish were the largest juvenile fish released during that year. With volunteer assistance in 1999, 13% of fish released in May-June received left maxillary clips, with a fraction of each group released during this time being marked.

Due to difficulties with detecting left maxillary clips in the field, efforts were made to mark fish with adipose clip and coded-wire tags (AD-CWT) in 2000. With

Table 1. Year, date of release, location of release, number released, number marked (left maxillary clips in 1998 and 1999; AD-CWT in 2000), and size at release (g/fish) for juvenile chinook salmon released by Rowdy Creek Hatchery, Smith River, California, during May and June of 1998-2000.

Year	Date of Release	Location of Release	Number Released	Number Marked	Percentage Marked	Size at Release
1998	24-May	Hatchery	169,000	0	0.0	4.4
	28-May	Hatchery	91,500	0	0.0	6.1
	6-Jun	Boat ramp	4,687	4,687	100.0	10.6
	6-Jun	Boat ramp	6,283	6,283	100.0	7.4
	6-Jun	Boat ramp	116,340	0	0.0	6.5
	13-Jun	Boat ramp	97,202	0	0.0	6.1
	Total		485,012	10,970	2.3	
1999	14-Jun	Boat ramp	15,184	5,044	33.2	8.7
	16-Jun	Boat ramp	95,030	9,724	10.2	4.1
	17-Jun	Boat ramp	93,670	13,195	14.1	6.3
	24-Jun	Boat ramp	116,948	15,224	13.0	5.2
	Total		320,832	43,187	13.5	
2000	28-May	Hatchery	72,250	0	0.0	5.3
	12-Jun	Hatchery	67,710	0	0.0	6.1
	12-Jun	Hatchery	51,810	51,810	100.0	6.9
	12-Jun	Hatchery	11,616	0	0.0	4.7
	12-Jun	Hatchery	1,206	0	0.0	13.6
	14-Jun	Hatchery	30,492	0	0.0	6.9
	Total		235,084	51,810	22.0	

assistance from CDFG's Cooperative Rearing Progam and Rowdy Creek Hatchery personnel, over 50,000 fish were marked (22% of total releases), with AD-CWT from May 22 to June 2 of 2000 (Table 1). In 2000, I had proposed to mark a constant fraction of all release groups to ensure representative marking, and to increase accuracy regarding the estimated daily proportions of hatchery fish (Hankin 1982). However, hatchery personnel released a large number of unmarked fish prior to release of marked fish. In all project years, variable hatchery marking and release practices complicated statistical separation of naturally-produced and hatchery-produced juvenile chinook salmon in the Smith River estuary.

METHODS

Fish Collection and Marking Protocols

In the summer of 1998 and early summer of 1999, a rotary screw trap (E.G. Solutions) with a 2.44 m diameter cone supported by pontoons was used to passively capture fish approximately 2 km above the estuary. Juvenile chinook salmon were trapped for five days each week from early June to late August in 1998, and for four days each week from late June to mid-July in 1999. The screw trap was operated two to three days per week from late August to late September of 1998. A single trapping occasion was defined as the time between the initial set during the afternoon to the time when the trap was checked the following morning, encompassing the evening and night periods when juvenile salmonids most commonly migrate (Reimers 1973).

The trap was deployed at a location where there was enough water velocity to produce at least 5 revolutions per minute, and where it could still sample the stream margin, at the edge of the thalweg and near the head of a pool. The cone was set as close to the bottom as physically possible. In 1999, a weir was created on the nearshore side of the upstream end of the trap to encourage fish to enter the trap. The weir was formed by attaching a 15.24 m long by 1.83 m deep seine from the outer edge of the pontoon on the trap at an upstream angle to the shore, where the net was anchored by boulders. Fish entered the submerged lower half of the cone, and were retained in the live box at the downstream end of the trap. Prior to marking, all juvenile chinook salmon were transferred from the live box into buckets, anesthetized with dissolved CO_2 gas, measured to the nearest mm fork length, and individually weighed to the nearest

0.1g. Other fish species were noted and released. Barring technical marking difficulties, on days that trap catch exceeded 25 juvenile chinook salmon, all juvenile chinook salmon were marked (see below). Marked fish were typically held in aerated buckets of river water for up to ten minutes, prior to being released approximately 15 m downstream from the trap.

In late summer of 1999 and summer of 2000, fish were actively pursued at six sites in the estuary (Figure 2) with a 45.7 m long by 2.4 m deep beach seine with 0.95 cm diagonal mesh. Two days per sampling week were allocated to marking, one day each in the upper and middle reaches. Marking primarily occurred at five sites (three upper and two middle reach sites) from late July to mid-August in 1999, and at four sites (two upper and two middle reach sites) from mid-June to late September in 2000. Fish captured within the upper and middle reaches received contrasting marks.

All collected juvenile chinook salmon were either placed in buckets containing estuary water or in 0.9 x 0.6 x 0.6 m floating live wells with 0.95 cm mesh. Marks were applied when daily catch of juvenile chinook salmon exceeded 50 fish. It was assumed that the number of recaptures would be negligible if fewer than 50 fish were marked. Prior to marking, fish were anesthetized with CO_2 gas and examined for previous marks. Previously marked fish were measured to the nearest mm fork length and their specific mark was recorded, but they did not receive new marks. During a typical marking day, all newly marked fish or a systematic sample of at least 50 marked fish were measured to the nearest mm fork length. Prior to release, juvenile chinook salmon were typically held in aerated buckets or floating live wells for up to two hours

after handling to allow for adequate recovery time. The same measurement protocol was applied to recapture days. All sampling methods were approved by the Humboldt State University IACUC (approval number 98/99.F.94.B).

Throughout the study, a unique mark was applied during each week of marking to differentiate among marked groups, and to allow for the calculation of days since marking for recaptured fish. For fish marked at the screw trap in 1998 and 1999, the number of days post-marking was typically calculated with a possible error of up to four days. Due to changes in our weekly marking schedule, it became possible to calculate the number of days since marking to within two days in 1999 and to the nearest day in 2000 for recaptures of fish marked within the estuary.

In 1998, marks were applied by injecting one of four colors (orange, green, yellow, and red) of a VIjet tag (Northwest Marine Technologies) into the fin rays of fish to produce a unique batch mark. A subsequent experiment (Humboldt State University IACUC approval number 97/98.F.43.B) conducted at the HSU hatchery on juvenile rainbow trout suggested that it was difficult to distinguish between orange, green, and yellow tags after 11 weeks. In 1999 and 2000, marks were instead applied using freeze brands. Dry ice and ethanol were mixed into a slurry and transferred to an insulated branding apparatus, where cold was conducted through an aluminum rod to a 10 mm branding symbol (Fujihara and Nakatani 1967). Fish were pushed against the brand with steady pressure for approximately 3-5 s. Combinations of brand symbols and varying body locations were used to produce unique marks to identify each week of branding.

In 1999, a total of 70 juvenile rainbow trout, ranging in size from 62 to 91 mm fork length, were marked with freeze brands at the Humboldt State University fish hatchery on 5 March, 10 March, 24 March, and 15 April (Humboldt State University IACUC approval number 98/99.F.60.B). Fish were examined at least weekly from 8 March to 2 April, once every two weeks from 2 April to 26 May, and approximately monthly from 26 May to 6 August. Based on results from this experiment, freeze brands could be detected on over 98% of marked fish after at least five weeks; on 81% of marked fish after at least 8 weeks; on 77% of marked fish after at least 10 weeks; and on 44% of marked fish after at least 13 weeks post marking (Appendix A).

Recapture Protocol

With the exception of occasional sampling effort from 21 June to 22 July of 1999 in the approximately 2 km of freshwater habitat between the screw trap and the estuary, recapture effort was restricted to the estuary itself for all three project years. During 1998, recapture effort consisted of a) beach seining with a 15.2 m long by 1.8 m wide pole seine with 0.65 cm mesh, b) boat electrofishing, and c) boat deployment of a 45.7 m long by 1.8 m deep beach seine with 0.65 cm mesh. In 1999, recapture effort primarily consisted of boat deployment of a 45.7 m long by 2.4 m deep beach seine. The primary method of seining for recapturing was the same as the method described for capturing fish to mark in the latter half of the 1999 field season and during the entire 2000 field season.

From June to late August of 1999 and 2000, recapture sampling occurred five days a week, with two days devoted to the combined efforts of marking and recapture. From August through October, sampling primarily consisted of recapture effort, and was typically conducted once or twice weekly. In 1999, sampling typically occurred between 0900 and 1700, whereas in 2000, sampling typically took place during an 8 h period of time between 0600 and 1900.

Various locations within the estuary were sampled in an attempt to find the optimal locations for sampling, in terms of both fish abundance and practicality of sampling by beach seining. In 1999, four sites (two upper reach sites and two middle reach sites) proved most effective (Figure 2). These sites became part of our standardized protocol for 2000, although the two upper reach sites yielded relatively few fish in June of 2000. Consequently, two new upper reach sites were selected in June 2000 (Figure 2).

Standardization of Recapture Effort

Because calculation of "disappearance rate" assumes that the decline in catch-per-unit effort (CPUE) of marked fish is a direct reflection of the decline in the true numbers of marked fish that remain in the estuary, it is critical that recapture effort be standardized to the maximum degree possible. To achieve this objective, in 2000 we restricted our seining to incoming tides (when seining was most effective), fixed our sampling locations, standardized sampling order of locations and the number of sets per location, and refined location-specific seining techniques.

The typical weekly sampling program was conducted on the days and locations shown in Table 2. Beginning in early July of 2000, sites were visited in the same order each sampling day. At each site, two sets were typically conducted, with at least 20 minutes separating the end of the first set from the start of the second set. Modifications to the protocol occurred when an unusually large number of fish (i.e., several hundred) were captured at a single location. Under these conditions, not all sites could be visited within the standardized timeframe, or holding stress, due to high densities of fish within our live wells, made it necessary to release at least some fish prior to conducting a second set. Standardization of recapture effort was generally achieved with a high degree of success (Table 3).

Throughout the season, we attempted to use the same techniques for each set at a given site. The proportion of recapture effort differed among sites, but the total recapture effort applied over all four sites was the same for each recapture day.

Because of the low number of recaptured fish in the upper reach in the 2000 field season, we based residence time estimates on middle reach sampling sites. Recapture effort was defined as 1 d for each complete sampling (two sets per site) of the two middle reach sites during one sampling day. From June to late August, weekly recapture effort was typically 4 d. Recapture effort was reduced to 1 or 2 d weekly from late August to early October.

Table 2. Weekly sampling schedule from 13 June to 27 August 2000, Smith River estuary, California (Upper 1 = upper reach site 1, Upper 2 = upper reach site 2, Middle 1 = middle reach site 1, Middle 2 = middle reach site 2) . Site locations are delineated in Figure 2.

	Location				Mark (M) and/or
Day	Upper 1	Upper 2	Middle 1	Middle 2	Recapture (R)
Monday	X	X	X	X	R
Tuesday	X	X			M/R
Wednesday			X	X	M/R
Thursday	X	X	X	X	R
Friday	X	X	X	X	R

Table 3. Percentage success for achieving standardization of recapture effort during the 2000 sampling season, Smith River estuary, California (based on the total number of sampling occassions or total number of site visits).

Standardization Goal	Percentage Success	n
Incoming tide restriction	100.0	59
Completed sampling for all designated sites	96.6	59
2 sets/site	97.8	178

Estimation of Residence Time

Estimation of Disappearance Rate

Recapture effort was standardized to ensure that the relationship between the number of recaptures and the actual number of marked fish present was as consistent as possible. The importance of this relationship to the estimation of disappearance rate can best be illustrated by deriving the model used to fit the recapture data from an assumed exponential model. If capture probability (γ) is fairly low (i.e., γ <10%), it is reasonable to assume that capture probability is constant and directly proportional to recapture effort, f_j. Then, for a given group of fish marked on day i, the expected number of recaptures on calendar date j is:

$$E(R_{i,j}) = \gamma_j \cdot M_{i,j} = a \cdot f_j \cdot M_{i,j} \qquad (1)$$

where R_{ij} is the number of recaptures from group i on day j; a is a "catchability" coefficient (an assumed constant) which is equivalent to the capture probability for one unit of recapture effort, defined as one day of completely sampling the two middle reach sites; f_j is the quantity of recapture effort on any given sampling day; and M_{ij} is the number of fish marked on day i that are present and available for capture in the estuary on day j. If recapture effort had not been standardized (fixed), then γ_j would vary with f_j so that $E(R_{ij})$ would not have been a simple proportion of M_{ij}.

The value of M_{ij} depends on the initial numbers marked and the process whereby marked fish leave the estuary. If an exponential model is assumed to be appropriate for describing the nature of decline for marked fish, then:

$$M_{i,j} = M_{0_i} \cdot e^{-z(j-i)} \quad (2)$$

where M_{0_i} is the initial number of fish marked and released on day i; z is the disappearance rate parameter; and j-i is the number of days at large since release, calculated as the difference between the calendar date of mark and release (i) and the calendar date of recapture (j).

Substituting Equation (2) into Equation (1), we have, for $f_j = f$ = constant:

$$E(R_{i,j}) = a \cdot f \cdot M_{0_i} \cdot e^{-z(j-i)} = \gamma \cdot M_{0_i} \cdot e^{-z(j-i)} \quad . \quad (3)$$

In this study, I used generalized linear models (S-Plus Version 3.3, function glm()) to estimate γ and z in the equation $\ln(r_{i,j}) = \ln(\gamma) + \ln(M_{0_i}) - z(j-i)$, where $r_{i,j}$ are the observed recoveries. Recapture effort from the upper reach or days of incomplete sampling of the middle reach were not included in the analysis. I used generalized linear models because this approach, unlike the linear regression approach, allows for a non-normal error distribution. I fitted the 2000 recapture data using the generalized linear model family Poisson, because data expressed in the form of counts (i.e. number of recaptures) typically have a Poisson error distribution (McCullagh and Nelder 1989). The primary objectives of my analyses were to 1) estimate disappearance rate, mean residence time, and residency half-life for marked groups of juvenile chinook salmon released in 2000, and 2) determine if disappearance rate differed among these release groups in a statistically significant manner.

I first determined if the effect of days at large on the number of recaptures was significant, and if it was reasonable to assume a constant capture probability among all

groups released in the middle reach (except for the 24 August group and the two September groups). The three final release groups were omitted from the analysis due to the scarcity of recapture effort applied after their release. The effect of days at large on the number of recaptures was judged significant when a chi-squared test rejected the null hypothesis at α=0.05.

To assess the validity of the assumption of constant capture probability, two separate models were fitted to the recapture data. One model allowed disappearance rates (β_k) and capture probabilities (α_k) to vary among groups, and was represented by:

$$\ln(r_{i,j}) = \ln(M_{0_i}) + \alpha_0 + \beta_0(j-i) + \alpha_1 Z_1 + \beta_1 Z_1(j-i) + \ldots + \alpha_8 Z_8 + \beta_8 Z_8(j-i) \qquad (4)$$

where α_0, α_1, … , α_8 are the intercept parameters; β_0, β_1, … , β_8 are slope parameters; Z_1 is a dummy variable with value 1 for the second group or 0 for any other group, Z_2 is a dummy variable with value 1 for the third group or 0 for any other group, and so forth. The second model, which assumed a constant capture probability, was:

$$\ln(r_{i,j}) = \ln(M_{0_i}) + \alpha_0 + \beta_0(j-i) + \beta_1 Z_1(j-i) + \ldots + \beta_8 Z_8(j-i) \qquad (5)$$

where α_0 is the intercept parameter, and β_0, β_1, … , β_8 are slope parameters. The reference category is represented when all dummy variables have a value of zero. The standard error and the t-value were calculated for each of the estimated slope coefficients. The first slope coefficient is equivalent to the disappearance rate for the reference group, and all other coefficients are adjustments to the disappearance rate for all other release groups.

The residual deviance, a measure of the goodness of fit (analogous to the residual sum of squares for linear regression), was compared between the two models in determining the most parsimonious model. Based on this criteria, the model assuming constant capture probability (Equation (5)) was judged the "better" model.

I pooled data from release groups if a) the groups were temporally adjacent, and b) based on t-test results for the slope coefficients, the status of statistical significance (significant or not significant) with regards to the disappearance rate of the reference group was the same for all such groups. This resulted in a small number of "categories", each consisting of recovery data for a set of temporally adjacent release groups. Then, for each category, a dummy variable analysis was conducted to confirm that the effect of days at large on number of recaptures was significant (α=0.05), and the effect of release group on slope was not significant (α=0.05). After categories were defined and validated in this way, a dummy variable analysis was conducted with dummy variables coding for all defined categories. The model used for this analysis was:

$$\ln(r_{i,j}) = \ln(M_{0_i}) + D_0 + D_1(j-i) + D_2V_1(j-i) + D_3V_2(j-i) + D_4V_3(j-i) \qquad (6)$$

where D_0 is a common capture probability parameter; D_1, D_2, D_3, and D_4 are slope parameters; V_1 , V_2 and V_3 are dummy variables coding for pooled categories corresponding to release groups. Subsequent categories were deemed to be statistically different from the first category if t-tests for the slope coefficients rejected null hypotheses at α=0.05. The objective of the final dummy variable analysis was to

determine whether fish released earlier in the season (June, July) were disappearing from the estuary at a statistically different rate than fish released later in the season (August).

Estimation of Mean Residence Time

I define mean residence time as the expected value of residence time for an individual fish (*E(T)*):

$$\mu_T = E(T) = \sum_{t=0}^{\infty} t \cdot p(t) \tag{7}$$

where t is a particular number of days spent in the estuary, and $p(t)$ is the probability of spending t days in the estuary.

If one assumes that the probability of leaving the estuary on a given day following estuary entrance, θ, is independent of the prior amount of time spent in the estuary, then:

$$p(t) = (1-\theta)^{t-1} \cdot \theta, \tag{8}$$

the product of the probability of not leaving the estuary on days 1, 2, …, through *t-1* $[(1-\theta)^{t-1}]$ and the probability of leaving on day t (θ). If a group of fish were marked on day i, then one would expect the number of marked fish remaining in the estuary on day j to be:

$$E(M_{i,j}) = M_{0_i} \cdot (1-\theta)^{(j-i)}. \tag{9}$$

If one assumes that the exponential model (Equation (2)) is also appropriate for describing the pattern of decline in marked fish, then:

$$E(M_{i,j}) = M_{0_i} \cdot (1-\theta)^{(j-i)} = M_{0_i} \cdot e^{-z(j-i)} \tag{10}$$

where z is the disappearance rate. Thus, $(1-\theta) = e^{-z}$, or:

$$\theta = 1 - e^{-z}. \tag{11}$$

If one substitutes Equation (11) into Equation (8), the probability of the residence time for an individual fish can be expressed in terms of the disappearance rate as:

$$p(t) = e^{-z(t-1)} \cdot (1 - e^{-z}). \tag{12}$$

Finally, if one substitutes Equation (12) into the original expression for mean residence time (Equation (7)), the formal expression for the estimated mean residence time is:

$$\hat{\mu}_T = \sum_{t=1}^{\infty} t \cdot p(t) = \sum_{t=1}^{\infty} t \cdot e^{-\hat{z}(t-1)} \cdot (1 - e^{-\hat{z}}). \tag{13}$$

For calculation purposes, assuming a fish does not spend more than one year in the estuary, the equation:

$$\hat{\mu}_T \doteq \sum_{t=1}^{365} t \cdot e^{-\hat{z}(t-1)} \cdot (1 - e^{-\hat{z}}) \tag{14}$$

is nearly identical in value to Equation (13). Once I estimated the disappearance rate ($\hat{z}$), this value was substituted into Equation (14) to produce an estimate of mean residence time.

Estimation of Residency Half-life

Residency half-life was described by Myers and Horton (1982) as a measure of the time by which 50% of hatchery-released coho salmon (*Oncorhynchus kisutch*) had disappeared from their sampling sites. The estimation of residency half-life relies on the use of the exponential model to estimate a disappearance rate, and hence involves the

same assumptions previously stated for estimating disappearance rate. We defined residency half-life as the amount of time it takes for 50% of a marked group of fish to leave the estuary. For the exponential model, $M_{i,j} / M_{0_i} = .5 = e^{-zt_{50\%}}$, so that residency half-life can be expressed as:

$$\hat{t}_{50\%} = \frac{-\ln(.5)}{\hat{z}} \tag{15}$$

where $\hat{z}$ is the estimated disappearance rate.

Simulation of Residence Time Estimation

Computer simulations (using S-Plus Version 3.3) were used to determine the degree to which the exponential model might be applicable to patterns of fish remaining over time, when the probability of leaving the estuary was not independent of time previously spent in the estuary. If it is true that there is a threshold size for entering the ocean (Healey 1982, Simenstad et al. 1982) and that juvenile chinook salmon spend at least some time growing in the estuary (Healey 1982), then it is reasonable to conclude that the probability that an individual fish leaves the estuary should increase with the amount of time previously spent in the estuary. We used the logistic distribution to simulate this possibility (Figure 3). For the logistic model, the probability density function can be expressed as:

$$f(x;\mu,\sigma) = \frac{\pi}{\sigma\sqrt{3}} \cdot \frac{e^{-\frac{\pi}{\sqrt{3}}\left(\frac{x-\mu}{\sigma}\right)}}{\left[1+e^{-\frac{\pi}{\sqrt{3}}\left(\frac{x-\mu}{\sigma}\right)}\right]^2} \tag{16}$$

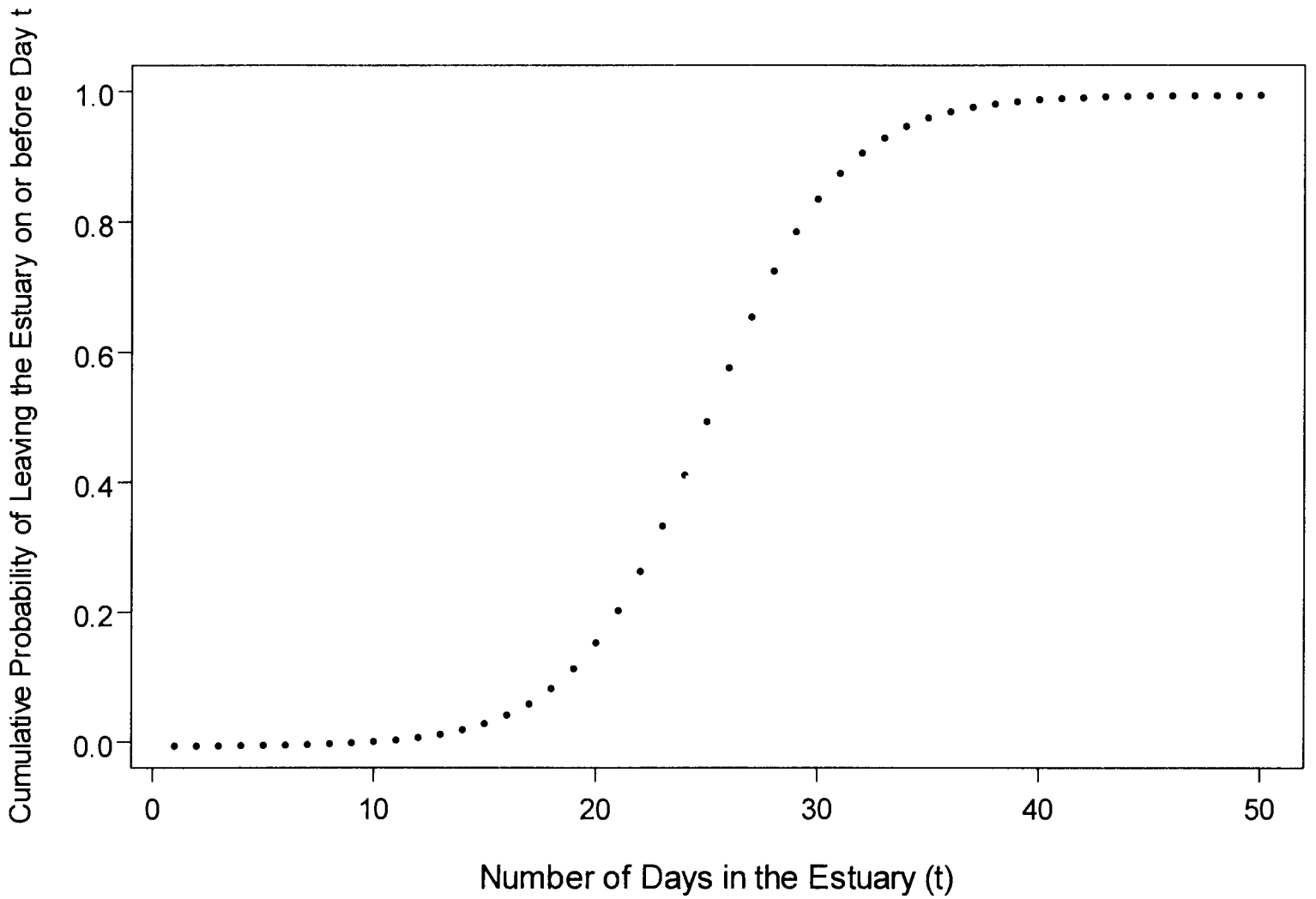


Figure 3. Cumulative probability of leaving the estuary on or before day "t" plotted against the number of days in the estuary (t), based on an assumed logistic distribution of residence times (mean = 25 d, variance = 29.6088).

where μ is the mean and σ is the standard deviation of the logistic random variable X, where x is continuous (Balakrishnan 1991). Within the context of the simulations, x represents an individual fish's residence time.

Individual simulations were intended to mimic a process whereby individual fish entered the estuary and then either remained in or left the estuary according to the amount of time that they had previously spent in the estuary. Based on the patterns of screw trap captures of downstream-migrating chinook salmon during 1998, I assumed that the number of downstream migrants entering the estuary from 8 June to 23 September (a) totalled 100,000 fish (an arbitrary choice) and (b) were normally distributed over this period of time (mean calendar entrance date = 205, variance = 225). Simulations kept track of the numbers of fish that entered the estuary on a given date. I used the logistic distribution (mean = 25 d, variance = $3\pi^2$) to simulate the distribution of estuary residence times for all fish entering the estuary. This approach is mathematically equivalent to simulating a logistic distribution for each daily group of fish entering the estuary, as demonstrated in Appendix B. The total number of fish present in the estuary on a given date thus consisted of those fish that had just entered on that date plus fish that had entered on previous dates but still remained in the estuary. Each of these simulated fish had a known history of prior estuary residence.

I simulated mark and release of all fish captured in the estuary on each of three dates (July 1, August 1, and September 1). Based on estimates of capture probability from the analysis of 2000 recapture data, I assumed that field sampling could capture 1% of all fish that were present in the estuary on a given date. I then generated a simulated

sequence of the numbers of marked fish that were recaptured in the estuary over time for each of these three mark and release dates. A generalized linear model with an assumed Poisson error distribution was then fit to these simulated patterns of numbers remaining in the estuary over time to estimate the disappearance rate, $\hat{z}$, assuming the exponential decay model that has been typically applied in this mark-recapture setting. Based on the calculated $\hat{z}$, mean residence times and residency half-lifes were calculated using Equations (15) and (16), respectively.

The aforementioned simulation process was repeated 10,000 times, and the expected values of the estimated disappearance rates, mean residence times, and residency half-lifes were calculated. These expected values were then compared with the true mean residence time and true residency half-lifes based on the assumed logistic distribution parameters that were used to drive the simulations.

Size Trends

Size trends of chinook salmon captured either in the estuary or in freshwater were analyzed by graphical inspection. Weekly mean fork lengths of chinook salmon were plotted against time for the entire estuary sampled from 8 June to 21 September in 1998, and for each reach of the estuary sampled from 21 June to 24 September in 1999 and from 5 June to 7 October in 2000. Also, for fish captured at the screw trap from 8 June to 23 September in 1998 and from 17 June to 4 August in 1999, weekly mean fork lengths of chinook salmon were plotted against calendar date for each year.

Estimation of the Proportion of Hatchery Fish

A secondary objective was to estimate the proportion of hatchery juvenile chinook salmon fingerlings that were present in the Smith River estuary. For 1998, we could not estimate the proportion of hatchery fish due to the low percentage (<3%) of marked fish (Table 1) and the low recovery rate of these marked fish. In 1999 and 2000, however, we estimated proportions of hatchery fish for each estuary reach and sampling day. The calculation of the proportion of hatchery fish assumes that no differential mortality exists between hatchery marked and unmarked fish, and no marks are lost between release and recapture. During 1999, an almost constant fraction of all release groups was marked and, therefore, the proportion of hatchery fish could be estimated with greater certainty than in 2000, when 72,250 unmarked fish were released two weeks prior to release of marked fish.

For 1999, the fraction ($\hat{q}$) of hatchery fish released with marks was estimated as:

$$\hat{q} = \frac{Q}{\hat{A}} \tag{17}$$

where Q is the number of fish marked, and $\hat{A}$ is the estimated total number of fish reported as released by Rowdy Creek Hatchery. The proportion of hatchery fish on day j for fish captured in estuary reach s was then estimated as:

$$\hat{h}_{s,j} = \frac{C_{s,j}}{N_{s,j}} \cdot \frac{1}{\hat{q}} \tag{18}$$

where $\hat{h}_{s,j}$ is the estimated proportion of hatchery fish, $C_{s,j}$ is the number of adipose-clipped hatchery clipped fish that were recaptured, $N_{s,j}$ is the number of fish examined

for marks from reach s on day j, and $\hat{q}$ is the fraction of hatchery fish released with marks.

Due to release practices in 2000, the fraction of hatchery fish released with marks was estimated as a range, with the lower limit calculated under the assumption that none of the aforementioned 72,250 unmarked fish remained in the study area:

$$\hat{x} = \frac{Q}{\hat{A} - 72{,}250} \tag{19}$$

The lower limit of the daily proportion of hatchery fish was then estimated as:

$$\hat{g}_{s,j} = \frac{C_{s,j}}{N_{s,j}} \cdot \frac{1}{\hat{x}} \tag{20}$$

The upper limit of the daily proportion of hatchery fish was estimated assuming that all 72,250 unmarked fish remained in the study area. I used Equation (17) to estimate the fraction of fish released with marks, and Equation (18) to estimate the upper limit of the daily proportion of hatchery fish. For simplicity, point estimates based on the average of upper and lower limits of daily estimated proportions of hatchery fish are used throughout the text. Estimated daily proportions of hatchery fish were compared across time for each season and reach.

RESULTS

Mark-Recapture Summary

Recovery of Rotary Trap-marked Fish

From 5 June to 23 September of 1998, a total of 3,611 juvenile chinook salmon were captured at the rotary screw trap located approximately 2 km upstream from the estuary, with daily catches ranging from 2 to 225 individuals (Figure 4, Appendix C). Trap capture reached a peak from late July to early August, with a steady decline immediately following. Only a single marked fish was recaptured in the estuary proper; this fish had been marked between 12 August to 18 August, and was recaptured 0 – 6 d past marking (Table 4).

From 17 June through 21 July of 1999, 882 juvenile chinook salmon were captured at the rotary screw trap and 775 of these fish were marked (Table 4). On 4 August, 46 juvenile chinook salmon were trapped, none of which were marked. Daily catch ranged from 6 to 117, and peaked on 2 July (Appendix C). From 25 June to 24 September, juvenile chinook salmon were captured with beach seines in the estuary; numbers examined for marks were: 33 in June, 3,070 in July, 2,796 in August, and 988 in September (Appendix D). Only five screw trap-marked fish were recaptured within the estuary, with individual values for days at large ranging from 1 – 3 d past marking to 18 – 21 d past marking (Table 5).

From 21 June to 2 August if 1999, 1,051 fish were captured above the estuary by seining techniques within the 2 km stretch between the trap and the estuary, and were examined for marks. One fish was recaptured with a pole seine near the screw trap as

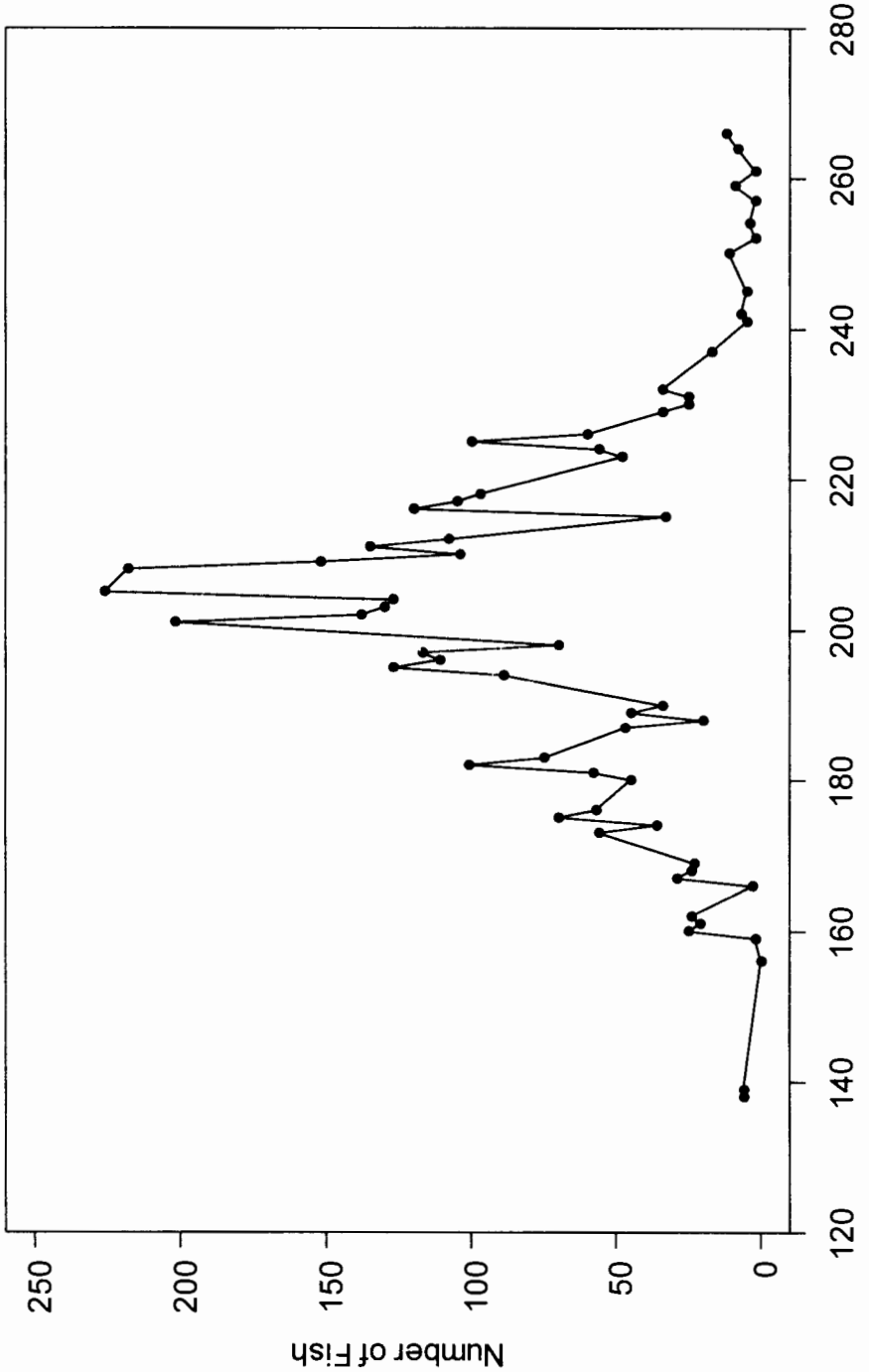


Figure 4. Daily capture of juvenile chinook salmon at the rotary screw trap located above the Smith River estuary, California, 1998.

Table 4. Summary of marking location, number of marked fish, estuary sample size, and number of estuary recaptures for juvenile chinook salmon in the Smith River estuary, California, 1998-2000.

Year	Marking Location	Number of Marks	Estuary Sample Size	Number of Estuary Recaptures
1998	Screw trap	2,913	373	1
1999	Screw trap	775	6,887	5
	Estuary	1,732		95
2000	Estuary	3,494	12,904	280

Table 5. Dates of marking, number marked, recapture date, number of recaptures, location of recaptures, and days at large for juvenile chinook salmon marked at the rotary screw trap located approximately 2 km above the estuary, and recaptured either above the estuary or within the upper, middle, or lower reach of the Smith River estuary, California, 1999.

Dates of Marking	Number Marked	Recapture Date	Number of Recaptures	Location of Recapture	Days at Large
23-25 June	96		0		
30 June - 3 July	221	14 July	1	Above estuary	11-14
7-10 July	251	12 July	1	Above estuary	2-5
		14 July	2	Above estuary	4-7
		20 July	1	Above estuary	10-13
		22 July	1	Above estuary	12-15
		27 July	1	Upper reach	17-20
		28 July	2	Middle reach	18-21
13-16 July	161	16 July	1	Lower reach	1-3
		3 August	1	Middle reach	18-21
19, 21 July	46		0		

late as 11-14 d past marking, and one fish was recaptured approximately 1 km above the estuary as late as 12-15 d past marking (Table 5).

Recovery of Fish Captured and Marked within the Estuary

In 1999, individual values for days at large ranged from 2-3 d to 31 d (Table 6). Only one marked fish was captured in a reach other than where it was originally marked; one upper reach marked fish from the 26-27 June release group was recaptured in the middle reach, 2-3 d past marking. In 1999, the vast majority of sampling within the upper reach occurred at sites on the south bank of the estuary, whereas the majority of sampling within the middle reach occurred at sites on the north bank. In 1999 and 2000, it was unknown whether marked fish were recaptured more than once.

In 2000, recaptured fish exhibited a range of days at large from 1-72 d (Table 7, Appendix E). Although fewer fish were marked in August (588) than in June (1,178) or July (716) of 2000, there was nearly a two-fold difference in the number of middle reach marks recaptured from August marked groups (119) compared to the number of recaptures from June (61) or July (63) marked groups (Table 7). There was also a decreased level of sampling effort expended from 28 August to 7 October. Beginning with the week of 28 August, sampling effort decreased from four visits to each of the four sites per week to one visit per site for each week (except for the week of 25 September, when two visits were made to each site). From 16 June through 7 October, large numbers of juvenile chinook salmon were captured by beach seine and examined for marks: 3,422 in June, 4,730 in July, 3,466 in August, 672 in September, and 614 in October (Appendix E).

Table 6. Marking location, dates of marking, number marked, number recaptured, and days at large for juvenile chinook salmon marked and recaptured in the Smith River estuary, California, 1999.

Marking Location	Dates of Marking	Number Marked	Number Recaptured	Days at Large
Upper reach	20,22 July	449 [a]	6	4-6
			4	5-7
			5	7-9
			7	11-13
			2	19-21
			2	20-22
Upper reach	26-27 July	235	15	2-3
			13	6-7
			1	14-15
			6	15-16
Middle reach	28 July	498 [b]	3	6
			2	12
			3	15
			1	22
			2	31
Upper reach	2 August	263	10	3
			1	8
			1	9
			1	17
Middle reach	3 August	289 [c]	3	6
			2	9
			2	16
			2	25
Upper reach	10-11 August	55	1	8-9

[a] Includes 172 fish captured from a site approximately 1 km above the estuary.
[b] Includes 81 fish captured from a site designated an upper reach site in 2000.
[c] Includes 88 fish captured from a site designated an upper reach site in 2000.

Table 7. Marking location, date of marking, number marked, number recaptured, and maximum days at large for juvenile chinook salmon marked and recaptured in the Smith River estuary, California, 2000.

Marking Location	Date of Marking	Number Marked	Number Recaptured	Days at Large
Upper reach	21 June[a]	170	4	2-15
	28 June	40	0	
	Total	210	4	
	6 July	103	1	5
	2 August	119	6	5-16
	9 August	376	10	13-53
	Total	495	16	
Middle reach	15 June	724	24	1-32
	22 June	147	9	11-28
	29 June	307	28	1-36
	Total	1178	61	
	7 July	156	15	4-31
	13 July	254	25	1-26
	20 July	204	14	1-72
	27 July	102	9	1-37
	Total	716	63	
	3 August	315	72	1-65[b]
	10 August	53	7	1-38
	24 August	220	40	1-44[b]
	Total	588	119	
	17 September	97	9	6-20[b]
	24 September	107	7	6-13[b]
	Total	204	16	

[a] Fish marked on 21 June were marked at a site not sampled thereafter.

[b] Days at large for fish captured on the final day of sampling.

In contrast to 1999, year 2000 sampling of the upper reach was primarily conducted on the north bank. All middle reach sampling in 2000 occurred on the north bank as well. It was common for fish marked and released in the middle reach to be captured in the upper reach. About 19% (45 of 243) of all marked fish released in the middle reach and recaptured in the estuary were captured in the upper reach (Appendix E).

In 2000, a total of 808 fish were marked and released in the upper reach (Table 7). Twenty-one fish marked in the upper reach were recaptured, with nine of these marked fish being recaptured in the middle reach.

Estimates of Disappearance Rate and Residence Time

Two separate models relating the number of recaptures to the number of days at large were initially fit to the 2000 recapture data (Appendix E). One allowed disappearance rate and capture probability to vary among release groups (Equation (4)) and another allowed disappearance rate to vary among release groups (Equation (5)). For both models, chi-squared tests indicated that the effect of days at large on the dependent variable (number of recaptures) was significant ($p<0.0001$). The effect of release group on slope was also significant ($p<0.0001$). Residual deviances were 175.1615 on 236 residual degrees of freedom for the model assuming constant capture probability, compared to 169.8218 on 228 residual degrees of freedom for the model with varying capture probability. Only a relatively small decrease in residual deviance was achieved with the inclusion of the eight additional terms needed to allow capture

probability to vary. Therefore, the model assuming constant capture probability (Equation (5)) was utilized for estimation and further analysis.

The August release groups were designated as the first two groups in the dummy variable analysis. An August release group was used as the reference group, due to the large number of middle reach marked fish recaptured from August mark groups compared with the number of recaptures from either June or July mark groups (Table 7). The 3 August release group was chosen as the reference group, because a substantially greater number of marked fish were released on 3 August (315) than on 10 August (53).

Based on results of t-tests for each of the model coefficients (Table 8), I initially placed individual release groups into two distinct categories, with the August release groups comprising the first category, and the June and July release groups comprising the second category. However, after fitting a dummy variable model separately to each category, chi-squared tests indicated that release group did not have a significant effect on slope for the first category (p=0.9147), but did have a significant effect on slope for the second category (p=0.0369). Results of t-tests for slope coefficients of these separate model fits (Appendix F) defined four categories: 1) the August release groups, 2) the 15 June release group, 3) the three groups released from 22 June to 7 July, and 4) the three groups released from 13 July to 27 July. For each of these four categories, separate dummy variable analyses revealed that days at large had a significant effect on the number of recaptures (p<0.05), but release group did not have a significant effect on slope (p>0.05) (Appendix G).

Table 8. Results of generalized linear model analysis relating the number of recaptures to the number of days at large for marked juvenile chinook salmon in the Smith River estuary, California, 2000. Refer to Equation (5) for description of model parameters.

Release Date	Parameter	Estimate	Standard Error	t value	p
	β_0	-4.4229	0.1487	-29.75	<0.0001
3-Aug	β_1	0.0262	0.0089	2.95	0.0035
10-Aug	β_2	0.0025	0.0227	0.11	0.9132
15-Jun	β_3	0.1017	0.0179	5.67	<0.0001
22-Jun	β_4	0.0514	0.0183	2.80	0.0055
29-Jun	β_5	0.0511	0.0139	3.67	0.0003
7-Jul	β_6	0.0429	0.0167	2.56	0.0110
13-Jul	β_7	0.0822	0.0227	3.62	0.0004
20-Jul	β_8	0.1138	0.0353	3.23	0.0014
27-Jul	β_9	0.0628	0.0310	2.03	0.0439

A final generalized linear model analysis was conducted, using the category of August release groups as the reference category, to determine if fish released earlier in the season (June, July release groups) disappeared from the estuary at a significantly different rate from those released later in the season (August release groups). Chi-squared tests indicated that the effect of days at large on number of recaptures was significant ($p<0.0001$), and that the effect of category on slope was also significant ($p<0.0001$). Based on t-tests conducted for the fitted generalized linear model coefficients, all three June and July categories disappeared at a significantly different rate from the category of August release groups ($p<0.0001$) (Table 9). The estimated August disappearance rate was low, 0.0264, and the estimated mean residence time was high, 38.33 d, as compared to those for other periods (Table 10). For June and July categories, the estimated disappearance rates were considerably greater, ranging from 0.0751 – 0.1278, and estimated mean residence times were considerably less, ranging from 8.34 – 13.82 d. Estimated residency half-lifes for June and July categories ranged from 5.42 – 9.23 d, whereas the residency half-life for August groups was 26.24 d.

Simulations of Residence Time Estimation

For these simulations, the true mean residence time and residency half-life were assumed to be 25.0 d, and an assumed exponential model was used to estimate mean residence time based on mark-recapture data. Results from 10,000 simulations indicate that the estimators for mean residence time (Equations (13), (14)) and residency half-life (Equation (15)) would have serious negative bias if the logistic model were the correct

Table 9. Results of dummy variable analysis conducted through the use of generalized linear models for estimating disappearance rate of designated categories of release groups of marked juvenile chinook salmon in the Smith River estuary, California, 2000.

Category	Release Date	Parameter	Estimate	Standard Error	t value	p
		D_0	-4.4250	0.1485	-29.80	<0.0001
1	3-Aug 10-Aug	D_1	0.0264	0.0086	3.08	0.0023
2	15-Jun	D_2	0.1014	0.0178	5.71	<0.0001
3	22-Jun 29-Jun 7-Jul	D_3	0.0487	0.0107	4.55	<0.0001
4	13-Jul 20-Jul 27-Jul	D_4	0.0865	0.0174	4.96	<0.0001

Table 10. Estimates of disappearance rate, mean residence time, and residency half-life for designated categories of release groups of marked juvenile chinook salmon, Smith River estuary, California, 2000.

		Estimated Values		
Category	Release Date	Disappearance Rate	Mean Residence Tim	Residency Half-life
1	3-Aug 10-Aug	0.0264	38.33 d	26.24 d
2	15-Jun	0.1278	8.34 d	5.42 d
3	22-Jun 29-Jun 7-Jul	0.0751	13.82 d	9.23 d
4	13-Jul 20-Jul 27-Jul	0.1129	9.37 d	6.14 d

description of estuary use by juvenile chinook salmon. The expected values of estimated mean residence time ranged from 8.18 – 10.84 d, and the expected values of estimated residency half-life ranged from 5.32 – 7.16 d (depending on the choice of release date) (Table 11). Compared to a true mean residence time and residency half-life of 25.0 d, the expected values of these estimated values were only 33 – 43% and 21 – 29% of the true values, respectively.

The timing of simulated mark and release affected the estimation of disappearance rate by the exponential model. On average, fish marked and released later in the season disappeared from the estuary at a faster rate; the expected value of the estimated disappearance rate increased from 0.100 to 0.135 as the simulated release date progressed from 1 July to 1 September (Table 11). Also, the expected values of the estimated mean residence time and residency half-life varied over the course of the simulated period of time. Relative to the assumed time of peak immigration into the estuary (24 July), estimates based on mark and release groups prior to this date were closest to the true value. Fish simulated as released in July had an expected value of estimated mean residence time that was 43% of the true mean, compared to 39% for the simulated August release group and 33% for the simulated September release group.

Size Trends

Sizes of Estuarine Captures

Similar trends in fish size were observed during 1998, 1999, and 2000. Fish captured in the estuary typically showed an initially rapid increase in weekly mean size

Table 11. Summary of mark-recapture simulation results, based upon an assumed logistic distribution of residence times and 10,000 total simulations. $E(\hat{z})$ = expected value of the estimated disappearance rate, $E(\hat{\mu}_T)$ = expected value of the estimated mean residence time, and $E(\hat{t}_{50\%})$ = expected value of the estimated residency half-life. The true mean and true half-life of the simulated logistic distribution of residence times were 25.0 d.

Simulated Release Date	Expected Values of Estimates		
	$E(\hat{z})$	$E(\hat{\mu}_T)$	$E(\hat{t}_{50\%})$
1 July	0.100	10.84 d	7.16 d
1 August	0.110	9.66 d	6.34 d
1 September	0.135	8.18 d	5.32 d

from June to early July, followed by a gradual increase in weekly mean size until early to mid-August, when fish size began to increase rapidly again with time.

In 1998, fish size increased relatively rapidly from mid-June to mid-July, ranging from 69.0 mm to 86.1 mm, gradually increased from mid-July to mid-August, ranging from 86.1 mm to 89.1 mm, then rapidly increased from mid-August to late September, ranging from 89.1 mm to 109.0 mm (n>20) (Figure 5, Appendix H).

In 1999, sufficient numbers of fish were captured to allow comparison of fish size within the upper and middle reaches. Fish size increased gradually from late June to mid-August of 1999, ranging from 75.1 to 83.5 mm fork length in the upper reach, and from 80.5 to 85.1 mm fork length in the middle reach (n>20) (Figure 6, Appendix H). From early August to late September of 1999, fish size increased rapidly, ranging from 83.5 to 106.7 mm in the upper reach, and from 85.1 mm to 109.2 mm in the middle reach. Due to sporadic success in capturing fish in the lower reach, sample sizes exceeded 20 fish in only four of the 14 weeks of sampling; weekly mean fork length ranged from 81.4 to 88.1 mm from mid-July to mid-August.

From early June to early July of 2000, fish size increased rapidly, ranging from 73.1 – 86.7 mm in the upper reach and from 75.4 –84.9 mm in the middle reach. Fish size increased slowly from early July to mid-August, ranging from 86.7 – 90.3 mm in the upper reach, and from 84.9 – 88.2 mm in the middle reach (Figure 7, Appendix H). From mid-August to early October, mean fish size again increased relatively rapidly from 87.8 mm to 117.9 mm in the upper reach, and from 88.2 mm to 112.9 mm in the middle reach.

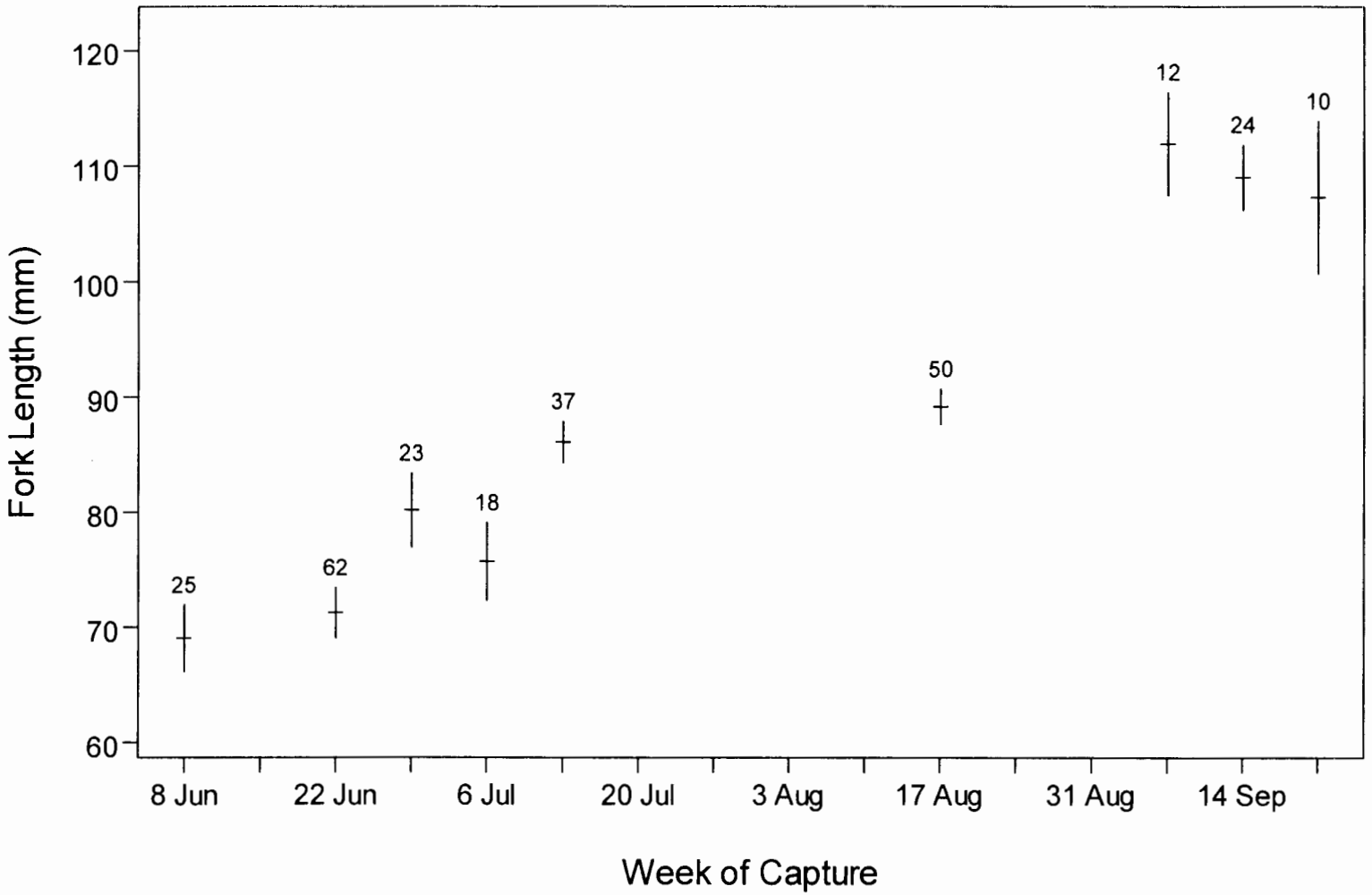


Figure 5. Weekly mean fork lengths (horizontal bars), 95% confidence intervals (vertical bars), and sample sizes of juvenile chinook salmon captured and measured in the Smith River estuary, California, 1998.

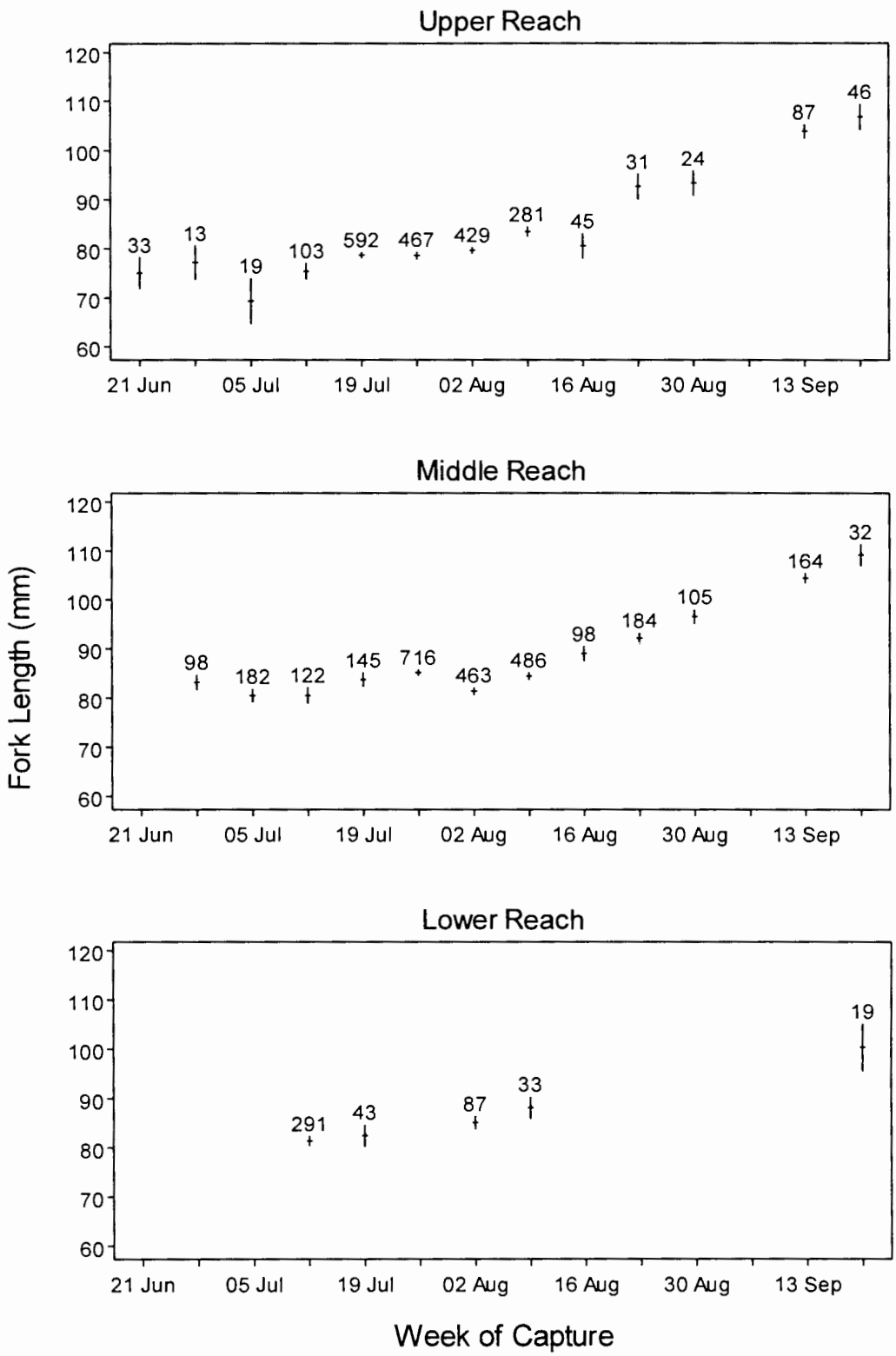


Figure 6. Weekly mean fork lengths (horizontal bars), 95% confidence intervals (vertical bars), and sample sizes of juvenile chinook salmon captured and measured in the upper, middle, and lower reaches of the Smith River estuary, California, 1999.

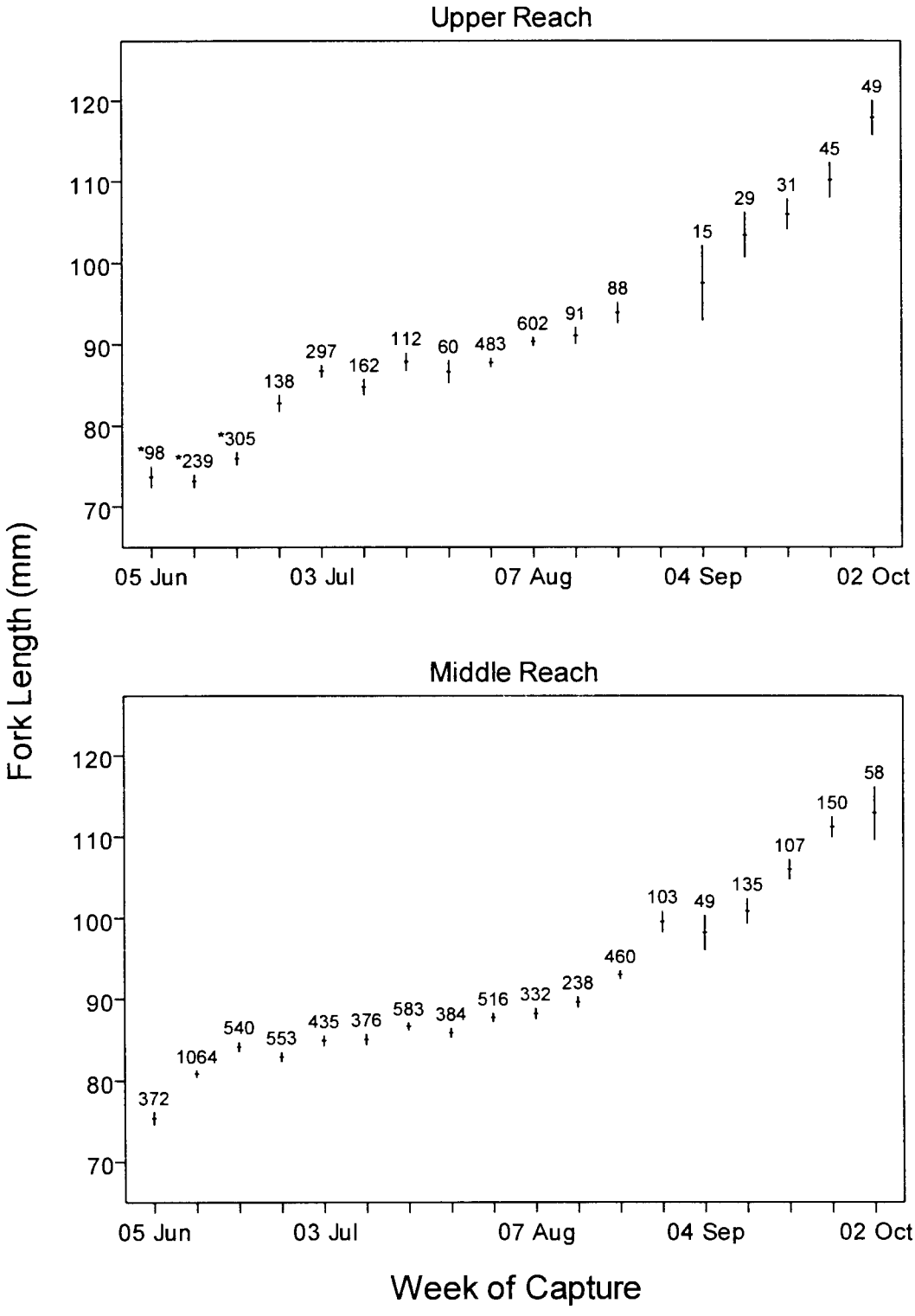


Figure 7. Weekly mean fork lengths (horizontal bars), 95% confidence intervals (vertical bars), and sample sizes of juvenile chinook salmon captured and measured in the upper and middle reaches of the Smith River estuary, California, 2000. Asterisks (*) indicate sampling at south bank sites; all other sites were located on the north bank.

Sizes of Fish Captured at the Screw Trap

From early June through late September of 1998, and from mid-June through early August of 1999, size data on juvenile chinook salmon were collected for fish captured at the screw trap located approximately 2 km above the estuary. Assuming that fish captured in the screw trap located above the estuary were actively migrating downstream, the mean size of these fish should be close to the mean size at the time of estuary entrance. The trend in fish size observed at the screw trap generally paralleled that of the estuary, with sizes gradually increasing from June to August, and rapidly increasing from August to late September (Figure 8, Appendix I).

Sizes of Recaptured Fish

Because marked fish were not individually tagged, and relatively few marked fish were recaptured, it was not possible to statistically analyze the growth of marked fish. Mean fork lengths of marked and recaptured fish are, however, presented in Appendix J.

Estimates of the Proportion of Hatchery Fish

Recovery of Maxillary-clipped Fish in 1999

In 1999, estimated daily proportions of hatchery fish peaked within the three different study reaches at 1 to 33 d following the final release date (Figure 9, Appendix K). Estimated daily proportions of hatchery fish reached a maximum of 0.23 (33 fish examined) in the upper reach on 25 June, one day following the final release on 24 June 1999. The maximum estimated daily proportion of hatchery fish for the middle reach

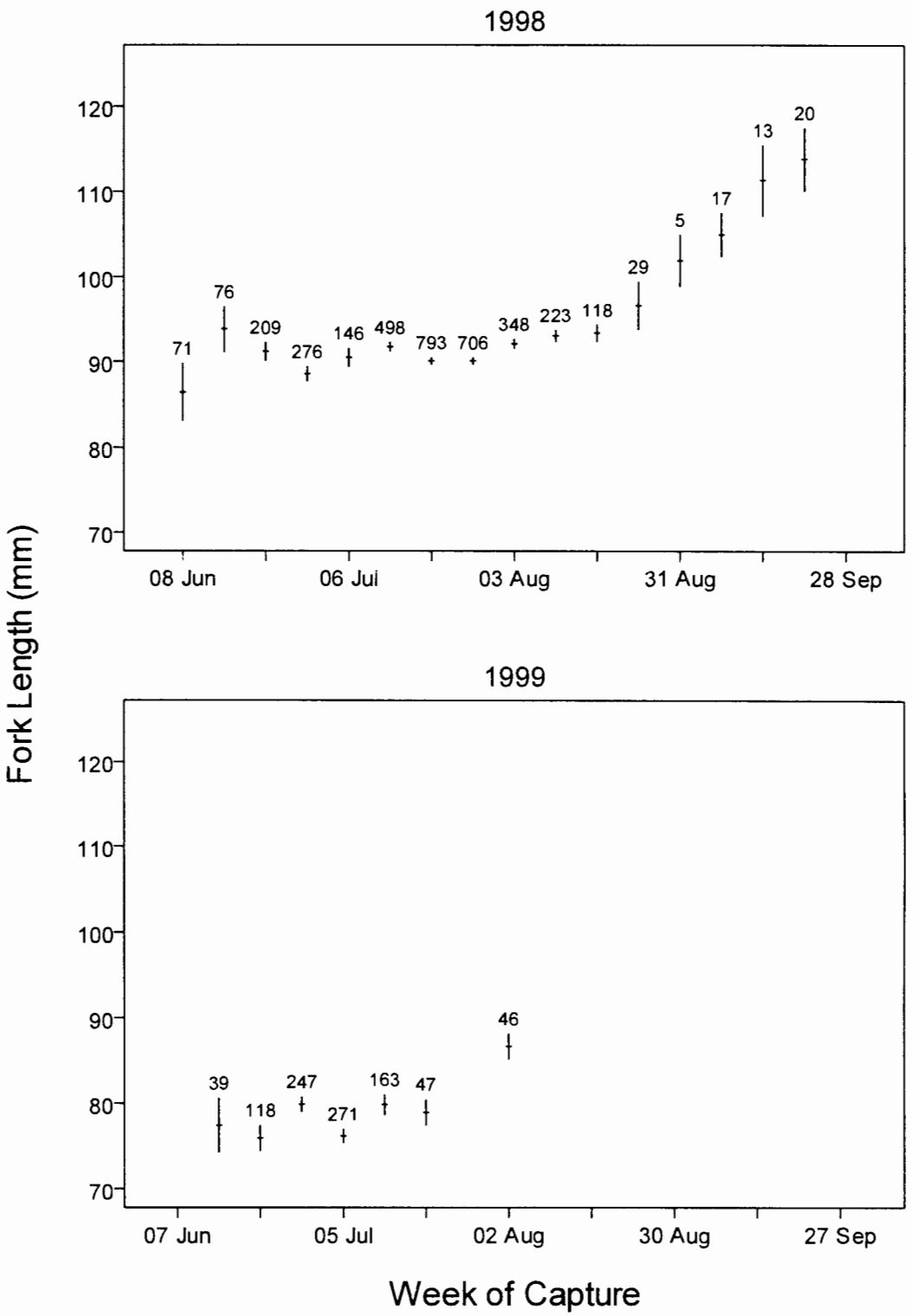


Figure 8. Weekly mean fork lengths (horizontal bars), 95% confidence intervals (vertical bars), and sample sizes of juvenile chinook salmon captured and measured at the screw trap located above the Smith River estuary, California, 1998 and 1999.

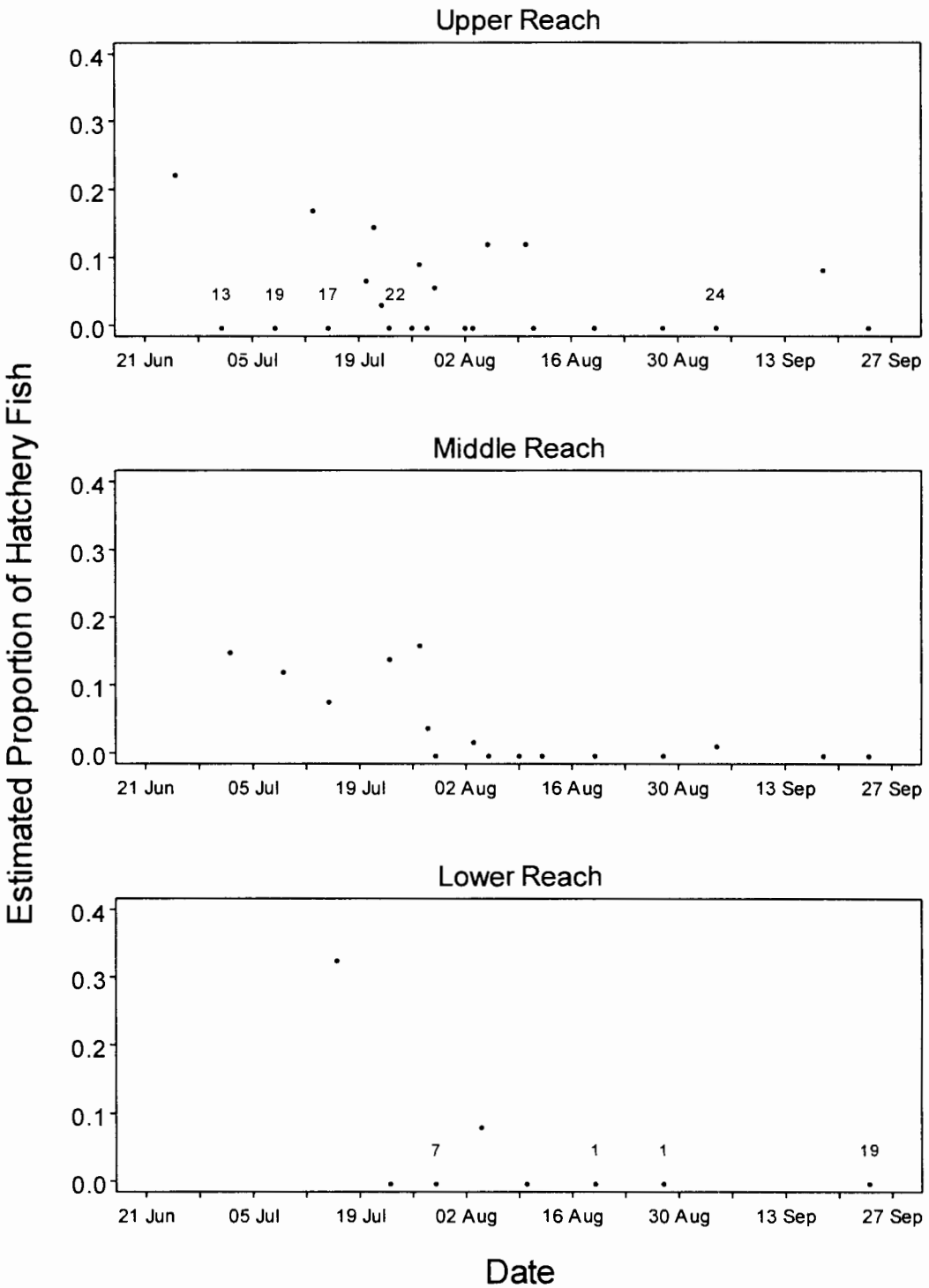


Figure 9. Estimated proportions of juvenile hatchery chinook salmon within the upper, middle, and lower reaches of the Smith River estuary, California, from 21 June through 24 September, 1999. The number of fish examined for marks is indicated above estimates based on fewer than 30 fish. Sampling in the middle and lower reaches was initiated on 2 July and 16 July, respectively.

was 0.16 (275 fish examined) on 27 July, 33 days following the final release. The maximum estimated daily proportion of hatchery fish for the lower reach was 0.33 (294 fish examined) on 16 July, 22 days following the final release date.

The daily proportion of hatchery fish was also estimated for the freshwater area within 2 km above the estuary based on sampling from 21 June to 2 August. Based on the examination of greater than 30 fish on a given sampling date, the maximum estimated daily proportion of hatchery fish was 0.55 (218 fish examined) on 12 July, 18 days following the final release date (Appendix K).

Recovery of Fish Marked with AD-CWT in 2000

In the upper reach, when greater than 30 fish were examined, estimated daily proportions of hatchery fish reached a maximum of 0.27 (130 fish examined) on 28 June, 16 days following release (Figure 10, Appendix L). The maximum value for the estimated daily proportion of hatchery fish in the middle reach was 0.31 (556 fish examined) on 16 June, 4 days following release.

Hatchery-marked fish were captured as late as 18 September in 1999 (86 d post-release) and 25 September in 2000 (104 d post-release). These late recaptures indicate that at least some hatchery fish were residing in the estuary for extended periods of time.

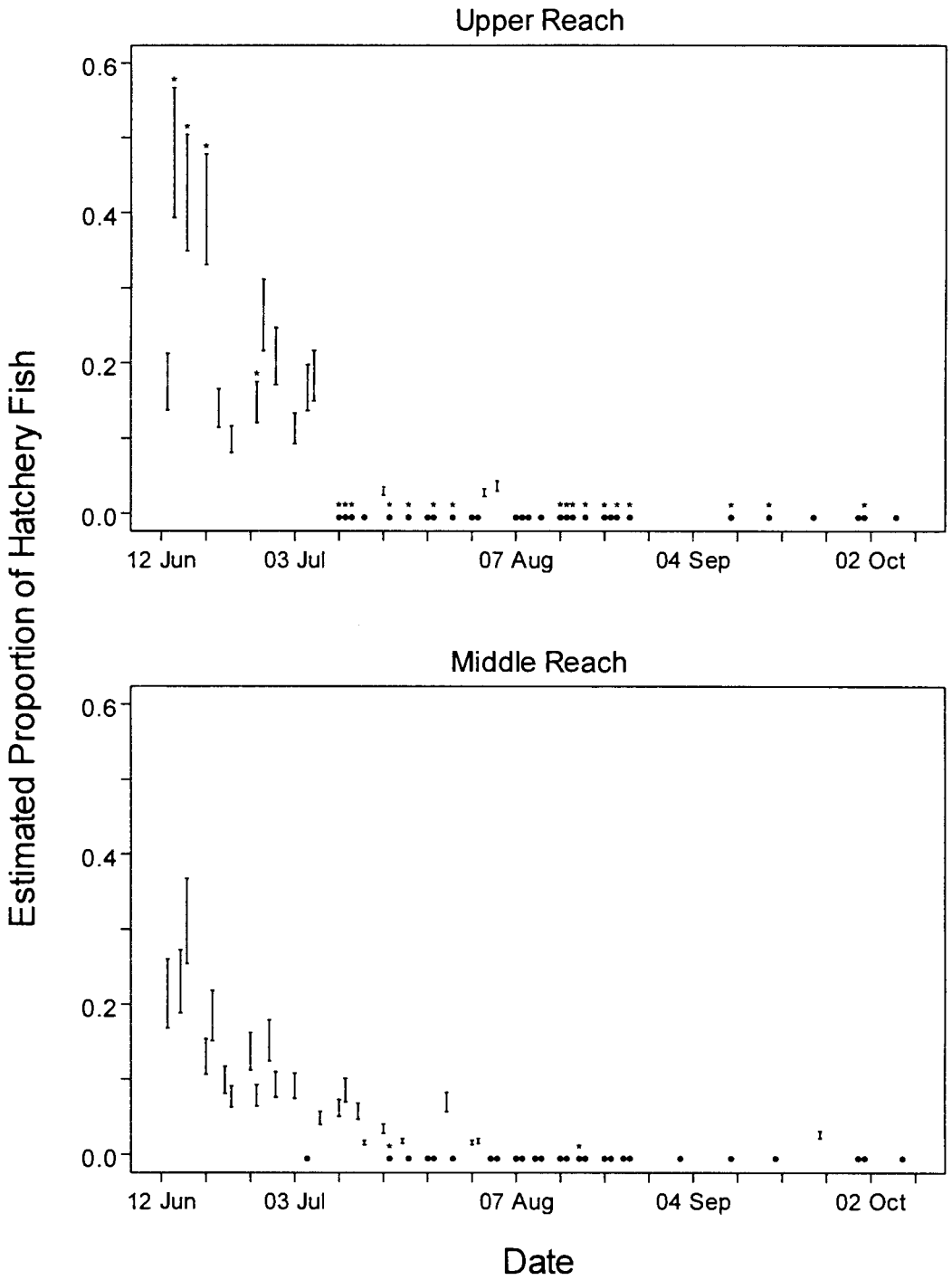


Figure 10. Estimated proportion (or range in proportion (I)) of juvenile hatchery chinook salmon within the upper and middle reaches of the Smith River estuary, California, from 13 June through 7 October, 2000. Asterisks (*) denote estimates based on fewer than 30 fish.

DISCUSSION

Results of Residence Time Estimation

Fingerling smolts tend to take greater advantage of estuaries within the southern range of the Pacific Northwest, most notably in Oregon (Healey 1991). Healey (1982) hypothesized that fingerling smolts may not spend extended periods of time in the estuaries of British Columbia, due to the abundance of sheltered coastal habitats in these northern areas. In contrast, juvenile chinook salmon may depend on the sheltered habitat provided by estuaries on the more open coast of Washington, Oregon and California, and therefore may stay longer in these estuaries. For Washington coastal estuaries, Simenstad et al. (1982) reported individual residence times for chinook salmon ranging from 6 d – 189 d. Nicholas and Hankin (1988) found that for Oregon estuaries, juvenile chinook salmon typically entered in May and, as a species, remained in the estuary through mid-summer or fall. Fisher and Pearcy (1990) found that juvenile fall chinook salmon remained in Coos Bay, Oregon, for approximately one to two months prior to ocean entrance. Based on scale analyses of adult chinook salmon returning to the Sixes River, Reimers (1973) found that most of the returning adults had a life history of rearing in freshwater habitat and the estuarine environment for about three months each.

In this study, estimated mean residence times ranged from 8.3 d – 38.3 d for categories of groups of estuary-captured chinook salmon that were marked and released from 15 June through 10 August of 2000 (Table 10). For groups released in June and July, the mean residence times ranged from 8.3 to 13.8 d, compared to a mean residence time of 38.3 d for August release groups. The influence of unmarked hatchery fish on

estimates of mean residence time for release groups in June and July is unknown. Based on estimated daily proportions of hatchery fish, it appears that the majority of fish in the estuary were wild fish (Figures 9, 10). Residence time estimates from the Smith River estuary, California, suggest that juvenile chinook salmon spend an extended period of time in the estuary, and that fish entering later in the season reside in the estuary longer than those entering earlier in the season. In the nearby Klamath River, California, juvenile chinook salmon entering the estuary later in the season (August and September) also stayed longer than those entering earlier (June and July) (Wallace 2000).

Critique of Prior Methods Used for Estimating Residence Time

Researchers have typically used mark-recapture experiments to develop estimates of residence time (Healey 1980, Congleton et al. 1981, Myers and Horton 1982, Levings et al. 1986, Macdonald et al. 1988), but few of these researchers have provided a clear description of the methods used to estimate "mean residence time". Some common problems observed in past research regarding residence time estimation involve: 1) lack of standardization of capture methods, 2) questionable methods of estimating disappearance rate, 3) ambiguous or inconsistent definition of "mean residence time", and 4) lack of discussion regarding whether an exponential decay model is biologically appropriate.

Healey (1980), Myers and Horton (1982), Levings et al. (1986), and Macdonald et al. (1988) all fit an exponential model to the declining pattern of catch-per-unit-effort (CPUE) of marked fish to estimate a disappearance rate. CPUE has typically been

assumed to be proportional to the abundance of marked fish present within the estuary. It has been expressed as the average number of recaptures per set (Healey 1980), mean daily number of recaptures per week of sampling (Myers and Horton 1982), or as the average number of recaptures per successful (non-zero catch) set (Macdonald et al. 1988). The most common calculation for the CPUE of marked fish (e.g., Healey 1980, Macdonald et al. 1988) can be expressed as: $CPUE_k=C_k/E_k$, where C_k is the total number of fish recaptured in all sets on day k, and E_k is the number of sets conducted on day k. For the relationship of CPUE and actual abundance to be consistent over time, capture probability must be assumed to be proportional to the amount of recapture effort expended.

In past studies that relied on the use of CPUE to estimate residence time, there was substantial variability in recapture effort across sampling periods. For example, Healey (1980) conducted a variable number of beach seine sets per recapture day across the sampling period. Such variability may produce an inconsistent relationship between CPUE and abundance. If a single set catches the majority of fish at a particular location, then subsequent sets may yield few fish. Therefore, if only one set were made, then CPUE would be much higher than it would be if multiple sets were made. Levings et al. (1986) conducted the same number of sets per location, but during each sampling occasion (3-4 d) visited each location a variable number of times. It may be unreasonable to assume that the probability of catching a fish at one particular location is the same as that for another location. Validity of the aforementioned assumptions is therefore problematic when recapture effort is carried out in a non-standardized fashion.

For the 2000 field season, special emphasis was placed on standardization by sampling the same locations of the Smith River estuary during each day, with the same number of sets conducted at each site. Seining operations were also standardized by sampling only during incoming tides. Recapture effort was the same for each sampling day, thereby making it likely that capture probability was constant over time. Therefore, it was also likely that the number of marked fish recaptured on a given sampling day provided a consistent index of the number of marks actually present in the estuary.

The process of estimating a disappearance rate has been described adequately (Healey 1980, Congleton et al. 1981, Levings et al. 1986, Macdonald et al. 1988), although the methods used have been questionable at times. Because the natural logarithm of CPUE is regressed against days at large, problems arise when CPUE is zero for a given sampling day, but few papers have addressed this issue. Healey (1980) did not explicitly mention how zero values for CPUE were handled in his regression analysis, but it appears that these zero values were not included in his regression procedures. Levings et al. (1986) altered their data by adding a value of one to each calculated CPUE before conducting their analysis. Macdonald et al. (1988) excluded zero CPUE values from their data. Instead of utilizing CPUE, Congleton et al. (1981) used estimated population size as the dependent variable. These methods are either inaccurate, using altered or incomplete data sets (Healey 1980, Levings et al. 1986, Macdonald et al. 1988), or, in the case of Congleton et al. (1981), indirect, performing regression analyses on estimated values rather than actual observed values.

For this study, I attempted to utilize collected data in the most direct way possible. The dependent variable was the number of recaptured juvenile chinook salmon. Data expressed in the form of counts do not typically have a normal error distribution. Instead, a Poisson error distribution is more appropriate for such data (McCullagh and Nelder 1989). The method of generalized linear models was used for the first time to our knowledge, in the context of estimating mean residence time for salmonids in estuaries. Generalized linear models allow specification of a non-normal error distribution, and also allow zero values for the dependent variable to be included in the analysis.

Mean residence time has either not been defined clearly (e.g., Healey 1980, Levings et al. 1986) or consistently (e.g. Congleton et al. 1981, Macdonald et al. 1988) by past researchers, making evaluations of these estimates difficult. Even when mean residence time has been defined, variations have existed in the terminology and methods used. Congleton et al. (1981) estimated a "weighted mean residence time" by averaging the mean time to disappearance of each 10% of a marked group. A "mean residence time" was calculated by Macdonald et al. (1988) by substituting the mean CPUE of marked fish into their fitted regression equation, and solving for time. Although such estimates may provide some crude measures of mean residence time, precisely what these measures represent is unknown and unspecified. In this study, mean residence time was defined as the expected number of days spent in the estuary by an individual fish (see Equation (7)).

None of the studies referenced previously have addressed whether the exponential model is truly appropriate for describing the nature of estuary entrance and exit by juvenile chinook salmon. The bias of an estimate of mean residence time depends, in part, on how closely an exponential model approximates true behavior. Estimation of a disappearance rate from mark-recapture data does not necessarily rely on any assumptions being met; such a rate can be validly estimated as part of a curve-fitting exercise. However, if the estimated disappearance rate is thereafter used to estimate mean residence time, one must invoke an assumption that the probability of leaving the estuary on a given day is independent of the amount of time that a juvenile has spent previously in the estuary.

Implications of Computer Simulations

To examine how a time-dependent probability of leaving the estuary would affect estimation of mean residence time, computer simulations were conducted. Results of computer simulations based on a logistic distribution of residence times suggest that mean residence time will be severely underestimated if the probability of leaving the estuary depends on prior time spent in the estuary. Estimated mean residence times for *simulated groups of marked fish released on 1 July (10.84 d), 1 August (9.66 d), and 1* September (8.18 d) were all less than half of the true mean residence time of 25 d (Table 11).

Biological factors that could affect the probability of an individual fish leaving the estuary include growth and the physiological transition to seawater. Either factor

would likely increase the probability of an individual fish leaving the estuary with increased time spent in the estuary. Based on simulation results, it therefore appears likely that the usual estimator for mean residence time (see Equation (13)) is negatively biased for all groups of fish marked during the experiment.

Assuming that the physiological preparation for transition to seawater affected all release groups the same, the probability of an individual leaving the estuary on a given day may have differed among release groups due to varying patterns of estuarine use. Size trends of estuary-captured fish suggest that at least some chinook salmon were increasing in size during residence in the Smith River estuary, and that there may be at least two distinct patterns of estuarine use. It appears that fish arriving in the estuary earlier in the season do not reside as long or grow as much (if at all) as those arriving later in the season. In contrast, there is evidence of increased growth and extended residence for fish marked and released during August.

The lack of recaptures from June and July release groups indicates that few fish from that release group were residing for an extended period in the estuary, hence few fish were staying long enough to experience substantial estuarine growth. Size trend data support this contention; there was only a gradual change in weekly mean fork length for fish captured in June and July as compared to August and September, when there was a rapid increase in weekly mean fork length (Figure 7). Size trends at the screw trap (located above the estuary) suggest that fish also enter the estuary at a larger size in August and September (Figure 8). However, based on results regarding residence time, fish marked in June and July appear to be using the estuary differently from those

marked in August. The estimated mean residence time for the category of August release groups (38.33 d) was nearly three times greater than any of the estimates of mean residence time for June or July categories (8.34 – 13.82 d) (Table 10). Based on estimates of mean residence time and observed size trends, fish marked in June and July probably experienced only limited or no growth, whereas fish marked in August were highly likely to be growing. Hence, the estimator for mean residence time may be the most biased for fish marked in August.

While these computer simulations provided valuable insight, it is important to note that more research is needed to determine what is the most likely distribution of residence times for juvenile chinook salmon in a "typical" estuary of the Pacific Northwest. I used the logistic distribution because it allowed the probability of leaving the estuary to change (increase) with an increasing amount of time an individual spends in the estuary. The logistic distribution is not necessarily an accurate reflection of the true distribution of individual residence times, however acquiring information about the true distribution of residence times for chinook salmon in an estuary may require investigations on an estuary where it is possible to trap and mark fish as they enter and leave, ideally with some kind of passive capture technique. This type of study would require marks identifying individual fish, and may only be possible on rivers smaller than the Smith River.

Proportions of Hatchery Fish

The proportion of hatchery chinook salmon in the Smith River estuary has not been estimated prior to this study. In 1999, when hatchery fish were released 2 km above the estuary, I found that the estimated daily proportion of hatchery fish reached maximums of 0.23 at 1 d post-release in the upper reach, 0.16 at 33 d post-release in the middle reach, and 0.33 at 22 d post-release in the lower reach (Figure 9, Appendix K). Estimated daily proportions of hatchery fish in the estuary remained relatively constant (about 0.15) through late July, nearly a month after the final release. In limited sampling above the estuary, the maximum estimated daily proportion of hatchery fish was 0.55 (218 fish examined) on 12 July, 18 days following the final release date (Appendix K).

In 2000, when fish were released into Rowdy Creek, estimated daily proportions of hatchery fish reached maximums of 0.27 in the upper reach 16 d after the release of marked fish, and 0.31 in the middle reach 4 d after the release of marked fish (based on sample sizes of greater than 30 fish examined) (Figure 10, Appendix L). Following 11 July, about one month after the release of marked fish, estimated daily proportions of hatchery fish did not exceed 0.10.

Based on these estimates, the proportions of hatchery chinook salmon in the Smith River estuary were at times substantial. Particularly when fish were released above the estuary, there appears to be potential for competition between wild and hatchery fish. Patterns of estuary use in the Smith River may be similar for wild and hatchery fish. Because some hatchery-marked fish were captured as late as September, it seems that some hatchery fish reside in the estuary for at least as long as wild fish.

Past research (Levings et al. 1986, Fisher and Pearcy 1990) also suggests that hatchery-released chinook salmon may grow in estuaries at rates similar to wild fish.

Conclusions

Based on this study, there is substantial evidence that juvenile chinook salmon spend an extended period of time in the Smith River estuary. There were at least two distinct patterns of estuary use. Juvenile chinook salmon marked and released later in the season (i.e. August) remained in the estuary for significantly longer periods of time than those marked in June or July. This dichotomy of estuarine use by juvenile chinook salmon has also been described by Wallace (2000) for the Klamath River estuary. It also appeared, based on overall estuary size trends and estimated mean residence times, that fish arriving in the estuary late in the season (i.e. August) may have experienced substantial growth in the estuary. Data collected in other studies also supports a finding that juvenile chinook salmon exhibit substantial growth in other Pacific Northwest estuaries. Such growth implies that the underlying assumption of a time or size-independent probability of leaving the estuary is not valid. Computer simulations based on a time-dependent probability of leaving the estuary indicated that use of the exponential model under these circumstances could lead to severe negative bias in estimates of mean residence time. The importance of this result is that many studies may have underestimated the amount of time that juvenile anadromous salmonids spend in estuaries. Consequently, fisheries biologists may not fully appreciate the value of estuaries for these fish. I strongly urge that future research be conducted to find a more

appropriate model for estimating mean residence time for chinook salmon based on mark-recapture. In most river systems, the typical assumption of a time-independent probability of leaving the estuary is unrealistic.

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Appendix A. Date marked, number marked, number of marks detected, and percentage tag retention for juvenile rainbow trout marked with freeze brands at Humboldt State University fish hatchery, California, 1999.

Date	Number	Number of Marks Detected by Date of Examination														% Tag Retention			
Marked	Marked	3/8	3/10	3/12	3/17	3/24	3/26	4/2	4/12	4/19	4/28	5/14	5/26	6/28	8/6	5 wk	8 wk	10 wk	13 wk
03/05/99	10	10	10	10	10	10	10	10	10	10	10	10	9	8	4	100.0	100.0	100.0	80.0
03/10/99	10			10	10	10	10	10	10	10	10	10	10	10	1	100.0	100.0	100.0	100.0
03/24/99	20						20	20	20	20	20	20	16	13	4	100.0	80.0	65.0	65.0
04/15/99	30									27	30	29	29	21	0	96.7	70.0	70.0	0.0
Total																98.6	81.4	77.1	44.3

Appendix B. Simulation of a logistic distribution of residence times for fish entering an estuary.

Two separate computer programs were written (using S-Plus Version 3.3) to show that simulating a logistic distribution of residence times for all fish entering the estuary was mathematically equivalent to simulating a logistic distribution of residence times for each daily group of fish entering the estuary. For both approaches, I assumed an entrance pattern where 1,000 fish entered on day 1, 5,000 on day 2, and 2,000 on day 3. I assumed a mean of 8.0 and variance of 0.7 π^2 for the logistic distribution of residence times. In program "sim1dz022803", I simulated the distribution of residence times for all fish entering the estuary only once per repetition, whereas in program "hankest022803", I simulated a logistic distribution of residence times for each daily group of fish entering the estuary. The simulated numbers of fish remaining in the estuary on dates 5, 10, and 15 (exprem5, exprem10, and exprem15) were calculated to determine if the two programs generated equivalent calculations of the expected numbers of fish remaining in the estuary as a function of the number of days following tagging. The results from 10,000 repetitions of the two simulation processes were:

```
> sim1dz022803()
      exprem5 exprem10 exprem15
[1,] 7992.412 4306.551   10.679
> hankest022803()
      exprem5 exprem10 exprem15
[1,] 7992.372 4307.475   10.723 .
```

After conducting the first run of simulations, I edited the computer programs to include variance among the 10,000 calculations of the number of fish remaining on dates 5, 10,

Appendix B. Simulation of a logistic distribution of residence times for fish entering an estuary (continued).

and 15 (var5, var10, and var15). The following are results from the second run of simulations:

```
> sim1dz022803()
      exprem5     var5 exprem10    var10 exprem15    var15
[1,] 7992.426 7.426126  4306.53 1704.134  10.7085 10.66479
> hankest022803()
      exprem5     var5 exprem10    var10 exprem15    var15
[1,] 7992.367 7.463484 4307.405 1695.453  10.7484 10.54215 .
```

I considered the aforementioned results to be evidence of mathematical equivalence between the two different simulation approaches.

Appendix C. Date and number of juvenile chinook salmon captured at the screw trap located approximately 2 km above the Smith River estuary, California, 1998-1999.

Date	Number Captured	Date	Number Captured	Date	Number Captured
05/18/98	6	07/20/98	202	09/11/98	4
05/19/98	6	07/21/98	138	09/14/98	2
06/05/98	0	07/22/98	130	09/16/98	9
06/08/98	2	07/23/98	127	09/18/98	2
06/09/98	25	07/24/98	226	09/21/98	8
06/10/98	21	07/27/98	218	09/23/98	12
06/11/98	24	07/28/98	152	06/17/99	8
06/15/98	3	07/29/98	104	06/18/99	31
06/16/98	29	07/30/98	135	06/23/99	35
06/17/98	24	07/31/98	108	06/24/99	11
06/18/98	23	08/03/98	33	06/25/99	61
06/22/98	56	08/04/98	120	06/26/99	9
06/23/98	36	08/05/98	105	06/29/99	6
06/24/98	70	08/06/98	97	06/30/99	29
06/25/98	57	08/11/98	48	07/01/99	37
06/29/98	45	08/12/98	56	07/02/99	117
06/30/98	58	08/13/98	100	07/03/99	55
07/01/98	101	08/14/98	60	07/07/99	73
07/02/98	75	08/17/98	34	07/08/99	74
07/06/98	47	08/18/98	25	07/09/99	82
07/07/98	20	08/19/98	25	07/10/99	42
07/08/98	45	08/20/98	34	07/13/99	32
07/09/98	34	08/25/98	17	07/14/99	39
07/13/98	89	08/29/98	5	07/15/99	40
07/14/98	127	08/30/98	7	07/16/99	53
07/15/98	111	09/02/98	5	07/19/99	19
07/16/98	117	09/07/98	11	07/21/99	28
07/17/98	70	09/09/98	2	08/04/99	46

Appendix D. Location, date, and number of juvenile chinook salmon captured by beach seine, Smith River estuary, California, 1998-1999.

Location Date	Number Captured	Location Date	Number Captured	Location Date	Number Captured
Upper Reach		Upper Reach		07/15/99	188
06/08/98	25	06/25/99	33	07/23/99	157
06/22/98	27	07/01/99	13	07/27/99	275
06/29/98	23	07/08/99	19	07/28/99	551
08/17/98	25	07/13/99	86	07/29/99	74
09/07/98	12	07/15/99	17	08/03/99	379
Middle Reach		07/20/99	106	08/05/99	87
06/22/98	10	07/21/99	250	08/09/99	282
07/06/98	18	07/22/99	217	08/12/99	436
07/13/98	37	07/23/99	22	08/19/99	202
08/17/98	25	07/26/99	180	08/28/99	499
09/14/98	24	07/27/99	79	09/04/99	533
Lower Reach		07/28/99	84	09/18/99	183
06/22/98	25	07/29/99	124	09/24/99	96
09/21/98	10	08/02/99	277	Lower Reach	
Above Estuary		08/03/99	93	07/16/99	294
06/21/99	24	08/05/99	60	07/23/99	47
06/30/99	25	08/10/99	60	07/29/99	7
07/01/99	27	08/11/99	221	08/04/99	89
07/08/99	9	08/19/99	45	08/10/99	33
07/12/99	218	08/28/99	31	08/19/99	1
07/13/99	158	09/04/99	24	08/28/99	1
07/14/99	239	09/18/99	87	09/04/99	0
07/20/99	133	09/24/99	46	09/18/99	0
07/22/99	139	Middle Reach		09/24/99	19
07/27/99	69	07/02/99	98		
08/02/99	10	07/09/99	182		

Appendix E. Date, numbers of juvenile chinook salmon examined, recapture location (M = middle reach, U = upper reach), and numbers of fish recaptured for groups marked and released in the middle reach of the Smith River estuary, California, 2000.[a]

Date	Number of Fish Exam.	Recap. Loc.	Date and Number Marked and Released											
			Date:	6/15	6/22	6/29	7/7	7/13	7/20	7/27	8/3	8/10	8/24	9/17	9/24
			Number:	724	147	307	156	254	204	102	315	53	220	97	107
06/16/00	556	M [b]		5											
	9	U [b]		0											
06/19/00	59	M		0											
	19	U		0											
06/20/00	540	M		3											
06/21/00	247	U [c]		0											
06/22/00	155	M		1											
06/23/00	199	M		1	0										
	39	U		0	0										
06/26/00	559	M		4	0										
06/27/00	49	M [b]		0	0										
	26	U		0	0										
06/28/00	131	U [b]		1	0										
06/29/00	329	M		1	0										
06/30/00	413	M [d]		2	0	4									
	92	U		0	0	0									
07/03/00	504	M		4	4	8									
	102	U		0	0	0									

Appendix E. Date, numbers of juvenile chinook salmon examined, recapture location (M = middle reach, U = upper reach), and numbers of fish recaptured for groups marked and released in the middle reach of the Smith River estuary, California, 2000 (continued).[a]

Date	Number of Fish Exam.	Recap. Loc.	Date and Number Marked and Released											
			Date:	6/15	6/22	6/29	7/7	7/13	7/20	7/27	8/3	8/10	8/24	9/17	9/24
			Number:	724	147	307	156	254	204	102	315	53	220	97	107
07/05/00	161	M		0	0	3									
	299	U		0	0	2									
07/06/00	105	U		0	1	0									
07/07/00	158	M		0	0	1									
07/10/00	124	M		1	1	0	0								
	14	U		0	0	0	0								
07/11/00	224	M		0	1	1	1								
	5	U		0	0	0	0								
07/12/00	7	U		0	0	0	0								
07/13/00	266	M		0	0	0	1								
07/14/00	245	M		0	0	2	2	7							
	136	U		0	0	0	0	0							
07/17/00	335	M		1	1	2	3	4							
	129	U		0	0	0	1	0							
07/18/00	14	M		0	0	0	0	0							
	3	U		0	0	0	0	0							
07/19/00	0	U		0	0	0	0	0							
07/20/00	212	M		0	1	0	1	3							

Appendix E. Date, numbers of juvenile chinook salmon examined, recapture location (M = middle reach, U = upper reach), and numbers of fish recaptured for groups marked and released in the middle reach of the Smith River estuary, California, 2000 (continued).[a]

Date	Number of Fish Exam.	Recap. Loc.	Date and Number Marked and Released											
			Date:	6/15	6/22	6/29	7/7	7/13	7/20	7/27	8/3	8/10	8/24	9/17	9/24
			Number:	724	147	307	156	254	204	102	315	53	220	97	107
07/21/00	154	M		0	0	0	2	0	2						
	26	U		0	0	0	0	0	0						
07/24/00	111	M		0	0	0	0	0	2						
	31	U		0	0	0	0	0	0						
07/25/00	201	M		0	0	1	2	2	1						
	16	U		0	0	0	0	0	0						
07/26/00	0	U		0	0	0	0	0	0						
07/27/00	110	M		0	0	0	0	0	0						
07/28/00	75	M		0	0	0	0	2	0	1					
	13	U		0	0	0	0	0	0	0					
07/31/00	708	M [d]		0	0	0	0	1	2	0					
	242	U		0	0	0	0	0	0	1					
08/01/00	425	M		0	0	3	1	2	0	0					
	73	U		0	0	0	0	2	1	0					
08/02/00	139	U		0	0	0	0	1	1	0					
08/03/00	326	M		0	0	0	0	0	2	1					
08/04/00	117	M		0	0	1	0	0	0	1	13				
	106	U		0	0	0	0	0	0	0	4				

Appendix E. Date, numbers of juvenile chinook salmon examined, recapture location (M = middle reach, U = upper reach), and numbers of fish recaptured for groups marked and released in the middle reach of the Smith River estuary, California, 2000 (continued).[a]

Date	Number of Fish Exam.	Recap. Loc.	Date and Number Marked and Released											
			Date:	6/15	6/22	6/29	7/7	7/13	7/20	7/27	8/3	8/10	8/24	9/17	9/24
			Number:	724	147	307	156	254	204	102	315	53	220	97	107
08/07/00	169	M		0	0	0	1	0	0	1	4				
	129	U		0	0	0	0	0	2	1	1				
08/08/00	78	M		0	0	0	0	0	1	0	3				
	215	U		0	0	0	0	1	0	1	1				
08/09/00	385	U		0	0	0	0	0	0	0	3				
08/10/00	53	M		0	0	0	0	0	0	0	0				
08/11/00	32	M		0	0	0	0	0	0	0	2	0			
	141	U		0	0	0	0	0	0	0	6	1			
08/14/00	123	M		0	0	0	0	0	0	0	4	1			
	18	U		0	0	0	0	0	0	0	0	0			
08/15/00	44	M		0	0	0	0	0	0	0	2	2			
	26	U		0	0	0	0	0	0	0	0	0			
08/16/00	28	U		0	0	0	0	0	0	0	0	0			
08/17/00	4	M		0	0	0	0	0	0	0	0	0			
08/18/00	102	M		0	0	0	0	0	0	0	2	0			
	19	U		0	0	0	0	0	0	1	1	0			
08/21/00	104	M		0	0	0	0	0	0	0	3	0			
	3	U		0	0	0	0	0	0	0	0	0			

Appendix E. Date, numbers of juvenile chinook salmon examined, recapture location (M = middle reach, U = upper reach), and numbers of fish recaptured for groups marked and released in the middle reach of the Smith River estuary, California, 2000 (continued).[a]

Date	Number of Fish Exam.	Recap. Loc.	Date and Number Marked and Released											
			Date:	6/15	6/22	6/29	7/7	7/13	7/20	7/27	8/3	8/10	8/24	9/17	9/24
			Number:	724	147	307	156	254	204	102	315	53	220	97	107
08/22/00	126	M		0	0	0	0	0	0	0	3	2			
	64	U		0	0	0	0	0	0	0	0	0			
08/23/00	12	U		0	0	0	0	0	0	0	1	0			
08/24/00	250	M [d]		0	0	0	0	0	0	0	6	0			
08/25/00	146	M		0	0	0	0	0	0	0	4	0	8		
	9	U		0	0	0	0	0	0	0	0	0	1		
09/02/00	103	M		0	0	0	0	0	0	1	2	0	1		
	0	U		0	0	0	0	0	0	0	0	0	0		
09/10/00	49	M		0	0	0	0	0	0	0	1	0	1		
	15	U		0	0	0	0	0	0	0	0	0	0		
09/16/00	29	U		0	0	0	0	0	0	0	0	0	1		
09/17/00	135	M		0	0	0	0	0	0	0	2	1	8		
09/23/00	32	U		0	0	0	0	0	0	0	0	0	0	1	
09/24/00	144	M		0	0	0	0	0	0	0	1	0	10	3	
09/30/00	27	M		0	0	0	0	0	0	0	0	0	2	0	0
	138	U		0	0	0	0	0	1	0	0	0	1	0	1
10/01/00	408	M		0	0	0	0	0	0	0	1	0	2	3	3
	4	U		0	0	0	0	0	0	0	0	0	0	0	1

Appendix E. Date, numbers of juvenile chinook salmon examined, recapture location (M = middle reach, U = upper reach), and numbers of fish recaptured for groups marked and released in the middle reach of the Smith River estuary, California, 2000 (continued).[a]

Date	Number of Fish Exam.	Recap. Loc.	Date and Number Marked and Released											
			Date:	6/15	6/22	6/29	7/7	7/13	7/20	7/27	8/3	8/10	8/24	9/17	9/24
			Number:	724	147	307	156	254	204	102	315	53	220	97	107
10/06/00	90	U		0	0	0	0	0	0	0	1	0	2	0	0
10/07/00	112	M [d]		0	0	0	0	0	0	0	1	0	3	2	2

[a] Beginning on June 28, the locations of the two upper reach sites were changed. The order of sampling changed from middle reach then upper reach to upper reach then middle reach beginning on 3 July.

[b] One of the two designated sites was not visited during these sampling days.

[c] One additional site was sampled on 6/21; it was not revisited thereafter.

[d] Only one set was conducted at one of the two middle reach sites; two sets were conducted at the other site.

Appendix F. Results of t-tests conducted for slope coefficients of generalized linear models fitted to two categories of release groups of marked juvenile chinook salmon from the Smith River estuary, California, 2000.

Category	Release Groups	Slope Coefficient	Standard Error	t value	*p*
1	3-Aug	0.0230	0.0109	2.1105	0.0442
	10-Aug	0.0024	0.0223	0.1062	0.9162
2	15-Jun	0.1312	0.0195	6.7376	<0.0001
	22-Jun	-0.0514	0.0237	-2.1702	0.0311
	29-Jun	-0.0515	0.0203	-2.5329	0.0120
	7-Jul	-0.0597	0.0224	-2.6705	0.0082
	13-Jul	-0.0194	0.0268	-0.7242	0.4698
	20-Jul	0.0129	0.0381	0.3382	0.7356
	27-Jul	-0.0390	0.0342	-1.1388	0.2561

Appendix G. Results of generalized linear model analyses summarizing the effect of days at large on the number of recaptures and of release group on slope for separate categories of release groups of chinook salmon from the Smith River estuary, California, 2000.[a]

Category	Release Groups	Effect of:	df	Deviance	Residual df	Residual Deviance	*p*
1	3-Aug 10-Aug	Days at large on number of recaptures	1	5.540	28	29.495	0.0186
		Release group on slope	1	0.011	27	29.484	0.9147
2	15-Jun	Days at large on number of recaptures	1	38.772	38	19.32169	<0.0001
3	22-Jun 29-Jun 7-Jul	Days at large on number of recaptures	1	70.267	102	78.025	<0.0001
		Release group on slope	2	0.165	100	77.860	0.9209
4	13-Jul 20-Jul 27-Jul	Days at large on number of recaptures	1	34.748	70	47.09746	<0.0001
		Release group on slope	2	1.335	68	45.76206	0.5129

[a] Probability values are based on chi-squared tests.

Appendix H. Week, sample size (n), location (upper reach, middle reach, lower reach), mean fork length (mm), and standard deviation (SD) for juvenile chinook salmon captured using beach seine, Smith River estuary, California, 1998-2000.

Location		Fork Length		Location		Fork Length	
Week of:	n	Mean	SD	Week of:	n	Mean	SD
1998				Upper Reach			
Upper Reach				09/13/99	87	103.9	6.60
06/08/98	25	69.0	7.13	09/20/99	46	106.7	8.89
06/22/98	27	70.4	8.50				
06/29/98	23	80.2	7.52	Middle Reach			
08/17/98	25	88.1	4.55	06/28/99	98	83.2	7.70
09/07/98	12	111.9	7.04	07/05/99	182	80.5	9.39
				07/12/99	122	80.5	9.28
Middle Reach				07/19/99	145	83.7	9.01
06/22/98	10	69.3	8.58	07/26/99	716	85.1	8.25
07/06/98	18	75.7	6.87	08/02/99	463	81.4	8.31
07/13/98	37	86.1	5.52	08/09/99	486	84.4	8.78
08/17/98	25	90.2	6.30	08/16/99	98	89.0	7.80
09/14/98	24	109.0	6.72	08/23/99	184	92.1	8.01
				08/30/99	105	96.6	8.29
Lower Reach				09/13/99	164	104.4	6.89
06/22/98	25	73.0	9.16	09/20/99	32	109.2	6.32
09/21/98	10	107.3	9.23				
				Lower Reach			
1999				07/12/99	291	81.4	9.32
Upper Reach				07/19/99	43	82.4	7.54
06/21/99	33	75.1	9.00	08/02/99	87	85.1	6.65
06/28/99	13	77.2	5.75	08/09/99	33	88.1	6.63
07/05/99	19	69.4	9.74	08/16/99	1	83.0	--
07/12/99	103	75.4	8.52	08/23/99	1	84.0	--
07/19/99	592	78.7	7.97	09/20/99	19	100.4	10.02
07/26/99	467	78.6	8.91				
08/02/99	429	79.7	7.54	2000			
08/09/99	281	83.5	8.56	Upper Reach			
08/16/99	45	80.6	8.78	06/05/00	98	73.7	6.76
08/23/99	31	92.7	7.00	06/12/00	239	73.1	6.26
08/30/99	24	93.4	6.01	06/19/00	305	75.9	7.28

Appendix H. Week, sample size (n), location (upper reach, middle reach, lower reach), mean fork length (mm), and standard deviation (SD) for juvenile chinook salmon captured using beach seine, Smith River estuary, California, 1998-2000 (continued).

Location		Fork Length		Location		Fork Length	
Week of:	n	Mean	SD	Week of:	n	Mean	SD
Upper Reach				Middle Reach			
06/26/00	164	82.3	6.29	06/05/00	372	75.4	8.16
07/03/00	297	86.7	6.71	06/12/00	1064	80.9	7.29
07/10/00	162	84.8	6.52	06/19/00	585	83.9	7.22
07/17/00	112	87.9	5.97	06/26/00	553	83.0	7.04
07/24/00	60	86.6	5.40	07/03/00	435	84.9	6.93
07/31/00	483	87.8	6.38	07/10/00	376	85.0	6.56
08/07/00	602	90.3	6.64	07/17/00	583	86.6	5.70
08/14/00	91	91.1	4.90	07/24/00	384	85.9	6.20
08/21/00	88	93.9	6.27	07/31/00	516	87.7	6.64
09/04/00	15	97.5	8.41	08/07/00	332	88.2	6.63
09/11/00	29	103.5	7.37	08/14/00	238	89.6	5.58
09/18/00	31	106.0	5.07	08/21/00	460	93.0	6.14
09/25/00	45	110.2	7.26	08/28/00	103	99.6	6.91
10/02/00	49	117.9	7.57	09/04/00	49	98.2	7.64
				09/11/00	135	100.9	9.21
				09/18/00	107	106.0	6.62
				09/25/00	150	111.2	8.09
				10/02/00	58	112.9	12.53

Appendix I. Week of capture, sample size (n), mean size (fork length in mm or weight in g), and standard deviation for juvenile chinook salmon captured at the rotary screw trap located above the Smith River estuary, California, 1998 and 1999.

Week of:	FL(mm)			Weight (g)		
	n	Mean	SD	n	Mean	SD
06/08/98	71	86.4	14.32	a	a	a
06/15/98	76	93.8	11.79	a	a	a
06/22/98	209	91.2	8.11	a	a	a
06/29/98	276	88.6	7.45	145	7.8	1.84
07/06/98	146	90.5	6.82	144	8.3	1.91
07/13/98	498	91.7	6.83	497	8.6	2.00
07/20/98	793	90.1	6.28	758	8.4	3.75
07/27/98	706	90.1	5.53	705	8.4	1.57
08/03/98	348	92.1	5.52	346	8.9	1.65
08/10/98	223	93.0	5.43	164	9.4	1.82
08/17/98	118	93.4	5.57	118	9.3	1.57
08/24/98	29	98.3	6.44	29	10.6	1.90
08/31/98	5	99.8	4.81	5	11.1	1.84
09/07/98	17	104.9	5.02	17	13.0	1.82
09/14/98	13	111.3	6.98	13	15.6	2.98
09/21/98	20	113.8	7.97	20	17.4	4.51
06/14/99	39	77.4	9.86	a	a	a
06/21/99	118	75.9	8.23	a	a	a
06/28/99	247	79.9	7.08	a	a	a
07/05/99	271	76.2	7.10	a	a	a
07/12/99	163	79.3	5.60	a	a	a
07/19/99	47	79.0	5.30	a	a	a
08/02/99	46	86.7	5.21	a	a	a

[a] No fish weighed during these weeks.

Appendix J. Location of marking (M) or recapturing (R), date, days at large, number marked (number measured, if different), mean fork length (mm), and standard deviation (SD) of chinook salmon marked and recaptured in the Smith River estuary, California, 2000.

M/R		Days at		Fork Length		M/R		Days at		Fork Length	
Location	Date	Large	Number	Mean	SD	Location	Date	Large	Number	Mean	SD
M						M					
Middle	06/15/00		730 (765)	82.3	6.82	Upper	06/21/00 [a]		170 (246)	74.7	6.98
R						R					
Middle	06/16/00	1	5	79.4	4.03	Upper	06/23/00	2	1	80.0	
Middle	06/20/00	5	3	79.3	1.54	Middle	07/03/00	12	1	86.0	
Middle	06/22/00	7	1	103.0		Upper	07/05/00	14	1	93.0	
Middle	06/23/00	8	1	93.0		Upper	07/06/00	15	1	80.0	
Middle	06/26/00	11	4	87.0	8.34						
Upper	06/28/00	13	1	82.0		M					
Middle	06/29/00	14	1	85.0		Middle	06/22/00		147 (96)	83.5	7.24
Middle	06/30/00	15	2	83.0	2.12	R					
Middle	07/03/00	18	4	86.5	4.61	Middle	07/03/00	11	4	84.5	4.21
Middle	07/10/00	25	1	95.0		Upper	07/06/00	14	1	93.0	
Middle	07/17/00	32	1	94.0		Middle	07/10/00	18	1	95.0	
						Middle	07/11/00	19	1	72.0	
						Middle	07/17/00	25	1	75.0	
						Middle	07/20/00	28	1	77.0	

Appendix J. Location of marking (M) or recapturing (R), date, days at large, number marked (number measured, if different), mean fork length (mm), and standard deviation (SD) of chinook salmon marked and recaptured in the Smith River estuary, California, 2000 (continued).

M/R		Days at		Fork Length		M/R		Days at		Fork Length	
Location	Date	Large	Number	Mean	SD	Location	Date	Large	Number	Mean	SD
M						M					
Middle	06/29/00		300 (167)	82.1	6.39	Upper	07/06/00		103 (102)	86.6	6.83
R						R					
Middle	06/30/00	1	4	81.8	2.22	Upper	07/11/00	5	1	86.0	
Middle	07/03/00	4	8	80.4	5.93						
Upper	07/05/00	6	2	92.5	3.54	M					
Middle	07/05/00	6	3	89.3	3.21	Middle	07/07/00		156 (57)	85.1	5.84
Middle	07/07/00	8	1	88.0		R					
Middle	07/11/00	12	1	89.0		Middle	07/11/00	4	1	89.0	
Middle	07/14/00	15	2	81.5	6.36	Middle	07/13/00	6	1	88.0	
Middle	07/17/00	18	2	93.5	2.12	Middle	07/14/00	7	2	78.0	8.49
Middle	07/25/00	26	1	93.0		Middle	07/17/00	10	3	86.7	5.13
Middle	08/01/00	33	3	95.3	2.89	Upper	07/17/00	10	1	90.0	
Middle	08/04/00	36	1	98.0		Middle	07/20/00	13	1	91.0	
						Middle	07/21/00	14	2	90.0	1.41
						Middle	07/25/00	18	2	84.0	5.66
						Middle	08/01/00	25	1	84.0	
						Middle	08/07/00	31	1	90.0	

Appendix J. Location of marking (M) or recapturing (R), date, days at large, number marked (number measured, if different), mean fork length (mm), and standard deviation (SD) of chinook salmon marked and recaptured in the Smith River estuary, California, 2000 (continued).

M/R		Days at		Fork Length		M/R		Days at		Fork Length	
Location	Date	Large	Number	Mean	SD	Location	Date	Large	Number	Mean	SD
M						Middle	07/24/00	4	2	85.5	3.54
Middle	07/13/00		253 (95)	83.5	6.12	Middle	07/25/00	5	1	82.0	
R						Middle	07/31/00	11	2	82.5	14.85
Middle	07/14/00	1	7	82.3	6.55	Upper	08/01/00	12	1	89.0	
Middle	07/17/00	4	4	87.5	5.45	Upper	08/02/00	13	1	103.0	
Middle	07/20/00	7	3	87.3	7.64	Middle	08/03/00	14	2	84.5	17.68
Middle	07/25/00	12	2	87.0	0.00	Upper	08/07/00	18	2	88.0	19.80
Middle	07/28/00	15	2	86.0	5.66	Middle	08/08/00	19	1	92.0	
Middle	07/31/00	18	1	76.0		Upper	09/30/00	72	1	129.0	
Middle	08/01/00	19	2	87.5	14.85						
Upper	08/01/00	19	2	91.0	5.66	M					
Upper	08/02/00	20	1	87.0		Middle	07/27/00		102 (87)	85.8	5.89
Upper	08/08/00	26	1	81.0		R					
						Middle	07/28/00	1	1	90.0	
M						Upper	07/31/00	4	1	80.0	
Upper	07/20/00		204 (207)	87.4	5.72	Middle	08/03/00	7	1	84.0	
R						Middle	08/04/00	8	1	79.0	
Middle	07/21/00	1	2	78.0	4.24	Upper	08/07/00	11	1	85.0	

Appendix J. Location of marking (M) or recapturing (R), date, days at large, number marked (number measured, if different), mean fork length (mm), and standard deviation (SD) of chinook salmon marked and recaptured in the Smith River estuary, California, 2000 (continued).

M/R		Days at		Fork Length		M/R		Days at		Fork Length	
Location	Date	Large	Number	Mean	SD	Location	Date	Large	Number	Mean	SD
M						M					
Middle	07/27/00		102 (87)	85.8	5.89	Middle	08/03/00		311 (118)	87.3	5.71
R						R					
Middle	08/07/00	11	1	86.0		Middle	08/04/00	1	13	84.5	3.91
Upper	08/08/00	12	1	86.0		Upper	08/04/00	1	4	88.0	6.98
Upper	08/18/00	22	1	91.0		Middle	08/07/00	4	4	89.8	2.06
Middle	09/02/00	37	1	96.0		Upper	08/07/00	4	1	91.0	
						Middle	08/08/00	5	3	81.3	3.06
M						Upper	08/08/00	5	1	88.0	
Upper	08/02/00		119 (76)	90.2	6.29	Upper	08/09/00	6	3	90.3	4.04
R						Middle	08/11/00	8	2	86.5	7.78
Middle	08/07/00	5	1	94.0		Upper	08/11/00	8	6	89.2	8.52
Upper	08/08/00	6	1	88.0		Middle	08/14/00	11	4	86.3	4.79
Upper	08/09/00	7	1	86.0		Middle	08/15/00	12	2	90.5	0.71
Middle	08/14/00	12	1	95.0		Middle	08/18/00	15	2	97.0	4.24
Upper	08/16/00	14	1	97.0		Upper	08/18/00	15	1	95.0	
Middle	08/18/00	16	1	98.0		Middle	08/21/00	18	3	90.7	7.02
						Middle	08/22/00	19	3	91.0	6.24

Appendix J. Location of marking (M) or recapturing (R), date, days at large, number marked (number measured, if different), mean fork length (mm), and standard deviation (SD) of chinook salmon marked and recaptured in the Smith River estuary, California, 2000 (continued).

M/R		Days at		Fork Length		M/R		Days at		Fork Length	
Location	Date	Large	Number	Mean	SD	Location	Date	Large	Number	Mean	SD
M						Middle	08/22/00	13	1	92.0	
Middle	08/03/00		311 (118)	87.3	5.71	Middle	08/24/00	15	1	95.0	
R						Middle	09/10/00	32	1	104.0	
Upper	08/23/00	20	1	95.0		Upper	09/16/00	38	1	123.0	
Middle	08/24/00	21	6	92.3	5.61	Middle	09/24/00	46	1	111.0	
Middle	08/25/00	22	4	95.8	2.75	Upper	09/30/00	52	2	120.0	1.41
Middle	09/02/00	30	2	102.5	3.54	Middle	10/01/00	53	1	116.0	
Middle	09/10/00	38	1	109.0							
Middle	09/17/00	45	2	101.5	12.02	M					
Middle	09/24/00	52	1	106.0		Middle	08/10/00		53 (53)	90.1	5.38
Middle	10/01/00	59	1	105.0		R					
Upper	10/06/00	64	1	115.0		Upper	08/11/00	1	1	88.0	
Middle	10/07/00	65	1	116.0		Middle	08/14/00	4	1	85.0	
						Middle	08/15/00	5	2	84.5	0.71
M						Middle	08/22/00	12	2	92.5	6.36
Upper	08/09/00		376 (145)	92.4	6.60	Middle	09/17/00	38	1	101.0	
R											
Upper	08/22/00	13	2	98.0	1.41						

Appendix J. Location of marking (M) or recapturing (R), date, days at large, number marked (number measured, if different), mean fork length (mm), and standard deviation (SD) of chinook salmon marked and recaptured in the Smith River estuary, California, 2000 (continued).

M/R		Days at		Fork Length		M/R		Days at		Fork Length	
Location	Date	Large	Number	Mean	SD	Location	Date	Large	Number	Mean	SD
M						M					
Middle	08/24/00		212 (118)	94.0	5.81	Middle	09/17/00		97 (106)	100.3	8.97
R						R					
Middle	08/25/00	1	8	91.1	4.09	Upper	09/23/00	6	1	107.0	
Upper	08/25/00	1	1	99.0		Middle	09/24/00	7	3	96.7	6.81
Middle	09/02/00	9	1	95.0		Middle	10/07/00	20	2	111.0	4.24
Middle	09/10/00	17	1	94.0							
Upper	09/16/00	23	1	98.0		M					
Middle	09/17/00	24	8	98.3	9.04	Middle	09/24/00		107 (73)	107.11	6.76
Middle	09/24/00	31	10	104.8	6.78	R					
Middle	09/30/00	37	2	99.5	4.95	Upper	09/30/00	6	1	113.0	
Upper	09/30/00	37	1	116.0		Middle	10/01/00	7	3	113.7	10.79
Middle	10/01/00	38	2	108.5	3.54	Upper	10/01/00	7	1	108.0	
Upper	10/06/00	43	2	126.0	8.49	Middle	10/07/00	13	2	108.0	8.49
Middle	10/07/00	44	3	99.3	4.16						

[a] Fish marked on 21 June were marked at a site not sampled thereafter.

Appendix K. Capture location, date, number of maxillary clips recaptured, number of fish examined, and estimated proportion of hatchery-marked juvenile chinook salmon released by Rowdy Creek Hatchery, California, from 14 June to 24 June, 1999.

Location Date	# Max. Clips	# Fish Exam.	Est. Prop. Hatch.	Location Date	# Max. Clips	# Fish Exam.	Est. Prop. Hatch.
Above Estuary				Middle Reach			
21-Jun	3	24	0.911	2-Jul	2	98	0.152
30-Jun	1	25	0.297	9-Jul	3	182	0.122
1-Jul	1	27	0.275	15-Jul	2	188	0.079
8-Jul	1	9	0.825	23-Jul	3	157	0.142
12-Jul	16	218	0.545	27-Jul	6	275	0.162
13-Jul	10	158	0.470	28-Jul	3	551	0.040
14-Jul	4	239	0.124	29-Jul	0	74	0.000
20-Jul	4	133	0.223	3-Aug	1	379	0.020
22-Jul	3	139	0.160	5-Aug	0	87	0.000
27-Jul	0	69	0.000	9-Aug	0	282	0.000
2-Aug	0	10	0.000	12-Aug	0	436	0.000
				19-Aug	0	202	0.000
Upper Reach				28-Aug	0	499	0.000
25-Jun	1	33	0.225	4-Sep	1	533	0.014
1-Jul	0	13	0.000	18-Sep	0	183	0.000
8-Jul	0	19	0.000	24-Sep	0	96	0.000
13-Jul	2	86	0.173				
15-Jul	0	17	0.000	Lower Reach			
20-Jul	1	106	0.070	16-Jul	13	294	0.328
21-Jul	5	250	0.149	23-Jul	0	47	0.000
22-Jul	1	217	0.034	29-Jul	0	7	0.000
23-Jul	0	22	0.000	4-Aug	1	89	0.083
26-Jul	0	180	0.000	10-Aug	0	33	0.000
27-Jul	1	79	0.094	19-Aug	0	1	0.000
28-Jul	0	84	0.000	28-Aug	0	1	0.000
29-Jul	1	124	0.060	4-Sep	0	0	
2-Aug	0	277	0.000	18-Sep	0	0	
3-Aug	0	93	0.000	24-Sep	0	19	0.000
5-Aug	1	60	0.124				
10-Aug	1	60	0.124				
11-Aug	0	221	0.000				
19-Aug	0	45	0.000				
28-Aug	0	31	0.000				
4-Sep	0	24	0.000				
18-Sep	1	87	0.085				
24-Sep	0	46	0.000				

Appendix L. Capture location, date, number of AD-CWT's recaptured, number of fish examined, and minimum and maximum estimated daily proportions of hatchery-marked juvenile chinook salmon released by Rowdy Creek Hatchery, California, on 12 June, 2000.

Location Date	# AD-CWT	# Fish Exam.	Est. Prop. Hatch.		Location Date	# AD-CWT	# Fish Exam.	Est. Prop. Hatch.	
			Min.	Max.				Min.	Max.
Upper Reach					18-Aug	0	19	0.000	0.000
13-Jun	12	223	0.137	0.212	21-Aug	0	3	0.000	0.000
14-Jun	1	8	0.393	0.567	22-Aug	0	64	0.000	0.000
16-Jun	1	9	0.349	0.504	23-Aug	0	12	0.000	0.000
19-Jun	2	19	0.331	0.478	25-Aug	0	9	0.000	0.000
21-Jun	9	247	0.115	0.165	2-Sep	0	0		
23-Jun	1	39	0.081	0.116	10-Sep	0	15	0.000	0.000
27-Jun	1	26	0.121	0.175	16-Sep	0	29	0.000	0.000
28-Jun	9	131	0.216	0.312	23-Sep	0	32	0.000	0.000
30-Jun	5	92	0.171	0.247	30-Sep	0	138	0.000	0.000
3-Jul	3	102	0.092	0.133	1-Oct	0	4	0.000	0.000
5-Jul	13	299	0.137	0.197	6-Oct	0	90	0.000	0.000
6-Jul	5	105	0.150	0.216					
10-Jul	0	14	0.000	0.000	Middle Reach				
11-Jul	0	5	0.000	0.000	13-Jun	11	167	0.168	0.260
12-Jul	0	7	0.000	0.000	15-Jun	46	766	0.189	0.272
14-Jul	0	136	0.000	0.000	16-Jun	45	556	0.254	0.367
17-Jul	1	129	0.024	0.035	19-Jun	2	59	0.107	0.154
18-Jul	0	3	0.000	0.000	20-Jun	26	540	0.151	0.218
19-Jul	0	0			22-Jun	4	155	0.081	0.117
21-Jul	0	26	0.000	0.000	23-Jun	4	199	0.063	0.091
24-Jul	0	31	0.000	0.000	26-Jun	20	559	0.112	0.162
25-Jul	0	16	0.000	0.000	27-Jun	1	49	0.064	0.093
26-Jul	0	0			29-Jun	13	329	0.124	0.179
28-Jul	0	13	0.000	0.000	30-Jun	10	413	0.076	0.110
31-Jul	0	242	0.000	0.000	3-Jul	12	504	0.075	0.108
1-Aug	0	73	0.000	0.000	5-Jul	0	161	0.000	0.000
2-Aug	1	139	0.023	0.033	7-Jul	2	158	0.040	0.057
4-Aug	1	106	0.030	0.043	10-Jul	2	124	0.051	0.073
7-Aug	0	129	0.000	0.000	11-Jul	5	224	0.070	0.101
8-Aug	0	215	0.000	0.000	13-Jul	4	266	0.047	0.068
9-Aug	0	385	0.000	0.000	14-Jul	1	245	0.013	0.019
11-Aug	0	141	0.000	0.000	17-Jul	3	335	0.028	0.041
14-Aug	0	18	0.000	0.000	18-Jul	0	14	0.000	0.000
15-Aug	0	26	0.000	0.000	20-Jul	1	212	0.015	0.021
16-Aug	0	28	0.000	0.000	21-Jul	0	154	0.000	0.000

Appendix L. Capture location, date, number of AD-CWT's recaptured, number of fish examined, and minimum and maximum estimated daily proportions of hatchery-marked juvenile chinook salmon released by Rowdy Creek Hatchery, California, on 12 June, 2000 (continued).

Location Date	# Max. Clips	# Fish Exam.	Est. Prop. Hatch.		Location Date	# Max. Clips	# Fish Exam.	Est. Prop. Hatch.	
			Min.	Max.				Min.	Max.
Middle Reach					18-Aug	0	102	0.000	0.000
24-Jul	0	111	0.000	0.000	21-Aug	0	104	0.000	0.000
25-Jul	0	201	0.000	0.000	22-Aug	0	126	0.000	0.000
27-Jul	2	110	0.057	0.082	24-Aug	0	250	0.000	0.000
28-Jul	0	75	0.000	0.000	25-Aug	0	146	0.000	0.000
31-Jul	3	708	0.013	0.019	2-Sep	0	103	0.000	0.000
1-Aug	2	425	0.015	0.021	10-Sep	0	49	0.000	0.000
3-Aug	0	326	0.000	0.000	17-Sep	0	135	0.000	0.000
4-Aug	0	117	0.000	0.000	24-Sep	1	144	0.022	0.032
7-Aug	0	169	0.000	0.000	30-Sep	0	27	0.000	0.000
8-Aug	0	78	0.000	0.000	1-Oct	0	408	0.000	0.000
10-Aug	0	53	0.000	0.000	7-Oct	0	112	0.000	0.000
11-Aug	0	32	0.000	0.000					
14-Aug	0	123	0.000	0.000					
15-Aug	0	44	0.000	0.000					
17-Aug	0	4	0.000	0.000					