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Emigration of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in the Feather River, 2005-2007.

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Summary

This report presents the results from the past three seasons of the Feather River Study Chinook salmon emigration survey (2005-2007). The 2007 season was the tenth year Rotary Screw Traps were fished throughout the emigration period (December through June).

Four rotary screw trap (RST) locations were used to assess the timing and general abundance of juvenile Chinook salmon, steelhead and other fishes emigrating the Feather River. Within the low flow channel (lfc), one RST (Eye Riffle) was stationed at river mile (RM) 60.1, approximately one mile above the Thermalito Afterbay Outlet. The Eye Riffle RST was used during the 2005 and 2006 trapping seasons. Due to extremely high flows and subsequent changes in channel morphology, the Eye Riffle RST was moved 1 river mile upstream to Steep Riffle (RM 61) at the end of the 2006 trapping season. Within the high flow channel (hfc), two RSTs fished in tandem just above Herringer Riffle at RM 46, approximately 4.3 river miles upstream of the City of Live Oak Recreation Area boat ramp. These traps were used in the hfc during the 2005 and 2006 trapping seasons. During the 2007 trapping season, one RST was used in the hfc. This RST was placed just below Sunset Pumps at RM 38.

Although Chinook salmon and steelhead were the primary targets of trapping efforts, records were kept on all fish species caught. Thirty-three species were caught during three seasons of trapping. Chinook salmon was the dominant species, comprising over 98% of the catch. Of the total salmon catch, 532,362 (53%) were caught in the lfc and 492,567 (47%) were caught in the hfc.

Approximately 89 and 74% of the salmon trapped and measured in the lfc and hfc, respectively, were less than 50 mm, demonstrating that most Feather River salmon emigrate well before smolting. Salmon ranged from 21 to 299 mm fork length. Salmon emigration was observed as soon as the traps were deployed in November/December, peaked in January through March, and continued in June at very low levels. Separate fall-run Chinook emigration estimates were developed for the low flow channel and high flow channel. Over three trapping seasons (2005-2007), passage estimates ranged from 2.4 to 10.3 million fall-run-sized salmon in the lfc. An emigration estimate of 13.8 million fall-run-sized salmon was generated during the 2005 trapping season in the hfc.

In general, environmental variables such as river flow (cfs), turbidity and temperature did not influence fall-run emigration between December and May. However, during the 2005 trapping season, elevated turbidity in the lfc was shown to be significant in influencing emigration. Despite that result, the onset of spawning the previous fall probably plays a larger role in determining when juvenile salmon emigrate the Feather River. Although no stream-type life-history strategies are evident in the Feather, alternative patterns to a strict ocean-type model may exist.

Based on adult escapement, average fecundity and the emigration estimate, the egg-to-fry survival rate for fall-run Chinook juveniles was 8% within the lfc in 2005. The egg-to-fry survival rate was 3% and 4% during the 2006 and 2007 trapping seasons, respectively. The emigration index (per capita production) of juveniles ranged from a low of 100 in 2006 to a high of 293 in 2005.

A total of 290 wild young-of-the-year steelhead were captured in the lfc during the three-year period. In the hfc, 355 wild young-of-the-year and four wild yearling steelhead were captured during the 2005 – 2007 trapping seasons.

Introduction

In 1996 DWR began to monitor salmon and steelhead in support of the Federal Energy Regulatory Commission (FERC) relicensing of the State Water Project's Oroville Facilities and to address issues raised by the Central Valley Project Improvement Act's (CVPIA) Anadromous Fish Restoration Program (USFWS 1997a). To this end, DWR initiated a study to identify the timing and magnitude of emigration of naturally produced salmon relative to different physical conditions and spawning population size. Although the main focus of the study is salmon and steelhead, other fish species were also recorded.

This study is the first on the emigration of salmonids and other fish species in the Feather River since the 1970’s (Painter et al. 1977). The salmon emigration study has the following objectives:

(1) Document general salmonid emigration attributes, such as timing, abundance and composition by species, race, and life stage.
(2) Investigate the influence of factors thought to initiate emigration, such as flow, turbidity, and water temperature.
(3) Develop annual indices of juvenile salmon production by relating information on spawning intensity and emigration. Use the indices to examine the effects of physical and biological factors on Feather River salmon production.

Salmon emigration is monitored primarily using rotary screw traps (RSTs). Two RST locations are used, one at the lower end of each of the two study reaches. The traps are operated for approximately seven months (December through June). Two trap locations are necessary because flow is strictly regulated above the Thermalito Outlet and therefore emigration cues and species composition may be different for the two reaches. Furthermore, two traps were used in the hfc in the 2005 and the beginning of the 2006 trapping seasons to increase capture of salmonids for trap efficiency trials.

The following report is a summary of salmon emigration between December 2004 and June 2007, representing three consecutive seasons of trapping efforts. Although the trapping season begins at the end of one calendar year and continues into the middle of the next (i.e. December through June), trapping years will be referenced by the spring season. For example, the 2004/2005 trapping period that progressed from December 2004 through June 2005 will be referenced as the 2005 season.

Methods

Study Area

The Fish Barrier Dam, just downstream of the Thermalito Diversion Dam, is the upper limit for upstream migrating fish. The base of the Fish Barrier Dam is where the fish ladder begins, guiding fish into the Feather River Hatchery. The hatchery was built by DWR to mitigate for the loss of Chinook salmon and steelhead spawning and rearing habitat resulting from the construction of Oroville Dam and ancillary facilities.

The lower Feather River (Figure 1) is located within the Central Valley of California, draining an extensive area of the western slope of the Sierra Nevada. Lake Oroville, created by the completion of Oroville Dam in 1967, has a capacity of approximately 3.5 million acre-feet (maf) of water and provides flood control, water supply, power generation, and recreation. Flow in the lower Feather River below the reservoir is regulated through releases from Oroville Dam, Thermalito Diversion Dam, and the Thermalito Afterbay Outlet. Under normal operations, the majority of water released from Lake Oroville is diverted at Thermalito Diversion Dam into the Power Canal and Thermalito Forebay. Water released from the Forebay is used to generate power as it is discharged into Thermalito Afterbay. Water is returned to the Feather River through the Thermalito Afterbay Outlet, and then flows southward to the confluence with the Sacramento River at Verona. The remainder of the flow, typically 600-650 cubic feet per second (cfs), flows through the low flow channel (lfc). The reach between Oroville Dam and the confluence with the Sacramento River has a low gradient.

The salmonid emigration study area (Figure 2) is 29 river miles long and consists of the entire lfc and the upper 13 miles of the high flow channel (hfc). The lfc extends from the Fish Barrier Dam at river mile (RM) 67.25 to the Thermalito Outlet (RM 59). The hfc extends from the Thermalito Outlet to the confluence with the Sacramento River. The Yuba River (RM 27.5) is 16.5 river miles further downstream from Honcut Creek. The study is focused on the upper 29 river miles (RM 38 to 67) of the lower river because it is (1) the portion of the river where most Chinook salmon and steelhead spawn and initially rear, making them more affected by project operations and, (2) sampling in this reach provides the greatest opportunity to enumerate emigrating salmon and steelhead fry. River miles 0 to 37 are comprised mostly of flat-water habitat and fine substrates generally unsuitable for salmonid spawning.

Field Collection Methods

Eight-foot RSTs are the main sampling devices used for the emigration survey. RSTs are sturdy, relatively easy to move within the stream, easy to operate and maintain, are able to capture fish without harm in fast-moving water, and can be used to sample continuously. A RST operates in the following manner to capture fish: with the trapping cone lowered into flowing water, water strikes the baffles on the inside of the trapping cone, causing the cone to rotate. Fish enter the upstream end of the rotating trapping cone, become trapped inside the trapping cone, and are carried rearward into a live box.

Four rotary screw trap (RST) locations were used to assess the timing and general abundance of juvenile Chinook salmon, steelhead and other fishes emigrating the Feather River (Figure 2). Within the lfc, one RST (Eye Riffle) was stationed at river mile (RM) 60.1, approximately one mile above the Thermalito Afterbay Outlet. The Eye Riffle RST was used during the 2005 and 2006 trapping seasons. Due to extremely high flows and subsequent changes in channel morphology, the Eye Riffle RST was moved 1 river mile upstream to Steep Riffle (RM 61) at the end of the 2006 trapping season. Within the hfc, two RSTs fished in tandem just above Herringer Riffle at RM 46, approximately 4.3 river miles upstream of the City of Live Oak Recreation Area boat ramp. These traps were used in the hfc during the 2005 and 2006 trapping seasons. During the 2007 trapping season, one RST was used in the hfc. This RST was placed just below Sunset Pumps at RM 38.

Several trap locations are needed because operation of the Oroville Complex results in two substantially different flow regimes: flow in the low flow channel is strictly regulated (generally about 600-650 cfs), while the high flow channel is subject to flow fluctuations from 800 to 40,000+ cfs during emigration. Therefore, emigration cues and species composition may differ between the two reaches. The RST sites were selected based on the following criteria for RST installation, operation, and maintenance: (1) depth greater than six feet at minimum flow; (2) velocity greater than two feet per second at minimum flow; (3) suitable anchoring point(s); (4) limited public access; and (5) general ability to capture juvenile salmonids.

The RSTs were fished continuously for approximately seven months (December through June), except for short periods when river conditions became unsafe or when heavy debris loads occurred due to high river flows. When serviced, trapped fish were removed from the live box, identified to species and counted. All fish were counted by hand if numbers permitted. When juvenile salmon were highly abundant, a simple volume displacement method was used to count them in increments of 1000. Fork length (to the nearest millimeter) was measured for up to 50 individuals of each salmonid species. Up to 25 non-salmonids were also measured and counted during processing. All fish were then released back to the river, except for salmon retained for coded-wire tagging and trap efficiency evaluations.

All Chinook salmon individuals were assigned to a race based on the length/date criterion set forth in the Sacramento River Daily Length Table (Greene 1992). All live salmon and steelhead that were measured were also inspected for characters such as presence of parr marks, silvery appearance, and deciduous scales to determine life stage. A simple designation was used for each salmon measured:

(1) yolk sac fry/parr: yolk sac is clearly visible.
(2) fry: may have parr marks but yolk sac is not fully absorbed
(3) parr: clearly parr, a darkly pigmented fish with characteristic dark, oval-to round-shaped parr marks on its sides and yolk sac is fully absorbed.
(4) intermediate: between parr and smolt. Usually has fading parr marks and some scale loss.
(5) smolt: highly faded or completely lacking parr marks, bright silver or nearly white color and heavy scale loss.

A salmon tagging station was set up at the Thermalito Afterbay Outlet to coded-wire tag (CWT) in-channel produced juvenile salmon. Juvenile salmon captured in the RSTs were transported to the tagging station and implanted with a CWT half-tag (Northwest Marine Technology, Inc., Washington) by a contractor, Big Eagle and Associates. The tagged salmon were held overnight while a sub-sample was checked for tag shedding and survival. Tagged salmon were released at the boat ramp just above the Thermalito Afterbay Outlet.

Other measurements collected daily at each RST included: water clarity (turbidity, measured in NTUs), water temperature, sample period, average trapping cone revolutions per minute, and the total number of trapping cone revolutions during the sample period. Additionally, overall trap performance was evaluated by determining whether the trap was fishing was good, fair or poor during the trapping period. Simply put, a "good" code meant the trap was fishing normally; a "fair" code was assigned when the trap was spinning very slowly or was partially blocked with debris and "poor" code was assigned when the trap was not spinning or operating properly. Daily mean river flow (cfs) for the Thermalito trap was obtained by adding the Thermalito Diversion Dam flow (CA Department of Water Resources gauge AO 5191) to the Feather River Fish Hatchery Outflow (CA Department of Water Resources gauge AO 5990). River flow for the Live Oak trap was obtained by adding the Thermalito trap flow to the Feather River Outlet-Thermalito Afterbay flow (CA Department of Water Resources gauge AO 5975).

Trap Efficiency and Emigration Estimate

Trap efficiency was evaluated using fish collected in the RSTs. Seventy-nine evaluations (over the three year period) were conducted using salmon captured in their respective traps (i.e. salmon trapped at Steep Riffle were only used for Steep trap efficiency evaluations). Evaluations were typically performed between December and March, the period when nearly all emigration occurred. For each evaluation, approximately 500 to 2000 marked fish were transported roughly two kilometers upstream of each RST. Fish were released in equal proportions along the river margin (i.e. if 1000 fish were tagged, approximately 500 were released on river right and 500 on river left). Because holding trials revealed insignificant losses of fish held for 24 hours after marking, fish were generally released within an hour of marking. However, when elastomer tags were applied in addition to Bismarck Brown, fish were generally held for 24 hours prior to release. Furthermore, previous diel sampling (DWR 2002) revealed that nearly all salmon were captured at night and therefore time of release was unlikely to influence recapture rates. Only healthy fish (based on visual observations) were released and the time of release was recorded (i.e. time of day). RST catch was monitored for recaptures for several days after marked fish were released. Although most recaptures occurred within the first three days of release, all traps were monitored for up to seven days based on previous observations that nearly all recaptures occurred in that time-period. However, because the traps were searched daily for marked fish, individuals could be recovered several weeks after release. Mortality between the release point and the trap was assumed to be negligible.

All salmon were marked with Bismarck Brown (Spectrum Chemical, Gardena, California) dye at a concentration of 2.8 grams to 115 L of water for 30 minutes. Many releases had fish additionally tagged with colored latex elastomer (Northwest Marine Technology, Shaw Island, Washington). The secondary tag served two purposes; (1) it allowed release groups for the hfc and lfc to be identified separately, and (2) it provided long-term identification of marked individuals (tags often lasted several months).

Trap efficiency was defined as the proportion of the total number of emigrants that were captured as they moved past the trap. The approximate estimate of trap efficiency (*TE*) for each sampling period is similar to that given by Roper and Scarnecchia (2000):

$$TE = \frac{\sum_{i=1}^{n} R_{ji}}{M_j}$$

Where R_{ji} is the number of recaptured fish from the j^{th} release group on the i^{th} day, and M_j is the number of marked fish released. This estimate of efficiency assumes that (1) all released fish continue downstream after release, (2) handling and marking does not affect fish behavior, (3) mortality rates are zero, and (4) marked fish mix randomly with unmarked fish.

Efficiency values were only applied to data for their respective year and location. Although efficiency tests were performed separately each week, two adjoining weeks of efficiency values were averaged to calculate daily trap efficiency and daily emigration past each trap for the respective time-period. This was done to avoid bias associated with few recaptures (less than 7; Roper and Scarnecchia, 1999). For weeks between 1 December and 15 April without efficiency tests, the average efficiency value for the year was used to calculate daily passage. Efficiency values were only applied to RST catch between 1 December and 15 April, with the exception of the RST located at Herringer in 2005. Efficiency trails continued until 15 May at that location, therefore efficiency values were used until 15 May. For periods when the trap was set for less than seven consecutive days, daily catch for the un-sampled period (*DCU*) was estimated by the following formula, where CS1 = total catch in the sample days before the un-sampled period; CS2 = the total catch after the un-sampled period; D_1 = the number of days in sample period one and D_2 = the number of days in sample period two.

$$DCU = \frac{\sum(C_{S1}) + \sum(C_{S2})}{D_1 + D_2}$$

Daily passage estimates (DPE) were not made for periods when the trap was set for less than seven consecutive days, so as to avoid making unreasonable inferences about longer un-sampled periods (Roper and Scarnecchia, 2000). Daily passage estimates and 95% confidence intervals were calculated by Chapman's (1951) modification of Seber's (1973) expression:

$$DPE = [(Mj + 1)(Cj + 1)/(Rj + 1)] - 1$$

Whereby *Mj* is the number of marked salmon released for the trap efficiency during time period *j*, *Cj* is the number of unmarked salmon captured in the trap during the time period *j* and *Rj* is the total number of recaptures during period *j*. Daily confidence intervals (95%) for the period are calculated as

$$C.I. = DPE + Z_{\alpha(2)}[(VarDPE)]^{1/2}$$

where

$$Var(DPE) = DPE^2(Cj - Rj)/[(Cj+1)(Rj+2)]$$

The annual emigration estimate (*EE*) was the sum of Daily Passage Estimates plus the sum of raw daily catch (DC) for periods without DPEs.

$$EE = \sum_{d=dec.1}^{Apr.15}(DPE) + \sum_{d=Apr.15}^{July1}(DC)$$

The resulting emigration estimate is inherently low for two reasons. First, it uses only raw catch before December 1 and after 15 April (with the exception of the RST at Herringer in 2005) and in periods when the trap is fished for less than seven consecutive days. However, very few fish emigrate before 1 December or after 15 April. Second, and more importantly, the trap is not fished during high flows (> 15,000 cfs) and debris loads.

The emigration estimate for the river can then be used to calculate an emigration index (*EI*) or using the spawning escapement estimate from the previous fall. The emigration index is a per-capita production estimate that may be used to compare production from year to year. The index is calculated by dividing the emigration estimate (*EE*) for the river by the estimated number of adult/grilse females (*F*) determined by the fall escapement survey.

$$EI = \frac{EE}{F}$$

Juvenile salmon survival rate (*SR*) for the low flow channel is computed as follows

$$SR = \frac{EE}{SF \times 5522}$$

Where *SF* is the number of successfully spawned females in the low flow channel, *5522* is the expected average fecundity of Feather River Chinook salmon females (personal communication with Armando Quinones, California Department of Fish and Game) and *EE* is the total juvenile fall-run salmon emigration estimate for the Low Flow Channel.

Due to unequal sampling effort among years, trapping effort (in hours per month) and number of salmon captured per hour (CPH) is reported for each year. Effort calculations were only performed for days when trapping performance was good or fair. The effects of river flow, temperature and turbidity on emigration timing were examined with simple linear regression. Each variable (e.g. river flow) was reduced to a weekly average and plotted against the corresponding passage estimate for the respective week.

Results

RST Catch and Species Composition

Thirty-two species (excluding Chinook salmon) were caught during the three survey years, 13 native and 19 non-native (Table 1). This is similar to the number of species caught in previous years of trapping (DWR 2002, DWR 2007). Chinook salmon was the dominant species, comprising over 98% of the total catch for all three years combined. Of the total salmon catch, 532,362 (53%) were caught in the lfc and 492,567 (47%) were caught in the hfc (Tables 2 and 3).

The large numbers of salmon resulted in a high proportion of native fish (98.4%) in the total catch. Non-natives were also prevalent; 83.8% of all non-salmonids were non-native (Table 1). The proportion of native fish, including salmonids, did not differ between the lfc and the hfc: 98.6% of the fish captured in the lfc were native species, while 98.8% of the fish captured in the hfc were native.

Salmon Emigration

Salmon were caught in the RSTs as soon as they were deployed. Monthly salmon catch at each RST is reported in Tables 2 and 3. The highest daily catch in the hfc was 27,950 on 23 February 2005. The highest daily catch in the lfc was 17,090 on 6 March 2007. Catch was highest in the lfc from December through March of each year. In the hfc, salmon catch remained high from January through mid-April. Salmon catch declined rapidly at both traps around mid-April each year (Figures 3-8; Tables 2-3). The lfc averaged just 2.2% of the total catch for the months of April, May and June for all three years, while the hfc averaged 5.5% of the total catch for the same time period. In contrast, January, February and March averaged 86.2% and 92.5% of the total Chinook catch in lfc and hfc, respectively.

Salmon fork lengths ranged from 24 to 200 mm in the lfc and 21 to 299 mm in the hfc. Weekly mean fork length ranged from 31 to 73 mm in the lfc and 32 to 81 mm in the hfc. Mean fork length at each RST changed little until late April, then steadily increased until the end of trapping (Figures 10 and 11).

Trap Efficiency and Emigration Estimates

Seventy-nine efficiency evaluations were conducted during the three-year study period (Tables 4 and 5). Recapture percentages in the lfc RSTs ranged from 0% to 14.4% and averaged 4.3% ($\pm$ 4.5 SD) over the three-year period. The RSTs in the hfc had recapture percentages ranging from 0% to 8.4% and averaged 2.3% ($\pm$ 2.1 SD) over the same three-year period. Emigration estimates for fall-run sized fish from 2005-2007 are presented in Tables 2 and 3.

Emigration index values and survival rates fluctuated over the three year period (Table 6). The index estimates the number of juvenile Chinook salmon that pass the lfc RST per adult female salmon that spawned in the lfc of the Feather River. For example, during the 2005 trapping season approximately 293 juvenile Chinook salmon passed the Eye Riffle RST for every female that spawned in the lfc in fall 2004. This corresponds to a survival of 8% from the time of egg deposition to capture at the Eye Riffle RST during the 2005 trapping season.

Coded-wire Tagging of Naturally Spawned Salmon

A summary of DWR tagging efforts of naturally produced fall-run Chinook salmon is presented in Table 8. In addition, Table 9 provides a summary of all naturally produced Feather River Chinook salmon CWT recoveries retrieved from the Regional Mark Information System (RMIS) database. To this point, low return rates of naturally produced Chinook have precluded formal analysis of the data. Increased tagging effort may provide greater returns allowing us to evaluate the return success of naturally produced fish compared to hatchery stock.

Spring-run-sized Chinook

Figure 12 illustrates that the majority of spring-run-sized fish caught at the traps are small. They are nearly identical in size to the fall-run emigrating at the same time, clearly illustrating the uncertainties of using the Daily Length Table alone as an indicator of race.

Figure 12 also illustrates the emigration patterns and catch distribution for spring-run-sized fish. In the lfc, during the three year period, the highest catch was in December. In the hfc, the highest catch was also in December, except in 2007 at the Sunset RST, which did not begin fishing until January. Spring-run were caught at both traps throughout most of the sampling period, with a general decline from January to March—a typical fall-run or Ocean-type emigration pattern. After rearing in the river to a larger size, a very small group of Spring-run-sized fish passed Sunset Pumps in April.

Late-fall-sized Chinook

Very few late-fall-run Chinook were present in the Feather River. Shortly after emergence, late-fall Chinook were captured at RSTs in the lfc and the hfc (Figure 13). Catch at both traps peaked between March and May, then quickly dropped. The highest number of late-fall-run Chinook were caught at the Steep Riffle RST in April 2007 (Table 3). Sixty-six percent of all the late-fall-run Chinook were caught in the lfc and nearly all were captured as fry (Tables 2 and 3 and Figure 13).

Steelhead

Over the three years, a total of 1405 steelhead were caught at both locations. Of those, 641 were naturally produced (wild) YOY steelhead (<150 mm) captured within the high flow and low flow channels (Figure 14; Tables 2 and 3). Only four wild yearlings were captured during all three trapping seasons. Two adult wild steelhead (>250 mm) were caught during the 2007 trapping season.

Steelhead catch predominantly occurs in March and April at both locations, with much lower catch in May and June (Figure 15). Average fork length of wild steelhead was 26.3 mm ($\pm$ 7.9 SD) in the lfc and 24.5 mm ($\pm$ 7.2 SD) in the hfc. Wild steelhead catch remained consistently low with the exception of the 2005 trapping season at the Herringer RST (Table 1, Figure 16). Approximately 45% of all wild steelhead trapped was caught in the lfc, while 55 % was caught in the hfc (Table 1).

Influence of Flow, Temperature and Turbidity on Emigration

Flows were maintained at approximately 600 cfs year round during the 2005 and 2007 trapping seasons in the lfc (Figure 3). However, there were several large fluctuations above 10,000 cfs during the 2006 trapping season. Hfc flows ranged from a low of 1,053 cfs in April 2005 to a high of 80,392 cfs in January 2006. There was no evidence of a relationship between flow and Chinook salmon catch in the lfc or hfc (Table 7). Fry passage in the lfc varied through time, while flows remained nearly constant. Furthermore, although flows fluctuated in the hfc, salmon catch did not respond accordingly (Figure 4).

Turbidity varied among years in the lfc and hfc, but remained lower in the lfc (Figures 7 and 8). In general, there was no relationship between turbidity and passage in the hfc or lfc. However, during the 2005 trapping season, turbidity had a statistically significant relationship with salmon passage in the lfc (Table 7, Linear regression; $R^2 = 0.65$, df = 18, $P = 0.00$, y = 2E – 06x + 0.64). As weekly average turbidity increased, the weekly salmon passage estimate increased.

In general, there was not a statistically significant relationship between temperature and salmon passage (Table 7). However, there was a significant relationship between temperature and salmon passage in the lfc during the 2007 trapping season (Table 7, Linear regression; $R^2 = 0.28$, df = 16, $P = 0.02$, y = -41838x + 660307). Despite this result, it is unlikely that temperature was biologically significant in influencing winter or early spring emigration because the average daily temperature never exceeded 14.0° C (57.2° F) until May, when 99% of the population had already emigrated (Figures 5 and 6). Average daily water temperature ranged from 7 to 18.5°C at RST locations in the lfc and 6 to 22°C at RST locations in the hfc (Figures 5 and 6). Water temperature was low during winter and steadily increased from March until the end of the sampling period at both locations.

Effort

Effort was generally consistent in the lfc during the 2005 and 2007 trapping seasons (Table 9). Due to the high flow events in 2006, effort at the Eye Riffle and Herringer RSTs was lower because the traps were frequently pulled. Effort was doubled at Herringer in 2005 and at the beginning of 2006 with the addition of a second RST. During the 2005 and 2006 trapping seasons catch rates were greatest in January and February in the lfc and the hfc (Table 9). However, during the 2007 trapping season catch rates were highest in March. Low effort and low catch rates due to extremely high flows in 2006 may have caused an underestimate of the number of salmon emigrating the Feather River (Table 9).

Discussion

Salmon Emigration: Trap Efficiency, Estimates and Timing

The accuracy of the emigration estimate is affected by several factors, the most important being trap efficiency. Searching for marked fish among thousands can be problematic. However, Bismarck Brown has consistently proven to be a safe, easy, and reliable method of mass marking individuals. Marked fish can be easily identified as many as five days after marking. Furthermore, salmon were often given an additional elastomer mark, making positive identification reliable for several weeks. Additionally, over 95% of the recaptures occurred within the first two days of release, the time when positive identification of marked fish is greatest. Due to the low recapture rates and few efficiency trails in the hfc during the 2006 and 2007 trapping seasons, no passage estimates were generated.

A factor that likely underestimated salmon passage at Eye Riffle during the 2006 season was the lack of trapping during sustained high flow conditions. For example, eighteen days of trapping were missed from the end of December through mid-January near the probable peak of emigration. There is no reliable method to estimate passage during such long periods when the trap is not fishing. Roper and Scarnecchia (1999) used regression analysis of flow and catch to predict passage when traps could not be fished, but only for shorter periods of time (a few days). In addition, this requires a reliable relationship between flow and passage that has been problematic to develop on the Feather River. Similar to previous years, the relationship between river flow and salmon passage in 2006 at Eye Riffle was not statistically significant (P = 0.63). The relationship between the onset of adult spawning the previous fall and the onset of emigration has proved more valuable for predicting passage at the traps (DWR 2002, 2007). Future work will continue to focus on all variables thought to predict passage when the traps are not fishing. Efforts are in place to measure trap efficiency under varying flow conditions, release locations and turbidity levels in both the lfc and hfc. However, sustained high flows may continue to be problematic for sampling with RSTs.

The emigration pattern of fall-run Chinook varied during the three trapping years in the low flow channel. However, peak emigration occurred from mid-December through mid-March when most salmon were just fry or parr, demonstrating an ocean-type life history. The emigration estimate in the low flow channel also varied. Interestingly, the highest emigration estimate in the lfc (2005 trapping season) did not correspond with the highest escapement estimate (2007 trapping season). This may have been due to a higher egg-to-fry survival rate during the 2005 trapping season. Egg-to-fry survival rates may be affected by a variety of factors including hyporheic water temperature, oxygen saturation levels, and subsurface flow (Malcolm et al. 2003). The amount of available spawning habitat containing suitable embryo incubation conditions may be limited on the FR when escapement estimates are high. Consequently, superimposition may reduce survival in the heavily used upper reaches of the lfc (Kindopp 1999). It is also important to emphasize that the 2006 emigration estimate in the lfc was likely underestimated due to extremely high flows, therefore the 2006 egg-to-fry survival rate was likely underestimated as well.

In the hfc, there was a slight change in the timing of salmon catch between the 2005/2006 trapping seasons and the 2007 trapping season. The majority of the salmon catch occurred during the months of January, February, and March during the 2005 and 2006 trapping seasons. However, in 2007, the bulk of the salmon catch took place in February, March, and April. The difference in timing may have been a result of moving the trap eight river miles downstream prior to the beginning of the 2007 trapping season. Without passage estimates for the 2006 and 2007 trapping seasons, it is difficult to evaluate differences in emigration timing and abundance among trapping years.

Emigration Variables and Timing

This study confirmed, like previous survey results (DWR 1999a, DWR 2002, DWR 2007), that the bulk of the emigrating salmon are pre-smolt. Most salmon captured were smaller than 50 mm fork length (89% in the lfc and 74% in the hfc). The high percentages of salmon smaller than 50 mm indicate that most salmon smolt downstream of river mile 46 in the high flow channel. During the 2007 trapping season, 60% of the salmon at Sunset Pumps (river mile 38) were less than 50 mm, indicating that the majority of FR salmon may smolt in the lower reaches of the hfc. In future trapping seasons, when flows are adequate, the placement of a rotary screw trap below river mile 38 may demonstrate where and when most FR salmon begin to smolt.

In all years, over 97% of the juvenile salmon had already passed the lfc screw traps by 1 April, and over 94% of the juvenile salmon had passed the hfc traps by 1 April. These results demonstrate that temperature is not a driving force for the winter emigration pattern often observed. In addition, the most favorable temperatures for rearing juvenile Chinook salmon range between 13-18°C (Moyle 2002). Average daily temperatures never exceeded 14.0° C until 1 May during all trapping seasons at the lfc and hfc RSTs.

Environmental variables such as flow and turbidity also (when muted or stabilized) appeared to have a small role in salmon emigration in the Feather River. However, during the 2005 trapping season in the lfc, turbidity did have a statistically significant relationship with salmon passage. As turbidity increased, salmon passage increased. This may demonstrate that when turbidity is elevated and large numbers of salmon are present, they emigrate at a greater rate. Also, during the 2006 trapping season, it was difficult to monitor changes in turbidity and catch at both traps due to high flow events. The lfc experienced several unusually high flow events that prevented the trap from fishing on several occasions during peak emigration. While no statistically significant relationship between weekly average turbidity and salmon passage was established, the strength of the relationship may have been affected by large gaps in the passage data. Large increases in turbidity are accompanied by large increases in flow, often preventing the traps from fishing continuously.

It is likely that increased turbidity will stimulate emigration, however many years of trapping data indicate that Chinook fry and parr still emigrate the Feather River in the absence of strong environmental cues. A combination of increased flows and highly elevated turbidity probably allows fry and parr the greatest opportunity for survival as they emigrate the Feather River. However, if flow pulses cannot be generated, increasing turbidity alone could still provide greatly increased survival for salmon smolts and fry.

Although it appears that flow, turbidity and temperature have little effect on emigration, it is possible that the altered flow regime on the Feather River mutes these historical emigration signals. Snider and Titus (1995) found that the timing of both fry and fingerling emigration was substantially different from that before construction of Folsom Dam on the American River. Additionally, measuring emigration during larger flow events (>15,000 cfs) is nearly impossible due to high debris loads. This creates bias toward more easily measured variables. It is also possible that warmer water on the valley floor (as compared to historical spawning grounds at higher elevations) causes fry to develop and emerge sooner than the river is capable of supporting them. The result is immediate and massive emigration due to a lack of food base in the winter/early spring. Historically, salmon may have emerged a month later and exploited the spring and summer food web. Perhaps salmon emigrate soon after emergence because competition for food in the LFC is so great that fry must disperse downstream to find adequate rearing habitat. Unwin (1986) found that the initial mass migration of Chinook fry in Glenariffe stream, New Zealand, was most likely a result of competition for rearing habitat. Healey (1991) reported that a large downstream movement of Chinook fry immediately after emergence is typical of most populations. He further reports that “the downstream migration of stream- and ocean-type Chinook fry, when spawning grounds are well upstream, is probably a dispersal mechanism that helps distribute fry among the suitable rearing habitats.” Salmon might also emigrate early to avoid high temperatures on the Sacramento Valley floor in the spring and summer. Unfortunately, the history of emigration in the Feather River is poorly known. Even the extensive sampling performed by Painter et al. (1977) between 1968 and 1973 provides little insight into the reasons for early emigration of fry.

The end of emigration in all three years was similar to previous years (DWR 1999a, DWR 2002, DWR 2007). Painter and others (1977) found that, in 1968 through 1975, emigration could occur at least through the end of June in some years. Warner (1955) found that emigration ended around 1 June (in 1955). Snorkel surveys (DWR, unpublished data) and the rapid increase in fork length at both traps between 23 March and the end of trapping implies that some Chinook use the upper river as a nursery area in the spring. Changing photoperiod and temperature together might create a migration cue for these fish. Roper and Scarnecchia (1999) found that photoperiod, or a correlated variable, was a migratory cue in the South Umpqua River, Oregon. However, the emigration peak in the South Umpqua is in summer, when long days might provide a strong cue. Furthermore, fish remaining in the river for several months grow larger and may have an advantage during emigration. They may be more adept at avoiding predators, finding food, and be more physically prepared to smolt. However, fish emigrating in late spring may encounter much warmer conditions. Flain (in Unwin, 1986) reported that Chinook juveniles that reared in fresh water for several months to a year comprised 76% of the adult angler catch in the Rakaia River, although they comprised only 5% of the juvenile population. It is possible that a similar pattern of prolonged stream residence is successful on the Feather River and other Central Valley streams. Salmon rearing into the spring and summer could emigrate in the fall when temperatures are more suitable for passing the lower river and estuary. It is unknown if these late emigrants contribute substantially to the adult population. Current and future work focusing on otolith microstructure of Feather River Chinook will hopefully provide answers to questions circulating about various rearing strategies.

Spring-run-sized Chinook

Although catch numbers were modest, the 2005 trapping season provided the highest catch of Spring-run size fish at both trapping locations (Table 2 and 3). During the last three trapping seasons emigration timing was similar to all previous years (DWR 2002, DWR 2007). Spring-run-sized salmon were caught as soon as the RSTs were deployed (November and December), indicating that emigration began immediately after emergence.

The size difference between supposed fall and spring-run emigrants was typically only a few millimeters, demonstrating the difficulty of using the Daily Length Table alone as an indicator of race (Greene, 1992). As previously mentioned, most spring-run-sized salmon were small upon capture. Although probability of catch decreases as fish get larger, there is no reason to expect that great numbers of larger (>75 mm) spring-run-sized salmon were actively avoiding the traps at either location. In fact, a relatively large group (159) of parr (60 mm) were caught in the Sunset RST in late February in 2007 (Figure 12). Throughout spring, many fall-run salmon are captured in the 60-100 mm range. This data, along with previous RST sampling, snorkel surveys and electrofishing implies that a true stream-type life-history no longer exists for spring-run in the Feather River (assuming it existed). This would suggest an ocean-type life-history pattern typical of fall-run Chinook in the Feather River and many other central valley rivers. While some larger fish of presumably all races (fall, spring and late-fall) do persist throughout the summer (DWR unpublished data), there is no data to support the current existence of a true stream-type life-history for any race of salmon in the Feather River. Variations to the ocean-type life-history probably still exist in the Feather, however distinct populations that use these strategies exclusively are not apparent. Due to very low catch and the uncertainty of race designations, no emigration estimate was generated for the population of “spring-run” or late-fall Chinook juveniles in the Feather River.

Late-fall-sized Chinook

Late-fall Chinook abundance and emigration timing was similar to previous years (DWR 2007). Low catches in the lfc and hfc suggest little production of late-fall-sized Chinook in the Feather River. Most late-fall-sized Chinook appear to emigrate soon after emergence. Essentially all late-fall-sized salmon that were captured passed the traps within a month of emergence. This implies an emigration pattern similar to fall-run-sized fish. However, dive surveys (DWR, unpublished data) indicate that many late-fall-sized Chinook rear in the Feather River well into the summer. The capture of several smolt sized (120 mm) late-fall-run salmon (Figure 13, Figure 14) further supports the potential for an alternative life history strategy. Patterns of occurrence of late-fall-sized fish are subject to the same caution as for spring-run-sized fish. Their identification is based on the Daily Length Table, which provides little separation from fall-run-sized fish. However, the observations of adults spawning as late as March and the capture of smolt sized salmon indicate that a true late-fall-run may still exist. The small number of late-fall juveniles captured and emigration pattern variability prohibit any firm conclusions about the status of this run.

Steelhead

Wild steelhead catch has declined since the 2004 trapping season. During the three year period nearly all wild steelhead fry were captured in the RSTs in March, April, and May. The capture of wild juveniles indicates a modest number of steelhead continue to spawn in the lower Feather River.

Very few wild yearling steelhead were caught during this study. This is probably attributable to several factors: 1) the scarcity of adults; 2) the ability of the larger fish to avoid capture; and 3) their lack of movement. Unlike most emigrating salmon, few juvenile steelhead appear to emigrate the Feather River when they are susceptible to capture (immediately after emergence). Emigration typically peaks in March and continues through April in most years. Most steelhead probably set up a “home-range” and rear until they reach or surpass a size at which capture by screw trap is unlikely. Dive surveys confirm that even 60 mm salmon and steelhead can avoid the RSTs under some conditions of location and water velocity, making it difficult to gather information on steelhead emigration patterns (DWR, unpublished data). These observations further support the need for other methods (mark-recapture and dive surveys) to understand the basic life history of fry, juvenile and adult steelhead in the Feather River.

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Table 1. Summary of Non-Chinook fishes caught at all screw trap locations over a three year period.

Common Name	Scientific Name	Origin*	Eye (lfc) 2005	Eye (lfc) 2006**	Steep (lfc) 2006**	Steep (lfc) 2007	Herringer (hfc) 2005	Herringer (hfc) 2006	Sunset (hfc) 2007	**Total**
American Shad	*Alosa sapidissima*	I	0	0	0	0	0	0	6	**6**
Bigscale Logperch	*Percina macrolepida*	I	0	0	0	1	0	0	1	**2**
Bluegill	*Lepomis macrochirus*	I	0	34	2	23	4	239	26	**328**
Black Bullhead	*Ameiurus melas*	I	0	0	1	0	0	0	2	**3**
Black Crappie	*Pomoxis nigromaculatus*	I	0	0	0	0	0	1	1	**2**
Brown Bullhead	*Ameiurus nebulosus*	I	0	2	0	0	0	0	4	**6**
Channel Catfish	*Ictalurus punctatus*	I	0	0	0	0	0	1	4	**5**
Common Carp	*Cyprinus carpio*	I	0	0	0	0	11	1	9	**21**
Fathead Minnow	*Pimephales promelas*	I	0	0	0	3	0	0	0	**3**
Golden Shiner	*Notemigonus crysoleucas*	I	0	2	2	3	2	3	16	**28**
Green Sunfish	*Lepomis cyanellus*	I	0	0	0	0	0	1	5	**6**
Hard Head	*Mylopharadon conocephalus*	N	27	2	2	1	203	132	23	**390**
Hitch	*Lavinia exilicauda*	N	1	1	0	0	0	1	2	**5**
Largemouth Bass	*Micropterus salmoides*	I	2	3	0	1	41	8	15	**70**
Pacific Lamprey	*Lampetra tridentata*	N	105	47	0	235	282	4	59	**732**
Prickly Sculpin	*Cottus asper*	N	5	0	0	6	85	0	12	**108**
Pumpkinseed	*Lepomis gibbosus*	I	0	0	0	1	1	0	4	**6**
Steelhead (Clipped)	*Oncorhynchus mykiss mykiss*	N	1	0	0	0	6	4	746	**757**
Steelhead (Wild)	*Oncorhynchus mykiss mykiss*	N	197	16	2	79	351	2	6	**653**
Redear Sunfish	*Lepomis microlophus*	I	0	1	0	0	0	6	30	**37**
Riffle Sculpin	*Cottus gulosus*	N	4	0	0	0	0	9	0	**13**
River Lamprey	*Lampetra ayresi*	N	8	0	0	0	81	10	0	**99**
Sacramento Pikeminnow	*Ptychocheilus grandis*	N	49	9	1	16	105	100	195	**475**
Sacramento Splittail	*Pogonichthys macrolepidotus*	N	0	0	0	0	0	0	2	**2**
Sacramento Sucker	*Catostomus occidentalis*	N	9	5	0	9	15	14	108	**160**
Smallmouth Bass	*Micropterus dolomieu*	I	0	0	0	0	2	0	87	**89**
Speckled Dace	*Rhinichthys osculus*	N	0	0	0	2	12	5	0	**19**
Tule perch	*Hysterocarpus traski*	N	2	2	1	1	117	24	14	**161**
Wakasagi	*Hypomesus nipponensis*	I	260	3567	6	3397	795	2751	1750	**12526**
Warmouth	*Lepomis gulosus*	I	1	6	19	5	1	39	2	**73**
Western Mosquitofish	*Gambusia affinis*	I	5	20	7	1	4	78	2	**117**
White Catfish	*Ameiurus catus*	I	0	0	0	0	0	0	11	**11**
White Crappie	*Pomoxis annularis*	I	0	0	0	0	0	1	0	**1**
Total			**676**	**3717**	**43**	**3784**	**2118**	**3434**	**3142**	**16914**

* N = Native, I = Introduced, ** Trap was moved from Eye to Steep on 05 May 2006

Table 1 continued.

Common Name	Scientific Name	Origin*	Eye (lfc) 2005	Eye (lfc) 2006**	Steep (lfc) 2006**	Steep (lfc) 2007	Herringer (hfc) 2005	Herringer (hfc) 2006	Sunset (hfc) 2007	**Total**
Unidentified Bass	*Micropterus sp.*	I	0	0	551	1	0	2	143	**143**
Unidentified Lamprey	*Lampetra sp.*	N	38	9	5	35	106	114	13	**13**
Unidentified Minnow	Cyprinidae	N	0	0	0	2	3	1	2465	**2465**
Unidentified Sculpin	*Cottus sp.*	N	898	103	4	208	144	14	153	**153**
Unidentified Sunfish	*Lepomis sp.*	I	0	19	9	17	0	61	5	**5**
Unidentified juvenile Ictalurid	*Ictaluridae sp.*	I	0	0	0	0	0	1	4	**4**
Total			**936**	**131**	**569**	**263**	**253**	**193**	**2783**	**2783**

* N = Native, I = Introduced

** Trap was moved from Eye to Steep on 05 May 2006

Table 2. Monthly catch for four races of Chinook salmon caught during the 2005 & 2006 trapping years at Eye and the 2006 & 2007 trapping years at Steep. Monthly estimates were included for fall Chinook only. Races were determined using size criteria for Central Valley Chinook salmon (Greene 1992).

Eye	2004		2005						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
Fall Chinook (caught)	0	8411	54159	12687	6808	1215	178	—	**83458**
Fall Chinook (estimate)	—	1065616	6483210	1770965	941125	60341	178	—	**10321435**
% of Estimate	—	10	63	17	9	1	—	—	**100**
Spring Chinook	110	1378	265	7	6	13	0	—	**1669**
Late Fall Chinook	0	0	0	0	0	83	7	—	**90**
Winter Chinook	0	1	0	0	0	0	0	—	**1**

	2005		2006						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
Fall Chinook (caught)	0	19188	12050	25045	2382	18	—	—	**58683**
Fall Chinook (estimate)	—	854275	407628	986607	193153	3567	—	—	**2445230**
% of Estimate	—	35	17	40	8	0	—	—	**100**
Spring Chinook	2	931	237	15	3	0	—	—	**1188**
Late Fall Chinook	0	0	0	0	0	0	—	—	**0**

Steep	2005		2006						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
Fall Chinook (caught)	—	—	—	—	—	—	73	—	**73**
Spring Chinook	—	—	—	—	—	—	1	—	**1**
Late Fall Chinook	—	—	—	—	—	—	7	—	**7**

	2006		2007						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
Fall Chinook (caught)	—	35167	110071	109350	151435	9023	395	—	**415441**
Fall Chinook (estimate)	—	414954	1381001	1260079	1317934	122082	395	—	**4496445**
% of Estimate	—	9	31	28	29	3	—	—	**100**
Spring Chinook	—	999	19	22	10	11	0	—	**1061**
Late Fall Chinook	—	1	0	0	0	555	143	—	**699**

Table 3. Monthly catch for four races of Chinook salmon caught during the 2005 & 2006 trapping years at Herringer and the 2007 trapping year at Sunset. Monthly estimates were included for fall Chinook only. Races were determined using size criteria for Central Valley Chinook salmon (Greene 1992).

Herringer	2004		2005						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
Fall Chinook (caught)	0	6721	67810	227446	99450	4018	2046	5	**407496**
Fall Chinook (estimate)	0	190642	1565196	7986034	3669168	298139	108666	5	**13817849**
% of Estimate	0	1	11	58	27	2	1	0	**100**
Spring Chinook	33	1690	138	94	81	62	4	0	**2102**
Late Fall Chinook	1	1	0	0	0	54	5	0	**61**
Winter Chinook	0	0	0	0	1	0	0	0	**1**

	2005		2006						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
Fall Chinook (caught)	—	5071	3941	9335	1888	116	1017	—	**21368**
Spring Chinook	—	1205	65	45	18	3	3	—	**1339**
Late Fall Chinook	—	0	0	0	0	7	2	—	**9**

Sunset	2006		2007						
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
Fall Chinook (caught)	—	—	5452	7621	31833	13666	315	486	**59373**
% of total caught	—	—	9	13	54	23	1	1	**100**
Spring Chinook	—	—	6	173	59	230	4	1	**473**
Late Fall Chinook	—	—	1	0	0	340	2	0	**343**
Winter Chinook	—	—	0	0	0	2	0	0	**2**

Table 4. Trap efficiency data for the Feather River Eye and Steep RSTs, from 2005-2007.

Mark Type	Release Date	Recovery Period	# Marked	# Recaptured	% Recaptured
Eye 2005					
BB	12/26/04	12/26/04 -12/31/04	998	9	0.90
BB/ Green Nose	12/31/04	12/31/04 - 1/6/05	653	1	0.15
BB	1/7/05	1/7/05 - 1/11/05	740	5	0.68
BB/ Orange Nose	1/12/05	1/12/05 -1/20/05	1044	15	1.44
BB/ Pink Nose	1/21/05	1/21/05 - 1/28/05	997	14	1.50
BB/ Green Nose	1/29/05	1/29/05 - 2/1/05	993	5	0.50
BB/ White Nose	2/2/05	2/2/05 - 2/9/05	996	4	0.40
BB/ Pink & Orange Nose	2/10/05	2/10/05 - 2/17/05	1994	20	1.00
BB/ Green & Orange Nose	2/18/05	2/18/05 - 2/24/05	1987	22	1.11
BB/ White & Orange Nose	2/25/05	2/25/05 - 3/2/05	1981	1	0.05
BB/ Pink & Orange Nose	3/3/05	3/3/05 - 3/8/05	1996	8	0.40
BB/ Green & Red Nose	3/9/05	3/9/05 - 3/16/05	1954	22	1.13
BB/ Pink & Yellow Nose	3/17/05	3/17/05 - 3/25/05	1735	20	1.15
BB/ Green Nose	3/26/05	3/26/05 - 4/5/05	788	4	0.51
BB/ Pink Nose	4/6/05	4/6/05 - 4/10/05	633	5	0.79
Eye 2006					
BB	12/17/05	12/17/05 - 12/20/05	466	10	2.15
BB	12/21/05	12/21/05 - 12/23/05	990	19	1.92
BB	1/20/06	1/20/06 - 1/22/06	1200	42	3.50
BB	1/23/06	1/23/06-1/26/06	999	31	3.10
BB	1/31/06	1/31/06 - 2/2/06	1081	19	1.76
BB	2/3/06	2/3/06 - 2/6/06	1503	26	1.73
BB	2/7/06	2/7/06 - 2/9/06	1004	34	3.39
BB/ Pink Nose	2/10/06	2/10/06 - 2/15/06	1015	37	3.65
BB	2/16/06	2/16/06 -2/22/06	1010	26	2.57
BB/ Pink Nose	2/23/06	2/23/06 -2/25/06	1012	24	2.37
BB/ Blue Nose	2/26/06	2/26/06 - 2/28/06	1027	16	1.56
BB/ Orange Nose	3/6/06	3/6/06 -3/8/06	686	0	0.00
BB	3/21/06	3/21/06 - 3/24/06	1063	24	2.26
BB/ Orange Nose	3/28/06	3/28/06 - 3/30/06	594	1	0.17
Steep 2007					
BB	12/22/06	12/22/06 - 12/25/06	997	93	9.33
BB	12/26/06	12/26/06 - 12/30/06	989	86	8.70
BB	12/31/06	12/31/06 - 01/06/07	996	65	6.53
BB	1/7/07	01/07/07 - 01/11/07	1000	44	4.40
BB	1/12/07	01/12/07 - 01/20/07	998	130	13.03
BB	1/21/07	01/21/07 - 01/27/07	998	120	12.02
BB	1/28/07	01/28/07 - 02/02/07	955	85	8.90
BB	2/3/07	02/03/07 - 02/09/07	998	15	1.50
BB	2/10/07	02/10/07 - 02/16/07	994	100	10.06
BB	2/17/07	02/17/07 - 02/28/07	996	97	9.74
BB	3/1/07	03/01/07 - 03/03/07	1114	112	10.05
BB	3/4/07	03/04/07 - 03/10/07	993	142	14.30
BB	3/11/07	03/11/07 - 03/14/07	991	109	11.00
BB	3/15/07	03/15/07 - 03/18/07	1095	99	9.04
BB	3/19/07	03/19/07 - 03/26/07	988	109	11.03
BB	3/27/07	03/27/07 - 04/03/07	993	143	14.40
BB	4/4/07	04/04/07 - 04/07/07	992	39	3.93

Table 5. Trap efficiency data for the Feather River Herringer and Sunset RSTs, from 2005-2007.

Herringer 2005

Mark Type	Release Date	Recovery Period	# Marked	# Recaptured	% Recaptured
BB	12/21/04	12/21/04 -12/29/04	770	35	4.55
BB/ Orange Nose	12/30/04	12/30/04 - 1/4/05	1328	42	3.16
BB	1/5/05	1/5/05 -1/11/05	717	24	3.35
BB	1/12/05	1/12/05 - 1/17/05	1169	29	2.48
BB	1/18/05	1/18/05 - 1/23/05	996	67	6.73
BB	1/24/05	1/24/05 - 1/28/05	999	36	3.60
BB	1/29/05	1/29/05 - 2/2/05	996	44	4.42
BB	2/3/05	2/3/05 - 2/9/05	1000	60	6.00
BB	2/10/05	2/10/05 -2/14/05	996	25	2.51
BB	2/15/05	2/15/05 - 2/18/05	995	41	4.12
BB	2/19/05	2/19/05 - 2/28/05	982	16	1.63
BB	3/1/05	3/1/05 - 3/6/05	997	30	3.01
BB	3/7/05	3/7/05 - 3/9/05	999	40	4.00
BB	3/10/05	3/10/05 - 3/15/05	1000	35	4.50
BB	3/16/05	3/16/05 -3/20/05	998	84	8.42
BB	3/21/05	3/21/05 - 3/25/05	1524	14	0.92
BB	3/26/05	3/26/05 - 4/1/05	990	10	1.01
BB	4/2/05	4/2/05 - 4/14/05	1049	24	2.19
BB	4/15/05	4/15/05 - 4/19/05	257	4	1.56
BB	4/20/05	4/20/05 -4/23/05	403	2	0.50
BB	4/24/05	4/24/05 - 4/30/05	314	4	1.27
BB	5/12/05	5/12/05 -5/17/05	346	6	1.73
Herringer 2006					
BB	1/9/06	1/9/06 - 1/11/06	416	2	0.48
BB	1/11/06	1/11/06 -1/13/06	292	0	0.00
BB/ Green Nose	1/23/06	1/23/06 - 1/26/06	941	0	0.00
BB/ Pink Nose	1/27/06	1/27/06 - 2/1/06	605	0	0.29
BB/ White Nose	2/2/06	2/2/06 - 2/6/06	1017	3	0.29
BB/ Green Nose	2/7/06	2/7/06 - 2/10/06	1019	2	0.20
BB	2/11/06	2/11/06 - 2/18/06	2178	4	0.18
BB/ Green Nose	2/19/06	2/19/06 - 2/25/06	1175	11	0.94
BB	2/26/06	2/26/06 - 3/1/06	1339	15	1.12
Sunset 2007					
BB	3/13/07	03/13/07 - 03/15/07	981	6	0.61
BB	4/1/07	04/01/07 - 04/03/07	782	6	0.77

Table 6. Emigration indices and egg-to-fry survival rates for the Feather River lfc, calculated from emigration estimates and prior year's escapement data.

2005 Trap Year			Emigration Index	Survival Rate
	Emigration Estimate ('05 - lfc)	10,321,435	293	
	Total Escapement ('04 - lfc)	37,058		0.08
Sampled (*n*=3082)	% Females	65%		
	% Females Spent	66%		
Estimated	Total Females	35,276		
	Total Females Spent	23,201		

2006 Trap Year			Emigration Index	Survival Rate
	Emigration Estimate ('06 -lfc)	2,445,230	100	
	Total Escapement ('05 - lfc)	36,220		0.03
Sampled (*n*=6994)	% Females	68%		
	% Females Spent	69%		
Estimated	Total Females	24,459		
	Total Females Spent	16,883		

2007 Trap Year			Emigration Index	Survival Rate
	Emigration Estimate ('07 - lfc)	4,496,050	110	
	Total Escapement ('06 - lfc)	59,273		0.04
Sampled (*n*=4242)	% Females	68%		
	% Females Spent	50%		
Estimated	Total Females	40,773		
	Total Females Spent	20,303		

Table 7. Regression statistics for salmon passage on the Feather River between 2005-2007. Weekly average turbidity, flow, and water temperature was compared with the weekly passage estimate at each trap for each trapping year.

		Eye			Herringer*		
		P-value	*n*	R^2 (adj.)	*P*-value	*n*	R^2 (adj.)
2005	Turbidity	0.00	19	62.7%	0.75	24	0.0%
	Flow	0.61	18	0.0%	0.27	25	1.1%
	Temperature	0.20	19	4.1%	0.54	25	0.0%
2006	Turbidity	0.58	15	0.0%	—	—	—
	Flow	0.63	16	0.0%	—	—	—
	Temperature	0.79	16	0.0%	—	—	—
		Steep			Sunset *		
		P-value	*n*	R^2 (adj.)	*P*-value	*n*	R^2 (adj.)
2007	Turbidity	0.87	15	0.0%	—	—	—
	Flow	0.75	16	0.0%	—	—	—
	Temperature	0.02	16	27.5%	—	—	—

* No passage estimate was made for Herringer in 2006 and Sunset in 2007

Table 8. Release totals for naturally produced, coded-wire-tagged Feather River Chinook salmon from 2005-2007. All coded-wire-tagged salmon were released at the boat launch just above Thermalito Afterbay Outlet (RM 60).

2005		2006		2007		
Code #	# of fish	Code #	# of fish	Code #	Release date	# of fish
06-1-1-2-0	11,926	—	—	06-1-1-4-9	1/23/2007	11,578
06-1-1-2-1	12,046	—	—	06-1-1-4-8	1/29/2007	11,787
06-1-1-2-2	12,062	—	—	06-1-1-4-7	1/29/2007	11,310
06-1-1-2-3	12,216	—	—	06-1-1-7-2	2/21/2007	11,768
06-1-1-2-4	11,740	—	—	06-1-1-5-0	2/21/2007	11,082
06-1-1-2-5	12,768	—	—	06-1-1-7-1	2/21/2007	11,456
06-1-1-2-6	12,402	—	—	06-1-1-7-4	2/28/2007	12,071
06-1-1-2-7	12,369	—	—	06-1-1-7-5	3/1/2007	11,693
06-1-1-2-8	12,381	—	—	06-1-1-7-3	3/1/2007	11,336
06-1-1-2-9	11,776	—	—	06-1-1-9-1	3/5/2007	11,822
06-1-1-3-0	12,868	—	—	06-1-1-7-7	3/5/2007	12,080
06-1-1-3-1	12,426	—	—	06-1-1-7-8	3/7/2007	11,780
06-1-1-3-2	12,241	—	—	06-1-1-7-9	3/7/2007	11,892
06-1-1-3-3	12,155	—	—	06-1-1-8-0	3/15/2007	11,651
06-1-1-3-4	12,199	—	—	06-1-1-8-1	3/15/2007	11,880
—	—	—	—	06-1-1-7-6	3/15/2007	9,894
—	—	—	—	06-1-1-8-2	3/15/2007	5,488
less mortality	-11200	less mortality	—	less mortality		-2275
TOTAL	**172,375**	**TOTAL**	**0**	**TOTAL**		**188,293**

Table 9. Recovery totals for naturally produced CWT Feather River Chinook salmon. Data were retrieved from the Regional Mark Information System (RMIS) database. URL:<http://www.rmpc.org>. [9 January 2009].

Recovery Type	**Recovery location**	**Brood year**								
		1997	1998	1999	2000	2001	2002	2003	2004	Total
Stray	American R. to Colusa	–	–	–	–	–	–	–	1	**1**
	Butte Creek	2	–	–	–	–	–	1	–	**3**
Hatchery	Feather River Hatchery	7	2	2	5	–	–	–	–	**16**
In-river	Feather River	1	–	–	–	–	–	–	–	**1**
	Feather River - low flow		1	1	6	–	–	–	–	**8**
Ocean/Bay Catch	Astoria Sport	–	1	–	–	–	–	–	–	**1**
	Big Lagoon- Centerv. Bea.	–	–	–	–	–	1	–	–	**1**
	Brookings Sport	–	–	–	–	–	–	–	1	**1**
	C.Vizcaino- Navarr. Hd.	1	1	–	–	–	–	–	1	**3**
	Coos Bay Troll	–	3	1	–	–	–	–	–	**4**
	Depoe Bay Sport	–	–	–	1	–	–	–	–	**1**
	Fort Ross - Pigeon Pt.	21	1	–	–	–	–	1	1	**24**
	Fort Ross - Point Sur	7	–	–	–	–	–	–	–	**7**
	Garibaldi Troll	1	–	–	–	–	–	–	–	**1**
	Marine Area 1	–	–	–	–	1	–	–	–	**1**
	Marine Area 2	1	–	–	–	–	–	–	–	**1**
	Newport Troll	8	3	3	3	–	–	–	–	**17**
	Pigeon Pt.- Point Sur	14	1	3	–	–	–	–	–	**18**
	Pigeon Pt.- Ca/Mex. Bor.	1	–	–	–	–	–	–	–	**1**
	Point Sur - Ca/Mex. Bor.	1	–	–	–	–	–	–	–	**1**
	Pt. Arena - Pt. Reyes	–	–	1	1	–	–	–	–	**2**
	Pt. Reyes - Pigeon Pt.	1	2	2	4	1	1	–	–	**11**
	Siuslaw Bay Troll	1	–	–	–	–	–	–	–	**1**
	Span. Flat - C.Vizcaino	–	1	–	–	–	–	–	–	**1**
	Span. Flat - Pt. Arena	–	–	1	1	–	–	–	–	**2**
	Total	**67**	**16**	**14**	**21**	**2**	**2**	**2**	**4**	**128**

Table 10. Monthly trapping effort and catch per hour of all fish species at both trapping locations from 2005-2007.

	High flow channel		**Low flow channel**	
	Herringer		*Eye*	
2005	Effort (hours)	Catch/hour	Effort (hours)	Catch/hour
November	854.0	0.9	477.5	0.3
December	1397.9	38.9	715.0	14.0
January	1470.0	325.6	749.1	73.5
February	1307.8	1074.9	686.4	18.6
March	1398.9	467.3	718.3	9.8
April	1372.8	20.1	696.6	2.2
May	1334.0	11.1	652.0	0.5
June	51.3	0.3	—	—
Total	**8332.5**		**4217.5**	
	Herringer		*Eye and Steep**	
2006	Effort (hours)	Catch/hour	Effort (hours)	Catch/hour
November	46.3	0.4	20.5	1.3
December	1057.8	6.8	641.8	32.2
January	844.5	6.4	314.8	47.7
February	592.0	17.3	634.5	39.9
March	647.3	3.3	686.8	3.8
April	413.0	0.5	144.0	0.3
May	547.0	2.6	310.8	2.2
June	168.5	0.4	—	—
Total	**4270.0**		**2732.5**	
	Sunset		*Steep*	
2007	Effort (hours)	Catch/hour	Effort (hours)	Catch/hour
November	—	—	—	—
December	—	—	284.3	127.7
January	555.5	10.2	718.0	153.8
February	491.3	17.4	667.3	165.1
March	710.5	45.1	656.8	233.1
April	660.0	21.8	707.5	15.0
May	645.0	0.6	450.5	1.4
June	543.0	9.4	—	—
Total	**3605.3**		**3484.3**	

*Trap was moved from Eye to Steep on 05 May 2006

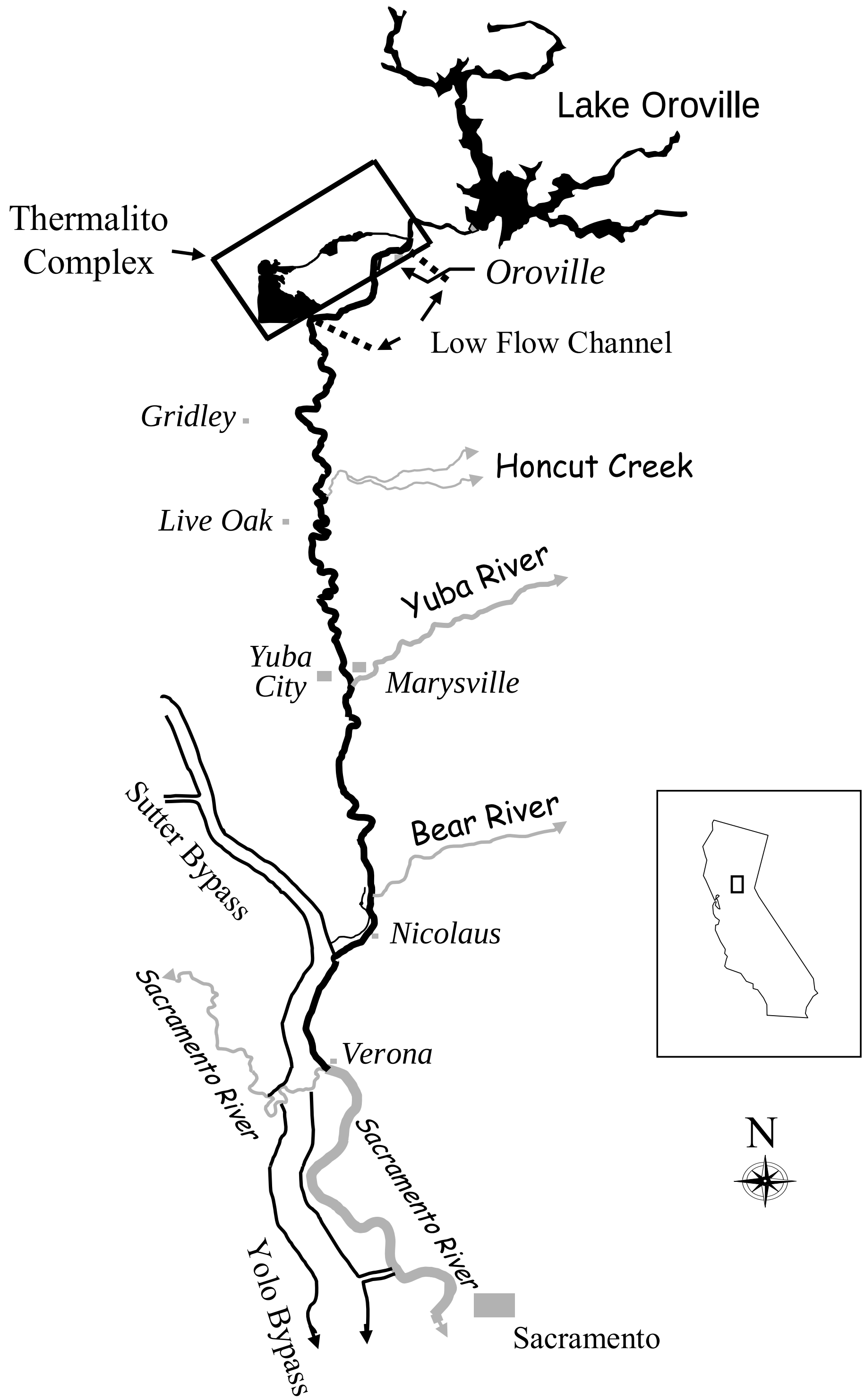

Figure 1 Lower Feather River (Feather River below Oroville Dam) and associated tributaries between Oroville Dam and the confluence with the Sacramento River.

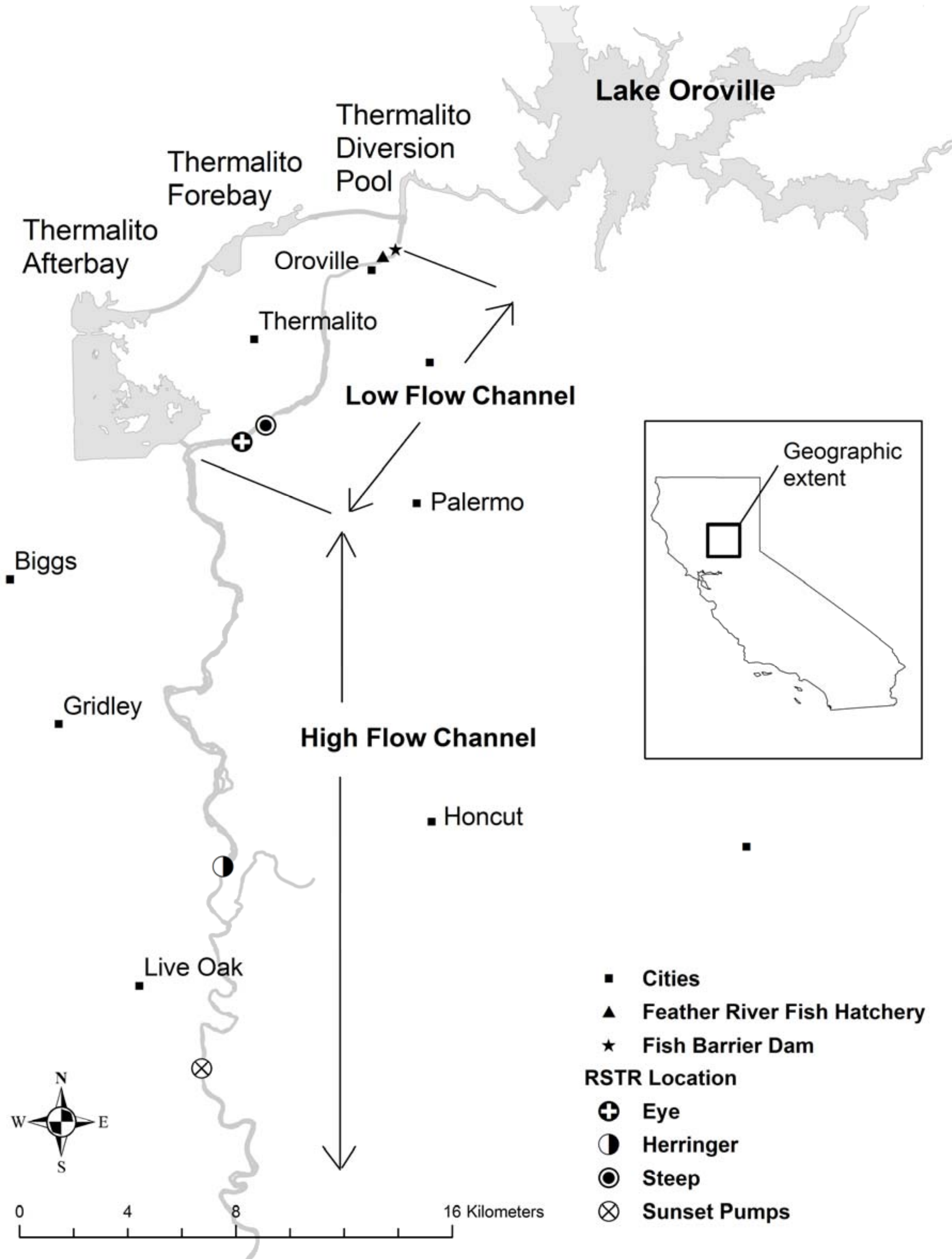

Figure 2. Lower Feather River study area and 2005 – 2007 rotary screw trap locations.

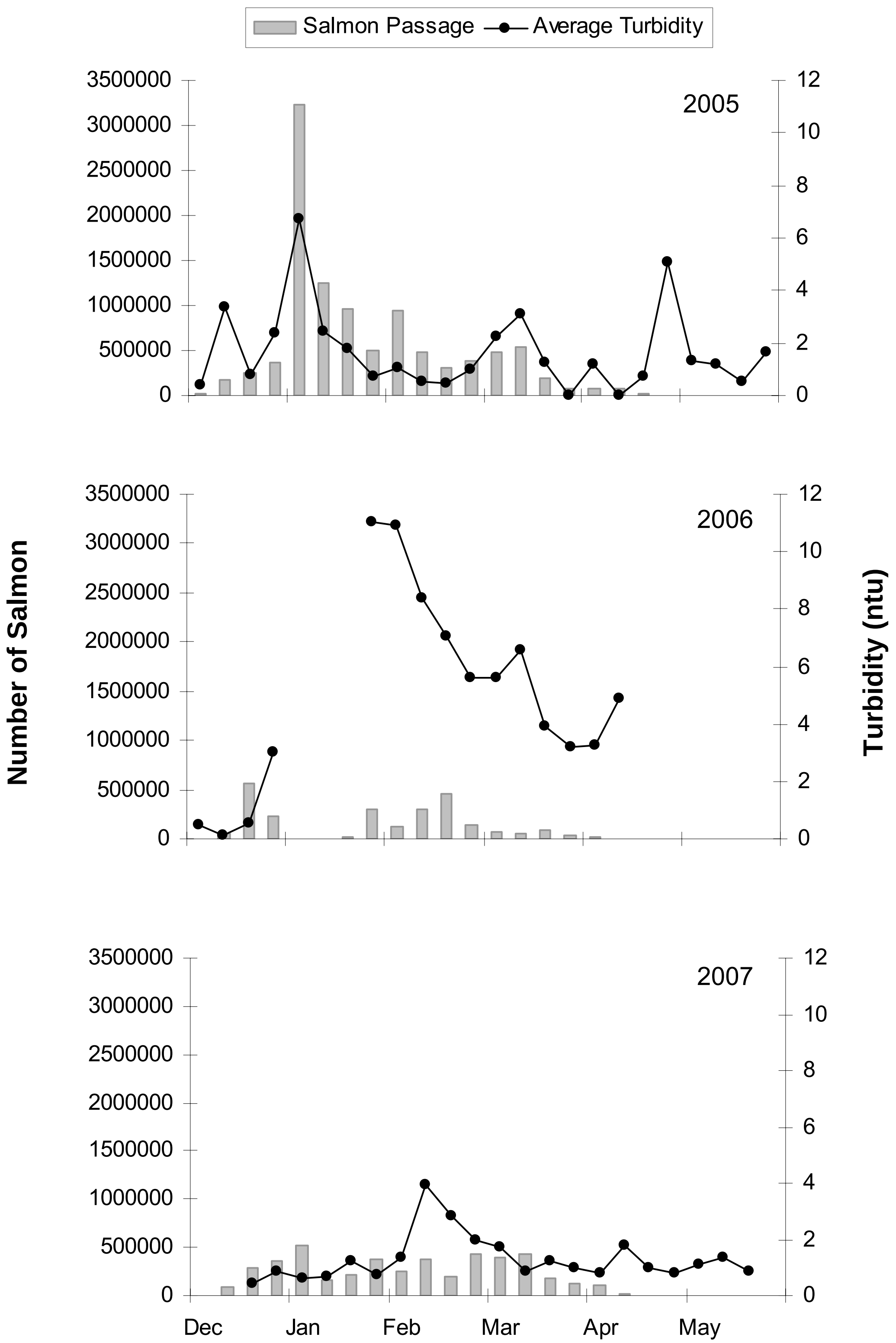

Figure 3. Estimated weekly passge for fall-run-sized juvenile Chinook salmon associated with weekly average turbidity during the 2005-2007 trapping years in the low flow channel.

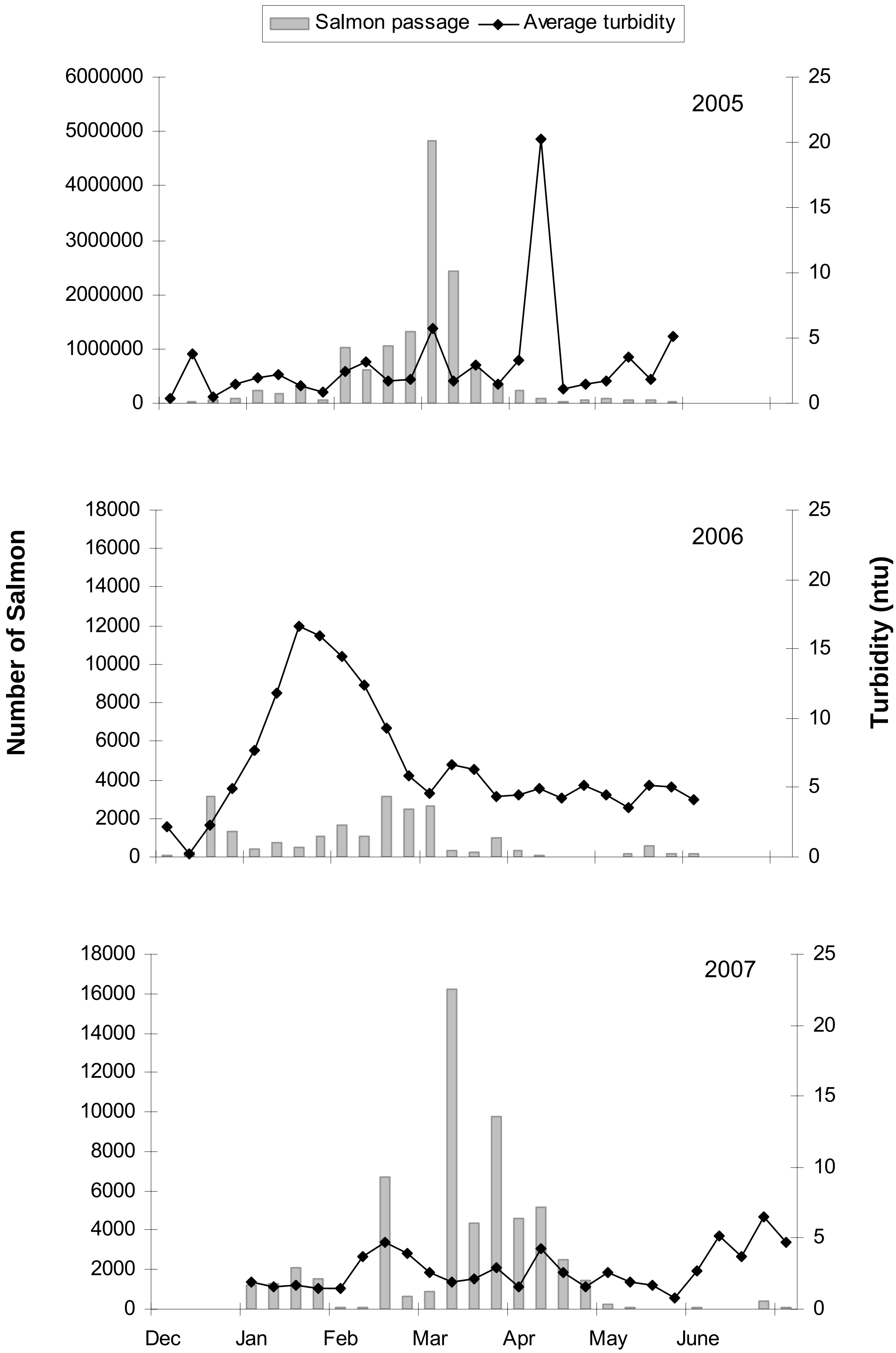

Figure 4. Estimated weekly passage (top) and catch (middle & bottom) for fall-run-sized juvenile Chinook salmon associated with weekly average turbidity during the 2005-2007 trapping years in the high flow channel.

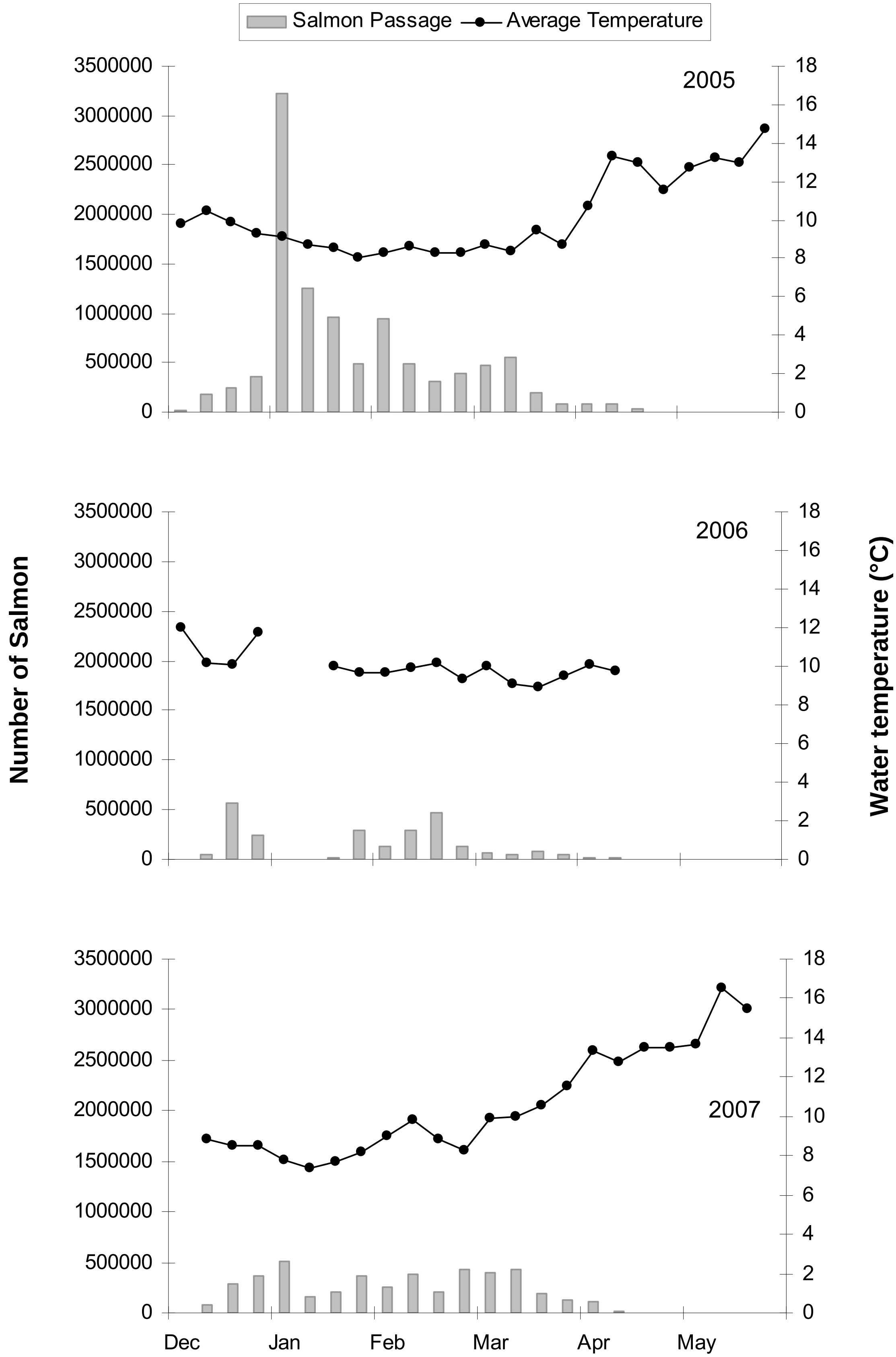

Figure 5. Estimated weekly passage for fall-run-sized juvenile Chinook salmon associated with weekly average temperature during the 2005-2007 trapping seasons in the low flow channel.

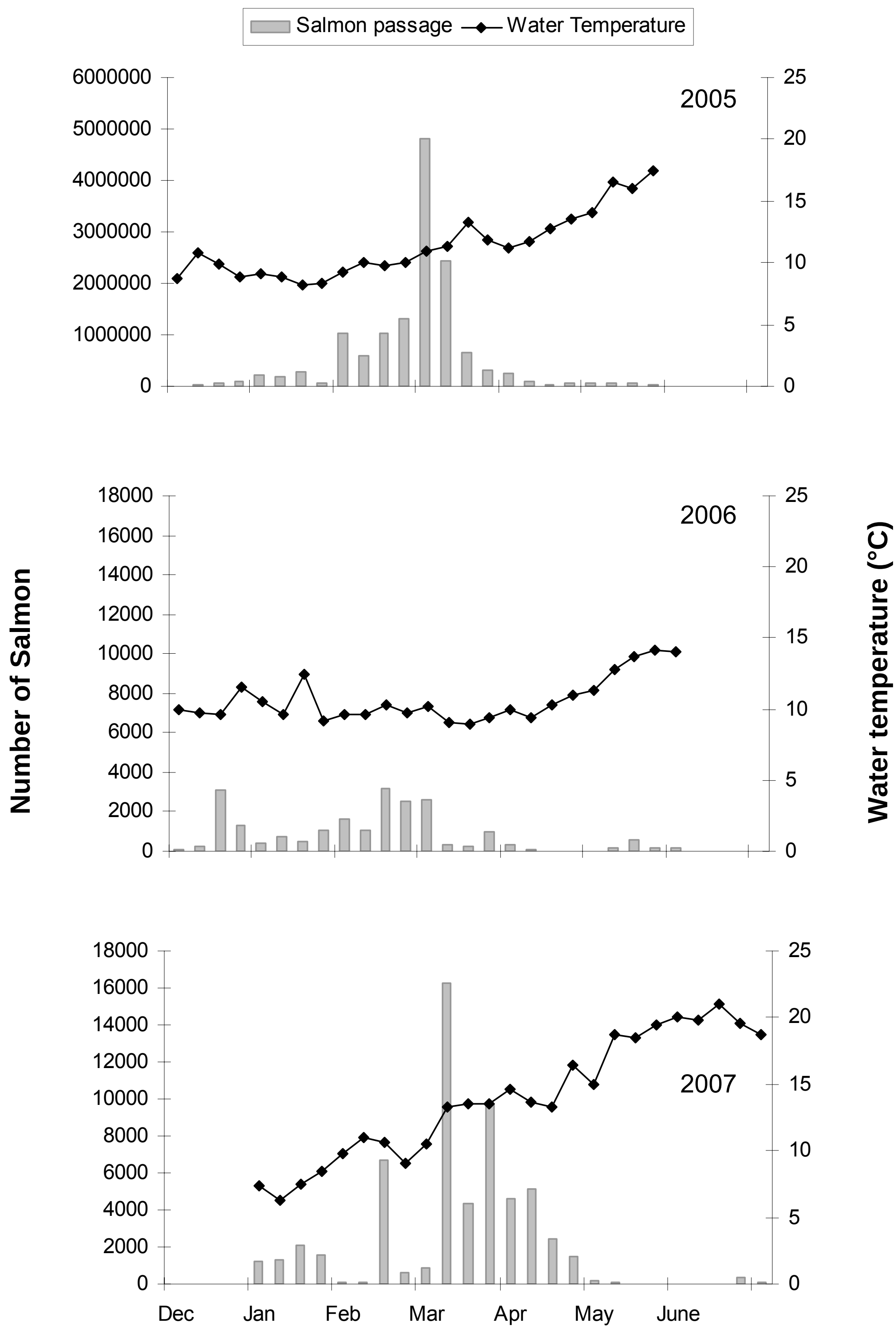

Figure 6. Estimated weekly passage (top) and catch (middle and bottom) for fall-run-sized juvenile Chinook salmon associated with weekly average temperature during the 2005-2007 trapping seasons in the high flow channel.

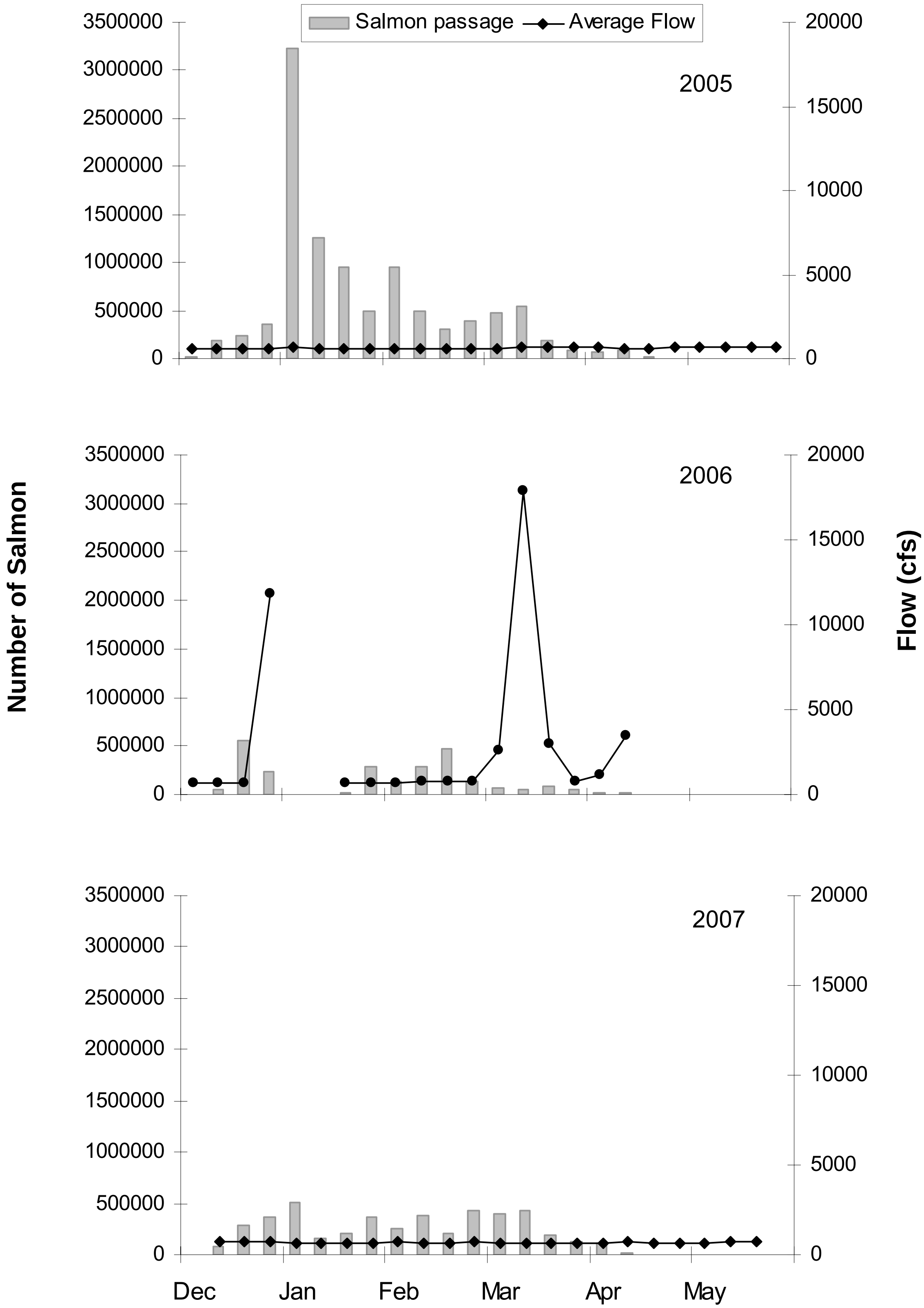

Figure 7. Estimated weekly passage for fall-run-sized juvenile Chinook salmon associated with weekly average flow during the 2005-2007 trapping seasons in the low flow channel.

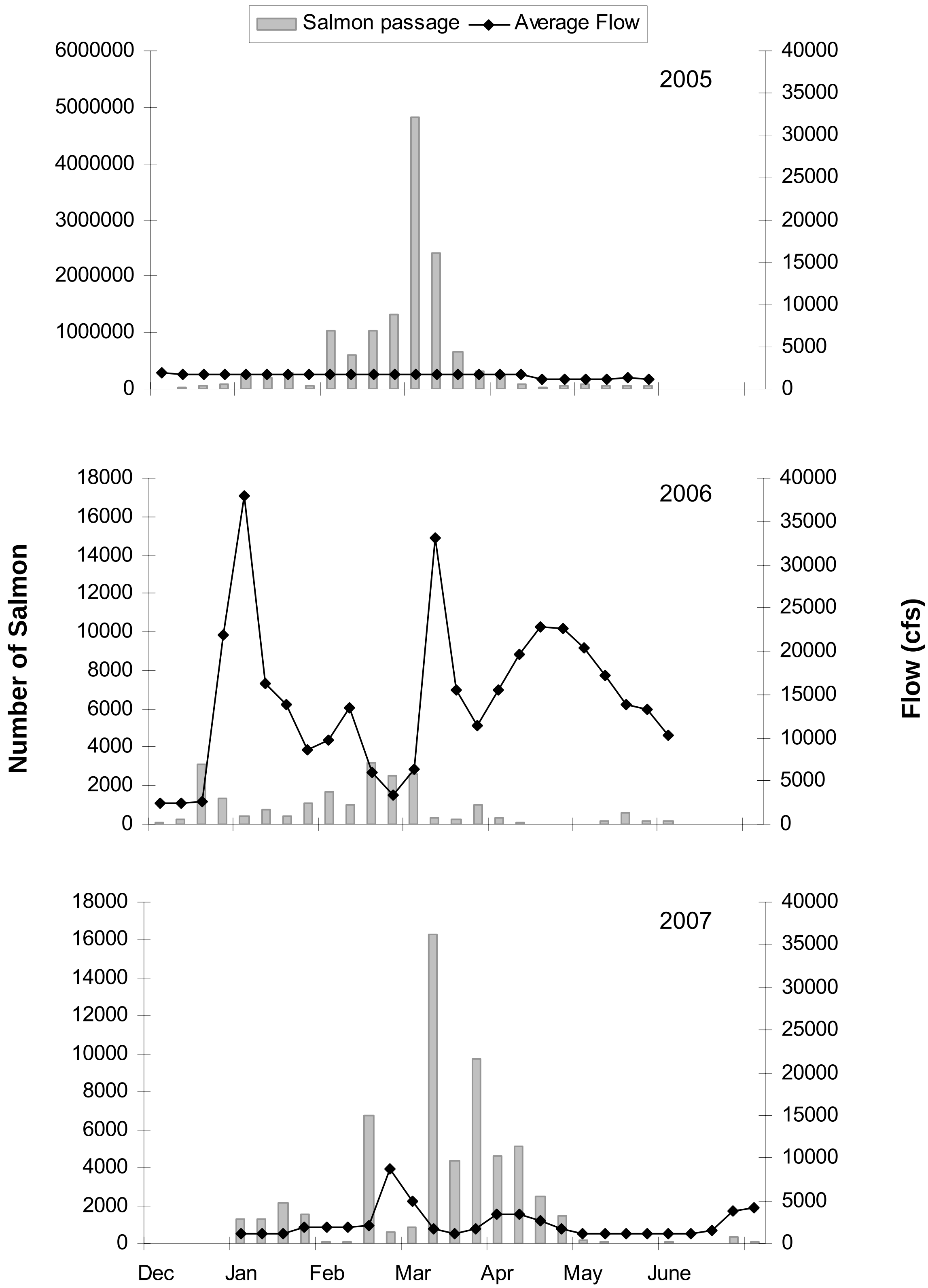

Figure 8. Estimated weekly passage (top) and catch (middle and bottom) for fall-run-sized juvenile Chinook salmon associated with weekly average flow during the 2005-2007 trapping seasons in the high flow channel.

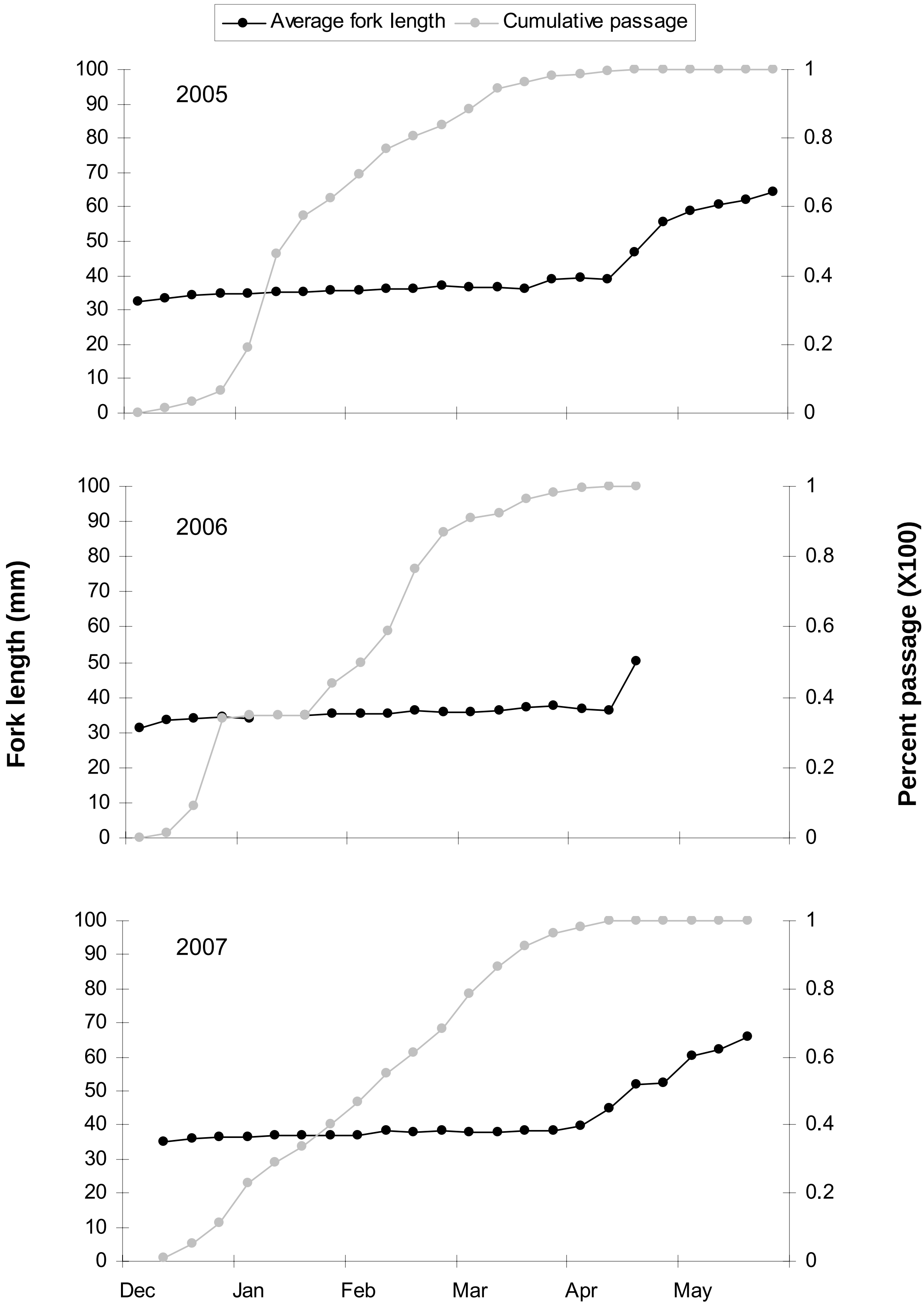

Figure 9. Average weekly fork length (mm) and cumulative passage for fall-run-sized juvenile Chinook salmon during the 2005-2007 trapping seasons in the low flow channel.

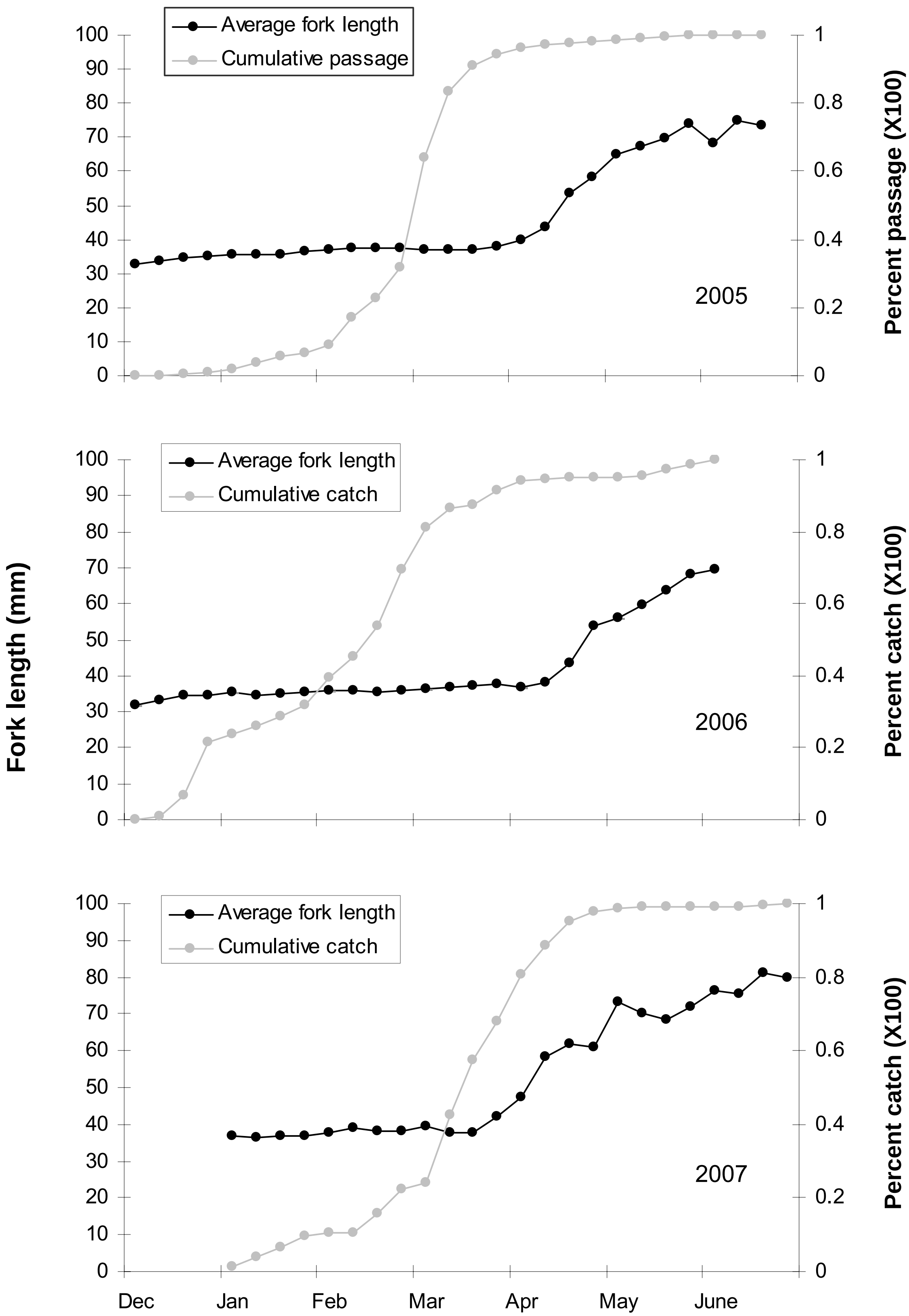

Figure 10. Average weekly fork length (mm) and cumulative passage (top) and cumulative catch (middle and bottom) for fall-run-sized juvenile Chinook salmon during the 2005-2007 trapping seasons in the high flow channel.

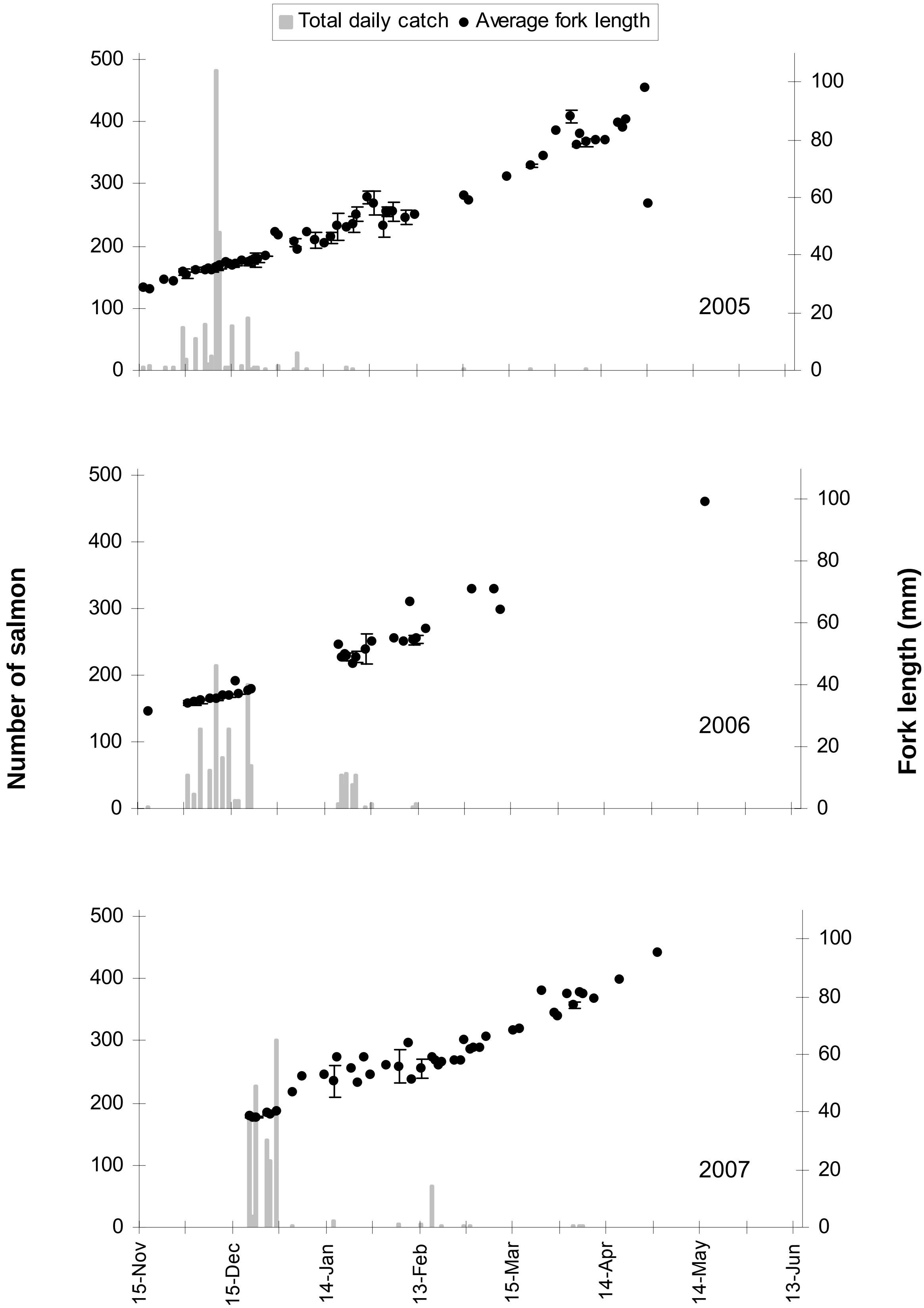

Figure 11. Daily catch distribution and average daily fork length (±1 S.D. for n ≥3) for spring-run-sized Chinook salmon caught in the low flow channel during the 2005-2007 trapping years.

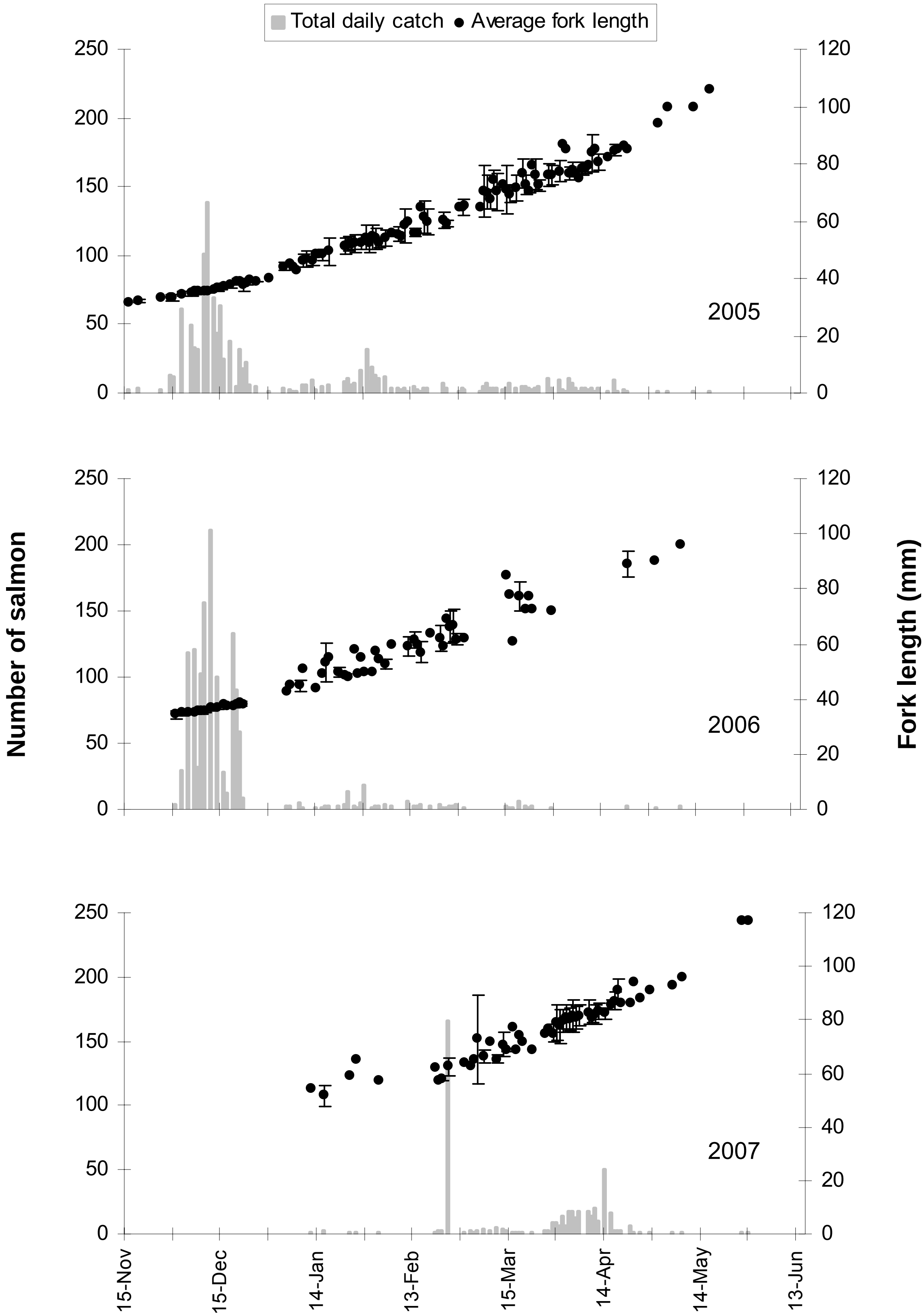

Figure 12. Daily catch distribution and average daily fork length (±1 S.D. for n ≥3) for spring-run-sized Chinook salmon caught in the high flow channel during the 2005-2007 trapping years.

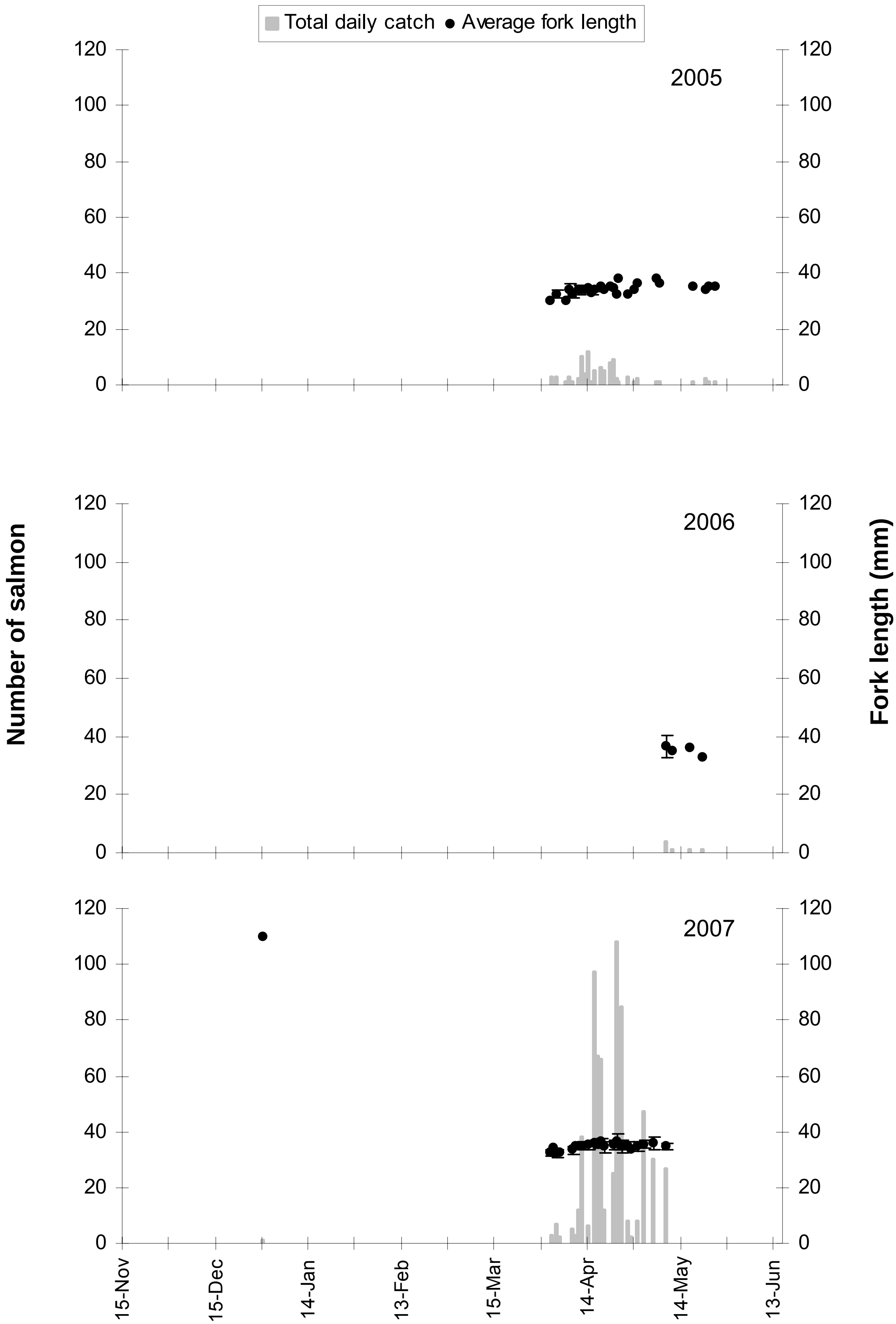

Figure 13. Daily catch distribution and average daily fork length (±1 S.D. for n ≥3) for late- fall-run-sized Chinook salmon caught in the low flow channel during the 2005-2007 trapping years.

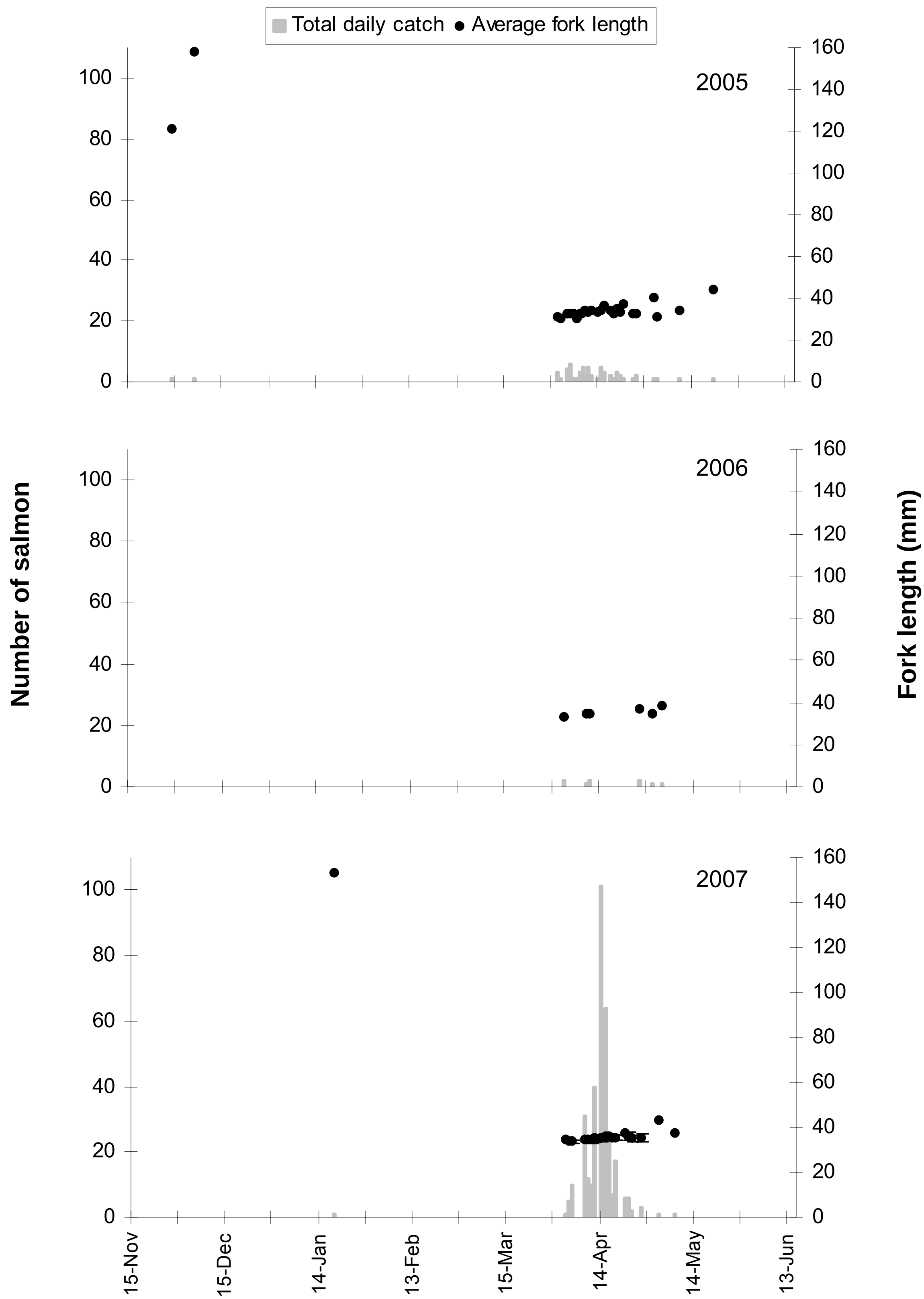

Figure 14. Daily catch distribution and average daily fork length (±1 S.D. for n ≥3) for late-fall-run sized Chinook salmon caught in the high flow channel during the 2005-2007 trapping years.

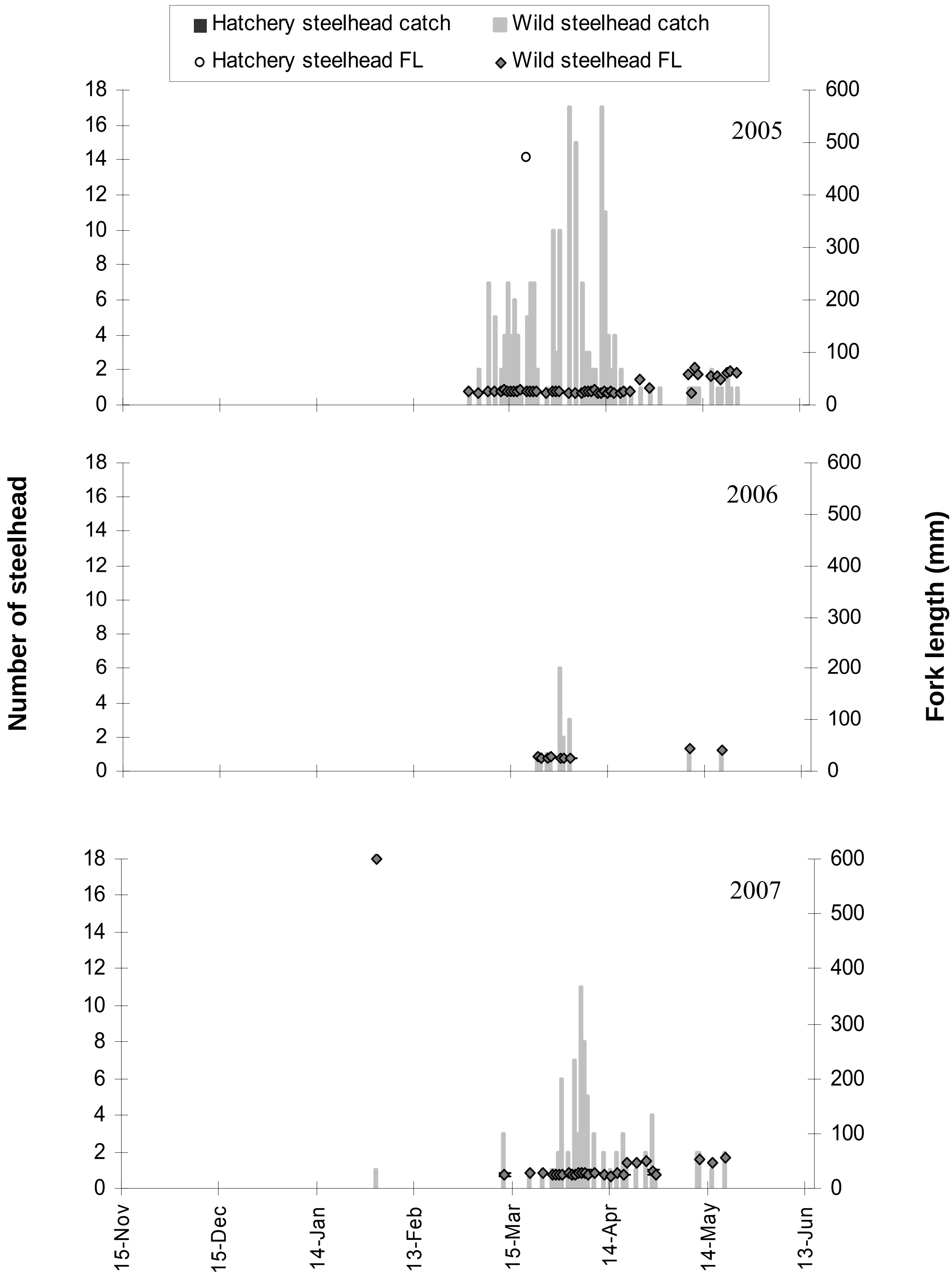

Figure 15. Daily catch distribution and average daily fork length (±1 S.D. for n ≥3) for hatchery and wild steelhead caught in the low flow channel during the 2005-2007 trapping years.

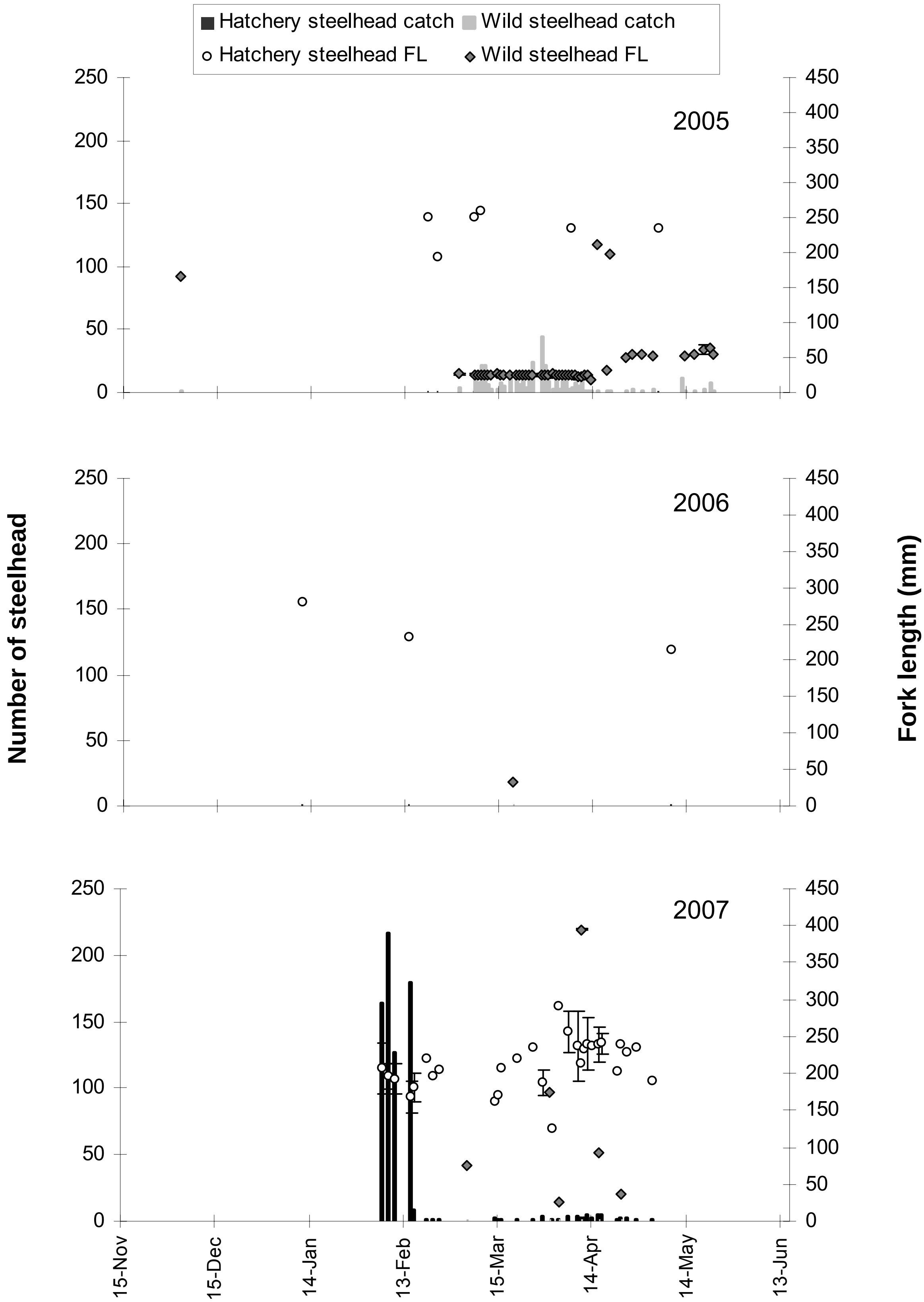

Figure 16. Daily catch distribution and average daily fork length (±1 S.D. for n ≥3) for hatchery and wild steelhead caught in the high flow channel during the 2005-2007 trapping years.

APPENDIX I

APPENDIX I (list of tables)

Table A1. Monthy catch, juvenile passage estimates (JPE) with 95% confidence intervals (C.I.), and cumulative passage for fall-run-sized Chinook salmon captured in the low flow channel of the Feather River during the 2005 – 2007 trapping seasons.

2005 – Eye

Month	Raw Catch	JPE	Lower 95% C.I.	Upper 95% C.I.	Cumulative Passage (%)
Dec	8,411	1,065,616	559,497	1,571,734	4.4%
Jan	54,159	6,483,210	3,287,272	9,679,148	54.4%
Feb	12,687	1,770,965	1,081,350	2,460,580	81.8%
Mar	6,808	941,125	594,318	1,287,933	97.1%
Apr	1,206	60,341	42,930	76,229	99.9%
May	178	178	—	—	100.0%
Total	**83,449**	**10,321,435**	**5,565,366**	**15,075,624**	

2006 – Eye and Steep

Month	Raw Catch	JPE	Lower 95% C.I.	Upper 95% C.I.	Cumulative Passage (%)
Dec	19,188	854,275	561,683	1,146,867	13.4%
Jan	12,050	407,628	309,191	506,065	39.8%
Feb	25,045	986,607	736,531	1,236,683	77.0%
Mar	2,382	193,153	21,217	365,089	96.9%
Apr	18	3,567	0	7,467	99.9%
May	73	73	—	—	100.0%
Total	**58,756**	**2,445,303**	**1,628,622**	**3,262,170**	.

2007 – Steep

Month	Raw Catch	JPE	Lower 95% C.I.	Upper 95% C.I.	Cumulative Passage (%)
Dec	36,012	414,954	351,107	478,801	3.8%
Jan	110,071	1,381,001	1,153,684	1,608,317	26.6%
Feb	107,585	1,260,079	1,064,826	1,455,332	54.6%
Mar	151,435	1,317,934	1,151,316	1,484,552	86.7%
Apr	9,023	122,082	88,116	152,396	99.5%
May	395	395	—	—	100.0%
Total	**414,521**	**4,496,445**	**3,809,049**	**5,179,398**	

Table A2. Monthy catch, passage estimates (JPE) with 95% confidence intervals (C.I.), and cumulative passage for fall-run-sized Chinook salmon captured in the high flow channel of the Feather River during the 2005 trapping season.

2005 – Herringer

Month	Raw Catch	JPE	Lower 95% C.I.	Upper 95% C.I.	Cumulative Passage (%)
Dec	6,721	190,642	146,550	234,734	0.7%
Jan	67,812	1,565,196	1,229,541	1,900,852	5.4%
Feb	227,446	7,986,034	5,880,827	10,091,241	32.0%
Mar	99,450	3,669,168	2,714,929	4,623,407	91.7%
Apr	4,017	298,139	179,060	417,217	98.2%
May	2,045	108,666	58,360	158,117	99.8%
Jun	5	5	—	—	100.0%
Total	**407,491**	**13,817,844**	**10,209,266**	**17,425,568**	

APPENDIX II

APPENDIX II (list of figures)

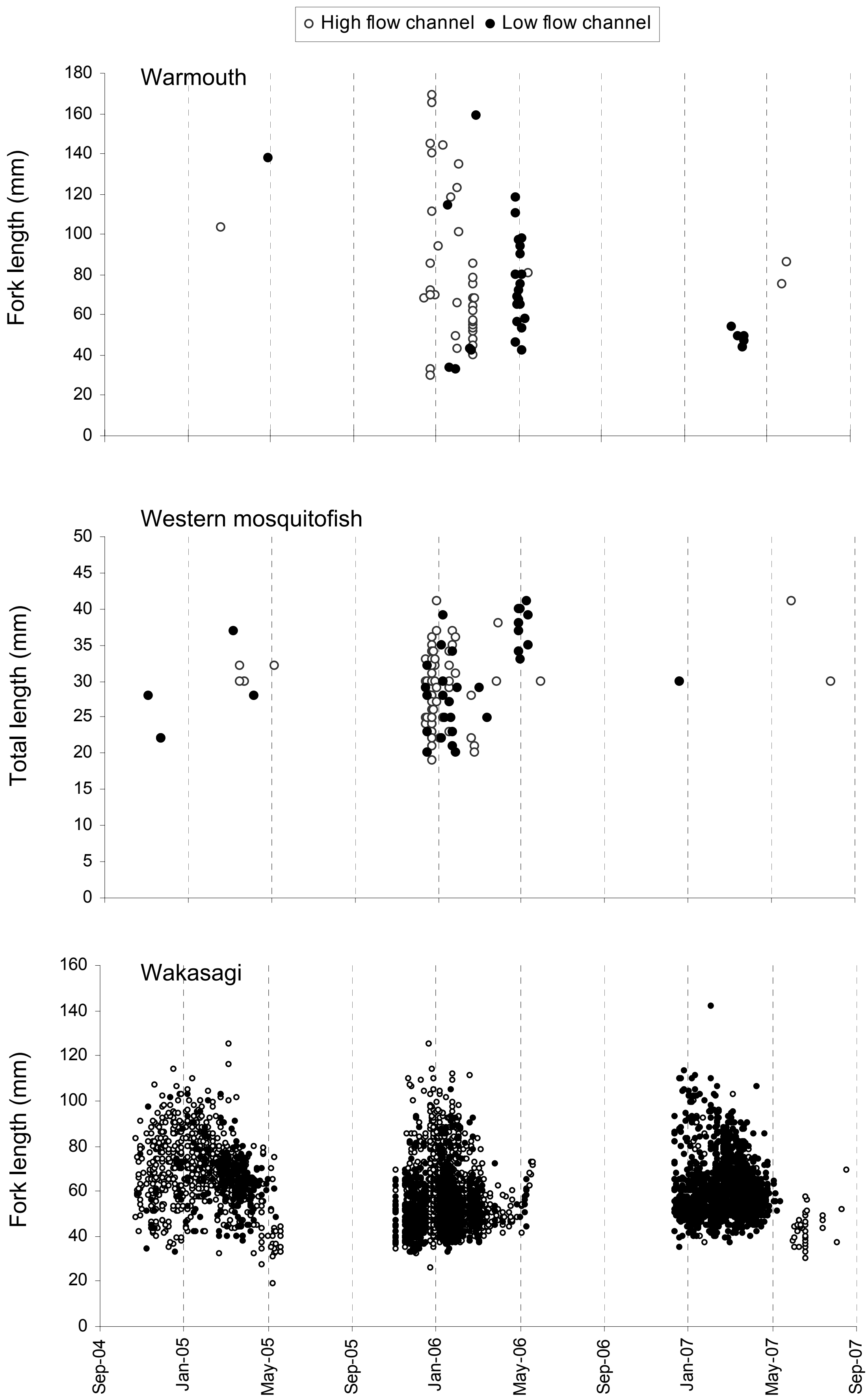

Figure A1. Length distributions for Warmouth, Western mosquitofish, and Wakasagi caught in lower Feather River RSTs during trapping years 2005-2007. Note Y-axis scale change.

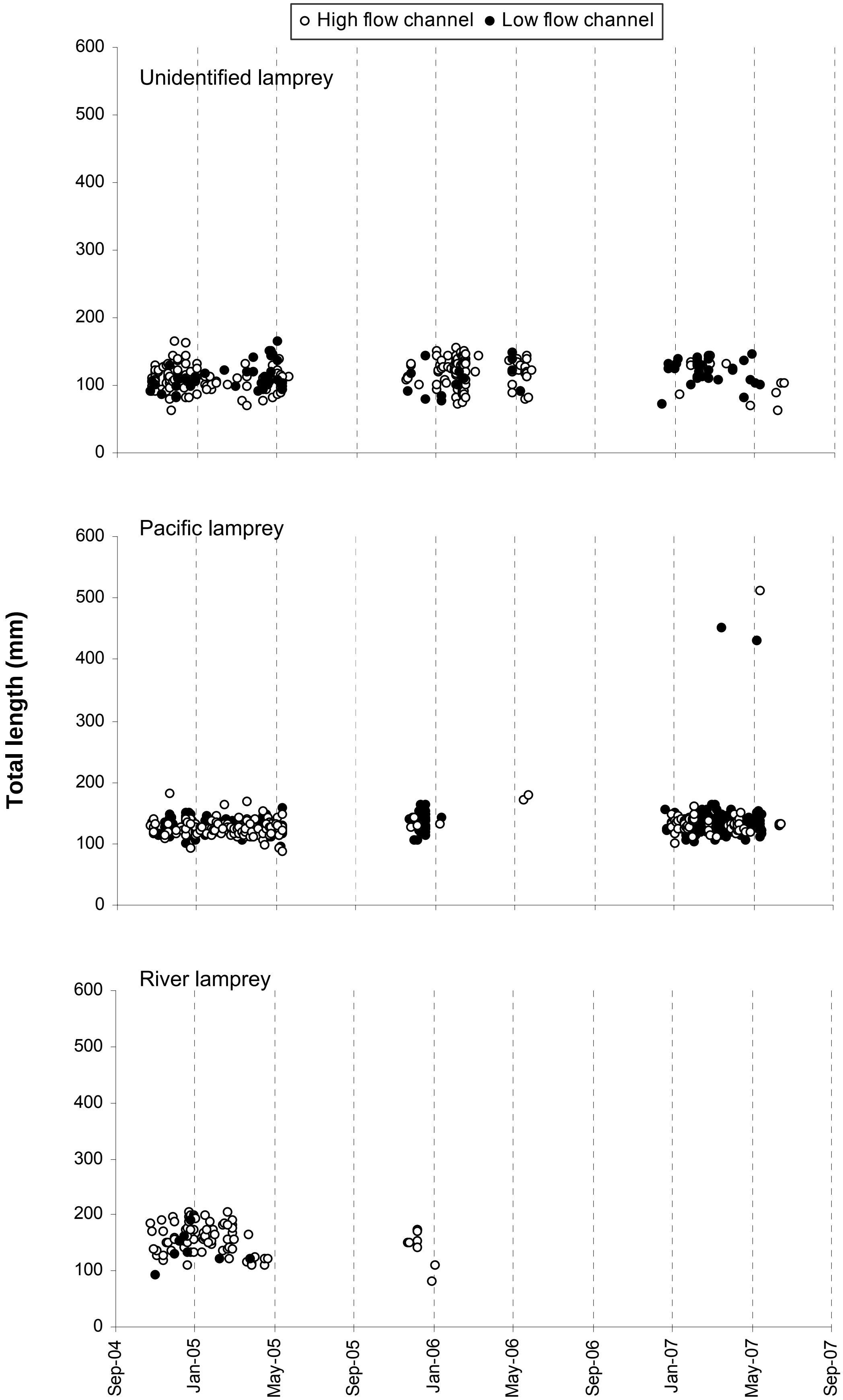

Figure A2. Length distributions for unidentified lamprey, Pacific lamprey, and River lamprey caught in lower Feather River RSTs during trapping years 2005-2007.

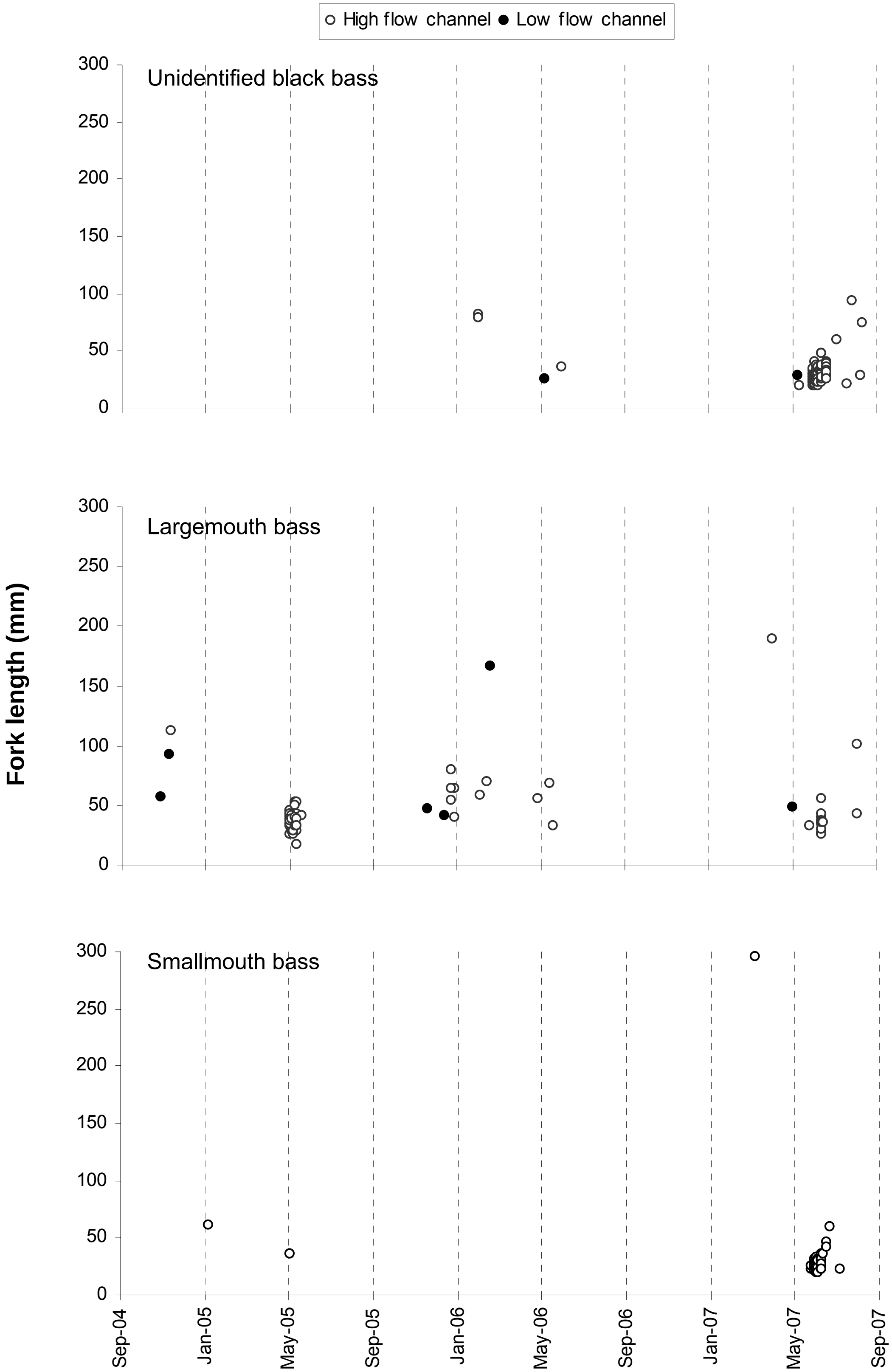

Figure A3. Length distributions for black bass, Largemouth bass, and Smallmouth bass caught in lower Feather River RSTs during trapping years 2005-2007.

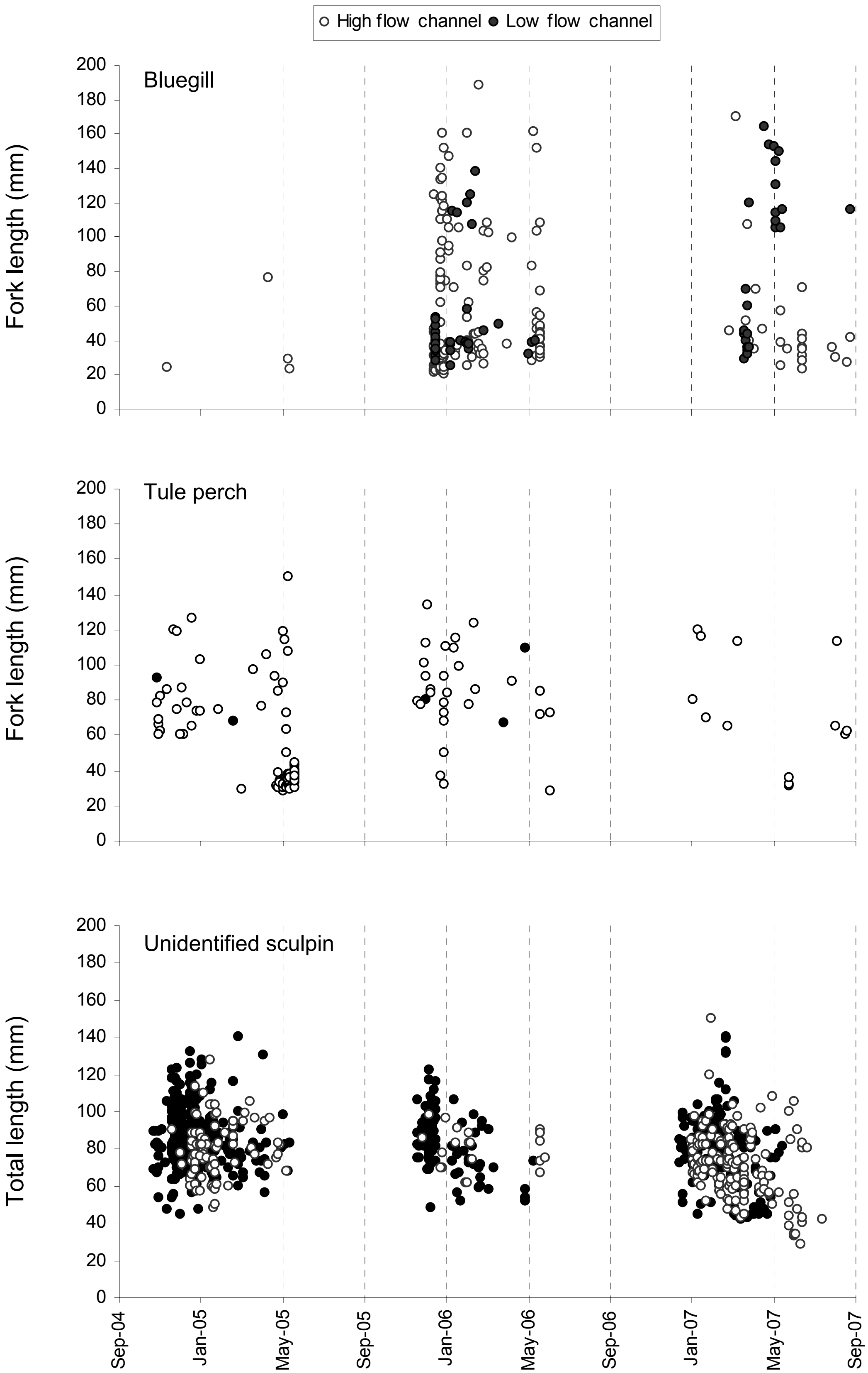

Figure A4. Length distributions for Bluegill, Tule perch, and sculpin caught in lower Feather River RSTs during trapping years 2005-2007.

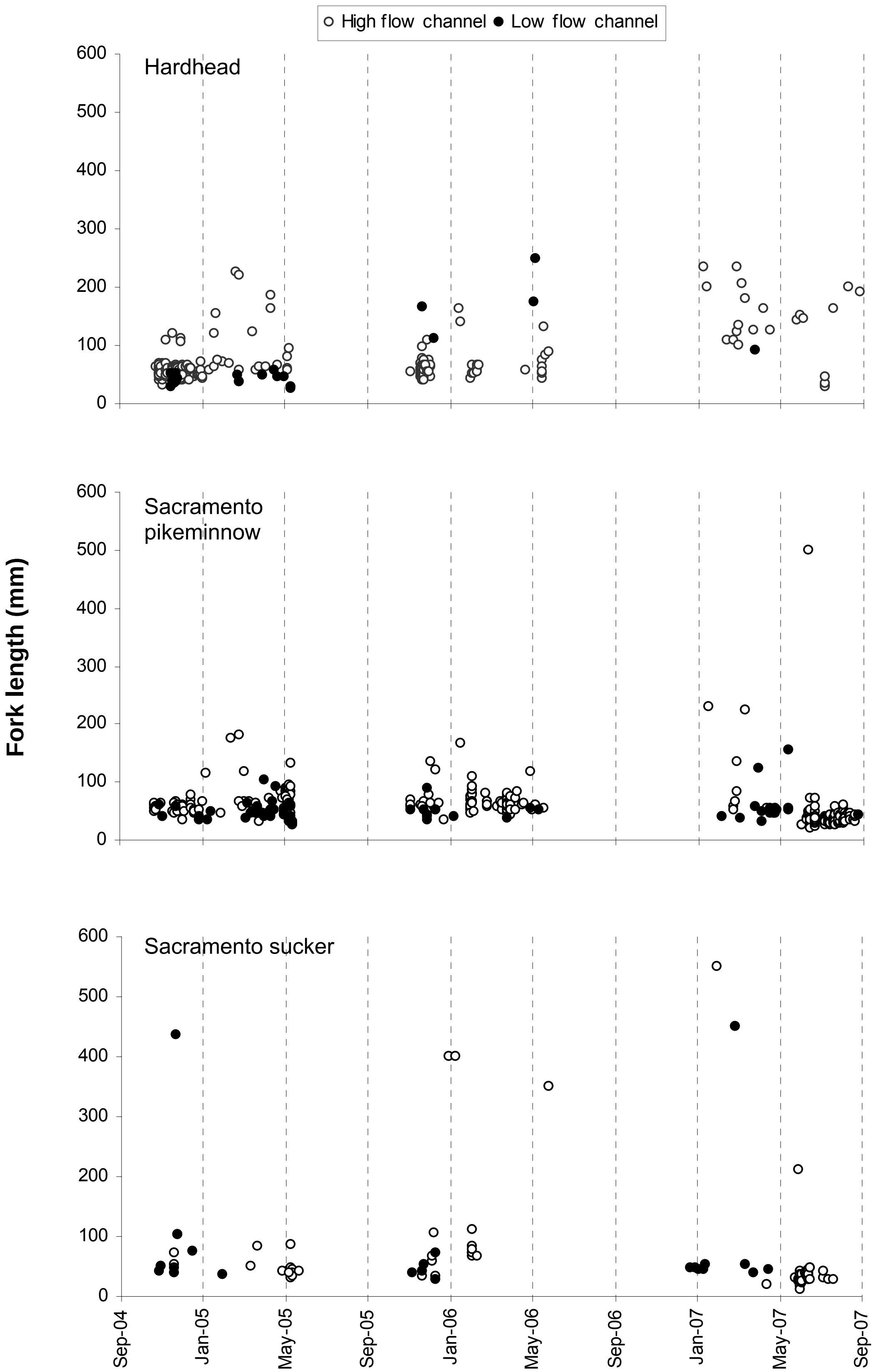

Figure A5. Length distributions for Sacramento sucker, Sacramento pikeminnow, and Hardhead caught in lower Feather River RSTs during trapping years 2005-2007.