STUDY 7.

SALMONID SMOLT YIELD FROM THE SITUK RIVER

Rationale

Salmonid smolt yield from the flood zone is a direct measure of potential impacts of flooding on salmonid production from the Situk River.

Objectives

Objectives of this study were to determine the total number of salmonid smolts that migrate in spring and summer from the entire Situk River; to partition smolt numbers from areas inside and outside the predicted flood zone; and to characterize migration timing, size, and age of migrant juvenile salmonids.

Summary of Results

Rotary-screw traps were fished at the upstream limit of the predicted flood zone and 3 km from the river mouth in 1990. Fish were marked and released 1 km upstream of each trap; recaptures were used to estimate fish numbers at each trap and survival between traps. Estimated total smolt yield from the river was 893,000 sockeye (including 128,000 ocean-type sockeye), 168,000 coho, 67,000 chinook, and 26,000 steelhead. Estimated survival between traps was 49% for coho smolts, 46% for chinook, and 84% for sockeye. High smolt mortality between traps probably was due to predation. Calculations based on the catch difference between the two traps indicate that 34% of sockeye (100% of ocean-type sockeye), 33% of coho smolts, 45% of chinook, and 0% of steelhead migrated from inside the flood zone.

METHODS

Fish Capture

Two rotary-screw traps were fished from April to mid-August 1990 at two sites: upriver, at the upstream limit of predicted flooding 20 km from the river mouth; and downriver, 3 km from the river mouth (Fig. 7.1). The upriver trap fished the area outside the flood zone; the downriver trap fished almost the entire river; the difference between traps represented the flood zone.

Each trap was a revolving stainless-steel, 2-mm-mesh cone on aluminum pontoons (Fig. 7.2). The cone entrance was 2.4 m in diameter, and one-half (2.2 m^2) was submerged. An internal screw rotated the cone 3-6 rpm depending on water velocity (which ranged 70-170 cm/s). Fish passing through the cone collected in a live box where a revolving drum removed small debris. The traps were tied to shore and braced in the thalweg at river constrictions (16 m wide upriver and 24 m wide downriver; 1.2-2.4 m deep at both sites). The trap fished 6-11% of river cross-section upriver and 4-8% downriver. We built fences (5 m long, 6-mm mesh) in a "V" shape in front of each trap to funnel fish into the traps. Mean daily water temperature ranged from

3°C in April to 16°C in August (Fig. 7.3). River stage (measured with a staff gauge at each trap) fluctuated because of storms at least once each month (Fig. 7.4).

Trapped fish were removed each day and sorted by size (fry, parr, and smolts) into flow-through boxes with negligible water velocity. Because few Dolly Varden parr and smolts were captured (121 upriver and 41 downriver), their yield could not be estimated; therefore Dolly Varden data are not included in this report. Up to 100 randomly selected fish per species and size group per week were measured for FL. Length frequencies for each species (combined size groups) were plotted by weighting each size group's frequencies (in 3- or 5-mm increments) by the group's proportion in the catch on days fry were enumerated. Fish ages determined from scale samples from up to 50 fish per species per week (except pink and chum) were compared with FL frequencies to determine age composition. Condition factor was calculated by dividing g weight by mm FL cubed (Ricker 1975) and multiplying by 10^5.

We enumerated parr and smolts daily and fry three times a week. To estimate fry on intervening days, we used the average catch in adjoining enumeration days. When too numerous to count, fry were estimated. Three samples of fry were weighed and counted by species; total numbers were calculated from mean weight and species composition of the samples and total weight of the fry catch. Size groups were adjusted as fish grew (Table 7.1). In April, for example, all fry were less than 45 mm long, and in July coho fry were less than 65 mm and steelhead fry were less than 50 mm. Chinook larger than 45 mm were always considered smolts. Sockeye fry were classified as ocean type regardless of size, if their eyes were small relative to their head size.

Smolt Yield

Numbers of migrant smolts and parr were estimated by the trap-efficiency method by releasing marked fish upstream of each trap. At least 3 days per week during the entire study, up to 1,000 smolts and 1,000 parr per species were marked with a tattoo as described in Study 4. We changed mark color on Monday and stopped marking on Thursday. Three colors (Alcian Blue, neutral red, and black India ink) were rotated the first 9 weeks. Neutral red was dropped after week 9 because of problems with retention and survival. Different mark positions were used at each trap. Upriver, salmon smolts were tattooed on the upper caudal fin or on both upper and lower caudal fin; steelhead smolts between the pelvic fins; and parr on the anal fin. Downriver, salmon smolts were tattooed on the lower caudal fin; steelhead smolts on the ventral caudal peduncle; and parr on both upper and lower caudal fin. Marked fish were held until dusk, moved in aerated tubs 1 km upstream, and released in quiet water. Recaptures were generally made soon after release: 2-28% within 1 d and 90% within 1 week. To estimate fish numbers, all recaptures were treated as if they occurred the same marking week as when released. Each day, all trapped smolts and parr were checked for marks, and up to 25 randomly selected recaptures of each species, size group, and mark were measured for FL.

Short-term mark survival (fish survival and mark retention) was determined by periodically holding a random sample of 25 marked fish per species. Fish were held in aerated tubs or flow-through boxes, and after 1 day, live fish with visible marks were counted. Short-term mark survival was calculated as

$$\hat{s} = s/h \; ; \qquad (1)$$

$\hat{s}$ is estimated survival and retention of marks, s is number of surviving fish with visible marks, and h is number of marked fish held. The number of surviving marks was calculated as

$$\hat{M} = m\hat{s} \; ; \qquad (2)$$

$\hat{M}$ is estimated number of surviving marks, and m is number of marks released.

Mark retention and fish survival after 1 day were generally high, but differed between species ($P < 0.001$; G test) and mark color ($P < 0.001$). Mark retention was 100% for coho and chinook, but 96% for sockeye and 97% for steelhead. Blue and black marks were retained better (98-99%) than red marks (90%). Mark retention was a problem in weeks 8 and 9 because of Panjet malfunction; data from weeks 7 and 10 were averaged to estimate fish numbers in weeks 8 and 9. Sockeye smolts were fragile, and their 1-day survival (mean, 95%) was lower ($P < 0.05$) than for other smolts (mean, 99%; Table 7.2). Blue- or black-marked sockeye survived better ($P < 0.05$) than red-marked sockeye. Sockeye survival differed ($P < 0.01$) between marking weeks downriver, but was similar ($P = 0.32$) between weeks upriver.

The proportion of marked fish recaptured (trap efficiency) was used to expand the unmarked catch and estimate fish numbers. Trap efficiency was estimated by

$$\hat{E} = R/\hat{M} \; ; \qquad (3)$$

$\hat{E}$ is estimated trap efficiency, and R is number of marked fish recaptured. Fish number was estimated by

$$\hat{N} = U/\hat{E} \; ; \qquad (4)$$

$\hat{N}$ is estimated number of fish, and U is unmarked catch. Trap efficiency and mark survival were first calculated separately for each week and then tested for differences between consecutive weeks. If similar ($P > 0.05$; Chi-square test), data were pooled.

Trap efficiency differed widely between species and marking weeks (Fig. 7.5). Overall trap efficiency for smolts was greatest for chinook (24%), intermediate for coho (12%) and sockeye (7%), and least for steelhead (3%). Trap efficiency depended on river stage, position of the trap and fences, and amount of debris on the trap. Differences between species probably reflected differences in migratory behavior and ability to avoid the trap. Efficiency generally increased during the study as we adjusted traps and fences.

Size of recaptured smolts was compared with the size of marked fish released to determine whether trap efficiency differed by fish size within a species size group. Length frequencies of coho, chinook, and sockeye showed significant but small differences between marked and recaptured fish ($P < 0.05$; Kolmogorov Smirnov test). More recaptured fish than marked fish were middle-size range, but steelhead smolt recaptures were similar in size to the marked steelhead released ($P > 0.10$; Fig. 7.6). Thus, trap efficiency tended to be greater for the middle range size group, but differences were small, and the effect on population estimates was probably insignificant.

Variance for $\hat{N}$ each week was determined by the bootstrap method (Efron and Tibshirani 1986) with 1,000 iterations. Each bootstrap iteration involved calculating $\hat{N}^*$ by equations (1-4) after drawing s^* from the binomial distribution $(h,\hat{s})$, R^* from the binomial distribution $(\hat{M}, \hat{E})$, and U^* from the binomial distribution $(\hat{N}, \hat{E})$, where asterisks denote bootstrap values. Variance of weekly $\hat{N}$ was summed to obtain variance for the total migration[21].

[21]A Fortran program for calculating bootstrap variance is available from the authors on request.

Because ocean-type sockeye at the downstream trap were not distinguished from other sockeye until week 10, we partitioned sockeye estimates between ocean-type and other smolts in weeks 1-9 based on proportions of the age groups in the catch. The number in each age group was calculated as

$$\hat{N}_j = \hat{p}_j \hat{N} \; ; \qquad (5)$$

$\hat{N}_j$ is estimated number of age group j; $\hat{p}$ is proportion of age group j; and $\hat{N}$ is estimated number of all sockeye. Variance (V) of each age group's $\hat{N}$ was calculated as

$$V(\hat{N}_j) = \hat{N}^2 V(\hat{p}_j) + \hat{p}_j^2 V(\hat{N}) + V(\hat{p}_j) V(\hat{N}) \; ; \qquad (6)$$

symbols are defined above. Because few ocean-type sockeye were captured at the upstream trap, we did not distinguish between ocean-type and other sockeye.

Because fish mortality between traps would cause an underestimate of the flood zone's contribution, we estimated fish mortality from the equation

$$\hat{S} = R_d / (\hat{E}_d \hat{M}_u) \; ; \qquad (7)$$

$\hat{S}$ is estimated survival of marked fish between traps; R_d is number of upriver-marked fish recaptured downriver; $\hat{E}_d$ is estimated efficiency of the downriver trap; and $\hat{M}_u$ is number of marks released at the upriver trap (after subtracting 1-day mortality). Important assumptions were that marking did not affect survival (other than initially), all surviving marked fish migrated past the downriver trap, and all recaptured marked fish were counted. Because many parr apparently remained in the area between traps and did not go to sea, their survival was not estimated.

RESULTS

Migration Characteristics

Sockeye smolts migrated mostly from mid-May to mid-July; ocean-type sockeye migrated primarily in June (Fig. 7.7). Overall, sockeye smolts were 64-89% age 1, and about 5% were age 2 (Table 7.3). Ocean-type sockeye were nearly one-third of the sockeye at the downriver trap but were rare upriver. Mean FL of age-1 and -2 sockeye was similar at both traps; the monthly mean ranged from 63 to 74 mm (Figs. 7.8, 7.9). Mean FL of ocean-type sockeye increased from 36 mm in April to 62 mm in July (Fig. 7.9).

Coho smolts migrated mostly from mid-May to late June, with peaks in late May upriver and early June downriver (Fig. 7.10); coho parr were most numerous in June and July (Fig. 7.10) during freshets (Fig. 7.4). Smolts were larger and older upriver than downriver ($P < 0.05$; Kolmogorov-Smirnov test). Mean FL was 107 mm upriver and 101 mm downriver (Figs. 7.11, 7.12). Nearly 60% were age 2 or 3 upriver, compared to 83% age 1 and 17% age 2 or 3 downriver (Table 7.3). The decline in size and age of smolts downriver could be explained by predation during migration between the traps and by an influx of smaller, younger smolts from inside the flood zone.

Chinook smolts migrated in June and July, beginning 1 week earlier upriver than downriver and peaking at both traps in July (Fig. 7.13). Some age-1 smolts (monthly means, 80-97 mm FL) were caught in April and May, but 99.9% of smolts were age 0 (Table 7.3; Figs. 7.14, 7.15). Mean FL of chinook smolts at the upriver trap increased gradually between June and August (from 66 to 85 mm upriver and from 61 to 89 mm downriver).

The migration of steelhead smolts was bimodal, particularly at the upriver trap (Fig. 7.16). Their number was greatest in late May and late June upriver, and in late June and mid-July downriver. The steelhead parr migration also was bimodal, with a small peak in mid-May and a larger peak in mid-June (Fig. 7.16). Age of smolts was similar at the two traps: 11% age 2, 82% age 3, and 7% age 4 (Table 7.3). Mean FL of smolts ranged from about 120 mm for age-2 smolts to 180 mm for age-4 smolts (Figs. 7.17, 7.18).

Condition of chinook and coho smolts was greater than sockeye and steelhead smolts (Table 7.4). Condition generally declined with age, except for sockeye at the upriver trap, where condition increased with age.

Rate of migration between the traps was greater for sockeye, coho, and steelhead smolts than chinook smolts. The time required to accumulate 90% of the downriver recaptures of upriver-marked smolts was 5 days for sockeye, 6 days for coho and steelhead, and 9 days for chinook (Fig. 7.19). Average migration rate of sockeye and coho (10 km/d) was two times faster than chinook (5 km/d). Some smolts from the upriver trap were recaptured downriver within 12 hours, indicating the fastest migration was 33 km/d.

Salmonid Fry

About 850,000 fry were caught upriver, and 4 million fry were caught downriver (Table 7.5). Pink fry far exceeded all other species, comprising 85% of fry upriver and 97% downriver. Coho fry were numerous, particularly upriver, and chum fry were numerous downriver. Few sockeye fry were caught and most were from downriver. Steelhead and chinook fry were uncommon upriver and were absent downriver. Based on the difference between traps, most pink, chum, and sockeye fry migrated from inside the flood zone, and most coho, steelhead, and chinook fry migrated from outside the flood zone.

Coho and steelhead fry migrated later than the other species (Figs. 7.20, 7.21). Coho fry migrated mostly from mid-April to late May upriver and from mid-June to August downriver. The coho fry migration peaked in mid-May upriver and in July downriver. Steelhead fry migrated from early July to early August at both traps. Pink, chum, sockeye, and chinook fry migrated mostly from mid-April to mid-May, with peaks in late April and early May.

Length of fry was generally greater downriver than upriver. Mean FL of ocean-type sockeye in June, for example, was 54 mm upriver and 58 mm downriver (Figs. 7.8, 7.9). Mean FL of coho fry increased from 35 mm in April at both traps to 51 mm upriver and 64 mm downriver in August (Figs. 7.11, 7.12). Mean FL of chinook fry upriver remained at 40 mm in April and May (Fig. 7.14), apparently because of continuous downstream migration of newly emerged fry. No chinook fry were caught downriver in April and May, and after May, they were considered smolts. Mean FL of steelhead fry in July and August was 33 mm upriver and 46 mm downriver (Figs. 7.17, 7.18). Mean FL of pink and chum fry from both traps was 35 and 37 mm, respectively.

Smolt Yield

About 117,000 smolts and 3,000 parr were trapped upriver; 69,000 smolts and 22,000 parr were trapped downriver (Table 7.6). Excluding fry, the upriver catch consisted of 62% sockeye smolts, 18% coho smolts, 16% chinook smolts, and 4% other groups; the downriver catch consisted of 35% sockeye smolts (including ocean type), 26% coho smolts, 23% coho parr, 14% chinook smolts, and 2% other groups. Thus, the main difference between traps was the greater proportion of coho parr at the downriver trap.

Based on estimated trap efficiency, a total of about 1.1 million parr and smolts passed the upriver trap, and 1.3 million passed the downriver trap (Table 7.6). Most of these migrants were smolts: 95% upriver and 90% downriver. Thus, the Situk River's total smolt yield was 1.2 million fish.

Sockeye made up most of the smolts at both traps (68% upriver and 77% downriver; Table 7.6). About 700,000 sockeye smolts (probably of lake origin) passed the upriver trap, and 765,000 smolts and 128,000 ocean-type sockeye passed the downriver trap. Total smolt yield from the Situk River was nearly 900,000 sockeye.

Estimated coho smolts were more numerous at the upriver trap than downriver ($P < 0.01$; t-test): 230,000 upriver but only 168,000 downriver—a 27% decline (Table 7.6). Parr, however, were much more numerous downriver than upriver: 127,000 downriver compared to 31,000 upriver. By catch difference, nearly 100,000 parr came from the flood zone, and an unknown number of these became smolts. The combined total of coho parr and smolts was 261,000 upriver and 295,000 downriver.

As with coho smolts, estimated chinook smolts were more numerous upriver than downriver ($P < 0.01$; t-test): 80,000 passed upriver, but only 67,000 passed downriver—a 16% decline (Table 7.6). This apparent decline would be greater if chinook fry that moved downstream in spring were added to the upriver population estimate. Chinook fry were not estimated by mark-recapture because of small size (<45 mm FL), but 2,149 chinook fry were caught in the upriver trap in April and May, and no fry were caught downriver. Based on likely trap efficiency of 5%, over 40,000 chinook fry probably entered the flood zone in spring and later migrated past the downriver trap. Thus, the total loss of chinook smolts and fry between traps was probably about 44%.

Estimated steelhead smolts were equally abundant (26,000 fish) at both traps (Table 7.6). Parr, however, were more numerous upriver than downriver: 28,000 upriver and only 8,000 downriver. The difference between traps indicates that about 20,000 parr migrated into the flood zone and remained there. Precision of estimates, however, was poor for both smolts and parr because of low trap efficiency (0-15%).

Estimated survival of marked fish between the upriver and downriver traps corroborated the decline in smolt populations between traps. Survival of marked smolts was 49% for coho, 46% for chinook, and 42% for sockeye (Table 7.7); too few steelhead were caught to estimate survival. Survival of coho and chinook stayed in a narrow range of only 38-42% during most of the migration. Chinook survival increased to 81-90% in the last 2 weeks. Sockeye survival was variable, ranging from 4 to 69%.

Survival of sockeye could have been underestimated because of delayed handling mortality. Initial handling mortality was negligible (<1%) in coho, chinook, and steelhead, but was nearly 3% in sockeye smolts (Table 7.8). Handling mortality in recaptured coho, chinook, and steelhead was also negligible, but about 6% in sockeye, indicating a delayed mortality from marking in sockeye.

Problems identifying marks also contributed to underestimating survival of sockeye. Mark recognition was tested in June by double marking sockeye on both upper caudal (the usual upriver mark) and lower caudal (the downriver mark) and releasing them at the upriver trap along with regular releases. At the downriver trap, double marks were observed at nearly three times the rate of single marks ($P < 0.001$; Chi-square test; Table 7.9), indicating that workers were less efficient in observing marks from upriver than marks applied by themselves. Because of this bias, sockeye survival may have been underestimated by two-thirds. An estimate of sockeye survival based only on double-caudal marks was 79% (Table 7.10).

Based on the difference in smolt populations at the two traps and estimated survival of smolts between the traps, the contribution from the flood zone to the river's total smolt yield was 33% of coho, 45% of chinook, and 34% of sockeye (Table 7.11). Because of possible incomplete mark recognition, delayed handling mortality of marked fish, and increased vulnerability of marked fish to predators, smolt survival between traps may have been underestimated and the contribution from the flood zone may have been overestimated.

DISCUSSION

Migration Characteristics

Migration timing of coho, sockeye, and steelhead smolts in the Situk River was similar to other Alaska rivers. The peak migration of coho smolts in early June is similar to that reported by Thedinga and Koski (1984) and Crone and Bond (1976), and the peak migration of sockeye smolts in early June is similar to that reported by Foerster (1968). Peak migration of steelhead smolts in the Situk River (mid-June) was 1 week later than in Petersburg Creek (Jones 1974).

Age of sockeye smolts was similar to other rivers in the Yakutat forelands (McBride 1986), but it differs from most of Alaska because of the ocean-type stock. Migration timing and size of ocean-type sockeye were similar to that in the Taku River, Southeast Alaska (McPherson et al. 1988; Murphy et al. 1991); ocean-type sockeye from both rivers migrate in mid-June at a mean FL of 54-58 mm.

Age and migration timing were unusual for Alaska chinook and resembled ocean-type chinook in the Pacific Northwest and British Columbia (Healey 1983). Except for the Deshka River (Delaney et al. 1982), Alaska chinook smolts are mostly age 1 (Taylor 1990). Peak migration in other Alaska rivers is in late May (e.g., Murphy et al. 1991); in the Situk River, the peak was in July. Smolt trapping verifies conclusions from Study 4 that most Situk River chinook go to sea at age 0.

The migration rate of smolts was comparable to other studies. Sockeye smolts migrated 10 km/d in the Situk River, 5-8 km/d in the Babine Lake, British Columbia, watershed (Johnson and Groot 1963), and at least 6 km/d in Little Togiak Lake and 7 km/d in Lake Nerka, Alaska (Burgner 1962). Coho smolts in the Chehalis River, Washington, migrated 29 km/d (Moser et al. 1991) compared to a maximum of 33 km/d in the Situk River. Chinook smolts in the Sacramento River migrated 10-18 km/d (Kjelson et al. 1982), more than twice the 5 km/d in the Situk River.

Smolt Yield

The lower numbers of coho and chinook smolts at the downriver trap than at the upriver trap can best be explained by mortality of fish as they migrated between the traps. Surveys of the main-stem river in August and September showed negligible numbers of smolts that may have remained in fresh water rather than migrating to sea (Study 3). Differences in trap efficiency also do not explain the loss of smolts because mark-recapture methods accounted for differences in catchability. Thus, the decline in fish between traps probably resulted from mortality in the main-stem river.

Predation could account for high smolt mortality. River otters (*Lutra canadensis*), mink (*Mustela vison*), common mergansers (*Mergus merganser*), belted kingfishers (*Megaceryle alcyon*), and great blue herons (*Ardea herodias*), as well as Dolly Varden, are all common in the Situk River and are potential predators of juvenile salmonids (Alexander 1979; Wood 1987). Abundant salmonid fry and smolts may attract predators to the river, and such predator concentrations could cause high smolt mortality. Predation mortality of Atlantic salmon smolts in two Swedish rivers was 50% (Larsson 1985), and mergansers caused up to 10% mortality in juvenile salmonids in a British Columbia stream (Wood 1987). At least 100 mergansers occur along the Situk River during the smolt migration (senior author's pers. observ.). If each merganser consumed 400 g of fish per day (Wood and Hand 1985) during the 7-week smolt migration, they would consume 200,000 10-g smolts. The combined effect of all predator species could explain the observed loss of migrating smolts.

Sockeye and steelhead smolts did not decline between traps, indicating less predation than coho and chinook. The principal source of sockeye smolts inside the flood zone is probably Old Situk River, but it produces only about 6,000 age-1 smolts (Study 6), and there are no known sources of large numbers of steelhead smolts. Thus, sockeye and steelhead smolts appear to have much lower mortality during migration than coho and chinook, perhaps because of differences in size and behavior. Sockeye migrated faster than either coho or chinook, and steelhead were the largest and most secretive. More research is needed to assess predator-prey relationships in migrating smolts.

Predation mortality in migrating smolts appears to be greater than generally realized. Losses are more evident when smolt yield is partitioned between different areas of a watershed. In our study, we did not anticipate that more than one-quarter of the migrating smolts would disappear between upriver and downriver traps. Such heavy mortality may have important consequences for a river's salmon production and a manager's ability to conserve or restore depleted salmon stocks. More research is needed to fully quantify predation of migrating smolts and assess its consequences for fisheries.

Our estimates of the number of chinook, sockeye, and steelhead smolts appear realistic compared to expected smolt yields based on average production of adults. For chinook, if the estimated 67,000 smolts had a marine survival of 3% (Lister and Argue 1989), they would produce 2,010 adults; the river's average adult return is 2,000. For sockeye, if the 900,000 smolts had a marine survival of 10% (Foerster 1968), they would produce 90,000 adults; the average return is 100,000 adults. For steelhead, if the estimated 26,000 smolts had a marine survival rate of 16% (Ward and Slaney 1988), they would produce 4,160 adults; the average return is 5,000 adults (Johnson 1990, 1991).

Our estimate of coho smolts appears low compared to expected smolts based on average coho returns. The estimated 168,000 coho smolts would have to survive at a 36% rate to produce the average return of 60,000 adults. Marine survival of coho typically ranges from 5 to 20% (Shapovalov and Taft 1954; Thedinga and Koski 1984; Elliott and Sterritt 1991). The true number of smolts was probably underestimated because many age-1 parr (which we estimated separately from smolts) later transformed to smolts and migrated to sea. The combined number of parr and smolts was about 300,000 fish, which would produce 60,000 adults if marine survival was 20%. The coho parr migration from Old Situk River peaks in April (Study 6), providing plenty of time for the nearly 100,000 parr from there to grow enough to become smolts.

Loss of marks and mortality of marked fish would decrease trap efficiency, causing an overestimate of smolts. Overall mark retention and short-term survival were high at both traps. Other studies have demonstrated high survival and good mark retention of tattooed fish. Alcian blue tattoos on the ventral body are recognizable for at least a year (Cane 1981), and coho parr we marked in the laboratory with blue and black tattoos showed 100% survival and mark retention after 2 months. Mark loss, therefore, probably did not affect population estimates. Mortality could be important if marking increases a fish's vulnerability to predators. Because most marked fish quickly migrated back downstream past the trap (90% within 1 week), effects of mark mortality on our results were probably minor.

Few other studies have used two traps to partition smolt yield between areas of a river. Dempson and Stansbury (1991) used two traps 10 km apart to estimate number of Atlantic salmon smolts migrating from the Conne River. Our study demonstrated that smolt yield can be partitioned, but methods must account for fish mortality between traps and mark recognition efficiency.

Although smolt yield is probably the best measure of salmonid production from a watershed as a whole, it may give only a partial measure of the contribution of specific areas within a watershed. Fish move seasonally, complicating the assessment of an area's production. In the Situk River, an estimated 70% of the river's juvenile salmonids rear in the flood zone in summer, but many move to other wintering areas from which they migrate to sea the following spring. Many parr also migrate to staging areas in spring before they develop smolt characteristics. Complementary studies of summer rearing areas (Study 3) and surveys for residual parr (Study 4) should be considered along with smolt yield to fully evaluate the contribution from the flood zone.

Table 7.1—Size range of different size groups of each species by marking week for fish caught at upriver and downriver traps, Situk River, 1990.

Species	Week	Size range (mm)
Coho:		
fry	1-7	<45
	8-10	<50
	11-12	<55
	13-20	<60
parr	1-7	45-60
	8-10	50-70
	11-12	55-70
	13-20	60-75
smolt	1-7	>60
	8-10	>70
	11-12	>70
	13-20	>75
Sockeye:		
fry	1-12	<45
	13-20	<50
smolt	1-12	≥45
	13-20	≥50
Chinook:		
fry	1-20	<45
smolt	1-20	≥45
Steelhead:		
fry	1-20	<45
parr	1-11	45-100
	12-20	45-120
smolt	1-11	>100
	12-20	>120

Table 7.2—Percent survival of smolts held 24 h after marking at upriver and downriver traps, May to July 1990. A dash indicates no test.

Mark		Survival (%)			
Week	Color	Coho	Sockeye	Chinook	Steelhead
		Upriver			
5/07 - 5/13	Black	100	100	—	100
5/21 - 5/27	Red	100	89	—	—
5/28 - 6/03	Blue & Red	100	98	—	100
6/04 - 6/10	Black	100	92	—	—
6/11 - 6/17	Black	100	100	100	100
6/18 - 6/24	Blue	—	100	—	—
6/25 - 7/01	Black	90	97	100	—
7/02 - 7/08	Blue	100	78	—	100
7/16 - 7/22	Blue	—	98	—	—
		Downriver			
5/07 - 5/13	Red	100	97	100	100
5/21 - 5/27	Black & Red	100	99	—	100
5/28 - 6/03	Black & Red	100	90	—	100
6/04 - 6/10	Blue	100	100	—	—
6/11 - 6/17	Black & Blue	100	100	—	100
6/18 - 6/24	Red	—	89	—	—
6/25 - 7/01	Blue	100	97	94	100
7/09 - 7/15	Blue	100	—	100	—

Table 7.3—Age composition of juvenile salmonids captured in upriver and downriver traps in the Situk River, April to August 1990.

Species	Total aged per species	Age composition (%) 0	1	2	3	4
		Upriver				
Coho smolt	245		44.2	47.8	8.0	
Coho non-smolt		94.6	5.2	0.2		
Sockeye smolt	170	4.5	89.4	6.1		
Chinook smolt	55	99.9	0.1			
Steelhead smolt	112		0.3	6.6	83.0	10.1
Steelhead non-smolt		37.1	51.3	5.5	5.6	0.4
		Downriver				
Coho smolt	309		82.7	16.8	0.5	
Coho non-smolt		73.8	26.0	0.2		
Sockeye smolt	241	32.8	63.7	3.5		
Chinook smolt	99	99.9	0.1			
Steelhead smolt	112			7.3	80.1	12.6
Steelhead non-smolt		6.8	70.7	12.4	10.1	

Table 7.4—Condition factor of smolts captured in the upriver and downriver traps in the Situk River, April to August 1990. Standard deviation is in parentheses.

Age	Coho	Sockeye	Chinook	Steelhead
		Upriver		
0		0.81 (0.08)	0.99 (0.17)	
1	0.98 (0.11)	0.85 (0.14)		
2	0.98 (0.04)	0.87 (0.10)		0.95 (0.35)
3	0.95 (0.04)			0.90 (0.19)
4				0.87 (0.08)
		Downriver		
0		0.89 (0.08)	1.03 (0.08)	
1	0.99 (0.07)	0.85 (0.15)		
2	0.96 (0.06)	0.82 (0.07)		0.92 (0.05)
3				0.84 (0.07)
4				0.88 (0.06)

Table 7.5—Estimated catch of salmonid fry in upriver and downriver traps on the Situk River, April to August 1990. On days they were not counted, number of fry was estimated by extrapolating the catch from adjacent days.

	Catch (thousands of fish)	
Species	Upriver	Downriver
Pink	729	3,907
Chum	1	83
Coho	120	33
Sockeye	1	6
Chinook	2	0
Steelhead	2	0
Total	855	4,029

Table 7.6—Total catch and estimated number ($\hat{N}$) of juvenile salmonids at upriver and downriver traps on the Situk River, April to August 1990.

	Catch		$\hat{N}$ in thousands of fish (95% C.I.)	
Species, stage	Upriver	Downriver	Upriver	Downriver
Sockeye smolts:				
Age >0	74,460	30,125	701 (646-756)	765 (545-984)
Age 0	0	1,179	0 (0-0)	128 (90-166)
Coho:				
Smolts	22,131	23,740	230 (216-244)	168 (138-197)
Parr	1,997	20,941	31 (22-40)	127 (116-142)
Chinook smolts	19,335	13,033	80 (74-85)	67 (59-68)
Steelhead:				
Smolts	1,124	534	26 (15-38)	26 (0-72)
Parr	1,466	659	20 (15-41)	8 (5-12)
Total	120,513	90,211	1,088	1,289

Table 7.7—Smolt survival between traps, calculated from upriver marks released, downriver recaptures, and downriver trap efficiency. Symbols refer to equation (5). Data included are for weeks with >100 marked fish released. Data for weeks 8 and 9 were omitted because of Panjet malfunction. Too few steelhead were caught to estimate survival.

Week	Marks released ($\hat{M}_u$)[a]	Recaptures downriver (R_d)[b]	Expanded marks ($R_d/\hat{E}$)[c]	% Survival of marks ($\hat{S}$)
		Coho smolts		
10	1,836	146	1,209	66
11	1,528	107	630	41
12	1,409	99	558	40
13	638	33	251	39
15	114	8	48	42
Total	5,539	325	2,696	49
		Chinook smolts		
11	159	7	35	22
12	1,177	103	483	41
13	834	66	354	40
14	879	100	338	38
15	762	63	320	42
16	769	48	307	40
17	444	59	400	90
18	194	20	157	81
Total	5,218	466	2,394	46
		Sockeye smolts		
6	417	1	18	4
7	1,213	9	287	24
10	934	10	511	55
11	1,214	15	837	69
12	1,647	23	713	43
13	1,150	21	409	36
14	711	50	271	38
15	639	26	347	54
16	170	1	39	23
Total	8,095	156	3,432	42

[a]Estimated number after accounting for 24-h survival and mark retention.

[b]Total recaptures over 1-3 week period.

[c]Number of recaptures divided by downriver trap efficiency in week of recapture.

Table 7.8—Handling mortality of smolts and parr caught in the upriver trap.

	Released alive	Died	% Mortality
		Unmarked catch	
Coho	75,357	64	0.1
Chinook	20,104	44	0.2
Steelhead	3,239	23	0.7
Sockeye	73,018	2,016	2.7
		Recaptured fish	
Coho	806	6	0.7
Chinook	1,398	6	0.4
Steelhead	55	0	0.0
Sockeye	1,021	64	5.9

Table 7.9—Comparison of the percentage of sockeye marked with single and double-caudal tattoos, released at the upriver trap, and later observed at the downriver trap. Data are from marking weeks 12 and 13 only.

	Single black	Single blue	Double black or blue
Marks released upriver	1,313	982	503
Number observed downriver	14	13	16
% Observed downriver	1.1	1.3	3.2

Table 7.10—Estimated survival of double-caudal marked sockeye between traps in the Situk River, 18 June to 1 July 1990, based on equation (5). Symbols are defined in the text.

Week	Marks released ($\hat{M}_u$)	Downriver recaptures (R_d)	Trap efficiency ($\hat{E}_d$)	Expanded recaptures ($R_d/\hat{E}_d$)	% Survival ($\hat{S}$)
12	334	8	0.032	250	
13	164	7	0.050	140	
14	0	1	0.184	5	
Total	498	16		395	79

Table 7.11—Estimated contribution of the flood zone, based on difference in estimated number of smolts at upriver and downriver traps and estimated survival between traps. Smolt numbers ($\hat{N}$) are in thousands.

	Upriver $\hat{N}$	% Survival	Upriver survivors	Downriver $\hat{N}$	% Flood zone contribution
Coho	230	49	113	168	33
Chinook	80	46	37	67	45
Sockeye	701	84*	589	893	34

*Survival based on double-caudal marks only (79%) and estimated 6% marking mortality (Tables 7.8 and 7.10).

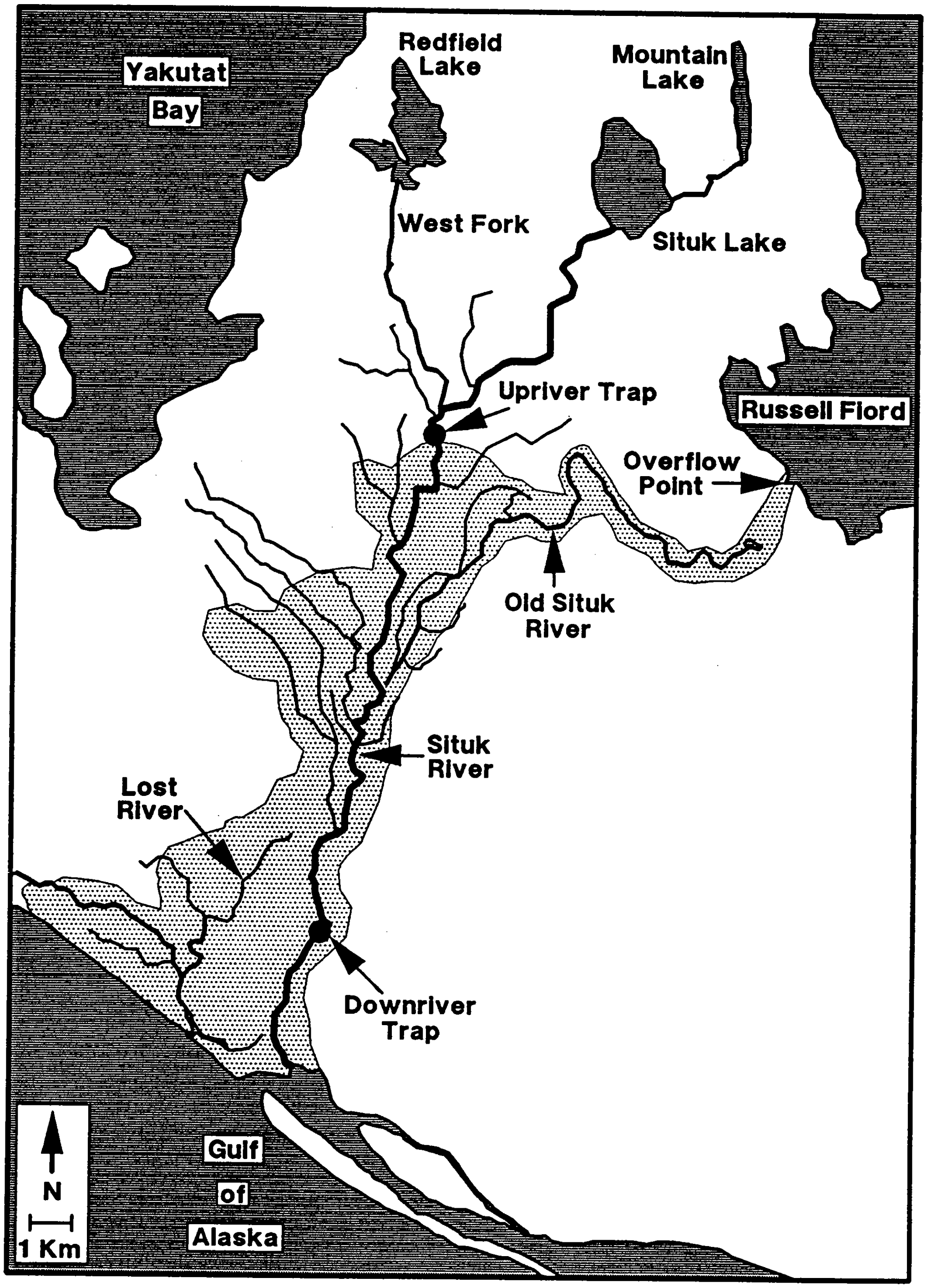

Figure 7.1—Map showing location of two rotary-screw traps used to catch juvenile salmonids on the Situk River. The predicted flood zone is stippled.

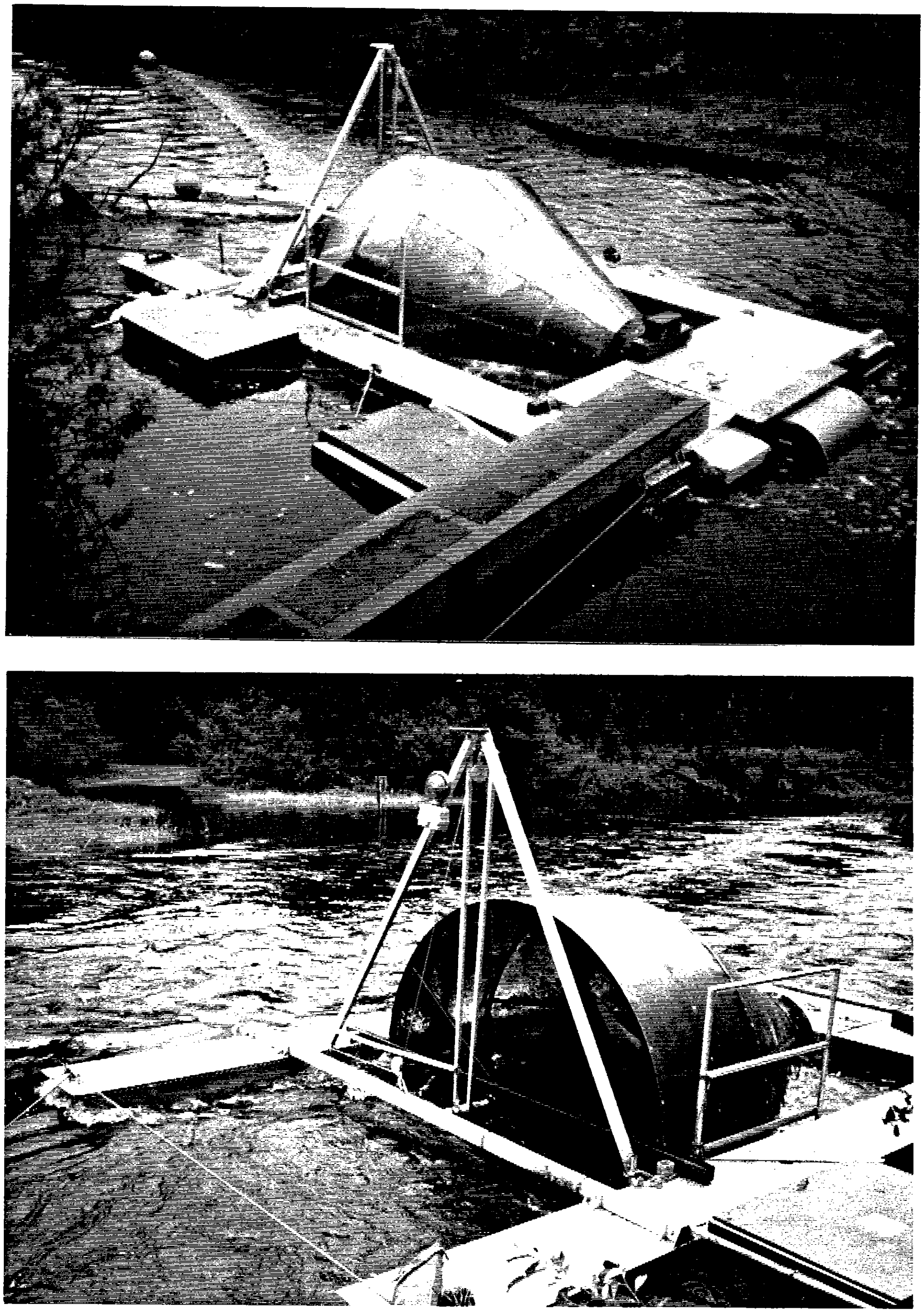

Figure 7.2—Rotary-screw fish trap on the Situk River in April 1990.

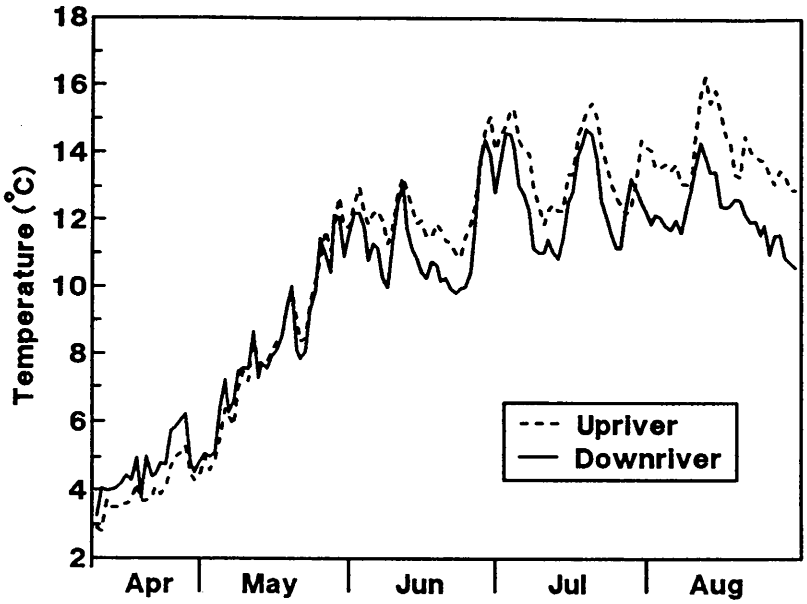

Figure 7.3—Mean daily water temperature of the Situk River at upriver and downriver traps, April to August 1990.

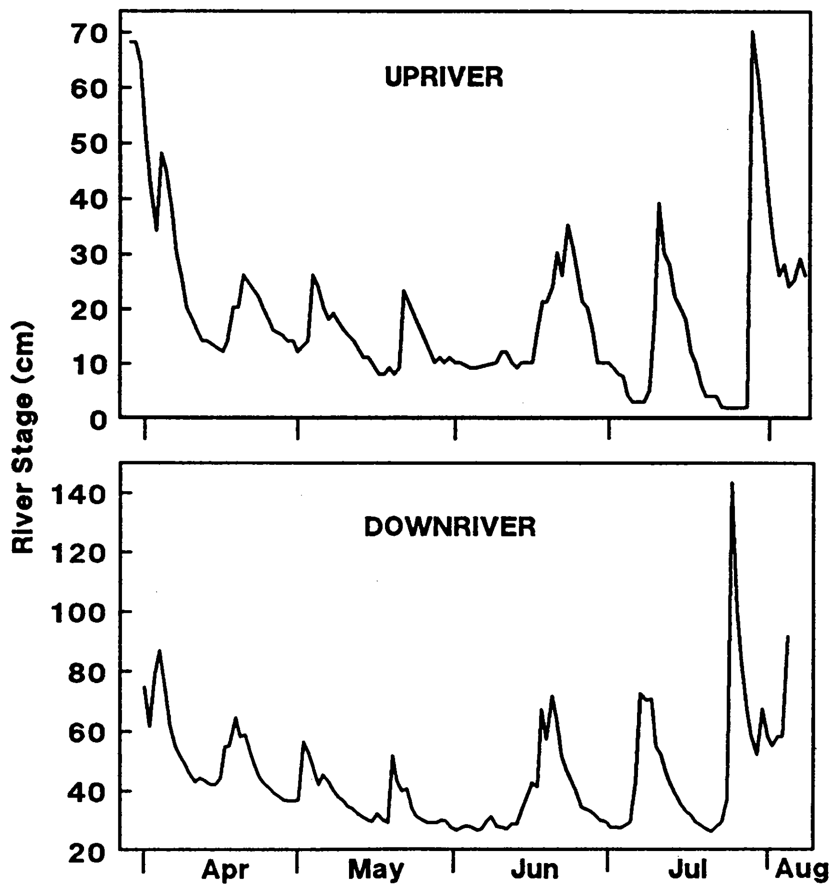

Figure 7.4—River stage of the Situk River at upriver and downriver traps, April to August 1990.

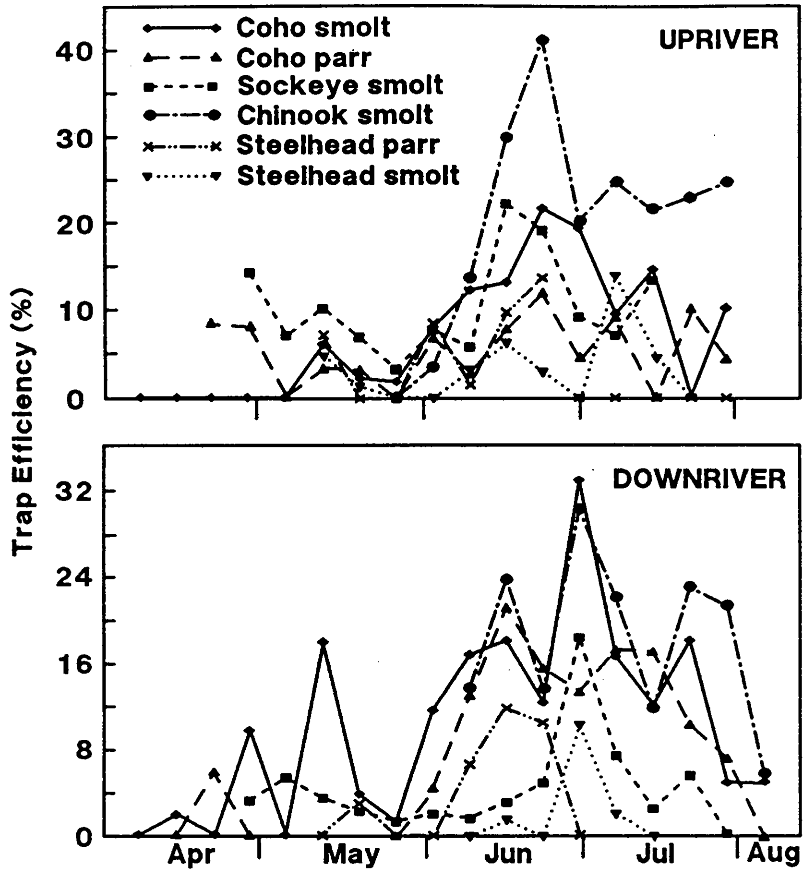

Figure 7.5—Trap efficiency (percentage of marked fish recaptured) for different species and size groups of juvenile salmon from the upriver and downriver traps on the Situk River, April to August 1990.

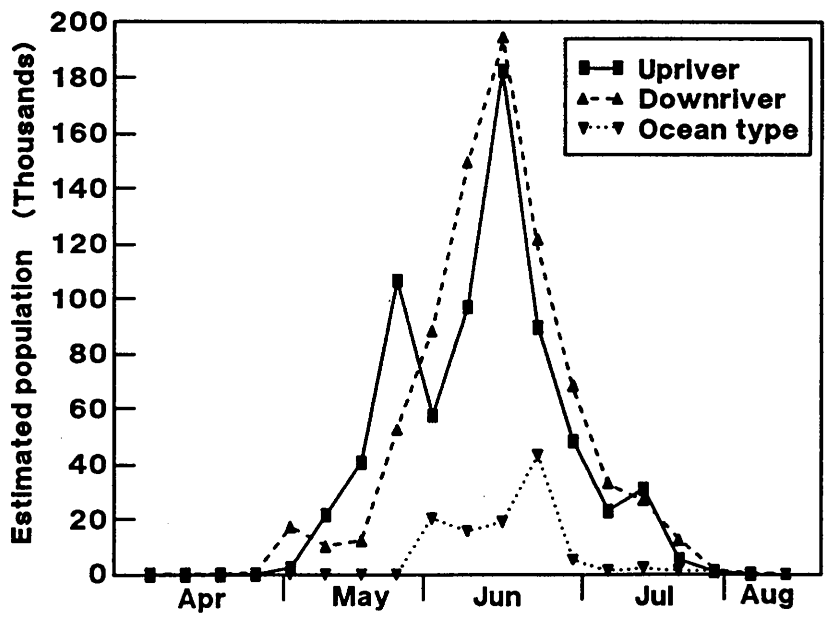

Figure 7.7—Estimated number of sockeye smolts at upriver and downriver and ocean-type sockeye at the downriver traps on the Situk River, April to August 1990.

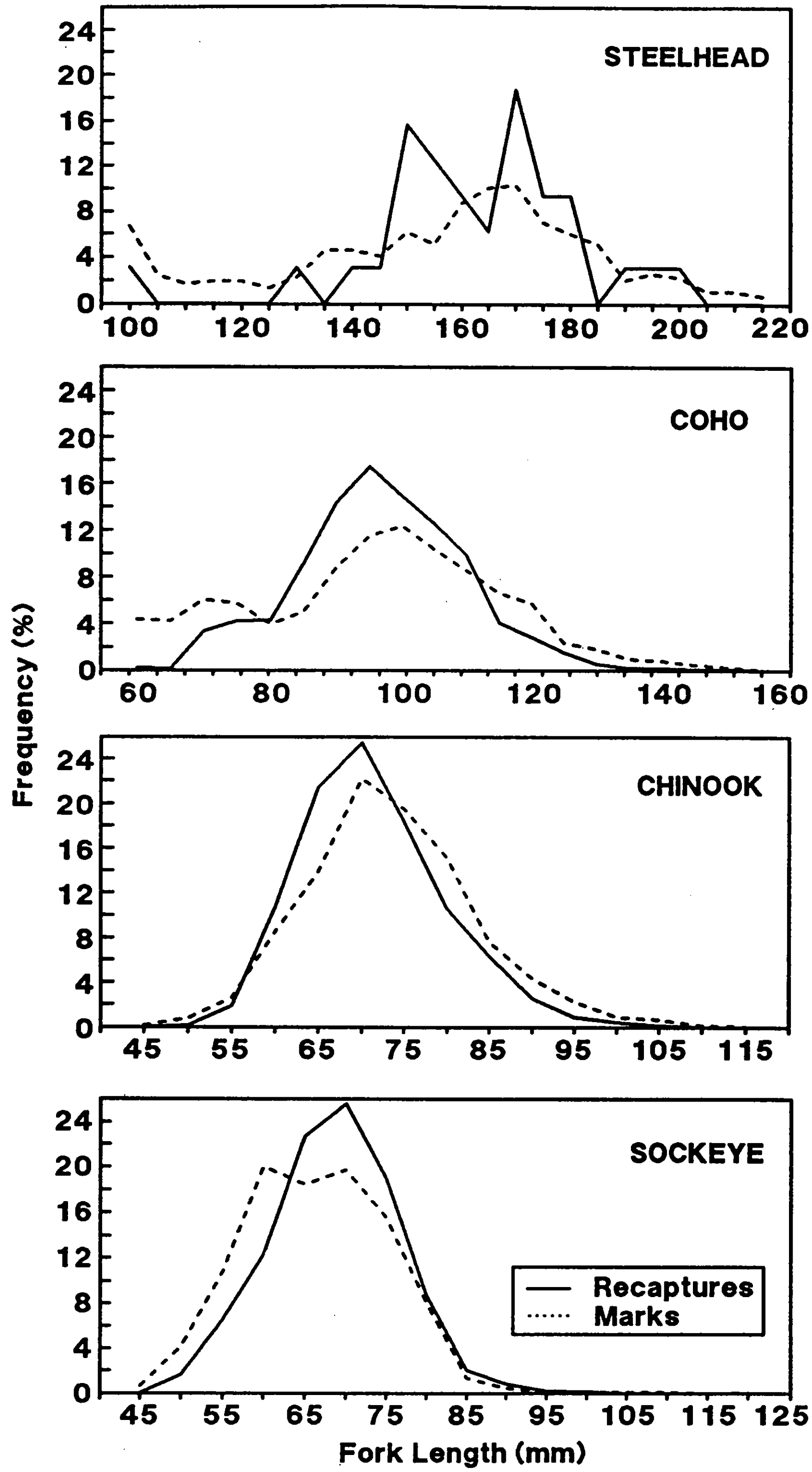

Figure 7.6—Comparison of length frequencies of marked steelhead, coho, chinook, and sockeye smolts released (broken lines) with those subsequently recaptured (solid lines) in the Situk River, April to August 1990.

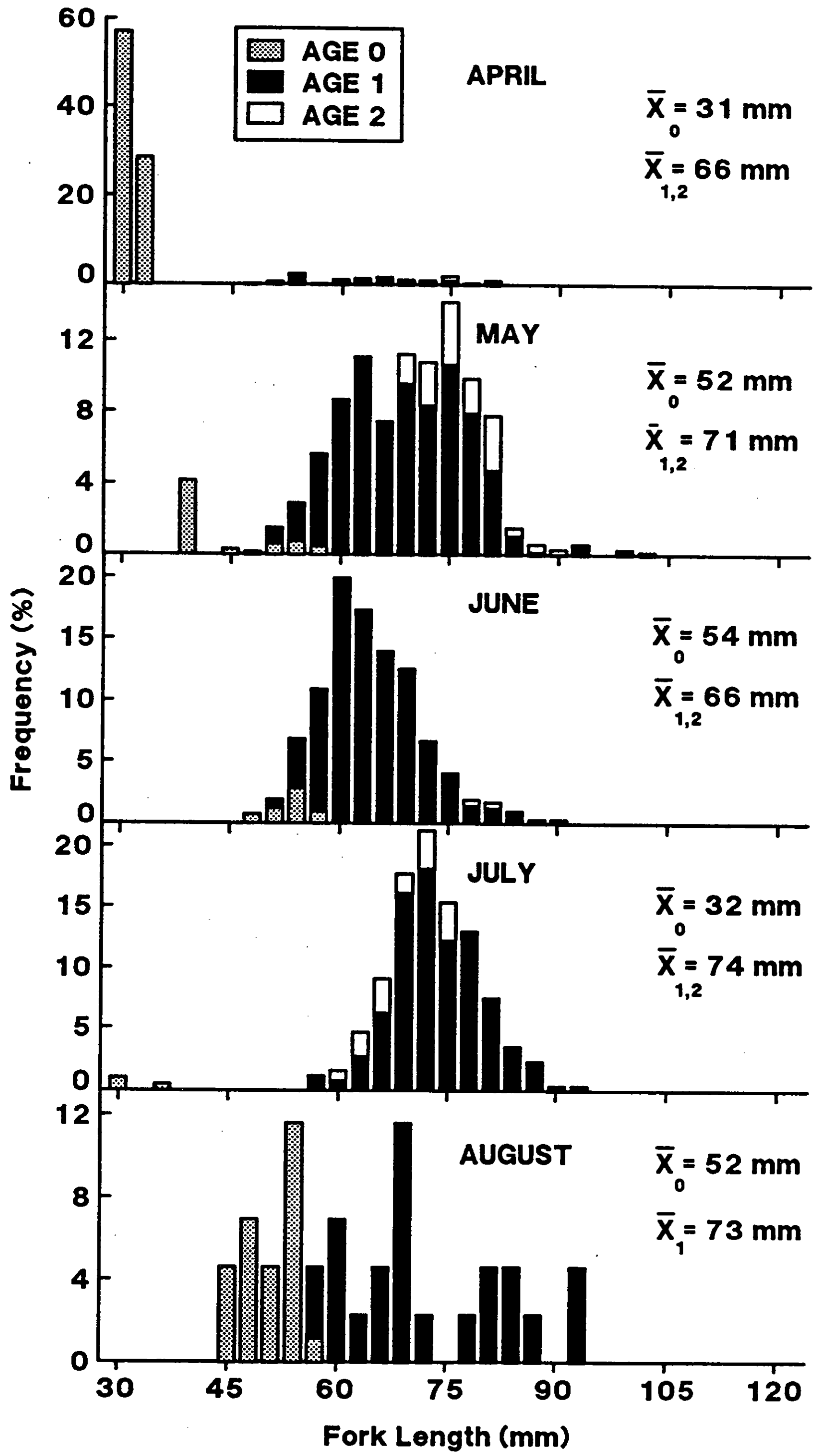

Figure 7.8—Length frequencies and mean length ($\bar{x}$) of juvenile sockeye by age group at the upriver trap in the Situk River, April to August 1990.

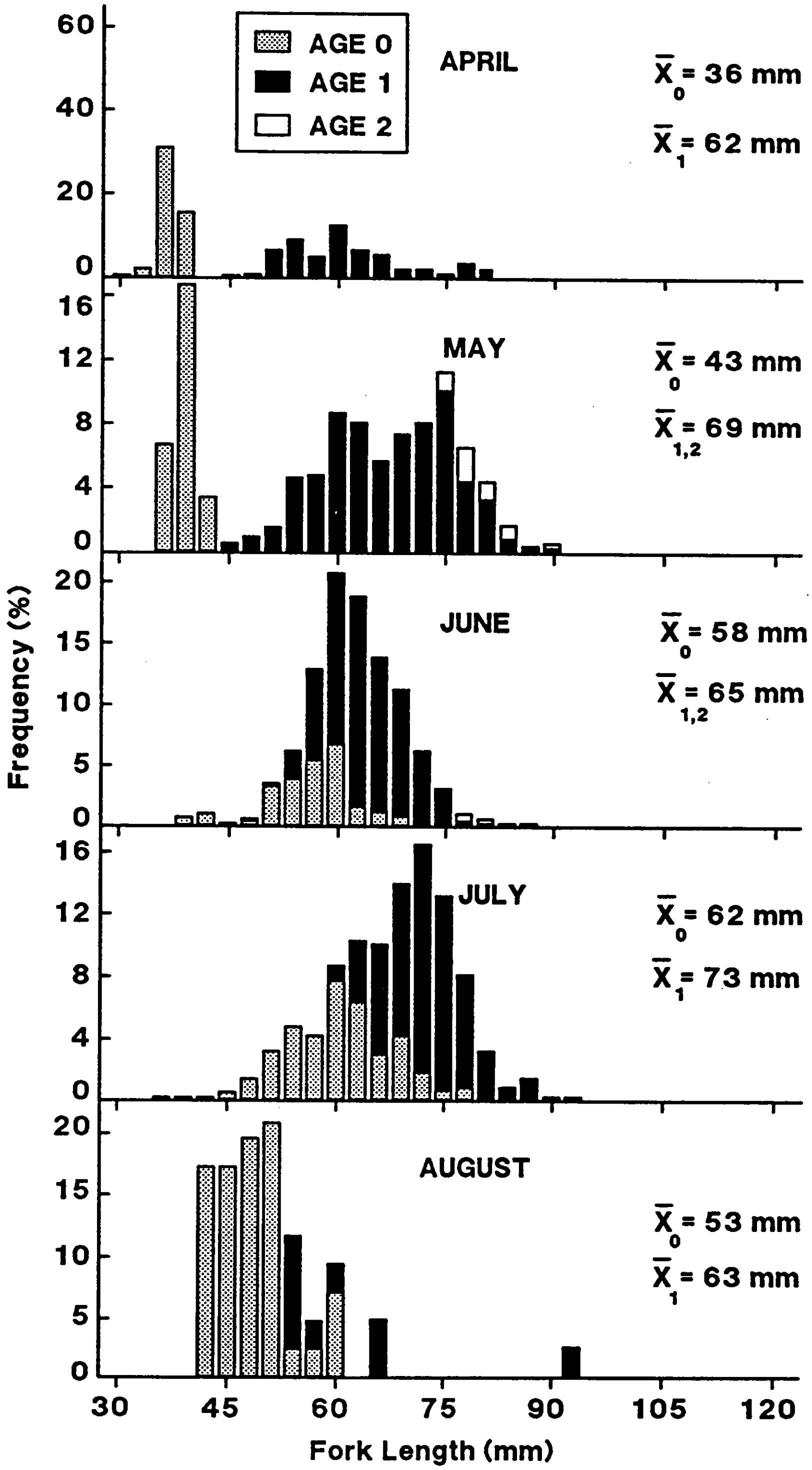

Figure 7.9—Length frequencies and mean length ($\bar{x}$) of juvenile sockeye by age group at the downriver trap in the Situk River, April to August 1990.

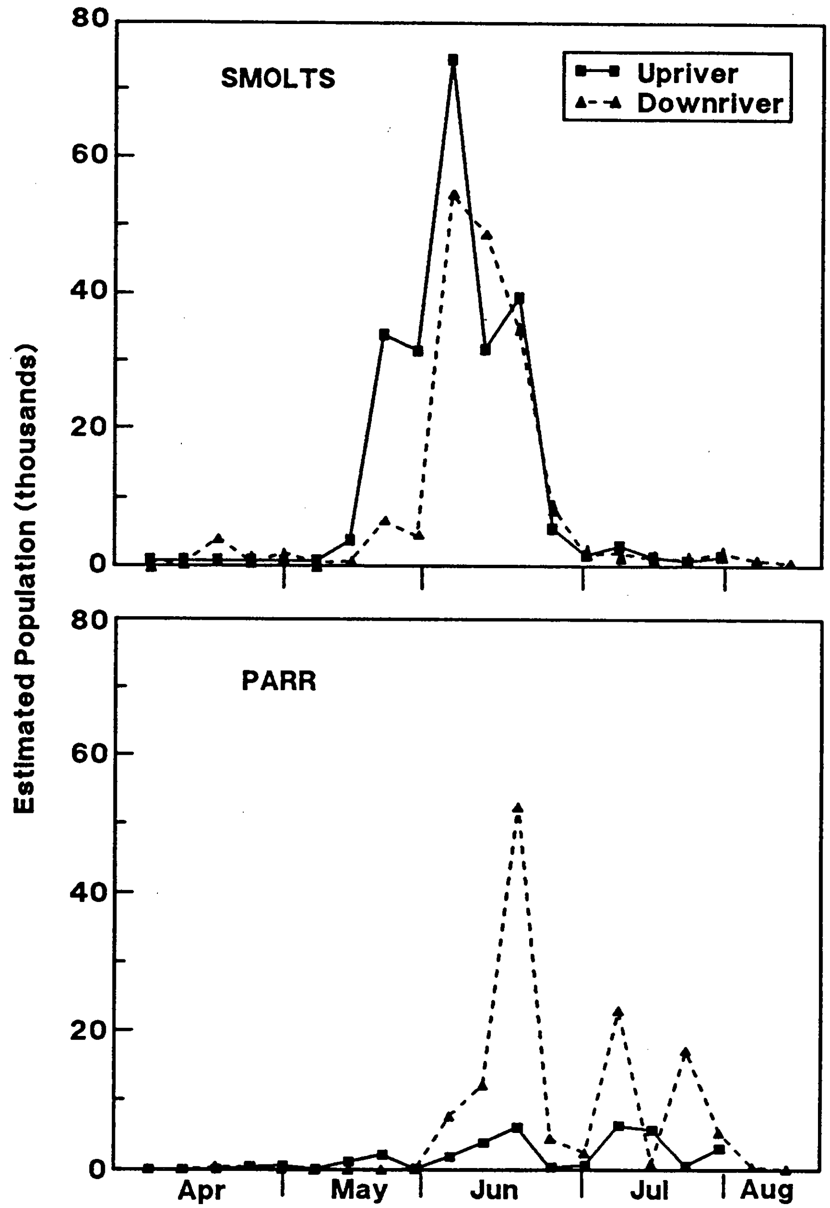

Figure 7.10—Estimated number of coho smolts and parr at upriver and downriver traps on the Situk River, April to August 1990.

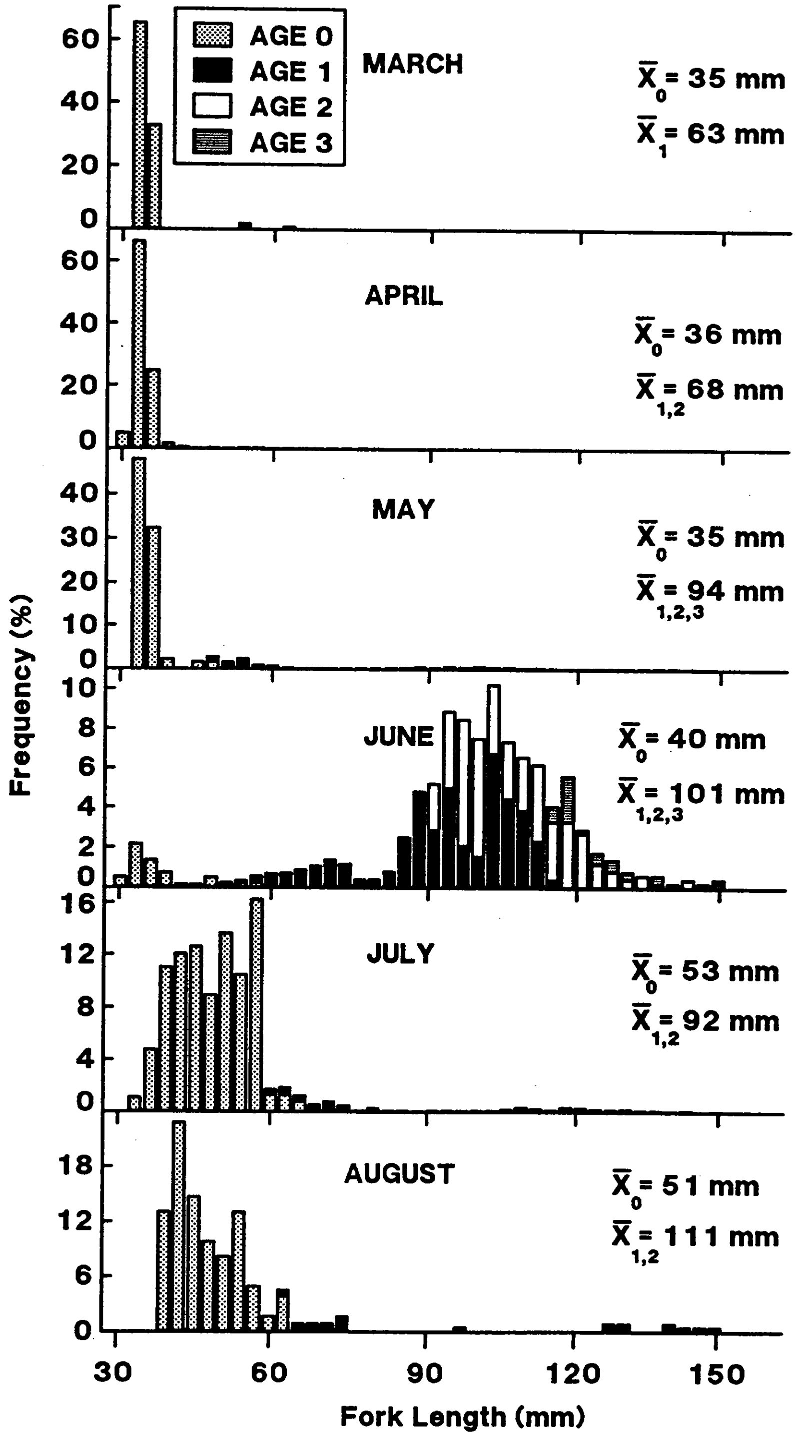

Figure 7.11—Length frequencies and mean length ($\bar{x}$) of juvenile coho by age group at the upriver trap in the Situk River, April to August 1990.

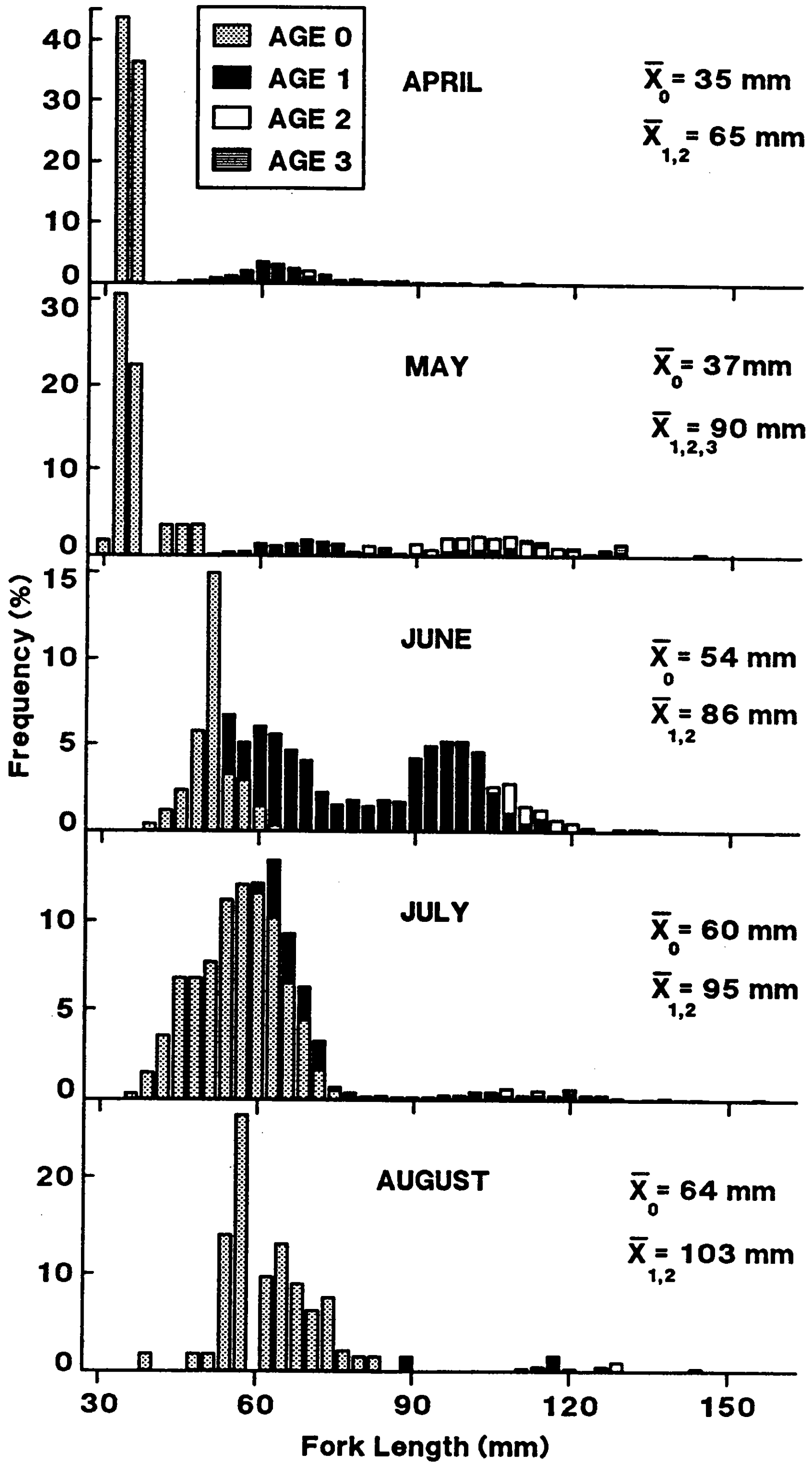

Figure 7.12—Length frequencies and mean length ($\bar{x}$) of juvenile coho by age group at the downriver trap in the Situk River, April to August 1990.

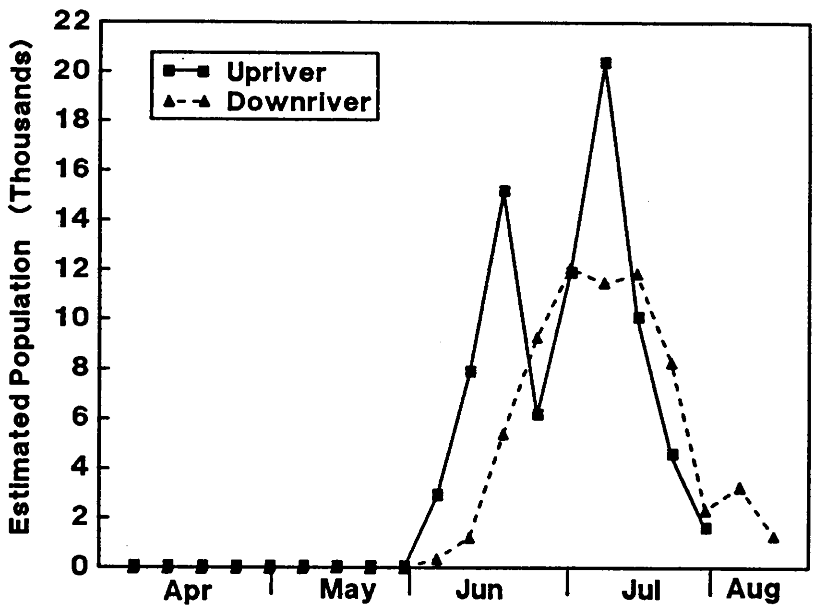

Figure 7.13—Estimated number of chinook smolts at upriver and downriver traps on the Situk River, April to August 1990.

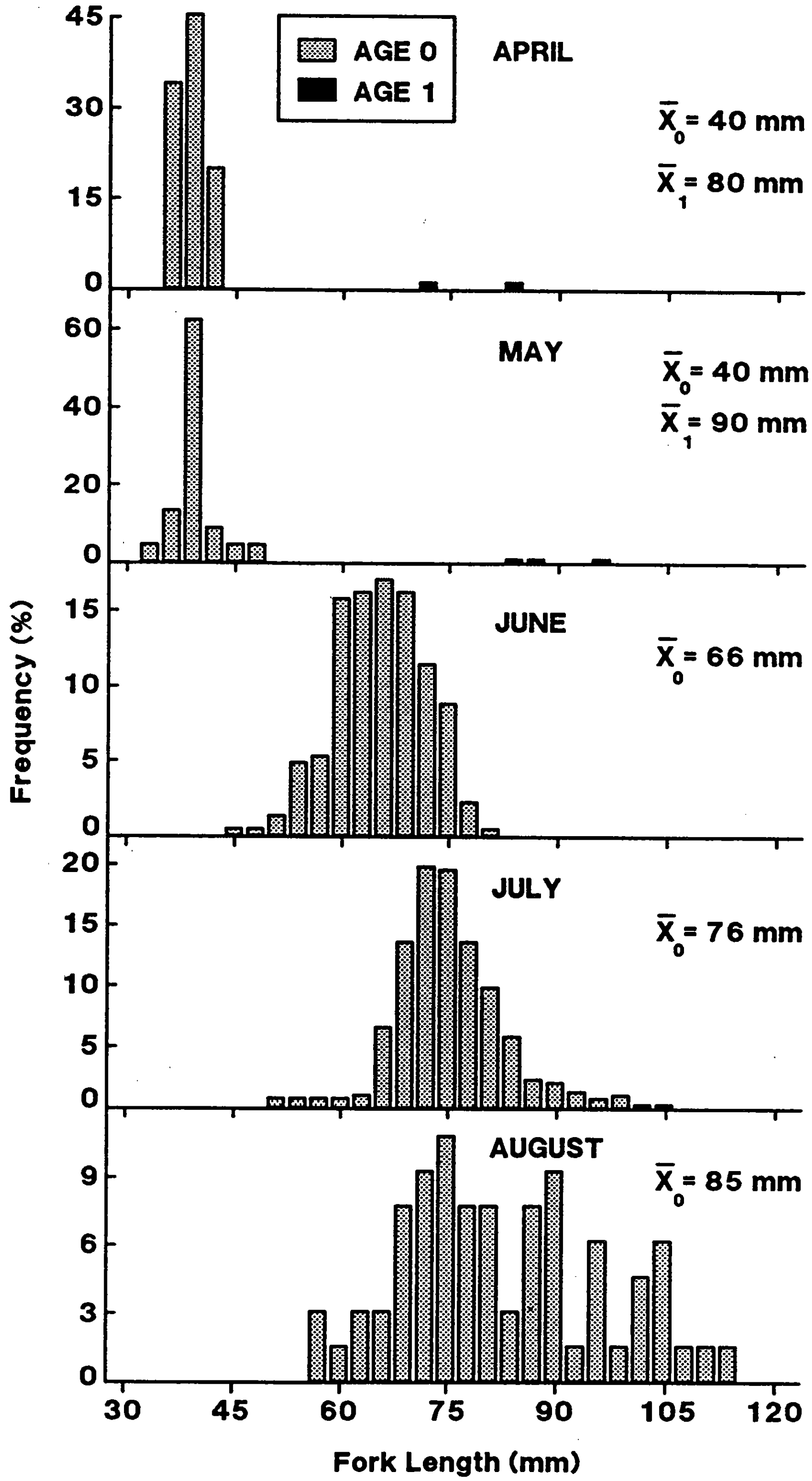

Figure 7.14—Length frequencies and mean length ($\bar{x}$) of juvenile chinook by age group at the upriver trap in the Situk River, April to August 1990.

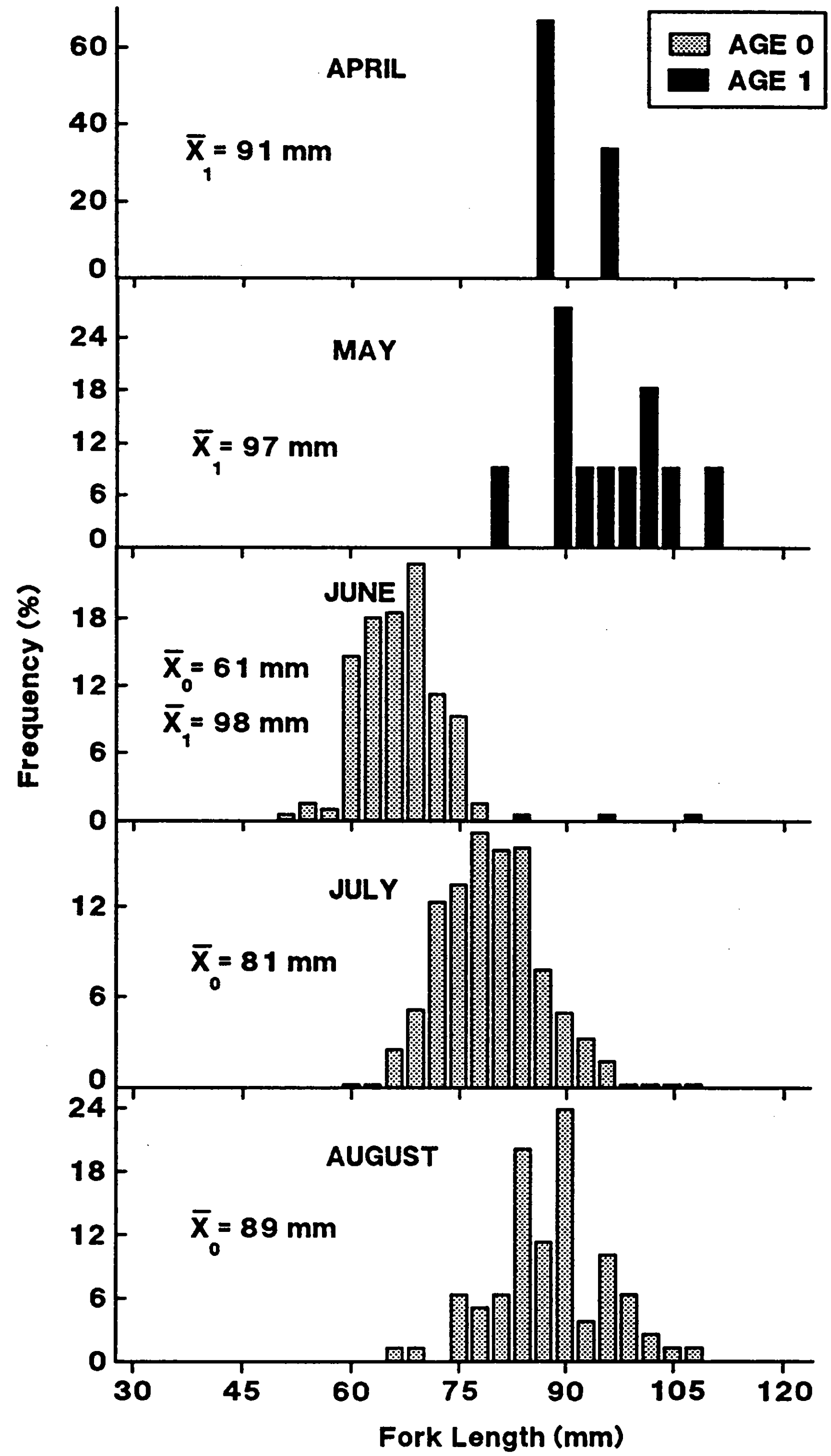

Figure 7.15—Length frequencies and mean length ($\bar{x}$) of juvenile chinook by age group at the downriver trap in the Situk River, April to August 1990.

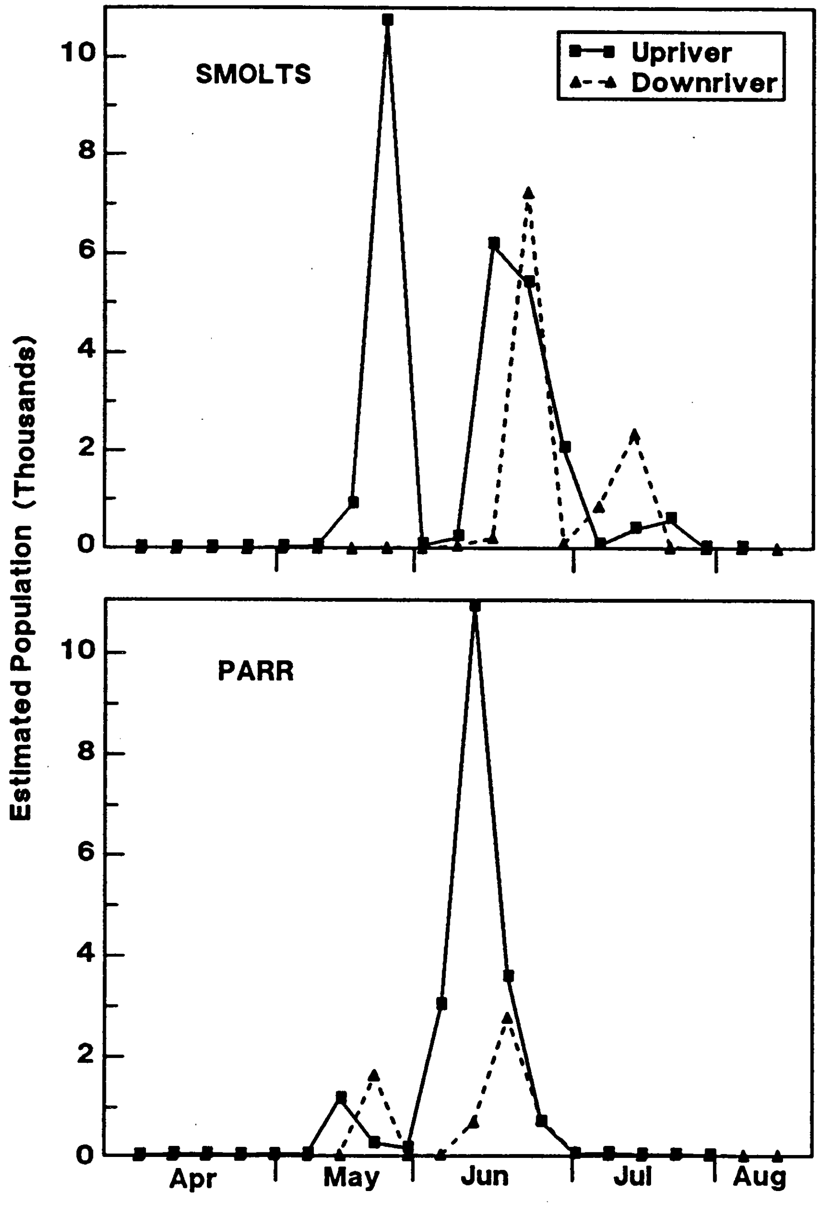

Figure 7.16—Estimated number of steelhead smolts and parr at upriver and downriver traps on the Situk River, April to August 1990.

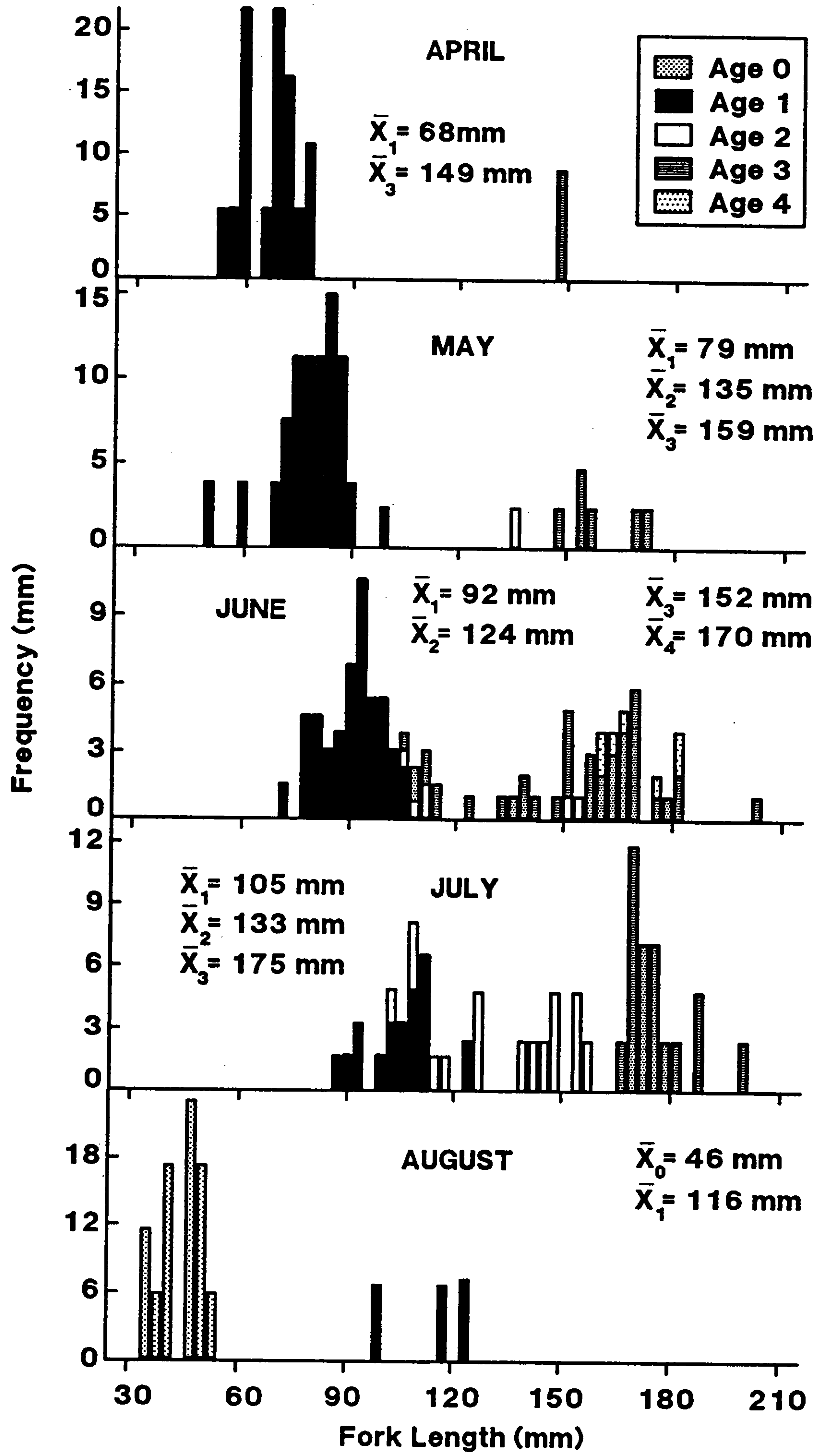

Figure 7.17—Length frequencies and mean length ($\bar{x}$) of juvenile steelhead by age group at the upriver trap in the Situk River, April to August 1990.

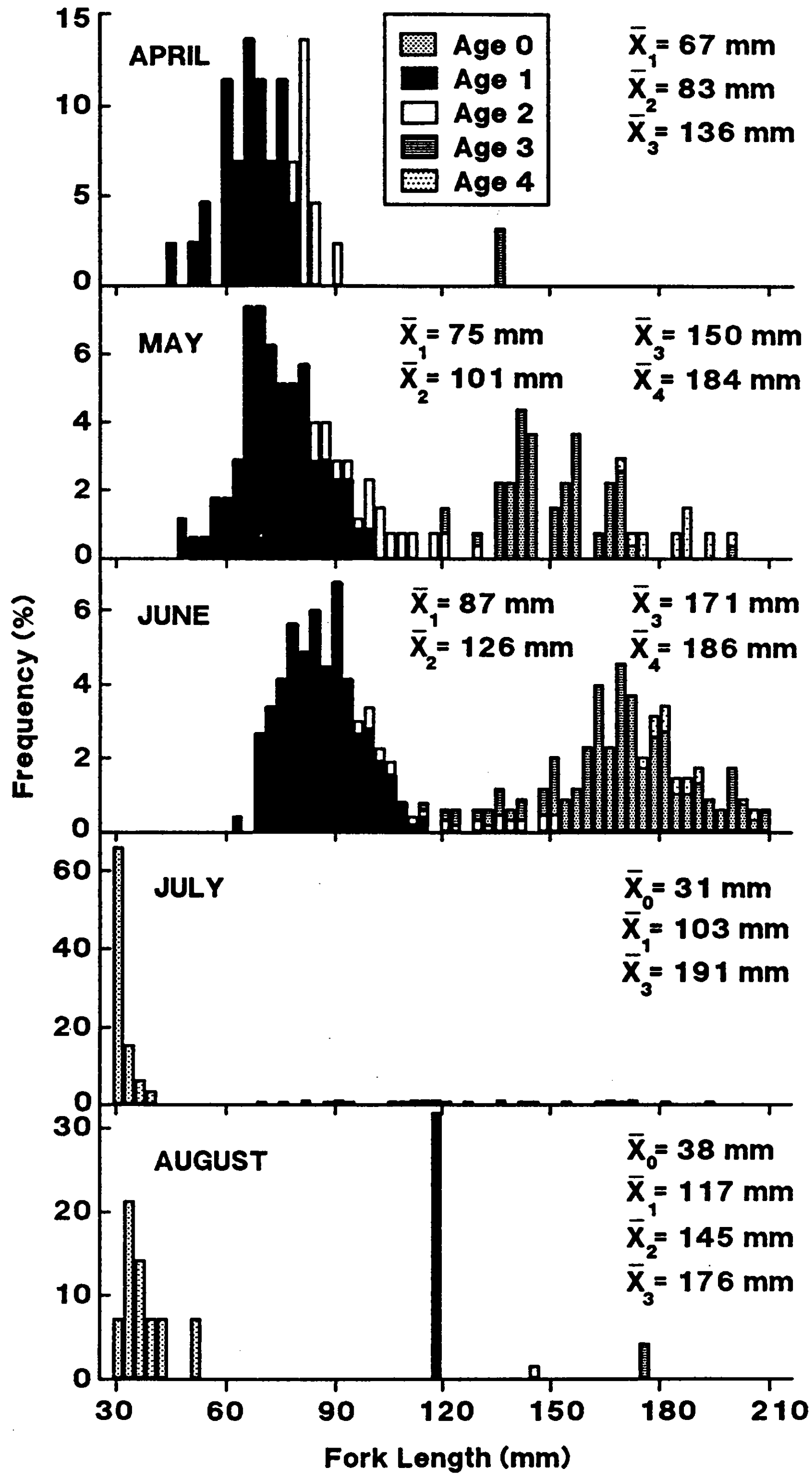

Figure 7.18—Length frequencies and mean length (x̄) of juvenile steelhead by age group at the downriver trap in the Situk River, April to August 1990.

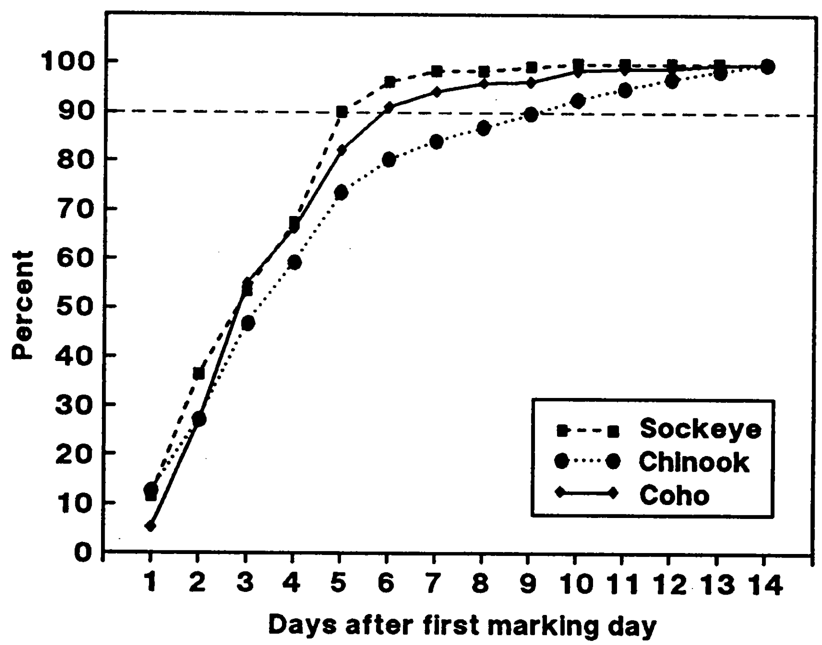

Figure 7.19—Cumulative percentage of recaptures at the downriver trap of marked smolts released at the upriver trap on the Situk River in relation to mean number of days between marking and recapture, April to August 1990.

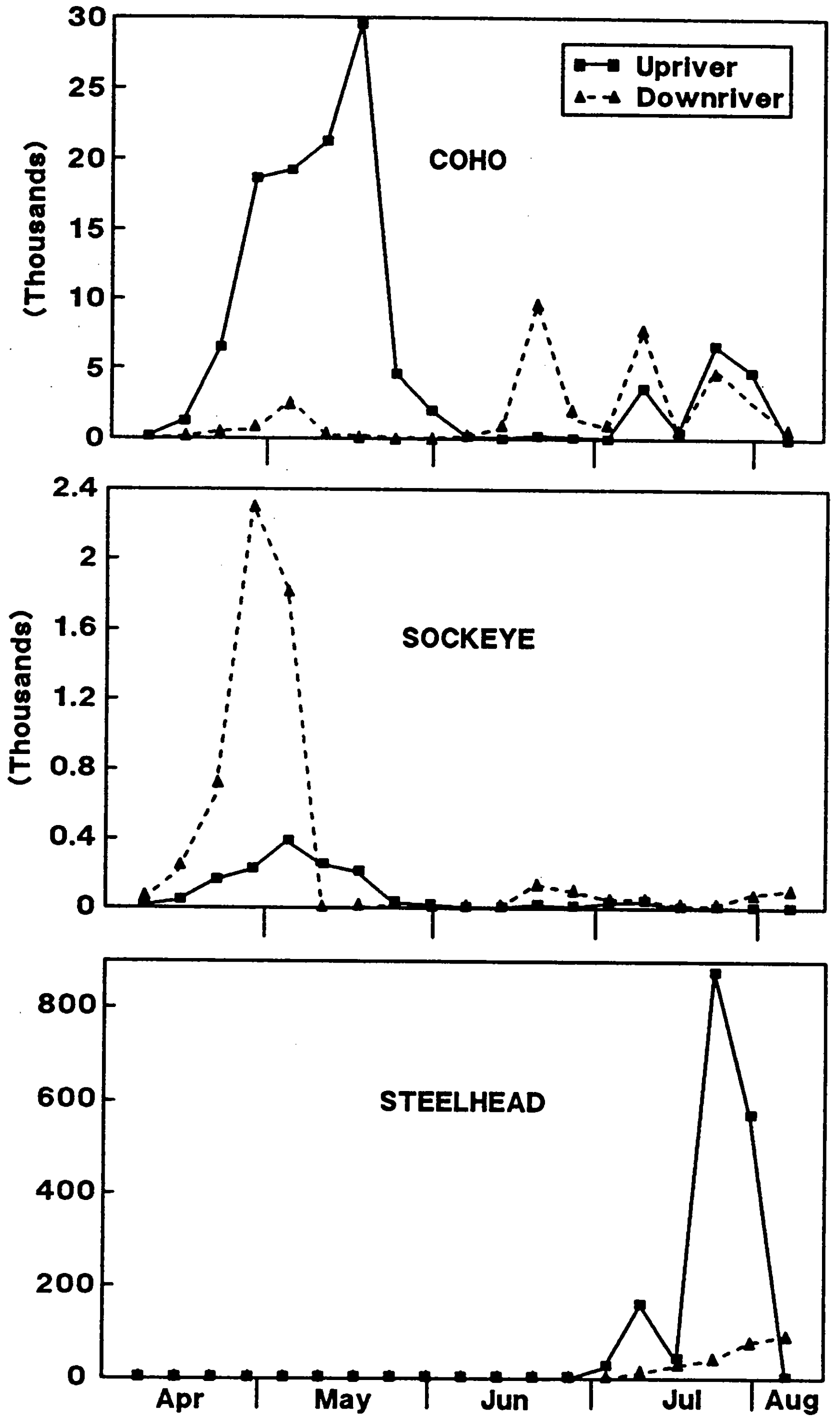

Figure 7.20—Estimated catches of coho, sockeye, and steelhead fry at upriver and downriver traps on the Situk River, April to August 1990.

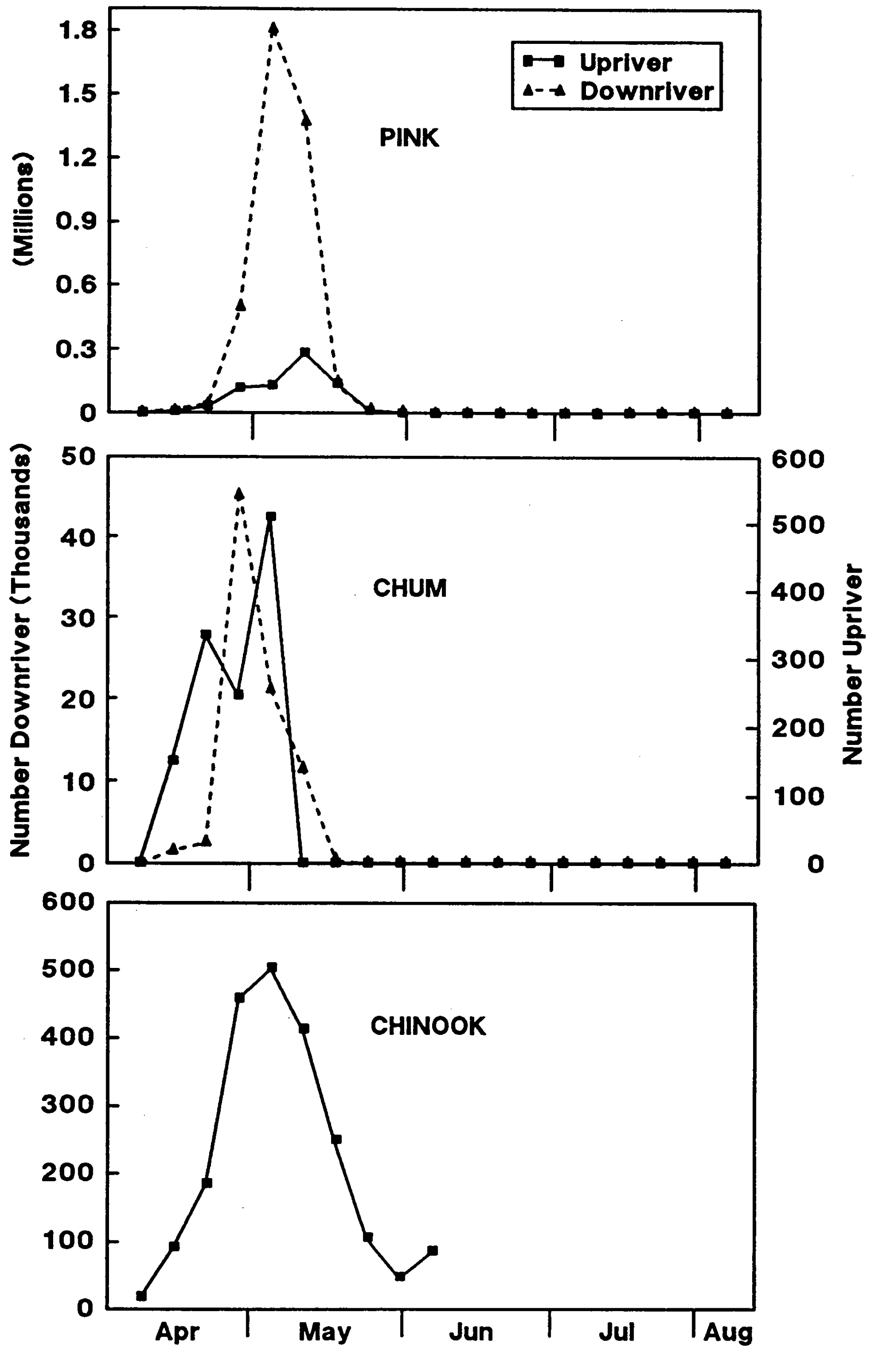

Figure 7.21—Estimated catches of pink, chum, and chinook fry at upriver and downriver traps on the Situk River, April to August 1990.