CALIFORNIA DEPARTMENT OF FISH AND GAME
Environmental Services Division
Stream Flow and Habitat Evaluation Program

Lower American River
EMIGRATION SURVEY
November 1993 - July 1994

by

Bill Snider

and

Robert G. Titus

August 1995

SUMMARY

Two rotary screw traps were used to collect information on emigrating anadromous fishes in the lower American River. Both traps were deployed near river-mile 9 during mid-November 1993. One trap fished continuously into mid-July 1994; the second trap broke down and was removed in early April.

Emigrants of four anadromous fishes were collected: chinook salmon, steelhead trout, Pacific lamprey and American shad. A total of 162,089 salmon emigrants was collected between 13 January and 13 July 1994. Nine wild yearling steelhead were collected between 20 December 1993 and 20 February 1994. Thirty-two young-of-the-year steelhead were collected between 27 March and 26 June 1994, 169 Pacific lamprey emigrants were collected between November and early-July, and seven American shad emigrants were collected in late-November.

Chinook salmon emigrants were described by life stage as fry, parr, silvery parr and smolts. Most of the salmon collected were fry (96.7%). Parr comprised 1.6% of the salmon catch, silvery parr comprised 1.4% and smolts comprised 0.3%. Fry were collected between 13 January and 23 May, parr between 2 February and 20 May, silvery parr between 3 March and 13 July, and smolts between 8 April and 11 June.

Chinook salmon fry ranged from 24 to 45 mm in fork length (FL); the upper size limit was subjectively determined using data from this and a concurrent seine-based sampling of the lower American River. Chinook salmon parr ranged from 45 to 72 mm FL. Silvery parr ranged from 45 to 81 mm FL, and smolt ranged from 58 to 96 mm FL. Fulton's condition factor (*K*) was determined for representatives of each life stage. *K* increased with size for all life stages. We expected *K* values to decrease during smolting, as observed for anadromous salmonids that smolt as yearlings, or older. Since we did not observe a decrease in *K* for young-of-the-year fall-run chinook salmon, it is possible that either the fish identified as smolts had not yet reached the stage of development when condition factor decreases, or this phenomenon does not occur in younger, smaller smolting salmonids.

Timing of chinook salmon emigration was comparable to that observed during 1988 and 1989, but was much earlier than that observed during 1945 through 1947. Increases in turbidity were coincident with early peaks in fry emigration. Flow and temperature were constant for prolonged periods. Changes in these conditions were not associated with changes in emigration.

Trap efficiency was evaluated using marked chinook salmon. The first evaluation was conducted in mid-March and involved marking salmon collected by seine upstream of the trap. The second evaluation was conducted during most of April and involved marking fish collected in the trap. A third evaluation was conducted in late-April and also used salmon collected by seine upstream of the trap. All groups of

fish were released at the same location, 1 km upstream of the trap. The first two evaluations produced comparable recapture rates (< 1%). No salmon were recaptured during the third evaluation.

Comparisons of catch-rates and size-composition between the two traps showed that trap location substantially influenced results.

Downstream environmental conditions conducive to salmon growth and survival prior to ocean entry can strongly influence cohort survival of lower American River chinook salmon. The significance of the downstream environs is clearly supported by the large proportion of "pre-smolt" salmon emigrants. Nearly all emigrants required additional growth and development after leaving the lower American River and before entering the ocean if they were attain a size conducive to survival to adulthood. No salmon emigrants appeared ready to move directly from the natal stream to the ocean.

RECOMMENDATIONS

- The emigration surveys should be continued for at least another three years (through 1997) to define associations between flow, temperature and emigration.

- Efficiency should be routinely determined using both seine caught fish collected upstream of the trap site, and trap caught fish to allow comparisons over time and under different flow conditions.

- The subsample of 50 fish of each species for measurements should be evaluated to determine how it represents size distribution and life stage composition. Preferably, all captured salmonids (up to 1,000 per day per trap) should be measured and characterized as either yolk-sac fry, fry, parr, silvery parr or smolts.

- Other methods of emigration sampling should be used in conjunction with screw traps to determine the potential selectivity of screw traps for smaller fish (i.e., fish less than 100 mm FL). For example, Kodiak trawling should be conducted one or more times per week, as recommendations by Beak Consultants, Inc. (1988).

INTRODUCTION

The timing and life stage composition of emigrating chinook salmon can directly affect cohort survival. Chronic changes in emigration can ultimately affect population persistence (Park 1969). Various abiotic conditions are known to directly and indirectly alter emigration. Some of these conditions can be affected by human alteration of the aquatic environment. Flow change (increases and decreases), flow magnitude, water temperature, turbidity, and habitat availability are some conditions that may be altered and affect emigration.

Fall-run chinook salmon emigration from the lower American River is vulnerable to all such conditions potentially resulting from flow regulation at Folsom Dam. An important objective of the lower American River Technical Advisory Committee to the Alameda County Superior Court is to identify relationships between timing, magnitude and composition of emigrating chinook salmon in the lower American River compared with flow, temperature and other factors potentially controlled by operation of the Folsom Project.

Since emigration can be influenced by man-caused disturbances in environmental conditions, it is essential that the relationships between such conditions and emigration, and ultimately survival to spawning, be understood if management of altered systems is to accommodate both short and long-term survival. Evaluation of the emigrating population can also relate production and survival of chinook salmon to precedent conditions of spawning, incubation and rearing. As such, monitoring fall-run chinook salmon emigration in the lower American River has been part of a comprehensive investigation of the influences of altered flow on chinook salmon habitat requirements.

Our investigation of chinook salmon emigration has several objectives. The primary objective is to identify the general attributes of emigration in the lower American River, including timing, abundance, fish size (life stage) composition and fish condition, and to relate these attributes primarily to flow dependent, environmental conditions. We aim to develop an empirically based model to link emigration with flow through repetitive investigations during years with varying chinook salmon population sizes and/or environmental conditions. Additionally, we plan to develop procedures to quantify or index the size of the emigrating population. Ultimately, we propose to associate production and survival with environmental conditions by combining emigration data with information being collected on spawner population size, numbers and distribution of redds, and the magnitude and dynamics of the rearing phase of chinook salmon precedent to emigration. Emigration evaluations conducted in the lower American River during 1992 and 1993 dealt primarily with overcoming the logistical difficulties innate to such a study (Snider 1992, Fothergill 1994). The 1994 investigation represents the first opportunity to collect data needed to achieve the objectives identified above.

BACKGROUND

Chinook Salmon Emigration

Size of young salmon upon entering the ocean has been directly related to the subsequent abundance of adults (Foerster 1968, Parker 1971, Mathews and Buckley 1976, Ricker 1976, Meyer 1979). As such, ultimate survival of an emigrant depends upon its life stage and condition at the onset of emigration and the suitability of downstream conditions for growth and survival. Pearcy (1992) described the delicate relationship between survival and emigration timing noting that it must occur when food availability and other environmental conditions downstream are compatible with the needs of the emigrant.

Young salmon can achieve optimum size and developmental stage for survival at the proper time through a variety of emigration behaviors. Early emigration by small, recently emerged salmon requires suitable growing and other habitat conditions in the downstream environs if they are to grow to a size accommodating successful ocean entry and ultimate survival to adulthood. Fish that reside in the natal stream for increasing periods require correspondingly less residence time in the estuary to achieve optimum size for ocean entry. However, even the largest emigrating fall-run chinook salmon use the estuary and continue to grow there before entering the ocean (Cannon 1982, Unwin and Lucas 1993). The additional growth likely contributes to a higher survival probability. Conditions required to optimize cohort survival therefore include natal stream conditions that optimize the number and size of emigrants remaining beyond emergence, and optimum estuarine conditions throughout the downstream migration period. Typically, however, optimum habitat conditions do not always occur throughout the salmon’s range. Timing of emigration becomes exceedingly more critical as the period and extent of suitable habitat availability decreases.

Many factors can affect emigration timing and the life stage at which a salmon begins to migrate. Timing of the spawning run, time of spawning, length of incubation, and time of emergence determine when young salmon first enter the natal stream and become subject to emigration stimuli. Once a young salmon leaves the redd it becomes subject to a variety of endogenous and external factors that might affect emigration. Various emigration inducing mechanisms have been theorized (Healey 1991). Early emigration has been associated with flow (Kjelson *et al.* 1981), turbidity (Spaar, 1986), fish density (Reimers 1968), and both sympatric and allopatric fish interactions (Lister and Walker 1966, Stein *et al.* 1972). Flow may directly influence migration by physically forcing the fish to retreat downstream. Young salmon experience a period of reduced swimming ability just before the time of complete yolk sac absorption (Thomas *et al.* 1969). High flow at this time could physically move fish downstream. Flow change could indirectly influence migration by affecting habitat availability, incurring density-dependent mechanisms. Increased turbidity could disorient fish and directly influence emigration or it could emulate reduced habitat availability indirectly influencing migration.

Salmon that remain in the natal stream well beyond emergence reduce risks associated with dependence upon availability of prolonged, suitable conditions downstream. Emigrating at an increasingly larger size increases the potential for successful smolting and likely increases the ability to withstand unfavorable conditions downstream, such as predation, supra optimal temperatures, etc. Later emigration also corresponds to the historical peak in spring runoff that accommodated movement through the system when available flow and temperature conditions were best and when downstream environs were likely most conducive to growth and survival.

Fall-run chinook salmon emigrants are typically characterized based upon the time spent rearing in the natal stream. Emigration usually occurs within the year of emergence and has consistently been described as comprising two distinct size groups (Healey 1991). Healey (1991) describes young-of-the-year fall-run chinook salmon emigrants as either fry or fingerlings, based upon feeding activity and corresponding fish size. He describes fry as recently emerged fish that generally have not started actively feeding. He reports several characteristic sizes for fry: < 40 mm fork length (FL), up to 45 mm FL and as large as 55 mm FL. Fingerlings are fish that have been actively feeding for some time and ranging in size from 50 to 120 mm FL. These latter fish were also described as "fingerling smolt," although it appears that this characterization was based solely on fish size (Kjelson and Brandes 1989).

Anadromous salmonid emigrants have also been characterized as fry, parr, silvery parr, and smolts based upon developmental stages (Titus 1991, Titus and Mosegaard 1992; based primarily on Allan and Ritter 1977). Fry is the short (days) transitional life stage beginning with independence from the yolk sac as the primary source of nutrition (usually coincident with emergence), and ending with dispersal from the redd area. The parr stage starts with dispersal from the redd and complete dependence on exogenous feeding for nutrition, and ends with the onset of smolting. Parr are typically characterized by distinct parr marks and the complete absence of a yolk sac. Silvery parr is the transitional life stage between parr and smolt and is characterized by faint or absent parr marks and a silvery appearance. Smolt, also traditionally defined by size, is the life stage that is morphologically, physiologically, and behaviorally prepared to enter the marine environment. Smolts are characterized by a bright silvery or whitish appearance, deciduous scales, and a reduced condition factor (i.e., a more streamlined form compared with the preceding life stages). Further classification of fall-run chinook salmon emigrants into these four life stages may allow a more precise definition of the relationships between environmental factors and development, migration and ultimate survival to spawning.

Central Valley Fall-run Chinook Salmon Emigration

Emigration has been monitored at various times and locations throughout the

Central Valley (Rutter 1903, Hatton 1940, Hatton and Clark 1942, Erkkila el al. 1950, USFWS 1953, Sasaki 1966, Painter *et al.* 1977, Schaffter 1980). Several pertinent conclusions concerning our objectives, can be drawn from these evaluations:

- Sampling gear can significantly affect the number and size of fish collected, influencing data interpretation and conclusions.

  The early studies used seine bags (Rutter 1903) and fyke traps (Hatton 1940, Hatton and Clark 1942). Later studies included seining, trapping, and trawling (Schaffter 1980). Some studies compared the efficiency of the various collection methods (USFWS 1953, Painter *et al.* 1977, Schaffter 1980). Results of these studies show that riffle-type fyke traps are very inefficient in collecting emigrating salmon. In comparison, round fyke traps collected more fish, however, timing of catch and temporal fish-size distributions from both these trap types were comparable (USFWS 1953, Painter *et al.* 1977). Neither riffle nor round fyke traps were very efficient at collecting large (>100 mm FL) fish.

  Seining can be effective at capturing both small and large fish (20–100+ mm FL) when emigration is associated with the shallower, bank areas of the stream. Schaffter (1980) found seining to become less effective at capturing large fish as their emigration progressed. Apparently, emigration of larger fish was associated with the deeper areas of the channel during the peak of large fish migration.

  Sampling with midwater trawls in the deeper, offshore portion of the channel is more effective collecting larger size groups than seines or traps during all periods of migration (Schaffter 1980). Beak Consultants Inc. (1988) effectively used Kodiak trawls, designed to fish the upper portion of the water column, to sample emigrants in the lower American River. They collected a wide range of chinook sizes and life stages, plus yearling, smolt-sized steelhead emigrants (Beak Consultants Inc. 1988, unpubl. data). Recent use of Kodiak trawls is considered more effective at capturing emigrating salmon than the midwater trawl, primarily as to numbers of fish caught (P. Bratovich, Beak Consultants, Inc., pers. comm.). Rotary screw traps have proven effective in small to mid-sized streams (fourth order streams) (Thedinga et al, 1994, Kennen et al. 1994); their effectiveness in larger streams is unproven.

- Fall-run chinook salmon emigration in the Central Valley, monitored in the lower Sacramento River just upstream of the Delta, exhibited a bimodal size distribution (Schaffter 1980). Fry and fingerling emigrations are generally confined to specific periods; peak of migration may vary substantially within the migration period.
  Fall-run chinook salmon emigrate as fry, from December through May. Peak migration can occur from mid-February through mid-April. Fingerling emigration can begin in late March or early April and typically peaks during May–June (Sasaki 1966, Schaffter 1980).

- Fall-run emigration from Sacramento River tributaries generally paralleled the overall trends monitored in the lower Sacramento River. Much greater variation in peak timing and size ranges was evident.

  Fall-run chinook salmon emigration was monitored in the Feather River between 1969 and 1974 (Painter *et al.* 1977), and in the American River during 1945–1947 (USFWS 1953) and during 1988-1989 (Beak Consultants, Inc., 1988). Results also exhibited a bimodal size distribution. Fry emigration in the Feather River started as early as December and ended as late as May. Peak fry emigration was both polymodal, often apparently associated with an early peak (in January), and unimodal, when the peak was later (mid to late February). Fingerling emigration appeared to begin as early as late February and lasted into June. Peak fingerling emigrations occurred in late-March, April, and May.

  Fry emigration in the American River, between 1945 and 1947, began as early as January, but generally did not increase in numbers until March. Fry emigration peaked in April during all three study periods. Fingerling emigration occurred in late-May and lasted until the trapping ceased, as late as mid-June in 1946. In 1988, sampling did not begin until late April and no fry were caught. In 1989, fry emigration apparently peaked in early March, although sampling did not begin until 1 March. Fingerling emigration peaked in mid-May in both 1988 and 1989.

- Using size alone to identify smolts (≥70 mm) is questionable.

  Decreased condition factor has been successfully used as an indicator of smolting in a variety of salmonids (Folmar and Dickhoff 1980, Wedemeyer *et al.* 1980, Titus and Mosegaard 1992), although its utility in detecting smolting in under yearling chinook salmon is unclear. Condition factor should be lower for smolts than for parr.

  Fulton’s condition factor (*K*) did not decrease in smolt-sized salmon compared with parr-sized salmon caught in the lower American River in 1988 and 1989 (Beak Consultants, Inc., 1988). In fact, *K* appeared to increase with size throughout the size range of captured salmon (<40 mm to >90 mm FL).

- The Sacramento-San Joaquin Delta and estuary are principle rearing areas for emigrating fall-run chinook salmon juveniles (Messersmith 1966, Baracco 1980, Pickard *et al. 1982)*. Important growth occurs in these areas which increases overall survival (Kjelson *et al.* 1981, Cannon 1982).

Other Anadromous Fishes

Anadromous fish species other than chinook salmon that could be potentially captured emigrating from the lower American River include steelhead trout, Pacific lamprey and possibly American shad.

Steelhead Trout Juvenile steelhead in the Central Valley typically emigrate as yearlings (Schaffter 1980). Most steelhead emigrants enter the Delta between February and June, although emigrants have also been observed entering the Delta in the fall. Steelhead appear to rear in the estuary for short periods (Baracco 1980, Pickard *et al*. 1982).

Pacific Lamprey Few data have been reported concerning emigration of Pacific lamprey. In general, larval lamprey spend 3 to 7 years in the natal stream before transforming into “miniature adults” and emigrating. Size at metamorphosis is 140 to 160 mm (Moyle 1976).

American Shad On the East Coast, young shad remain in the natal streams until fall. Typically, by the end of November following hatching, all shad have left the freshwater environs. Hatton (1940) and Stevens (1966) reported similar emigration patterns in the Sacramento-San Joaquin system. Here, young shad are described as continuously moving seaward. Stevens (1966) described shad emigration as beginning immediately after hatching, with young shad first entering the Delta in late June and July and leaving the Delta during September, October and November. Peak migration into the Delta occurred in August and September; peak migration into salt water occurred in November. Juvenile emigrants averaged 46 mm in July and 106 mm in November. Meinz (1979) concluded that season-long rearing did not occur in the Sacramento River upstream of Knights Landing, or in the major tributaries, including the American River.

METHODS

Emigration evaluations are often problematic, especially in large streams (fifth order and larger). Flow during the migration period can be quite high and extremely variable. Debris problems are persistent. Large numbers and the typically small size of the target life stages coupled with a large stream cross section add to the logistical difficulties in meeting study objectives.

The lower American River, downstream from Nimbus Dam to the Sacramento River, is a large, sixth order stream (Figure 1). Flow in this 23-mile long section is regulated by Folsom Dam, operated by the U.S. Bureau of Reclamation (USBR) to provide water supply, flood protection, hydroelectric power production, and to maintain fish and wildlife habitats. Flow during the migration period can range from less than 1,000 cubic feet per second (cfs) to more than 20,000 cfs. Large amounts of debris typically accompany flow changes as increased stage picks up debris along the river's margin. Urban runoff from several flood control drains also introduces a variety of debris into the river.

During the first two years of this investigation (1992 and 1993), we tried various trapping methods at several locations in the lower river (Snider 1992, Fothergill 1994). Initially, fyke traps were fished in shallow, riffle areas near river mile 5, downstream of all known salmonid spawning habitat. The fyke traps fished effectively when flows were constant. However, chronic flow fluctuations required their continual relocation. As such, we abandoned the use of fyke traps in favor of two, 8-ft diameter, pontoon mounted, rotary screw traps.

Pontoon-mounted screw traps can be effectively fished under varying flow conditions if water depth is greater than the radius of the trap (>4 ft) and water velocity through the trap is sufficient to maintain rotation (>1 ft/s). Since the trap floats, it can continue to be fished as flow changes stage. The traps were fished at the same location at flows ranging from 800 cfs to the highest flow encountered (10,000 cfs).

During our early investigations, we identified river mile 9, near the Watt Avenue Bridge, as the downstream-most location where the traps could be fished continuously. Typically, the stage in the Sacramento River at its confluence with the American River increases each spring causing a backwater effect, increasing depth and substantially reducing velocities in the lowermost 5-6 miles of the American River. The trap would not function within this reach due to the low velocities. We identified the Watt Avenue site as the first location upstream of this reach that was greater than 4 ft deep and had velocities greater than 1 ft/s at 500 cfs, the lowest expected flow.

Anchoring the traps was another problem solved during the first two years. The cobble and sand substrate in the river's lower reach prevented the use of stakes or similar devices to anchor the trap. Large concrete blocks were placed just beneath the substrate to provide a secure anchor (Fothergill 1994). The blocks were placed at approximately 40 ft intervals across the channel to allow different anchoring patterns so the trap could be fished at nearly any point across the river (Figure 2).

The two rotary-screw fish traps were fished immediately downstream of the Watt Avenue bridge (Figure 1). The traps were situated on opposite sides of a large, mid-channel bar (Figure 2). When the bar was fully inundated, above approximately 6,000 cfs, flow direction uniformly paralleled the banks. Below 6,000 cfs, the bar diverted flow north through the deeper channel thalweg and south across a riffle into a deep run. One trap, designated the north trap, was situated approximately 40 ft from the north bank, within the thalweg. The second trap (south trap) was fished within the run about 100 feet from the south bank. The channel width at the trap locations ranged from 270 ft at 1,000 cfs to 360 ft at 1,750 cfs, the flow range during the study. The north channel width remained constant during this range of flows (160 ft); the north trap continuously fished about 6% of the north channel. The south channel width ranged from 110 to 200 ft.. The south trap fished 4% to 7% of the channel width as flow ranged from 1,000 to 1,750 cfs.

The north trap was deployed on 19 November 1993 (week -7)[1]; the south trap on 24 November 1993. Both traps were fished weekdays from 30 November 1993 through 31 January 1994. We intended to fish both traps continuously from 1 February 1994 through 30 June 1994. The south trap broke down on 8 April 1994 and was removed from the study. The north trap was fished continuously through 1 July 1994, and then was fished four more days - 8, 9, 12 and 13 July 1994 - before being removed. Unless otherwise noted, the data presented in this report are a combination of information collected from both traps through 7 April 1994, and from the north trap afterwards.

Both traps were serviced each morning. Trapped fish were removed, sorted, and counted by species. Up to 50 of each species were measured (length to the nearest 0.5 mm, and weight to the nearest 0.1 g). Fulton's condition factor, *K*, was calculated as 10^5(weight, g)/(FL, mm)^3. Measured salmonids were also inspected to detect yolk sac presence, and were visually classified as parr, silvery parr, or smolts, to identify their degree of smolting qualitatively. Parr were defined as darkly pigmented fish with characteristic dark, oval-to-round shaped parr marks on their sides. Silvery parr were defined as having faded parr marks and a sufficient accumulation of purines to produce a silvery, but not fully smolted, appearance. Smolts had highly faded parr marks, or lacked them completely, a bright silver or nearly white color, and deciduous scales. Scales were taken from all salmonids >100 mm FL. Other data collected each day included water transparency (secchi depth at the north trap) and effort (hours fished since last service).

Beak Consultants, Inc. provided water temperature data measured with an electronic thermograph deployed near river mile 22. Flow data were obtained from

---

[1] Week 1 corresponds to the week beginning 2 January 1994.

USBR release records for Nimbus Dam. The City of Sacramento provided turbidity data (Nephelometric Turbidity Units, NTU)) collected at the Fairbairn Water Treatment Plant at river mile 7.

Trap Efficiency Evaluation

Trap efficiency evaluations reported by Goldsmith (1994) and Thedinga *et al.* (1994) relied primarily on marking and recapturing trap-caught fish. Thedinga *et al.* (1994) released marked fish from 150 to 1,000 m upstream of their traps with no apparent difference in results. Goldsmith (1994) used seining to augment the number of marked fish when trap-catches were low. Kennen *et al.* (1994) used marked, hatchery fish released 250 m upstream of the trap to compare with results obtained using trap-caught fish. Seelback *et al.* (1985) determined that recapture of trap-caught fish was not significantly affected by the initial trap experience.

We evaluated trap capture efficiency using the two distinct mark-recapture approaches described above. One approach involved collecting fish by seine upstream of the trap location. Captured fish were fin-clipped, held in live cars for several hours, and then released about 1 km upstream of the traps. This approach was used twice. During 17-18 March 1994 (Test 1), 4,038 chinook salmon were captured, marked, and released as described. A subsample of 225 fish was measured and described as sac fry, parr, silvery parr, or smolts. On 27 April 1994 (Test 3), 1,270 chinook salmon were collected, marked and released. A subsample of 190 fish was measured and characterized, as above.

The second method involved marking trap-caught fish and moving them upstream about 1 km of the trap site. Beginning 30 March 1994 through 24 May 1994 (Test 2), all chinook salmon captured in the traps were dye marked, to distinguish them from seine-caught fish, fin clipped, and then released upstream. All marked fish were measured and described, as above. Fish recaptured in the traps were counted, measured, and characterized, as above.

RESULTS

General

Major flow changes (>100 cfs) were infrequent during the study period. They occurred only four times between 1 January 1994 and 1 June 1994 (Figure 3). Flow was nearly constant for prolonged periods between changes. Flow remained near 1,750 cfs during January, was reduced to near 1,500 cfs through March, and was reduced again to near 1,000 cfs through May. Water temperature remained below 50° F through 1 March 1994, and then steadily increased through June (Figure 4). Water temperature exceeded 60° F on 26 June, and 65° F on 16 July. The few rain events during the study period did not change flow or temperature within the study reach. Turbidity did coincidently change with these rain events. Peak changes in turbidity, (> 2 NTU), occurred in late January and during early to mid-February (Figure 5).

Twenty-two fish species were collected in the rotary screw traps (Table 1). Most of the fish caught were chinook salmon fry (total cumulative catch = 156,740) and fingerling (5,349), metamorphosed juvenile lamprey (189), juvenile squawfish (173), Japanese smelt (102) and adult American shad (81).

Chinook Salmon

Chinook salmon emigration spanned 27 weeks, from week 2, beginning 9 January 1994, through week 28, ending 16 July 1994 (Table 2). The highest daily catch occurred 23 February (14,887 fish, 677 fish/h) (Figures 6 and 7) which also corresponded with the highest weekly catch that occurred during week 8, beginning 20 February (56,608 fish, 242 fish/h) (Figures 8 and 9).

Salmon were caught during every week from week 2 (beginning 9 January) through week 25 (ending 25 June); no salmon were caught during weeks 26 and 27 (Figure 8). Catch-rate for week 2 (9 January) was 0.17 fish/h (Figure 9), increasing to 241.91 fish/h during week 8 (20 February) and decreasing nearly to zero during week 24 (12 June).

Salmon ranged in size from 24 to 96 mm FL (Table 2). Weekly mean size ranged from 36 to 83 mm FL (Table 2, Figure 10). Most (96%) of the fish collected through week 11 (20 March) were <40 mm FL (Figure 11); mean size was essentially constant ranging from 36-39 mm FL (Table 2, Figure 12). Mean weekly size gradually increased from week 12 through week 17 from about 39 to 69 mm (5 mm/week), while catch-rate declined from more than 10 fish/h to near 3 fish/h. Through the remainder of the study period, mean weekly size continued to increase from 70+ mm FL, while weekly catch-rate remained below 1 fish/h and continued to decline.

TABLE 1. Summary of fish species collected during the lower American River emigration survey, 11 November 1993 through 7 July 1994. The species are listed in alphabetical order, by common name.

Species (size)	Sample Period (Beginning date)													
	Nov 14	Jan 9	Jan 16	Jan 30	Feb 13	Feb 27	Mar 13	Mar 27	Apr 10	Apr 24	May 8	May 22	Jun 12	Jun 26
American shad (<75 mm)	7													
American shad (>300 mm)											1	27	29	24
Black bullhead (>150 mm)											1			
Bluegill (50-150 mm)	15									1			1	
Chinook salmon (≤50 mm)		26	6959	42971	80920	22501	4188	445	457	2	0	0	0	0
Chinook salmon (51-100 mm)				34	73	232	1047	976	409	622	142	71	13	1
Gambusia (<40 mm)				6									1	
Golden shiner (75-150 mm)	1		1	1						1	1			
Goldfish (<50 mm)							1							
Green sunfish (75-150 mm)	4													
Hardhead (≤100 mm)	29								2		2		2	
Hardhead (>100 mm)												1		1
Hitch (75-150 mm)				1										
Japanese smelt (≤75 mm)	2			3	13	16	17	3	1					1
Japanese smelt (>75 mm)	1		2	14	6	12	5	1		1				
Lamprey ammocoete	7		1	19	4	3	3	7		1	1	1		1
Lamprey subadult (<200 mm)	7		1	24	7	6	11	7	18	13	7	48	18	2
Lamprey adult(>300 mm)				1			2	9	21	14	13	4	2	
Largemouth bass (<75 mm)												4		1
Redear sunfish (<150 mm)	4													1

Table 1. (Continued)

Species (size)	Sample Period (Beginning date)													
	Nov 14	Jan 9	Jan 16	Jan 30	Feb 13	Feb 27	Mar 13	Mar 27	Apr 10	Apr 24	May 8	May 22	Jun 12	Jun 26
Sculpin (<50 mm)				1										
Sculpin (50-100 mm)	6		6	18	6	7	6	12	6	2	3	1		
Sculpin (>100 mm)					1			1						
Splittail (<50 mm)	1													
Squawfish (≤50 mm)	47		1				1	18	4	1		2	1	
Squawfish (50-150 mm)	11		1	2			2	5	11	5	8	3	10	3
Squawfish (>300 mm)								1						
Steelhead (<50 mm)								1	2					
Steelhead (50-100 mm)							1	1	7	1				
Steelhead (100-300 mm)	1		7	1		1[2]		1[1]						
Steelhead (>300 mm)			1	1						1				
Sucker (<50 mm)	8			1		1	1	1					12	5
Sucker (50-150 m)	3			6	1	1		2	3					1
Sucker (>300 mm)						1				1				
Threadfin shad (≤50 mm)	2													
Threadfin shad (>50 mm)	1						1				1			
Tule perch (<100 mm)	11							1					1	
White catfish (≤100 mm)														1
White catfish (>100 mm)													1	

---

[2] Hatchery fish

Table 2. Summary of chinook salmon catch statistics, lower American River emigration survey, January-July 1994.

WEEK	BEGINNING DATE	TOTAL WEEKLY CATCH	CATCH /HOUR	SIZE STATISTICS (FL in mm)			
				Mean	Minimum	Maximum	Standard deviation
1	2 Jan 1994	0	0.00	-	-	-	-
2	9 Jan 1994	25	0.17	36.2	32	38	1.4
3	16 Jan 1994	407	2.79	35.8	31	40	1.54
4	23 Jan 1994	6,552	33.95	36.2	30	43	1.44
5	30 Jan 1994	4,905	17.09	36.6	30	45	1.99
6	6 Feb 1994	38,101	113.73	36.8	30	67	1.96
7	13 Feb 1994	24,385	72.36	36.8	24	52	2.08
8	20 Feb 1994	56,608	241.91	36.7	31	50	1.86
9	27 Feb 1994	19,118	57.24	36.6	30	74	2.62
10	6 Mar 1994	3,615	10.76	36.8	29	60	3.79
11	13 Mar 1994	1,791	5.35	38.9	31	66	6.84
12	20 Mar 1994	3,444	10.22	44.8	31	75	9.14
13	27 Mar 1994	824	2.47	51.6	33	76	8.68
14	3 Apr 1994	597	2.27	56.9	35	78	8.17
15	10 Apr 1994	554	3.30	61.7	41	81	8.21
16	17 Apr 1994	312	1.85	61.0	37	80	8.77
17	24 Apr 1994	491	3.56	69.0	46	92	6.78
18	1 May 1994	133	0.80	70.5	55	91	6.11
19	8 May 1994	93	0.65	71.0	60	81	4.52
20	15 May 1994	49	0.30	73.2	53	85	7.93
21	22 May 1994	17	0.35	75.7	73	77	1.54
22	29 May 1994	29	0.40	74.9	67	88	4.91
23	5 Jun 1994	25	0.18	73.7	62	85	5.88
24	12 Jun 1994	4	0.02	83.3	76	94	7.72
25	19 Jun 1994	9	0.05	79.3	68	96	9.92
26	26 Jun 1994	0	0.00	-	-	-	-
27	3 Jul 1994	0	0.00	-	-	-	-
28	10 Jul 1994	1	.02	85	85	85	

The catch (and catch-rate[3]) distribution was polymodal (Figures 6 and 7). Five major peak-migration events[4] occurred between 25 January and 29 March 1994, and two minor peak-migration events occurred after that. Major peak events occurred during week 4 (peak = 2,310 fish on 25 January), week 6 (peak = 9,314 fish on 9 February), weeks 7 through 8 (peak = 14,887 fish on 23 February), week 9 (peak = 7,689 fish on 28 February), and week 12 (peak = 960 fish on 26 March). Minor peak events occurred during week 15 (peak = 170 fish on 13 April) and week 17 (peak = 165 fish on 27 April). Salmon numbers were essentially an order-of-magnitude greater during major versus minor peak events.

The mean size of fish caught during each major peak event was less than 40 mm FL. The mean size of fish caught during each minor peak event was greater than 60 mm FL.

Three of the major peak events were coincident with substantial increases in turbidity (Figure 13). Turbidity increases of more than 2 NTU, typically from 1 to >3 NTU, immediately preceded the first three peak events (weeks 4, 6 and 7). Flow and temperature were essentially constant during all peak events (Figures 3 and 4).

Life Stage Distribution

Our attempt to classify emigrating chinook salmon by life stage, based strictly upon the characteristics described above (i.e., without size criteria), resulted in combining fry and parr into the parr classification. Some fish classified as parr were much shorter than 40 mm FL. This length is conservative for use as a fry size criterion according to Healey (1991). Length data for yolk-sac fry collected in this study strongly supports 40 mm FL as a maximum fry size criterion (Figure 14). Data collected during the 1994 fish community survey shown that salmon up to 45 mm FL were recently emerged chinook salmon (Snider and Titus 1995). We therefore, modified the parr data by reclassifying all fish less than 45 mm FL as fry.

Adjusting the fry and parr classifications based upon this size criterion resulted in a near normal, fry length-frequency distribution (Figure 15). The parr length-frequency distribution was predictably truncated at 45 mm FL (Figure 16). The resultant parr distribution is positively skewed suggesting that some fish less than 45 mm FL were parr. Any change in the fry size criterion would simply maintain a truncated parr distribution. Undoubtedly, the 40–50 mm FL group included both parr and fry. Since there were few fish affected by the reclassification, we were satisfied that the change was appropriate and would have little if any influence on our subsequent analysis of life stage distribution.

The size range for fry was 24–52 mm FL (Figure 15). The parr size range was from the assigned minimum 45 mm to 72 mm FL (Figure 16). The size range was

---

[3] Catch rate reflected catch since effort was essentially equal throughout the study.

[4] A 5-fold or greater increase in catch and a peak daily catch of near 1,000 fish or more.

45–81 mm FL for silvery parr (Figure 17), and 58–96 mm FL for smolts (Figure 18). Overall, mean size increased with time for each life stage. The largest representative of each life stage was caught during the latter portion of their respective capture period (Figures 19-22).

The size distribution for each life stage was distinct ($p<0.05$). We evaluated the difference between the fry and parr size distributions using the distributions defined in part by size criteria and based upon the unaltered field data. The difference between the fry and parr size distributions were significant ($p<0.05$) for both data sets.

Fry were greatest in abundance, comprising 96.7% of the total salmon catch. Parr comprised 1.6% of the total catch, silvery parr comprised 1.4%, and smolt comprised 0.3%.

Fry were caught from 13 January (week 2) through 23 May (week 21) (Figure 23; see also Appendix A). The peak of fry migration occurred during week 8 (20 February). Nearly all fry (98%) were caught by 27 March (week 13) (Figure 24).

Parr were caught from 2 February (week 5) through 20 May (week 20) (Figure 25). The peak of parr migration was during the week of 20 March (week 12). Most parr (98%) were captured by 22 April (week 16) (Figure 26).

Silvery parr were caught from 3 March (week 9) through the end of the study (Figure 27). Silvery parr migration did not exhibit a distinct peak. The majority of emigration occurred between weeks 12 and 17. Most silvery parr (98%) were caught by 11 May (week 19) (Figure 28).

Smolts were caught from 8 April (week 14) through 23 June (week 25) (Figure 29). Smolt migration peaked during the week of 24 April (week 17). Most smolts (97%) were caught by 11 June (week 23) (Figure 30).

Condition Factor

Condition factor was quite variable and was apparently dependent on life stage (Figure 31). Variation in *K* was especially great for fry and parr and was least variable for silvery parr and smolts (Table 3). Small errors in weight and length measurements could produce significant variability due to the small sizes associated with fry and parr. Variability could also be due to the significant change in weight versus length that occurs during the transition from yolk-sac fry to actively feeding fry. No attempt was made to delete outliers.

TABLE 3. Condition factor (*K*) statistics by life stage for chinook salmon collected during the lower American River emigration survey, January–July 1994.

K Factor	Fry	Parr	Silvery Parr	Smolt
Minimum	0.2	0.12	0.5	0.8
Maximum	2.3	2.4	1.64	1.86
Mean	0.79	1.01	1.07	1.14
Coefficient of variation	28%	18%	11%	11%
Standard deviation	0.22	0.18	0.12	0.13
Sample size	4,412	817	991	150

Mean *K* increased with each life stage and was greatest for smolts (Table 3, Figure 31). Regressing *K* on FL, using fish with FL > 45 mm to remove excessive heteroscedasticity introduced by the inclusion of yolk-sac fry and fry, showed *K* to increase with length (Figure 32). The slope was significantly different from zero (t-test, p=0.0001). Regressing *K* on FL for salmon classified as smolt showed no significant change in *K* versus length for salmon classified as smolts (Figure 33); the slope was not significantly different from zero (p>0.1).

Trap Efficiency Evaluation

Trap efficiencies of 0.0%, 0.84% and 0.94% were measured during the three tests conducted between 17 March and 27 April 1994 (Table 4).

TABLE 4. Trap efficiency test summaries, lower American River emigration study, January - July 1994.

Test	Period	Efficiency	Marked		Recaptured		Trap Catch	
			N	Mean FL (Range)	N	Mean FL (Range)	N	Mean FL (Range)
1	March 17-24	0.84	4038	38 31-53	34	37 32-50	570	40 31-66
2	March 30 April 27	0.94	1509	62 35-92	15	62 44-75	na	na
3	April 27-30	0	1270	45 32-64	0	-	290	70 46-92

Test 1 Thirty-four of the 4,038 (0.84%) fish marked and released were recaptured. Eighty-two percent of the recaptured fish were caught during the first two days of the test (18 and 19 March 1994). The last recaptured fish was taken 24 March 1994. The size distributions of marked and recaptured fish were not significantly different (Figure 34) (two-tailed *t*-test, $p>0.05$). However, there was a significant difference between the size distribution of marked and trap-caught fish ($p<0.01$) and between recaptured and trap-caught fish ($p<0.04$). Trap-caught fish were all those captured in the trap during the first three days of the recapture period, when more than 94% of recaptures were made.

Test 2 Fifteen of the 1,589 (0.94%) fish trapped, marked, and released back upstream were captured in the trap again. There was no significant difference between the size distributions of marked and recaptured fish (Figure 35) (two-tailed *t*-test, $p>0.96$).

Test 3 No marked fish were recaptured during Test 3. Mean size of marked (seine caught) fish was 45 mm FL (range: 32-64 mm FL) compared with a mean size of 70 mm FL for the 290 chinook salmon caught in the trap during the three days following release of the 1,270 marked salmon (Table 4). The marked fish were significantly smaller than the trap caught fish (two-tailed t-test, $p<0.001$: Figure 36).

Trap Comparison

During the period both traps fished concurrently, 1 January through 6 April, performance of the two traps was notably different. The north trap consistently caught more fish (Figure 37) (paired t-test, $p<0.05$). Size distribution was not different ($p>0.05$) through week 9 when most of the fish caught were fry, i.e., when variation in fish size was low. The size distribution of the catch in each trap differed significantly ($p<0.05$) beginning in week 10, when parr began to appear in the catch and fry size was more variable (Figure 38). Similarly, the first occurrence of parr, silvery parr, and smolts was consistently several days earlier in the north trap.

Steelhead

Juvenile steelhead captured in the screw traps represented three different groups: young-of-the-year (YOY; <150 mm FL), hatchery-produced subadults (150-349 mm FL, eroded fins), and in-river produced subadults (150-349 mm FL, non-eroded fins) (Table 5). Two adult-sized steelhead were also captured ($\geq$350 mm FL).

YOY steelhead were periodically captured between week 13 (27 March 1994) and week 26 (26 June 1994) (Figure 39). Thirty-one YOY were captured. Their mean size increased steadily from 27 mm FL in week 13 to more than 100 mm FL by week 23 (5 June 1994) (Figure 40).

In-river produced subadult steelhead ($n = 9$) were caught predominantly during the early part of the sampling period, from week -5 (2 December 1993) through week 7 (13 February 1994) (Figure 39). Fish size ranged from 210 to 304 mm FL. Hatchery-produced subadult steelhead ($n = 3$) were captured slightly later, from week 6 through 15 (6 February 1994 through 10 April 1994) (Figure 39). Fish size ranged from 241 to 296 mm FL.

All YOY steelhead were collected in the north trap. Subadult and adult catches were evenly distributed between both traps. The north trap caught seven subadults and one adult; the south trap caught five subadults and one adult.

TABLE 5. Summary of steelhead catch statistics, lower American River emigration survey, November 1993 - July 1994.

WEEK	BEGINNING DATE	CATCH STATISTICS			
		Young-of-the-year		Sub-adult (200-349 mm FL)	
		Count	FL (mm) mean (range)	Count	FL (mm) mean (range)
-5	02 Dec 1993	0		1	223
2	9 Jan 1994	0			
3	16 Jan 1994	0			
4	23 Jan 1994	0		6	235 (210-265)
5	30 Jan 1994	0		1	287
6	6 Feb 1994	0		1[4]	241
7	13 Feb 1994	0		1	304
8	20 Feb 1994	0		0	
9	27 Feb 1994	0		0	
10	6 Mar 1994	0		1[4]	296
11	13 Mar 1994	0		0	
12	20 Mar 1994	0		0	
13	27 Mar 1994	1	27	0	
14	3 Apr 1994	0		0	
15	10 Apr 1994	1	43	1[4]	276
16	17 Apr 1994	1	48	0	
17	24 Apr 1994	9	48 (37-60)	0	
18	1 May 1994	8	56 (48-64)	0	
19	8 May 1994	2	59 (56-61)	0	
20	15 May 1994	1	66	0	
21	22 May 1994	0		0	
22	29 May 1994	0		0	
23	5 Jun 1994	3	89 (69-114)	0	
24	12 Jun 1994	3	111 (97-118)	0	
25	19 Jun 1994	1	120	0	
26	26 Jun 1994	1	113	0	

[4] Hatchery fish

Pacific Lamprey

Three lamprey life stages were collected: ammocoetes, the filter feeding larval stage; subadult, recently metamorphosed from the ammocoete stage to a small, adult form; and large (>300 mm total length, TL) adult sea-run, spawning life stage (Table 1).

Ammocoetes (*n* = 45) were periodically collected from week -7 through week 27 (23 November 1993 through 3 July 1994) (Figure 41). The greatest weekly catch (14) was during week 6 (6 February 1994). Size, measured as total length (TL), ranged from 73 to 126 mm TL (mean = 106 mm TL) (Figure 42). Most ammocoetes were collected in the north trap (41 fish, or 85% of the catch).

Subadult lamprey (*n* = 169) were also periodically collected from week -7 through 27 (Figure 41). Subadults were continuously collected from week 5 through week 27; the highest catch (31) occurred during week 22 (29 May 1994). Size ranged from 96 to 143 mm TL (mean = 115 mm TL) (Figure 43). Most subadults were captured in the north trap (151 fish, or 89% of the catch).

The first adult lamprey was collected during week 6 (6 February 1994). The remainder (64 fish) was caught beginning week 12 (20 March 1994) (Figure 41). The peak catch occurred during week 17 (24 April 1994), and 80% of the catch occurred between weeks 14 and week 20. Size ranged from 381 to 550 mm TL (mean = 478 mm TL) (Figure 44). Most (99%) adults were caught in the north trap.

American Shad

Two life stages of American shad were collected: young-of-the-year and adults. YOY (*n* = 7) were collected during November - December 1993. Size ranged from 43 to 52 mm FL (mean = 49). Adult American shad (*n* = 81) were collected from week 21 through week 28 (weeks of 22 May 1994–10 July 1994; Figure 45). The highest catch occurred during week 25 (20). Size ranged from 330 mm FL to 530 mm FL (mean = 429 mm FL) (Figure 46).

DISCUSSION

Several significant findings have resulted from the emigration data reported herein, as discussed below.

- The timing of both fry and fingerling emigrations was substantially different from that recorded before construction of the Folsom Complex (1945-1947).

  The only data on salmon emigration in the lower American River prior to construction of the Folsom Project showed both fry and fingerling emigration to occur substantially later than that observed during the 1988 and 1989 trawling surveys and in the 1994 trapping survey. The 1944-1946 brood stocks had access to the upper reaches of the American River. The 1945-1947 emigration timing may have been due to longer incubation, later emergence, and slower growth associated with typically colder, more oligotrophic conditions found in the upper reaches of the American River.

  The emigration timing in 1994 was comparable to that described in the lower Sacramento River (near Hood) both prior to (1899, 1939-1941) and after (1973-1974) completion of Shasta Dam. It was also comparable to that observed in post-Oroville Dam Feather River (1967-1975).

- The downstream environs are very important to the survival of lower American River fall-run chinook salmon.

  Most (>96%) emigrating chinook salmon were fry, more than 99% of all emigrants were pre-smolt. No captured emigrants were 100 mm or greater. These findings suggest that the smolting process is not completed in the lower American River, but will continue downstream, likely in the Delta and the estuary. These facts point to the importance of the downstream environs to ultimate survival of American River chinook salmon.

  These findings also raise several questions concerning the relationships between flow and emigration and the relationships between emigration and ultimate survival to adulthood:

  1) Would different flows change the time spent in the lower American River, thus the life stage composition of emigrants? Late-winter and spring flows in 1994 were below both pre- and post-Folsom mean flows.

  2) What is the relationship between survival and life stage at emigration and environmental conditions within the natal stream, the Delta and the estuary?

- Significant differences in trap results are related to trapping location

The differences in catch, size and life stage composition between traps point to the strong influence of location on trapping results. Even though the two traps were essentially fished along the same transect, the differences in channel and flow attributes apparently strongly influenced trapping efficiency. It would also seem that changes in flow attributes would also influence trap efficiency at the same trap location. Efficiencies were apparently directly correlated with flow (Goldsmith 1994). Therefore, it is very important that trap efficiencies be constantly evaluated to account for changes in flow, trap location and other potential influences on trapping efficiencies. The efficiencies need to be available to calibrate the traps for ultimate comparisons of data within and between trapping surveys.

- Screw trap efficiency appears to be very low in large rivers.

Efficiencies of less than 1% are extremely low, but are consistent with other efficiency rates for similar traps in similarly large rivers (C. Hanson, Hanson Environmental, Inc. pers. comm.). Efficiencies in the Trinity River, California, reported by Goldsmith (1994) ranged from 0.3 to 5.6%. Thedinga *et al.* (1994) reported 24% efficiencies for chinook salmon using screw trap with fences that fished 6 - 11% of the cross section of a 24 m wide stream. Kennen *et al.* (1994) Reported efficiency estimates ranging from 11.2-17.3% for chinook salmon smolts in a small (7-9 m wide) stream.

Debris problems and the high recreational use of the lower American River may restrict the use of wings. Increasing the number of traps or using additional capture methods (e.g., trawl, round-fyke traps) could increase the cumulative efficiency. .

- Using length alone to distinguish smolts may be inappropriate - condition factor *K* continues to increase well beyond the size range associated with smolts.

We expected to see a marked change in appearance, a long-slender shape, and associated decrease in condition factor, as lipid content drops, for fish characterized as smolts. Typically, a change in shape and condition are associated with the latter phases of smolting, as observed in salmonids that smolt as older, larger fish; e.g., coho salmon, steelhead and brown trout. However, the expected changes were not evident in the salmon we identified as smolts, although *K* did not increase with length within the smolt group as it did for the preceding life stages. It is possible that a decrease in *K* does not become evident in fall-run chinook salmon smolts until late in the smolting process; i.e., as length approaches 100 mm FL, the size typically associated with completion of the smolt process (Cannon 1982, Healey 1991). The mean size of salmon we characterized as smolts was 74 mm (range: 58 - 96 mm FL).

Hoar (1976) speculated that smolt characteristics such as decreased condition and silvering were associated with size. Our findings, however, showed silvering to occur over a wide range of salmon sizes, beginning with fish as small as 45 mm FL, the smallest silvery parr collected, and as large as 72 mm FL, the largest parr collected. Decreased *K* however may be more closely associated with salmon size, or with the proximity of the salmon to completing the smolting transformation. As such, fish characterized as smolts might be more appropriately characterized as smolt*ing*; that is, that they have not yet completed the parr-smolt transformation. Fall-run chinook salmon emigrants may be more appropriately classified as smolts when *K* is noticeably reduced, perhaps in association with a size larger than that typically used to designate smolts (i.e., >70 mm FL) corresponding to a more advanced developmental stage. Regardless, there were no parallel trends in external characteristics (i.e. increased silvering along with decreased condition) in the fish captured during the emigration survey that demonstrated an advanced degree of smolting within the lower American River. Instead, there was a very strong suggestion that salmon observed emigrating during 1994 required further growth and development in the downstream environs of the Delta and estuary before fully transforming into smolts.

- Life stage characterization as used in this survey should provide a suitable basis for relating influences of flow and other habitat conditions on emigration.

  If habitat quantity and quality influence the rate of smolting or emigration behavior, it should be reflected in changes in the abundance and timing for each life stage. If emigration patterns are intrinsic, we should not see significant changes in relative timing or magnitude in life stage emigration regardless of habitat quantity or quality. Important consequences may be related to life stage emigration patterns, however many questions need further evaluation. For example, 1) would an increase in habitat availability change the proportion of parr, silvery parr and smolt emigrants, 2) is there a relationship between survival potential and the stage at which emigration occurs, 3) is there an overall increase in cohort survival potential associated with increasing the proportion of more developed emigrants, and 4) how do natal stream habitat conditions relative to conditions downstream affect survival potential of the various life stages and the cohort? Perhaps an intensive tagging program would help answer these questions.

- Increases in turbidity appear to induce fry emigration.

  Fry movement appeared to be directly related to extremely low turbidity changes. Turbidity changed from near 0 to 5 NTU's. A turbidity level of 5 NTU represents extremely clear water. Visibility would not change noticeably. Trap avoidance,

  sight feeding, predator avoidance, etc. would not be expected to change within the observed range.

- Fry emigration appeared to be influenced by relative time of emergence.

  Emergence, based upon the appearance of recently emerged salmon (< 45 mm FL) in the catch, occurred from early January through mid-April. However, the results of the concurrent seine survey (Snider and Titus 1994) and the size distribution of fish collected for marking during trap efficiency Test 3 (27 April) showed emergence to have extended beyond mid-April. The high proportion of small salmon marked during Test 3 (82% were < 52 mm FL) compared to the absence of similar sized fish caught in the trap (100% > 52 mm FL) suggest that late emerging fish remain in the natal stream longer than the early emergers.

REFERENCES

Allan, I.R.H, and J.A. Ritter. 1977. Salmonid terminology. J. Cons. Int. Explor. Mer. 37(3):293-299.

Baracco, A. 1980. Aquatic resources of Suisun Marsh with an analysis of the fishery effects of a proposed water quality maintenance plan. Calif. Dept. Fish Game Anad. Fish., Br. Admin. Rpt 80-13. 26 pp.

Beak Consultants, Inc. 1988. Smolt emigration assessment, lower American River fisheries investigation-progress report. Prepared for McDonough, Holland and Allen.

Bratovich P.B. Manager, Beak Consultants, Inc. Sacramento, Ca. (Personal communication).

Cannon, T.C. 1982. The importance of the Sacramento-San Joaquin Estuary as a nursery area of young salmon, striped bass and other fishes. By Envirosphere Company for National Marine Fisheries Service.

Erkkila, L.F., J.F. Moffit, O.B. Cope, B.R. Smith, and R.S. Nielson. 1950. Sacramento-San Joaquin Delta fishery resources: Effects of Tracy Pumping Plant and Delta Cross Channel. U.S. Fish and Wildl. Serv., Spec. Rpt. - Fisheries, 56:109.

Foerster, R.E. 1968. The sockeye salmon. Fish. Res. Board Can. Bull. 162, 422 p.

Folmer, L.C. and W.W. Dickhoff. 1980. The parr-smolt transformation (smoltification) and seawater adaption in salmonids. Aquaculture, 21:1-37.

Fothergill, K.R. 1994. Emigration survey lower American River 1993 Final Report. Ca. Dept. Fish Game, Environmental Services Division, unpubl. rpt.11 pp.

Goldsmith, G.H. 1993. Juvenile salmonid monitoring on the Trinity and Klamath rivers 1991. U.S. Fish. Wild. Serv. Annual Report Klamath River Fisheries Assessment Program. AFF-1-FRO-93-14.

Hatton, S.R. 1940. Progress report on the Central Valley fisheries investigation, 1939. Calif. Fish Game 26(4):334-373.

Hatton, S. R. and G.H. Clark. 1942. A second progress report on the Central Valley fisheries investigation. Calif. Fish Game 28(2):116-123.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). p. 311-394. *In*: Groot, C., and L. Margolis (eds.). <u>Pacific Salmon Life Histories</u>. UBC Press, Vancouver.

Hoar, W.S. 1976. Smolt transformation: evolution, behavior, and physiology. J. Fish. Res. Board Can. 33:1233-1252.

Kennen, J.G, S.J. Wisniewski, and N.H. Ringler. 1994. Application and modification of an auger trap to quantify emigrating fishes in Lake Ontario tributaries. N. Am. J. Fish. Mgmt. 14:828-836.

Kjelson, M.A., P.F. Raquel, and F.W. Fisher. 1981. Influences of freshwater inflow on chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento-San Joaquin Estuary. P. 88-102. *In*: R.D. Cross and D.L. Williams (eds.). Proceedings of the National Symposium on Freshwater Inflow to Estuaries. U.S. Fish Wildl. Serv. Biol. Serv. Prog. FWS/OBS-81/04(2).

Kjelson, M.A. and P.L. Brandes. 1989. The use of smolt survival estimates to quantify effects of habitat changes on salmonid stocks in the Sacramento-San Joaquin rivers, California. P. 100-115. *In*: C.D. Levings, L.B. Hotby, and M.A. Henderson (ed.) Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Can. Spec. Publ. Fish. Aquat. Sci. .

Lister, D.B. and C.E. Walker. 1966. The effect of flow control on freshwater survival of chum, coho, and chinook salmon in the Big Qualicum River. Can. Fish. Cult. 37:3-25.

Mathews, S.B. and R. Buckley. 1976. Marine mortality of Puget Sound coho salmon (*Oncorhynchus kisutch*). J. Fish. Res. Board Can. 33:1677-1684.

Meinz, M. 1979. Young American shad (*Alosa sapidissima*) ecology. Final Rpt, Job No. 4. U.S. Fish and Wildl. Serv., Anad. Fish Con. Act, AFB-17.

Messersmith, J. 1966. Fishes collected in Carquinez Strait in 1961-62. In: D.W. Kelley (ed.). Ecological studies of the Sacramento-San Joaquin Delta. Part I. Calif. Dept. Fish Game, Fish Bull. 133:57-63.

Meyer, J.H. 1979. A review of the literature on the value of estuaries and shoreline areas to juvenile salmonids in Puget Sound, Washington, U.S. Fish Wild. Serv.

Moyle, P.B. 1976. <u>Inland Fishes of California</u>. UC Press. 405 pp.

Painter, R.E., L.H. Wixom, and S.N. Taylor. 1977. An evaluation of fish populations and fisheries in the post-Oroville Project Feather River. Calif. Dept. Fish Game. Rpt. to Calif. Dept. Water Resources. 56 pp.

Parker, R.H. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28:1503-1510.

Park, D.L. 1969. Seasonal changes in downstream migration of age-group 0 chinook salmon in the upper Columbia River. Trans. Am. Fish. Soc. 2:315-317.

Pearcy, W.G. 1992. Ocean Ecology of North Pacific Salmonids. Univ. Wash. 179 pp.

Pickard, A., A. Baracco, and R. Kano. 1982. Occurrence, abundance, and size of fish at the Roaring River Slough intake, Suisun Marsh, California during the 1980-81 and the 1981-82 diversion seasons. Tech. Rpt. 3. Interagency Ecological Study Prog. for the Sacramento-San Joaquin Estuary. 14 pp.

Reimers, P. E. 1968. Social behavior among juvenile fall chinook salmon. J. Fish. Res. Board Can. 25:2005-2008.

Ricker, W.E. 1976. Review of the rate of growth and mortality of Pacific salmon in salt water, and non-catch mortality caused by fishing. J. Fish. Res. Board Can. 33:1438-1524.

Rutter, C. 1903. Natural history of the quinnat salmon. A report of investigations in the Sacramento River, 1896-1901. U.S. Fish. Comm., Bull. 22:65-141.

Sasaki, S. 1966. Distribution and food habits of king salmon, *Oncorhynchus tshawytscha,* and steelhead rainbow trout, *Salmo gairdnerii*, in the Sacramento-San Joaquin Delta. *In*: J.L. Turner and D.W. Kelley (eds.). Ecological studies of the Sacramento-San Joaquin Delta. Part II. Calif. Dept. Fish Game, Fish Bull. 136:108-114.

Schaffter R.G. 1980. Fish occurrence, size and distribution in the Sacramento River near Hood, California during 1973 and 1974. Calif. Dept. Fish Game Anad. Fish., Br. Admin. Rpt. 80-3. 52 pp.

Seelback, P.W. 1985. Smolt migration of wild and hatchery-raised coho and chinook salmon in a tributary of northern Lake Michigan. Mich. Dept. Nat. Resources, Fish. Res. Rpt.

Snider, B. 1992. Emigration survey lower American River 1992. Calif. Dept. Fish and Game, Environmental Services Division, unpubl. rpt. 14 pp.

Snider, B. and R. Titus. 1994. Fish community survey, lower American River January-July 1994. Calif. Dept. Fish Game, Environmental Services Division, unpubl. Rpt. 37 pp.

Spaar, S.A. 1986. Emigration of young chinook salmon from the Tehama-Colusa fish facilities. MS thesis, Humboldt State University.

Stein, R.A., P.E. Reimers, and J.D. Hall. 1972. Social interaction between juvenile coho salmon (*Oncorhynchus kisutch*) and fall chinook salmon (*O. tshawytscha*) in Sixes River, Oregon. J. Fish. Res. Board Can. 29:1737-1748.

Stevens, D.E. 1966. Distribution and food habits of the American shad *Alosa sapidissima*, in the Sacramento-San Joaquin Delta. *In*: J.L. Turner and D.W. Kelley (eds.). Ecological studies of the Sacramento-San Joaquin Delta. Part II. Calif. Dept. Fish Game, Fish Bull. 136:97-107.

Thedinga, J.F., M.L. Murphy, S.W. Johnson, J.M Lorenz, and K.V. Koski. 1994. Determination of salmonid smolt yield with rotary-screw traps in the Situk River, Alaska, to predict effects of glacial flooding. N. Am. J. Fish. Mgmt. 14:837-851.

Thomas, A.E., J.L. Banks, and D.C. Greenland. 1969. Effect of yolk sac absorption on the swimming ability of fall chinook salmon. Trans. Am. Fish. Soc. 98:406-410.

Titus, R.G. 1991. Population regulation in migratory brown trout (*Salmo trutta*). Acta Universitatis Upsaliensis, Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science. 328:1-24.

Titus, R.G. and H. Mosegaard. 1992. Fluctuating recruitment and variable life history of migratory brown trout, *Salmo trutta* L., in a small, unstable stream. J. Fish Biol. 41:239-255.

Unwin, M.J. and D.H Lucas. 1993. Scale characteristics of wild and hatchery chinook salmon (*Oncorhynchus tshawytscha*) in Rakaia River, New Zealand, and their use in stock identification. Can. J. Fish. Aquat. Sci. 50:2475-2484.

U.S. Fish and Wildlife Service. 1953. A plan for the protection and maintenance of salmon and steelhead in the American River, California, together with recommendations for action. U.S. Fish Wildl. Serv. and Calif. Dept. Fish Game. 47 pp.

Wedemeyer, G.A., R.L. Saunders and W.C. Clarke. 1980. Environmental factors affecting smoltification and early marine survival of anadromous salmonids. Nat. Mar. Fish. Serv. Marine Fisheries Review.

APPENDIX

FIGURES