CALIFORNIA DEPARTMENT OF FISH AND GAME
HABITAT CONSERVATION DIVISION
Native Anadromous Fish and Watershed Branch
Stream Evaluation Program

TIMING, COMPOSITION AND ABUNDANCE OF JUVENILE ANADROMOUS SALMONID EMIGRATION IN THE SACRAMENTO RIVER NEAR KNIGHTS LANDING OCTOBER 1998–SEPTEMBER 1999[1/,2/]

by

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December 2000

1/ Conducted by the Department of Fish and Game. Funded partially by the California Department of Water Resources through the Interagency Ecological Program.
2/ Stream Evaluation Program Technical Report No. 00-6

TABLE OF CONTENTS

SUMMARY . . . ii

INTRODUCTION . . . 1

METHODS . . . 3

RESULTS and DISCUSSION . . . 5
- General Sampling Conditions . . . 5
- Rotary Screw Trap Results . . . 8
  - Chinook Salmon Emigration . . . 8
    - Late-Fall-Run-Sized Chinook Salmon . . . 11
    - Winter-Run-Sized Chinook Salmon . . . 13
    - Spring-Run-Sized Chinook Salmon . . . 16
    - Fall-Run-Sized Chinook Salmon . . . 18
  - Steelhead Trout Emigration . . . 20
    - Young-of-the-year Steelhead . . . 20
    - Yearling Steelhead . . . 19
    - Adult Steelhead . . . 20
- Rotary Screw Trap Gear Efficiency Using Mark-Recapture . . . 22
- Relative Abundance Estimates . . . 24

ACKNOWLEDGMENTS . . . 27

REFERENCES . . . 27

FIGURES . . . 29

APPENDIX . . . A1

SUMMARY

Juvenile salmonids emigrating via the Sacramento River to the Sacramento-San Joaquin Delta (Delta) were sampled 0.5 miles downstream of the town of Knights Landing at river mile (RM) 89.5 from 27 September 1998–2 October 1999. Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*) were the target species. Sampling was conducted using one 8-ft diameter rotary screw trap (RST) from 27 September 1998 (week 40) through 29 October 1998 (week 44); two RSTs were used from 30 October 1998 (week 45) through 20 June 1999 (week 26); and three RSTs were used from 21 June 1999 (week 47) through the end of the survey. This period was the fourth consecutive year of emigration monitoring conducted by the California Department of Fish and Game (DFG) at Knights Landing (Snider and Titus 1998, 2000b, c).

Mean weekly flow ranged from 5,554 cfs in week 35 (22–28 August 1999) to 26,900 cfs in week 9 (21–27 February 1999). Mean daily flow peaked at 28,200 cfs on 11 February 1999. Mean weekly water temperature decreased from 62°F in week 40 (27 September–3 October 1998) to 43°F in week 52 (20–26 December 1998). Temperature then remained low (≤52°F) through week 16 (17 April 1999) before increasing overall from 56°F in week 17 to 64°F in week 22, 70°F in week 29, and eventually 74°F in week 35. Mean weekly water transparency, measured as Secchi disk depth, was very poor throughout the survey and ranged from <0.5 ft to 3.2 ft.

A total of 58,895 juvenile salmon was collected in 18,316 hours of trapping (3.22 fish/h). The total catch included 673 marked salmon, and 58,222 unmarked salmon. Fall-run salmon dominated both groups comprising 98% of the unmarked salmon catch (based upon size criteria) and 62% of the marked salmon catch (based upon coded-wire tag information). Late-fall-run salmon comprised 0.1% of the unmarked salmon catch and 19% of the marked salmon catch; 51% of the unmarked late-fall-run juveniles were from the 1998 brood year (BY) and 49% were from BY 1999. Winter-run salmon comprised 1% of the unmarked salmon catch and 19% of the marked salmon catch; >99% of the unmarked winter run were from BY 1998 and <1% were from BY 1999. Spring-run-sized salmon comprised 1% of the unmarked salmon catch. (No marked spring run were captured). However, based upon comparisons with hatchery-reared fall run released from Coleman National Fish Hatchery (CNFH) during late-spring, spring-run-sized fish collected after the hatchery fish releases were considered to be CNFH-produced fall run. As a result, 29% of spring-run-sized salmon were considered hatchery-produced fall run and only 0.7% of the unmarked salmon catch were considered spring run.

The primary migration period extended from mid-November 1998 (week 46) through mid-July 1999 (week 29). Emigration occurred in three phases: (i) phase 1 was coincident with the first increase in river flow, before many fall run were present; (ii) phase 2 was associated with a substantially greater flow increase and the presence of numerous fall run; and (iii) phase 3 was associated with the large releases of CNFH-produced fall run.

Phase 1 began during week 46 (8–14 November 1998) and lasted through week 3 (10–16 January 1999), peaking during week 51 (13–19 December 1998). Nearly all (95%) in-river-produced

late-fall-run yearling migration, 79% of BY 1998 in-river-produced winter-run migration, 74% of all spring-run migration, but only 1.2% of fall-run migration occurred during this phase. Phase 2 extended from weeks 4 through 13 (17 January–27 March 1999). Altogether, 83% of the total fall-run catch occurred during this phase. Peak catches occurred during weeks 5 and 7 (24–30 January 1999 and 7–13 February 1999), when a combined total of 26,183 fall-run emigrants was collected (46% of all captured fall run). Each peak was concurrent with a flow increase from about 14,000 cfs to more than 20,000 cfs.

The third phase of emigration is typically associated with large releases (>2 million) of hatchery-produced, fingerling-sized fall run into the upper Sacramento River. During 1998–1999, the first two releases of fingerling-sized fall run from CNFH were less than 1 million each. As a result, the phase 3 migration during 1998–1999 was not as pronounced as in previous years. Phase 3 began in week 14, four weeks following the release of nearly 0.5 million salmon and coincident with the release of another 0.9 million fish.

Thirty-seven in-river-produced (unmarked) late-fall-run juveniles from BY 1998 were collected from week 40 through week 5 (27 September 1998–30 January 1999). The highest catches occurred during weeks 48 ($n = 13$) and 49 ($n = 10$). A total of 35 in-river produced late-fall-run juveniles from BY 1999 was also collected: 34 during weeks 14 through 18 (28 March–1 May 1999) and one during week 33 (8–14 August 1999).

A total of 690 in-river produced winter-run chinook salmon from BY 1998 was collected from week 40 through week 13 (27 September 1998–27 March 1999). During the primary migration period, 44% of the catch of in-river produced winter run occurred in November, 33% in December, 10% in January, 7% in February, 3% in March and 2% in April. Ten winter run were collected several weeks prior to the primary migration period (weeks 40–45), and one winter run from BY 1999 was caught several weeks after the end of the primary emigration period (week 38, 12–18 September 1999).

In-river-produced spring-run chinook salmon (based on size criteria) first appeared in the RSTs during emigration phase 1 (week 48), and were captured during every week through week 9 (21–27 February 1999). A total of 396 in-river-produced spring-run juveniles was collected by RST.

Altogether, 56,901 unmarked, fall-run-sized juvenile salmon were collected. Fall run were first collected during week 49, the fourth week into the primary migration period, and then in every subsequent week through week 29 (17 July 1999). Distinction between in-river and hatchery-produced fall run was problematic after week 5 when nearly 0.75 million, unmarked hatchery-reared fall-run fry were released into the upper Sacramento River, immediately downstream of the Red Bluff Diversion Dam. As such, only fall-run-sized salmon caught prior to week 5 were known in-river-produced salmon. Beginning in week 10, nearly 8% of the fall run released into the upper river were marked. Based upon the ratio of marked fish to unmarked fish, about 38% of the fall run caught after week 10 were hatchery produced.

A total of 43 unmarked, yearling steelhead trout was caught between 29 November 1998 and 5 June 1999. Five percent were caught in December, 2% in January, 7% in February, 21% in March, 42% in April, 21% in May, and 2% in June. We also collected 82 marked steelhead from 17 January 1999 through 15 May 1999.

Estimates of the relative abundance of juvenile salmonids emigrating past Knights Landing are provided based upon a mean RST efficiency of 0.62% (range: 0.0%–1.91%; SD = 0.51%; 80% CI: 0.45%–0.79%; $n = 17$). The estimated number of in-river salmon that passed Knights Landing included 7,742 BY 1998 late-fall run and 5,645 BY 1999 late-fall run; 136,452 BY 1998 winter run and 161 BY 1999 winter run; 74,355 spring run; and 8,752,647 fall run. The estimated number of in-river produced yearling steelhead passing Knights Landing was 7,258.

The estimated number of hatchery-produced chinook salmon passing Knights Landing was 22,097 late-fall run, 22,742 winter run, and 937,837 fall run. The estimated number of hatchery-produced steelhead trout passing Knights Landing was 13,710.

Emigration from the upper Sacramento River system to the Delta is exclusively through Knights Landing until flow increases require diversion through the Sutter Bypass, upstream of Knights Landing. Typically, diversion to the bypass via the Tisdale Weir occurs when flow exceeds about 23,000 cfs. In 1998–1999, flow exceeded 23,000 cfs during weeks 49 and 50 (29 November–12 December 1998, and during weeks 7 through 12 (7 February–20 March 1999). Since the proportion of juvenile salmonids that emigrates through the bypass is unknown, the magnitude of salmonids emigrating to the Delta cannot be estimated by just using Knights Landing results. However, the temporal distribution and, likely, the relative abundance of juvenile salmonids migrating toward the Delta are reflected in the Knights Landing results.

INTRODUCTION

Juvenile anadromous salmonid emigration was monitored on the Sacramento River near Knights Landing (RM 89.5) for the fourth consecutive year (Snider and Titus 1998, Snider and Titus 2000b, c). Monitoring was conducted to develop information on timing, composition (race and species), and relative abundance of juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) emigrating from the upper Sacramento River system. This information provides early warning of emigration into the Sacramento-San Joaquin Delta (Delta) to enable implementation of management actions deemed necessary to protect juvenile anadromous salmonids as they pass into and through the Delta. Data acquired over several years will improve understanding of the attributes of emigration and identify implications of management actions both up- and downstream of the Delta relative to protection and recovery of the Sacramento River's anadromous salmonid populations.

The indigenous, anadromous salmonid populations of California's Central Valley have been severely reduced due to a variety of man-caused alterations to their environment. The region's chinook salmon and steelhead trout populations have been extirpated from most of their historic range and the existence of the few remaining depleted populations is constantly challenged. Beginning in the mid-1800's through the mid-1900's, the construction of dams on most of the major streams within the Valley progressively eliminated use of more than 90% of these fishes' historic habitat. Changes in water quality and drastic modifications in stream channel form began with the unbridled quest for gold in 1849 and continue today with escalating urban expansion and intensive agriculture and industrial development. Stream channels have been modified to protect cities and agriculture. Pollutants ranging from elevated water temperatures to urban and agricultural runoff and associated, sophisticated toxicants, including pesticides and treated effluent, have further degraded much of the region's stream habitats. Increasing water diversion continues to modify the timing and magnitude of flow that sustain most of the remaining habitat.

Emigrating fish are continually lost as they attempt to navigate the many diversions that lie between their natal streams and the Pacific Ocean. Potentially, the most imposing of these diversions are the State Water Project's Harvey Banks Delta Pumping Plant and the Central Valley Project's Tracy Pumping Plant, both located in the southern Sacramento-San Joaquin Delta. The work summarized in this report is a portion of an ongoing effort upon the part of water developers and fishery managers to reduce the deleterious impacts of these facilities on Central Valley salmon and steelhead, to preserve one of California's valued natural heritages.

Anadromous salmonids produced in the Sacramento River system upstream of the Feather River (RM 80) are of special concern. The upper Sacramento River and several of its tributaries (Figure 1) provide most of the essential spawning and rearing habitat for the Central Valley's depleted, anadromous salmonid populations. The winter-run chinook salmon[1], unique to

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[1] Listed as endangered under both the California and Federal Endangered Species acts.

California's Central Valley, spawns and rears exclusively in the upper Sacramento River. Central Valley spring-run chinook salmon[2] are nearly exclusive to the upper Sacramento system where remnant populations occur in a few isolated locations including Deer, Mill and Butte creeks (Figure 1). All late-fall-run chinook salmon, most steelhead trout[3] and a major portion of the natural, or in-river-produced, fall-run chinook salmon spawn and rear in the upper Sacramento River and its tributaries. The continued existence of these populations could well depend upon the ability to protect the juveniles as they emigrate from their natal waters, into and through the Delta on their way to the Pacific Ocean.

Accurate estimates of the abundance and timing of emigrating anadromous salmonids as they enter the Delta would improve the ability to address critical water management questions. Water management activities in the Delta can influence survival of anadromous salmonids. Various restrictions have been placed on project operations to protect juvenile salmonids migrating through and residing within the Delta. For example, Delta diversions are limited seasonally predicated on the presence of winter-run chinook salmon. Water management decisions could be considered for the other anadromous salmonids under increasing concern (i.e., spring-run chinook salmon and steelhead trout) if better information existed on timing, abundance, and overall emigration attributes. Improved estimates of the timing and relative abundance of these species as they enter the Delta should improve confidence in defining impacts and protective measures to enhance overall protection, and potentially maximize water management flexibility.

An appropriately located and operated monitoring site would provide early warning of emigrating juvenile salmonids entering the Delta and improve the ability to use water project flexibility and other actions to protect winter-run chinook salmon and, potentially, other anadromous species of concern. As such, representatives of agencies involved in fishery and water management issues within the Central Valley recommended establishing a monitoring station to:

1) Provide early warning to trigger Central Valley Project and State Water Project operation modifications (e.g., manipulation of Delta Cross Channel gate operation and water export levels).

2) Provide a monitoring station intermediate between the Glenn-Colusa Irrigation District (GCID) diversion and the Delta.

3) Provide opportunity to follow movement of juvenile salmonids downstream in response to various environmental conditions, including flow.

4) Determine the relative proportion of winter-run chinook salmon fry and pre-smolts that enter and potentially rear in the lower river and Delta through the fall and early-winter months.

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[2]Listed as threatened under both the California and Federal Endangered Species acts.

[3]Listed as threatened under the Federal Endangered Species Act.

5) Develop abundance estimates for juvenile salmonids entering the lower river and Delta.

To address the feasibility of monitoring the timing and abundance of juvenile anadromous salmonids emigrating exclusively from the upper Sacramento River system into the Sacramento-San Joaquin Delta, a pilot monitoring station was established near Knights Landing on the Sacramento River at RM 89.5 (Figure 1) in November 1995. Potentially, progenies of all Central Valley winter run and late-fall run, most spring run, a major portion of fall run, and most in-river-produced steelhead trout emigrate past the Knights Landing sampling site[4]. Other monitoring programs within the Sacramento River system are either too far upstream of the Delta to accurately monitor the timing and abundance of emigration into the Delta (e.g., Red Bluff Diversion Dam (RBDD) at RM 245 and GCID diversion at RM 206), or are too close to the Delta to discriminate fish originating from the upper Sacramento River system from those produced in the Feather and American rivers (e.g., Sacramento at RM 55).

Knights Landing was selected as the pilot monitoring site, relative to downstream locations, due to apparent favorable channel and flow conditions. It appeared to have greater opportunity for using a diversity of fish sampling methods including relatively efficient gear types such as rotary screw traps (RSTs). The river channel is relatively narrow and there is less flow than in the Sacramento River downstream of the Feather and American rivers and upstream of the Sutter Bypass. The site also provided an intermediate monitoring point between GCID, the next sampling station upstream (RM 206), and the Delta.

METHODS

Juvenile salmonids emigrating via the Sacramento River to the Delta were sampled 0.5 miles downstream of the town of Knights Landing at RM 89.5 (Figure 1) from 27 September 1998 through 2 October 1999. Sampling was conducted using one 8-ft diameter RST from 27 September 1998 (week 40) through 29 October 1998 (week 44); two RSTs were used from 30 October 1998 (week 45) through 20 June 1999 (week 25); and three RSTs were used from 21 June 1999 (week 26) through the end of the survey.

The RSTs were lashed together and located on the outside of a wide bend in the river approximately 100 ft from the east bank. Three 40-pound Dansforth anchors and 3/8" diameter wire ropes were used to position and secure the traps in the stream channel. The trap complex was also secured to the east bank with a safety line of 1/4" diameter wire rope. Water depth at the trap location was 18 ft at 10,000 cfs (Figure 2. Depth was 20 ft and mean current velocity was 3.0 ft/s at a flow of 15,000 cfs.

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[4]Emigrants can enter the Sutter Bypass, upstream of Knights Landing when flow in the vicinity of the bypass surpasses 23,000 cfs. The proportion of emigrants entering the bypass is unknown; their survival to the Delta is also unknown.

Data acquired from each trap per servicing included total time fished since the last servicing, current velocity at the trap opening, the average number of cone revolutions per minute, and the cumulative number of cone revolutions since the last servicing. All salmonids were counted by species, and race for chinook salmon[5]. All salmon classified as winter run, spring run and late-fall run were measured (fork length [FL] in mm and weight in g). At each trap servicing, up to 150 fall-run-sized salmon per trap were selected and measured using a random-stratified subsampling protocol. All juvenile steelhead trout were counted and measured. The traps were serviced up to two times per day: once in mid-morning and once near dusk.

The data are reported on a weekly time step to smooth variation in effort and trap efficiency while retaining sufficient detail to evaluate trends in timing and abundance. Data were typically reduced to weekly sums or weekly means. Weeks began on Sunday and ended on Saturday and were identified by number. Week 1 was defined as the first week of 1999 (i.e., contains 1 January 1999). Weeks prior to week 1 were consecutively numbered in descending order from 52; weeks after week 1 were numbered in ascending order.

Flow at Knights Landing was obtained from records of the U. S. Geological Survey gaging station at Wilkins Slough. Water transparency was measured each day at the RST using a Secchi disk following standard methods (Orth 1983). Water temperature was measured using electronic recording thermographs attached to the RSTs.

Trap efficiency was evaluated using a mark-and-recapture technique. All trapped chinook salmon (except winter-run-sized chinook) were marked using Bismark Brown *Y* stain (e.g., Deacon 1961) then released about 0.5 miles upstream of the traps. Our objective was to mark and release at least 100 salmon per trial. When <100 salmon were collected in a day, fish were held until ≥100 fish were available for marking, or up to 3 days maximum, whichever occurred first. Efficiency was calculated as the percentage of marked fish that were recaptured in the traps on a weekly basis. Salmon marking was initiated during week 52 (20–26 December 1998) and continued through week 21 (16–22 May 1999). No marked fish were released during weeks 1–3 and week 20 as fewer than 100 fish were collected during weeks 1–3 and fewer than 100 salmon were collected early enough during week 20 to allow marking.

All adipose-fin clipped (marked) fish were collected and coded-wire tags (CWTs) were read to determine the fish's origin including race. Information on race derived from the tag was compared with the original race designation based upon size. Race classification was changed to reflect the tag data for individual fish and groups of fish when the tagged fish appeared to represent the unmarked portion of the catch.

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[5]Salmon race was determined using size-at-time criteria developed by Frank Fisher (California Department of Fish and Game, Northern California - North Coast Region, unpubl. data).

RESULTS and DISCUSSION

General Sampling Conditions

Mean weekly flow ranged from 5,554 cfs in week 35 (22–28 August 1999) to 26,900 cfs in week 9 (21–27 February 1999) (Table 1). Mean daily flow peaked at 28,200 cfs on 11 February 1999 (Figure 3). The initial flow increase was higher and earlier than in the previous three survey years (Snider and Titus 1998, Snider and Titus 2000b, c). Mean weekly flow increased from about 6,600 cfs in early November to more than 11,000 cfs in mid November to more than 23,000 cfs[6] by the end of November (Table 1, Figure 3). Mean flow remained above 23,000 cfs from week 49 through week 50 (29 November–12 December 1998) then declined to about 8,700 cfs by week 3 (10–16 January 1999) before again increasing to more than 23,000 cfs in week 7 (7–13 February 1999). In 1996, the only other survey period when high flows occurred relatively early in the season, flow did not surpass 8,000 cfs until the last week of November and 23,000 cfs until mid-December (Snider and Titus 2000a). After a sustained high flow period above 23,000 cfs from week 7 through week 12, mean weekly flow gradually decreased to 10,000 cfs in week 19 then remained between about 7,500 and 10,000 cfs (weeks 20–32) before declining to the seasonal low during week 35.

Mean weekly water temperature decreased from 62°F in week 40 (27 September–3 October 1998) to 43°F in week 52 (20–26 December 1998) (Table 1). Temperature then remained low (≤52°F) through week 16 (17 April 1999) before increasing overall from 56°F in week 17 to 64°F in week 22, 70°F in week 29, and eventually 74°F in week 35 (Figure 3).

Mean daily water temperature was weakly negatively correlated with mean daily river flow ($r = -0.33$), and although there was a significant linear regression ($p<0.0001$) of temperature on flow, the model only explained about 10% of the variation in temperature as a function of flow. Looking at temperature by date (Figure 3), it is evident that water temperature at Knights Landing is primarily a function of seasonal variation in ambient temperature (i.e., cold in winter, warm in summer, with an overall gradual increase or decrease in thermograph during the intervening seasons).

Mean weekly water transparency (Secchi disk depth) was very poor throughout the survey (Figure 4), and ranged from <0.5 ft to 3.2 ft (Table 1). Transparency was inversely related to flow. Mean weekly transparency (as *ln* Secchi disk depth) was moderately negatively correlated ($r = -0.60$) with mean weekly river flow. There was a fair linear fit ($r^2 = 0.36, p<0.0001$) of *ln* Secchi disk depth on flow (Appendix Figure 1).

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[6] Flow >23,000 cfs at Wilkins Slough indicates that Sacramento River flow is being diverted into the Sutter Bypass (Bypass) at Tisdale Weir, and may be substantially higher upstream of the Bypass.

Table 1. Summary of mean weekly sampling conditions in the Sacramento River near Knights Landing during the juvenile salmonid emigration investigation, 27 September 1998–2 October 1999.

Week	Beginning date	Mean flow (cfs)	Mean water temperature F	Mean Secchi depth (ft)
40	27 Sep 1998	9,013	62	2.5
41	4 Oct 1998	8,377	61	2.1
42	11 Oct 1998	7,334	59	2.6
43	18 Oct 1998	6,307	60	3.0
44	25 Oct 1998	6,859	59	2.1
45	1 Nov 1998	6,623	53	3.2
46	8 Nov 1998	8,204	52	2.3
47	15 Nov 1998	11,679	52	2.0
48	22 Nov 1998	19,757	54	2.4
49	29 Nov 1998	24,543	48	0.5
50	6 Dec 1998	25,271	48	1.0
51	13 Dec 1998	21,943	50	1.1
52	20 Dec 1998	14,286	43	1.3
1	27 Dec 1998	10,339	45	1.5
2	3 Jan 1999	9,016	45	1.8
3	10 Jan 1999	8,670	46	2.2
4	17 Jan 1999	14,239	50	0.9
5	24 Jan 1999	21,443	45	0.9
6	31 Jan 1999	13,557	46	1.5
7	7 Feb 1999	25,729	47	0.5
8	14 Feb 1999	26,557	45	0.7
9	21 Feb 1999	26,900	47	0.8
10	28 Feb 1999	26,843	46	0.8
11	7 Mar 1999	26,457	45	1.1
12	14 Mar 1999	23,186	49	1.1
13	21 Mar 1999	18,971	52	1.1
14	28 Mar 1999	17,771	51	0.7
15	4 Apr 1999	12,943	49	1.2

Table 1 (cont.)

Week	Beginning date	Mean flow (cfs)	Mean water temperature F	Mean Secchi depth (ft)
16	11 Apr 1999	17,629	52	0.9
17	18 Apr 1999	16,214	56	0.9
18	25 Apr 1999	11,700	56	1.1
19	2 May 1999	10,363	56	1.2
20	9 May 1999	9,213	58	1.2
21	16 May 1999	8,096	59	0.9
22	23 May 1999	9,117	64	1.1
23	30 May 1999	9,911	59	1.0
24	6 Jun 1999	9,344	61	1.1
25	13 Jun 1999	7,544	63	1.5
26	20 Jun 1999	7,870	64	1.8
27	27 Jun 1999	7,981	65	1.5
28	4 Jul 1999	7,321	62	1.4
29	11 Jul 1999	7,499	70	1.5
30	18 Jul 1999	7,961	66	1.4
31	25 Jul 1999	7,866	65	1.4
32	1 Aug 1999	7,864	67	1.2
33	8 Aug 1999	6,714	66	1.0
34	15 Aug 1999	5,761	70	0.9
35	22 Aug 1999	5,554	74	1.2
36	29 Aug 1999	6,287	-	-
37	5 Sep 1999	6,903	69	1.1
38	12 Sep 1999	7,184	67	1.2
39	19 Sep 1999	7,060	68	1.7
40	26 Sep 1999	6,632	62	2.5

The RSTs were successfully operated over a wide range of flows (~5,500 to ~28,000 cfs; Figure 5). Interruptions in sampling were typically less than 24 h within a week and were generally due to debris buildup that disabled the traps. Longer interruptions occurred during weeks 48 and 52 of 1998 and week 1 of 1999 when the traps were raised during holidays. Debris-induced interruptions occurred during week 47 (15–22 November 1998), week 49 (29 November–5 December 1998), week 13 (21–27 March 1999), and week 20 (9–15 May 1999). During the primary migration period when two traps were fishing (week 45–week 26), the RSTs fished 94% of the time averaging 316 h/week out of a possible 336 h/week.

Rotary Screw Trap Results

Chinook Salmon Emigration

Eleven juvenile salmon were captured by RST prior to the typical initiation of the primary migration period (late November; Snider and Titus 1998). Eight winter-run-sized salmon were collected during week 40 of 1998, and one each during weeks 41 and 45 (Table 2). One late-fall-run-sized salmon was collected during week 40 (Table 2). The primary emigration period of 1998–1999 began during week 46 (8–14 November 1998) when 35 salmon were collected (Table 2, Figure 6). Thereafter, salmon were captured every week through week 29 (17 July 1999) (Table 2). Only two salmon were collected after week 29: one in week 33 and one in week 38.

Juvenile salmon migration occurred in three phases as represented by several modes in the catch and catch-rate distributions (Figure 6). The first phase was the initiation of emigration which was strongly linked to the initial flow increase of the season (Figure 7). This relationship was also observed during 1995, 1996 and 1997 (Snider and Titus 1998, Snider and Titus 2000b, c). During the 1998–1999 emigration period, the first phase began during week 46 (8–14 November 1998) and lasted through week 3 (10–16 January 1999). The mode representing this phase peaked during week 51 (13–19 December 1998) (Figures 6 and 7). Characteristic of this phase was the relatively high proportion of late-fall-, winter- and spring-run chinook salmon. Although the total catch during this phase was the lowest in magnitude, it was the highest in salmon race diversity. Nearly all (95%) in-river-produced late-fall-run yearling migration, 79% of BY 1998 winter-run migration, 74% of all spring-run migration, but only 1.2% of fall-run migration occurred during this phase.

The second phase of emigration was associated with a second increase in flow and an increased availability of fall-run fry to emigrate. During the 1998–1999 emigration period, phase 2 extended from weeks 4 through 13 (17 January–27 March 1999) (Figures 6 and 7). Altogether, 83% of the total fall-run catch occurred during this phase. Peak catches occurred during weeks 5 and 7 (24–30 January and 7–13 February1999) when a combined total of 26,183 fall-run emigrants was collected (46% of all captured fall run). Each peak was concurrent with a flow increase from about 14,000 cfs to more than 20,000 cfs (Figure 7).

Table 2. Weekly summary of catch statistics for chinook salmon caught by rotary screw trap in the Sacramento River near Knights Landing, 27 September 1998–2 October 1999.

Week	Effort (h)	Total catch	Catch/h	Size statistics (FL in mm)			
				Mean	Minimum	Maximum	Standard deviation
40	167.75	9	0.05	40.2	31.0	77.0	13.16
41	167.50	1	0.01	37.0	37.0	37.0	0
42	168.50	0	0.00	-	-	-	-
43	167.50	0	0.00	-	-	-	-
44	211.25	0	0.00	-	-	-	-
45	336.75	1	0.003	38.0	38.0	38.0	0
46	375.25	35	0.09	68.1	52.0	89.0	8.34
47	292.00	55	0.19	70.4	53.0	122.0	11.84
48	238.50	236	0.99	68.7	33.0	135.0	12.39
49	228.00	262	1.15	51.5	30.0	117.0	21.15
50	327.00	292	0.89	41.8	29.0	108.0	15.95
51	332.25	323	0.97	39.4	28.5	128.0	14.23
52	236.75	285	1.20	40.7	30.0	147.0	17.35
1	239.25	59	0.25	44.6	30.0	145.0	24.20
2	324.00	10	0.03	36.1	34.0	39.0	1.58
3	337.25	41	0.12	87.8	30.5	158.0	48.22
4	333.00	6,566	19.72	39.3	27.5	149.0	13.27
5	323.25	12,395	38.35	39.4	27.0	157.5	11.96
6	334.50	1,977	5.91	39.2	31.0	109.0	6.44
7	300.00	13,788	45.96	40.1	31.0	134.0	10.89
8	327.00	4,067	12.44	37.5	30.0	125.0	4.36
9	339.50	3,467	10.21	37.7	31.0	138.0	5.18
10	336.00	3,248	9.67	37.6	31.0	118.0	4.45
11	336.00	1,480	4.41	38.5	32.0	123.0	5.54
12	336.00	604	1.80	41.2	32.0	116.0	8.83
13	277.00	296	1.07	48.1	32.0	114.0	13.36
14	332.25	2,151	6.47	43.7	32.0	139.0	11.04

Table 2 (cont.)

Week	Effort (h)	Total catch	Catch/h	Size statistics (FL in mm)			
				Mean	Minimum	Maximum	Standard deviation
15	337.50	563	1.67	63.2	34.0	112.0	11.66
16	331.00	886	2.68	58.9	32.0	99.0	13.64
17	334.75	563	1.68	72.8	32.0	90.0	8.88
18	335.50	2,491	7.43	72.9	35.0	92.0	5.63
19	328.00	2,214	6.75	71.8	41.0	90.0	6.69
20	290.75	213	0.73	74.6	58.0	115.0	7.18
21	330.25	245	0.74	78.1	61.0	102.0	7.12
22	332.75	28	0.08	81.9	66.0	105.0	9.57
23	288.25	10	0.04	79.9	69.0	94.0	6.93
24	383.50	12	0.03	80.0	72.0	92.0	5.29
25	346.00	6	0.02	82.6	75.0	86.0	3.68
26	280.75	5	0.02	76.2	61.0	87.0	9.15
27	462.25	6	0.01	79.6	71.0	91.0	6.05
28	428.00	2	0.005	78.0	74.0	82.0	4.00
29	566.00	1	0.002	85.0	85.0	85.0	0
30	499.75	0	0.00	-	-	-	-
31	504.00	0	0.00	-	-	-	-
32	441.00	0	0.00	-	-	-	-
33	502.75	1	0.002	78.0	78.0	78.0	0
34	500.25	0	0.00	-	-	-	-
35	504.25	0	0.00	-	-	-	-
36	534.5	0	0.00	-	-	-	-
37	534.25	0	0.00	-	-	-	-
38	512.25	1	0.002	41	41	41	0
39	498.00	0	0.00	-	-	-	-
40	185.50	0	0.00	-	-	-	-
Total	18,315.75	58,895	3.22				

The distinction between phases 1 and 2 was clear during 1998-99 as was the case in 1995-96 and 1997-98, when the initial flow increase occurred before many fall run had emerged and had become available for emigration (Snider and Titus 1998, Snider and Titus 2000c). In 1996-97, however, the initial flow increase was closely followed by a much greater flow increase when large numbers of fall run were available, in effect overlapping phases 1 and 2 (Snider and Titus 2000b).

In the three previous survey years, the third phase was associated with the release of typically >2 million, hatchery-produced, fingerling-sized fall run into the upper Sacramento River. In 1998, the first two releases of fingerling-sized fall run from Coleman National Fish Hatchery (CNFH) were less than 1 million each. As a result, the phase 3 migration in 1998–1999 was not as pronounced. Phase 3 began in week 14, 4 weeks following the release of nearly 0.5 million salmon and coincident with the release of another 0.9 million fish (Table 3). The distribution depicting this phase was characterized by several peaks in catch (weeks 18 and 19) corresponding to the timing and magnitude of the larger hatchery releases (5–6 million fish each week) during weeks 17 and 18 (Table 3, Figure 6).

Size of salmon captured by the RSTs ranged from 27 to 158 mm FL (Table 2, Figures 8-20). Large salmon (>90 mm FL) were captured during every week between week 47 (15–21 November 1998) and week 27 (27 June–3 July 1999). Recently emerged-sized salmon (<45 mm FL) were captured in weeks 40, 41 and 45 of 1998 and then every week from week 48 through week 19 (Table 2). One recently emerged-sized salmon was caught during week 38 of 1999 (12–18 September 1999).

Late-Fall-Run-Sized Chinook Salmon

All late-fall run released from CNFH were marked. As such, we considered all unmarked late-fall-run chinook salmon to have been produced in-river, based on size criteria (F. Fisher and S. Greene, unpubl. data). The first in-river-produced late-fall-run chinook salmon was caught during week 40 (Table 4, Figure 21). Altogether, 37 in-river-produced late-fall-run juveniles from BY 1998 were collected from week 40 through week 5 (26 September 1998–30 January 1999). The highest catches occurred during weeks 48 ($n = 13$) and 49 ($n = 10$). These fish ranged from 77 to 136 mm FL (Table 4).

A total of 35 in-river-produced late-fall-run juveniles from BY 1999 was also collected: 34 from week 14 through week 18 (28 March–1 May 1999), and one during week 33 (Figure 21). These fish ranged from 32 to 78 mm FL (Table 4).

We collected 128 marked late-fall run (Table 5). These fish were collected from week 48 through week 9 (22 November 1998–27 February 1999) (Figure 22). Relatively high catches occurred during weeks 3–5 ($n = 94$) and week 7 ($n = 14$). Fifty of the 128 marked fish were late-fall-run-sized (BY 1997) of which 47 had CWTs that identified them as late-fall run from CNFH.

Table 3. Summary of juvenile chinook salmon and steelhead produced at Coleman National Fish Hatchery and released in the Sacramento River upstream of Knights Landing, including run, number marked with an adipose clip (with and without coded-wire tags [CWTs]), and release date and location.

Race (for chinook salmon)	Week of release (date)	Number marked w/CWT	Number marked w/o CWT	Number unmarked	Release location (RM)1/
		Chinook salmon			
Late-fall run	46 (12 Nov 1998)	137,993	2,045	0	CNFH (271.5)
Late-fall run	51 (15 Dec 1998)	127,224	4,628	0	CNFH (271.5)
Late-fall run	2 (4 Jan 1999)	505,948	31,864	0	CNFH (271.5)
Winter run	5 (28 Jan 1999)	147,392	6,516	0	CP (298)
Fall-run fry	5 (29 Jan 1999)	0	0	755,073	BRBR (240)
Fall run	9(26 Feb 1999)	0	0	3,000	LMP(229)
Fall run	10 (3 Mar 1999)	27,888	7,866	445,961	CNFH (271.5)
Fall run	11 (9 Mar 1999)	0	0	3,000	LMP (229)
Fall run	13 (26 Mar 1999)	0	0	3,000	LMP (229)
Fall run	14 (31 Mar 1999)	29,869	7,006	889,143	CNFH (271.5)
Fall run	16 (15 Apr 1999)	0	0	3,000	LMP (229)
Fall run	17 (20/21 Apr 1999)	359,021	89,240	5,134,684	CNFH (271.5)
Fall run	18 (27/28 Apr 1999)	466,501	17,524	5,556,291	CNFH (271.5)
		Steelhead			
	2 (5 Jan 1999)	358,760	7,321	0	Balls Ferry (276)
	3 (13 Jan 1999)	116,096	14,348	0	CNFH (271.5)

1/ CNFH = Coleman National Fish Hatchery; CP = Caldwell Park; BRBR = Bow River Boat Ramp; LMP = Los Molinos Park

(The three fish without a CWT were also classified as late-fall run from CNFH). CWT data also revealed that 55 marked fish classified by size as winter run and one classified by size as a spring run were actually late-fall run from CNFH.

We also classified 22 winter-run-sized marked salmon without CWTs as late-fall run as follows. We caught and retained 13 winter-run-sized fish that did not contain a CWT. Seven of these 13 fish were collected prior to the release of marked winter run (week 5) and were therefore classified as late-fall run. Based upon the proportion of winter-run-sized fish collected after week 5 that were verified by CWT as winter run versus late-fall run (45 of 48), we classified the six remaining winter-run-sized fish without a CWT as winter run. We also caught and released 72 marked, winter-run-sized salmon. These fish were released due to restrictions in our Section 10 permit issued by the National Marine Fisheries Service under the Federal Endangered Species Act for the collection of winter run at Knights Landing. We classified 15 of these 72 released fish as late-fall run based on an evaluation of the length frequency distribution of the released fish and the sizes of known late-fall run collected after week 6.

A total of 809,702 late-fall run produced at CNFH was marked, tagged with CWTs and released into Battle Creek, approximately 180 miles upstream of Knights Landing. Of these, an estimated 38,537 were marked but either shed or otherwise did not have a CWT when released. Three releases consisting of 11 distinct tag groups were made over a period of 9 weeks, between 12 November 1998 and 4 January 1999 (Table 3). We captured 7 (0.005%) fish from the first release, 19 (0.014%) from the second, and 77 (0.015%) from the third release (compositely in Table 5, Figure 22). Fish from the first release were collected at Knights Landing from 10 to 77 days after their release (mean = 52 days); fish from the second release were collected from 4 to 41 days later (mean = 19 days); and fish from the third release were collected 6 to 36 days later (mean = 17 days). The last fish from both the first and second release groups was collected in week 5, and the last fish from the third release group was collected during week 7, all during emigration phase 2 (Figure 6).

Winter-Run-Sized Chinook Salmon

As with late fall from CNFH, all winter run released from Livingston Stone National Fish Hatchery (LSNFH) were marked and all unmarked winter run (based on size) were considered to have been produced in-river. A total of 690 in-river-produced winter-run chinook salmon from BY 1998 was collected from week 40 of 1998 through week 14 of 1999 (27 September 1998–3 April 1999) (Table 4, Figure 21). During the primary migration period, 44% of the catch of in-river-produced winter run occurred in November, 33% in December, 10% in January, 7% in February, 3% in March, and 2% in April.

We observed three peaks in the catch of in-river produced winter run during the primary migration period, corresponding to the three emigration phases discussed above (Figure 21, cf. Figure 6). Winter-run catch first peaked in week 48 then declined to zero by week 2 (phase 1). Catch peaked again in week 5 (phase 2) then gradually declined before peaking a third time during week 14 (phase 3). About 79% of in-river-produced winter run (BY 1998) were captured during phase 1, coincident with the first major increase in flow. Some 19% were captured during

Table 4. Summary of catch and size range data for in-river-produced[1/] chinook salmon (by run) caught by rotary screw traps in the Sacramento River near Knights Landing, 27 September 1998–2 October 1999.

	Fall run[2/]		Spring run		Winter run		Late-fall run	
Week	Number	FL range	Number	FL range	Number	FL range	Number	FL range
40	0		0		8	31–39	1	77
41	0		0		1	37	0	
42	0		0		0		0	
43	0		0		0		0	
44	0		0		0		0	
45	0		0		1	38	0	
46	0		0		34	52–79	1	89
47	0		0		52	53–83	3	89–122
48	0		2	33–41	220	49–86	13	86–135
49	63	30–34	78	33–38	109	51–89	10	93–117
50	147	29–36	77	34–39	65	51–93	3	98–108
51	202	29–36	87	36–41	29	53–98	2	111–113
52	211	30–38	43	38–42	24	51–95	1	136
1	47	30–40	5	39–52	2	63–69	1	[4/]
2	9	34–39	1	[3/]	0		0	
3	18	31–40	1	51	0		0	
4	6,468	28–46	36	46–62	23	65–115	0	
5	12,277	27–47	38	47–62	45	66–129	2	132[4/]
6	1,923	31–48	7	50–60	10	70–101	0	
7	13,650	31–52	14	53–69	26	72–117	0	
8	4,054	30–55	4	57–65	6	75–125	0	
9	3,455	31–56	3	59–68	6	94–131	0	
10	3,235	31–60	0		6	92–118	0	
11	1,472	32–63	0		2	115–123	0	
12	595	32–66	0		6	94–116	0	
13	279	32–68	8	71–88	4	95–114	0	
14	2,108	32–73	27	72–96	11	98–139	1	33
15	466	35–77	77	75–90	0		1	34

Table 4 (cont.)

Week	Fall run[2/]		Spring run		Winter run		Late-fall run	
	Number	FL range	Number	FL range	Number	FL range	Number	FL range
16	826	35–80	30	79–99	0		25	32–36
17	520	38–84	10	85–90	0		4	32–37
18	2,316	42–88	6	87–92	0		3	35–39
19	2,055	41–90	0		0		0	
20	202	58–91	2	96–115	0		0	
21	234	61–95	1	102	0		0	
22	27	66–102	1	105	0		0	
23	10	69–94	0		0		0	
24	12	72–92	0		0		0	
25	6	75–86	0		0		0	
26	5	61–87	0		0		0	
27	6	71–91	0		0		0	
28	2	74–82	0		0		0	
29	1	85	0		0		0	
30	0		0		0		0	
31	0		0		0		0	
32	0		0		0		0	
33	0		0		0		1	78
34	0		0		0		0	
35	0		0		0		0	
36	0		0		0		0	
37	0		0		0		0	
38	0		0		1	41	0	
39	0		0		0		0	
40	0		0		0		0	
Total	56,901	27–102	396[3/] 162[5/]	33–69 46–115	690[6/] 1[7/]	31–139 41	37[6/] 35[7/]	77–136 32–78

1/ Unmarked salmon were considered in-river produced fish except as noted below.

2/ A large portion of the fall run listed in this table were likely of hatchery origin since in-river and hatchery-produced fall run could not be distinguished (see text).

3/ All spring-run sized fish collected after week 12 (shaded area) were considered fall run based upon CWT data and size distribution of fall run released from CNFH (see text).

4/ One fish was tallied only, not measured.

5/ Total captured after week 12, considered CNFH-produced fall run.

6/ BY 1998

7/ BY 1999

phase 2, in association with a second increase in flow and a large number of fall-run migrants. Two percent were captured during phase 3. Winter-run migration ended in week 14, immediately following the peak of emigration during phase 3 (Figure 21, cf. Figure 6). In addition, 10 winter run were collected several weeks prior to the primary migration period (weeks 40–45), and one winter run from BY 1999 was caught several weeks after the end of the primary emigration period, during week 38 (12–18 September 1999).

We captured 185 winter-run-sized marked salmon. Of these, 45 were confirmed to be winter run released from LSNFH (Table 5), 55 were identified as late-fall run from CNFH based on CWT codes, 13 did not have a CWT, and 72 were released eliminating the ability to check for and read CWTs. As discussed above, we identified 6 of the 13 winter-run-sized fish without a CWT and 57 of the 72 released fish as winter run. In addition, 19 spring-run sized salmon were identified as winter run based on CWT data and three untagged, spring-run-sized salmon were also considered winter run. Altogether, 130 marked fish were identified as hatchery-produced winter run: 64 confirmed by CWT data, 9 without CWT and 57 from the group of released, marked fish.

A total of 153,908 winter run were marked, tagged (CWT) and released into the upper Sacramento River on 28 January 1999 (week 5), about 200 river miles upstream of Knights Landing (Table 3). Of these, an estimated 6,516 (4%) lost or otherwise did not contain a CWT. The 64 (0.04%) confirmed marked winter run were captured from week 6 through week 15 (Table 5, Figure 22). Twelve percent (9 out of 73) of the marked winter run collected at Knights Landing, compared to 4% of the total winter run marked, tagged and released from LSNFH, lost or otherwise did not contain a CWT

Spring-Run-Sized Chinook Salmon

No hatchery-reared spring-run chinook salmon were released into the Sacramento River upstream of Knights Landing. Several thousand wild, spring-run juveniles caught in Butte Creek were marked and released back into Butte Creek. Butte Creek enters the upper portion of the Sutter Bypass and, depending upon flow conditions, the marked fish released into Butte Creek could have entered either the Sacramento River upstream of Knights Landing or the bypass. All unmarked, spring-run-sized chinook salmon captured through week 12 (14–20 March 1999; Figure 21) were considered in-river produced spring run. Beginning in week 13, all spring-run-sized salmon were considered fall-run juveniles based upon the following information:

- Following 3 weeks of zero catch, an increase in the catch of spring-run-sized salmon began in week 13 (8 were caught in week 13, 27 in week 14, and 77 in week 15, and 50 from week 16 through week 22) concurrent with the arrival of marked, hatchery-produced fall run released into the upper river during week 10 (Tables 3 and 5).

- Many of the fall run measured just prior to their release during week 10 were spring-run sized.

Table 5. Summary of catch and size range data for adipose-clipped, hatchery-produced chinook salmon (by run) caught by rotary screw traps in the Sacramento River near Knights Landing, 27 September 1998–2 October 1999.

	Fall run		Winter Run		Late-fall run	
Week	Number	FL range	Number	FL range	Number	FL range
40-47	No adipose-clipped salmon were caught Week 40 through 47					
48	0		0		1	121
49	0		0		2	107-114
50	0		0		0	
51	0		0		3	116-128
52	0		0		6	125-147
1	0		0		4	113-145
2	0		0		0	
3	0		0		22	107-158
4	0		0		39	84-149
5	0		0		33	62-158
6	0		35	56-100	2	106-109
7	0		84	67-98	14	106-134
8	0		2	82	1	114
9	0		2	81-95	1	138
10	7	38-53	0		0	
11	6	36-58	0		0	
12	3	42-52	0		0	
13	2	39-65	3	96-105	0	
14	1	62	3	89-95	0	
15	18	58-84	1	112	0	
16	5	61-87	0		0	
17	29	61-84	0		0	
18	166	57-85	0		0	
19	159	59-85	0		0	
20	9	68-80	0		0	
21	10	77-95	0		0	
No adipose-clipped salmon caught after Week 21						
Total	415	36-95	130	56-112	128	62-158

In-river-produced spring-run chinook salmon (based on size criteria) first appeared in the RSTs during phase 1 of emigration (week 48), and were captured during every week through week 9 (Table 4, Figure 21). A total of 396 in-river-produced spring-run juveniles was collected by RST (Table 4). Their catch distribution had two primary modes corresponding to emigration phases 1 and 2. The first mode peaked over a 3-week period (weeks 49–51) corresponding to the highest flows of phase 1. The second peak occurred during week 5 corresponding to the second major flow episode and a substantial increase in fall-run emigration.

Twenty-four spring-run-sized, marked salmon were caught by RST. All of these fish were caught after week 4. Of these 24 marked fish, 19 were identified as winter run, one as fall run, and one as late-fall run, based upon CWT information.

Fall-Run-Sized Chinook Salmon

Fall-run-sized chinook clearly dominated the catch of in-river-produced juvenile salmon in the RSTs. Altogether, 56,901 fall-run-sized salmon were collected (Table 4). Fall run were first collected during week 49, the fourth week into the primary migration period, and then in every subsequent week through week 29 (17 July 1999; Figure 21).

The catch distribution exhibited several peaks consistent with the emigration phases described above. As with the other salmon runs collected during the survey, the first peak occurred during the initial high flow event (weeks 46–3) followed by two, narrowly separated peaks during the second high flow event (weeks 4–13). The highest catches occurred during this second event. The last two peaks (week 14 and weeks 18–19) were coincident with the arrival of known (based on CWT data) hatchery-reared fall run released from CNFH (Table 3, Figures 21 and 22).

Distinction between in-river and hatchery-produced fall run was problematic throughout much of the monitoring period due to the release of unmarked hatchery-reared fish into the upper river system. In week 5, nearly 0.75 million hatchery-reared fall-run fry were released into the upper Sacramento River, immediately downstream of RBDD (Table 3). These fish were unmarked and otherwise indistinguishable from in-river-produced fall run. As such, all fall-run-sized salmon caught at Knights Landing prior to week 5 were known in-river-produced salmon, but were of unknown origin after week 5 when the first plant of hatchery-produced fall run was made.

More than 12 million, fingerling-sized (mean >70 mm FL) fall run from CNFH were released into the upper Sacramento River system from weeks 9 through 18. Nearly 8% of these fish were marked. Most of these fish were released into Battle Creek, near RM 271.5, during week 10 (3 March 1999), week 14 (31 March 1999), week 17 (20–21 April 1999), and week 18 (27–28 April 1999). In addition, 39,515 in-river produced fall run were captured at RBDD, tagged and released from weeks 5 through 15 (Kevin Niemala, USFWS, pers. comm.). These fish were fry ranging from 34 to 48 mm FL.

A total of 414 fall-run-sized, marked fish was caught by RST: 352 contained tags that identified them as fall run and 62 did not have tags but were considered fall run. In addition, one marked, spring-run-sized salmon was identified by CWT as a fall run. Altogether, 415 marked fall run were collected.

CWT data were obtained from 353 marked fall run captured at Knights Landing. We captured 14 (0.05%) fish from the first release, 19 (0.06%) from the second release, 139 (0.04%) from the third release, and 175 (0.04%) from the fourth release. Fish from the first release were collected at Knights Landing 3 to 43 days after release (mean = 17 days); fish from the second release were captured 6 to 27 days after release (mean = 14 days); fish from the third release were captured 2 to 29 days after release (mean = 8 days); and fish from the last release were captured 1 to 24 days after release (mean = 6 days). We also collected 6 (0.015%) of the in-river produced salmon caught, tagged and released at RBDD.

Based upon CWT recoveries, fall run from the first release into Battle Creek arrived at Knights Landing during week 10 (Table 5, Figure 22). The 415 marked fall run, in addition to 14,377 unmarked fall run, were collected from week 10 through the end of the survey (Tables 4 and 5, Figures 21 and 22). The marked fish accounted for 2.9% of all fall run collected during weeks 10–29 compared to 7.7% of all hatchery-released fall run. Assuming that survival of hatchery-produced fall run to Knights Landing was independent of tagging, about 38% of the fish caught at Knights Landing after week 10 were from CNFH.

Unmarked fall run ranged in size from 27 to 102 mm FL (Table 4). More than 74% of the unmarked fall run were recently emerged-sized fish (<45 mm FL). Recently emerged-sized fall run were collected from week 49 of 1998 through week 19 of 1999 (Table 4, Figure 8). Smolt-sized fall run (>70 mm FL) were collected from week 14 through week 29 and accounted for 13% of the total catch of marked fall run.

Steelhead Trout Emigration

Steelhead trout captured in the RSTs represented three age groups: young-of-the-year (<100 mm FL), both in-river and hatchery-produced yearlings (100–300 mm FL), and adults (>300 mm FL). Scales collected from fish >100 mm FL and marked fish will be analyzed and should help further define these groups.

Young-of-the-year Steelhead

Only two YOY steelhead (56 and 96 mm FL) were collected, both in week 49 (Table 6, Figure 23).

Yearling Steelhead

We collected 43 unmarked, yearling-sized steelhead from week 49 through week 23 (29 November 1998–5 June 1999) (Table 6, Figure 23). Five percent were caught in December, 2% in January, 7% in February, 21% in March, 42% in April, 21% in May, and 2% in June. More than 75% of these fish were caught during emigration phase 3, after week 13. The only notable peak in catch distribution occurred during week 15 (8 fish), one week after the release of nearly 1 million CNFH-produced fall run into the upper river system (Table 3). Only two, unmarked, yearling-sized steelhead were caught during the first phase and eight during the second phase (Table 6; Figure 23).

A total of 496,525 marked steelhead was planted about 180 river miles upstream from Knights Landing during weeks 2 and 3 (Table 3). We collected 82 (~0.02%) marked yearling steelhead from week 4 through week 20 (Table 6, Figure 23).

Unmarked yearling steelhead ranged from 113 to 278 mm FL (mean = 214 mm FL). There was no clear trend in size versus time of capture (Figures 24–29). Nearly identical to unmarked yearling steelhead, marked steelhead ranged from 115 to 280 mm FL (mean = 216 mm FL).

Adult Steelhead

Five adult-sized steelhead were collected (Table 6): one each in week 2 (348 mm FL), week 16 (326 mm FL), week 18 (475 mm FL), week 19 (403 mm FL), and week 22 (310 mm FL). These fish were likely ≥2-year-old smolts produced in-river. Scale analyses will provide further age-at-size information for these fish.

Table 6. Summary of catch statistics for steelhead trout caught by rotary screw trap in the Sacramento River near Knights Landing, 27 September 1998–2 October 1999.

Week	Catch statistics							
	Young-of-year		Yearling (no clip)		Yearling (adipose clip)		Adult	
	Count	Mean FL (mm) (range)	Count	Mean FL (mm) (range)	Count	Mean FL (mm) (range)	Count	Mean FL (mm) (range)
40-48	No steelhead caught Week 40 through Week 48							
49	2	76 (56-96)	2	176 (113-238)	0		0	
50	0		0		0		0	
51	0		0		0		0	
52	0		0		0		0	
1	0		0		0		0	
2	0		0		0		1	348
3	0		0		0		0	
4	0		1	195	14	212 (179-270)	0	
5	0		0		16	220 (190-263)	0	
6	0		0		5	214 (203-235)	0	
7	0		1	253	11	220 (193-232)	0	
8	0		0		1	192	0	
9	0		2	212 (201-222)	1	235	0	
10	0		1	215	3	216 (202-226)	0	
11	0		1	194	1	209	0	
12	0		1	201	1	201	0	
13	0		1	196	2	217 (203-230)	0	
14	0		5	230 (161-260)	13	220 (115-280)	0	
15	0		8	219 (175-266)	4	215 (208-234)	0	
16	0		3	220 (197-240)	3	211 (206-218)	1	326
17	0		2	181 (157-204)	4	196 (145-237)	0	
18	0		5	221 (196-276)	1	215	1	475
19	0		1	206	0		1	403
20	0		1	202	2	227 (225-228)	0	
21	0		0		0		0	
22	0		4	215 (179-278)	0		1	310
23	0		4	216 (196-246)	0		0	
24-40	No steelhead caught Week 24 through Week 40							
Total	2	76 (56-96)	43	214 (113-278)	82	216 (115-280)	5	372 (310-475)

RST Gear Efficiency Using Mark-Recapture

Salmon were marked for efficiency evaluations beginning in week 52 (Table 7). A total of 27,567 chinook salmon was marked from week 52 through week 21. Overall, 106 (0.38%) salmon were recaptured. The percent recaptured, by week, ranged from 0% during week 12 to 1.91% during week 6. The mean trap efficiency during the 22-week period was 0.62% (SD = 0.51%).

For comparison, mean ± SD RST efficiency on other large Central Valley rivers was: 0.81% ± 0.89% on the upper Sacramento River at Balls Ferry (RM 278) during 1997–1998 (California Department of Fish and Game 1999); 0.8% (range = 0.39%–1.75%) at Thermalito and 0.2% (range = 0%–0.53%) at Live Oak on the Feather River during 1997–1998 (California Department of Water Resources 1999); and 0.75% ± 0.70% at Watt Avenue on the lower American River during 1996–1997 (Snider and Titus 2000a). Mean trap efficiency at Knights Landing was thus within the range of RST efficiencies seen on other large Central Valley rivers.

The size distributions of marked and recaptured salmon were compared for size-selectivity by the RSTs. Overall, marked salmon averaged (±SD) 45.1 ± 14.4 mm FL (n = 22,100) while recaptured salmon averaged 44.8 ± 13.4 mm FL (n = 101), and the medians of these two distributions were not significantly different (Mann–Whitney W test, p>0.27). Graphical analysis of the distributions (Figure 30) did reveal one notable difference, though, that no salmon >80 mm FL were recaptured in the RSTs. However, only 333 (1.5%) of the 22,100 salmon marked and released during 17 weeks of gear efficiency trials were >80 mm FL, and at a mean efficiency of 0.62%, only two salmon from that size group would be expected to be recaptured, assuming equal likelihood of recapture among all sizes. Unfortunately, insufficient information is available this year to clearly determine if there is any bias regarding capture of larger fish with RSTs at Knights Landing. Investigations done in 1996 (Snider and Titus 1998) did indicate that the RSTs were not biased in collection of larger fish, based on trawling conducted concurrent with trapping.

There were no significant correlations between weekly trap efficiency and the number of fish marked per week ® = –0.43, p>0.08), number of fish caught per week ® = –0.35, p>0.16), mean weekly water transparency ® = 0.42, p>0.09), and mean weekly water temperature ® = 0.26, p>0.30). There was a significant but relatively weak negative correlation between efficiency and mean weekly flow ® = −0.57, p<0.02). In four seasons of trapping at Knights Landing, we have found no consistent relationship between trap efficiency and these variables (Table 8). Few significant correlations have been observed and correlations with each variable have included conflicting positive and negative correlations in different years. Thus, those significant correlations observed are regarded as spurious.

Because trap efficiency at Knights Landing does not vary consistently with any measured factor, and to allow for determination of confidence intervals using standard statistical methods (e.g., Zar 1984), abundance estimates were calculated using the mean of weekly trap efficiency estimates (see below).

Table 7. Summary of capture efficiency test results for chinook salmon collected by rotary screw traps in the Sacramento River near Knights Landing, 27 September 1998–2 October 1999.

Week	Number marked	Number recovered	Efficiency (%)	Week	Number marked	Number recovered	Efficiency (%)
52	237	2	0.84	11	1,025	5	0.49
1	0	0	-	12	479	0	0.00
2	0	0	-	13	117	1	0.85
3	0	0	-	14	1,265	12	0.94
4	0	0	-	15	426	1	0.23
5	5,735	18	0.31	16	358	3	0.84
6	943	18	1.91	17	0	0	-
7	5,895	8	0.14	18	1,424	7	0.49
8	3,508	8	0.23	19	1,089	8	0.73
9	2,612	7	0.27	20	230	1	0.43
10	2,098	5	0.24	21	126	2	1.59
				Total	27,567	106	0.38

Table 8. Correlation matrix of weekly rotary screw trap capture efficiency for juvenile chinook salmon at Knights Landing on the Sacramento River, and (i) number of salmon marked per week for efficiency tests, (ii) total salmon catch per week, (iii) weekly mean water temperature, (iv) weekly mean water transparency (Secchi depth, ft), and (v) weekly mean river flow, in 1995–1996, 1996–1997, 1997–1998, and 1998–1999. * denotes a significant correlation at $p \leq 0.05$.

Season	No. salmon marked per week	Total salmon catch per week	Weekly mean water temp.	Weekly mean transparency	Weekly mean river flow
1995–96	0.22	0.62*	–0.32	–0.37	0.26
1996–97	–0.34	–0.30	–0.29	–0.21	0.41
1997–98	0.23	0.19	–0.31	0.24	–0.47*
1998–99	–0.43	–0.35	0.26	0.42	–0.57*

Relative Abundance Estimates

A primary objective of monitoring at Knights Landing is to make an abundance estimate for juvenile salmonids emigrating from the upper Sacramento River system into the lower river and Delta. Mean weekly trap efficiency (0.0062) and associated 80% confidence interval (0.0045–0.0079) were used to estimate the abundance of each salmon run and steelhead. Both the in-river and hatchery-produced portions of each group were estimated. Estimates of hatchery-produced juveniles were made only for groups containing marked fish. Thus, no attempt was made to determine the number of salmon captured at Knights Landing that came from the 0.8 million unmarked fall-run fry planted 29 January 1999.

In order to estimate the number of fish that passed Knights Landing during the entire emigration period, including those few weeks when trapping effort was less than 100%, we expanded the total catch of each species and race to represent 100% effort. The weekly catch was estimated for those weeks when trapping effort was less than 100% by expanding the catch in proportion to the percentage of actual effort. For example, if effort was 80% the estimate was made by dividing the actual catch by 0.8. The catch of unmarked fish was increased by 2,595 for fall run, 65 for spring run, 156 for winter run, 11 for BY 1998 late-fall run, and two for steelhead. The marked catch was increased by six for fall run, 11 for winter run, nine for late-fall run and three for steelhead. These numbers were added to the actual counts and used in the calculation of the total estimates (Tables 9 and 10).

The estimated number of marked and unmarked hatchery-produced fish was determined (Table 9). Estimated survival to Knights Landing of hatchery salmonids by run/species ranged from 2.7% to 14.8%.

In-river produced fish were estimated by subtracting the estimated hatchery-produced component passing Knights Landing (results from Table 9), by cohort, from the estimated total abundance of each cohort moving past the site (Table 10). Overall, an estimated 10.0 million chinook salmon (80% CI, 7.8 million–13.7 million) emigrated past Knights Landing into the lower Sacramento River and Delta. About 90% of those were estimated to have been produced in-river. An estimated 20,968 yearling steelhead (80% CI, ~16,500–28,900) emigrated past Knights Landing. In contrast to salmon, only 35% of those fish were estimated to have been produced in-river.

Emigration from the upper Sacramento River system to the Delta is exclusively through Knights Landing until flow increases require diversion through the Sutter Bypass, upstream of Knights Landing. Typically, diversion to the bypass via the Tisdale Weir occurs when flow exceeds about 23,000 cfs. In 1998–1999, flow exceeded 23,000 cfs during weeks 49 and 50 (29 November–12 December 1998, and during weeks 7 through 12 (7 February–20 March 1999). Since the proportion of juvenile salmonids that emigrate through the bypass is unknown, the magnitude of salmonids emigrating to the Delta cannot be estimated by just using Knights Landing results. However, the temporal distribution and, likely, the relative abundance of juvenile salmonids migrating toward the Delta are reflected in the Knights Landing results.

Table 9. Estimates (80% CI) of the number of hatchery-produced chinook salmon and yearling steelhead trout that passed the Knights Landing monitoring site at RM 89.5 on the Sacramento River, from 27 September 1998 through 2 October 1999.

	A	**B**	**C**	**D**	**E**	**F**	**G**
Cohort	Marked caught	Marked estimate (**A**/0.0062)	No. planted marked	Survival (**B**/**C**)*	No. planted unmarked	No. estimated unmarked (**D**×**E**)	No. estimated hatchery total (**B**+**F**)
Late-fall run	137	22,097 (17,342–30,444)[1/]	809,702	0.027 (0.021–0.038)	0	0	22,097 (17,342–30,444)
Winter run	141	22,742 (17,848–31,333)	153,908	0.148 (0.116–0.204)	0	0	22,742 (17,848–31,333)
Fall run	421	67,903 (53,291–93,556)	1,004,915	0.068 (0.053–0.093)	12,793,152	869,934 (678,037–1,189,763)	937,837 (731,328–1,283,319)
Steelhead	85	13,710 (10,759–18,889)	496,525	0.028 (0.022–0.038)	0	0	13,710 (10,759–18,889)

[1/] 80% CI of 0.0062 used in estimates was 0.0045–0.0079.

Table 10. Estimates (80% CI) of the number of in-river-produced chinook salmon and yearling steelhead trout that passed the Knights Landing monitoring site at RM 89.5 on the Sacramento River, from 27 September 1998 through 2 October 1999.

Cohort	A Total caught	B Estimated total (A/0.0062)[1/]	C Hatchery total (from Table 9)	D In-river-produced total (B−C)
Late-fall run (BY 1998)	185	29,839 (23,418–41,111)	22,097 (17,342–30,444)	7,742 (6,076–10,667)
Late-fall run (BY 1999)	35	5,645 (4,430–7,778)	0	5,645 (4,430–7,778)
Winter run (BY 1998)	987	159,194 (124,937–219,333)	22,742 (17,848–31,333)	136,452 (107,089–188,000)
Winter run (BY 1999)	1	161 (127–222)	0	161 (127–222)
Spring run	461	74,355 (58,354–102,444)	0	74,355 (58,354–102,444)
Fall run[1/]	60,081	9,690,484 (7,605,190–13,351,333)	937,837 (731,328–1,283,319)	8,752,647 (6,873,862–12,068,014)
Total salmon	61,750	9,959,677 (7,816,456– 13,722,222)	982,676 (766,518– 1,345,096)	8,977,001 (7,049,938–12,377,126)
Steelhead	130	20,968 (16,456–28,889)	13,710 (10,759–18,889)	7,258 (5,697–10,000)

1/ Includes spring-run-sized salmon collected after week 12.
2/ 80% CI of 0.0062 used in estimates was 0.005–0.008.

ACKNOWLEDGMENTS

The Knights Landing monitoring project is part of the Interagency Ecological Program (IEP) Salmonid Project Work Team's (SPWT) juvenile salmonid monitoring program. It was partially funded by the California Department of Water Resources (DWR) as part of DWR's contribution to the IEP. Many of the agencies and private entities involved in management activities within the Sacramento-San Joaquin Delta and its tributaries are represented on the SPWT, including the National Marine Fisheries Service, U. S. Fish and Wildlife Service, California Department of Water Resources, California Department of Fish and Game, State Water Contractors, and Metropolitan Water District.

We wish to thank the field crews consisting of Leah Aragon, Nina Bacey, Keely Carroll, Anthony Ciarico, Robert Coyan, Jamie Galos, Kim Gillespie, Bill Guthrie, Matt Icanberry, Jennifer Ikemoto, Warren Nichols, Shawn Oliver, Britt Pearson, Deanna Phelps, Glenn Sibbald, Bob Solecki, Ray von Flue, C. J. Weightman, and Celia Zamora of the California Department of Fish and Game. A special thanks goes to Katherine Berry and Glenn Sibbald for their assistance in data management and analysis and preparation of the numerous graphics.

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FIGURES

Sacramento River and tributaries

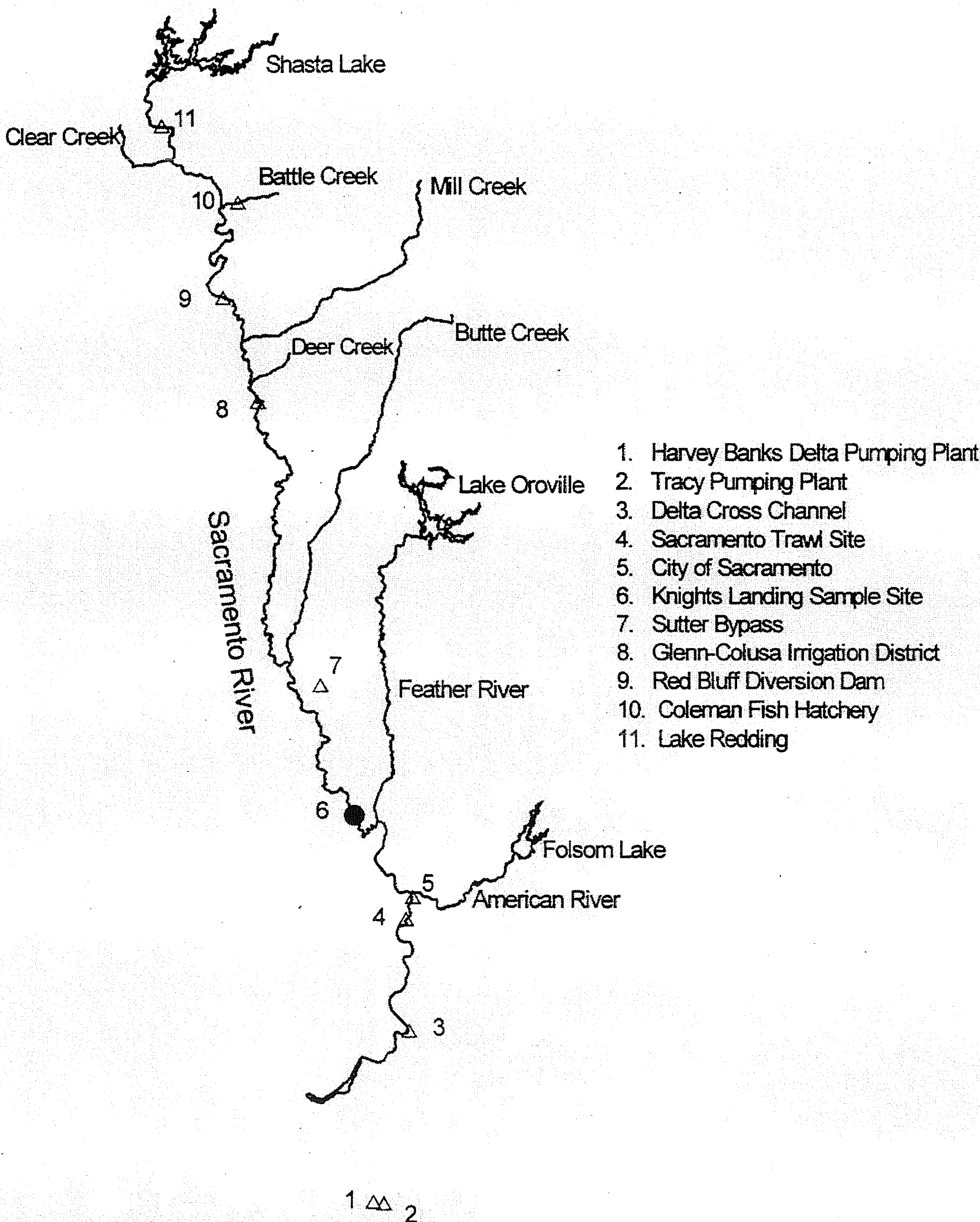


Figure 1. Relative location of Knights Landing monitoring site in the upper Sacramento River

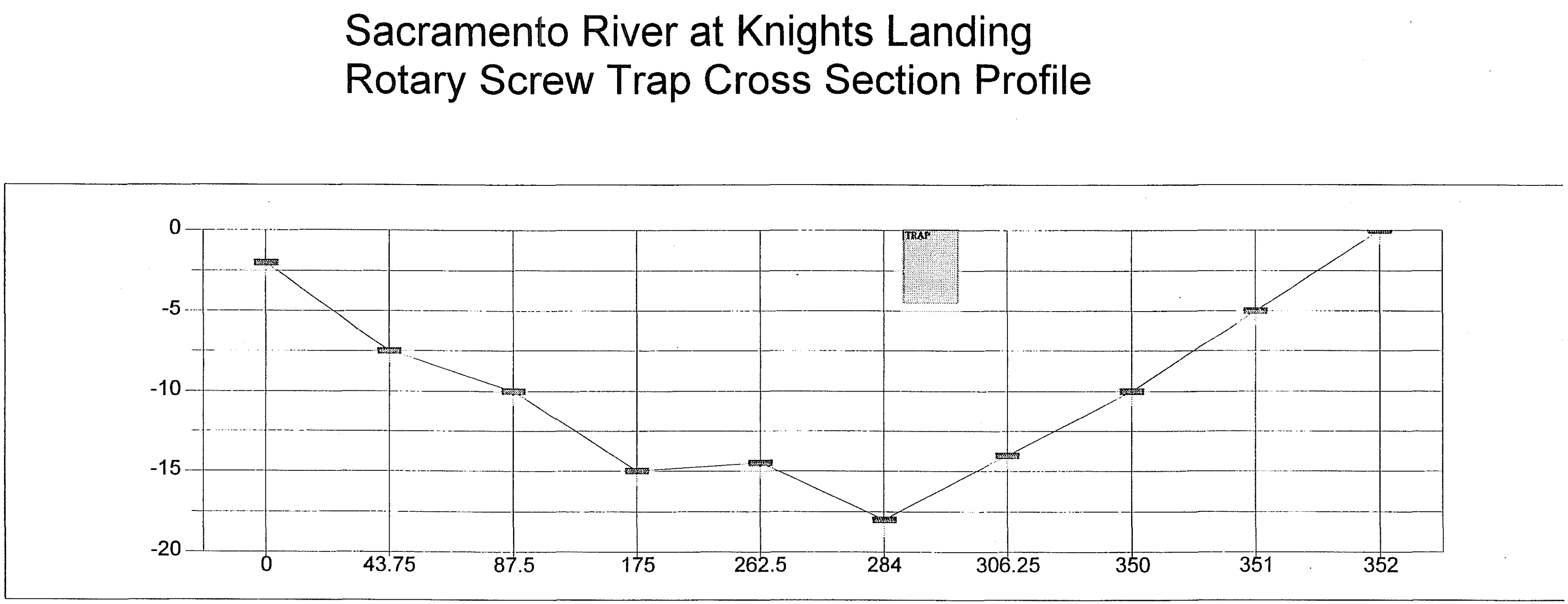


Figure 2. Cross section profile of Sacramento River at the Knights Landing rotary screw trap sampling location, River Mile 89.5.

Sacramento River flow and water temperature near Knights Landing

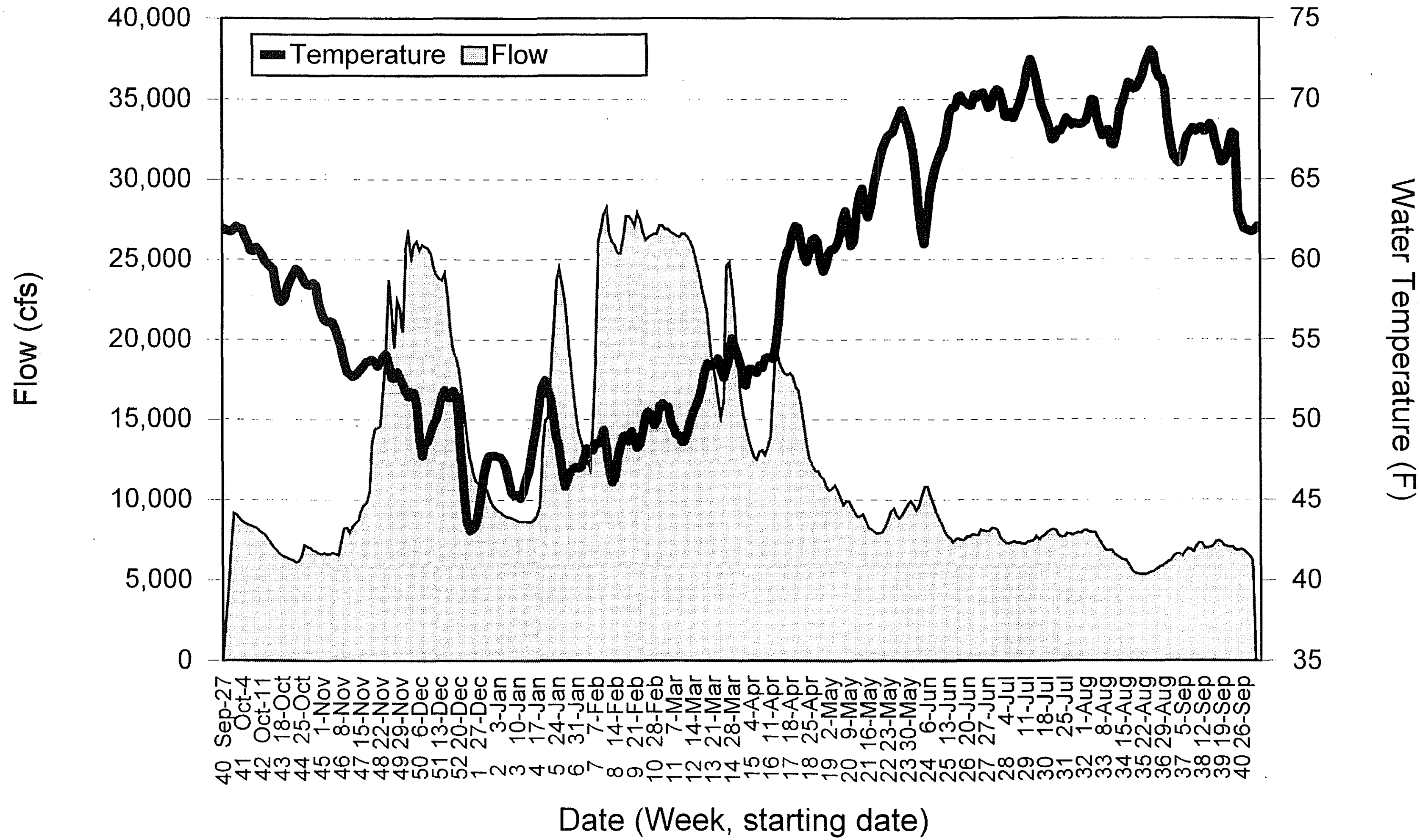


Figure 3. Mean daily flow measured in the Sacramento River near Knights Landing at Wilkins Slough, and mean daily water temperature measured at Knights Landing, 27 September 1998 - 2 October 1999.

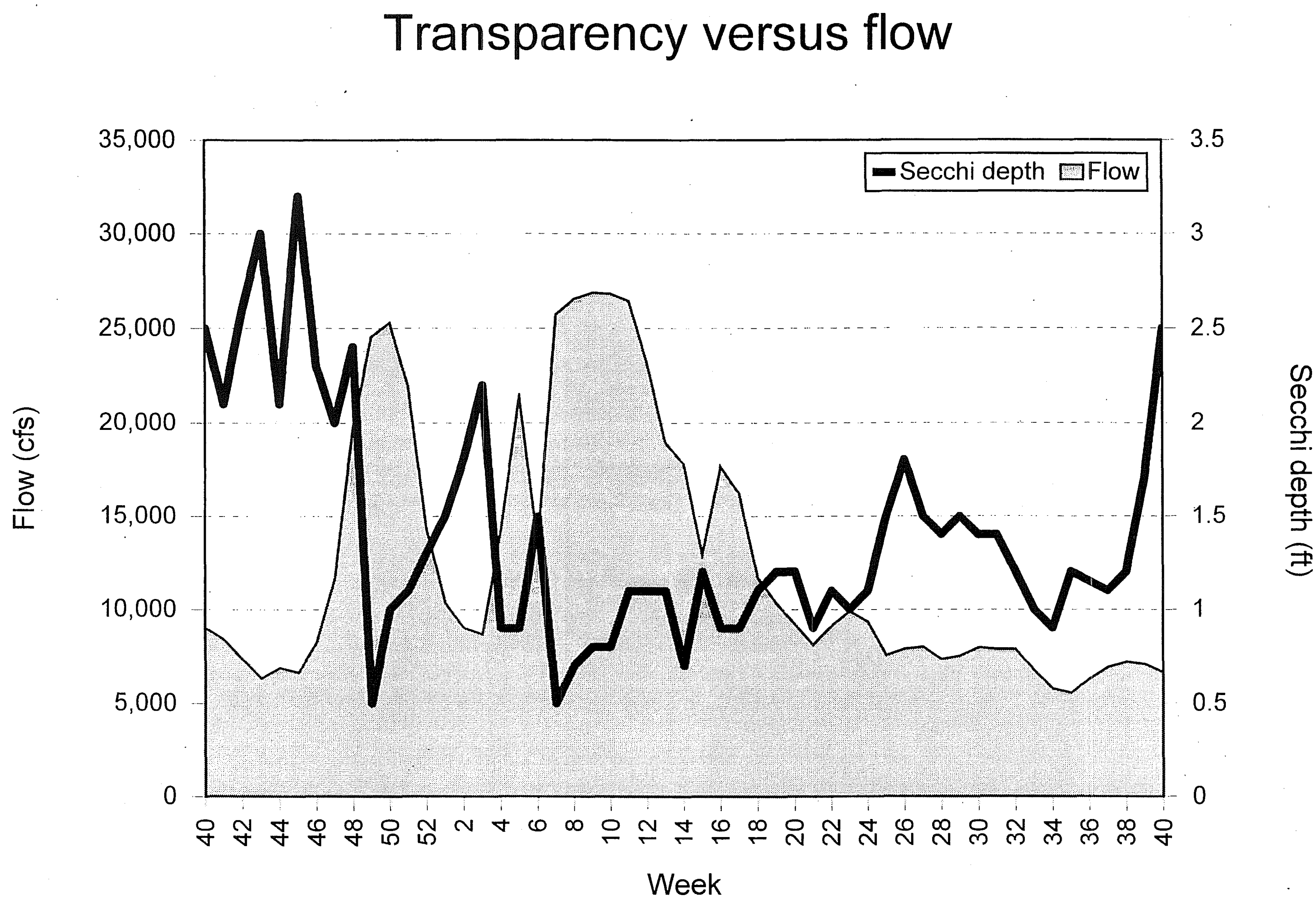


Figure 4. Mean weekly flow compared with mean weekly transparency (Secchi depth) measured in the Sacramento River near Knights Landing, 27 September 1998 - 2 October 1999.

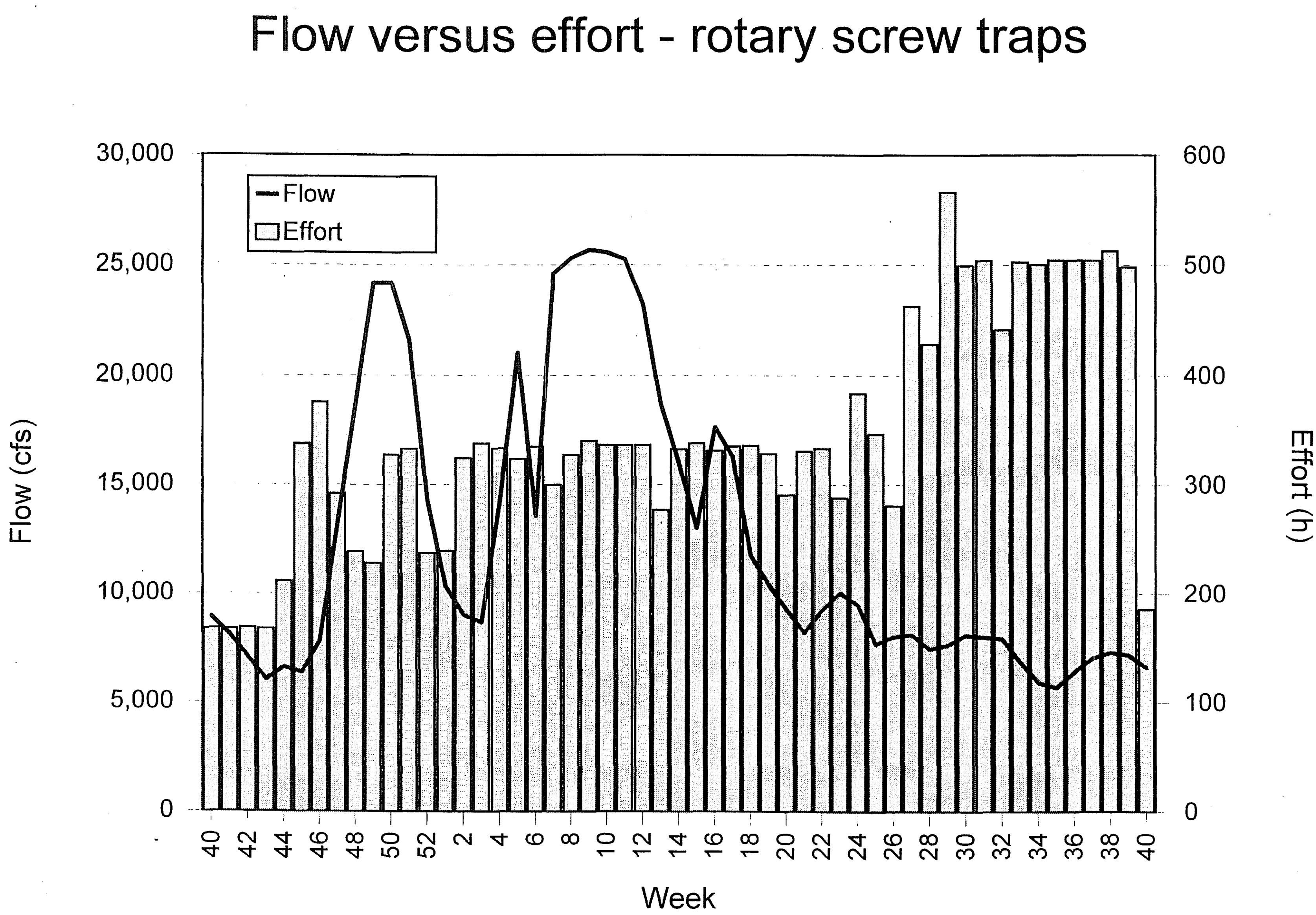


Figure 5. Mean weekly flow versus effort expended by rotary screw traps in the Sacramento River near Knights Landing, 27 September 1998 - 2 October 1999.

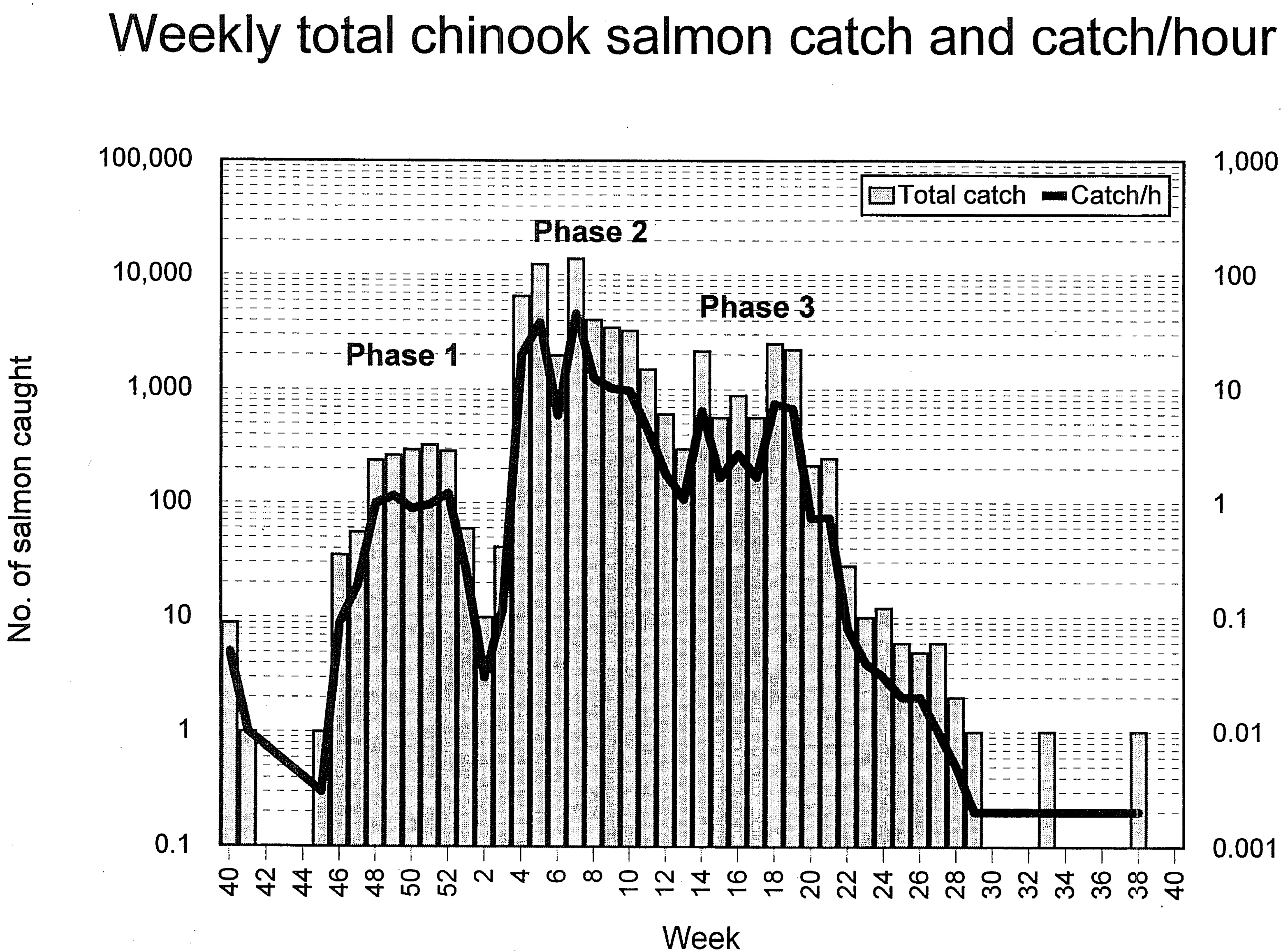


Figure 6. Comparison of weekly total catch and catch-rate for chinook salmon collected by rotary screw traps in the Sacramento River near Knights Landing, 27 September 1998 - 2 October 1999.

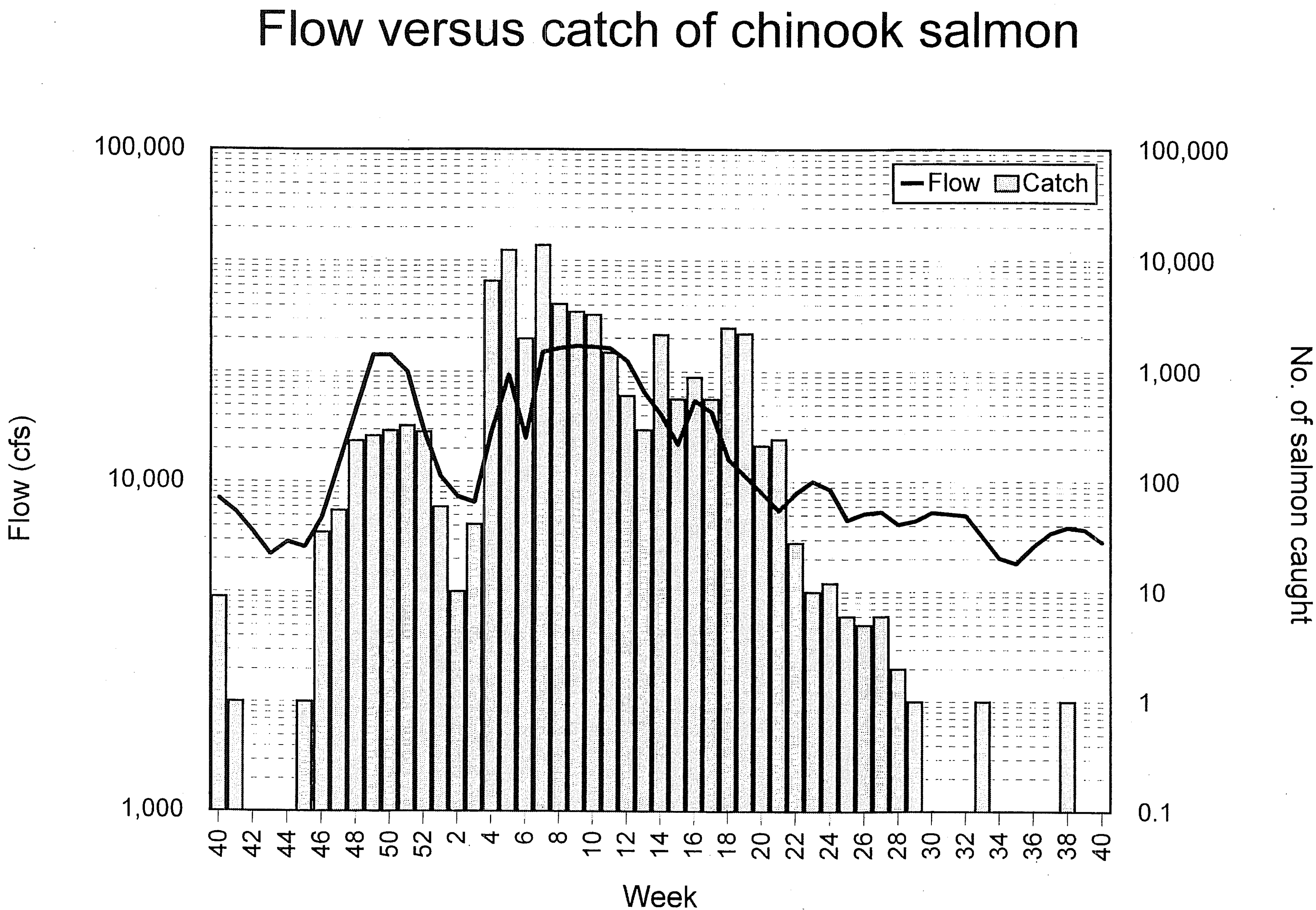


Figure 7. Comparison of mean weekly flow and weekly total catch of all chinook salmon collected by rotary screw traps in the Sacramento River at Knights Landing, 27 September 1998 - 2 October 1999.

Mean weekly size and size range of chinook salmon

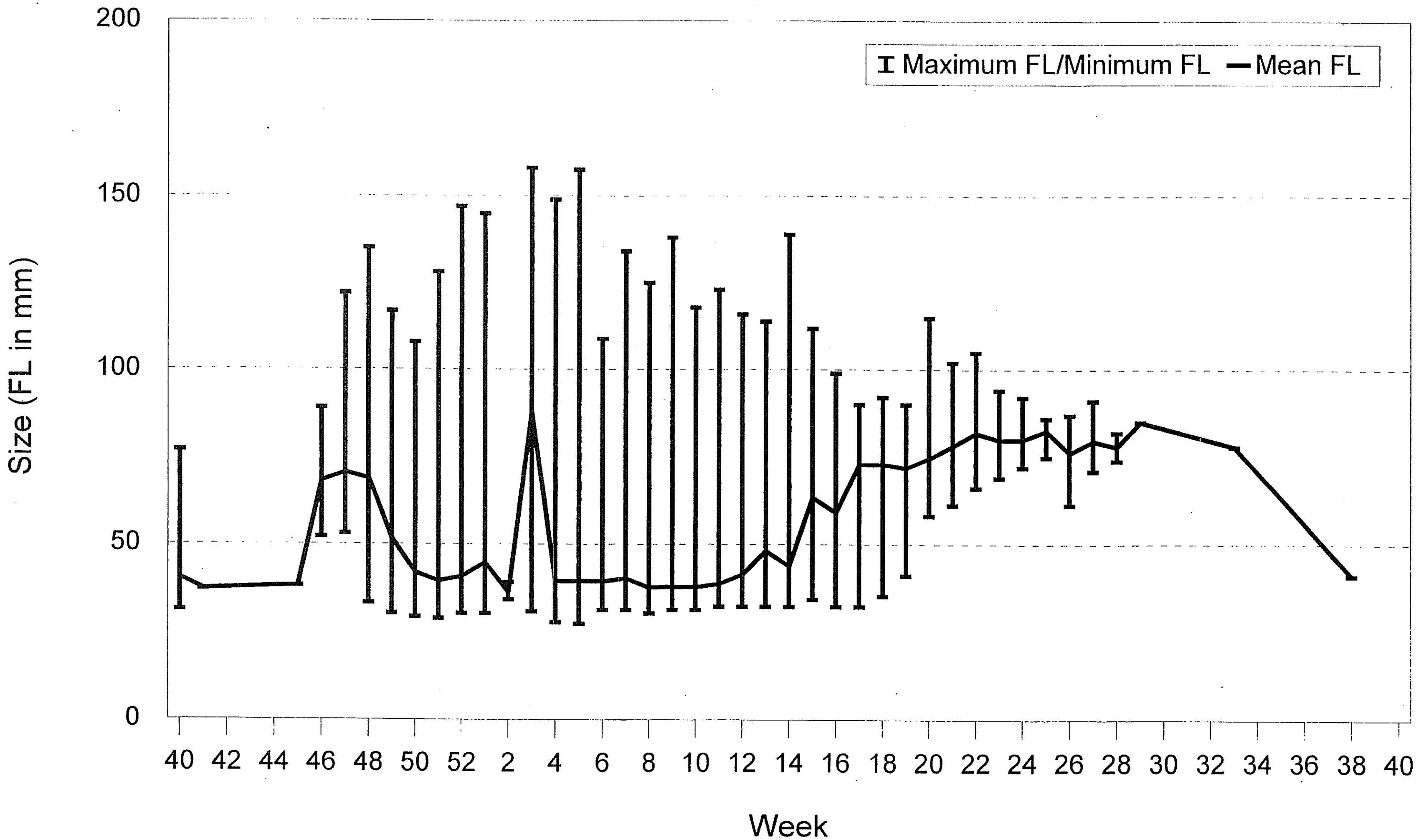


Figure 8. Mean weekly size (FL in mm) and size range of chinook salmon collected by rotary screw trap in the Sacramento River near Knights Landing, September 27 1998 - 2 October 1999.

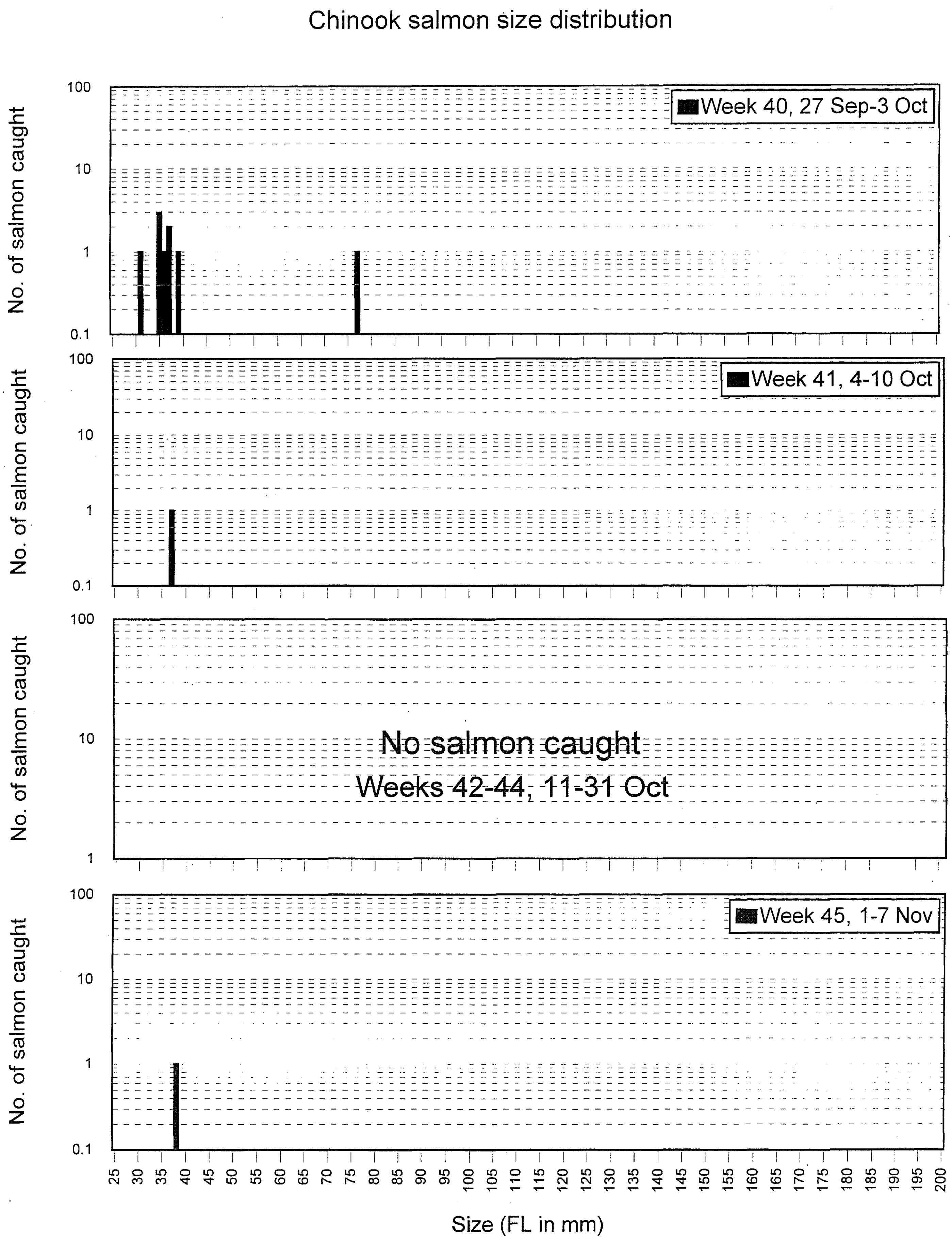


Figure 9. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 27 September through 7 November 1998.

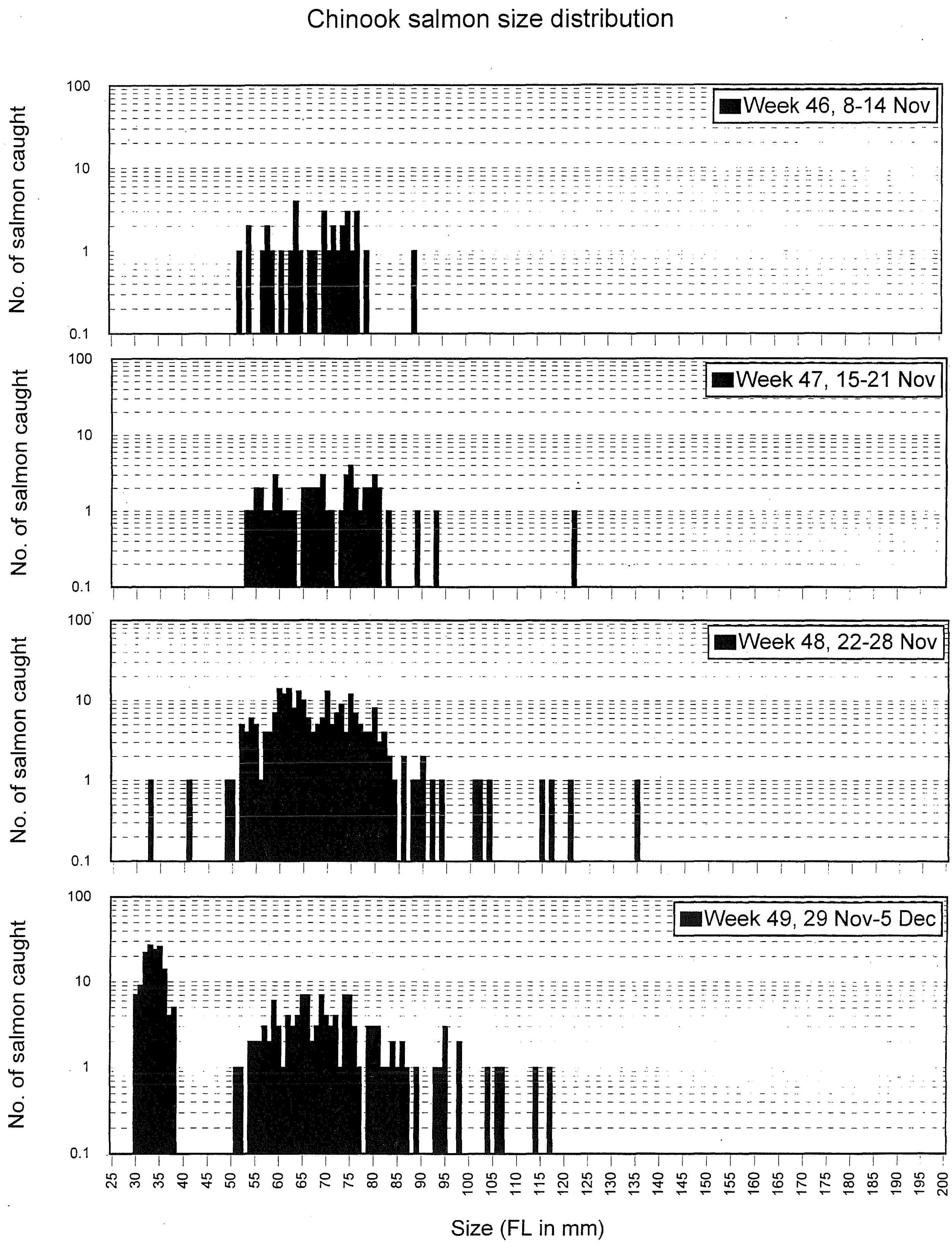


Figure 10. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 8 November through 5 December 1998.

Chinook salmon size distribution

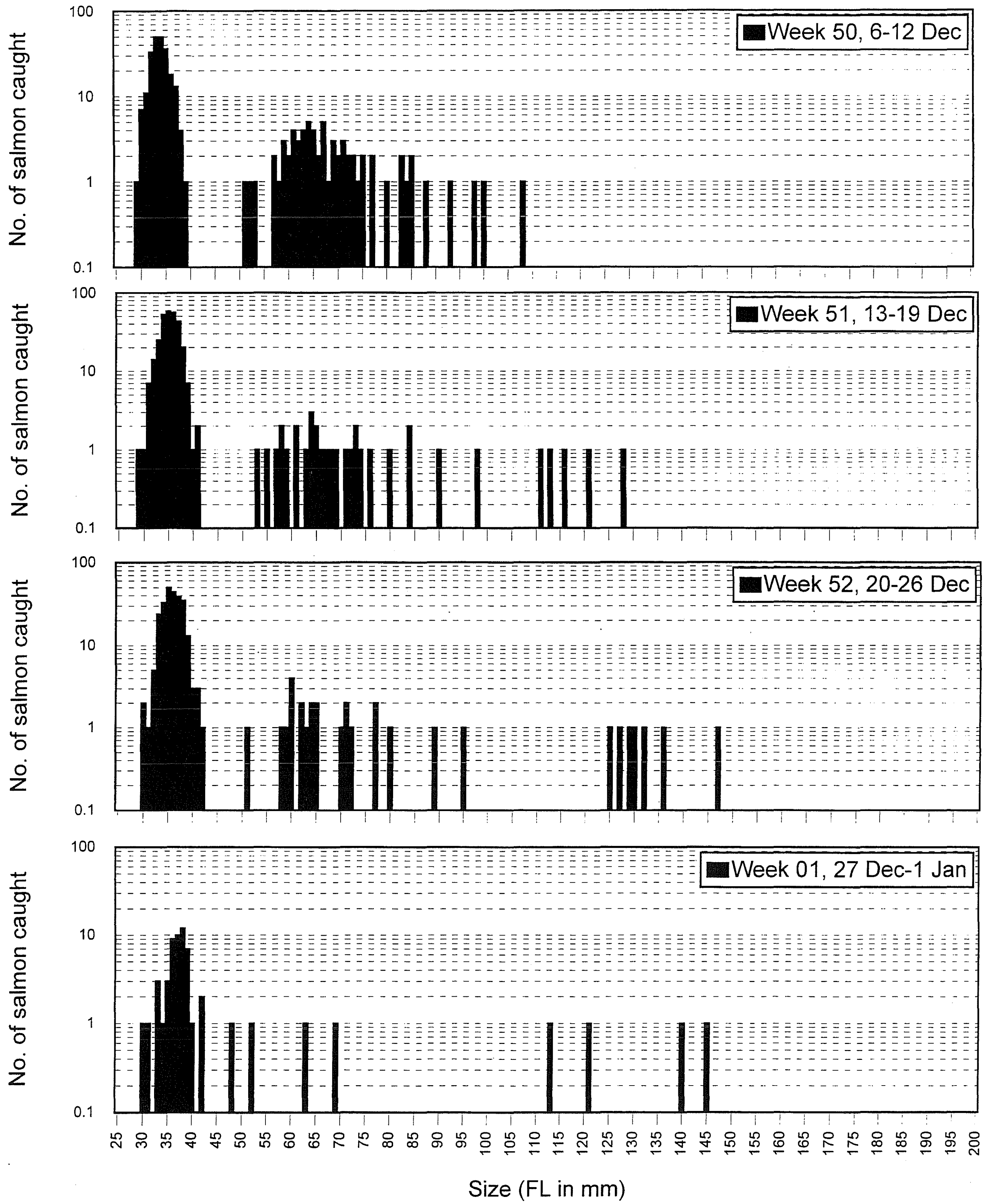


Figure 11. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 6 December 1998 through 2 January 1999.

Chinook salmon size distribution

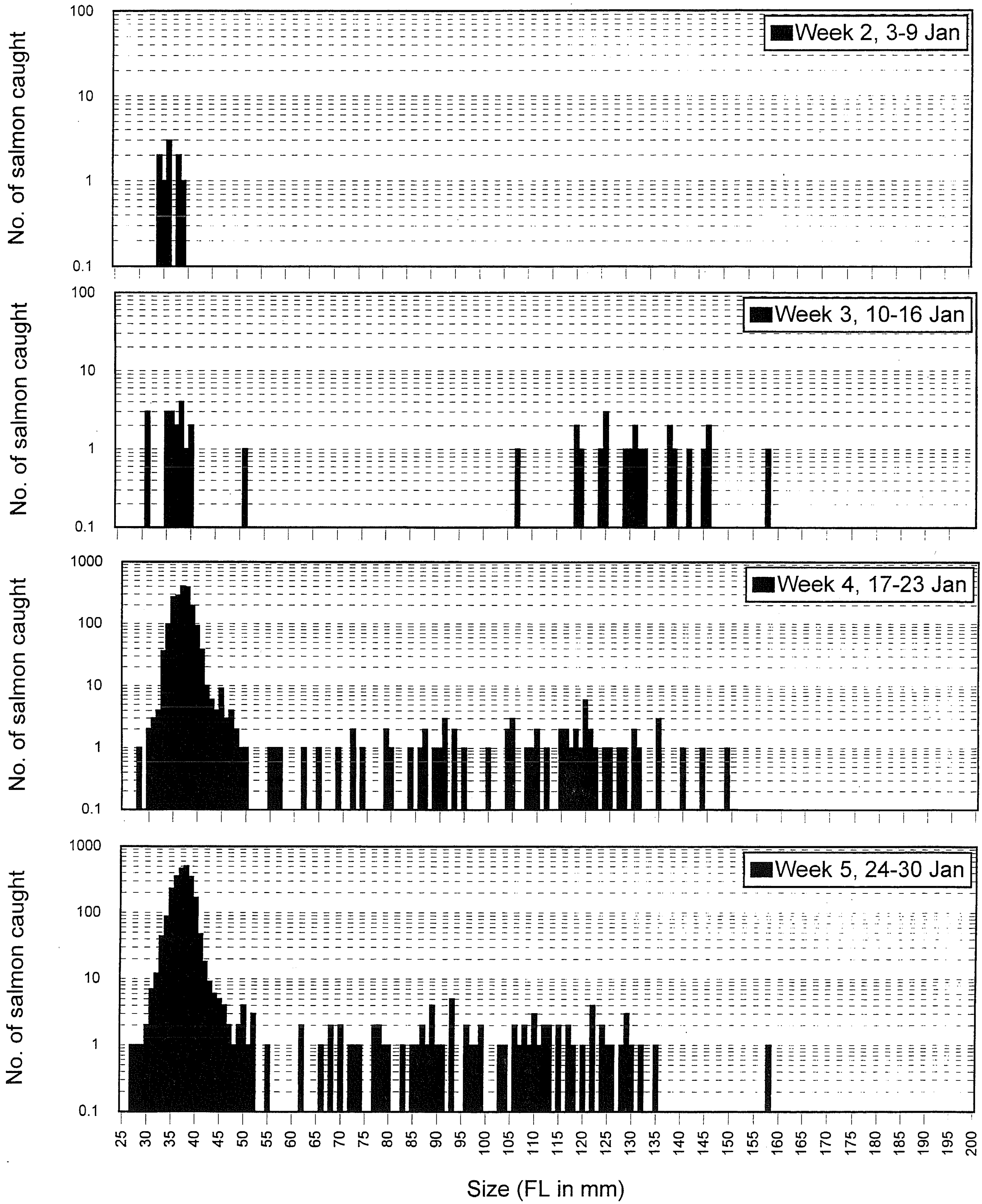


Figure 12. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 3 through 30 January 1999.

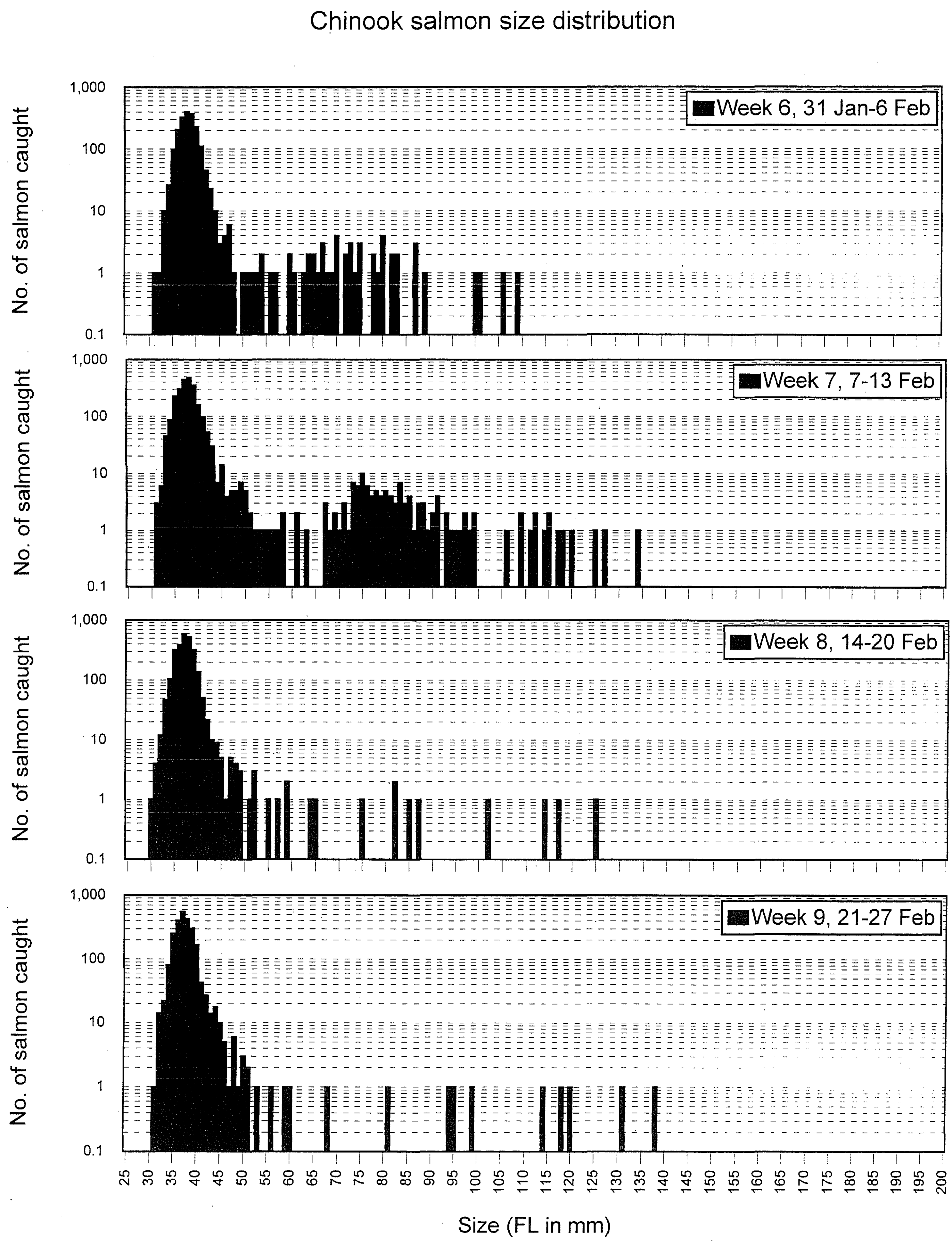


Figure 13. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 31 January through 27 February 1999.

Chinook salmon size distribution

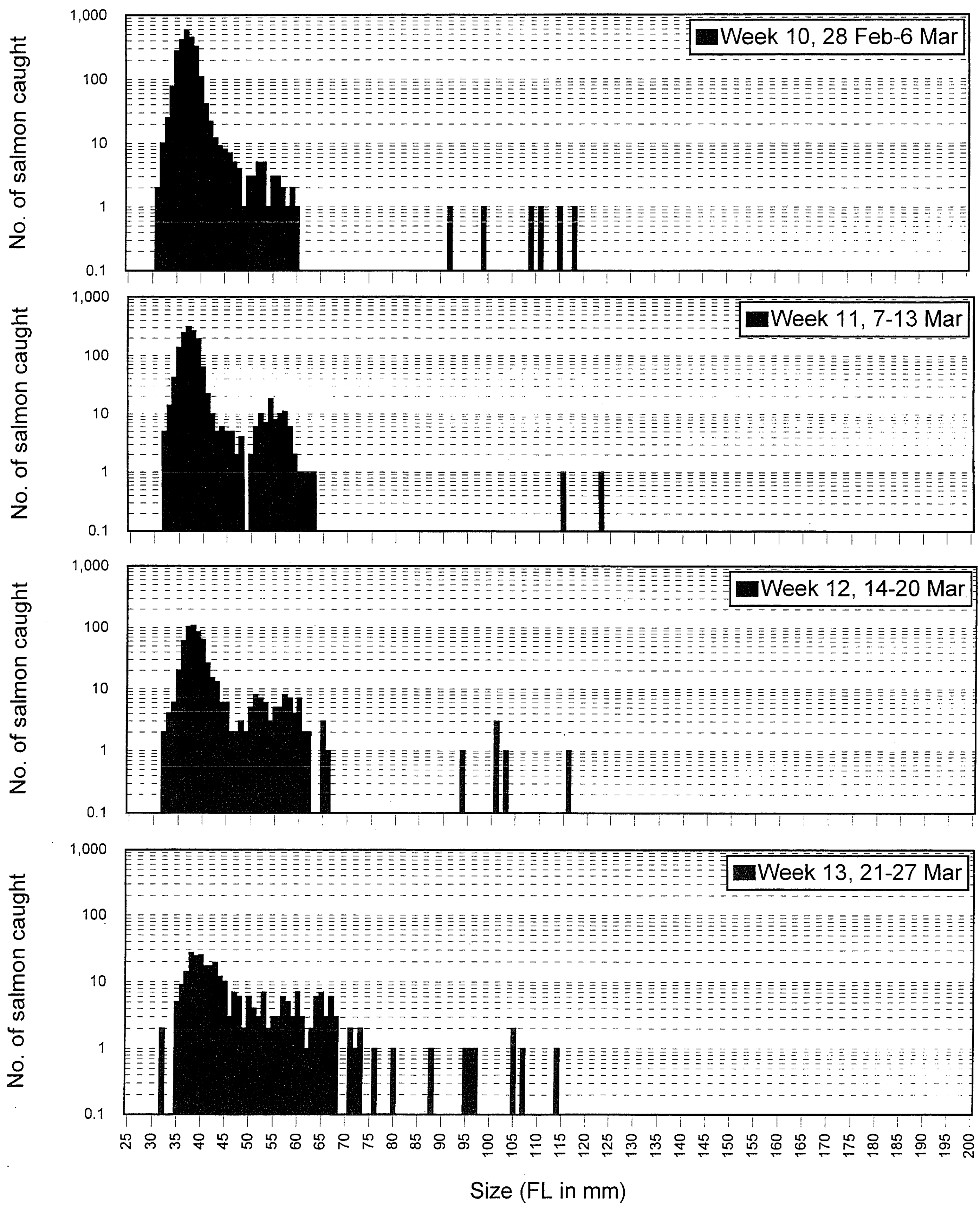


Figure 14. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 28 February through 27 March 1999.

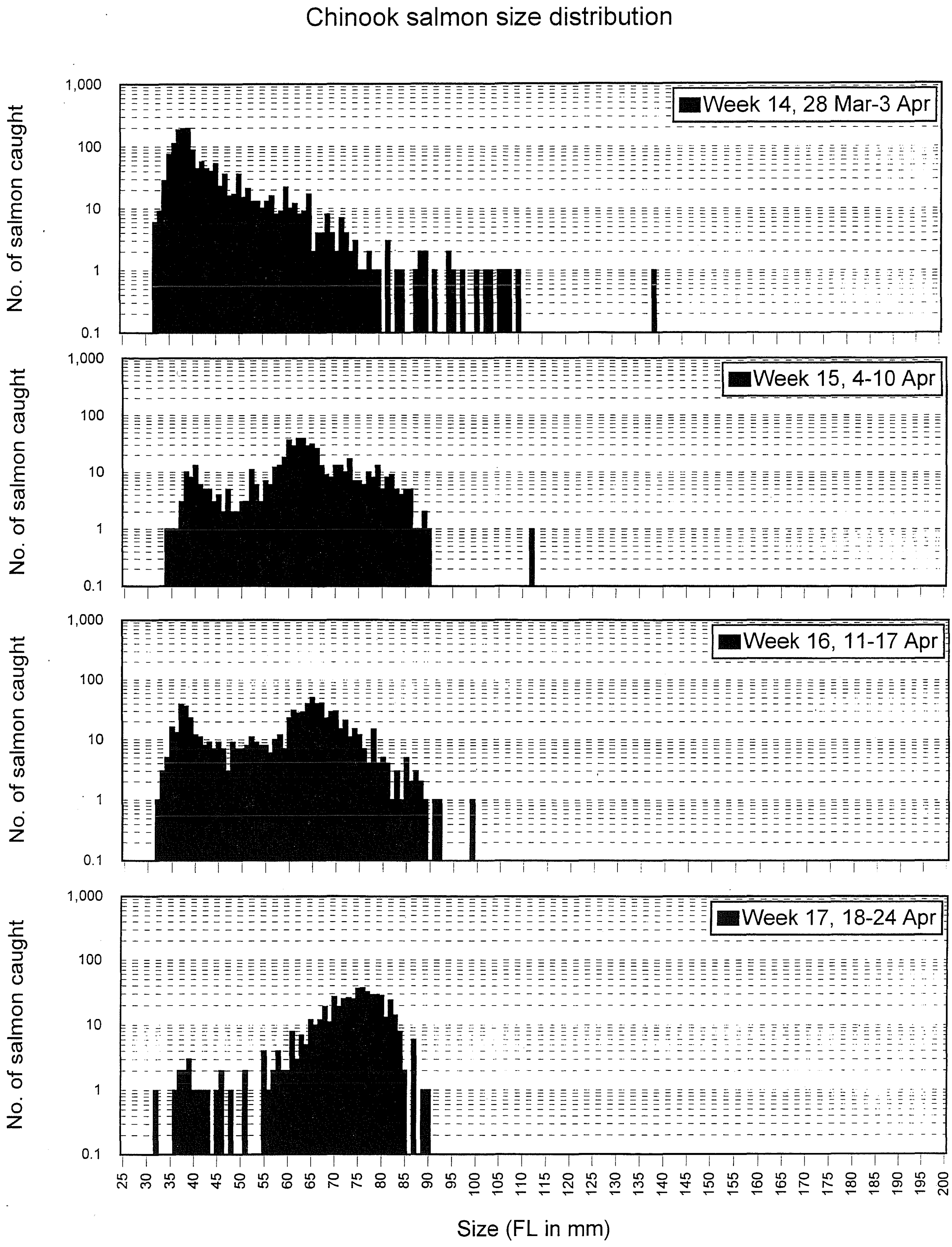


Figure 15. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 28 March through 24 April 1999.

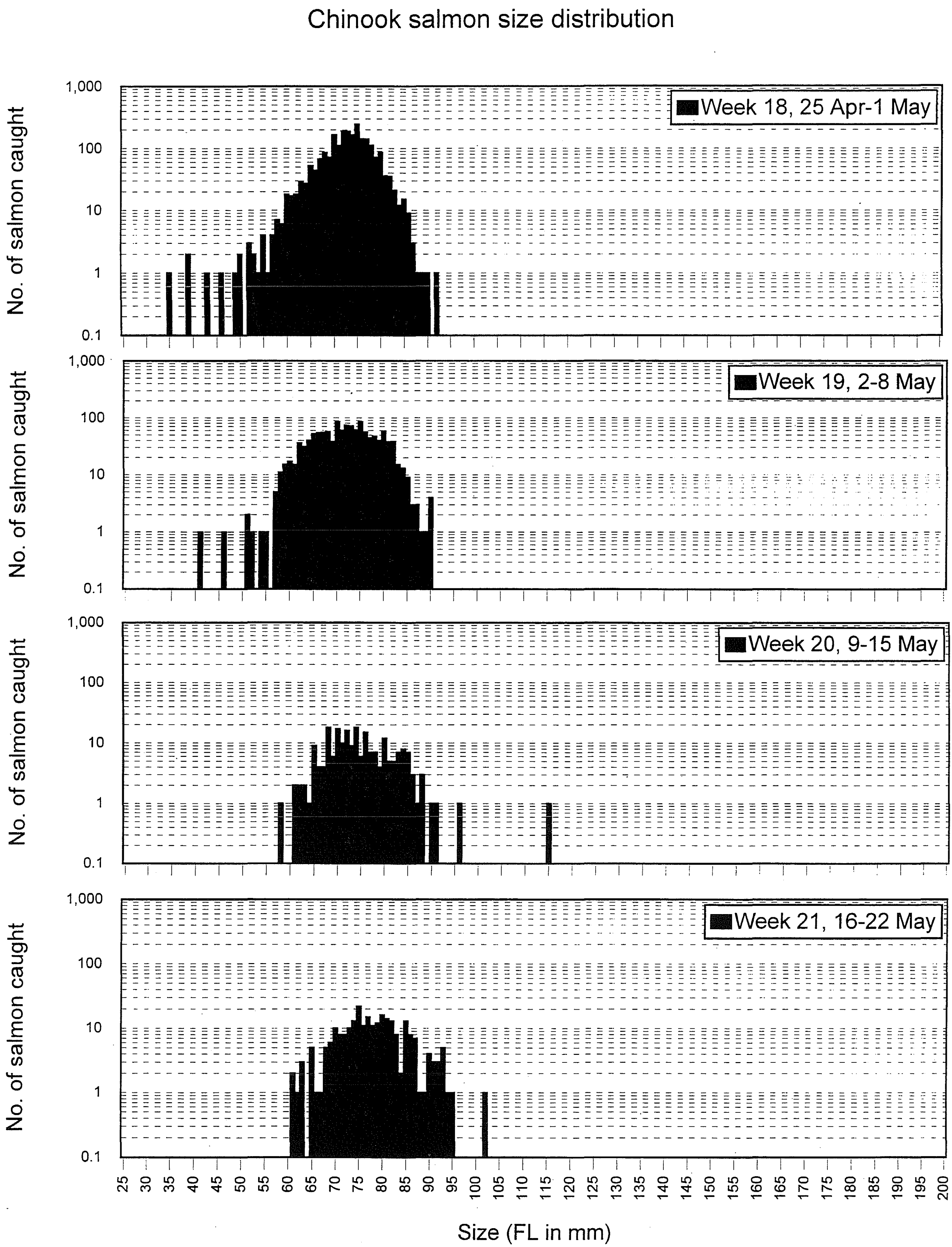


Figure 16. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 25 April through 22 May 1999.

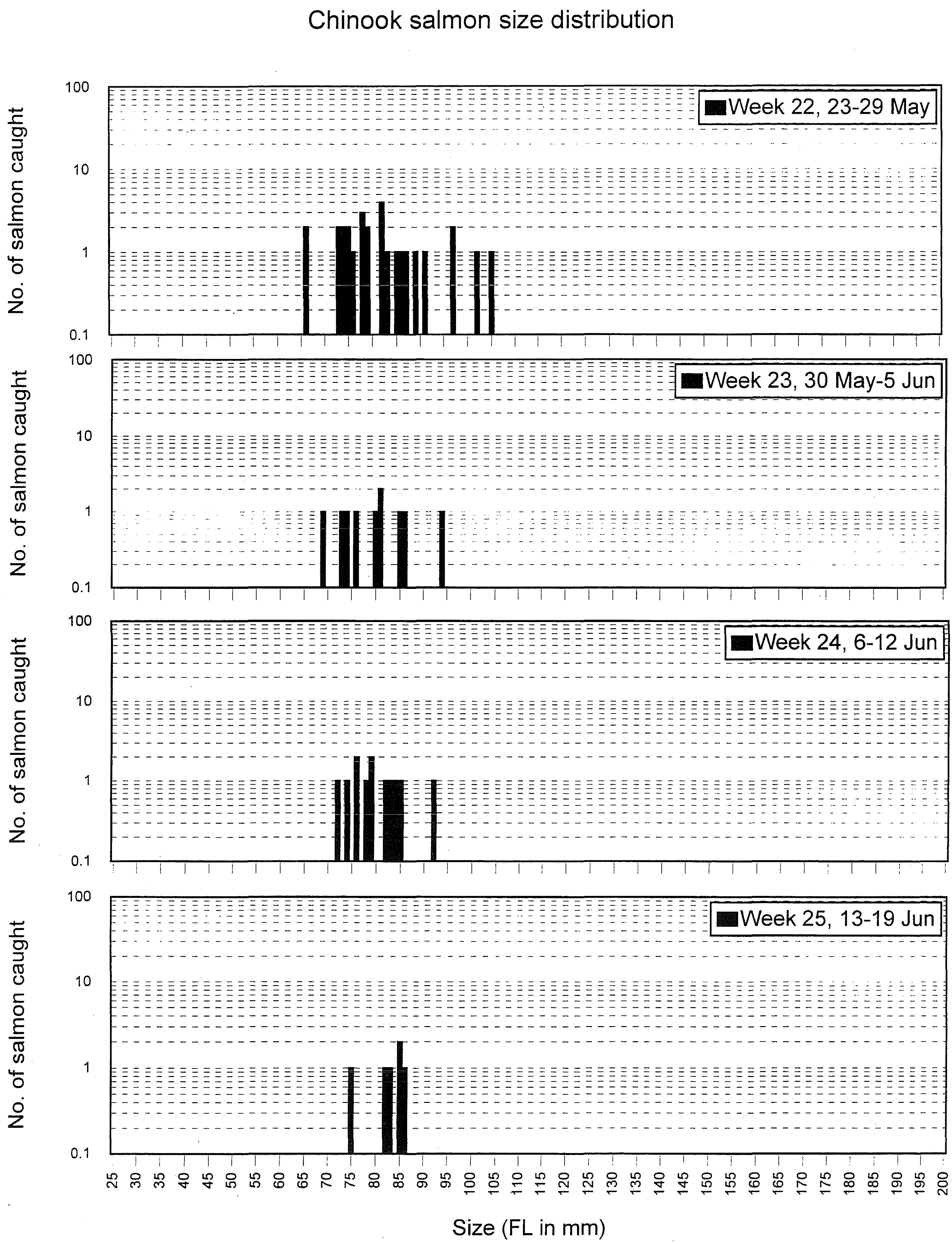


Figure 17. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 23 May through 19 June 1999.

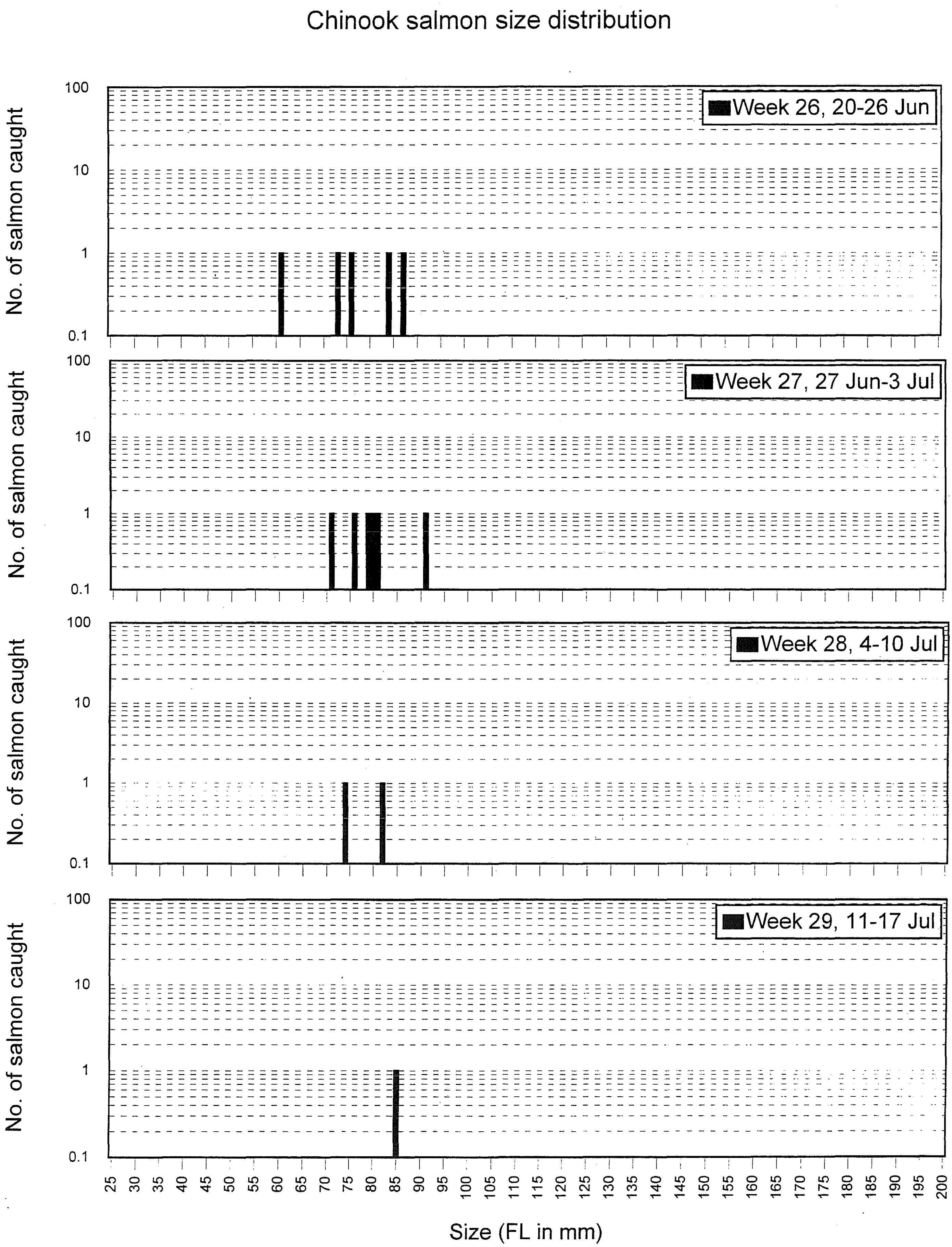


Figure 18. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 20 June through 17 July 1999.

Chinook salmon size distribution

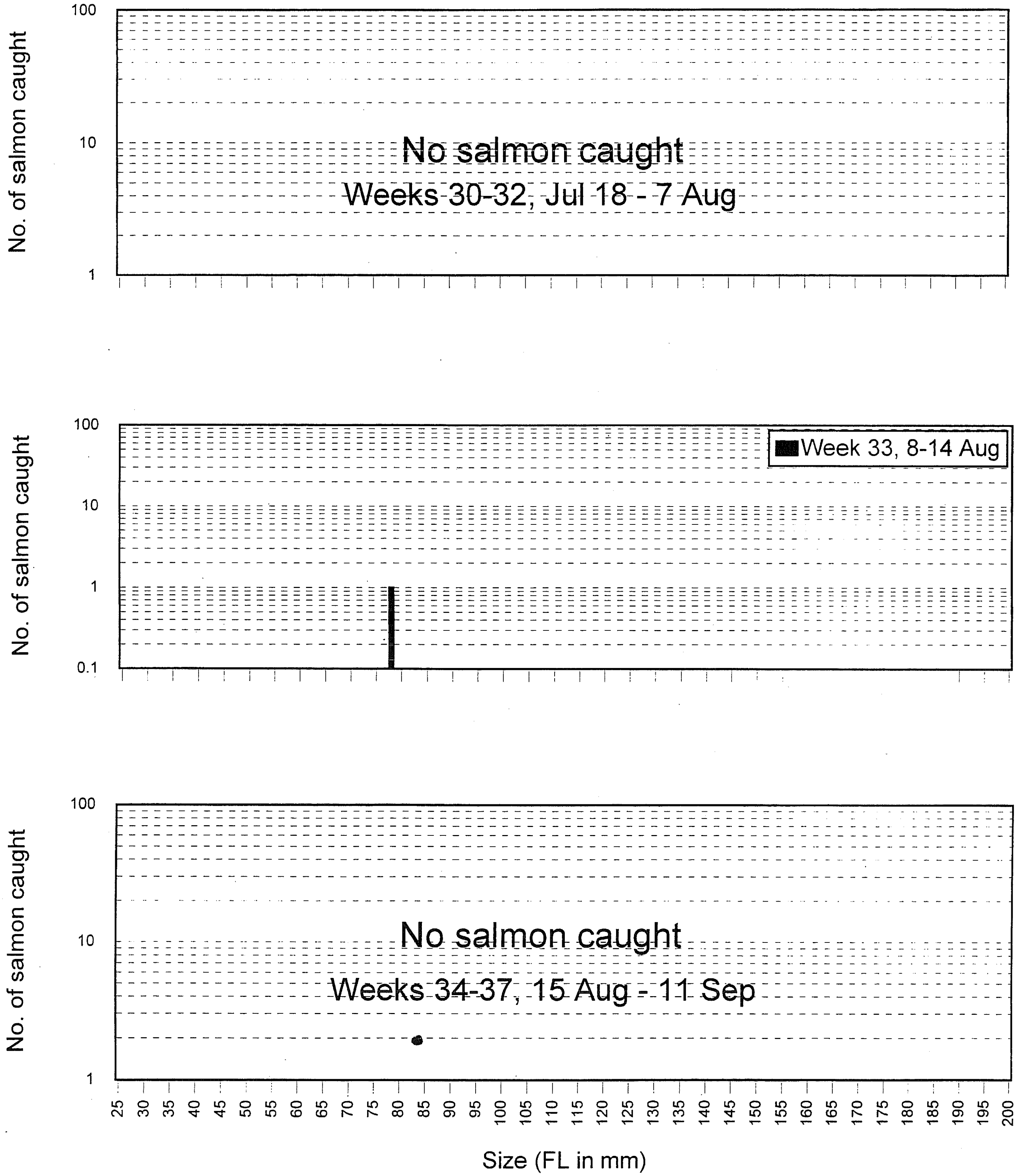


Figure 19. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 18 July through 11 September 1999.

Chinook salmon size distribution

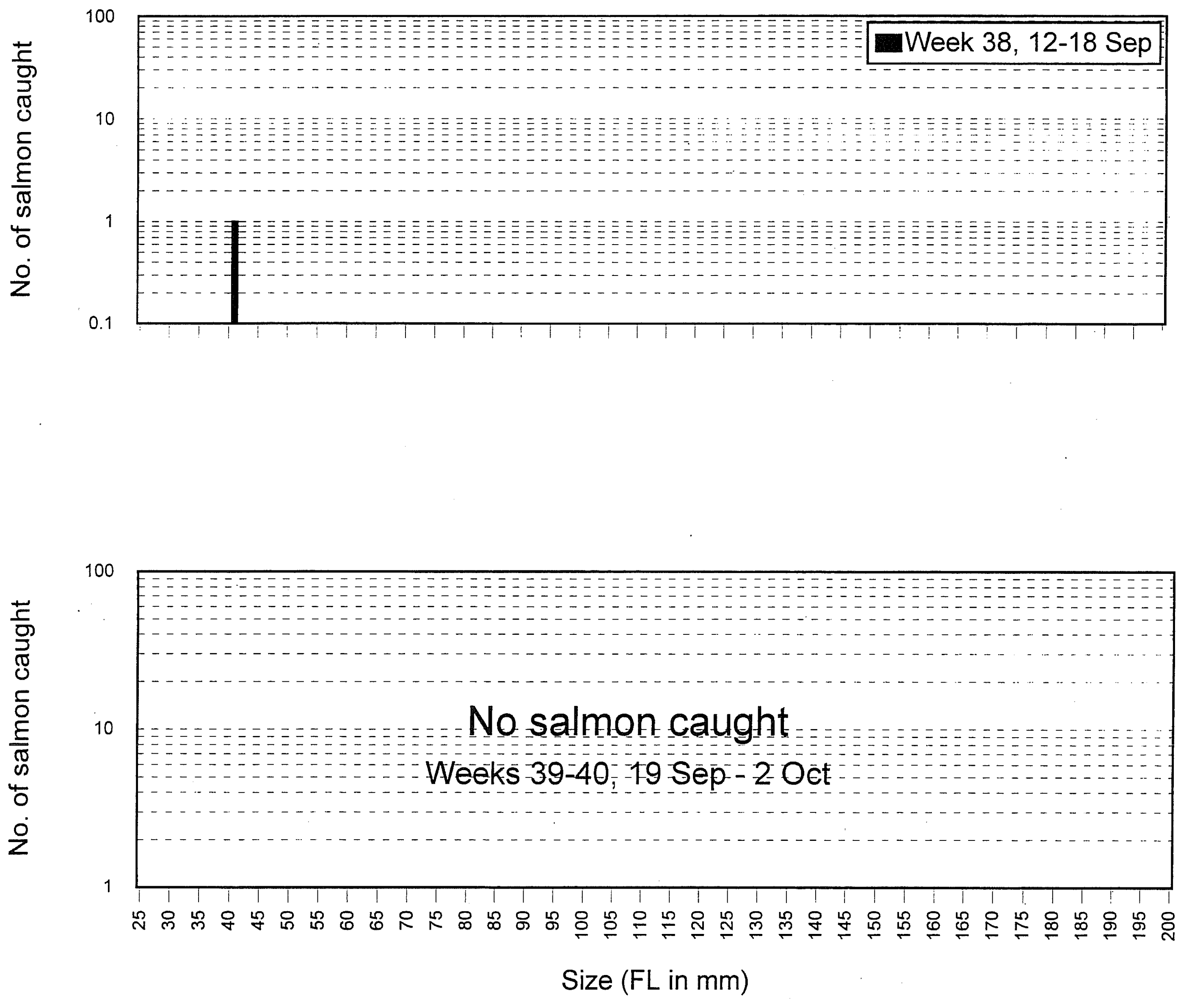


Figure 20. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 12 September through 2 October 1999.

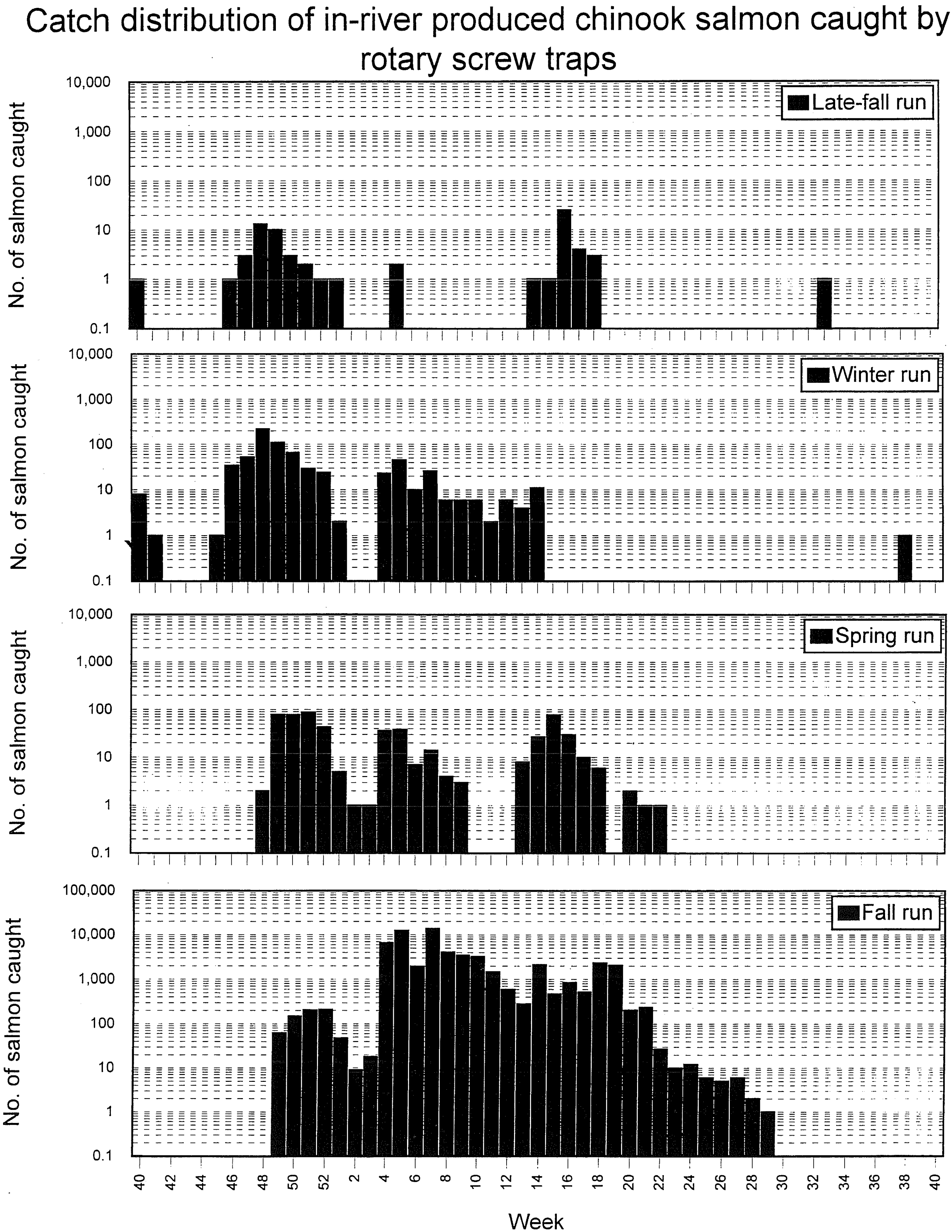


Figure 21. Catch distribution of in-river produced chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 27 September 1998 through 2 October 1999.

Catch distribution of adipose-clipped chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River

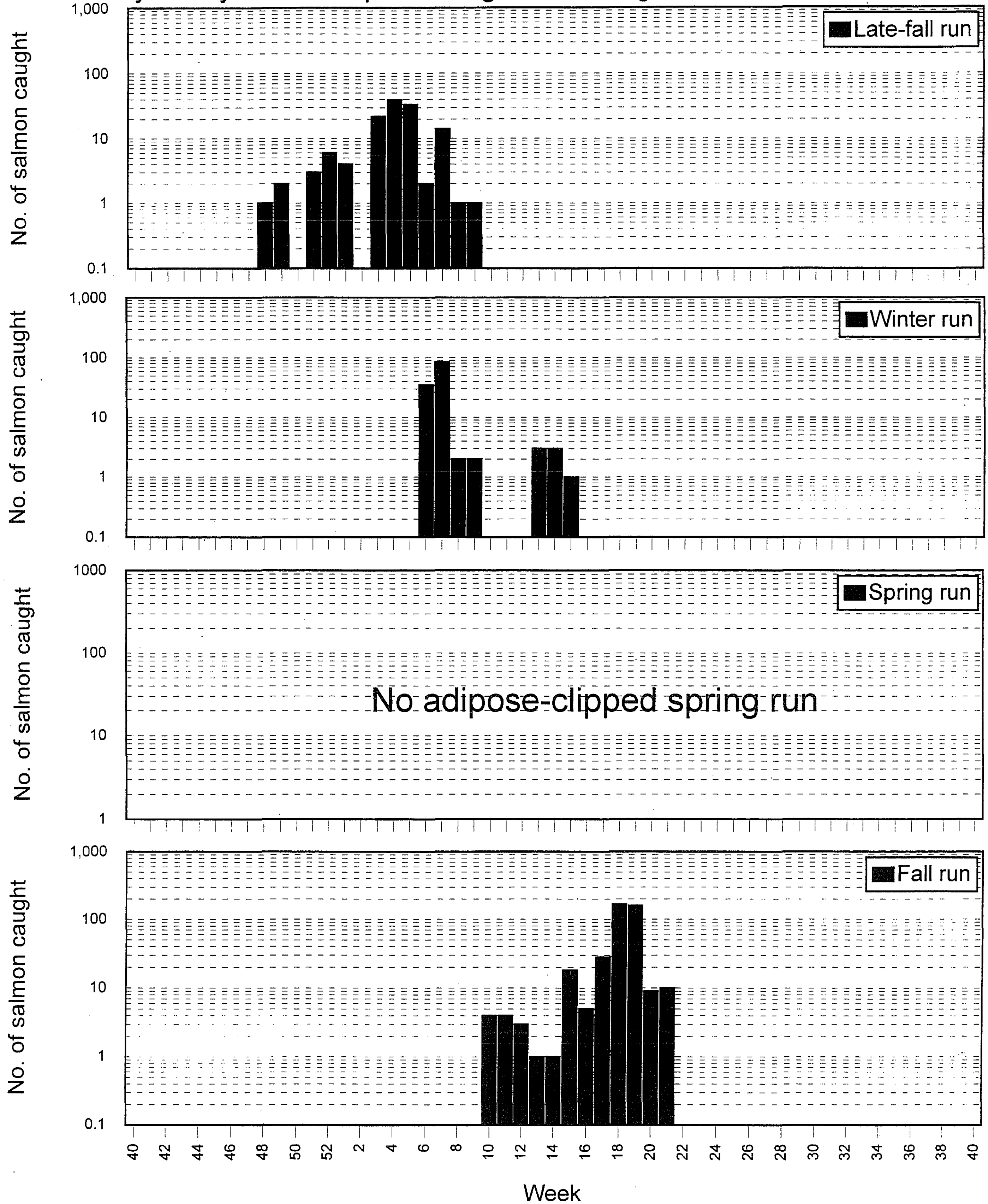


Figure 22. Catch distribution of adipose-clipped chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 27 September 1998 through 2 October 1999.

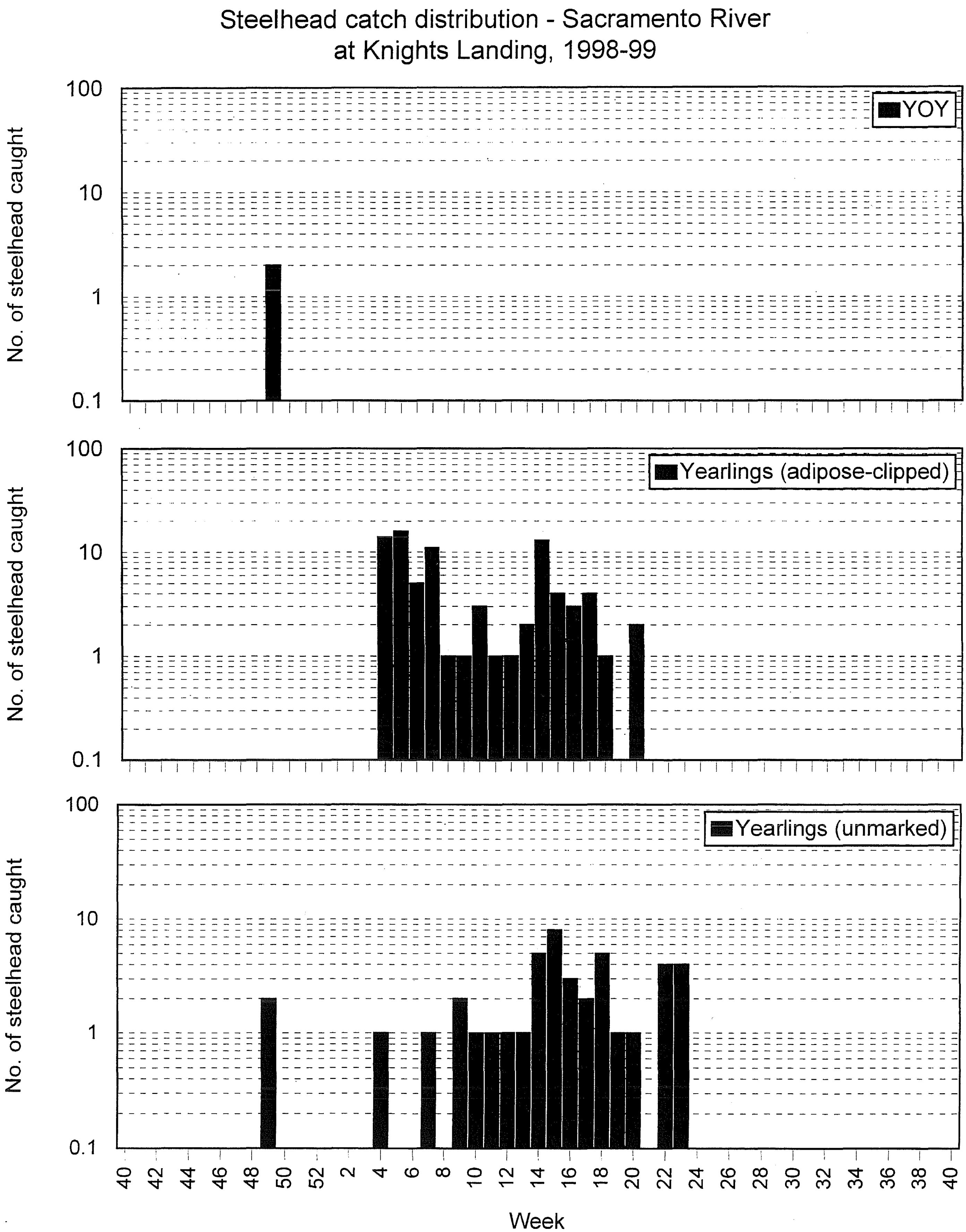


Figure 23. Catch distribution of young-of-year and yearling steelhead trout caught by rotary screw traps at Knights Landing, Sacramento River, 27 September 1998 through 2 October 1999.

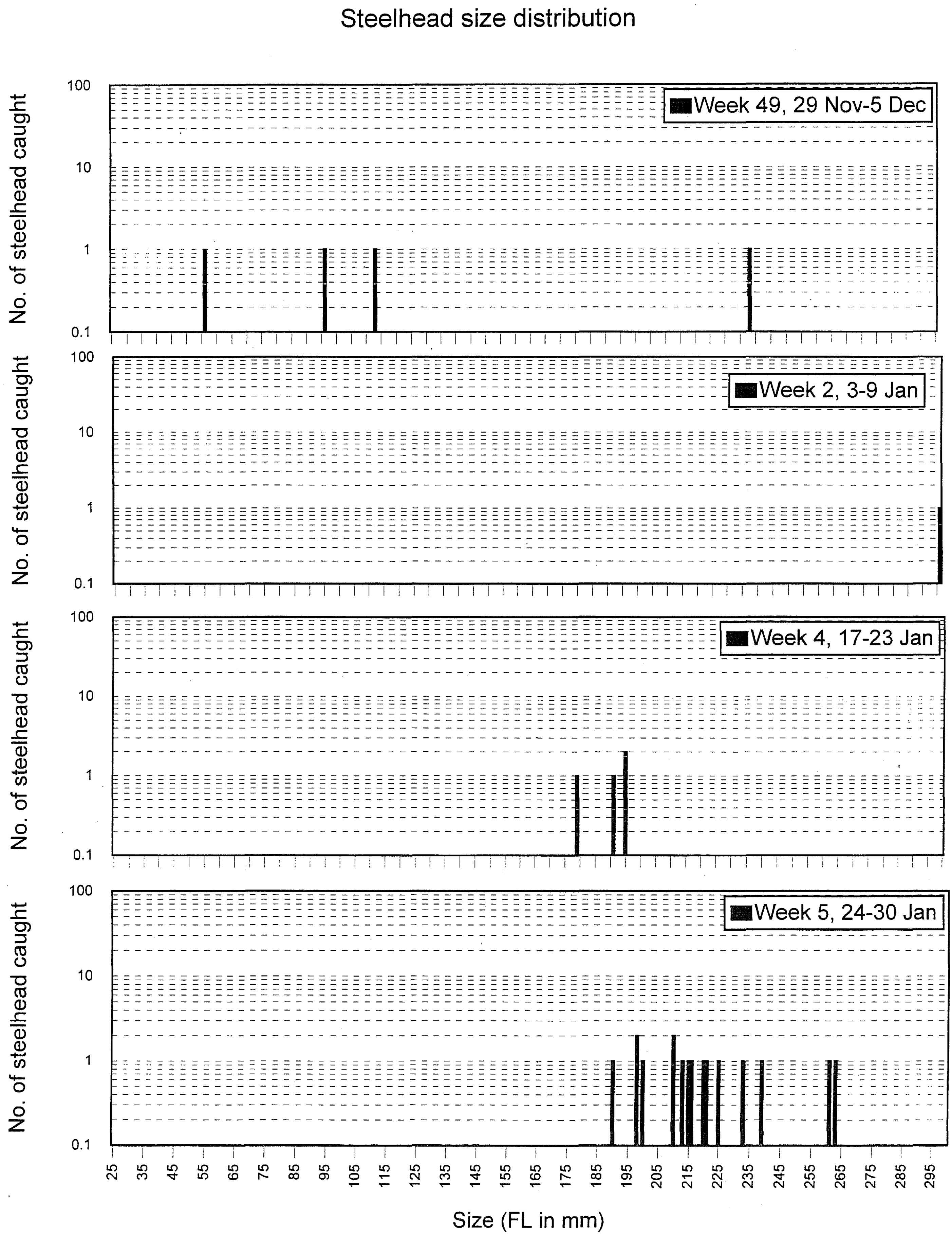


Figure 24. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 29 November 1998 through 30 January 1999.

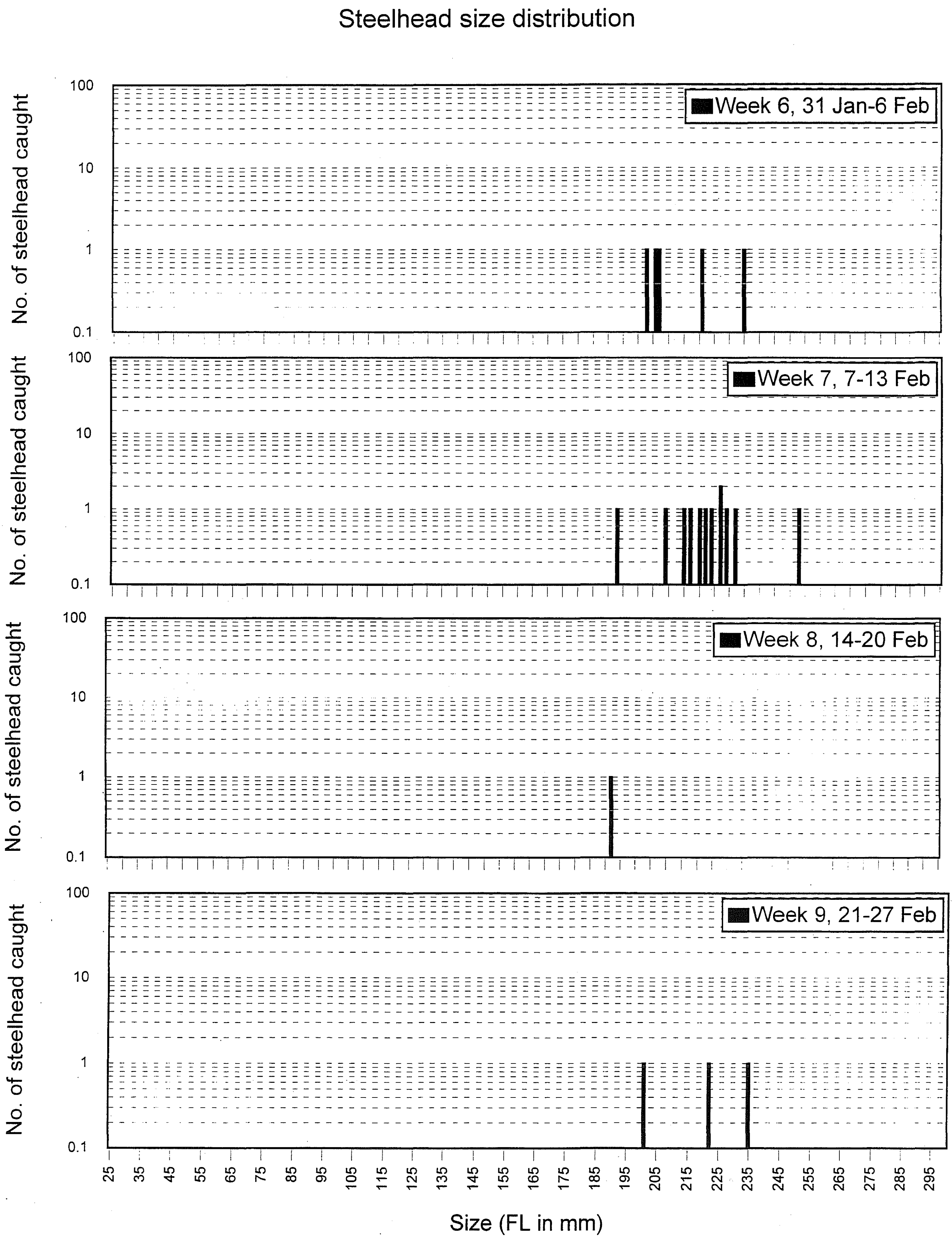


Figure 25. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 31 January through 27 February 1999.

Steelhead size distribution

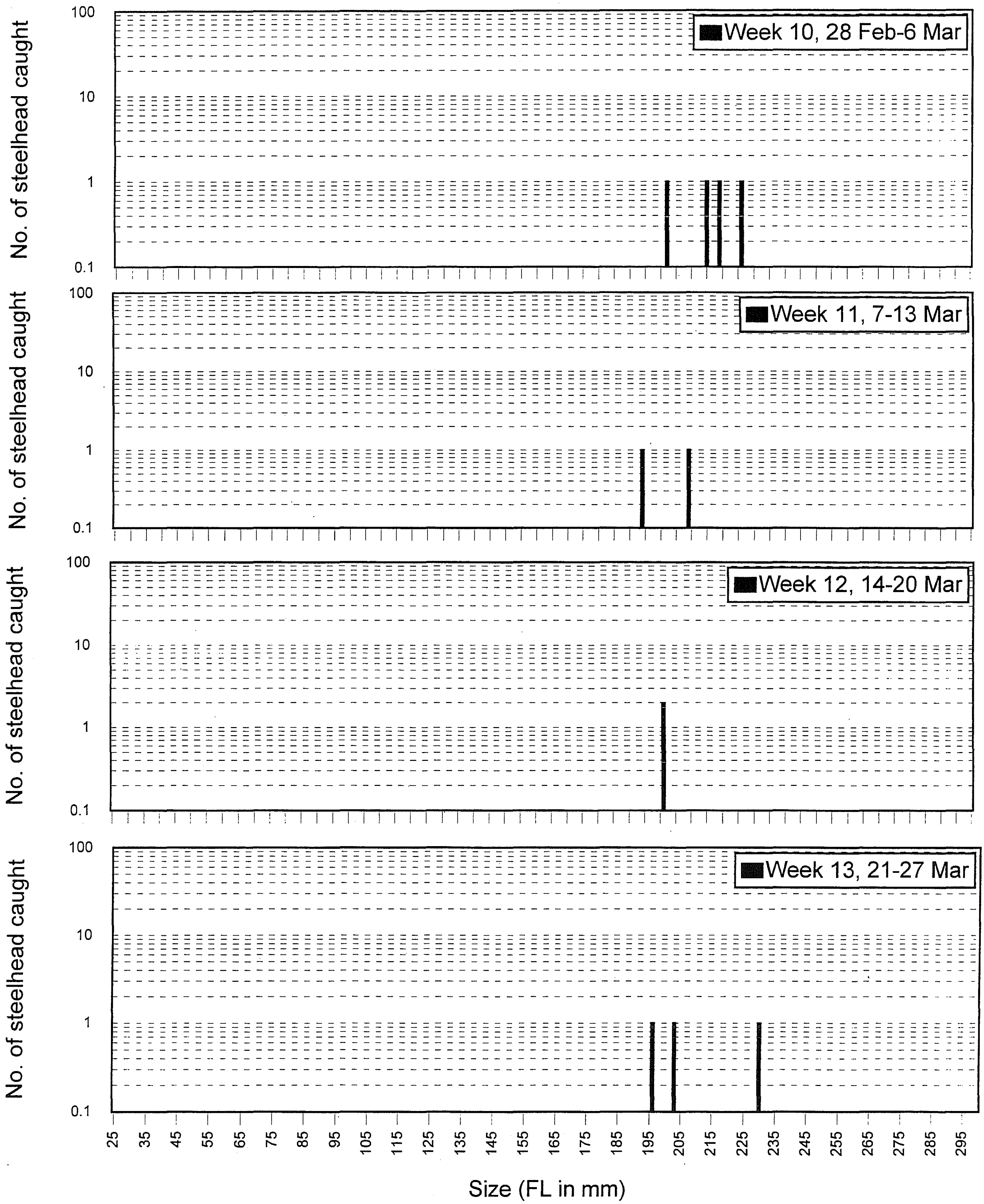


Figure 26. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 28 February 1999 through 27 March 1999.

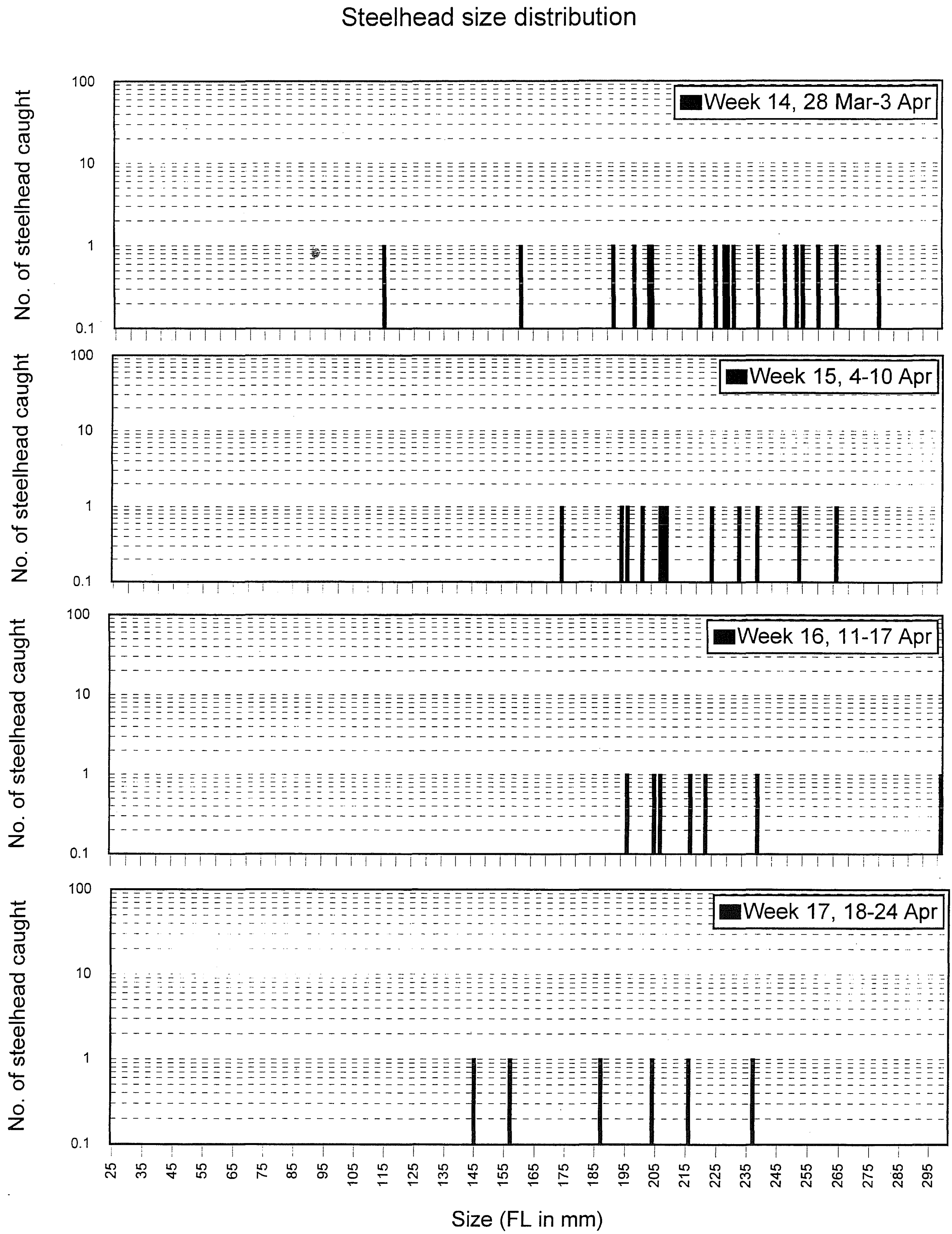


Figure 27. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 28 March 1999 through 24 April 1999.

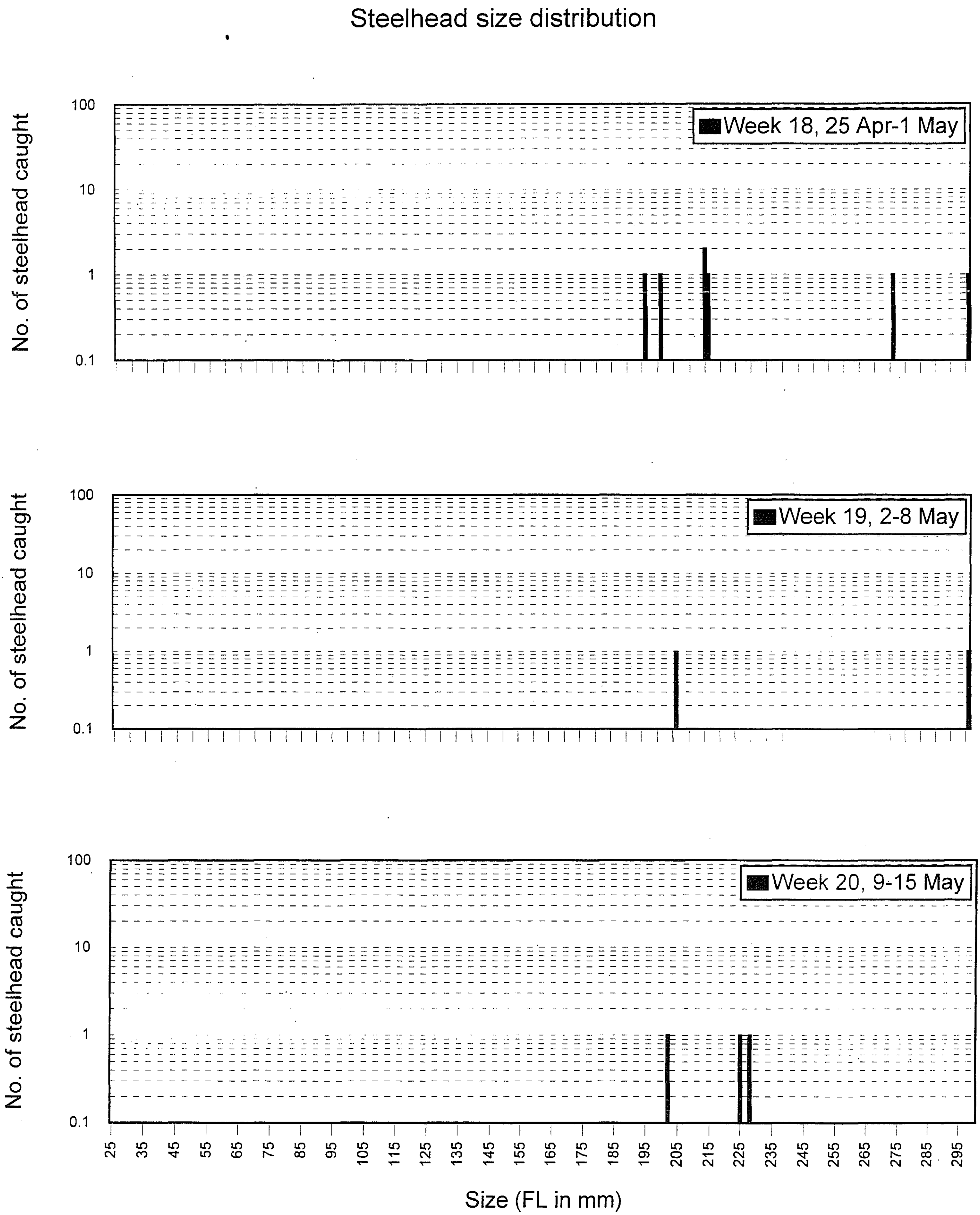


Figure 28. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 25 April 1999 through 15 May 1999.

Steelhead size distribution

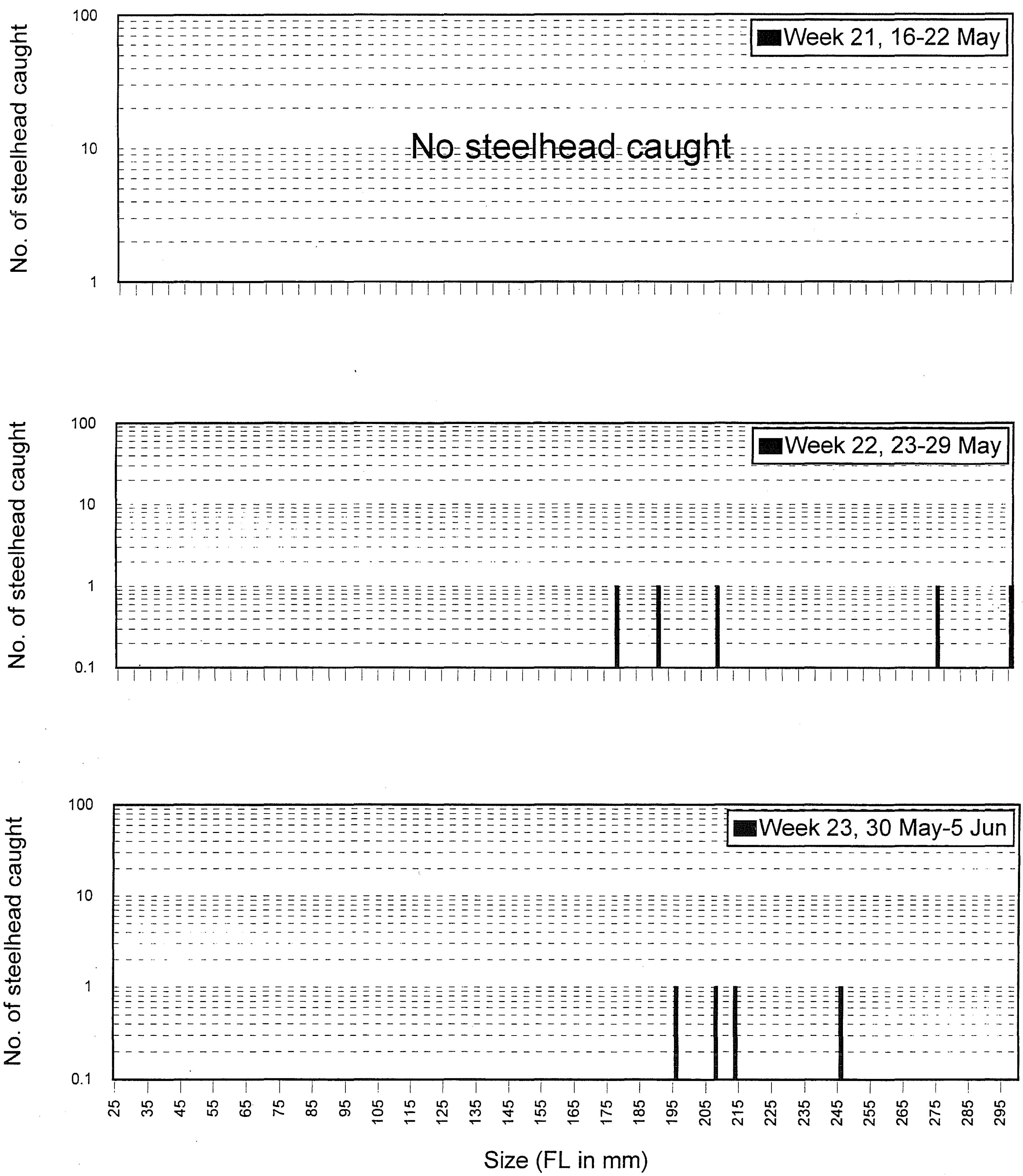


Figure 29. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 16 May 1999 through 5 June 1999.

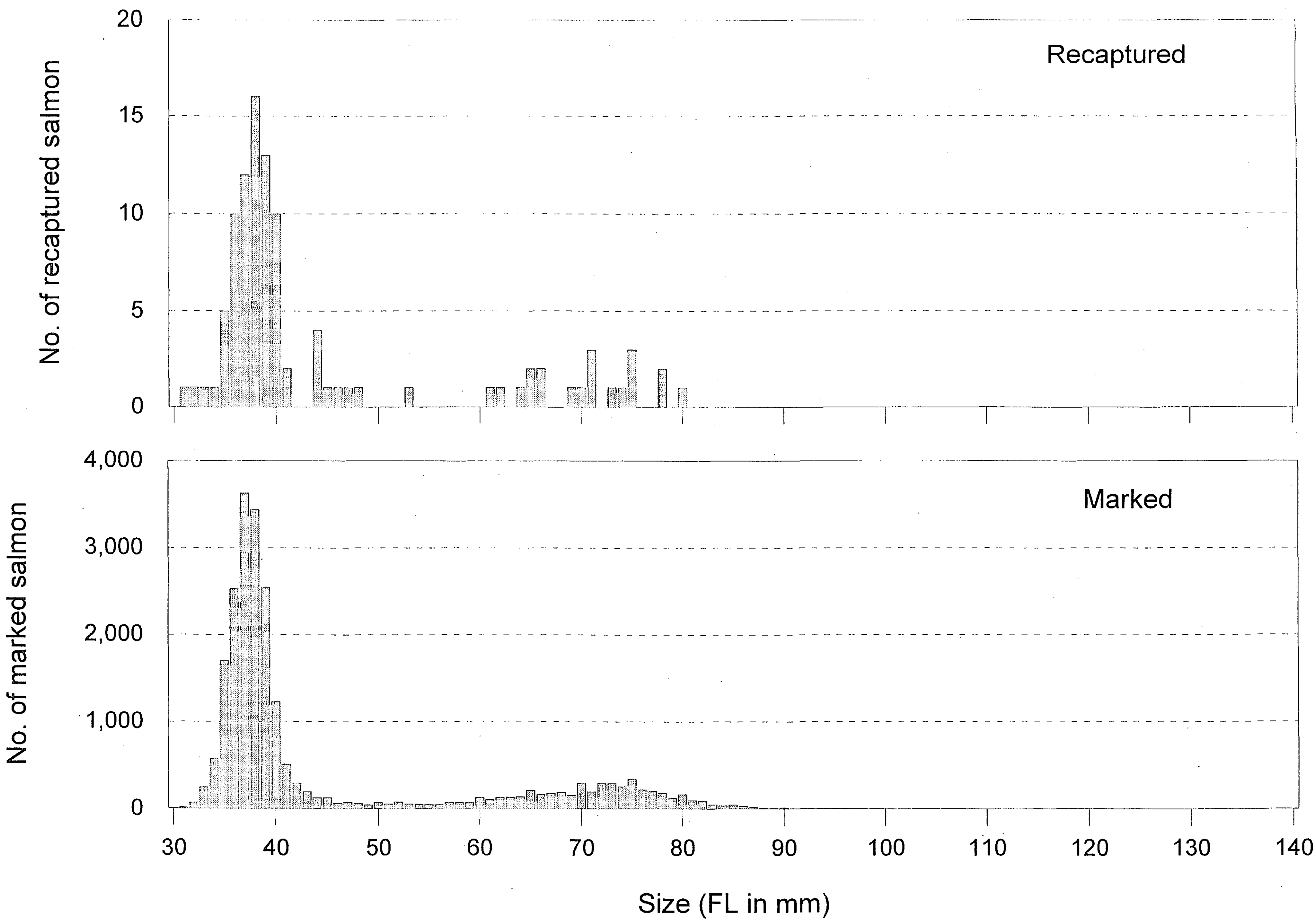
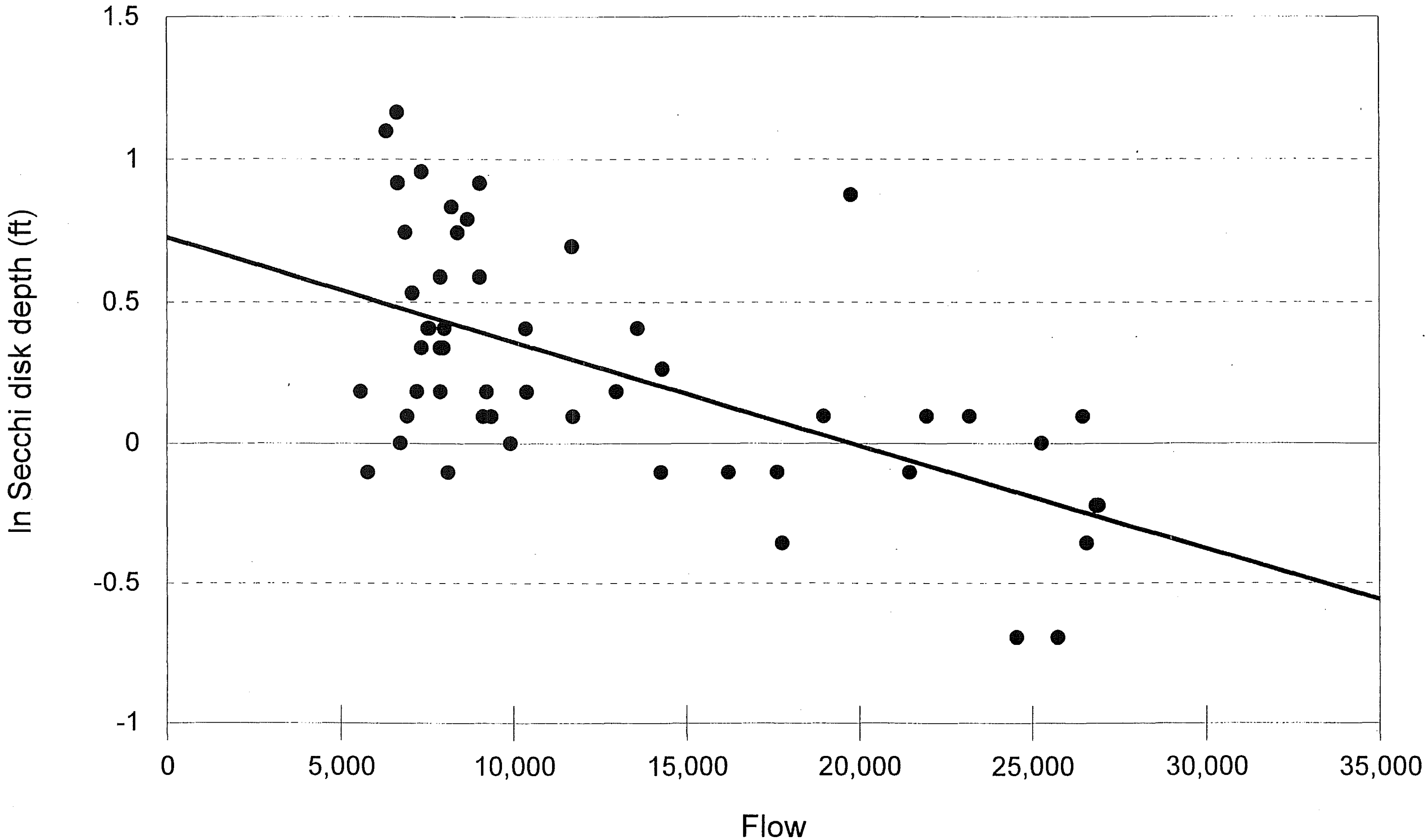


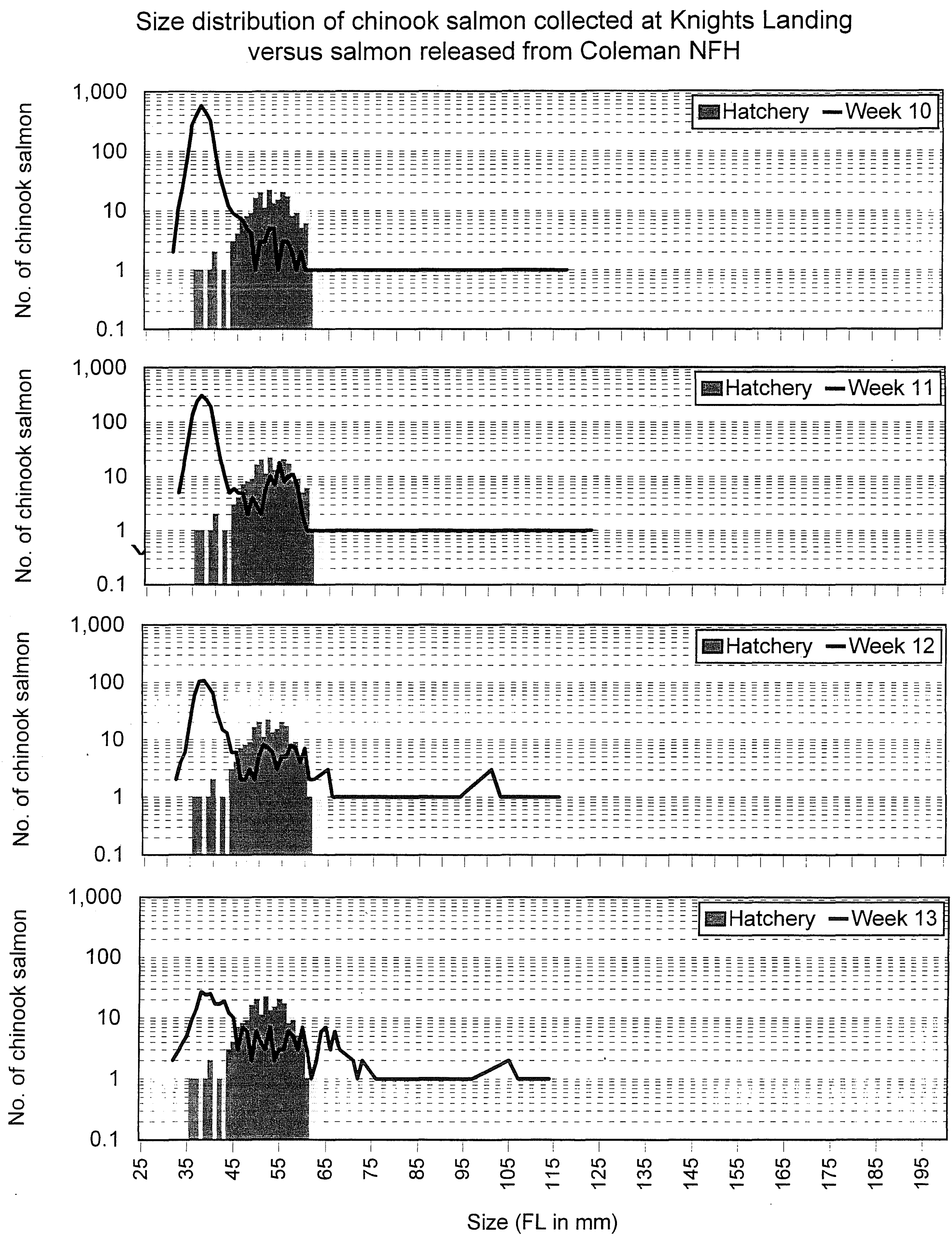
Figure 30. Comparison of length frequency distributions for salmon that were marked and salmon that were recaptured during the trap efficiency evaluations conducted on the Sacramento River near Knights Landing from 20 December 1998 through 22 May 1999.

APPENDIX

Comparison of water transparency and flow

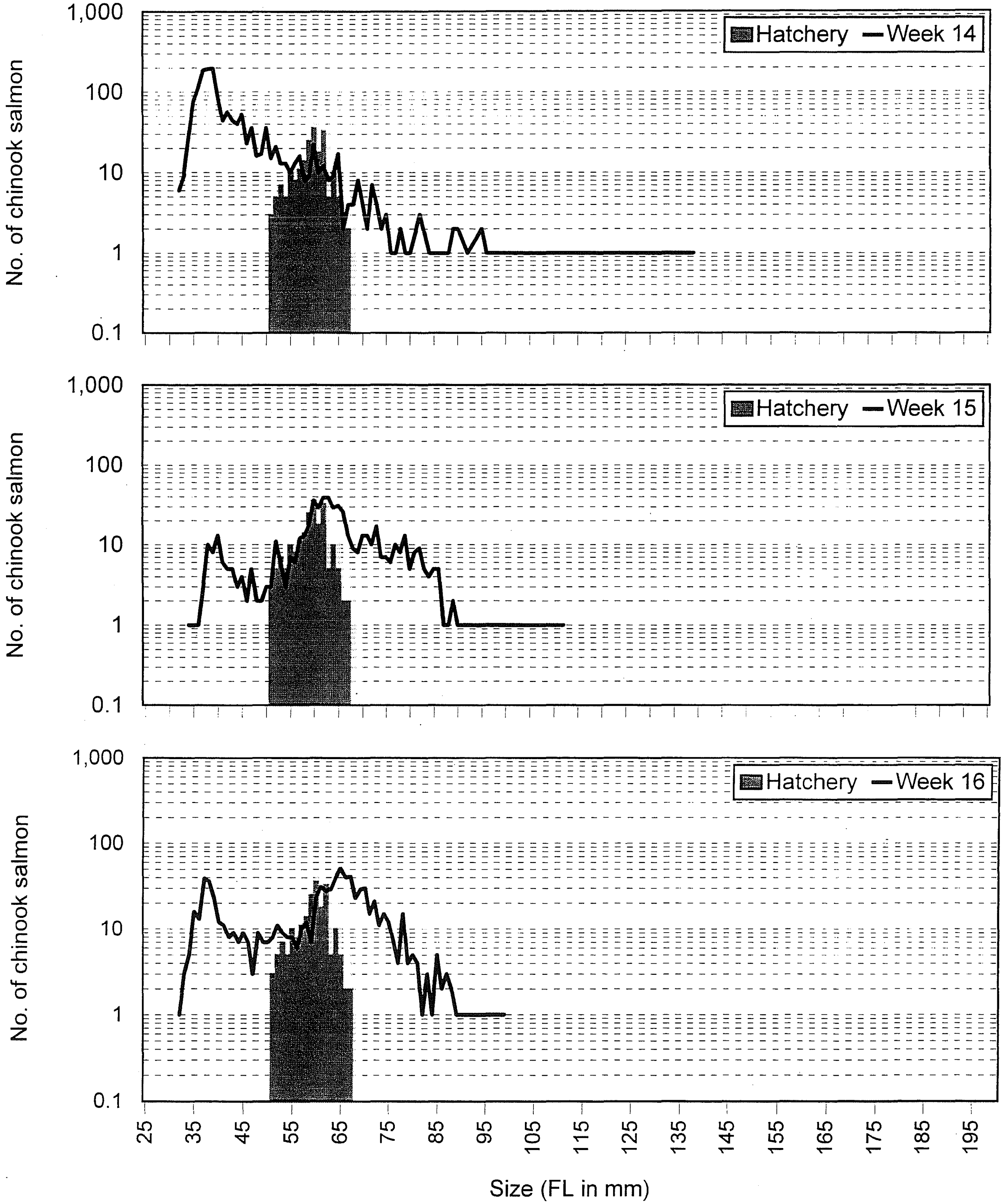


Appendix Figure 1. Comparison of water transparency (ln of Secchi disk depth) versus flow measured on the Sacramento River near Knights Landing, 27 September 1998 - 2 October 1999.



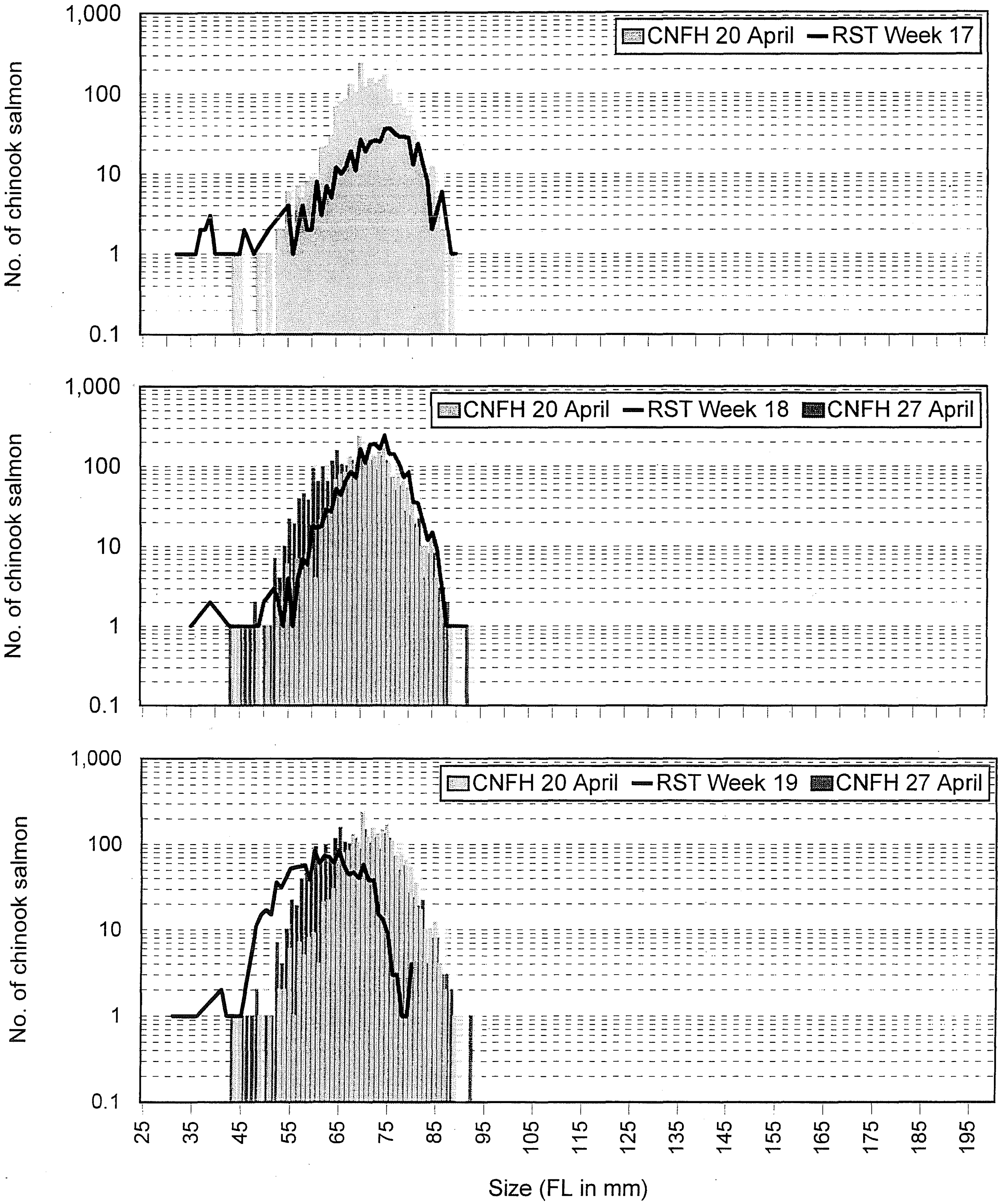
Appendix Figure 2. Size distribution of chinook salmon collected in the Sacramento River near Knights Landing compared with size distribution of Coleman NFH salmon released 3 March 1999.

Size distributions of chinook salmon collected at Knights Landing versus salmon released from Coleman NFH



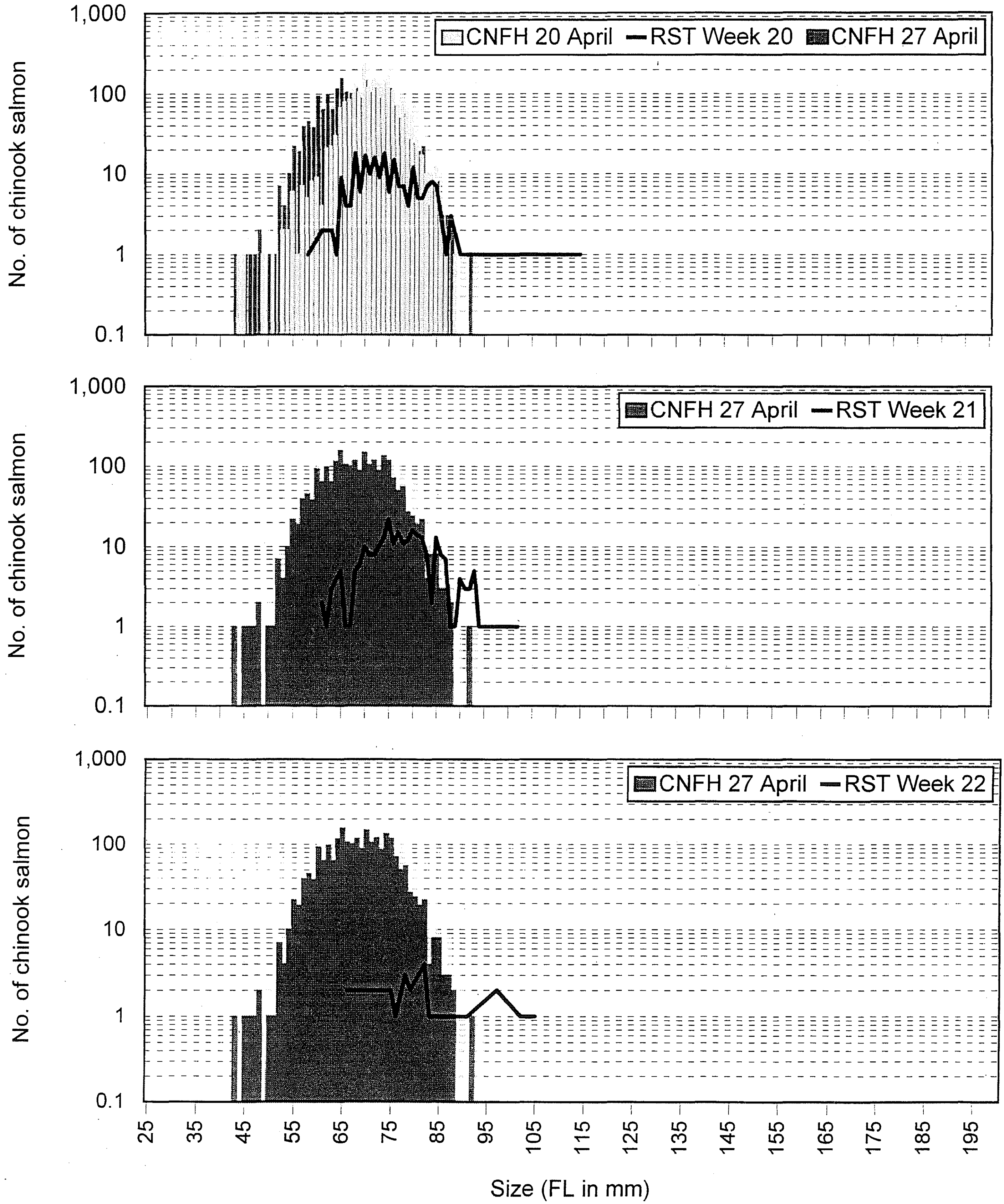
Appendix Figure 3. Size distribution of chinook salmon collected in the Sacramento River near Knights Landing compared with size distribution of Coleman NFH salmon released 31 March 1999.

Size Distributions of Chinook Salmon Collected at Knights Landing Versus Salmon Released from Coleman NFH



Appendix Figure 4. Size distribution of chinook salmon collected in the Sacramento River near Knights Landing compared with size distribution of Coleman NFH salmon released 20, 21 and 27, 28 April 1999.

Size distributions of chinook salmon collected at Knights Landing versus salmon released from Coleman NFH



Appendix Figure 5. Size distribution of chinook salmon collected in the Sacramento River near Knights Landing compared with size distribution of Coleman NFH salmon released 20/21 and 27/28 April 1999.