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 1997–SEPTEMBER 1998

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Stream Evaluation Program
Technical Report No. 00-05
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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 28 September 1997–3 October 1998. Chinook salmon *Oncorhynchus tshawytscha* and steelhead trout *O. mykiss* were the target species. Sampling was conducted using two 8-ft diameter rotary screw traps (RSTs) from 28 September 1997 to 21 June 1998; one RST was used after 21 June 1998. This period was the third consecutive year of emigration monitoring conducted by the California Department of Fish and Game (DFG) at Knights Landing (Snider and Titus 1998, 2000b).

Mean weekly flow ranged from 3,718 cfs in week 43 (19–25 October 1997) to 30,260 cfs in week 7 (8–14 February 1998). Peak mean daily flow was 30,995 cfs on 9 February 1998. Water transparency (Secchi disk depth) ranged from <0.3 ft to 3.3 ft. Mean weekly water temperature decreased from 65°F in week 40 (28 September–4 October 1997) to 46°F in week 52 (21–27 December 1997). It remained between 46°F and 52°F through week 11 (8–14 March 1998) before gradually increasing to 69°F by week 30 (19–25 July 1998). The maximum mean daily water temperature was 70°F during week 30 (19–25 July 1998).

A total of 69,218 juvenile salmon was collected in 13,905 hours of trapping (4.98 fish/h). The total catch included 485 marked salmon, and 68,733 unmarked salmon. Fall-run salmon dominated both groups comprising 97% of the unmarked salmon catch (based upon size criteria) and 67% of the marked salmon catch (based upon coded-wire tag information). Late-fall-run salmon comprised 0.2% of the unmarked salmon catch and 31% of the marked salmon catch; 32% of the unmarked late-fall-run juveniles were from the 1997 brood year (BY) and 68% were from BY 1998. Winter-run salmon comprised 1% of the unmarked salmon catch and 2% of the marked salmon catch; 96% of the unmarked winter run were from BY 1997 and 4% were from BY 1998. Spring-run-sized salmon comprised 2% 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, 68% of spring-run-sized salmon were considered hatchery-produced fall run and only 0.6% of the unmarked salmon catch were considered spring run.

The primary migration period extended from late November 1997 (week 47) through mid-June 1998 (week 26). 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 47 (16–22 November 1997) and lasted through week 1 (3 January 1998), peaking during week 49 (30 November–6 December 1997). Nearly all (95%) in-river-produced late-fall-run yearling migration, 78% of BY 1997 in-river-produced winter-run

migration, 69% of all spring-run migration, but only 0.5% of fall-run migration occurred during this phase. Phase 2 extended from weeks 1 through 10 (28 December 1997–7 March 1998). Altogether, 68% of the total fall-run catch occurred during this phase. The peak catch occurred during weeks 2 and 3 (4–17 January 1998), when 23,903 fall-run emigrants were collected (36% of all captured fall run). The peak was concurrent with a flow increase from less than 8,000 cfs to over 20,000 cfs. The third phase began during week 11, one week after the first release of fingerling-sized, CNFH-produced fall run.

Fifty-four in-river produced (unmarked) late-fall-run juveniles from BY 1997 were collected from week 47 (16–22 November 1997) through week 2 (4–10 January 1998). The highest catches occurred during weeks 48 (n = 17) and 49 (n = 22). A total of 115 in-river produced late-fall-run juveniles from BY 1998 was also collected: 112 during weeks 15 (5–11 April 1998) through 23 (31 May - 6 June 1998) and one each during weeks 34, 35 and 40 of 1998.

A total of 688 in-river produced winter-run chinook salmon from BY 1997 was collected from week 40 (28 September–4 October 1997) through week 13 (22–28 March 1998). During the primary migration period, 48% of the catch of in-river produced winter run occurred in November, 30% in December, 11% in January, 3% in February and 7% in March. Two winter run were collected several weeks prior to the primary migration period (weeks 40 and 41), and 28 winter run from BY 1998 were caught several weeks after the end of the primary emigration period.

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 10. A total of 380 in-river produced spring-run juveniles was collected by RST. Catch distribution appeared to have two modes corresponding to emigration phases 1 and 2, respectively.

Altogether, 66,666 unmarked, fall-run-sized juvenile salmon were collected. Fall run were first collected during week 49, the third week into the primary migration period, and then in every subsequent week through week 26 (21–27 June 1998). One fall run was also collected during week 28 and one during week 32. Distinction between in-river and hatchery-produced fall run was problematic after week 6, when more than 8 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 6 were known in-river produced salmon. Beginning in week 10, about 8% of the fall run released into the upper river were marked. Based upon the ratio of marked fish to unmarked fish, nearly 20% of the fall run caught after week 10 were hatchery produced.

A total of 110 unmarked, yearling steelhead trout was caught from 14 December 1997 through 16 May 1998. Less than 1% were caught in December, 10% in January, 5% in February, 70% in March, 9% in April and 5% in May. We also collected 129 marked steelhead from 4 January through 2 May 1998. There appeared to be three modes in the catch distribution of steelhead, similar in distribution to the phases identified for salmon emigration.

Estimates of the relative abundance of juvenile salmonids emigrating past Knights Landing are provided based upon a mean RST efficiency of 0.80% (range: 0.0%–4.08%; SD = 0.96%; 80% CI: 0.53%–1.07%; n = 22). The estimated number of in-river salmon that passed Knights Landing included 9,625 BY 1997 late-fall run and 16,250 BY 1998 late-fall run; 108,000 BY 1997 winter run and 3,500 BY 1998 winter run; 54,250 spring run; and 8,458,150 fall run. The estimated number of in-river produced yearling steelhead passing Knights Landing was 8,634.

The estimated number of hatchery-produced chinook salmon passing Knights Landing was 19,875 late-fall run, 1,125 winter run, and 575,269 fall run. The estimated number of hatchery-produced steelhead trout passing Knights Landing was 22,259.

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, flow exceeded 23,000 cfs during week 4 and remained above that level through most of the primary emigration period. 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 third consecutive year (Snider and Titus 1998, Snider and Titus 2000b). 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 California's Central Valley, spawns and rears exclusively in the upper Sacramento River. Central

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

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.

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

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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.

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 and can have difficulty in discriminating fish originating from the upper Sacramento River system and 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). Sampling occurred from 28 September 1997 through 21 June 1998 using two 8-ft diameter RSTs; one RST was used from 22 June 1998 through 3 October 1998.

The two 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 two 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 20 ft at a flow of 15,000 cfs; mean current velocity was 3.0 ft/s. The sample site cross sectional profile measured at 10,000 cfs is presented in Figure 2.

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

[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.

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 1998 (i.e., contains 1 January 1998). 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 beginning in week 44 of 1997. Prior to week 44, temperature was measured during each trap servicing using a hand-held thermometer.

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. Efficiency was calculated as the percentage of marked fish that were recaptured in the traps on a weekly basis. Salmon were generally marked and released each day beginning in week 2 (4 January 1998). 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.

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.

[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 3,718 cfs in week 43 (19–25 October 1997) to 30,260 cfs in week 7 (8–14 February 1998) (Table 1). Mean daily flow peaked at 30,995 cfs on 9 February 1998 (Figure 3). Mean weekly water temperature decreased from 65 °F in week 40 (28 September–4 October 1997) to 46 °F in week 52 (21–27 December 1997) (Table 1). It then remained between 46 °F and 52 °F through week 11 (8–14 March 1998) before gradually increasing to 69 °F by week 30 (19–25 July 1998). The minimum mean daily temperature was 45 °F during week 52 (21–27 December 1997) and the maximum mean daily temperature was 70 °F during week 30 (19–25 July 1998) (Figure 3).

Mean daily water temperature was weakly negatively correlated with mean daily river flow $r = -0.44$), and although there was a significant linear regression (p<0.0001) of temperature on flow, the model only explained about 19% of the variation in temperature as a function of flow. Looking at temperature by date (Figure 3), it seems 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).

Water transparency (Secchi disk depth) was very poor throughout the survey (Figure 4), and ranged from <0.3 ft to 3.3 ft (Table 1). Transparency was inversely related to flow. Mean weekly transparency (as *ln* Secchi disk depth) was highly negatively correlated $r = -0.88$) with mean weekly river flow. There was a good linear fit ($r^2 = 0.78$, p<0.0001) of *ln* transparency on flow (Appendix Figure 1).

The two RSTs were successfully operated within a fairly wide range of flows (<4,000 to >30,000 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 1997 and week 1 of 1998 when the traps were raised during holidays. Debris-induced interruptions occurred during weeks 50 (7–13 December 1997) and 14, 15 and 16 (29 March–18 April 1998). The only week during which neither trap was fishing for more than 24 h at a time was week 50. Overall, the two RSTs fished nearly 87% of the time averaging 291 h/week out of a possible 336 h.

Rotary Screw Trap Results

Chinook Salmon Emigration

Two juvenile salmon were captured by RST prior to the typical initiation of the primary migration period (late November; Snider and Titus 1998). One winter-run-sized salmon was collected on 3 October 1997 (week 40), and a second winter run was caught on 6 October 1997

Table 1. Summary of mean weekly sampling conditions in the Sacramento River near Knights Landing during juvenile salmonid emigration investigation, 28 September 1997–3 October 1998.

Week	Beginning date	Mean flow (cfs)	Mean water temperature (°F)	Mean Secchi depth (ft)
40	28 Sep 1997	5,781	65	2.4
41	5 Oct 1997	4,836	62	2.8
42	12 Oct 1997	4,408	61	3.0
43	19 Oct 1997	3,718	63	2.9
44	26 Oct 1997	3,778	59	3.3
45	2 Nov 1997	3,892	61	2.0
46	9 Nov 1997	4,396	56	2.4
47	16 Nov 1997	6,807	54	1.3
48	23 Nov 1997	10,004	55	1.0
49	30 Nov 1997	12,471	51	0.7
50	7 Dec 1997	12,529	50	1.0
51	14 Dec 1997	12,965	48	1.0
52	21 Dec 1997	9,016	46	1.4
1	28 Dec 1997	7,490	47	2.3
2	4 Jan 1998	13,943	48	0.8
3	11 Jan 1998	21,466	49	0.5
4	18 Jan 1998	27,830	50	0.4
5	25 Jan 1998	28,426	50	0.6
6	1 Feb 1998	29,781	50	0.3
7	8 Feb 1998	30,260	49	0.3
8	15 Feb 1998	29,510	49	0.3
9	22 Feb 1998	29,240	49	0.3
10	1 Mar 1998	27,465	51	0.7
11	8 Mar 1998	24,690	51	0.7
12	15 Mar 1998	22,615	57	0.5
13	22 Mar 1998	27,782	54	0.4

Table 1 (continued)

Week	Beginning date	Mean flow (cfs)	Mean water temperature (^oF)	Mean Secchi depth (ft)
14	29 Mar 1998	27,069	52	0.5
15	5 Apr 1998	25,824	53	0.7
16	12 Apr 1998	21,529	55	0.9
17	19 Apr 1998	18,606	60	1.3
18	26 Apr 1998	19,679	61	1.0
19	3 May 1998	19,460	59	1.0
20	10 May 1998	19,248	57	1.0
21	17 May 1998	20,300	59	1.1
22	24 May 1998	22,317	58	1.1
23	31 May 1998	25,639	61	0.7
24	7 Jun 1998	23,183	62	1.0
25	14 Jun 1998	21,217	64	1.2
26	21 Jun 1998	17,417	65	1.3
27	28 Jun 1998	14,932	65	1.4
28	5 Jul 1998	13,895	68	1.8
29	12 Jul 1998	12,329	68	1.5
30	19 Jul 1998	11,555	69	1.5
31	26 Jul 1998	11,472	69	1.2
32	2 Aug 1998	11,306	69	1.3
33	9 Aug 1998	11,136	69	1.1
34	16 Aug 1998	11,154	67	1.3
35	23 Aug 1998	11,250	66	1.6
36	30 Aug 1998	10,976	68	1.6
37	6 Sep 1998	11,032	67	1.7
38	13 Sep 1998	10,311	67	1.9
39	20 Sep 1998	9,509	64	2.3
40	27 Sep 1998	8,920	64	2.5

(week 41) (Table 2). Salmon were not captured again until 20 November 1997 (week 47) marking the beginning of the primary emigration of 1997–1998. Catch increased substantially with four salmon collected during week 47, 188 in week 48 and 545 in week 49 (Table 2, Figure 6). Thereafter, salmon were captured every week through week 26 (21–27 June 1998) (Table 2). Only three salmon were collected from week 27 through week 33 (28 June–15 August 1998): two in week 28 and one in week 32. At least one salmon was caught each week between week 34 and the end of the reporting period (3 October 1998).

Juvenile salmon emigration appeared to occur 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 that appears strongly linked to the initial flow increase of the season (Figure 7). This relationship was also observed during 1995 and 1996 (Snider and Titus 1998, Snider and Titus 2000b). During the 1997–1998 emigration period, the first phase began during week 47 (16–22 November 1997) and lasted through week 1 (28 December 1997–3 January 1998). The mode representing this phase peaked during week 49 (30 November–6 December 1997) (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, 78% of brood year (BY) 1997 winter-run migration, 69% of all spring-run migration, but only 0.5% of fall-run migration occurred during this phase.

The second phase of emigration was associated with a greater increase in flow and an increased availability of fall-run fry to emigrate. During the 1997–1998 emigration period, phase 2 extended from weeks 1 through 10 (28 December 1997–7 March 1998) (Figures 6 and 7). Altogether, 68% of the total fall-run catch occurred during this phase. The peak catch occurred during weeks 2 and 3 (4–17 January 1998) when 23,903 fall-run emigrants were collected (36% of all captured fall run). The peak was concurrent with a flow increase from less than 8,000 cfs to over 20,000 cfs (Figure 7). The distinction between phases 1 and 2 was clear during 1995 and 1997, when the initial flow increase occurred before many fall run had emerged and had become available for emigration (Snider and Titus 1998). In 1996, however, the initial flow increase was closely followed by a much greater flow increase when large numbers of fall run were available, in effect combining phases 1 and 2 (Snider and Titus 2000b).

The third phase was associated with large releases of hatchery-produced fall run into the upper Sacramento River near Red Bluff. In 1998, this phase began during week 11, one week after the first release of fingerling-sized fall run from Coleman National Fish Hatchery (CNFH) was made (Table 3). The distribution depicting this phase was characterized by several peaks in catch corresponding to the timing and magnitude of the hatchery releases (Figure 6).

Size of salmon captured by the RSTs ranged from 27 to 170 mm FL (Table 2, Figures 8-20). Large salmon (>90 mm FL) were captured during every week between week 48 (23–29 November 1997) and week 23 (31 May–6 June 1998). Recently-emerged-sized salmon (<45 mm FL) were also captured every week from week 48 through week 23, and from week 34 (16–22 August 1998) through the end of the survey period (3 October 1998).

Table 2. Weekly summary of catch and size statistics for chinook salmon caught by rotary screw traps in the Sacramento River near Knights Landing, 28 September 1997 - 3 October 1998.

Week	Effort (h)	Total catch	Catch/h	Size statistics (FL in mm)			
				Mean	Minimum	Maximum	Standard deviation
40	334.00	1	0.003	38.0	38	38	0.00
41	335.25	1	0.003	38.0	38	38	0.00
42	335.50	0	0.00	-	-	-	-
43	333.00	0	0.00	-	-	-	-
44	337.75	0	0.00	-	-	-	-
45	337.50	0	0.00	-	-	-	-
46	339.75	0	0.00	-	-	-	-
47	376.75	4	0.01	83.0	74	102	11.50
48	212.75	188	0.88	70.3	30	134	15.20
49	277.75	545	1.96	59.0	28	155	20.20
50	217.00	35	0.16	45.9	31	120	21.60
51	334.25	324	0.97	47.5	29	150	30.50
52	239.75	116	0.48	40.4	29	134	18.70
1	249.00	7	0.03	60.2	37	120	34.40
2	334.25	11,370	34.02	37.5	30	145	7.89
3	313.50	12,669	40.41	37.1	30	165	5.30
4	287.00	6,089	21.22	37.5	29	160	10.07
5	337.25	4,025	11.93	38.1	29	168	12.70
6	334.75	2,891	8.64	37.0	27	158	6.25
7	297.25	2,329	7.84	39.2	29	150	5.83
8	336.75	1,557	4.62	43.0	29	148	7.24
9	335.25	3,237	9.66	44.1	28	158	6.92
10	333.50	1,252	3.75	45.0	31	150	9.67
11	336.00	4,062	12.09	55.2	31	149	9.37
12	336.25	10,585	31.40	57.9	30	170	9.95
13	336.25	2,727	8.11	49.1	32	106	13.80
14	229.00	318	1.39	53.4	31	96	18.20
15	171.75	773	4.50	65.6	31	100	13.03
16	208.00	840	4.04	69.7	33	99	9.36
17	335.25	719	2.14	70.5	34	90	7.92
18	334.25	1,614	4.83	71.7	34	95	7.72
19	335.25	268	0.80	71.5	35	95	7.11
20	288.50	199	0.69	74.3	34	96	10.90
21	231.50	153	0.66	77.1	33	98	10.20
22	338.00	47	0.14	75.2	37	95	12.06

23	334.50	210	0.63	69.4	32	117	17.90

Table 2 (Continued)

				Size statistics (FL in mm)			
Week	Effort (h)	Total catch	Catch/h	Mean	Minimum	Maximum	Standard deviation
24	232.25	15	0.06	73.3	61	83	5.71
25	168.50	11	0.07	77.5	70	89	4.81
26	167.00	3	0.02	75.0	75	75	0.00
27	143.50	0	0.00	67.0	67	67	0.00
28	172.75	2	0.01	90.5	83	98	7.50
29	167.50	0	0.00	-	-	-	-
30	167.50	0	0.00	-	-	-	-
31	193.00	0	0.00	-	-	-	-
32	166.75	1	0.006	87.0	87	87	0.00
33	164.00	0	0.00	-	-	-	-
34	172.50	4	0.02	45.5	35	76	17.61
35	167.25	4	0.02	40.0	36	49	5.24
36	168.00	5	0.03	36.4	34	39	1.85
37	167.75	1	0.006	48.0	48	48	0.00
38	166.75	5	0.03	38.0	37	39	0.89
39	168.50	3	0.02	36.0	34	38	1.63
40	167.75	9	0.05	40.2	31	77	13.16
Total	13,905.25	69,218	4.98				

Table 3. Summary of juvenile chinook salmon 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.

Chinook salmon run	Week of release (Date)	Number marked w/CWT	Number marked w/o CWT	Number unmarked	Release location (RM)[1/]
Late-fall run	46 (10 Nov 1997)	133,975	7,794	0	CNFH (271.5)
Late-fall run	50 (9 Dec 1997)	125,250	5,155	0	CNFH (271.5)
Late-fall run	3 (12-14 Jan 1998)	438,437	21,679	0	CNFH (271.5)
Late-fall run	4 (22 Jan 1998)	117,191	4,868	0	CNFH (271.5)
Winter run	15 (9 Apr 1998)	20,846	425	0	CP (298)
Fall run	10 (4–6 Mar 1998)	203,010	14,523	2,483,331	CNFH (271.5)
Fall run	14 (31 Mar 1998)	268,821	28,724	3,273,109	CNFH (271.5)
Fall run	15 (7 Apr 1998)	132,885	16,409	1,655,239	CNFH (271.5)
Fall run	17 (22–23 Apr 1998)	310,771	63,526	4,324,851	CNFH (271.5)
Fall-run fry	6 (4 Feb 1998)	0	0	8,203,920	BRBD (243)
Steelhead	1–2 (2–9 Jan 1998)	0	401,062	0	CNFH (271.5)
Steelhead	2 (8 Jan 1998)	0	0	143,517	CNFH (271.5)

1/ CNFH = Coleman National Fish Hatchery; CP = Caldwell Park; BRBD = Below Red Bluff Diversion.

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 47 (Table 4, Figure 21). Altogether, 54 in-river produced late-fall-run juveniles from BY 1997 were collected from week 47 through week 2 (4–10 January 1998). The highest catches occurred during weeks 48 (n = 17) and 49 (n = 22). These fish ranged from 90 to 155 mm FL (Table 4).

A total of 115 in-river produced late-fall-run juveniles from BY 1998 was also collected: 112 from week 15 (5–11 April 1998) through week 23 (31 May–6 June 1998) and one each during weeks 34, 35 and 40 (Figure 21). These fish ranged from 31 to 77 mm FL (Table 4).

We collected 151 marked late-fall run (Table 5). These fish were collected from week 49 (30 November–6 December 1997) through week 12 (15–21 March 1998) (Figure 22). Relatively high catches occurred during weeks 51 (n = 25), 4 (n = 26) and 5 (n = 45). Ninety-three of the 151 marked fish were late-fall-run-sized (BY 1997) of which 91 had CWTs that identified them as late-fall run from CNFH. (The two fish without a CWT were also classified as late-fall run from CNFH). CWT data also revealed that an additional 48 of these marked fish were classified by size as winter run but were actually late-fall run from CNFH. We also classified 10 winter-run-sized marked salmon without CWTs as late-fall run based upon the proportion of marked winter-run-sized salmon bearing CWTs that were actually CNFH late-fall run (48 out of 48).

A total of 854,349 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 39,696 were marked but either shed or otherwise did not have a CWT when released. Four releases consisting of six distinct tag groups were made over a period of 10 weeks, between 10 November 1997 and 22 January 1998 (Table 3). Each tag group was comparable in size. We captured 5 (0.003%) fish from the first release, 40 (0.032%) from the second, 20, 38 and 9 (0.015% total) from the three tag groups released on 12, 13 and 14 January 1998, and 27 (0.022%) from the last release (Table 5, Figure 22). Fish from the first release were collected at Knights Landing from 21 to 51 days after their release (mean = 33 days); fish from the second release were collected from 5 to 101 days later (mean = 23 days); fish from the third release were collected 3 to 65 days later (mean = 22 days). The last fish from the second through fourth tag groups was collected in week 12, during emigration phase 3 (Figure 6), coincident with the peak catch during that phase and following the initial release of fingerling-sized CNFH produced fall run (Table 3). Twelve percent of all marked late-fall run were collected during phase 3 (weeks 11 and 12).

Winter-Run-Sized Chinook Salmon

As with late fall, all winter run released from CNFH were marked and all unmarked winter run (based on size) were considered to have been produced in-river. A total of 688 in-river produced winter-run chinook salmon from BY 1997 was collected from week 40 (28 September–4 October 1997) through week 13 (22–28 March 1998) (Table 4, Figure 21). During the primary migration period, 48% of the catch of in-river produced winter run occurred in November, 30% in December, 11% in January, 3% in February, and 7% in March.

We observed three peaks in catches of in-river produced winter run during the primary migration period, corresponding to the three phases of emigration discussed above (Figure 21, cf. Figure 6). Winter-run catch first peaked in week 49 then declined to a low in week 1 (phase 1). Catch peaked again in week 2 then gradually declined (phase 2) before peaking a third time during week 12 (phase 3). Over 78% of in-river produced winter run were captured during phase 1, coincident with the first major increase in flow. Some 13% were captured during phase 2, in association with increased flow and a large number of fall-run migrants. Nine percent were captured during phase 3. Much of the phase 3 movement of winter run occurred prior to the week 12 peak, possibly in response to the release of a large number of CNFH-produced fry into the upper Sacramento River during week 6. Winter-run migration ended in week 13, immediately following the peak of emigration during phase 3 (Figure 21, cf. Figure 6).

In addition, two winter run were collected several weeks prior to the primary migration period (weeks 40 and 41), and 28 winter run from BY 1998 were caught several weeks after the end of the primary emigration period, after week 33 (16 August–3 October 1998).

We captured 67 winter-run-sized marked salmon. Of these, only nine were confirmed to be winter run released from CNFH (Table 5). As discussed above, 48 of the 67 were identified as late-fall run from CNFH based on CWT codes, and 10 did not have a CWT. Based upon the proportion of late-fall to winter run for the fish with CWTs, we estimated that all 10 of the fish without tags were late-fall run.

Only 20,846 marked and tagged winter run (425 were marked without tags) were released into the upper Sacramento River on 9 April 1998 (week 15), about 200 river miles upstream of Knights Landing (Table 3). The nine (0.04%) confirmed marked winter run were captured from week 16 through week 19 (Table 5, Figure 22).

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, 28 September 1997–3 October 1998.

Week	Fall run[2/]		Spring run[3/]		Winter run		Late-fall run	
	Number	FL range	Number	FL range	Number	FL range	Number	FL range
40	0		0		1	38	0	
41	0		0		1	38	0	
42	0		0		0		0	
43	0		0		0		0	
44	0		0		0		0	
45	0		0		0		0	
46	0		0		0		0	
47	0		0		3	74–78	1	102
48	0		8	30–39	163	48–88	17	90–134
49	31	29–33	148	28–39	342	45–92	22	90–155
50	18	31–35	9	36–39	7	65–90	0	
51	196	29–37	77	36–42	17	60–99	9	106–124
52	88	29–38	19	38–40	5	65–87	0	
1	3	37–39	1	40	0		2	120
2	11,274	30–43	48	42–53	37	61–109	3	120–130
3	12,629	30–44	20	43–48	19	71–100	0	
4	6,037	29–47	11	46–58	15	74–100	0	
5	3,970	29–49	4	48–57	6	81–111	0	
6	2,876	27–50	4	50–53	3	80–117	0	
7	2,317	29–53	7	52–54	4	72–97	0	
8	1,547	29–55	4	57–62	4	88–113	0	
9	3,214	28–58	8	58–65	10	94–107	0	
10	1,227	31–60	12	60–78	9	99–122	0	
11	3,807	31–67	178	63–77	13	88–149	0	
12	10,199	30–68	272	66–89	26	92–120	0	
13	2,559	32–71	152	69–90	3	94–106	0	
14	248	31–71	68	72–96	0		0	
15	662	34–77	81	75–100	0		4	31–34
16	759	36–81	28	79–99	0		14	33–36
17	669	37–85	12	83–90	0		7	34–36
18	1,506	39–89	7	89–95	0		31	34–38
19	255	43–86	0		0		2	35–37
20	185	50–92	2	95–96	0		10	34–39
21	146	47–98	0		0		3	33–36

Table 4 (Continued)

Week	Fall run[2]		Spring run		Winter run		Late-fall run	
	Number	FL range	Number	FL range	Number	FL range	Number	FL range
22	44	70–95	0		0		3	37–38
23	168	53–109	2	110–117	0		38	32–41
24	15	61–83	0		0		0	
25	11	70–89	0		0		0	
26	3	75	0		0		0	
27	0		0		0		0	
28	2	83–98	0		0		0	
29	0		0		0		0	
30	0		0		0		0	
31	0		0		0		0	
32	1	87	0		0		0	
33	0		0		0		0	
34	0		0		3	35–36	1	34
35	0		0		3	36–38	1	49
36	0		0		5	34–39	0	
37	0		0		1	48	0	
38	0		0		5	37–39	0	
39	0		0		3	34–38	0	
40	0		0		8	31–39	1	77
Total	66,666	27–109	380 [4] 802 [5]	28–78 63–117	688 [6] 28 [7]	38–149 31–48	54 [6] 115 [7]	90–155 31–77

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. Less than 6% of fall run released from CNFH were marked.

3/ All spring-run-sized salmon collected after week 10 (shaded area) were considered CNFH-produced fall run based upon CWT data and size distributions of fall run released from CNFH (see text).

4/ Total captured before week 11, considered in-river produced spring run.

5/ Total captured after week 10, considered CNFH produced fall run.

6/ BY 1997

7/ BY 1998

Table 5. Summary of catch and size range data for marked, hatchery-produced chinook salmon (by run) caught by rotary screw traps in the Sacramento River near Knights Landing, 28 September 1997–3 October 1998.

Week	Fall run		Winter run		Late-fall run	
	Number	FL range	Number	FL range	Number	FL range
40-48	No marked salmon were caught weeks 40 through 48					
49	0		0		2	127–128
50	0		0		1	120
51	0		0		25	121–150
52	0		0		4	125–134
1	0		0		1	109
2	0		0		8	112–145
3	0		0		1	165
4	0		0		26	122–160
5	0		0		45	116–168
6	0		0		8	92–158
7	0		0		1	150
8	0		0		2	120–148
9	0		0		5	97–158
10	0		0		4	120–150
11	55	50–66	0		9	100–137
12	79	54–72	0		9	93–170
13	13	61–69	0		0	
14	2	67–73	0		0	
15	26	62–80	0		0	
16	38	60–80	1	77	0	
17	27	60–78	4	76–87	0	
18	67	65–82	3	76–92	0	
19	10	65–82	1	95	0	
20	2	76	0		0	
21	4	75–87	0		0	
22	0		0		0	
23	2	80–87	0		0	
No marked salmon caught after week 23						
Total	325	50–87	9	76–95	151	92–170

Spring-Run-Sized Chinook Salmon

No hatchery-reared spring-run chinook salmon were released 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 10 (1–7 March 1998; Figure 21) were considered in-river produced spring run. Beginning in week 11, all spring-run-sized salmon were considered fall-run juveniles based upon the following information:

- A substantial increase in the catch of spring-run-sized salmon began in week 11 (n = 55) concurrent with the arrival of marked, hatchery-produced fall run released into the upper river during week 10 (Table 5).

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

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 10 (Table 4, Figure 21). A total of 380 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 peak occurred during week 49, coincident with the first flow increase of the season. The second peak occurred during week 2 corresponding to the second major flow episode and a substantial increase in fall-run emigration.

Twenty spring-run-sized, marked salmon were caught by RST. All of these fish were caught after week 11. Of these 20 marked fish, four were identified as winter run and 16 were identified as 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, 66,666 fall-run-sized salmon were collected (Table 4). Fall run were first collected during week 49, the third week into the primary migration period, and then in every subsequent week through week 26 (21–27 June 1998; Figure 21). One fall run was also collected during each of weeks 28 and 32.

The catch distribution exhibited several peaks consistent with the emigration phases introduced earlier. As with the other salmon runs collected during the survey, the first peak occurred during the initial high flow event (weeks 49–52) followed by a peak during the second high flow event (weeks 2–3). The highest catches occurred during this second event. The last two peaks (weeks

12 and 18) 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 hatchery-reared fish into the upper river system. In week 6, more than 8 million hatchery-reared fall-run fry were released into the upper Sacramento River, immediately downstream of RBDD. 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 6 were known in-river produced salmon, but were of unknown origin after week 6 when the first plant of hatchery-produced fall run was made.

Beginning in week 10, ~ 8% of the fall run released into the upper river were marked. Four releases totaling nearly 13 million fall-run chinook salmon from CNFH were made into Battle Creek, near RM 271.5, during week 10 (4–6 March 1998), week 14 (31 March 1998), week 15 (7 April 1998), and week 17 (22–23 April 1998). A representative group from each plant was measured just prior to planting. Comparison of size distribution of fish from each plant with salmon collected at Knights Landing indicates that a large portion of salmon caught from weeks 11 through 26 were likely from CNFH (Appendix Figures 2–5).

A total of 314 fall-run-sized, marked fish was caught by RST: 288 contained tags that identified them as fall run, five contained tags that identified them as winter run, and 21 did not have tags but were considered fall run. In addition, 16 marked, spring-run-sized salmon contained tags that identified them as fall run. Altogether, 325 marked fall run were collected.

Based upon CWT recoveries, fall run from the first release into Battle Creek arrived at Knights Landing during week 11 (Table 5, Figure 22). From week 11 through the end of the survey, the 325 marked fall run, in addition to 21,555 unmarked fall run, were collected (Tables 4 and 5, Figures 21 and 22). The marked fish accounted for 1.5% of all fall run collected during weeks 11–23 compared to ~8% of all hatchery released fall run. Assuming that survival of hatchery-produced fall run to Knights Landing was independent of tagging, about 20% of the fish caught at Knights Landing after week 10 were from CNFH.

Steelhead Trout Emigration

Steelhead trout captured in the RSTs represented two age groups: 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.

<u>Adult Steelhead</u>

Four adult-sized steelhead were collected (Table 6): one in week 2 (339 mm FL), one in week 3 (310 mm FL), one in week 17 (445 mm FL), and one in week 20 (309 mm FL). These fish were likely two-year-old smolts produced in-river.

Yearling Steelhead

We collected 110 unmarked, yearling-sized steelhead from week 51 (14–20 December 1997) through week 20 (10-16 May 1998) (Table 6, Figure 23). Less than 1% were caught in December, 10% in January, 5% in February, 70% in March, 9% in April, and 5% in May. There were three primary peaks in their catch distribution which were coincident with the second and third phases of salmon emigration. The first peak occurred during week 4 (7 steelhead). The second and largest peak occurred during week 12, and the final peak occurred during week 18. The first mode was coincident with the start of the highest flow period (Figure 4), rather than the first flow increase associated with emigration phase 1 for salmon. Only one steelhead was caught during the first phase (Table 6; Figure 23). The second and third peaks were coincident with the first and third CNFH fall-run plants (Table 3).

A total of 401,062 marked steelhead was planted about 180 river miles upstream from Knights Landing during weeks 1 and 2 (2–9 January 1998) (Table 1). An additional 143,517 unmarked, CNFH produced steelhead were also released during week 2 (8 January 1998). We collected 129 (0.03%) marked yearling steelhead from week 2 through week 18 (Table 6, Figure 23).

Unmarked yearling steelhead ranged from 134 to 300 mm FL (mean = 220 mm FL). There was no clear trend in size versus time of capture (Figures 24–29). Marked steelhead ranged from 111 to 290 mm FL (mean = 216 mm FL).

Approximately 74% of the steelhead released from CNFH were marked. Assuming that 26% of unmarked steelhead caught after week 2, when the first marked fish was collected, were hatchery produced, the total number of in-river produced steelhead captured is estimated at 82 and the number of hatchery-produced steelhead is estimated at 157.

Table 6. Summary of catch statistics for steelhead trout caught by rotary screw trap in the Sacramento River near Knights Landing, 28 September 1997 - 03 October 1998.

Week	Catch statistics						
	Young-of-year	Yearling (no clip)		Yearling (adipose clip)		Adult	
	Count	Count	Mean FL (mm) (range)	Count	Mean FL (mm) (range)	Count	Mean FL (mm) (range)
40-50	No steelhead caught week 40 through week 50						
51	0	1	245	0		0	
52-1	No steelhead caught week 51 and week 1						
2	0	0		1	180	1	339
3	0	1	250	5	182 (130–210)	1	310
4	0	7	207 (165–255)	6	235 (214–260)	0	
5	0	3	228 (220–244)	3	221 (215–229)	0	
6	0	3	232 (210–246)	1	240	0	
7	0	1	190	3	230 (219–237)	0	
8	0	1	245	3	227 (210–245)	0	
9	0	1	209	4	229 (218–245)	0	
10	0	11	216 (178–250)	11	213 (185–255)	0	
11	0	22	223 (134–270)	22	216 (113–290)	0	
12	0	30	223 (153–275)	54	217 (111–283)	0	
13	0	13	231 (156–300)	10	215 (184–230)	0	
14	0	2	175 (175–176)	1	184	0	
15	0	0		0		0	
16	0	1	239	0		0	
17	0	2	191 (173–210)	0		1	445
18	0	8	207 (180–240)	5	199 (125–240)	0	
19	0	1	188	0		0	
20	0	2	212 (205–220)	0		1	309
21-40	No steelhead caught week 20 through week 40						
Total	0	110	220 (134–300)	129	216 (111–290)	4	351 (309-445)

RST Gear Efficiency Using Mark-Recapture

Salmon were marked for efficiency evaluations beginning in week 52 (Table 7). A total of 27,248 chinook salmon was marked from week 52 through week 24; 287 (1.05%) were recaptured. The percent recaptured, by week, ranged from 0% during four weeks (two weeks when the number marked was $\leq$100), to 4.08% during week 52. The mean trap efficiency during the 22-week period was 0.80% (SD = 0.96%).

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.

There were no significant correlations between weekly trap efficiency and the number of fish marked per week r = 0.23, p = 0.30), number of fish caught per week r = 0.19, p = 0.39), or mean weekly water transparency r = 0.24, p = 0.28). There was a significant but weak negative correlation between efficiency and mean weekly flow r = $-$0.47, p = 0.03). Because trap efficiency varied independently of 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).

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 (0.008) and associated 80% confidence interval (0.005–0.011) 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 8.2 million unmarked fall-run fry planted 4 February 1998.

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 (e.g., if effort was 80% the estimate was made by dividing the actual catch by 0.8). The catch of unmarked fish was increased by 3,807 for fall run, 54 for spring run, 176 for winter run from BY 1997, 15 for late-fall from BY 1997, 15 for late-fall from BY 1998 and 3 for steelhead. The marked catch was increased by 52 for fall run, 8 for late-fall run and 2 for steelhead. These numbers were added to the actual counts and used in the calculation of the total estimates (Tables 8 and 9).

The estimated number of marked and unmarked hatchery-produced fish was determined as shown in Table 8. Estimated survival to Knights Landing of hatchery salmonids by run/species ranged from 2.3% to 5.3%.

In-river produced fish were estimated by subtracting the estimated hatchery-produced component passing Knights Landing (results from Table 8), by cohort, from the estimated total abundance of each cohort moving past the site (Table 9). Overall, an estimated 9.2 million chinook salmon (80% CI, 6.7 million–14.6 million) emigrated past Knights Landing into the lower Sacramento River and Delta. About 94% of those were estimated to have been produced in-river. An estimated 30,500 yearling steelhead (80% CI, ~22,000–48,000) emigrated past Knights Landing. In contrast to salmon, only 27% 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 (California Department of Water Resources, Division of Flood Management, pers. comm., 14 July 1998). In 1998, flow exceeded 23,000 cfs during week 4 and remained above that level through the emigration period. 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.

Table 7. Summary of capture efficiency test results for chinook salmon collected by rotary screw traps in the Sacramento River near Knights Landing, 28 September 1997 - 03 October 1998.

Week	Number marked	Number recovered	Efficiency (%)	Week	Number marked	Number recovered	Efficiency (%)
52	49	2	4.08	13	1618	11	0.68
1	0	0	!	14	311	1	0.32
2	5197	44	0.85	15	227	1	0.44
3	1854	17	0.92	16	295	0	0
4	2356	3	0.13	17	279	1	0.36
5	1739	20	1.15	18	337	1	0.30
6	1797	10	0.56	19	116	2	1.72
7	1358	4	0.29	20	54	0	0
8	861	2	0.23	21	100	0	0
9	1557	13	0.83	22	0	0	!
10	916	10	1.09	23	0	0	!
11	682	7	1.03	24	218	0	0
12	5327	138	2.59	**Total**	**27,248**	**287**	**1.05**

Table 8. 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 28 September 1997 through 3 October 1998.

Cohort	**A** Marked caught	**B** Marked estimate (**A** ' 0.008)[1/]	**C** No. planted marked	**D** Survival (**B** ' **C**)*	**E** No. planted unmarked	**F** No. estimated unmarked (**D**×**E**)	**G** No. estimated hatchery total (**B**+**F**)
Late-fall run	159	19,875 (14,455–30,200)	854,349	0.023 (0.017–0.037)	0	0	19,875 (14,455–31,619)
Winter run	9	1,125 (818–1,800)	21,271	0.053 (0.038–0.085)	0	0	1,125 (818–1,800)
Fall run	377	47,125 (34,274–74,971)	1,038,669	0.045 (0.032–0.072)	11,736,530	528,144 (328,623–739,401)	575,269 (418,393–915,195)
Steelhead	131	16,375 (11,910–26,051)	401,062	0.041 (0.030–0.065)	143,517	5,884 (4,280–9,361)	22,259 (16,189–35,412)

1/ 80% CI of 0.0145 used in estimates was 0.005–0.011.

Table 9. 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 28 September 1997 through 3 October 1998.

Cohort	**A** Total caught	**B** Estimated total (**A** ' 0.008)[1/]	**C** Hatchery total (from Table 8)	**D** In-river-produced total (**B ! C**)
Late-fall run (BY 1997)	228	28,500 (20,728–45,341)	18,875 (13,727–30,200)	9,625 (7,000–15,312)
Late-fall run (BY 1998)	130	16,250 (11,819–25,852)	0	16,250 (11,819–25,852)
Winter run (BY 1997)	873	109,125 (79,367–173,607)	1,125 (818–1,800)	108,000 (78,548–171,817)
Winter run (BY 1998)	28	3,500 (2,545–5,600)	0	3,500 (2,545–5,600)
Spring run	434	54,250 (39,456–86,306)	0	54,250 (39,456–86,306)
Fall run [1/]	71,652	8,956,500 (6,514,062–14,248,895)	498,350 (358,168–804,401)	8,458,150 (6,151,612–13,456,070)
Total salmon	73,345	9,168,125 (6,679,977– 14,585,574)	518,350 (372,713– 836,401)	8,649,775 (6,290,981– 13,760,927)
Steelhead	244	30,500 (22,183–48,522)	21,866 (15,889–34,985)	8,634 (6,280–13,736)

1/ Includes spring-run-sized salmon collected after week 10.

2/ 80% CI of 0.0145 used in estimates was 0.005–0.011.

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 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.

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FIGURES

Sacramento River and tributaries

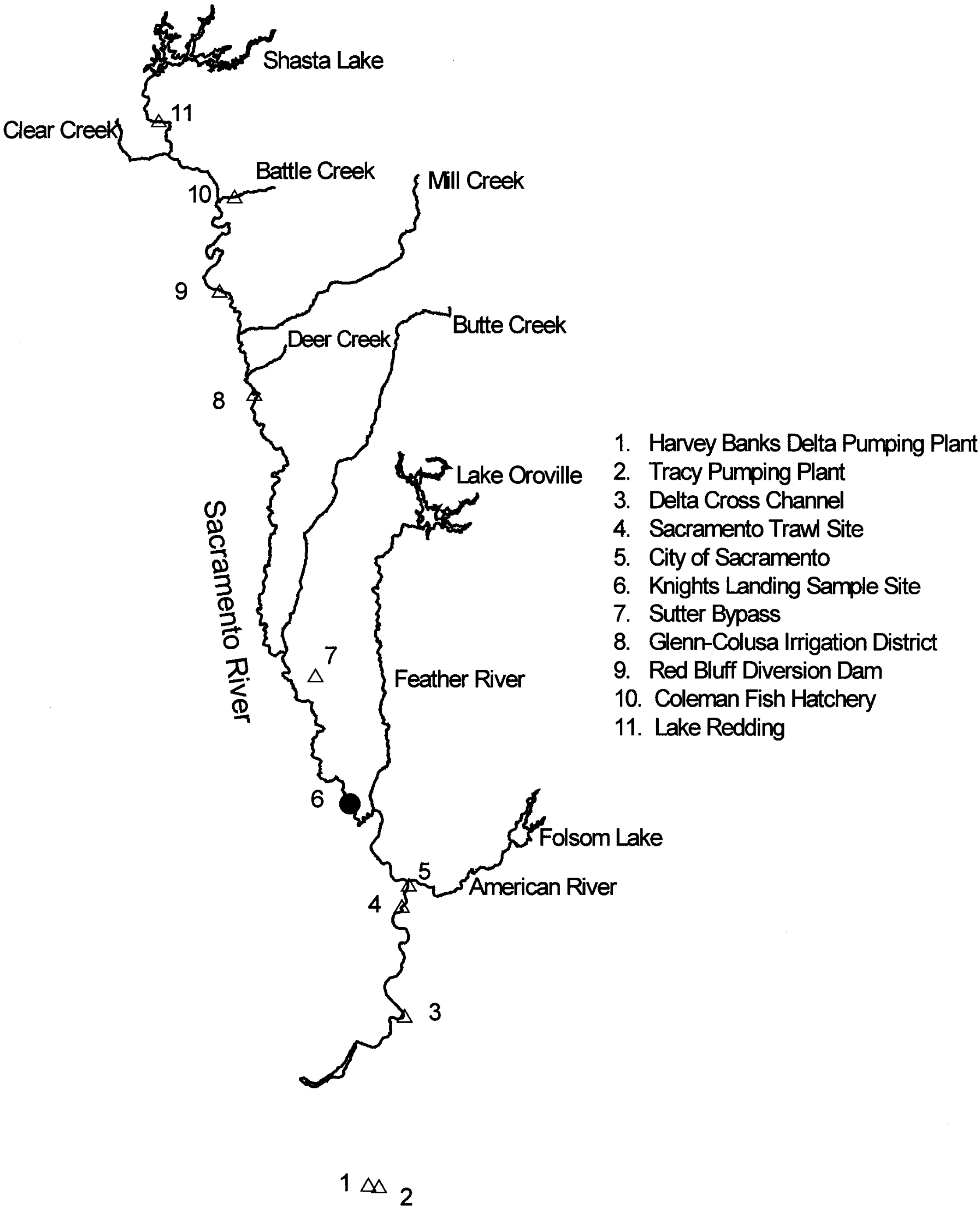


Figure 1. Relative location of Knights Landing monitoring site in the upper Sacramento River, November 1995 - July 1996.

Sacramento River at Knights Landing
Rotary Screw Trap Cross Section Profile

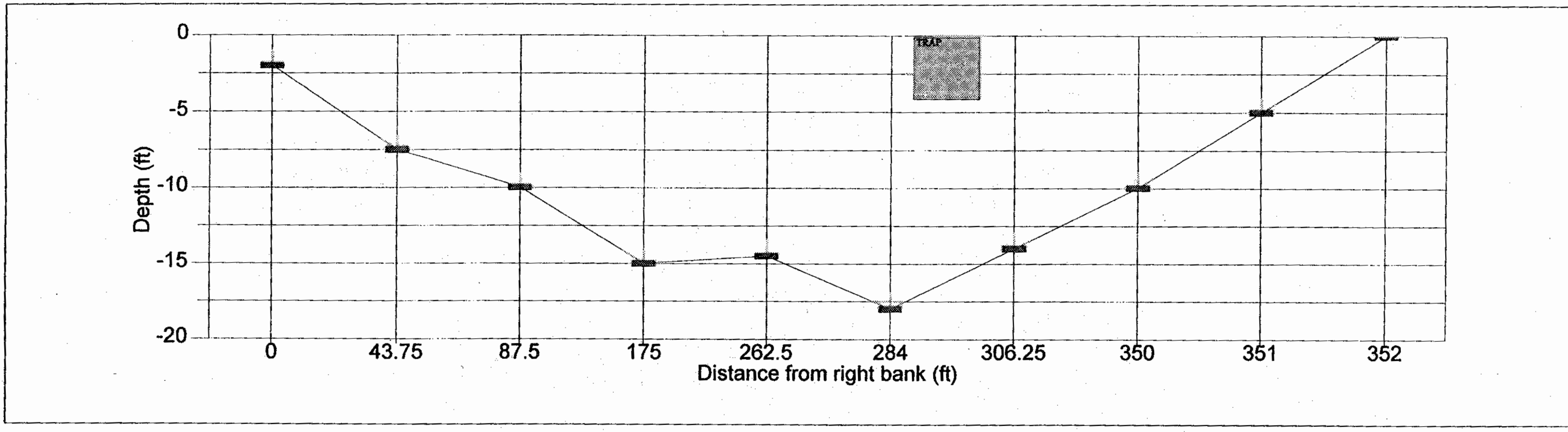


Figure 2. Cross section profile of Sacramento River at the Knights Landing rotary screw trap sampling location, River Mile 89.5.

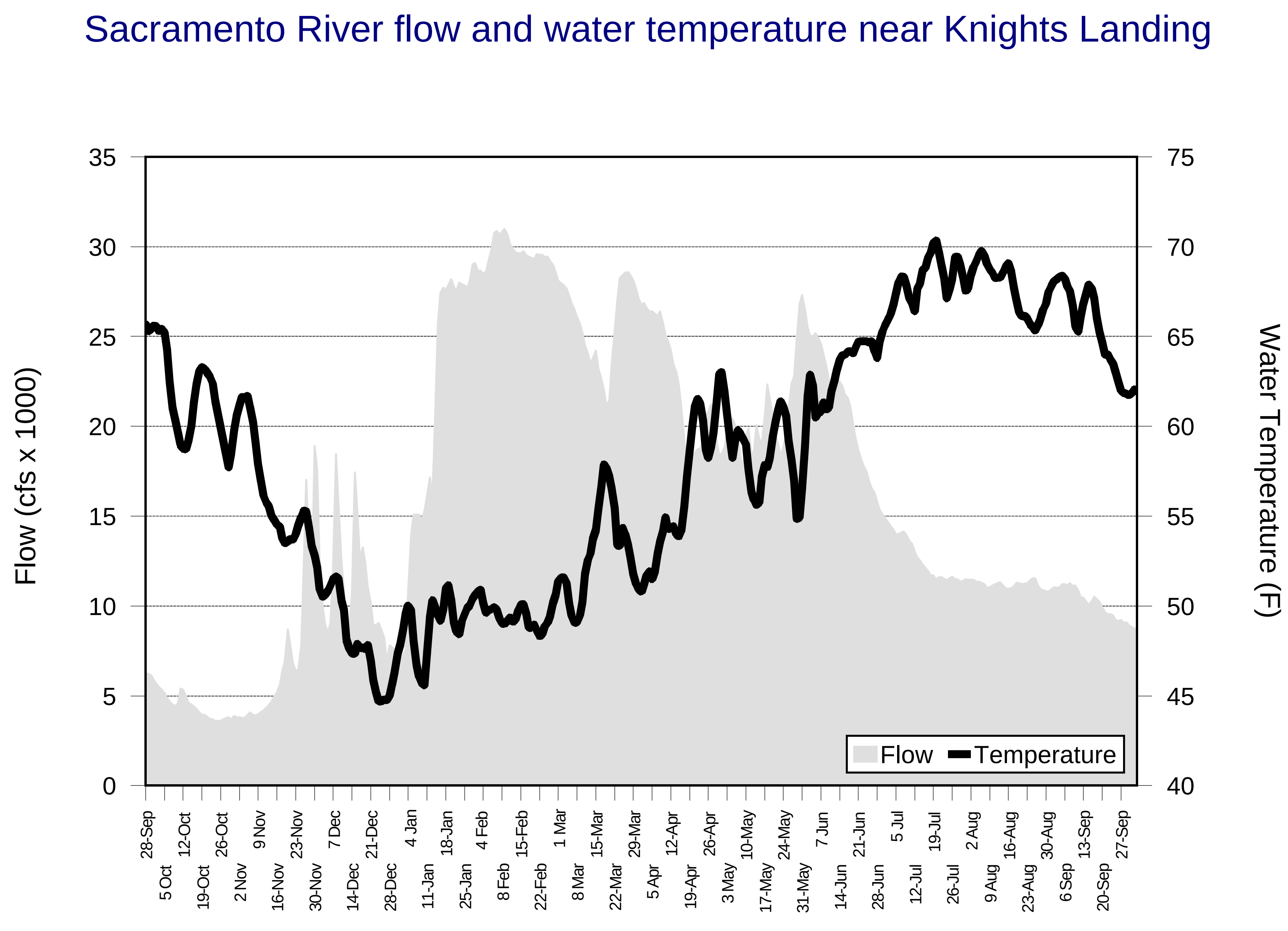


Figure 3. Mean daily flow measured in the Sacramento River near Knights Landing at Wilkins Slough, and mean daily water temperature measured at Knights Landing, 28 September 1997 - 3 October 1998.

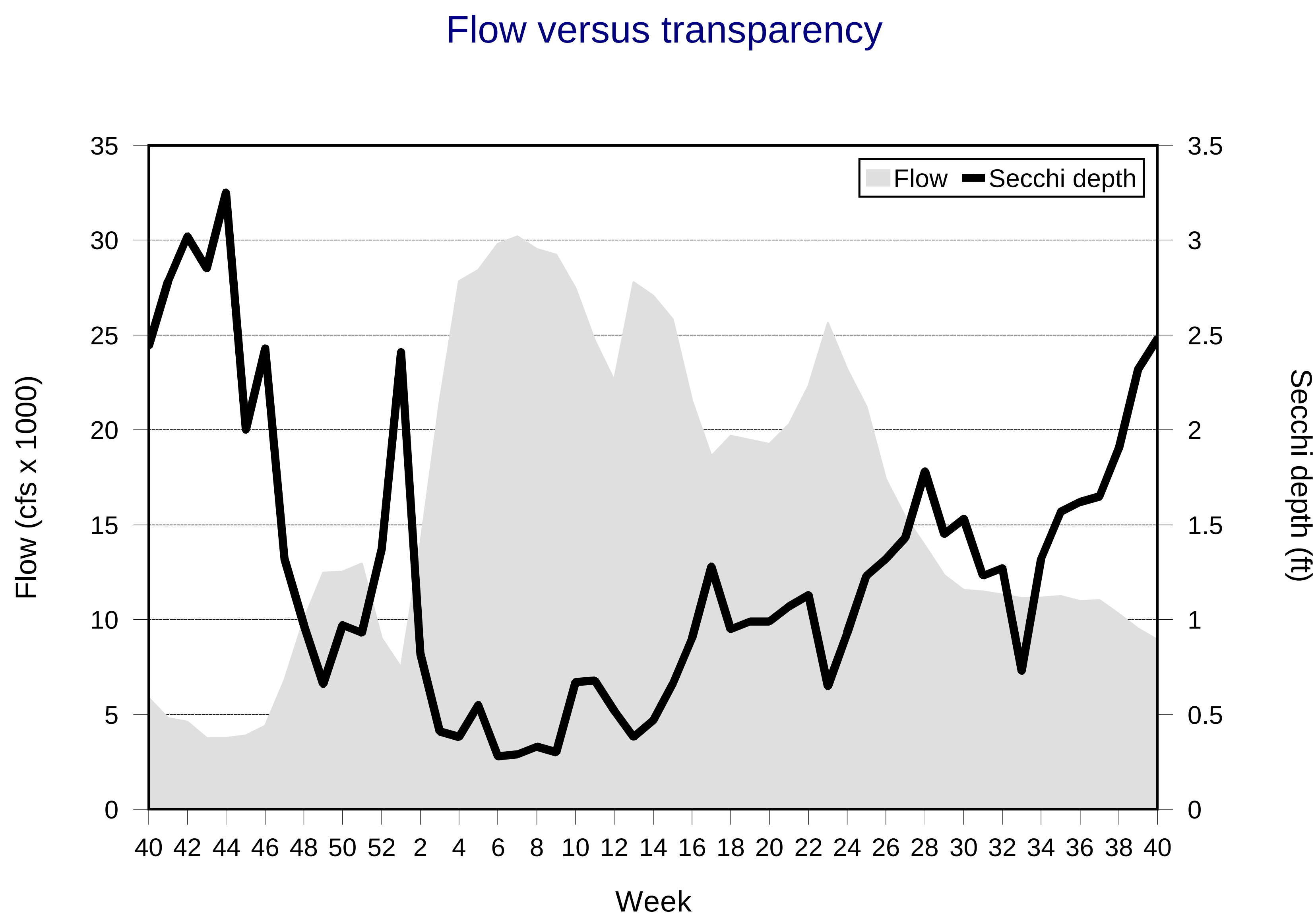


Figure 4. Mean weekly flow compared with mean weekly transparency (Secchi depth) measured in the Sacramento River near Knights Landing, 28 September 1997 - 3 October 1998.

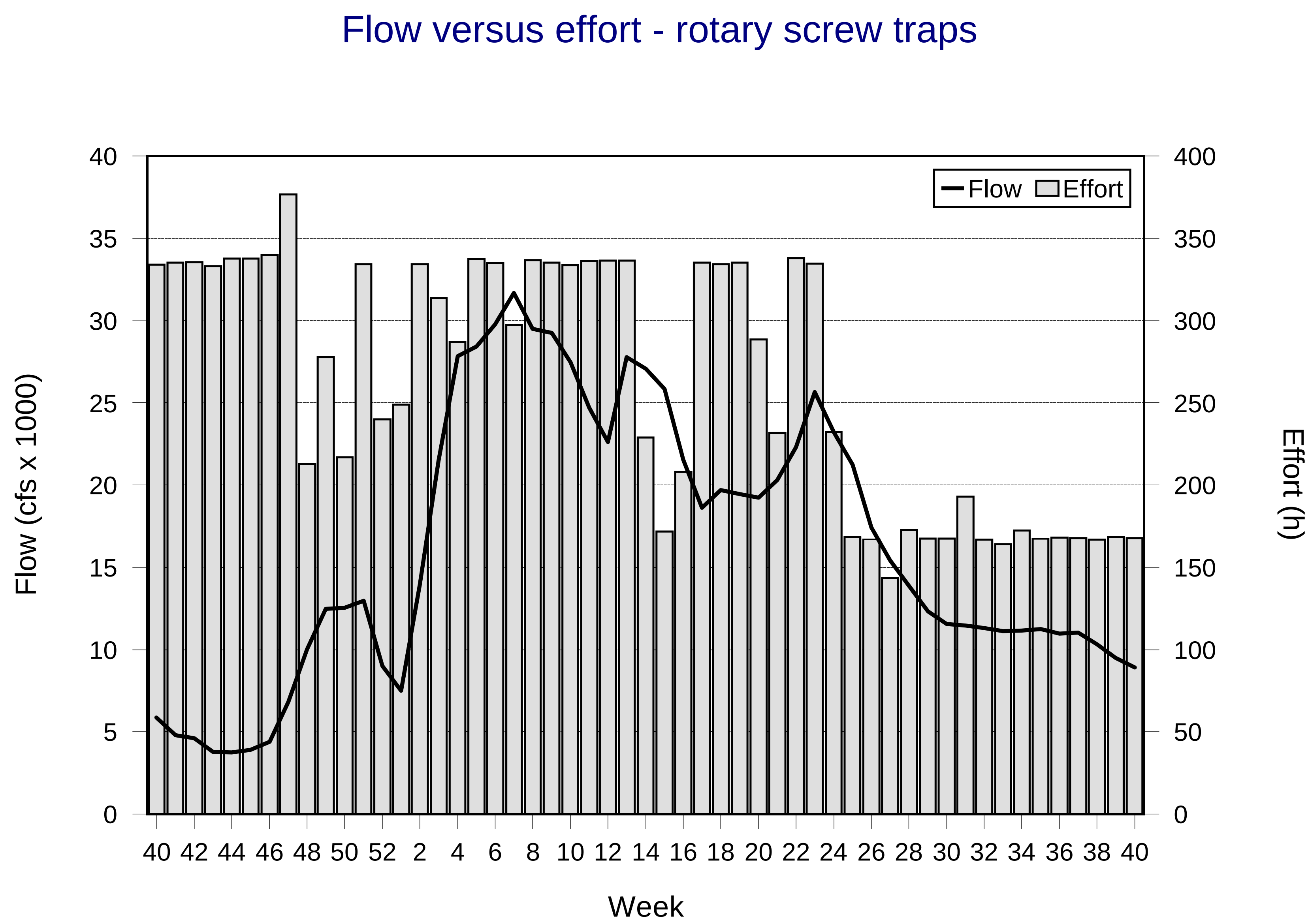


Figure 5. Mean weekly flow versus total weekly fishing effort expended by rotary screw traps in the Sacramento River near Knights Landing, 28 September 1997 - 3 October 1998.

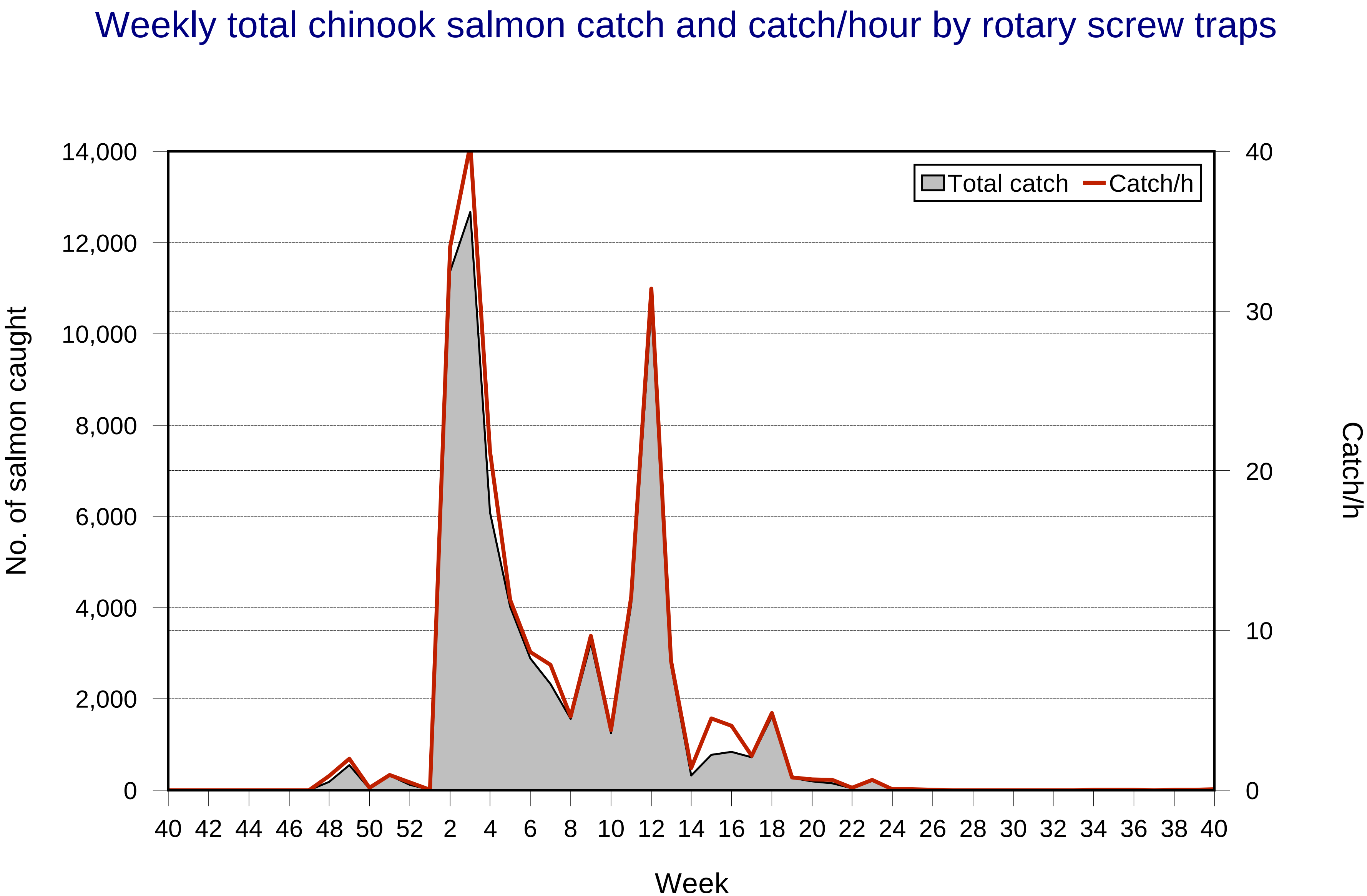


Figure 6. Weekly total catch and weekly catch rate of chinook salmon collected by rotary screw traps in the Sacramento River near Knights Landing, 28 September 1997 - 3 October 1998.

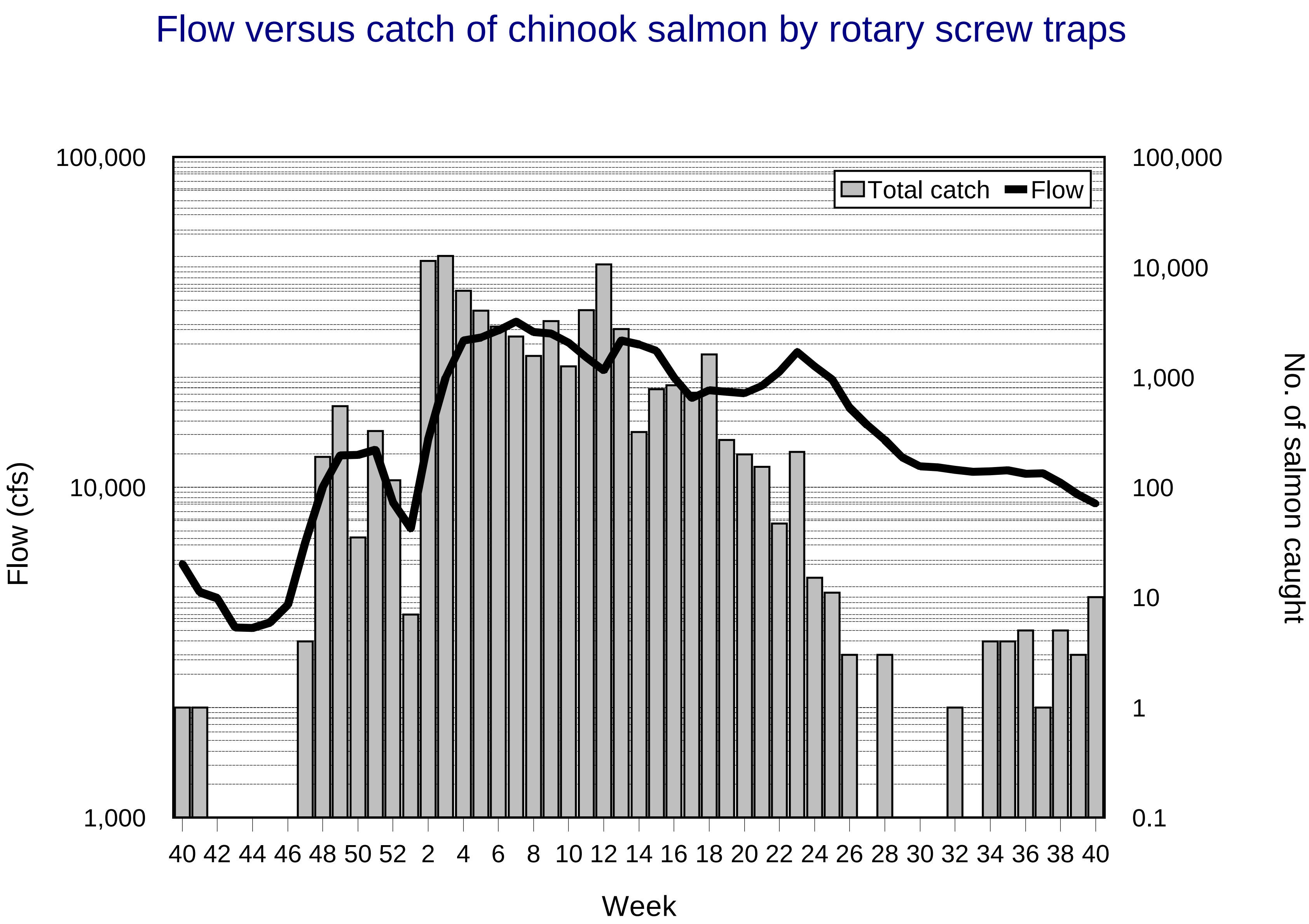


Figure 7. Comparison of mean weekly flow and weekly total catch of all chinook salmon collected by rotary screw traps in the Sacramento River near Knights Landing, 28 September 1997 - 3 October 1998. Note logarithmic scale on the y-axes.

Mean weekly size and size range for chinook salmon caught by rotary screw trap

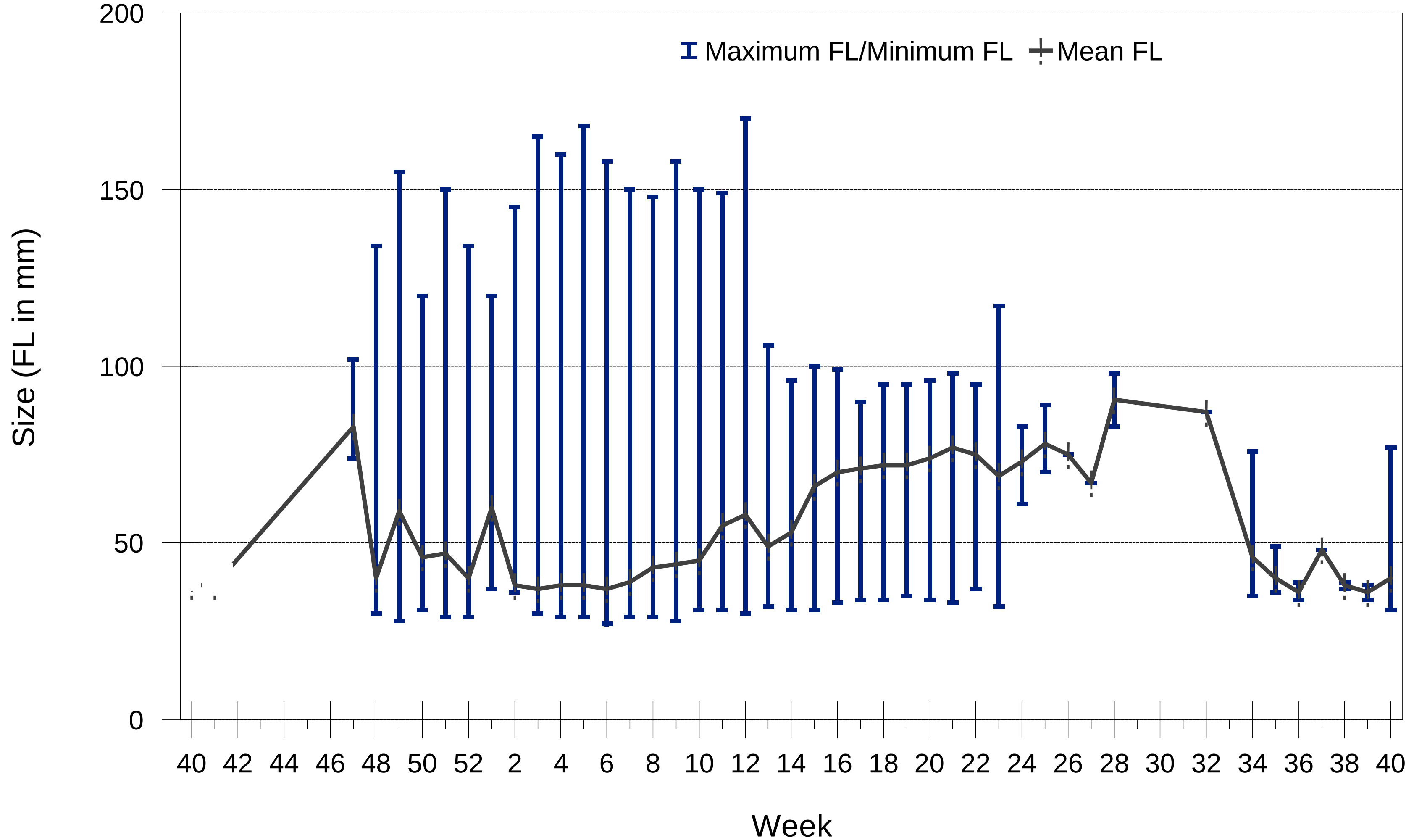


Figure 8. Mean weekly size (FL in mm) and size range of chinook salmon collected by rotary screw trap in the Sacramento River near Knights Landing, 28 September 1997 - 3 October 1998.

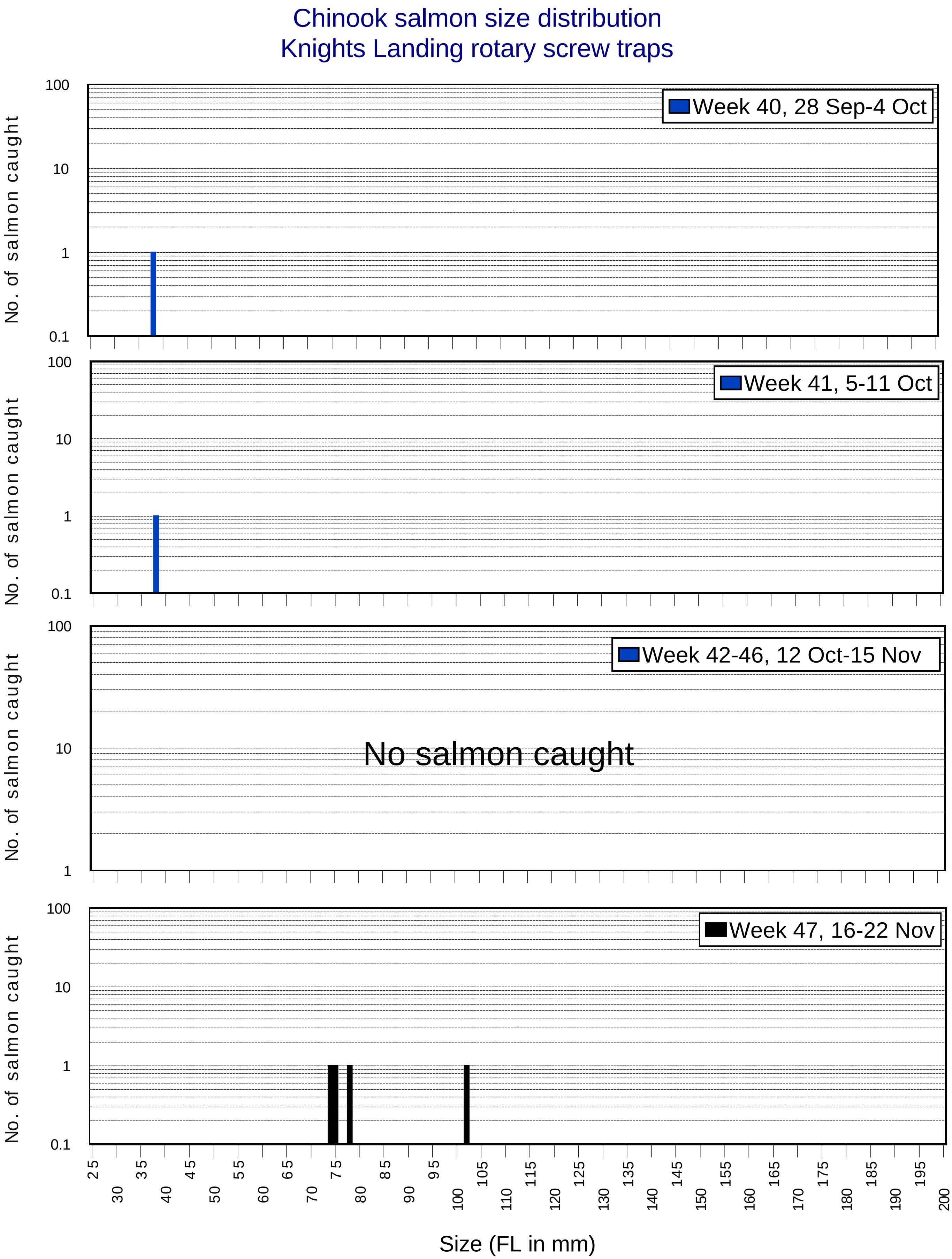


Figure 9. Size distribution of chinook salmon caught by rotary screw traps near Knight Landing, Sacramento River, 28 September through 22 November 1997.

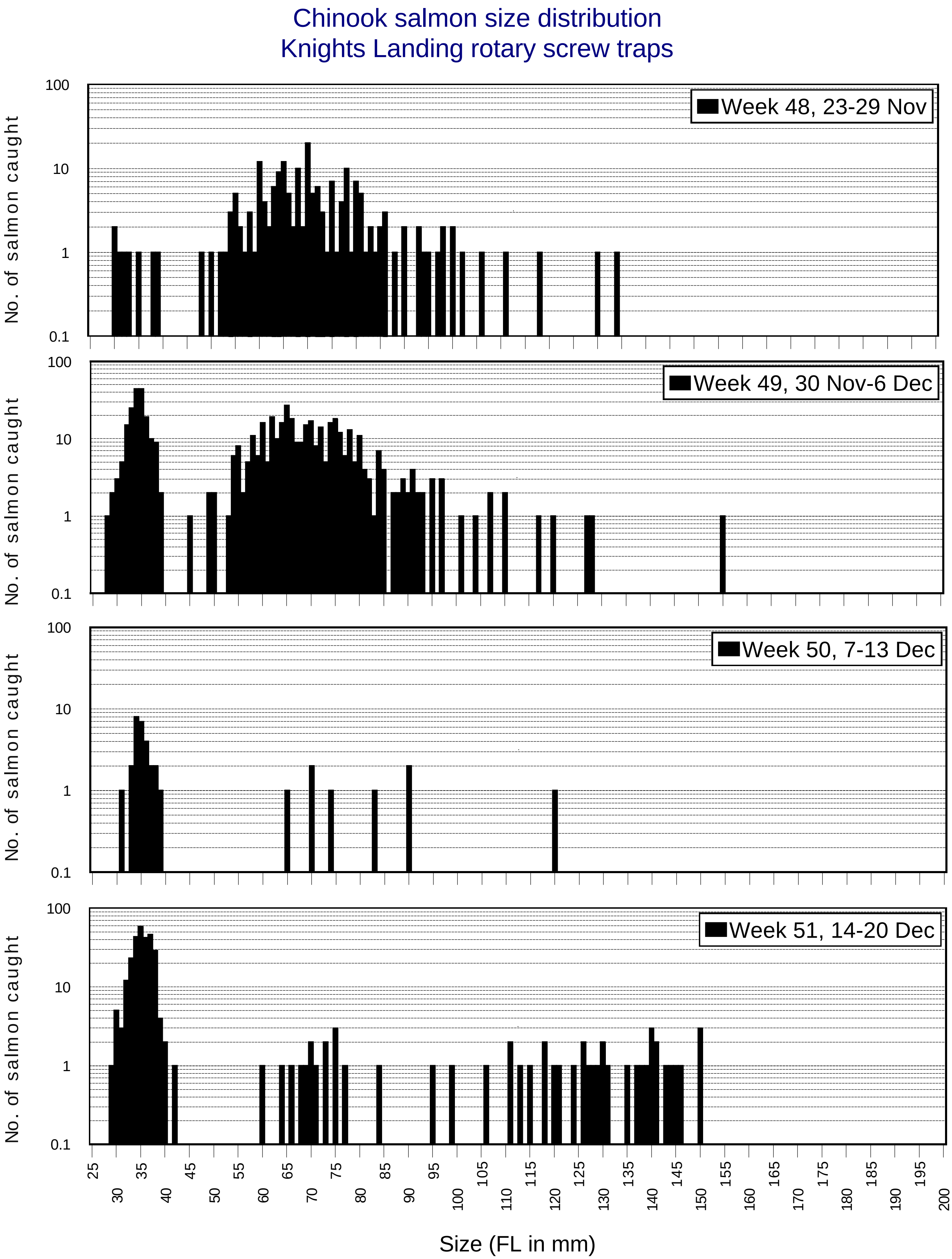


Figure 10. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 23 November through 20 December 1997.

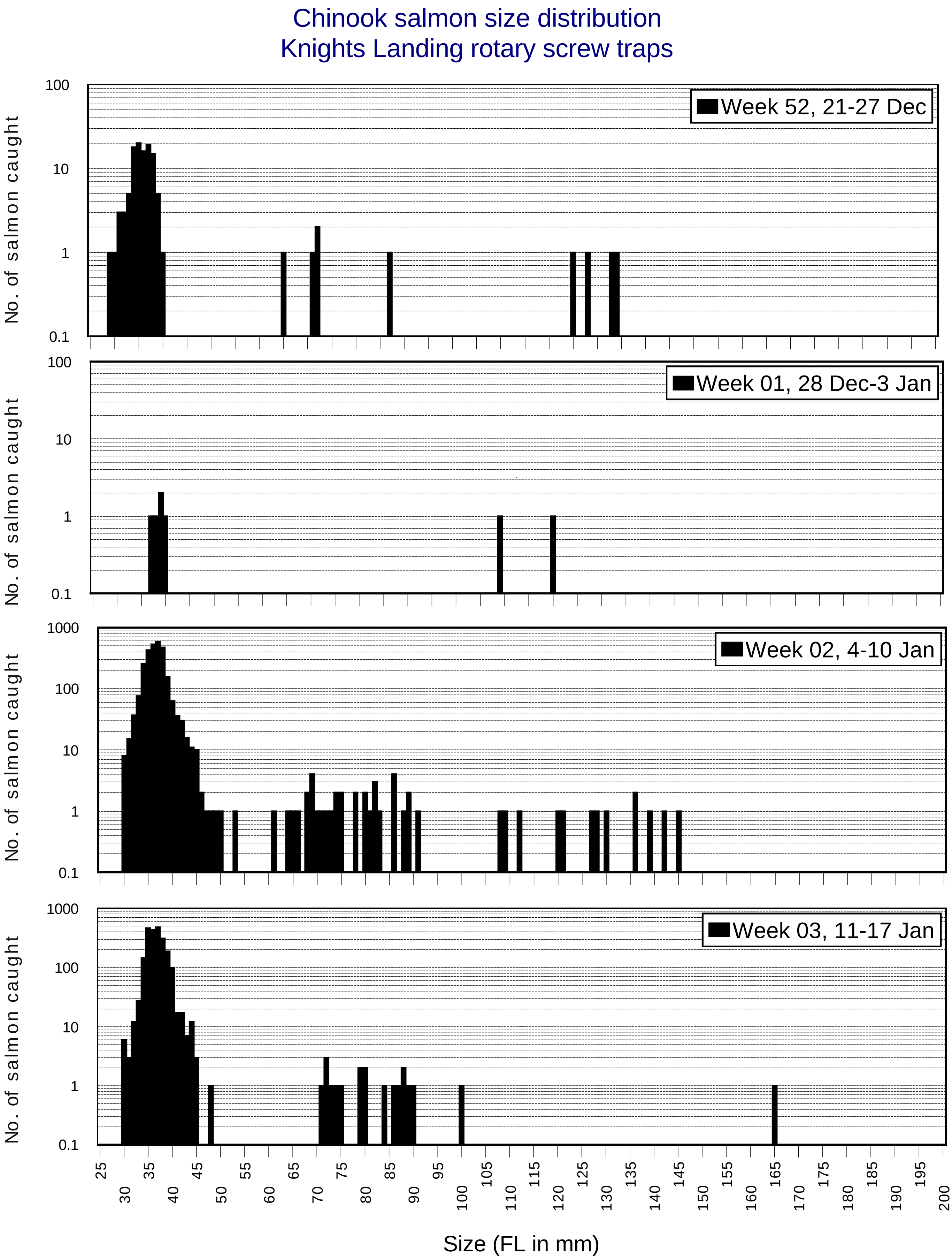


Figure 11. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 21 December 1997 through 17 January 1998.

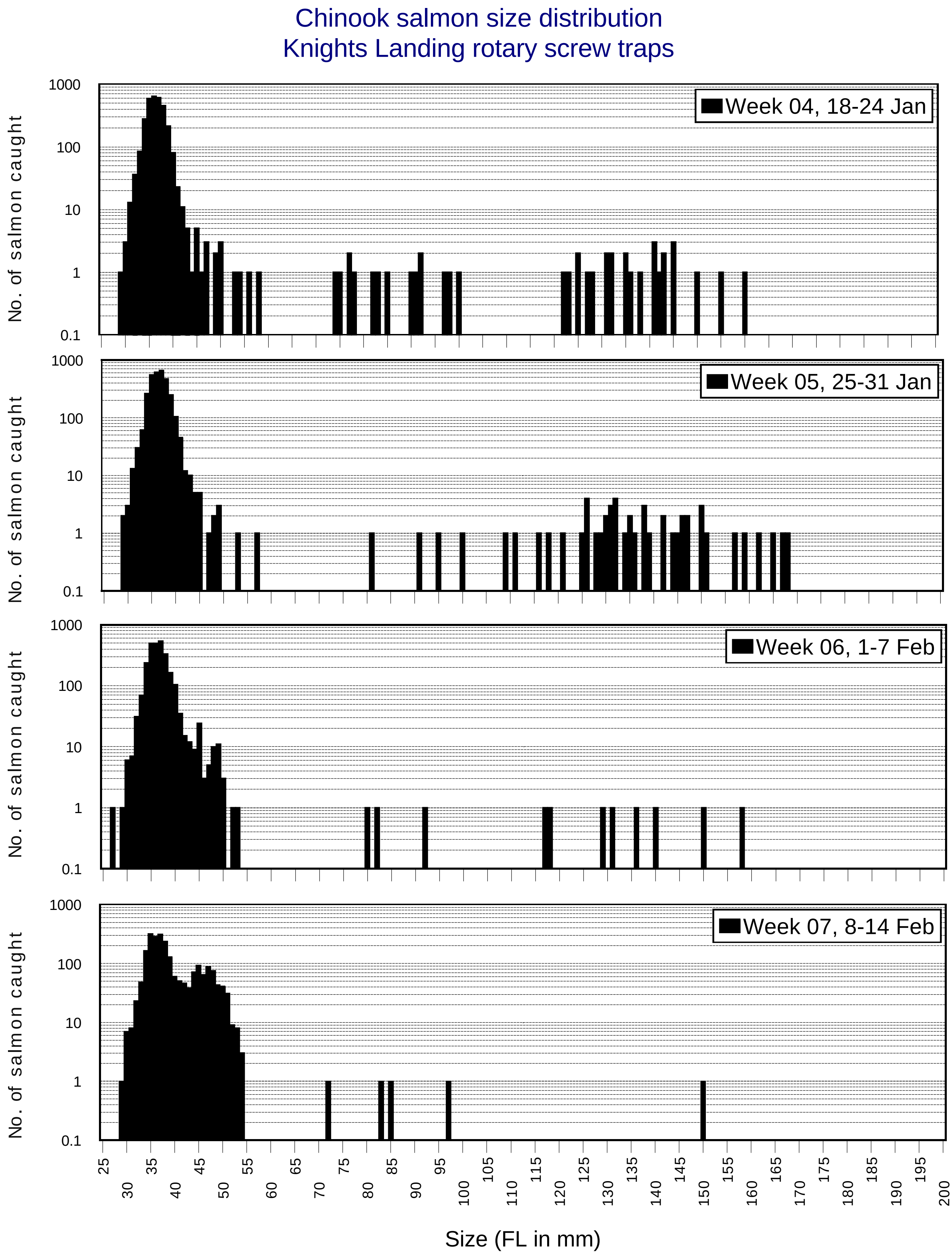


Figure 12. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 18 January through 14 February 1998.

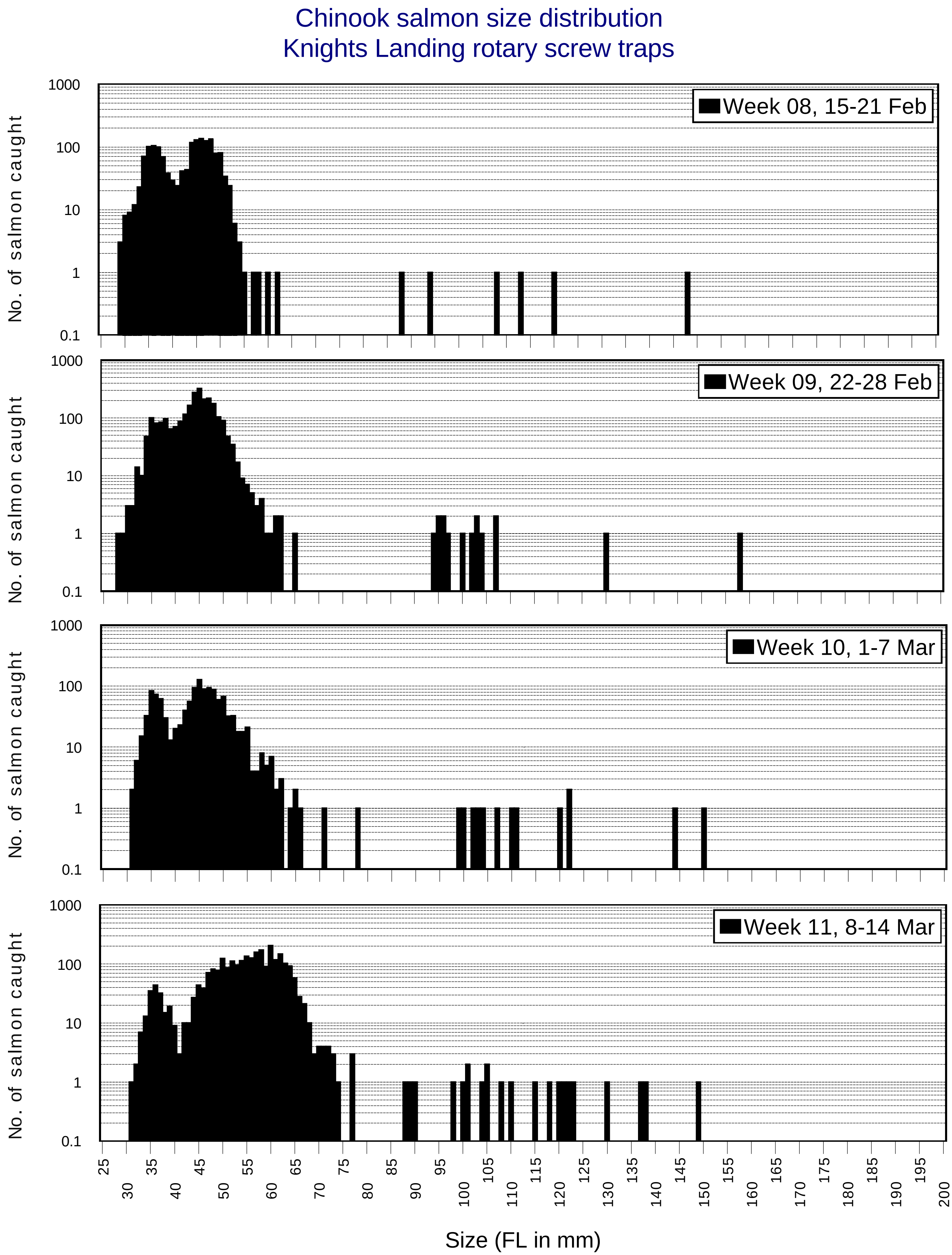


Figure 13. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 15 February through 14 March 1998.

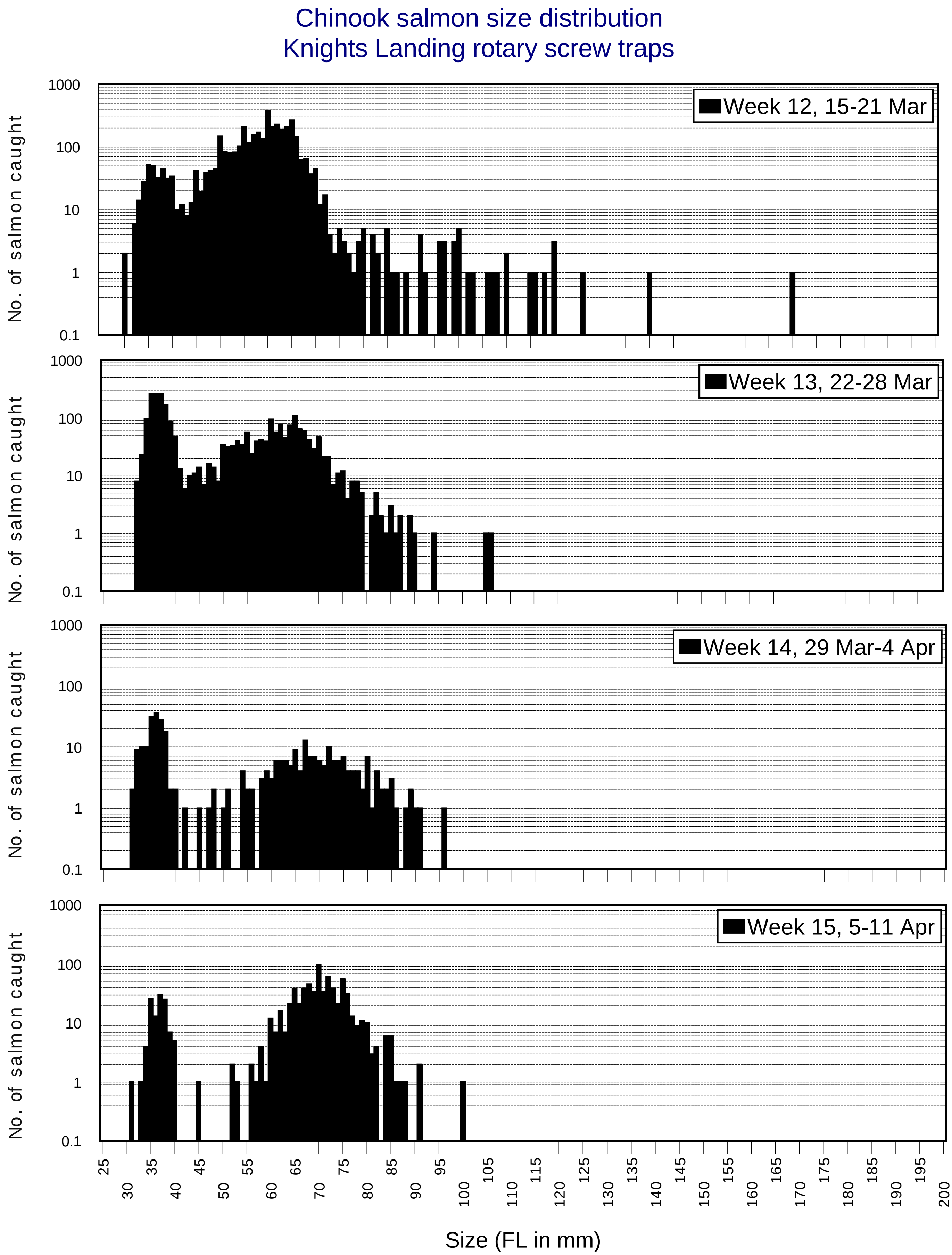


Figure 14. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 15 March through 11 April 1998.

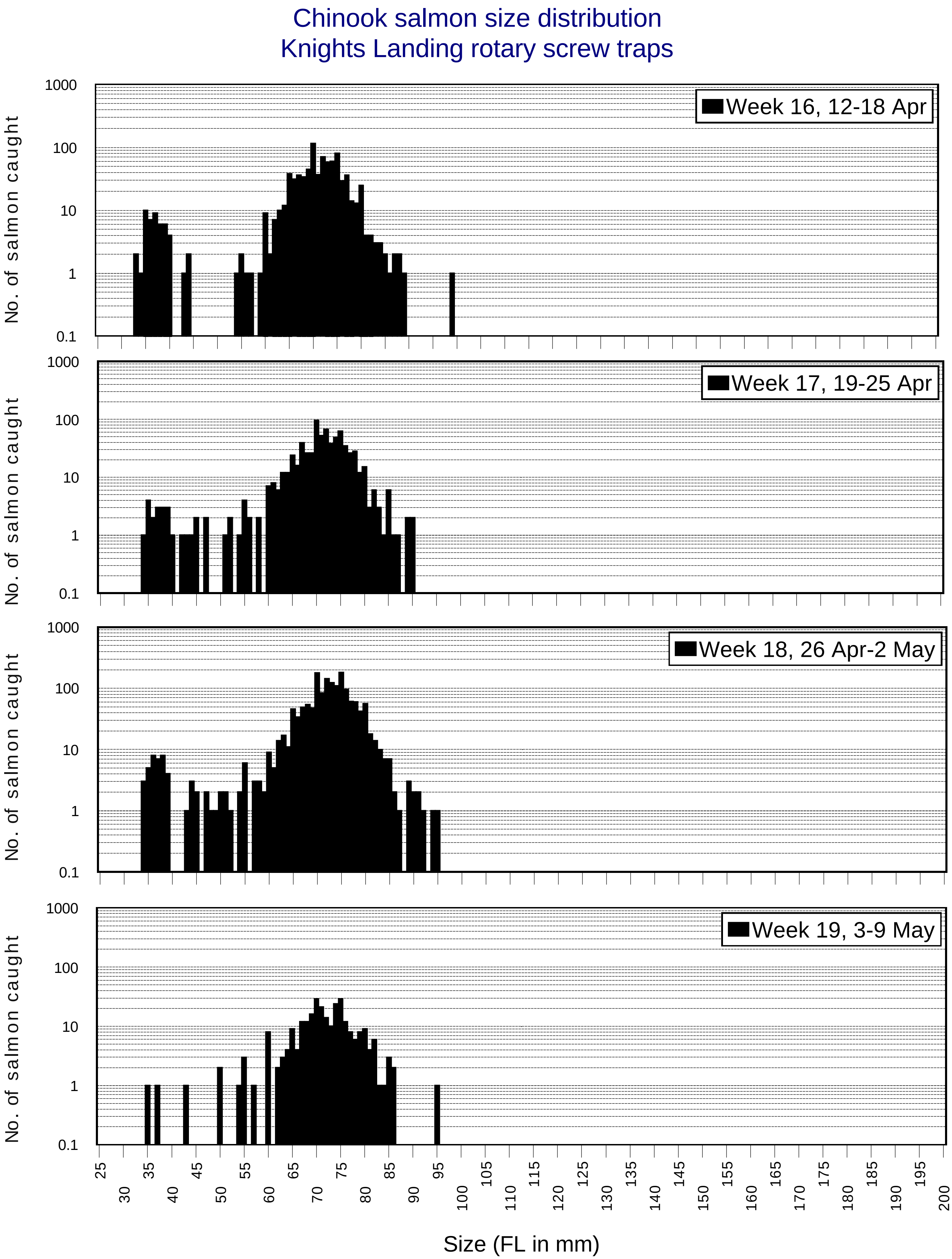


Figure 15. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 12 April through 09 May 1998.

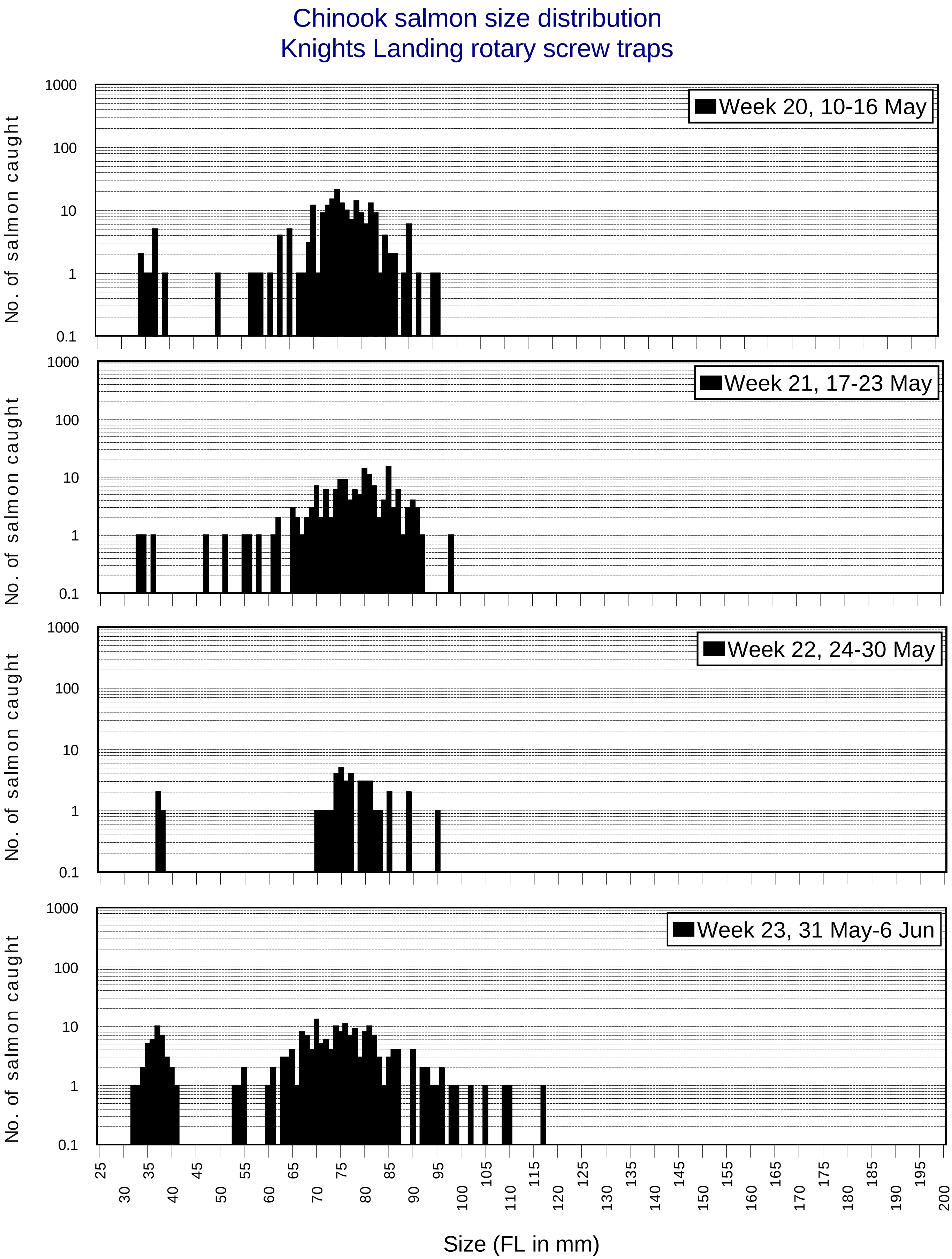


Figure 16. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 10 May through 06 June 1998.

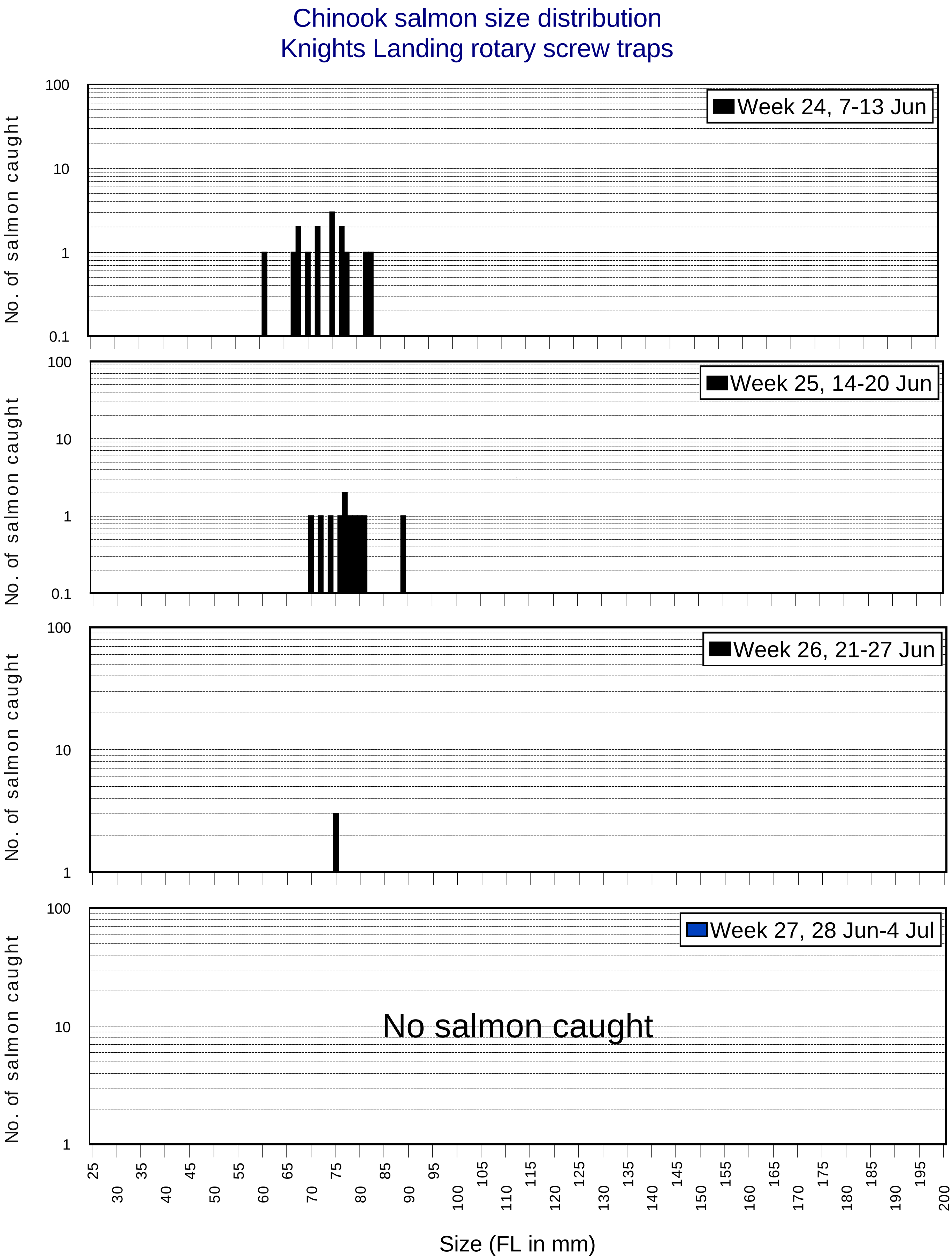


Figure 17. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 07 June through 04 July 1998.

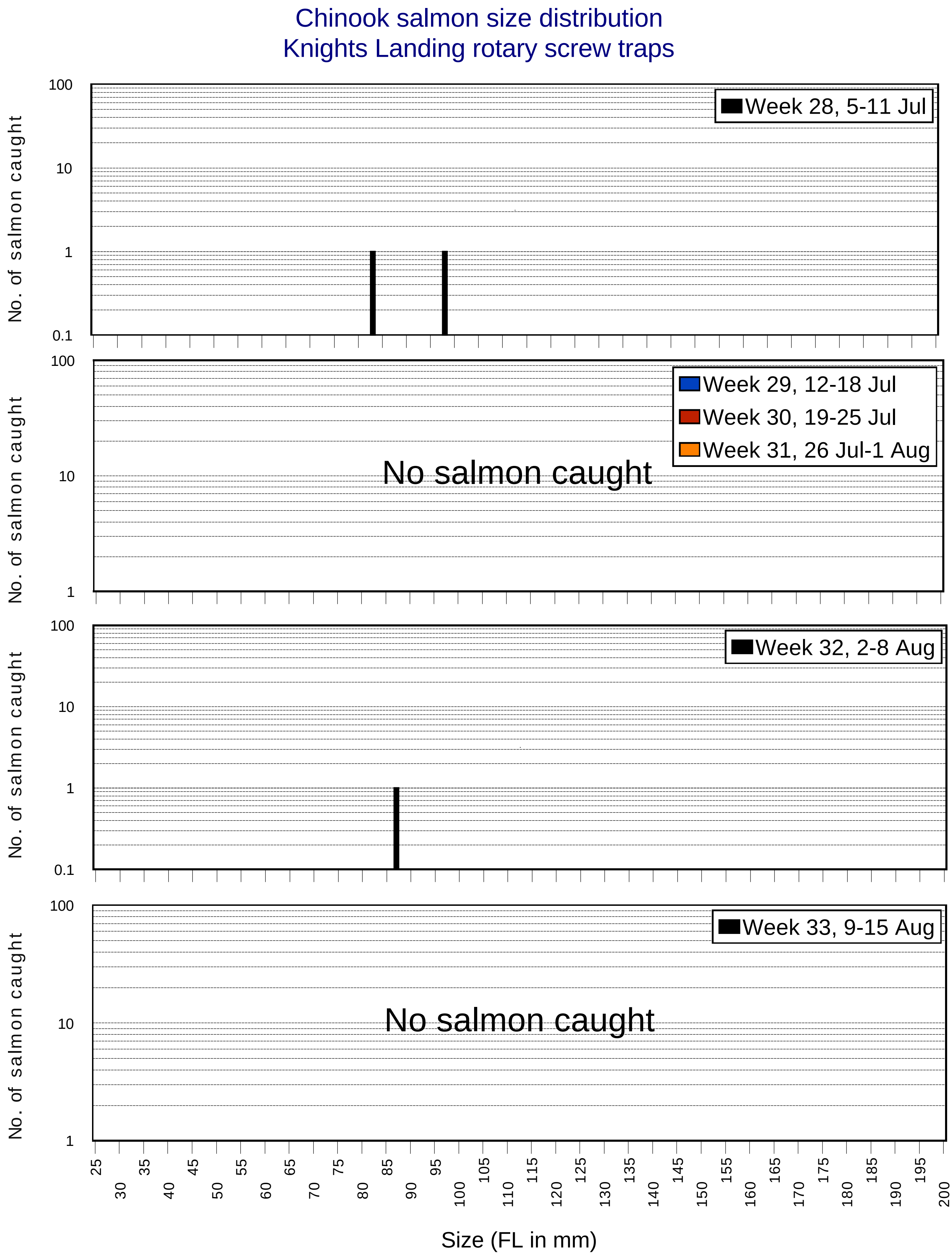


Figure 18. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 05 July through 15 August 1998.

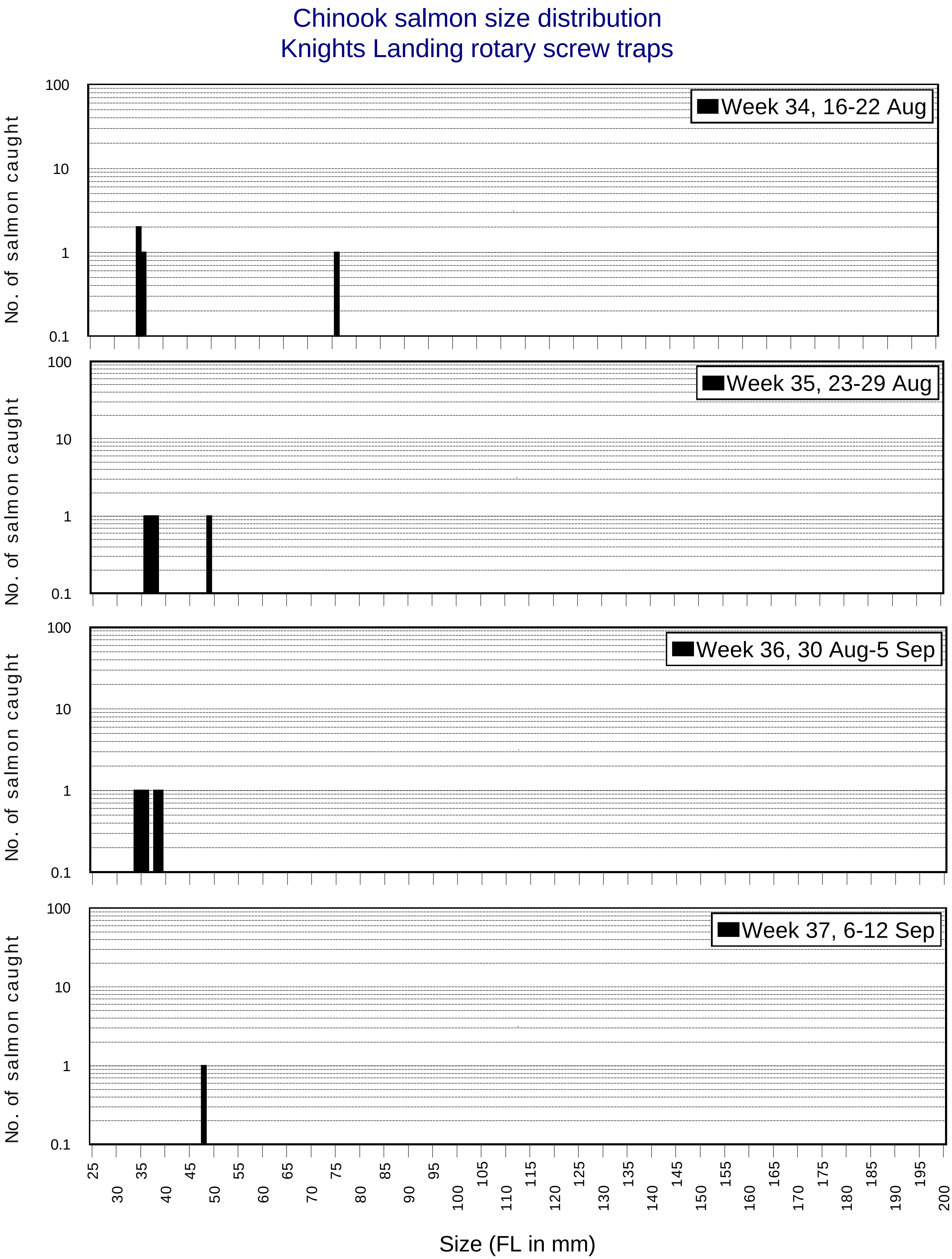


Figure 19. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 16 August through 12 September 1998.

Chinook salmon size distribution
Knights Landing rotary screw traps

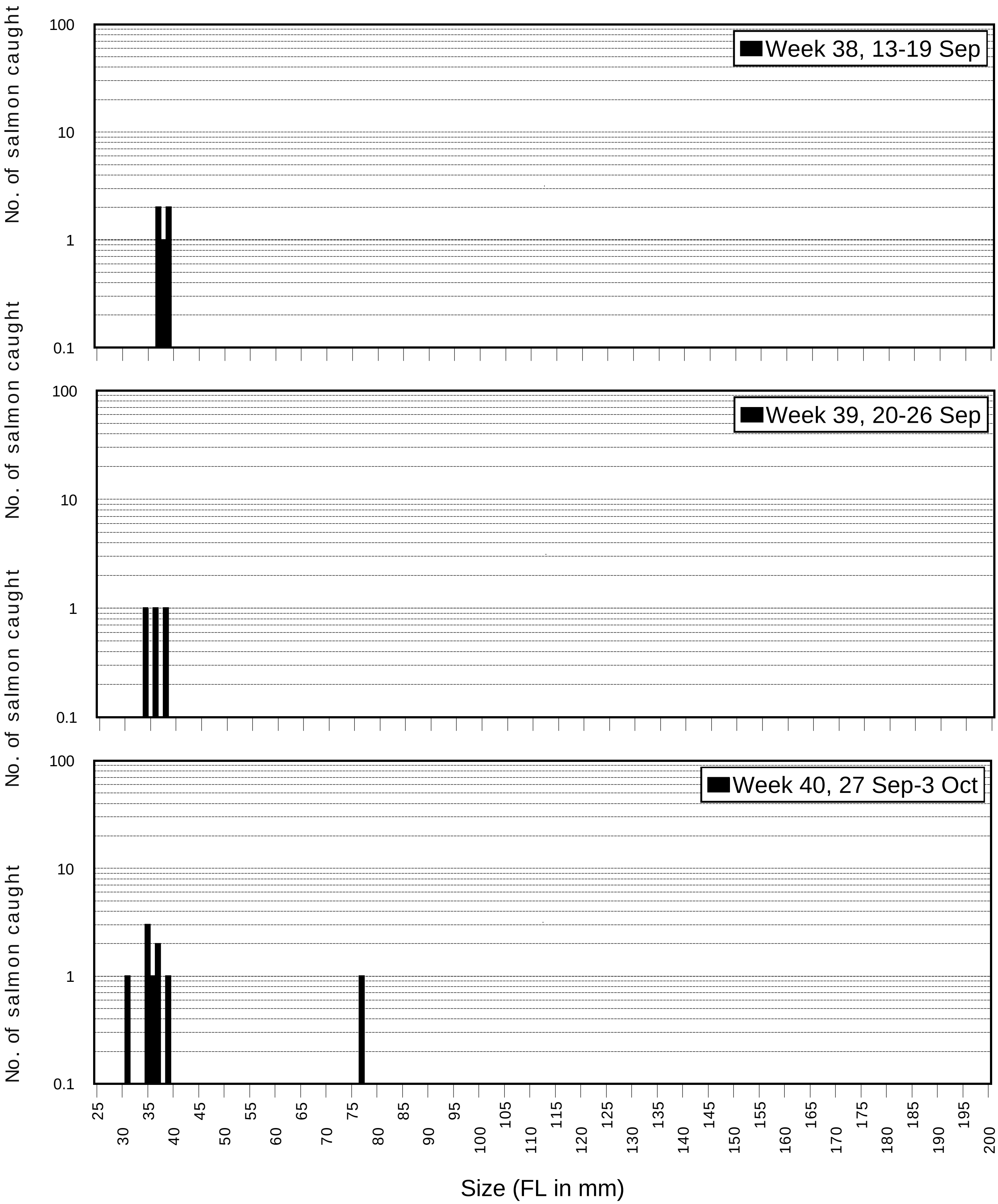


Figure 20. Size distribution of chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 13 September through 03 October 1998.

Catch distribution of in-river produced chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River

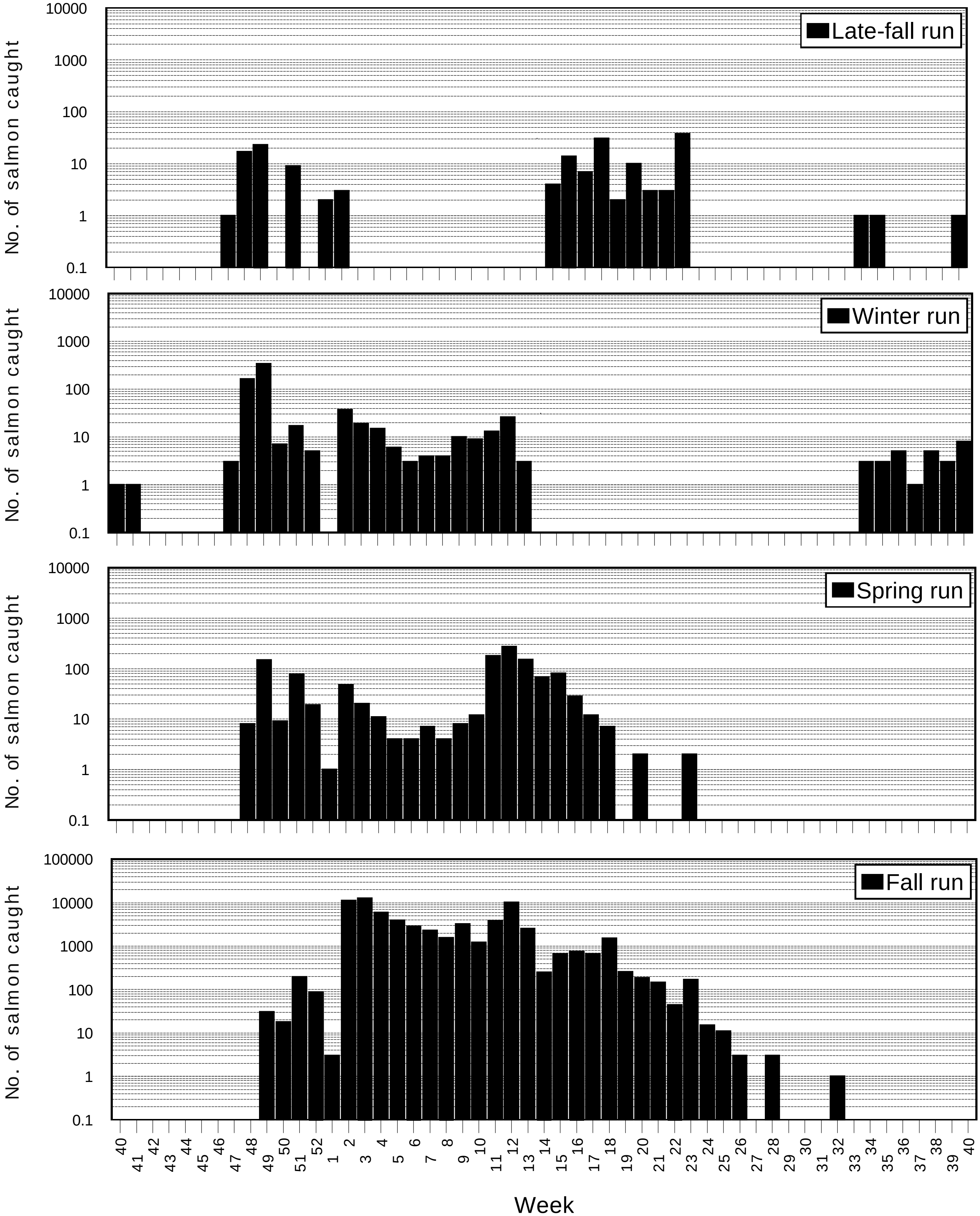


Figure 21. Catch distribution of in-river produced chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 28 September 1997 through 3 October 1998.

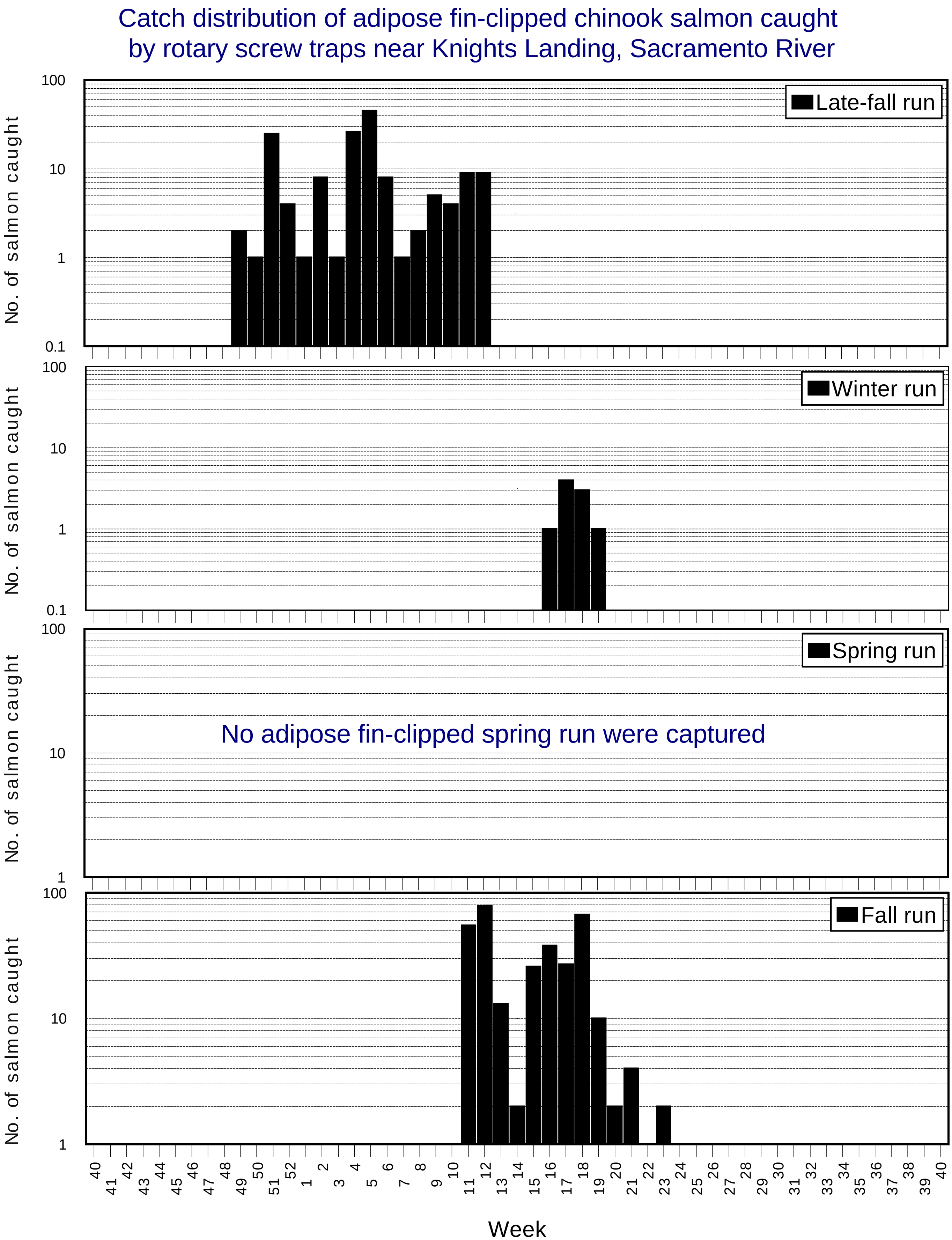


Figure 22. Catch distribution of adipose fin-clipped chinook salmon caught by rotary screw traps near Knights Landing, Sacramento River, 28 September 1997 through 03 October 1998.

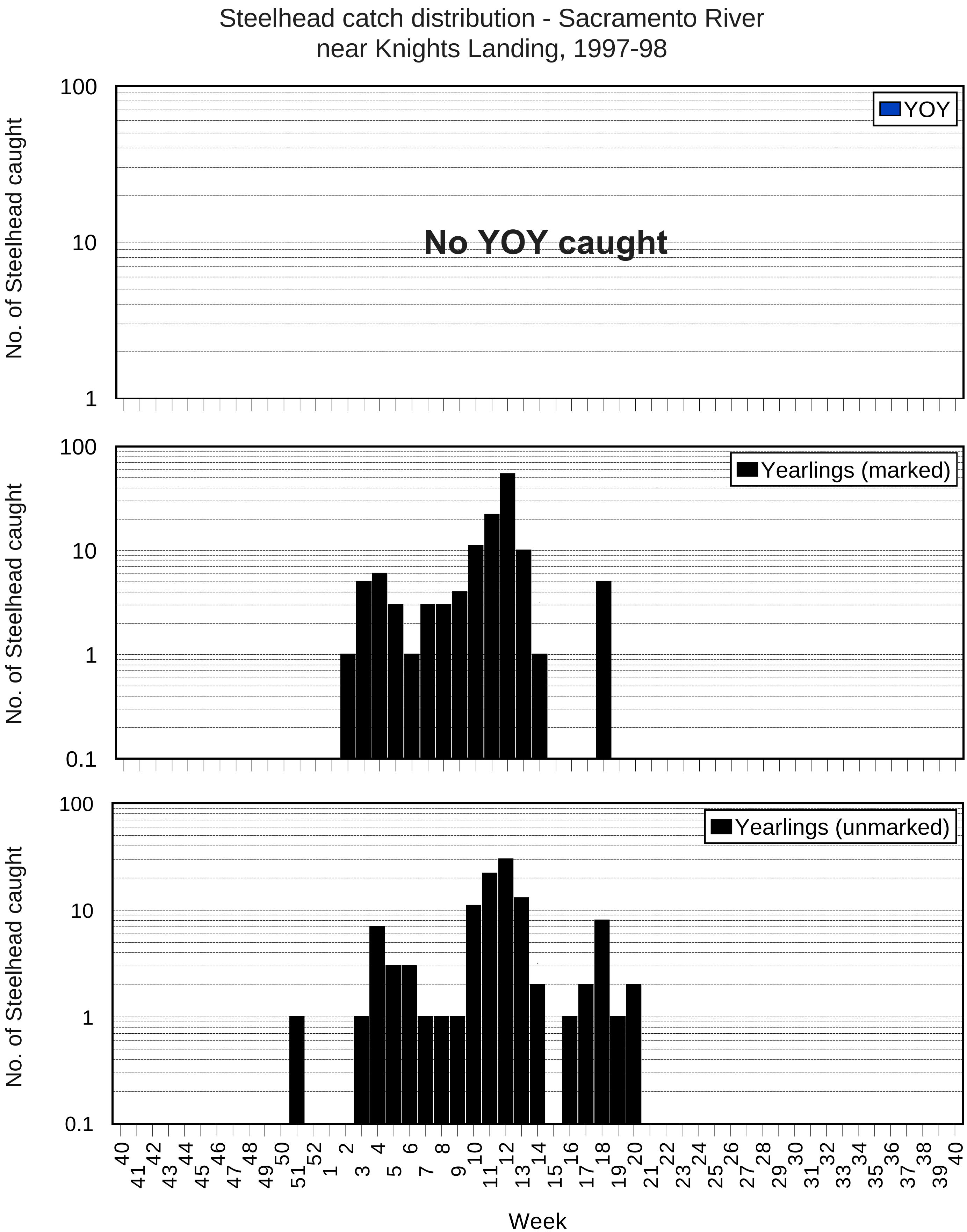


Figure 23. Catch distribution of young-of-year and yearling steelhead trout caught by rotary screw traps near Knights Landing, Sacramento River, 28 September 1997 through 3 October 1998.

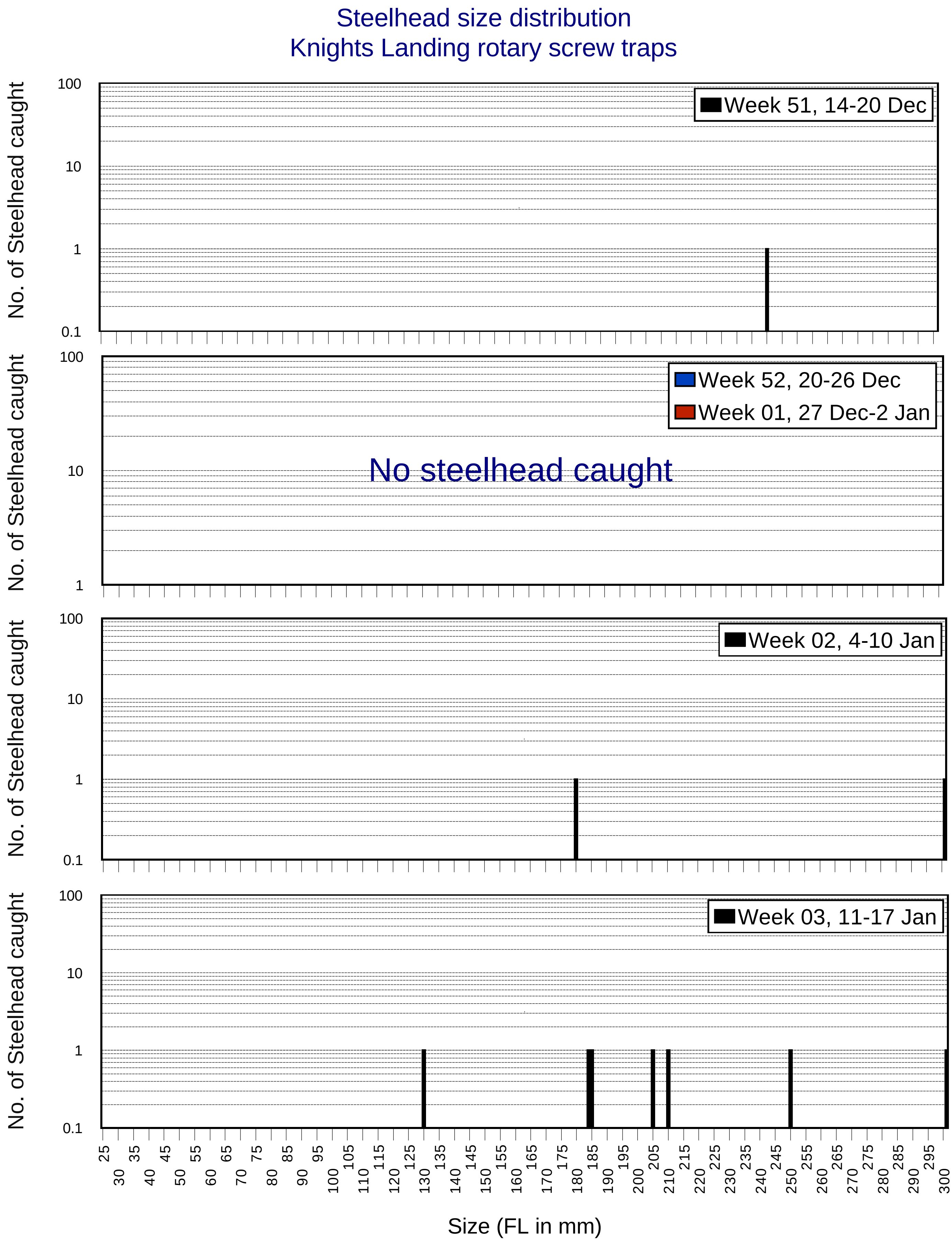


Figure 24. Size distribution of steelhead caught by rotary screw traps near Knights Landing, Sacramento River, 14 December 1997 through 17 January 1998.

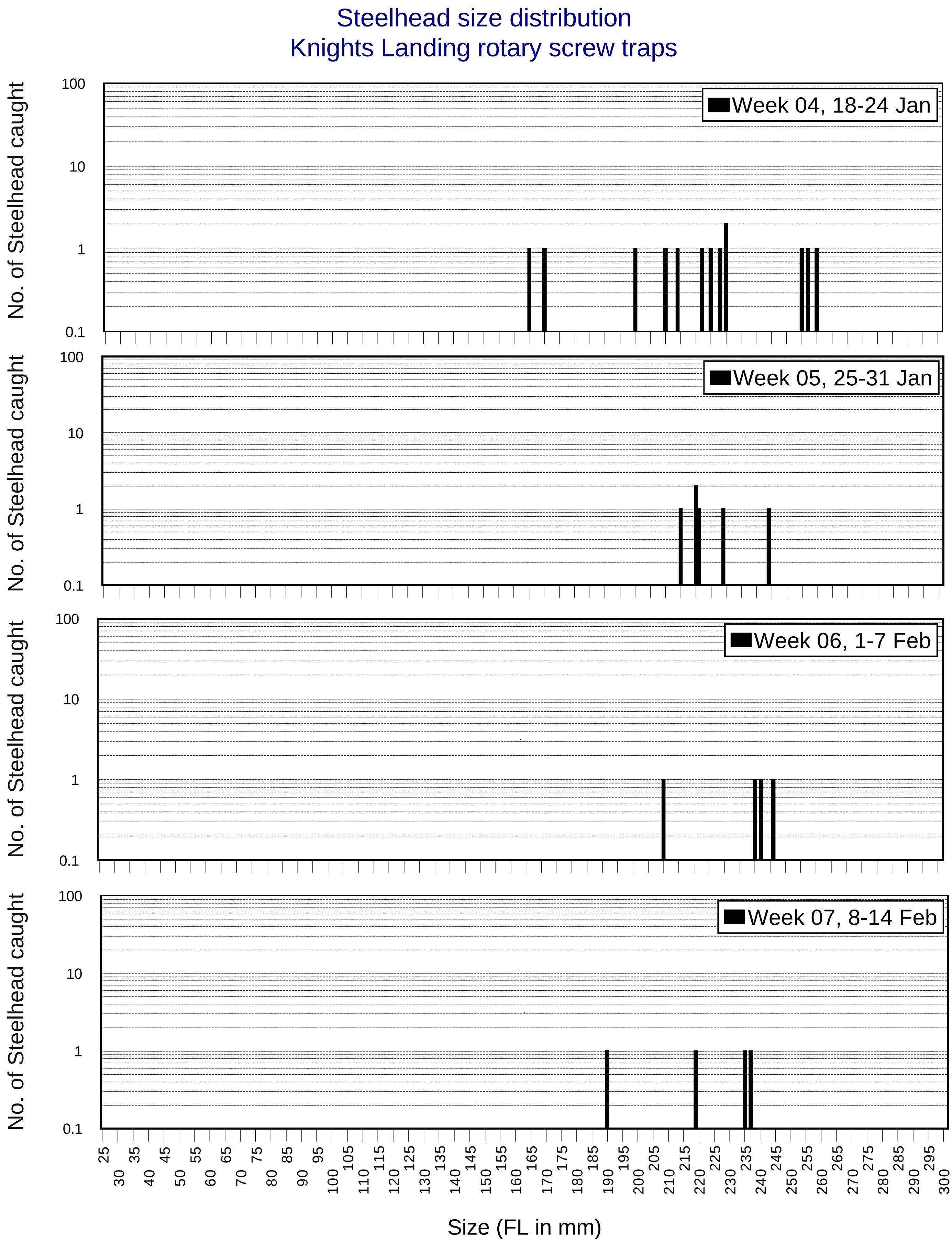


Figure 25. Size distribution of steelhead caught by rotary screw traps near Knights Landing, Sacramento River, 18 January through 14 February 1998.

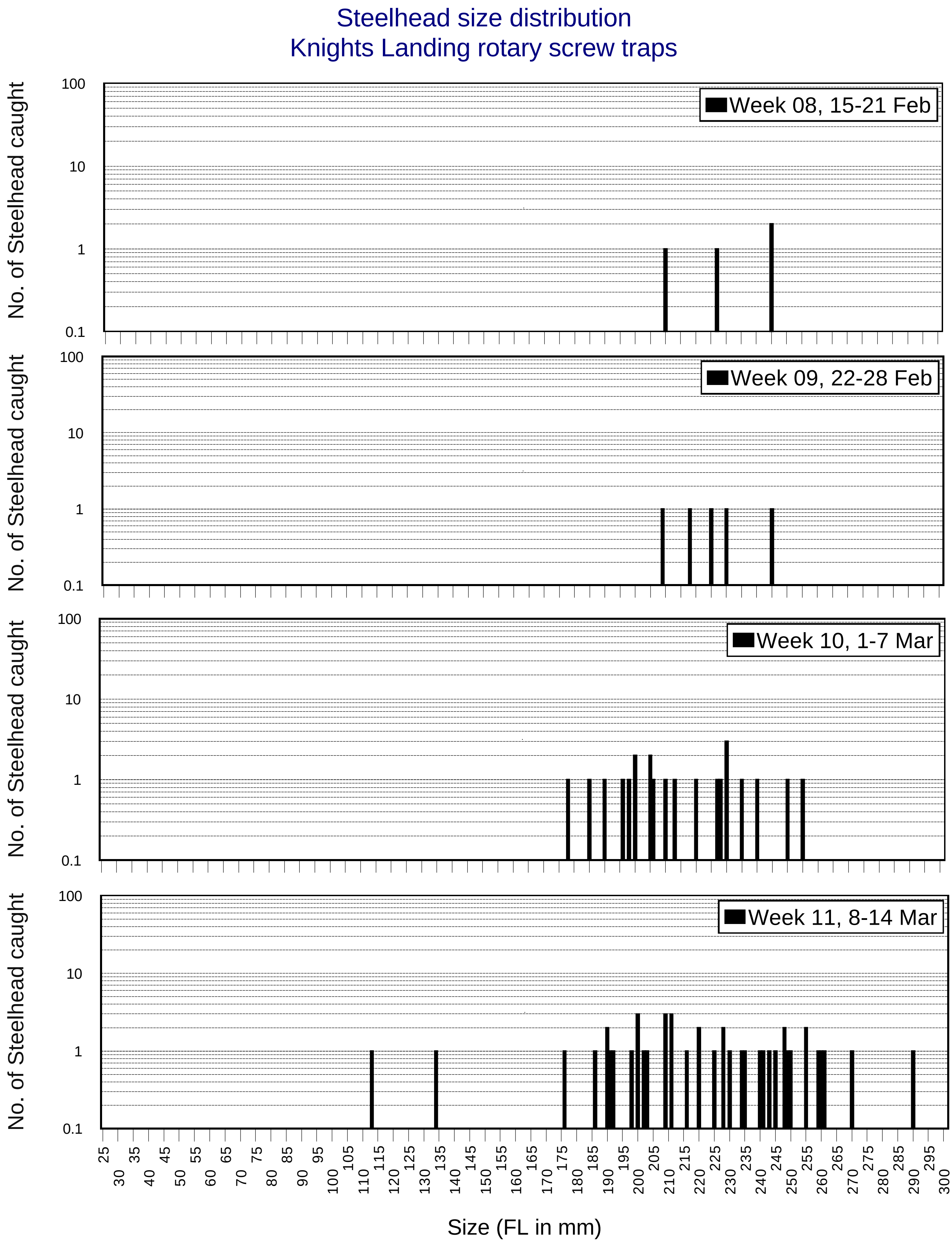


Figure 26. Size distribution of steelhead caught by rotary screw traps near Knights Landing, Sacramento River, 15 February through 14 March 1998.

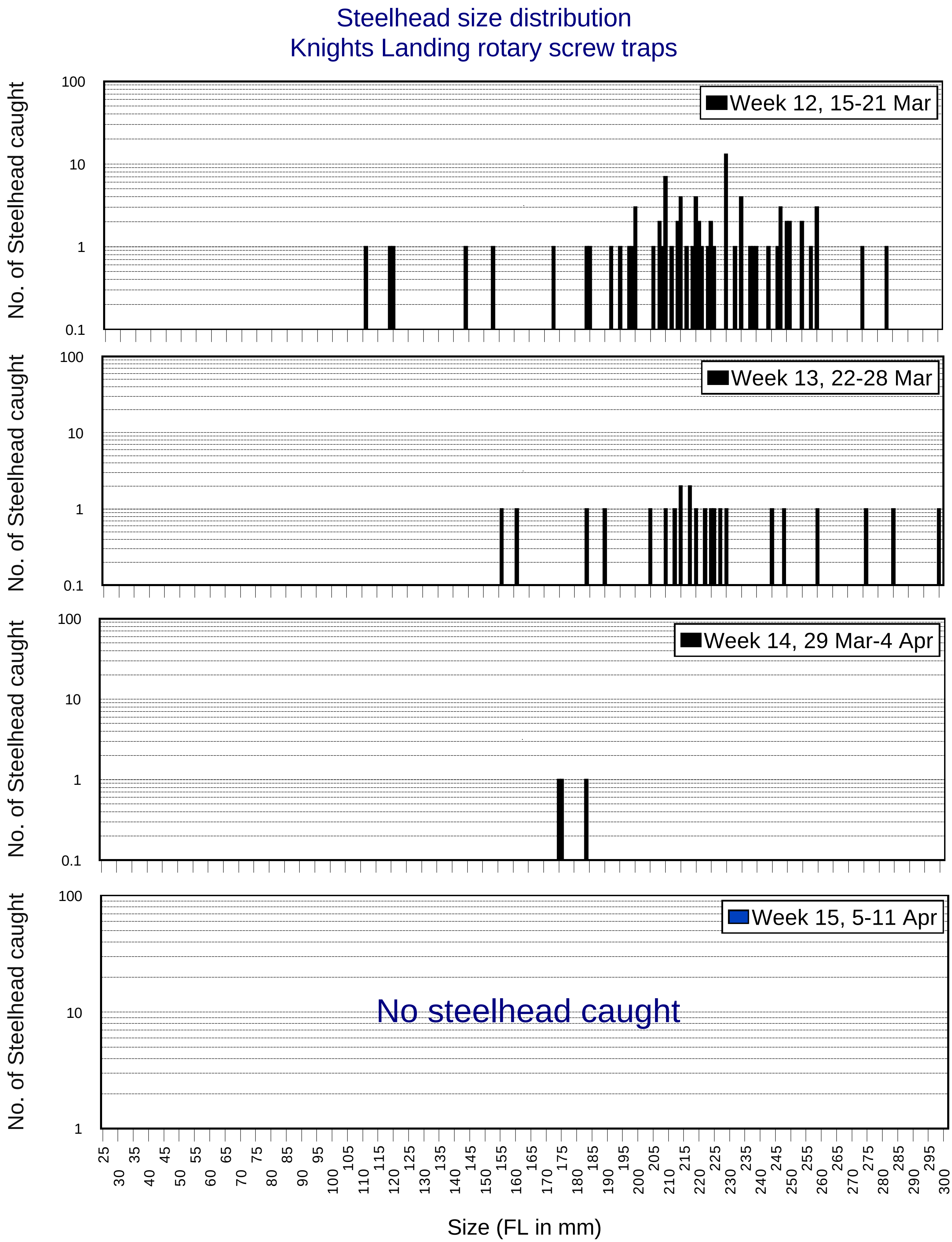


Figure 27. Size distribution of steelhead caught by rotary screw traps near Knights Landing, Sacramento River, 15 March through 11 April 1998.

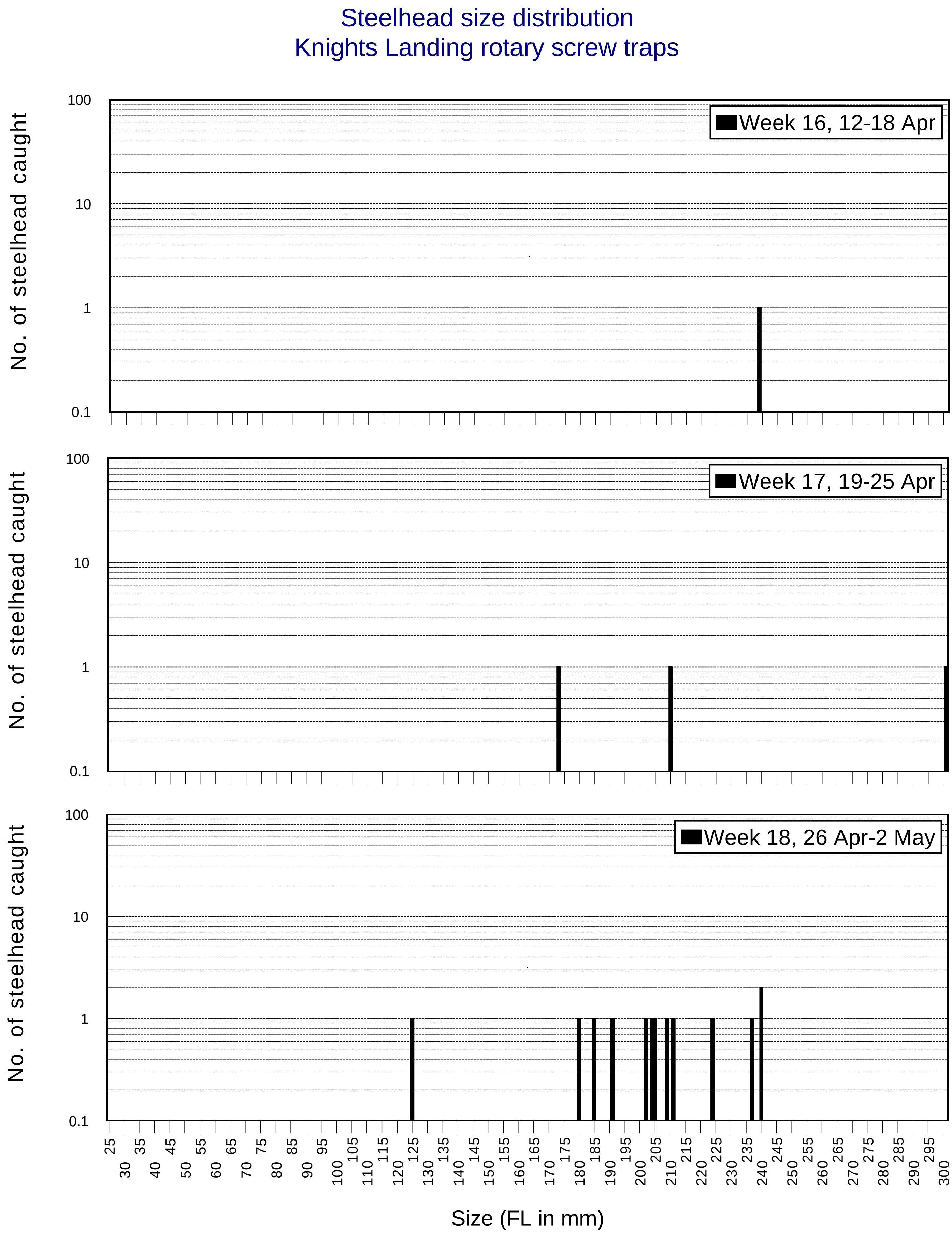


Figure 28. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 12 April through 02 May 1998.

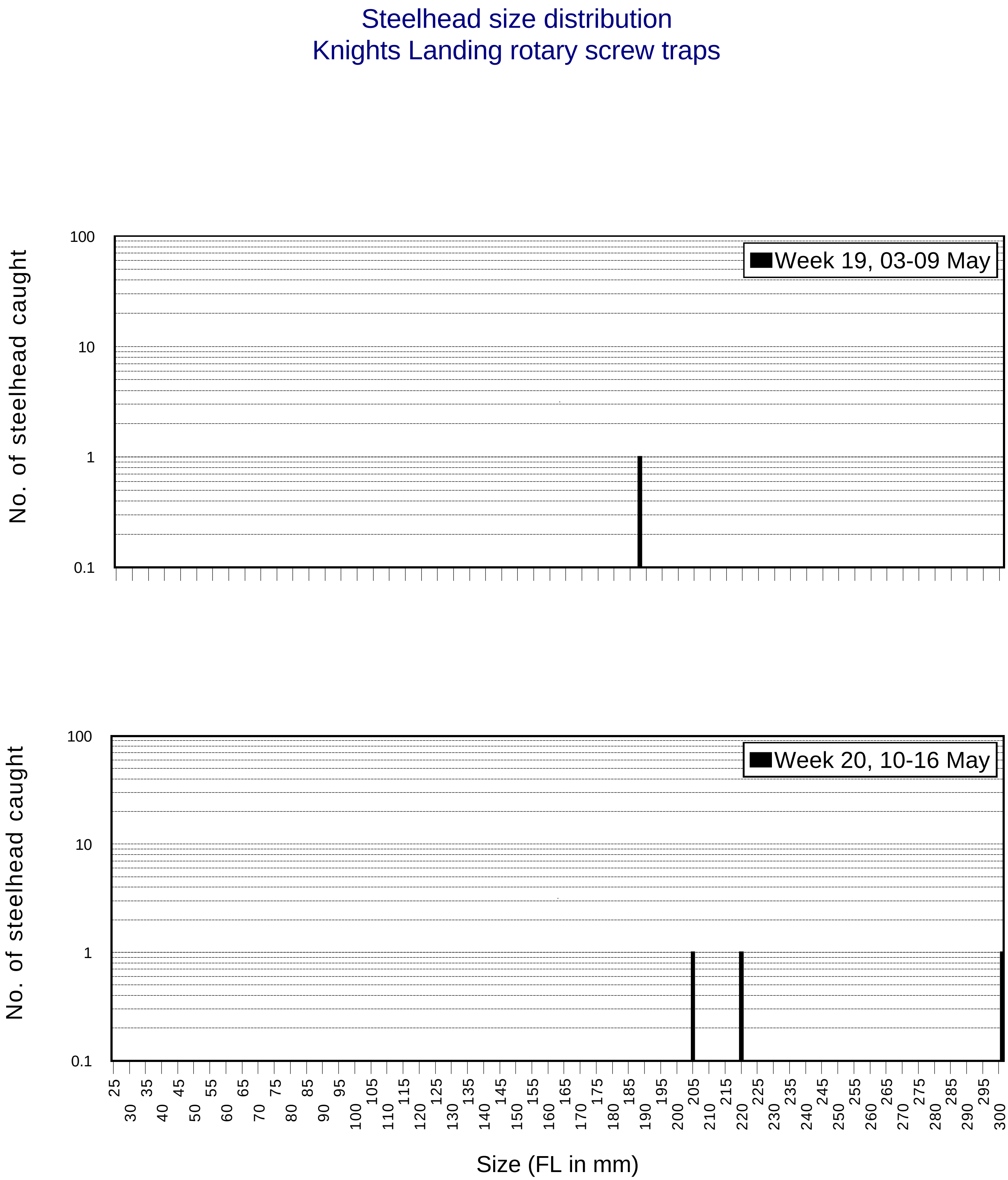
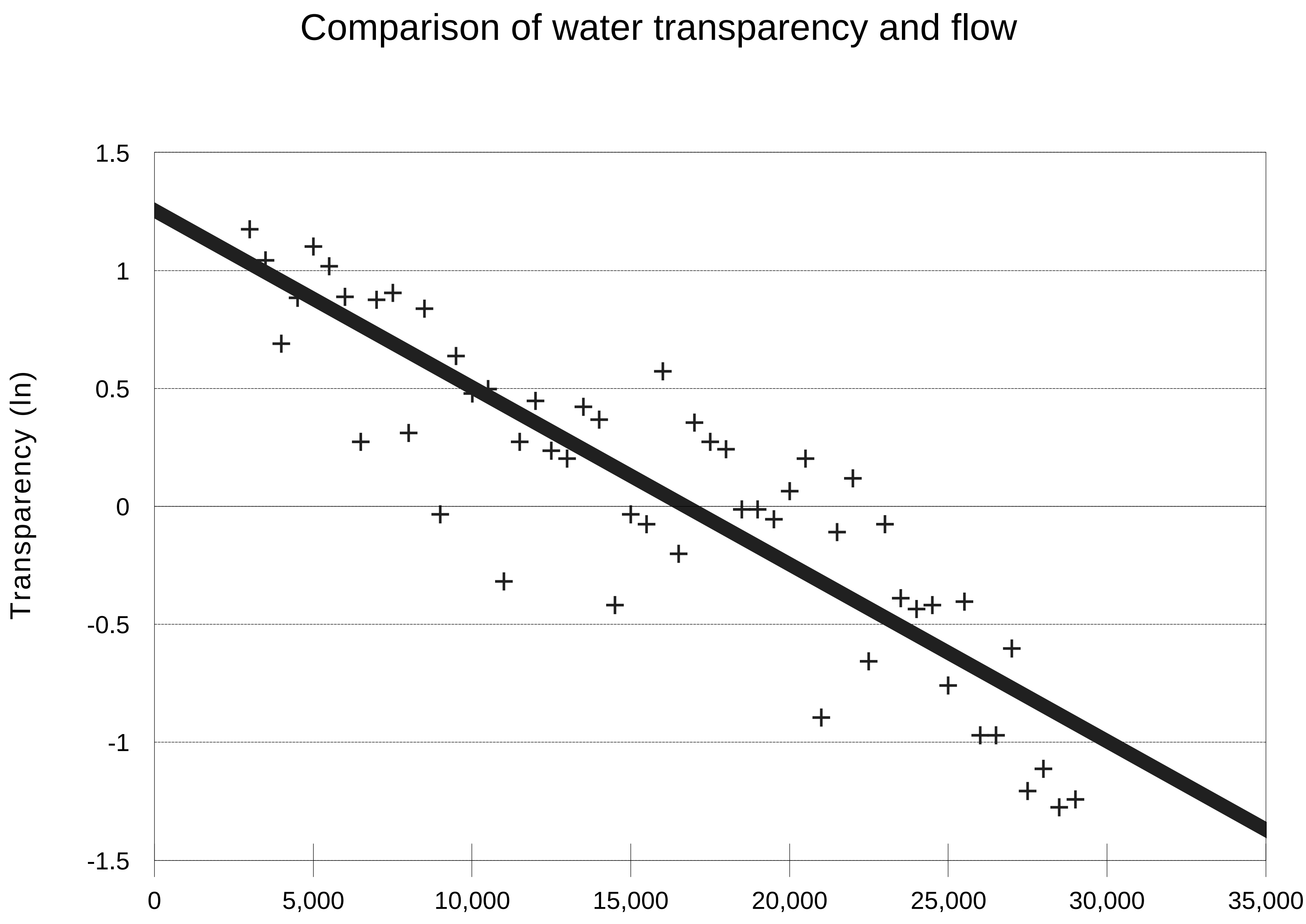


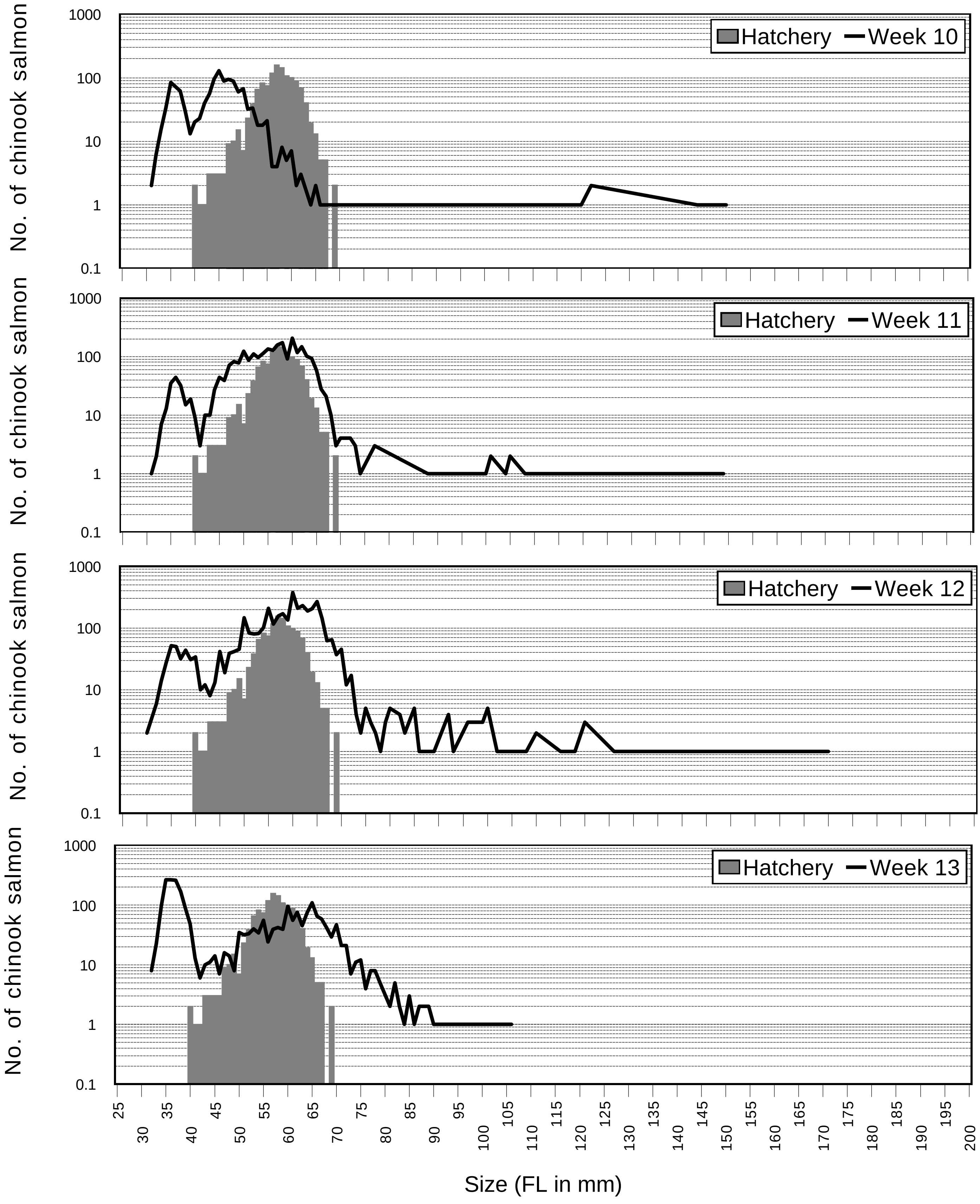
Figure 29. Size distribution of steelhead caught by rotary screw traps near Knights Landing, Sacramento River, 03 May through 16 May 1998.

APPENDIX



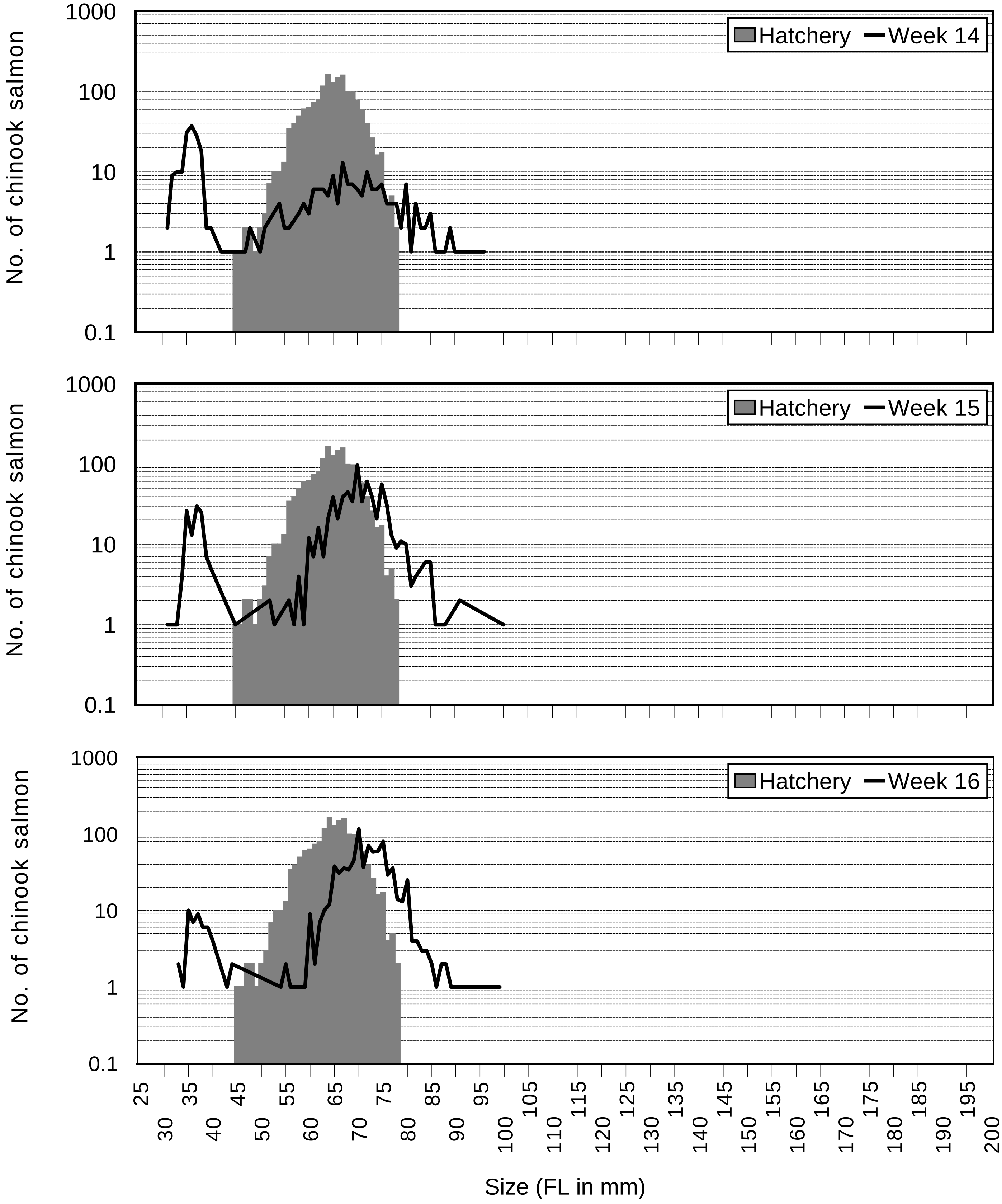
Appendix Figure 1. Comparison of water transparency (ln of Secchi disk depth) versus flow measured on the Sacramento River near Knights Landing, 28 September 1997 - 3 October 1998.

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



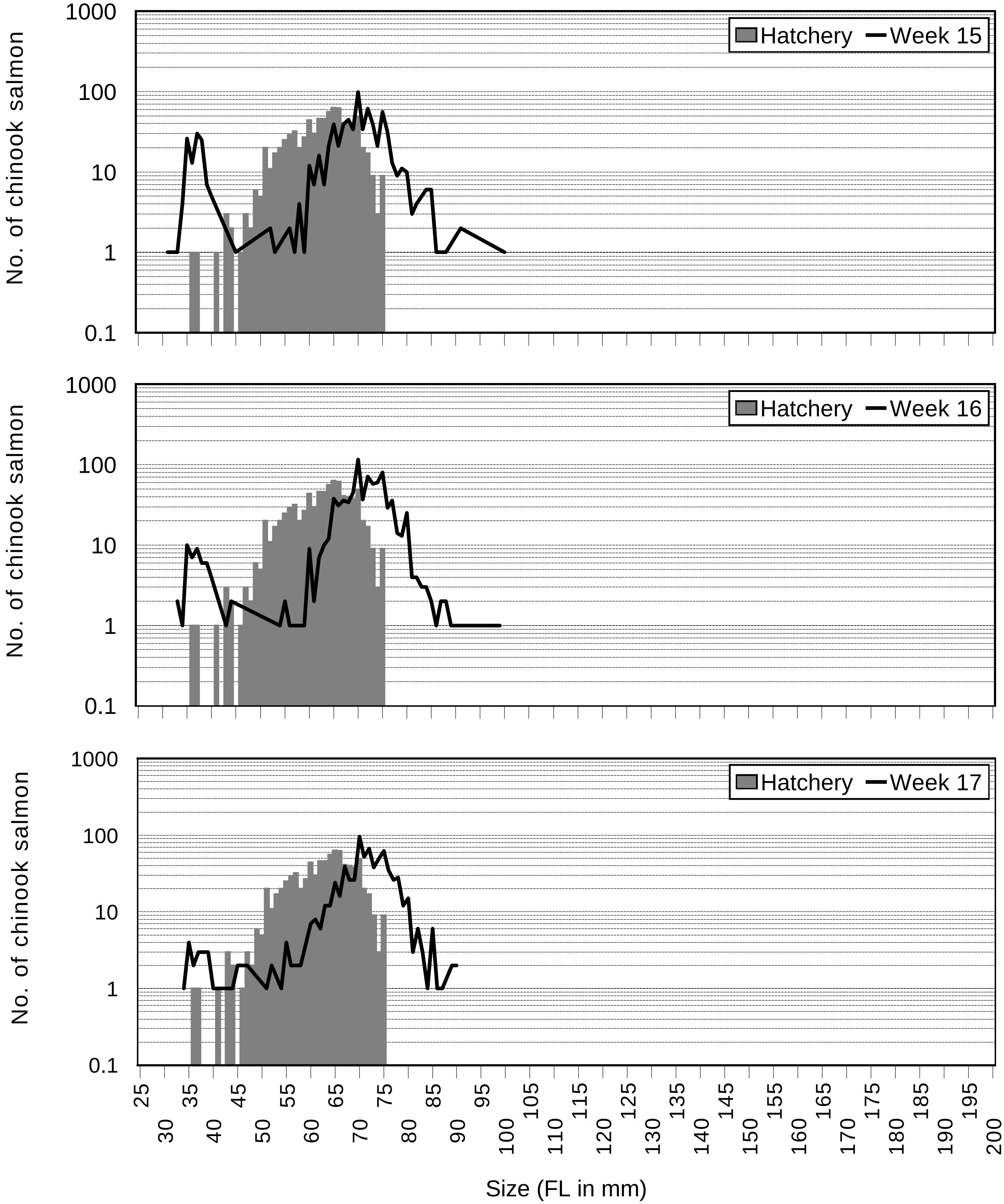
Appendix Figure 2. Size distribution of chinook salmon collected in the Sacramento River near Knights Landing compared with size distribution of Coleman NFH salmon released during week 10 (4 - 6 March 1998).

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



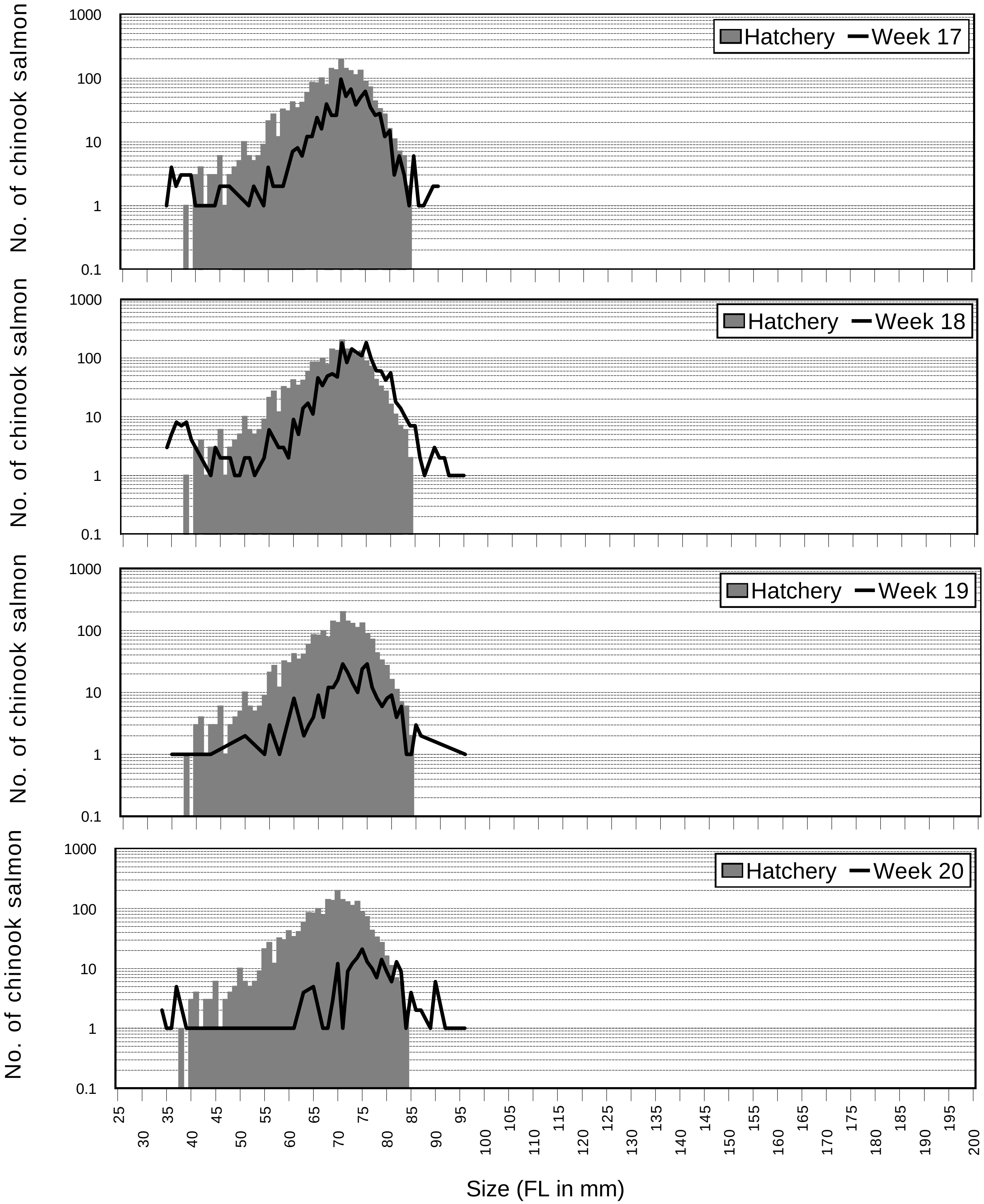
Appendix Figure 3. Size distribution of chinook salmon collected in the Sacramento River near Knights Landing compared with size distribution of Coleman NFH salmon released during week 14 (31 March 1998).

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 during week 15 (7 April 1998).

Size distribution 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 during week 17 (22 - 23 April 1998).