DEPARTMENT OF FISH AND GAME
Environmental Services Division
Stream Evaluation Program

EVALUATION OF JUVENILE ANADROMOUS SALMONID EMIGRATION IN THE SACRAMENTO RIVER NEAR KNIGHTS LANDING NOVEMBER 1995 - JULY 1996[1]

by

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SUMMARY

A pilot monitoring station was established on the Sacramento River at Knights Landing (river mile (RM) 89.5) to determine the feasibility of acquiring data on migration of juvenile anadromous salmonids from the upper Sacramento River (upstream of Feather River) to the Sacramento-San Joaquin Delta. Monitoring was primarily conducted using two rotary screw traps (RSTs). Fyke traps and a Kodiak trawl were also used to determine the relative efficiency of the three gear types.

The first RST was deployed on 19 November 1995. On 13 December 1995, debris brought by the first storm of the season temporarily interrupted fishing the single RST. Between 13 and 17 December 1995, we redeployed the first RST and deployed a second RST. From 17 December through 13 July 1996 the two RSTs fished a combined 84% of the time (mean effort = 284 h/week).

In general, the RSTs effectively sampled juvenile salmonids within the flow range present during the survey period (6,000 cfs to 29,000 cfs). Catch data appears to represent the timing and relative abundance of the various sizes of salmon available for sampling, based on comparisons with fyke trap and trawling catches and with size distribution of hatchery plants.

Measured RST efficiency averaged 1.04% (range: 0.015%-4.6%).

The first juvenile salmon was captured on 30 November 1995 after 125 h of fishing. No salmon were caught between 30 November and 13 December when fishing was interrupted. Juvenile salmon were captured during every week after the traps were restarted (17 December 1995) through 6 July 1996.

A total of 64,873 unmarked, juvenile salmon was caught by RST. Based upon size[1], we captured juveniles from each of the four runs of chinook salmon using the upper Sacramento River. Late-fall-run-sized chinook salmon from the 1995 brood year (n = 19) were caught between 30 November and 3 December. Late-fall-run salmon from the 1996 brood year (n = 18) were caught between 31 March and 25 May 1996. Winter-run-sized chinook salmon (n = 324) were caught from 17 December 1995 through 30 March 1996. Spring-run-sized chinook salmon (n = 5,463) were caught between 17 December 1995 and 18 May 1996. Fall-run-sized chinook salmon (n = 59,049) were caught between 17 December 1995 and 6 July 1996.

A total of 165 unmarked, yearling steelhead trout was caught between 17 December 1995 and 12 May 1996. Ten 10 young-of-the-year steelhead were caught between 31 March and 26 May 1996.

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[1] The run designation of each juvenile salmon measured was determined based on length at time (S. Greene and F. Fisher, unpubl. data).

We also caught 523 adipose-clipped salmon and 17 adipose-clipped steelhead from fish produced at Coleman National Fish Hatchery (CNFH) and planted within the upper Sacramento River system. Altogether, 93 late-fall-run (1995 brood year), 10 winter-run and 440 fall-run adipose-clipped salmon were caught.

The contribution of hatchery-produced salmon to the Knights Landing catch was evaluated based upon CWT data, and the size distributions and timing of the planted fish compared to subsequent catches at Knights Landing, We concluded that all fall-run sized salmon caught at Knights Landing prior to 3 February 1996 were in-river produced, but that no distinction could be made between in-river and hatchery-produced, fall-run sized salmon thereafter. Similarly, we determined that all spring-run sized salmon caught after 16 March 1996 were hatchery-produced fall run. Based upon the latter conclusion, we adjusted the number of spring-run caught by RST to 506, and the number of fall run caught to 64,006.

Preliminary estimates of the relative abundance of juvenile salmonids caught by RST are provided based upon the mean annual trap efficiency of 1.04%. The estimated number of in-river salmon that passed the Knights Landing sample site included 1,827 late-fall run (1995 brood year) and 1,731 late-fall run (1996 brood year), 31,153 winter run, 48,654 spring run and 5,161,417 fall run. The estimated number of in-river produced yearling steelhead passing Knights Landing was 11,741.

The estimated number of hatchery-produced chinook salmon passing Knights Landing was 8,942 late-fall run, 962 winter run and 558,679 fall-run. The estimated number of hatchery-produced steelhead trout passing Knights Landing was 5,759.

Comparison of RST and fyke trap results indicate that fyke traps were biased toward capture of small fish. We also concluded that fyke traps could not be fished consistently with the changing flow conditions observed at Knights Landing. Comparisons of RST and Kodiak trawl data (collected at Knights Landing) indicate that trawling was biased toward capture of larger fish.

Comparison of RST and Kodiak trawl data collected on the Sacramento River near Sacramento also indicated that trawling was biased toward larger fish.

INTRODUCTION

The indigenous, anadromous fish 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 lay between the ocean and their natal streams. 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 part 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.

The 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 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 Valley spring-run chinook salmon[2] are 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 ocean.

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[1] Listed as endangered by both the California and federal Endangered Species Acts.

[2]Petitioned for listing as endangered under the California Endangered Species Act.

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

More 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 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., 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 an index of juvenile salmonid abundance 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

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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.

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 dam 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 and potentially allowing use of more efficient gear types, including fyke and rotary screw traps (RSTs). The river channel is relatively narrow and flows relatively less compared with areas located downstream of the Feather and American rivers and upstream of Sutter Bypass. The site also provided monitoring intermediate 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 was initiated on 21 November 1995 and continued through 13 July 1996, the reporting period. Sampling was conducted using two 8-ft diameter RSTs and two 5 ft x 5 ft fyke traps (with 30 ft wings). Initially a 6 ft x 25 ft and subsequently (starting in Week 16) an 8 ft x 30 ft Kodiak trawl were also used.

The Knights Landing site was continuously sampled using two RSTs with only a few, brief interruptions early in the evaluation. Fyke traps were fished intermittently as conditions permitted. Kodiak trawling was conducted in the vicinity of the screw traps to evaluate relative gear success. Trawling was conducted one week (four days) per month beginning in March.

The first RST was deployed on 21 November 1995. It was located on the outside of a wide bend in the river approximately 100 ft from the east bank. The second RST was deployed on 17 December 1995. It was attached on the channel side of the first trap. Three 40-pound Dansforth anchors were used to hold the two traps. A safety line was attached between the trap complex and the east bank in case the anchors came loose. The traps were placed when flow was about 15,000 cubic feet per second (cfs). Depth of water at the trap location was 20 ft, water velocity at the trap was 3.0 ft/s. The sample site cross section profile measured at 10,000 cfs is presented in Figure 2.

The first fyke trap was deployed on 17 December 1995, about 1,000 ft upstream of the RSTs. It was located on the inside of a wide bend in the river about 10 ft from the west bank. The trap was placed on a gradually sloping sand bar in about 4 ft of water with wings extending back to the bank and out into the channel about 30 ft. A second fyke trap was located about 1,000 ft downstream of the RSTs on 24 April 1996. It was also located over a sand bar about 10 ft from the east bank.

Trawling was conducted using two boats and, initially, a 6 ft deep x 25 ft wide Kodiak trawl. The trawl was replaced with an 8 ft x 30 ft trawl in Week 16 after the first trawl was damaged. Each trawl effort was 20 minutes. Up to nine trawls were made per day, four days per sampling week. The first trawl was typically started at 0800 h.

Data acquired from each gear type per servicing included effort (measured using various parameters according to gear type) and number of juvenile salmonids collected by species. Greene and Fisher (unpubl. data) developed a system to categorize juvenile salmon in the Sacramento River by run (late-fall-, winter-, spring- and fall-run chinook salmon) based on length. This system was used to classify juvenile salmon collected at Knights Landing. All salmon classified, based on size, as winter run, spring run and late-fall run were measured (fork length (FL) in mm and weight in g). All juvenile steelhead trout were counted and measured. Up to 300 fall-run sized salmon were randomly selected and measured per trap per servicing. The traps were serviced up to two times per day: once in the morning and once near dusk.

The data reporting periods are weeks. Data are typically presented as weekly sums or weekly means. Weeks begin on Sunday and end on Saturday; and are identified by number (e.g., Week 1). Week 1 was defined as the first week of 1996 (i.e., contains 1 January 1996). 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 measurements made at Wilkins Slough. Visibility was measured each day at the RST using a Secchi disk following standard methods (Orth 1983).

Trap efficiency was evaluated by marking up to 300 salmon taken from each trap and releasing them approximately 2,500 ft upstream. Salmon were marked daily beginning in Week 4 (21 January) using Alcian blue dye and a specific pattern to indicate the week of marking. During the efficiency test, each fish we measured was also checked for marks. When all fish were not checked, the number of recovered fish was expanded based on the proportion of fish checked to the total number captured.

A second efficiency evaluation was made using salmon marked and released from Coleman National Fish Hatchery (CNFH). Six groups of marked and coded-wire tagged (CWT) hatchery-reared salmon were available for capture at Knights Landing during the survey period (Table 1).

Group 1: Late-fall-run chinook salmon released in Week 45 (267,398 marked) at CNFH near RM 271.5.

Group 2: Winter run released in Week 51 (51,267 marked) at RM 299.

Group 3: Late-fall run released Weeks 1 and 2 (529,845 marked) at CNFH near RM 271.5

Group 4: Fall run released Week 11 (338,355 marked) at CNFH near RM 271.5.

Group 5: Fall run released Week 13 (320,627 marked) at CNFH near RM 271.5.

Group 6: Fall run released Week 17 (274,423 marked) at CNFH near RM 271.5.

Table 1. Summary of hatchery fish plants made upstream of the Knights Landing monitoring location, including run, number marked with an adipose clip and date and location of plant.

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	45 (08-09 Nov 1995)	259,622	7,776	0	CNFH (271.5)
Late-fall run	1 (02-03 Jan 1996)	384,527	12,785	0	CNFH (271.5)
Late-fall run	2/3 (09-16 Jan 1996)	131,741	792	0	CNFH (271.5)
Winter run	51 (21 Dec 1995)	48,154	3,113	0	LKRP (299)
Fall run	11 (13-14 Mar 1996)	295,384	42,971	3,807,194	CNFH (271.5)
Fall run	13 (29 Mar 1996)	308,443	12,184	3,799,209	CNFH (271.5)
Fall run	17 (23 Apr 1996)	268,960	7,463	3,868,500	CNFH (271.5)
Fall-run fry	5 (29 Jan 1996)	0	0	1,319,814	BRBD (243)
Fall-run fry	6 (09 Feb 1996)	0	0	2,520,268	BRBD (243)
Fall-run fry	7 (15 Feb 1996)	0	0	1,018,075	BRBD (243)
Fall-run fry	8 (22 Feb 1996)	0	0	900,142	BRBD (243)
Fall-run fry	9 (27 Feb 1996)	0	0	783,815	BRBD (243)
Fall-run fry	10 (06 Mar 1996)	0	0	732,473	BRBD (243)

1/ LKRP Lake Redding Park; BRBD Below Red Bluff Diversion

Survival of the marked hatchery fish is unknown. Thus, the number of marked hatchery fish recaptured at Knights Landing relative to the total number released in the upper river provides a crude estimate of the minimum sampling efficiency at Knights Landing.

Size selectivity of RSTs was evaluated by comparing the size distributions of trap-caught salmon and Kodiak trawl-caught salmon during the same week (Weeks 12, 16 and 20).

Comparisons were also made between Knights Landing catches and results of concurrent sampling by Kodiak trawl in the Sacramento River near Sacramento (35 miles downstream). These comparisons were made to determine if emigration timing, by species and run, catch distribution and size distribution were consistent between the two sample sites.

All marked (adipose-clipped) fish were collected and the CWTs were read to determine the fish's source, 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.

RESULTS and DISCUSSION

General Sampling Conditions

Mean weekly flow ranged from 6,070 to 27,903 cfs (Table 2). Daily flow was as high as 29,261 cfs in February (Figure 3). Visibility (Secchi depth) ranged from 3.2 to less than 0.6 ft (Table 2). Visibility appeared to be inversely related to flow, although it was very poor throughout the survey (Figure 4). Mean weekly water temperature steadily decreased from 55° F (Week 47, 19-25 November 1995) to 45° F in Week 4 (21-27 January 1996) (Table 2, Figure 3) then gradually increased to the 60° F by Week 18 (28 April-5 May 1996). Thereafter, temperature steadily increased to 70° F by the end of the survey (7 July 1996).

The first storm of the year occurred on 13 December 1995 (Week 50), resulting in a substantial amount of woody debris being collected in the single RST. We decided to deploy the second trap at that time, requiring relocating the anchors and joining the two traps. The traps were restarted on 17 December (Week 51) and both fished continuously, with only short, infrequent interruptions typically due to debris buildup, throughout the rest of the survey period.

The two RSTs were successfully operated within a fairly wide range of flows (~6,000 to ~29,000 cfs) (Figure 5). Following brief interruption during Week 50, the two RSTs fished a combined 85% of the time averaging 284 h per week (out of a possible 336 h). At least one RST was fishing at all times. The fyke traps could not be fished during the high flow periods (beginning in Week 6) largely due to the accompanying large fluctuations in stage. The fyke traps were completely inundated during these high flow periods and were therefore removed until flows decreased and stabilized (Week 14).

Rotary Screw Trap Results

The first juvenile salmon captured by RST was a late-fall-run-sized fish (129.5 mm FL) caught on 30 November 1995 (Week 48). The single RST had fished 125 h before the first fish was collected. The second salmon was collected within the next 48 h on 2 December 1995 (late-fall run, 144 mm FL). No salmonids were collected between 2 and 12 December 1995. Fishing was

Table 2. Summary of sampling conditions in the Sacramento River near Knights Landing during juvenile salmonid emigration investigation, November 1995 - July 1996.

Week	Beginning date	Mean flow (cfs)	Mean water temperature F	Mean Secchi depth (ft)
47	19 Nov 1995	6,144	55	na
48	26 Nov 1995	6,089	53	na
49	03 Dec 1995	6,070	54	3.2
50	10 Dec 1995	14,941	54	1.9
51	17 Dec 1995	15,551	49	1.8
52	24 Dec 1995	9,595	49	1.8
1	31 Dec 1995	13,067	50	1.3
2	07 Jan 1996	9,438	50	1.9
3	14 Jan 1996	17,058	49	1.6
4	21 Jan 1996	22,886	45	0.7
5	28 Jan 1996	25,072	46	0.8
6	04 Feb 1996	26,927	51	0.6
7	11 Feb 1996	25,942	52	0.7
8	18 Feb 1996	27,903	51	0.6
9	25 Feb 1996	27,397	48	0.7
10	03 Mar 1996	26,865	51	0.5
11	10 Mar 1996	18,462	53	0.7
12	17 Mar 1996	11,579	56	0.8
13	24 Mar 1996	12,574	56	1.0
14	31 Mar 1996	15,220	56	1.1
15	07 Apr 1996	13,397	61	1.6
16	14 Apr 1996	11,852	57	2.0
17	21 Apr 1996	11,633	57	1.8
18	28 Apr 1996	9,936	62	1.7
19	05 May 1996	7,143	64	1.8
20	12 May 1996	9,486	65	1.7
21	19 May 1996	21,932	58	1.0
22	26 May 1996	15,742	63	1.4
23	02 Jun 1996	13,355	67	1.9
24	09 Jun 1996	12,345	68	2.6
25	16 Jun 1996	10,754	67	2.3
26	23 Jun 1996	9,846	66	2.4
27	30 Jun 1996	11,219	69	2.4
28	07 Jul 1996	11,276	70	2.7

stopped between 13 and 16 December 1995 (Week 50) in order to deploy the second RST, as discussed above. After the traps were restarted on 17 December 1995 (Week 51), the traps captured salmon every week through Week 27 (30 June-6 July 1996) (Table 3).

The number of chinook salmon caught ranged from one, (Week 27, 30 June-6 July 1996) to 11,301 (Week 7, 11-17 February 1996) (Table 3, Figure 6). There were several noticeable modes in the catch distribution (Figure 6). The first mode occurred during the initial flow increase of the season in, Week 51 (17-23 December 1995) representing the first major movement of salmon. Another mode occurred between weeks 3 and 10 (14 January-9 March 1996), peaking during Week 7. This mode was associated with the highest flow event of the season and increased fall-run fry emigration. A third mode occurred between Week 11 (10-16 March 1996) and Week 14 (31 March - 6 April 1996), peaking in Week 12 (17-23 March 1996), and a fourth during Week 18 (28 April - 4 May 1996), both associated with large releases of fall-run chinook salmon from CNFH.

The relationship between catch and weekly mean catch/h was fairly consistent (Figure 7). The variation in flow did not appear to influence sampling efficiency, while catch and catch rate both appeared to be directly related to flow (Figure 8). The highest catches and catch rates were observed during high flow periods (Weeks 3-9) when catch (catch/h) ranged from 2,075 to 11,301 salmon (6.2 to 33.6 salmon /h) and mean weekly flow ranged from 17,058 to 27,903 cfs. The highest flow during this period was 29,261 cfs, in Week 9, on 23 February 1996, when 401 salmon were caught with 48 h effort (8.4 salmon/h). The observed decreases in catch between peaks appeared to correspond to decreased flow.

Size of salmon captured by RST ranged from 26 to 198 mm FL (Table 3, Figures 9-16). Large salmon (FL >100 mm) were captured during every week between Week 51 (17-23 December 1995) and Week 14 (31 March - 06 April 1996). Recently emerged-sized salmon (FL <45 mm) were also captured every week from Week 51 through Week 14.

Two distinct modes in size distribution were observed during Week 51, the first week of high catches (Figure 9). The second mode gradually disappeared over the following two weeks. Beginning in Week 4 (Figure 10), a second mode in the distribution of small salmon began to appear. This distribution became very distinctive in Week 7 and continued until Week 12 when the first arrival of salmon planted from the CNFH obscured the ability to distinguish in-river produced salmon.

Table 3. Summary of catch statistics for chinook salmon caught by rotary screw trap in the Sacramento River near Knights Landing, November 1995 - July 1996.

Week	Effort (h)	Total catch	Catch/h	Size statistics (FL in mm)			
				Mean	Minimum	Maximum	Standard deviation
47	26.5	0	0				
48	170	2	.01	136.8	129.5	144	7.25
49	167	0	0				
50	73	0	0				
51	262	1,430	5.47	40.2	29	130	13.74
52	217	171	0.79	38.0	32	88	6.56
1	212	544	2.57	40.5	29	143	13.20
2	334	54	0.16	37.9	34	62	4.51
3	245	3,335	13.61	37.6	29	198	9.58
4	332	3,760	11.32	37.5	26	190	6.30
5	312	9,942	31.87	38.2	27	128	5.65
6	335	9,696	28.94	38.1	30	126	5.68
7	337	11,301	33.58	41.8	30	130	7.16
8	336	5,946	17.71	39.5	31	112	5.67
9	334	2,075	6.21	41.8	30	123	7.61
10	335	1,306	3.91	44.4	31	102	7.79
11	334	1,766	5.29	47.5	32	143	10.46
12	336	5,164	15.36	62.5	29	124	11.47
13	337	4,319	12.81	68.3	34	152	9.30
14	335	2,427	7.24	65.9	33	88	9.15
15	291	276	0.95	71.4	48	84	5.80
16	338	58	0.17	74.6	58.5	87.5	6.13
17	336	78	0.23	80.1	57.5	98	7.17
18	337	1,038	3.08	79.8	57	103	5.64
19	328	382	1.16	81.1	59	101	6.50
20	325	149	0.46	82.0	63	102	6.27
21	334	127	0.38	73.2	32	97	15.63
22	231	44	0.19	78.0	66	90	5.30
23	345	7	0.02	83.0	76.5	89	4.69
24	233	5	0.02	81.3	74.5	88	4.69
25	327	6	0.02	89.5	82.5	95.5	4.33
26	323	7	0.02	86.1	71	91	6.59
27	347	1	0.003	100	100	100	0
28	328	0	0				
Total	9792.5	65,416	6.68				

Late-fall-run-sized Chinook Salmon

All late-fall released from CNFH were adipose-clipped. As such, we considered all unmarked late-fall-run chinook salmon, based on size criteria (Greene and Fisher unpubl. data) to have been produced in-river.

The first salmon sampled at Knights Landing (Week 48, 26 November-2 December 1995) was an in-river produced late-fall chinook salmon (Table 4, Figure 17). Altogether, 19 in-river produced late-fall-run juveniles from the 1995 brood year were collected between Week 48 and Week 4 (21-27 January 1996). The largest number of this brood year's juveniles collected in one week was five, during weeks 51 and 1.

Eighteen in-river produced late-fall-run juveniles from the 1996 brood year were also collected: one in Week 14 and 17 in Week 21 (Figure 17).

In-river produced late-fall-run juvenile ranged from 105 to 198 mm FL for the 1995 brood year and from 32 to 42 mm FL for the 1996 brood year (Table 4, Figures 18-20).

We collected 93 adipose-clipped late-fall run (Table 5). These fish were collected from Week 51 (19 December 1995) through Week 13 (25 March 1996) (Figure 18). The highest catch occurred during Week 3 (19 fish). Fifty-one of the 93 clipped fish were late-fall-run sized (1995 brood year) of which 43 had CWTs that identified them as late-fall run from CNFH; the eight fish without CWTs were also considered late-fall run from CNFH. CWT data also revealed that an additional 35 adipose-clipped fish originally classified by size as winter run were actually late-fall run from CNFH. We also designated seven of eight winter-run sized adipose-clipped salmon without CWT as late-fall run based upon the proportion of adipose-clipped winter-run sized salmon baring CWT that were actually CNFH late-fall run (35 out of 43).

Winter-run-sized Chinook Salmon

As with late-fall, all winter run released from CNFH were adipose-clipped and all unmarked winter run (based on size) were considered to have been produced in-river.

A total of 324 in-river produced winter-run chinook salmon was collected by RST. The first of these winter run was captured during Week 51 (17-23 December 1995) and the last was collected during Week 13 (24-30 March 1996) (Table 4, Figure 17). Thirty-two percent of the catch of in-river produced winter run occurred in December, 23 % in January, 32% in February and 13% in March.

We observed two apparent peaks in the in-river produced winter-run catches. Catch first peaked in Week 51 then declined to a low in Week 2. Catch then began to increase in Week 3, peaking during Weeks 6 and 7. This trend appeared to be related to flow.

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, November 1995-July 1996.

	Fall run[2/]		Spring run[3/]		Winter run		Late-fall run	
Week	Number	FL range	Number	FL range	Number	FL range	Number	FL range
48	0		0		0		2	130-144
49	0		0		0		0	
50	0		0		0		0	
51	1,084	29-37	240	37-47	99	52-104	5	105-130
52	132	32-39	34	39-43	4	56-88	0	
1	441	29-41	73	40-51	24	56-113	5	113-131
2	35	34-42	0		1	62	1	143
3	3,295	29-45	8	45-51	9	64-108	4	126-198
4	3,698	26-47	30	46-56	18	78-126	2	153-190
5	9,854	27-49	46	49-66	27	78-128	0	
6	9,618	30-52	26	51-61	40	71-126	0	
7	11,239	30-54	14	53-68	38	73-130	0	
8	5,930	31-55	2	60-62	11	85-112	0	
9	2,058	30-58	7	60-73	10	88-123	0	
10	1,295	31-62	7	65-79	4	91-102	0	
11	1,721	32-65	19	64-87	21	93-143	0	
12	2,850	29-68	2,255	67-90	7	91-124	0	
13	1,972	34-71	2,163	62-93	11	96-152	0	
14	1,903	34-79	396	56-88	0		1	33
15	225	48-79	37	77-84	0		0	
16	45	59-81	7	79-88	0		0	
17	64	58-87	11	84-98	0		0	
18	914	57-91	70	82-103	0		0	
19	354	59-96	15	86-101	0		0	
20	144	59-94	3	100-102	0		0	
21	108	56-97	0		0		17	32-42
22	44	66-90	0		0		0	
23	7	77-89	0		0		0	
24	5	75-88	0		0		0	
25	6	83-96	0		0		0	
26	7	71-91	0		0		0	
27	1	100	0		0		0	
28	0		0		0		0	
Total	59,049	26-100	5,463	37-103	324	52-152	37	32-198

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 5% of fall run released from CNFH were marked.

3/ All spring-run sized fish collected after Week 11 were considered fall run (shaded area) based upon CWT data and size distributions of fall run released from CNFH (see text).

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, November 1995-July 1996.

	Fall run		Winter run		Late-fall run	
Week	Number	FL range	Number	FL range	Number	FL range
48	0		0		0	
49	0		0		0	
50	0		0		0	
51	0		0		2	105-126
52	0		0		1	129
1	0		0		1	110
2	0		0		17	123-169
3	0		0		19	110-165
4	0		0		12	121-166
5	0		1	70	14	107-158
6	0		1	71	11	108-140
7	0		5	69-79	5	112-149
8	0		1	86	2	103-131
9	0		0		0	
10	0		0		0	
11	0		0		3	109-130
12	48	53-77	1	95	5	105-120
13	171	59-81	1	107	1	136
14	127	58-80	0		0	
15	14	68-80	0		0	
16	6	68-80	0		0	
17	3	76-92	0		0	
18	54	71-96	0		0	
19	13	67-96	0		0	
20	2	90-94	0		0	
21	2	80-82	0		0	
No adipose-clipped salmon caught after Week 21						
Total	440		10		93	

We captured 51 winter-run sized adipose-clipped salmon. Of these, only eight were confirmed to be winter run released from CNFH. As discussed above, 35 of the 51 were identified as late-fall run from CNFH based on CWT codes, and eight did not have a CWT. Based upon the proportion of late-fall to winter run for the fish with CWTs, we estimated that only one of the eight fish without tags was a winter run. One spring-run sized adipose-clipped fish was identified as a CNFH produced winter run yielding a total of 10 adipose-clipped winter run (Table 5).

Adipose-clipped winter run were collected from Week 5 through Week 13, except during Weeks 9 and 10 (Table 5, Figure 18). The first adipose-clipped winter run was collected more than six weeks after being released into the Sacramento River nearly 200 miles upstream. The last adipose-clipped winter run was collected more than 14 weeks after being released.

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 adipose-clipped and released back into Butte Creek. Butte Creek enters the upper portion of the Sutter Bypass, and based upon flow conditions, the marked fish released into Butte Creek could have either entered the Sacramento River upstream of Knights Landing or entered the bypass. All unmarked, spring-run sized chinook salmon captured through Week 11 (10-16 March 1996) were considered in-river produced spring run. Beginning in Week 12, all spring-run sized salmon were considered fall-run juveniles based upon the following information:

- A substantial increase in the number of spring-run sized fish caught began in Week 12 concurrent with arrival of hatchery-produced fall run released into the upper river during Week 11 (19 in Week 11 and 2,255 in Week 12),

- Spring-run sized, adipose-clipped salmon collected during Week 12 were verified to be fall run released during Week 11, and

- Many of the fall run measured just prior to their release during Week 11 were spring-run sized

In-river produced spring-run chinook salmon (based on size criteria) first appeared in the RSTs during Week 51 and were captured during every week through Week 11, (except Week 2) (Figure 17). A total of 506 in-river produced spring-run juveniles was collected by RST (Table 4). Their catch distribution appeared to have two modes. The first peak occurred during Week 51, coincident with the first runoff of the season. The second peak occurred during Week 5 corresponding to the second major flow episode.

A total of 117 spring-run sized, adipose-clipped salmon were caught by RST. All of these fish were caught after Week 11 (Figure 18). Of these 117 clipped fish, 104 had tags, 13 did not. CWTs identified one fish as a winter run and the other 103 as fall run. Based upon the proportion of readable tags, all 13 clipped salmon without tags were classified as fall run.

Fall-run-sized Chinook Salmon

Fall-run chinook salmon juveniles (based upon size criteria) clearly dominated the juvenile salmon collected by RST. Altogether, 59,049 fall-run sized salmon juveniles were collected.

Fall run were first collected during Week 51 and then in every subsequent week through Week 27 (Figure 17). The catch distribution exhibited four apparent modes. As with the other salmon runs collected during the survey, the first mode occurred during the initial high flow event (Week 51) followed by a peak during the second high flow event (Weeks 5-7). The highest catches occurred during this second event. The last two peaks were coincident with the arrival of known hatchery-reared-fall run released from CNFH (based on CWT data).

Distinction between in-river and hatchery-produced fall run was problematic throughout much of the monitoring period due to the constant release of hatchery-reared fish into the upper river system. Beginning in Week 5 and lasting through Week 10, more than seven 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 5 when the first plant of hatchery-produced fall run was made.

Beginning in Week 11, a portion of the fall-run released into the upper river were adipose-clipped (~ 7%). Two plants of about four million fall-run chinook salmon each from CNFH were made into Battle Creek, near RM 271.5 during Week 11 (13 March 1996) and Week 13 (29 March 1996). About 300,000 fish from each group were tagged (CWT) and adipose-clipped. A third plant of about 275,000 marked and tagged salmon was made in Week 18 (23 April 1996). A representative group from each plant was measured just prior to planting.

Salmon with CWTs from the first plant into Battle Creek arrived at Knights Landing during Week 12 (Table 5, Figure 18). Adipose-clipped fish released into Battle Creek on 13 March 1996 were first caught at Knights Landing on 20 March 1996. Comparison of size distribution of fish from each plant with salmon collected at Knights Landing indicates that the bulk of salmon caught from weeks 12 through 7 were likely from the hatchery plants (Appendix Figures 1-4).

A total of 315 fall-run sized, adipose-clipped fish were caught by RST; 246 contained tags that identified them as fall run and 69 did not have tags but were also considered fall run. In addition, 101 adipose-clipped, spring-run sized salmon contained tags that identified them as fall run and 24 adipose-clipped spring-run sized fish without tags were classified as fall run. Altogether, 440 adipose-clipped fall run were collected.

Based upon the CWT data and the comparisons of size distribution of hatchery released salmon and salmon caught at Knights Landing after Week 11 (Appendix), it appears that many of the fish collected after Week 11 were fall-run hatchery plants. Similarly, even though the size-at-time criteria indicated that a large portion of the marked (and unmarked) salmon were spring-run chinook salmon, we concluded that all spring-run sized salmon caught after Week 11 were fall-run from CNFH.

Steelhead Trout

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

Adult Steelhead

Five adult-sized steelhead were collected: one in Week 1 (385 mm FL with adipose clip), one in Week 2 (468 mm FL), one in Week 10 (378 mm FL), one in Week 12 (518 mm FL), and one in Week 13 (345 mm FL).

Yearling Steelhead

We collected 165[5] unmarked, yearling-sized steelhead between 17 December 1995 (Week 51) and 12 May 1996 (Week 19) (Table 6, Figure 19). Less than 1% of these fish were caught in December, 61% in January, 16.5% in both February and March, and 3% in both April and May. There appeared to be four modes in catch distribution. The first and highest catch occurred during Week 4 (60 steelhead). Less prominent peaks occurred during weeks 7, 11 and 17-18. The first mode was coincident with the start of the highest flow period. The third and fourth modes appeared to be coincident with the first and third CNFH fall-run plants.

Unmarked yearling steelhead ranged from 82 to 290 mm FL (mean = 220 mm FL). There was no apparent trend in size versus time of capture (Figures 20-24).

We also collected 17 adipose-clipped yearling steelhead, between Week 1 and Week 21 (Table 6, Figure 19). A total 125,764 marked and 401,220 unmarked steelhead was planted about 180 river miles upstream during Week 1. The first marked steelhead was collected at Knights Landing on 17 January 1996 (Week 3).

Adipose-clipped steelhead ranged from 164 to 385 mm FL (mean = 218 mm FL).

Young-of-year steelhead

We collected 10 YOY steelhead (Table 6): one (47 mm FL) during Week 14 and nine (36-38 mm FL, mean 37 mm FL) during Week 21 (Figures 22-24).

[5] An 82 mm FL steelhead collected during Week 3 was included as a yearling.

Table 6. Summary of catch statistics for steelhead trout caught by rotary screw trap in the Sacramento River near Knights Landing, November 1995 - July 1996.

Week	Beginning date	Catch statistics					
		Young-of-year		Yearling (no clip)		Yearling (adipose clip)	
		Count	Mean FL (mm) (range)	Count	Mean FL (mm) (range)	Count	Mean FL (mm) (range)
47-50	21 Nov 1995	No steelhead caught Week 47 through 50					
51	16 Dec 1995	0		1	290	0	
52	23 Dec 1995	0		0		0	
1	30 Dec 1995	0		1	182	1	385[1/]
2	06 Jan 1 996	0		1	203	0	
3	13 Jan 1996	0		36	218 (82-255)	3	197 (164-217)
4	20 Jan 1996	0		60	221 (132-279)	5	200 (166-240)
5	27 Jan 1996	0		6	239 (211-273)	1	207
6	03 Feb 1996	0		9	233 (201-290)	0	
7	10 Feb 1996	0		8	235 (210-255)	2	203 (195-210)
8	17 Feb 1996	0		6	207 (194-238)	1	194
9	24 Feb 1996	0		0		0	
10	03 Mar 1996	0		1	199	0	
11	10 Mar 1996	0		8	204 (181-259)	1	190
12	17 Mar 1996	0		10	233 (196-280)	1	190
13	24 Mar 1996	0		8	235 (193-345)	0	
14	31 Mar 1996	1	47	5	204 (181-224)	0	
15	07 Apr 1996	0		0		0	
16	14 Apr 1996	0		0		0	
17	21 Apr 1996	0		1	187	0	
18	28 Apr 1996	0		2	204 (191-217)	0	
19	05 May 1996	0		3	213 (205-226)	0	
20	12 May 1996	0		0		1	205
21	19 May 1996	9	37 (36-38)	0		1	258
22-28	26 May 1996	No steelhead caught Week 22 through Week 28					
Total		10	39 (36-47)	165	221 (82-345)	17	218 (164-385)

1/ Adult-sized, marked fish

Fyke Trap Results

Unlike RSTs, the fyke traps could not be fished continuously during the higher flow events and when flow (stage) fluctuation required constant relocation. Initial trap deployment occurred after the first major flow increase in Week 51 and was only intermittently fished until the second high flow event forced us to remove it in Week 5 (Table 7, Figure 25). During that period, it was fished continuously (168 h) for only one week (Week 2), a low flow period. During the second deployment, beginning Week 14, flow conditions were relatively stable and the two fyke traps were fished for longer periods. However, they were still typically fished less than half-time and were not fished at all during Weeks 21 and 22 when flow increased.

Chinook salmon were caught in all but Week 3 of the initial deployment (weeks 51-5) (Figure 26). Ninety percent of the catch occurred during the second high flow event (weeks 4 and 5) when 1,911 chinook salmon were caught. Total catch was greatest during Week 4 (1,341 salmon); catch/h was greatest during Week 5 when 570 salmon were collected during a 43 h period (13.2 fish/h) (Table 7). Only five salmon were collected during the second deployment (weeks 14-20).

Fall-run juvenile salmon dominated the fyke trap catch (2,045 salmon, 96%), followed by spring run (61 salmon, 3%) and winter run (18 salmon, <1%) (Figure 26). No late-fall run and no steelhead were collected by fyke trap. Salmon caught by fyke trap were relatively small (mean = 37.8 mm FL, range = 23 - 91 mm FL) (Table 7, Figures 27 and 28).

No adipose-clipped salmon or steelhead trout were caught by fyke trap.

Gear Evaluations

RST Gear Efficiency using Mark-Recapture

Salmon were marked for efficiency evaluations beginning in Week 4 (Table 8). A total of 10,402 chinook salmon was marked from Week 4 through Week 22; 67 were recaptured. The estimated number of recaptured salmon was expanded to 109 based upon the proportion of measured to unmeasured salmon during the weeks when recaptures occurred but all the fish were not measured, thus checked for marks (Table 8). The percent recovered, by week, ranged from 0%, during four weeks (three weeks when the number marked was less than 100), to 4.6% during Week 6. The mean recapture rate during the 19-week period was 1.04%.

No relationships were observed between efficiency and the number of fish marked per week ($r^2 = 0.02$), mean weekly flow ($r^2 = 0.17$), or mean weekly visibility ($r^2 = 0.26$) (Figure 29). The total number caught per week appeared to be directly related to efficiency ($r^2 = 0.37$) indicating that the more fish emigrating the greater the efficiency.

Table 7. Summary of catch statistics for chinook salmon caught by fyke trap in the Sacramento River near Knights Landing, November 1995 - July 1996.

Week	Effort (h)	Total catch	Catch/h	Size statistics (FL in mm)			
				Mean	Minimum	Maximum	Standard deviation
51	96	116	1.20	40.5	30	83	12.10
52	106	46	0.43	36.7	33	44	1.89
01	103	38	0.36	40.8	30	81	10.96
02	168	7	0.04	38.7	37	42	2.12
03	94	0	0				
04	142	1,341	9.44	37.7	23	91	3.58
05	43	570	13.2	37.4	31	70	2.45
06 - 13	Fyke trap not fished weeks 6 through 13						
14	20	0	0				
15	0	0	0				
16	104	0	0				
17	133	0	0				
18	265	5	0.02	77	69	88	7.07
19	291	0	0				
20	146	0	0				
21 - 22	Fyke traps not fished weeks 21 and 22						
23	124	1	0.008	49.5			
24	152	0	0				
25	164	0	0				
26	167	0	0				
27	170	0	0				
Total	2,488	2,124	0.85				

Efficiency based upon Marked Hatchery Salmon and Steelhead

The percentages of marked hatchery fish released into the upper Sacramento River system and subsequently captured at Knights Landing were remarkably similar for winter-run and for late-fall-run salmon, and for steelhead yearlings. Ten of 51,154 marked winter run (0.02%), 93 of 797,243 marked late-fall run (0.012%), and 17 of 125,764 (0.014%) marked yearling steelhead were collected at Knights Landing. The percentage of marked fall run subsequently caught at Knights Landing was substantially higher (0.05%, 440 out of 935,405).

The percent captured from each of the three groups of marked fall run was quite variable. We collected 292 marked fall run from the first group of 338,355 salmon released during Week 11 (0.09%), 90 from the second group of 320,627 released during Week 13 (0.03%), and 58 from the third group of 276,423 released during Week 17 (0.02%).

RST versus Fyke

Results of the RST catches and fyke catches were compared for the period when both gear types were fished concurrently. Catch distribution was significantly different (Spearman Rank Correlation, $p < 0.001$).

The chinook salmon size distributions were significantly different (Mann-Whitney, $p < 0.001$) between RSTs and fyke traps during the weeks when both gear types were fished. The fyke traps did not collect many fish >50 mm FL (mean = 37.8 mm FL). The RSTs consistently collected larger chinook salmon during the concurrently sampled period (Figure 30).

RST versus Kodiak Trawl - Knights Landing

Kodiak trawling was conducted at Knights Landing concurrent with RST sampling during three weeks: Week 12, Week 16 and Week 20. Comparison of size distributions showed a significant difference between the two gear types (Mann-Whitney, $p<0.001$). The RST collected more small fish (mean = 63 mm FL) compared with the trawl (mean = 68 mm FL) (Table 9, Figure 31).

The mean size of fish caught by RST was less than by trawl due primarily to a greater proportion of small (<50 mm FL) salmon in the RST catch (Table 10). More than 15% of the salmon caught by the RST were less than 50 mm FL; only 4% of the trawl catch was <50 mm FL. Conversely, a greater proportion of the trawl's catches comprised large salmon (>80 mm FL) even though the number of these large fish collected by RST was higher (146 versus 65 by trawl). The conclusions made concerning relative abundance of various fish size groups would likely be different depending upon which data set was used. Which data set best represents the population is unknown, demonstrating the need for further investigations to compare gear (RST or trawl) sampling efficiency in a population with known attributes.

The relatively high number of small fish caught by RST is clearly exhibited by size comparisons of each salmon run collected by the two gear types. The smaller-sized fall run comprised 39.7% of the trawl catch versus 57.1% for the RSTs. Conversely, the larger-sized spring run and winter run comprised 58.5% and 1.8% in the trawl and 42.7% and 0.2% in the RSTs.

Comparison of Knights Landing and Sacramento (Kodiak Trawl) Results

Salmon emigration in the Sacramento River was also monitored by the U.S. Fish and Wildlife Service (FWS) at RM 55, near the City of Sacramento. Sampling was conducted using a Kodiak trawl and was concurrent with the RST sampling at Knights Landing from November 1995 through 6 April 1996.

The first chinook salmon collected by the FWS was on 13 December 1995, during Week 50. Sampling was temporarily discontinued at Knights Landing during Week 50. As such, comparisons of monitoring results from both sites cover the period from Week 51 (17-23 December 1995) through Week 14 ending 6 April 1996.

Table 8. Summary of capture efficiency test results for chinook salmon collected by rotary screw traps in the Sacramento River near Knights Landing, November 1995 - July 1996.

Week	Number marked	Number checked	Total counted	Actual number recovered	Expanded number recovered	Efficiency (%)
4	219	2,638	3,759	1	1	0.65
5	1,208	4,104	9,939	14	34	2.81
6	582	5,074	9,696	14	27	4.60
7	925	5,609	11,301	1	2	0.22
8	1,898	4,261	5,946	2	3	0.15
9	979	1,996	2,075	3	3	0.32
10	745	1,306	1,306	5	5	0.67
11	440	1,760	1,764	3	3	0.68
12	725	2,530	5,166	5	10	1.41
13	673	3,453	4,316	9	11	1.67
14	710	2,300	2,423	5	5	0.74
15	174	272	276	1	1	0.58
16	38	52	58	0	0	0
17	57	75	78	0	0	0
18	529	955	1,038	2	2	0.41
19	236	369	382	1	1	0.44
20	120	147	149	1	1	0.84
21	102	125	127	0	0	0
22	42	44	44	0	0	0
Total	10,402	37,070	59,843	67	109	1.04

Catch distribution between the two sites was significantly different (Spearman Rank Correlation, $p < 0.001$) (Figure 32). The catch distribution at Sacramento may have been strongly influenced by salmon emigration from the American and Feather rivers. The highest catch and catch rate at Sacramento occurred during Week 4, compared to Week 7 at Knights Landing. The peak of emigration from the American River was also during Week 4 (Snider unpublished data).

The differences in size distribution between Sacramento and Knights Landing may be explained by gear differences as well as differences in the populations being sampled. Size distributions of chinook salmon caught at Knights Landing differed by gear, as described above, more due to fewer salmon caught by Kodiak trawl than RST from the lower size range of fish present. A similar conclusion could be made in comparisons of size distributions from the Sacramento trawl and RST at Knights Landing (Figures 33-36). For example, beginning in Week 4, there appears to be a bimodal distribution in the smaller size groups (FL <55 mm) for salmon caught by RST that is not apparent in the trawl size distribution. This bimodal distribution continued through

Week 11 in the RST data. Similarly, the only normal (bell shaped) size distribution for spring-run juveniles occurred during Week 51 in the RST catch. Fish of the same size range were caught in the Sacramento trawl for that week, however, the distribution was positively skewed.

Overall, the two sites had similar trends in capture of both marked and unmarked salmon relative to run (per size-criteria) (Table 11). The proportion of marked salmon caught were quite comparable for both gear types for winter run (10.5% to 13.6 %, trawl to RST) and spring run (1.2 % to 2.0%, trawl to RST). The proportion was relatively high for late-fall-run marked fish for both gears (72% at Knights Landing and 78% at Sacramento). The proportion of marked fall run in the two gears' catches was the lowest at both sites. The ratios at Sacramento and the Knights Landing were comparable (0.29% to 0.39%).

Size statistics were also very similar (Table 11). No statistical testing of the size distributions by "run" was attempted due to the apparent bias associated with such tests when using size to define run. Tests comparing distributions by week would also be inappropriate since samples from the Sacramento site includes populations from the Feather and American rivers (and potentially Sutter Bypass) that are not available to be sampled at Knights Landing.

Table 9. Comparison of chinook salmon catch data collected during concurrently sampled weeks by rotary screw traps and Kodiak trawl in the Sacramento River near Knights Landing, March - May 1996.

	Rotary screw trap			Kodiak trawl		
Week	Number	Mean size (FL in mm)	Size range (FL in mm)	Number	Mean size (FL in mm)	Size range (FL in mm)
12	5,166	62.7	29-124	862	68.5	36-126
16	58	74.4	58.5-87.5	7	77.1	68-81
20	149	82.1	63-102	16	81.1	71-97
Total	5,373	64.0	29 -124	885	68.8	36-126

Table 10. Comparison of mean and proportion of size groups caught by trawl versus RST in the Sacramento River near Knights Landing, November 1995 - July 1996.

Gear		Size category (FL in mm)					
		>50	>60	>70	>80	>90	>100
RST	FL mean	67	71	76	88	102	110
	Number	2342	1807	887	118	23	10
	% composition	84.6	65.3	32.0	4.3	0.8	0.4
Trawl	FL mean	70	71	76	96	104	110
	Number	851	757	387	34	19	12
	% composition	96.2	85.5	43.8	10.8	2.1	1.4

Table 11. Comparison of number and sizes of for both marked and unmarked chinook salmon caught at Sacramento by Kodiak trawl and near Knights Landing by rotary screw traps, 17 December 1995 - 6 April 1996.

Chinook salmon run	Sacramento - Kodiak trawl						Portion of catch marked
	Marked			Unmarked			
	Number	FL mean (mm)	FL range (mm)	Number	FL mean (mm)	FL range (mm)	
Fall run	40	69	53 - 74	13,720	41	25 - 74	0.0029
Spring run	22	76	60 - 91	1,900	75	36 - 100	0.0115
Winter run	29	121	105 - 142	246	96	51 - 140	0.1055
Late-fall run	97	144	112 - 203	27	120	101 - 205	0.7823
Knights Landing - Rotary Screw Trap							
Fall run	231	68	53 - 74	59,628	43	26 - 79	0.0039
Spring run	116	73	68 - 81	5,716	69	37 - 93	0.020
Winter run	51	111	71 - 140	324	89	52 - 152	0.136
Late-fall run	51	138	105 - 169	20	131	33 - 198	0.718

Relative Abundance Estimates

A primary objective of monitoring at Knights Landing is to establish an abundance index for juvenile salmonids emigrating from the upper Sacramento River into lower river and the Delta. The following is an initial attempt to develop a simple abundance index using mean annual trap efficiency. Trap efficiency ranged from 0.15% to 4.60% (when marked fish were recovered) averaging 1.04%. (The RSTs captured between 1 out of 667 fish passing the sample location to 1 out of 22 fish, with a mean capture rate of 1 out of 96 fish). Assuming the efficiency range represents the potential magnitude of error about the mean, the estimate of fish passing the trap site could range from 23% to 427% of the actual number.

Juvenile salmonid catch abundance was estimated for both the in-river (naturally-produced) and hatchery-produced portions of each salmon run and for yearling steelhead trout. The estimates of hatchery-produced juveniles were made only for groups containing adipose-clipped (marked) fish. (No attempt was made to determine the number of salmon captured at Knights Landing that came from the nearly 7.3 million unmarked fall-run fry planted from 29 January through 6 March 1996).

For each salmon run and steelhead, the estimated number of marked and unmarked hatchery-produced fish was determined as presented in (Table 12). In-river produced fish were estimated by subtracting the estimated hatchery-produced component passing Knights Landing, by cohort, from the estimated total number of each cohort moving past our site (Table 13).

The relatively high proportion of in-river produced fall-run chinook salmon is surprising. Fall-run juvenile catches appeared to decline just prior to the large number of CNFH fall run were planted starting in mid March 1996. The fall-run catch increased immediately following the initiation of the plants and continued until immediately after plants were stopped. The size distribution in the Knights Landing catches closely approximated that measured for the stocked fish, also suggesting that the Knights Landing catches after 13 March 1996 were predominantly hatchery-produced salmon. The relatively low hatchery-produced portion of the catch, as estimated above, may be due to a variety of reasons, including a disproportionate mortality between the marked and unmarked hatchery salmon, a lower trap efficiency than was estimated (1.04%), or the large number of fish planted encouraged emigration of salmon rearing between the plant site and Knights Landing.

Table 12. Estimates 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, between 23 November 1995 and 13 July 1996.

Cohort	A Marked caught	B Marked estimate (A/0.0104)	C No. planted marked	D Survival (B/C)*	E No. planted unmarked	F No. estimated unmarked (D*E)	G No. estimated total (B+F)
Late-fall run	93	8,942	797,243	0.011	0	0	8,942
Winter run	10	962	51,267	0.019	0	0	962
Fall run	440	42,308	935,405	0.045	11,474,903	516,371	558,679
Steelhead	14	1,346	125,764	0.011	401,220	4,413	5,759

Table 13. Estimates 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 between 23 November 1995 and 13 July 1996.

Cohort	A Total caught	B Estimated total (A/0.0104)	C Hatchery total (from Table 12)	D In-river total (B-C)
Late-fall run (1995 BY)	112	10,769	8,942	1,827
Late-fall run (1996 BY)	18	1,731	0	1,731
Winter run	334	32,115	962	31,153
Spring run	506	48,654	0	48,654
Fall run	59,489	5,720,096	558,679	5,161,417
Steelhead	182	17,500	5,759	11,741

CONCLUSIONS

Juvenile salmonid emigration from the Sacramento River can be efficiently and effectively monitored using RSTs located near Knights Landing.

- The data obtained from RSTs at Knights Landing identified timing and relative abundance of emigrating chinook salmon, by run. (Based upon comparisons with emigration data concurrently collected at Sacramento).

- RST efficiency measured at Knights Landing was relatively high for a large stream (Snider and Titus 1995).

- RSTs were capable of fishing under variable flow conditions.

- RSTs did not appear to be biased toward smaller or larger salmonids when fished under the conditions present at Knights Landing in 1995 - 1996.

- RSTs fished at Knights Landing provide data on contribution of upper Sacramento River anadromous salmonid populations without influences from Feather and American rivers.

- Systematic evaluation of the screw traps using comparative gear (e.g., Kodiak trawls) within the same sample area, and continuous mark-recapture evaluations could enhance the utility of the abundance measurements made at Knights Landing.

- The influence of Sutter Bypass operation on successful emigration to the Delta, and thus on estimates of fish entering the Delta made at Knights Landing, needs to be evaluated.

ACKNOWLEDGMENTS

The Knights Landing pilot monitoring evaluation was originated by the Salmon Project Work Team (SPWT) of the Interagency Ecological Program.(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 US National Marine Fisheries Service, the US Fish and Wildlife Service, California Department of Water Resources, the California Department of Fish and Game, the State Water Contractors, the Metropolitan Water District, and the Bay Institute. The SPWT's strong support and encouraged the Department of Water Resources to fund the evaluation as an IEP project.

We would like to thank Craig Flemming, of the US Fish and Wildlife Service, for assisting in establishing the monitoring site. We also want to thank the field crews consisting of Al Daniel, Laird Henkel, Thomas Leehman, Leo Millon, Julia Morken, Kristina Neuman, Shawn Oliver,

Doug Post, Brian Rhodes, Mike Stiehr, Ross Wehnke, Linda Wells, Steve Whiteman, and Dave Van Baren of the California Department of Fish and Game. A special thanks goes to Katherine Taylor for her assistance in data management and analysis and preparation of the numerous graphics. Finally, we wish to thank Sharon Kramer, Katy Perry, Pat Brandes, Mark Pierce, and Bob Reavis for their review of the report.

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Snider, B. and R. G. Titus. 1995. Lower American River emigration survey, November 1993 - July 1994. Calif. Dept. Fish Game, Environmental Services Division, unpubl. rpt. 102 pp.

Orth, D. J. 1983. Aquatic habitat measurements. Pages 61-84 in: A. Nielsen and D. L. Johnson eds. *Fisheries Techniques*. American Fisheries Society, Bethesda, Md.

FIGURES

Sacramento River and tributaries

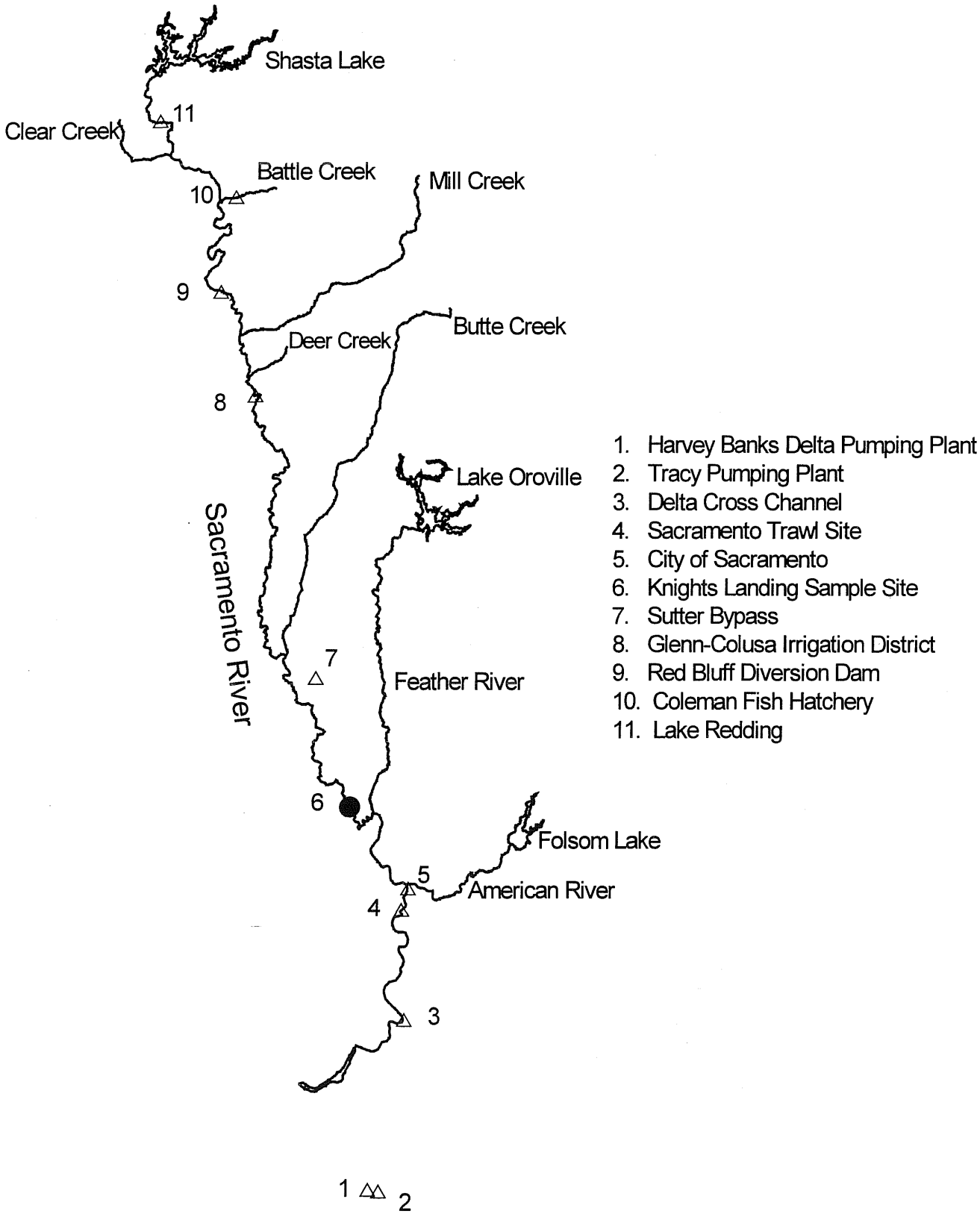


Figure 1. Relative location of Knights Landing monitoring site in the upper Sacramento River, November 1995 - July 1996.

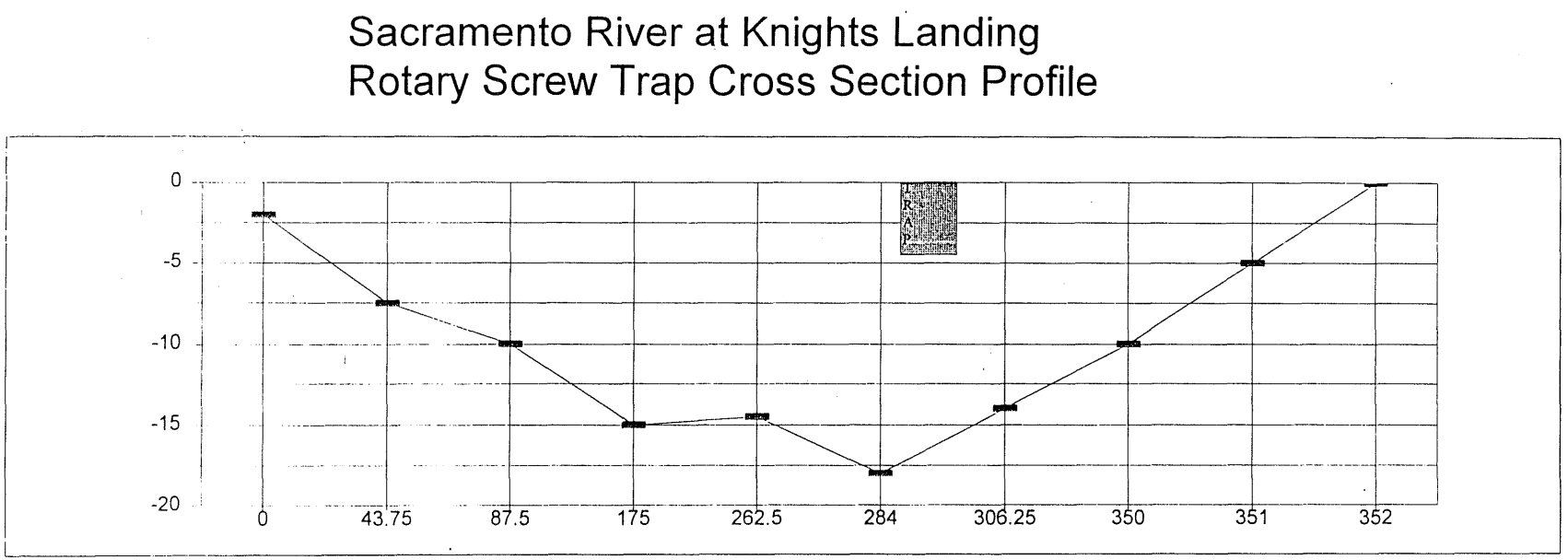


Figure 2. Cross section profile of Sacramento River at the Knights Landing rotary screw trap sampling location, River Mile 89.5.

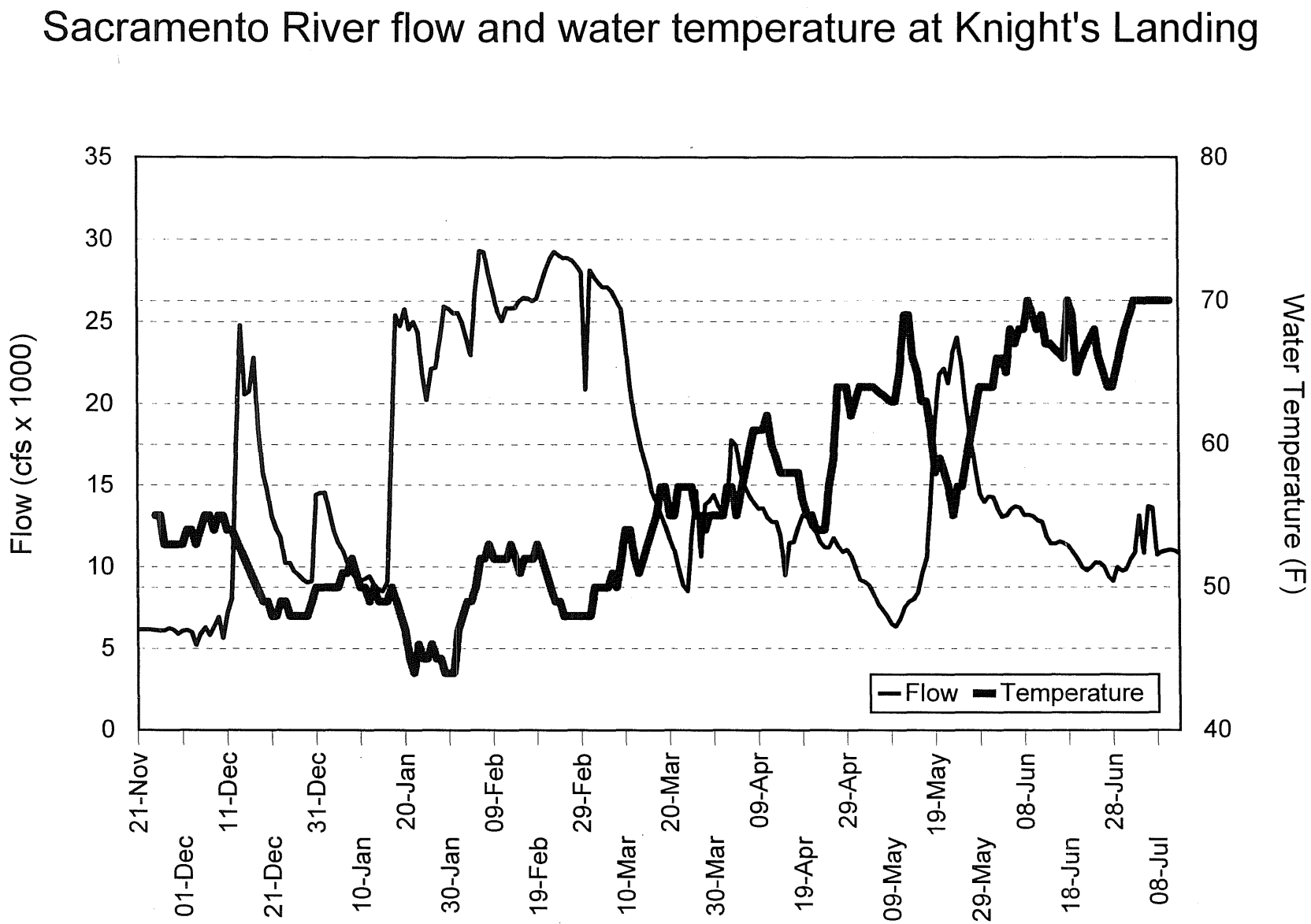


Figure 3. Mean daily flow measured in the Sacramento River near Knights Landing at Wilkins Slough, and mean daily water temperature measured at Knights Landing, November 1995 - July 1996.

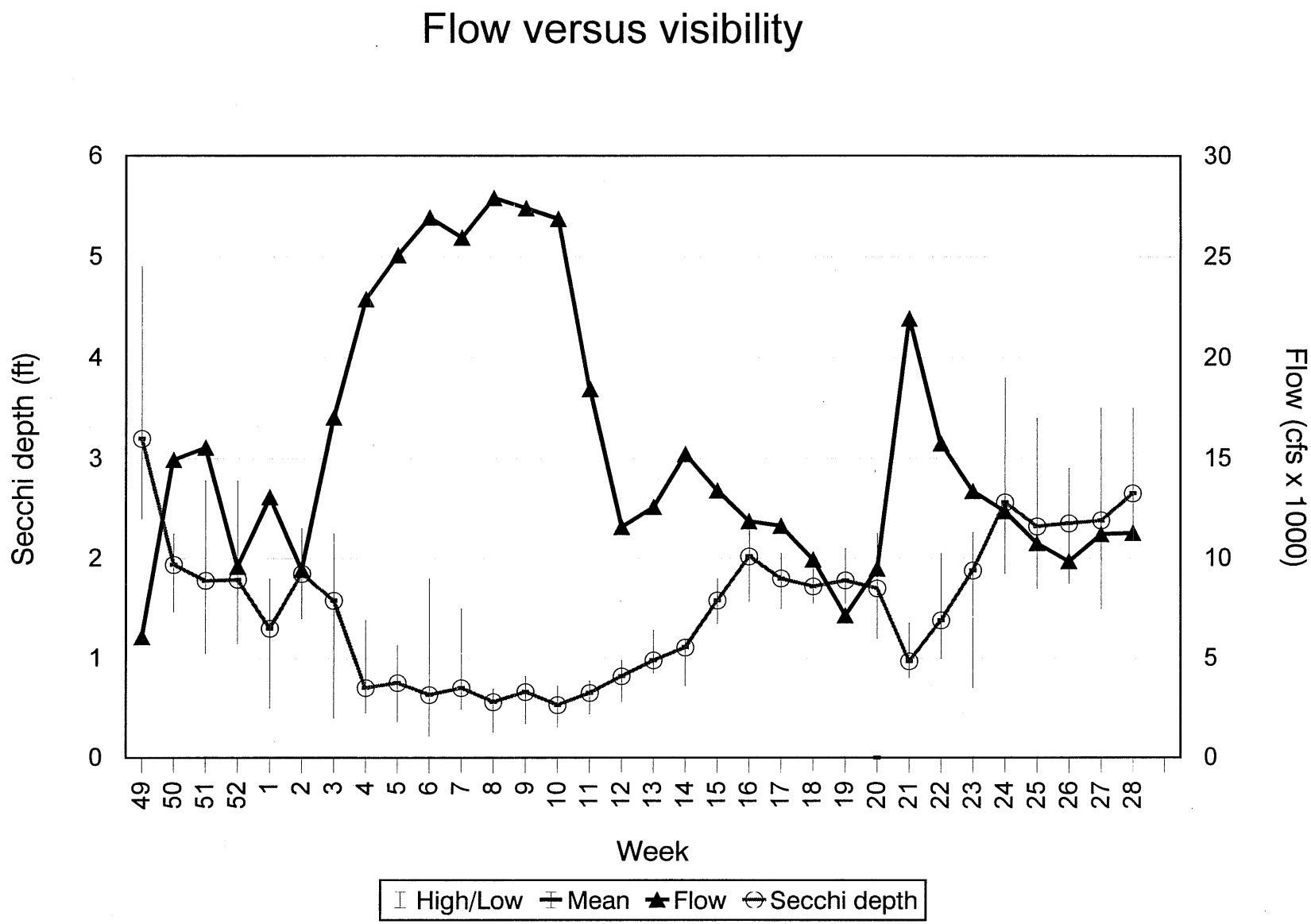


Figure 4. Mean weekly flow compared with mean weekly visibility (Secchi depth) measured in the Sacramento River near Knights Landing, November 1995 - July 1996.

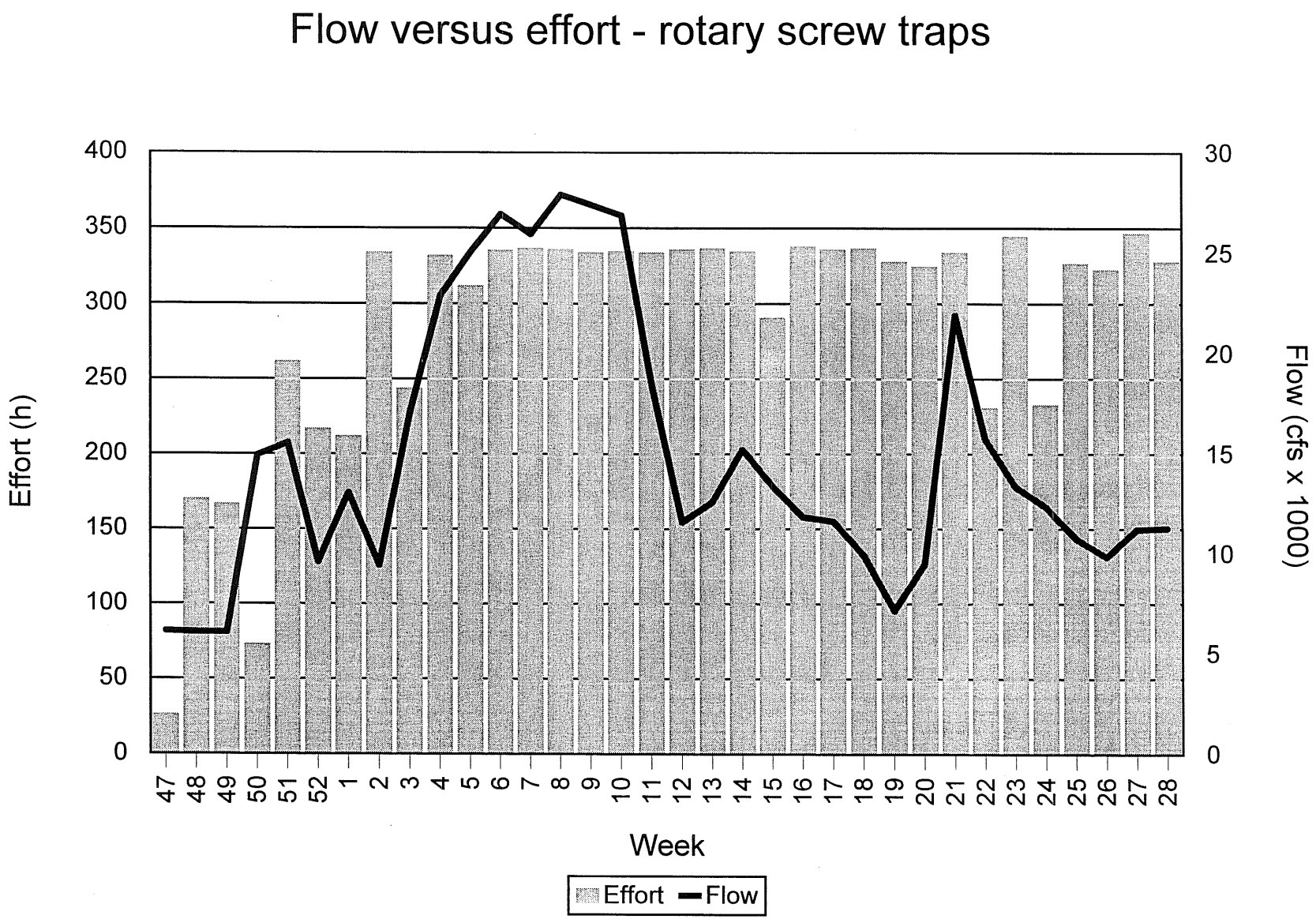


Figure 5. Flow versus effort expended by rotary screw traps in the Sacramento River near Knights Landing, November 1995 - July 1996.

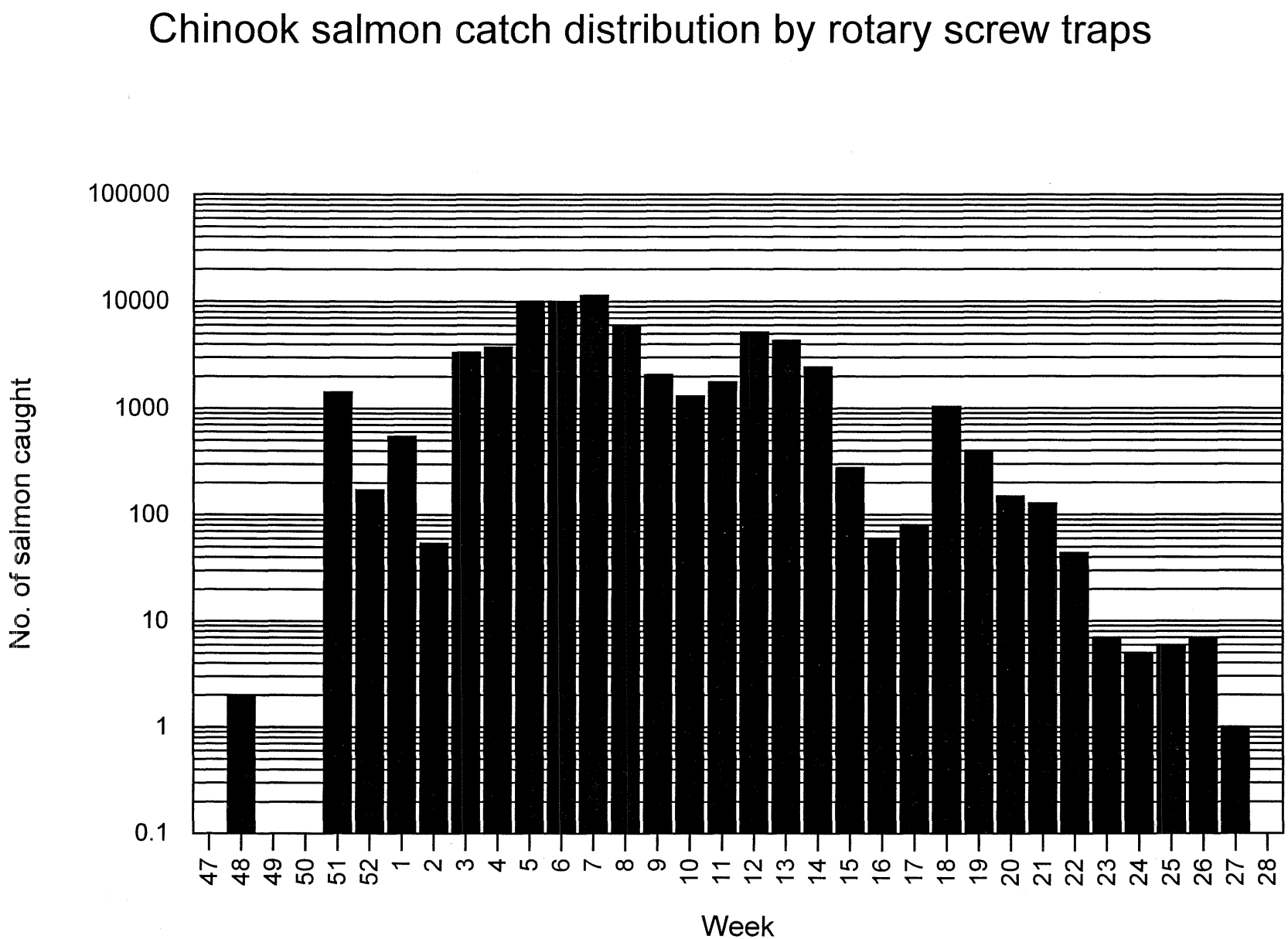


Figure 6. Mean weekly catch distribution for all chinook salmon caught by rotary screw trap at Knights Landing in the Sacramento River, 21 November 1995 through 13 July 1996.

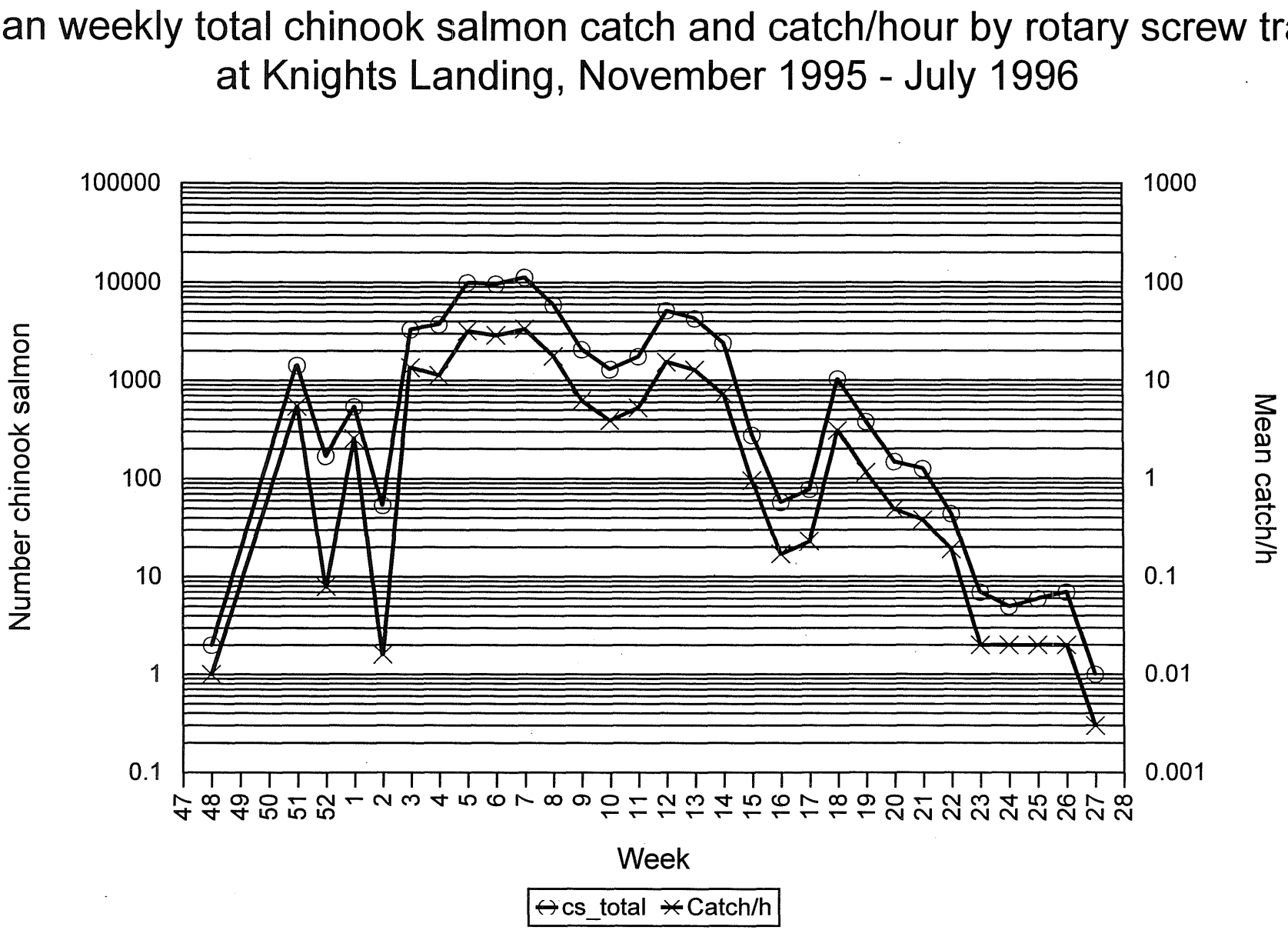


Figure 7. Comparison of catch and catch-rate for chinook salmon collected by rotary screw traps in the Sacramento River near Knights Landing, November 1995 - July 1996.

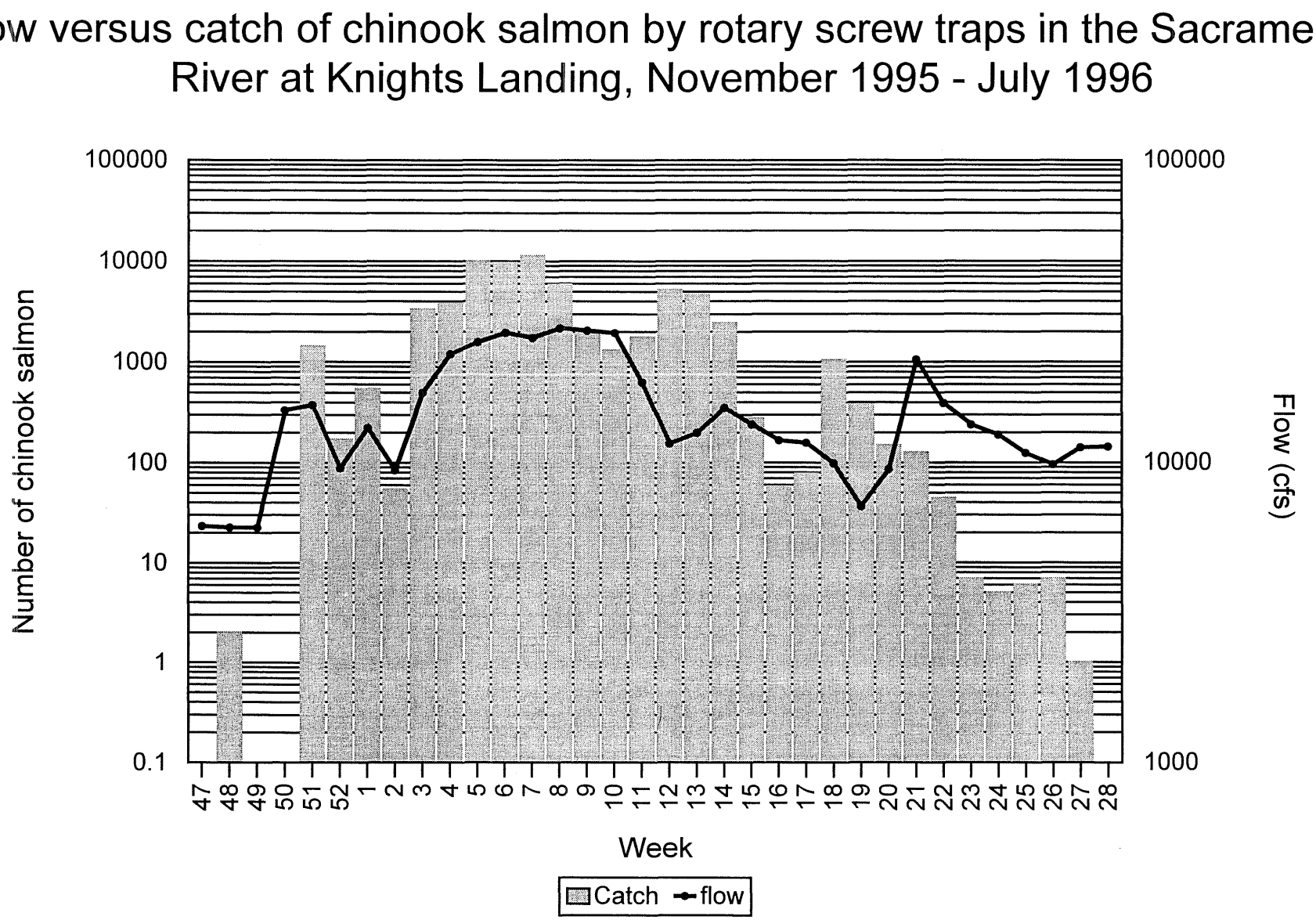


Figure 8. Comparison of mean weekly flow and mean weekly catch of all chinook salmon (includes adipose-clipped salmon) collected by rotary screw traps in the Sacramento River at Knights Landing, November 1995 - July 1996.

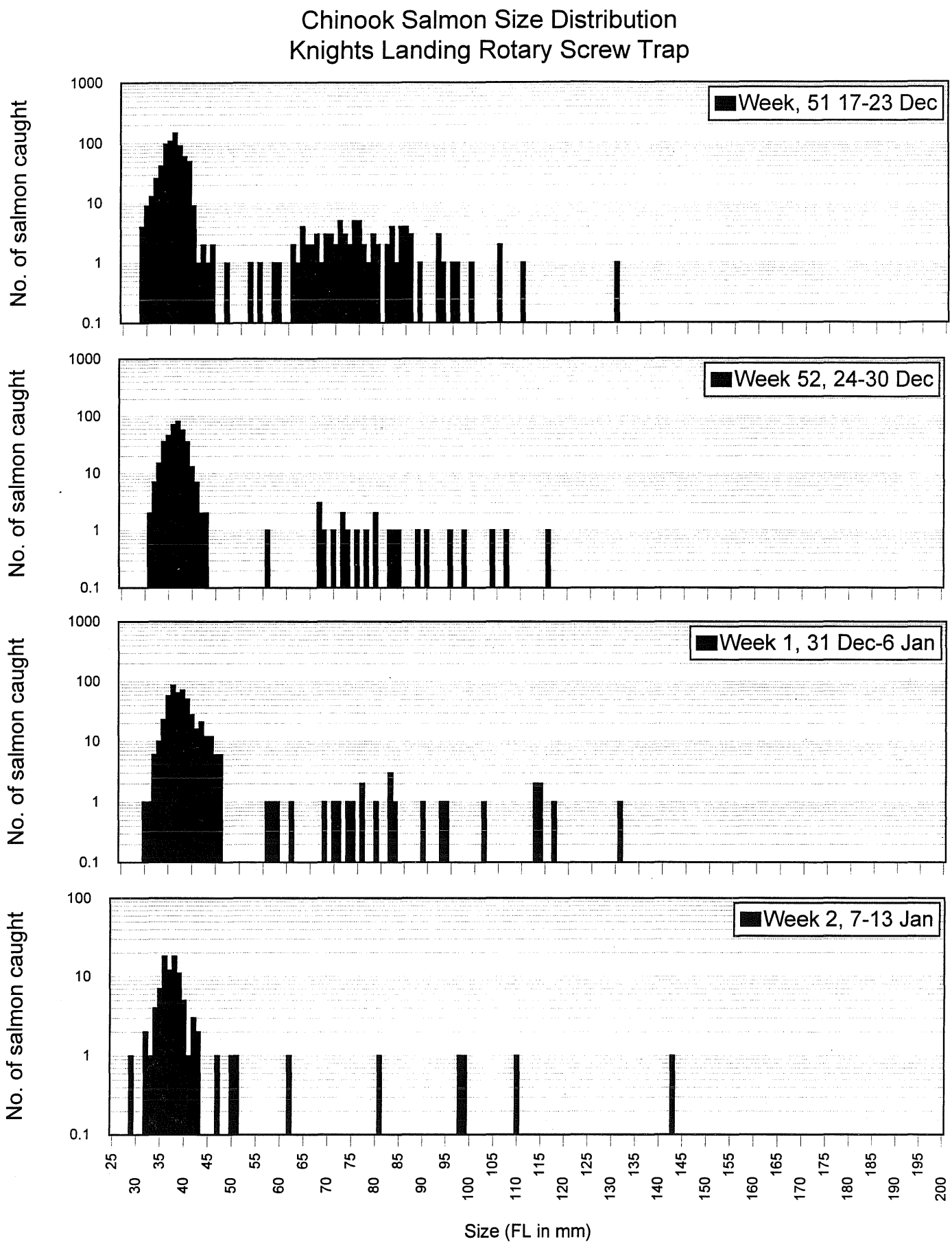


Figure 9. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 17 December 1995 through 13 January 1996.

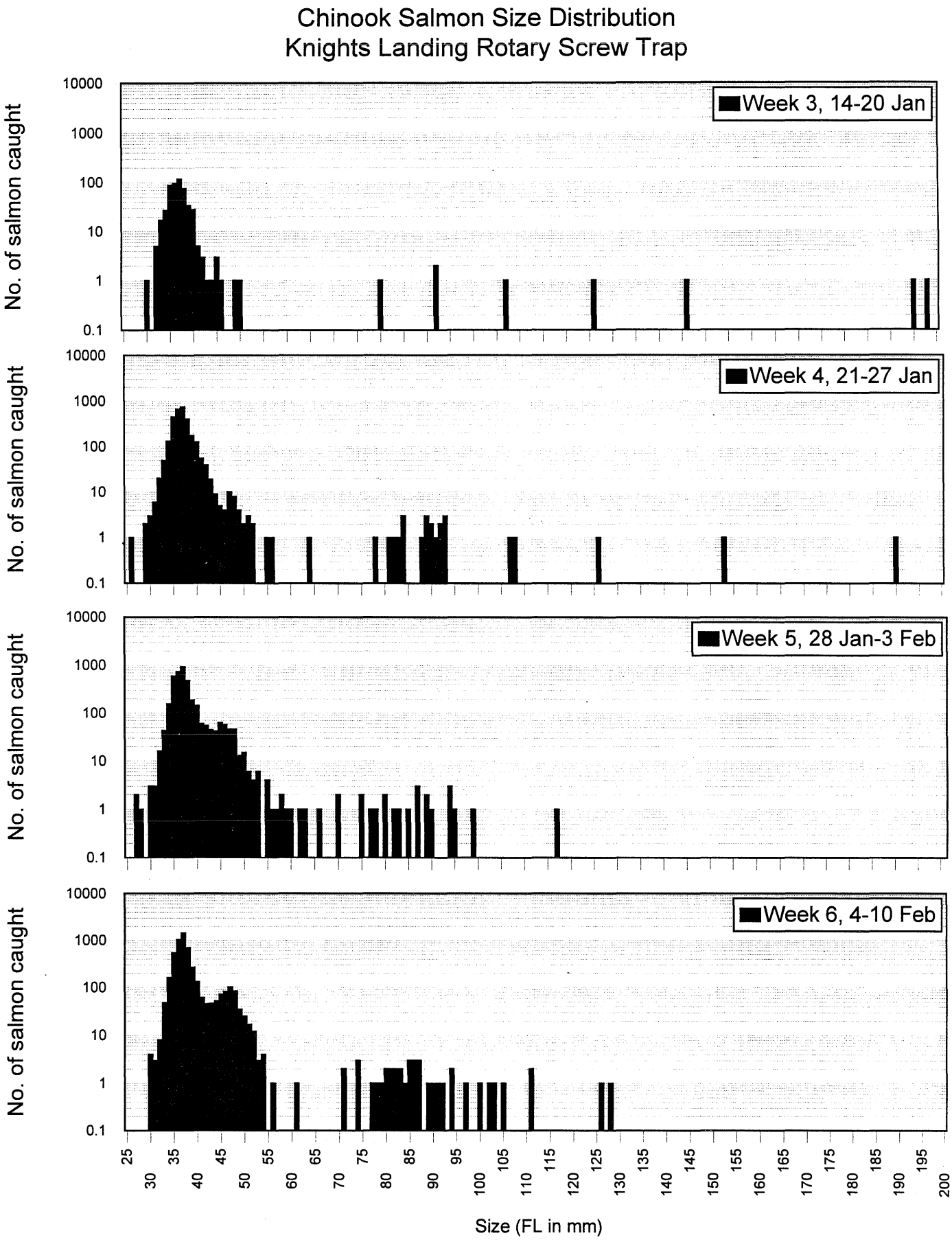


Figure 10. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 14 January through 10 February 1996.

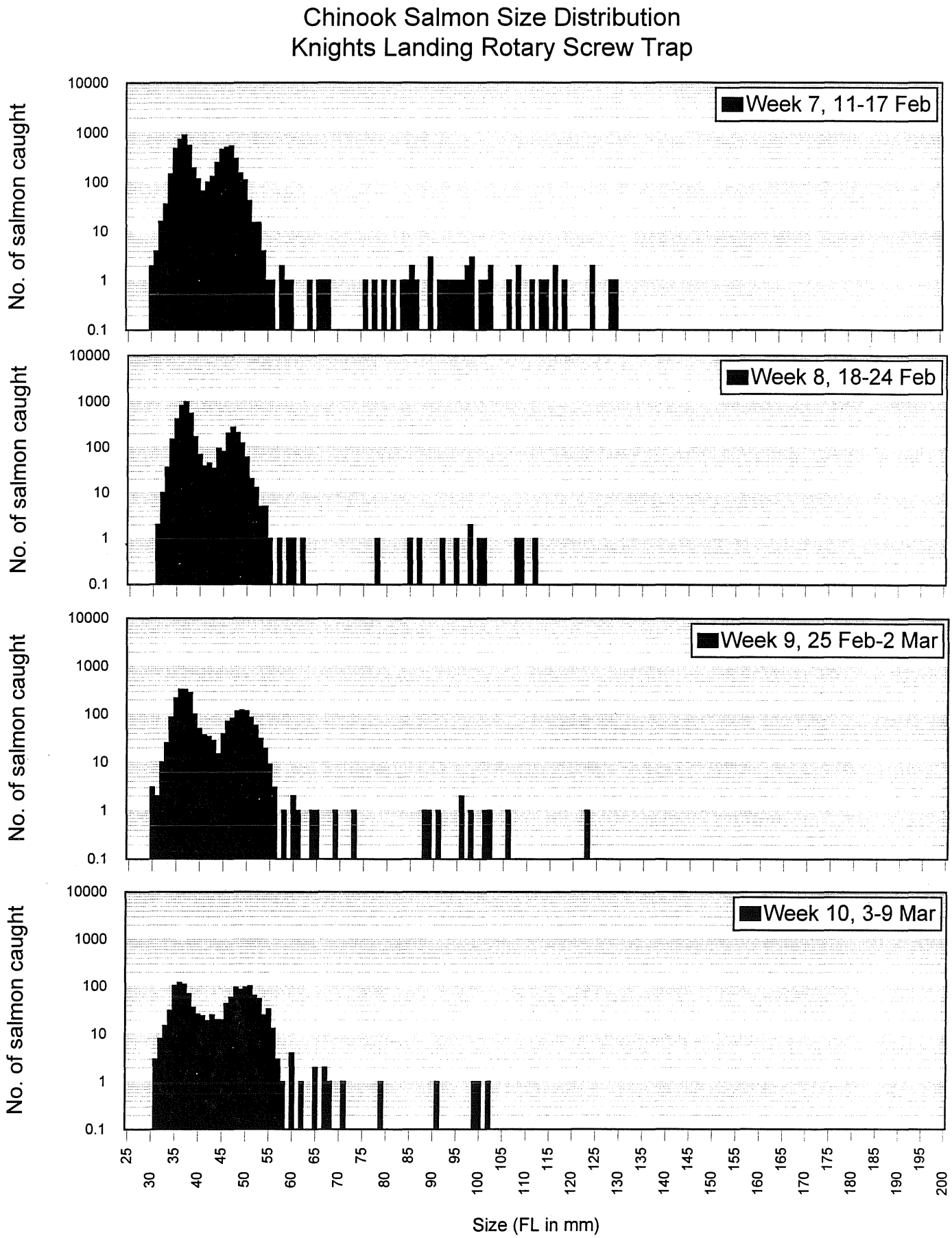


Figure 11. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 11 February through 09 March 1996.

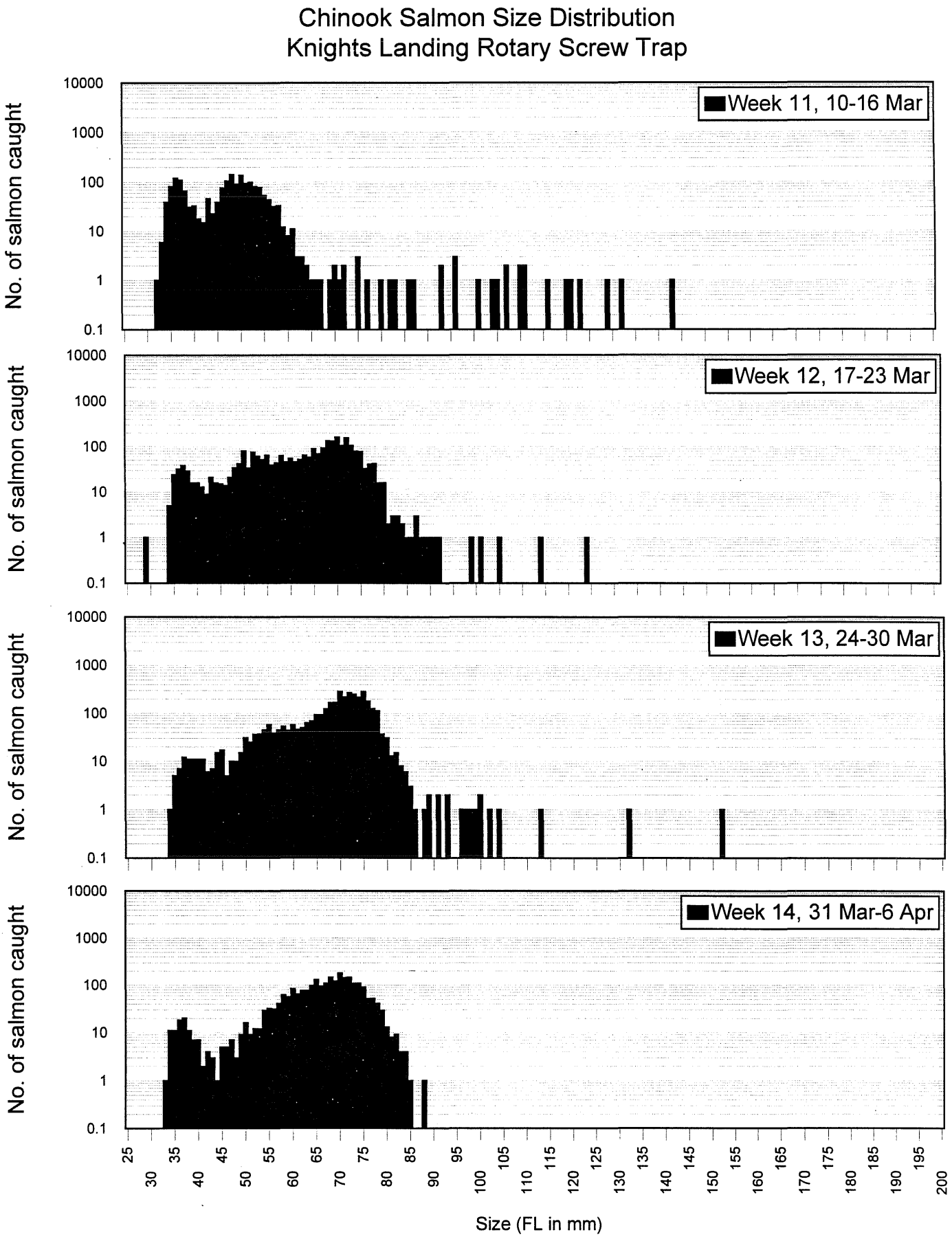


Figure 12. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 10 March through 06 April 1996.

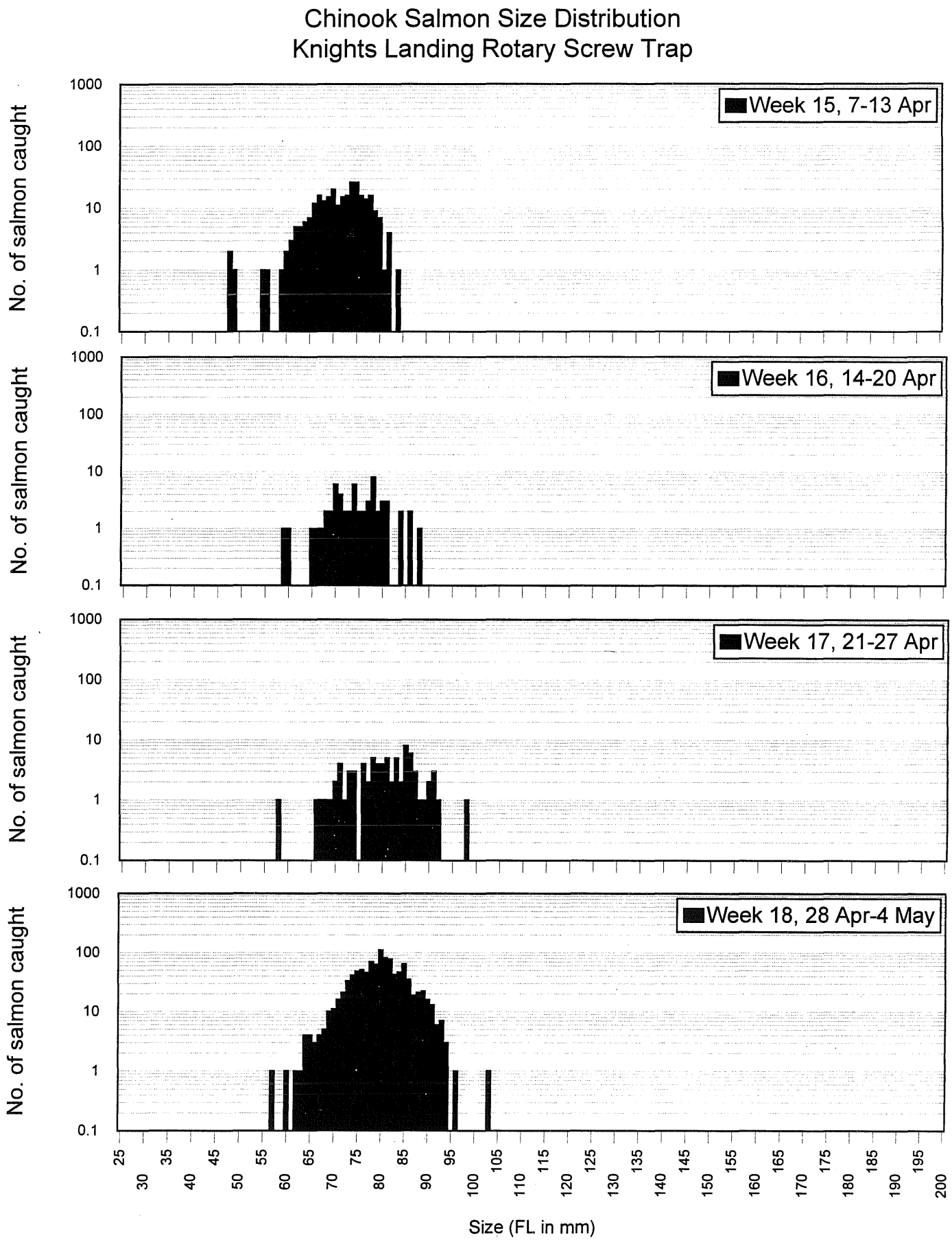


Figure 13. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 07 April through 04 May 1996.

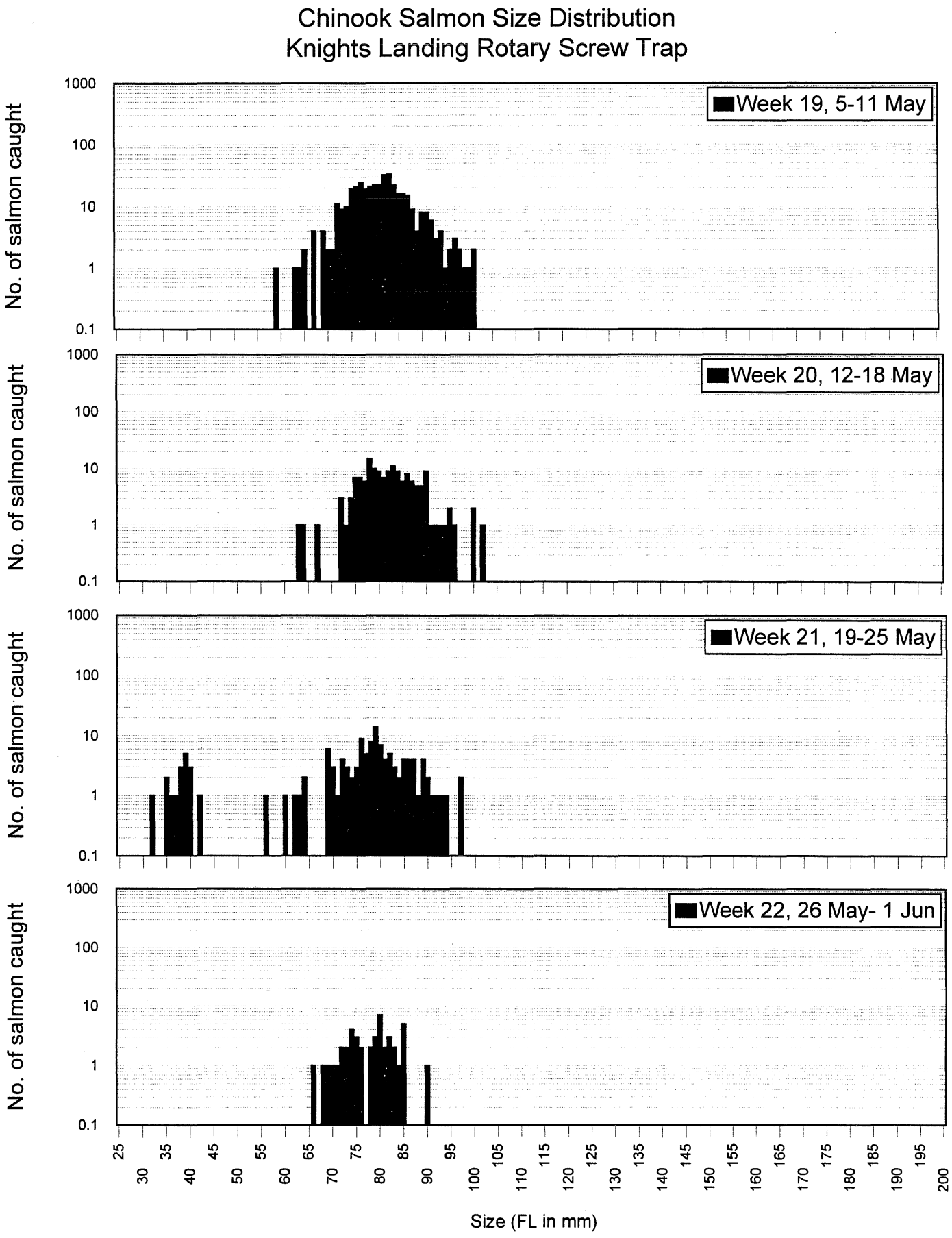


Figure 14. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 05 May through 01 June 1996.

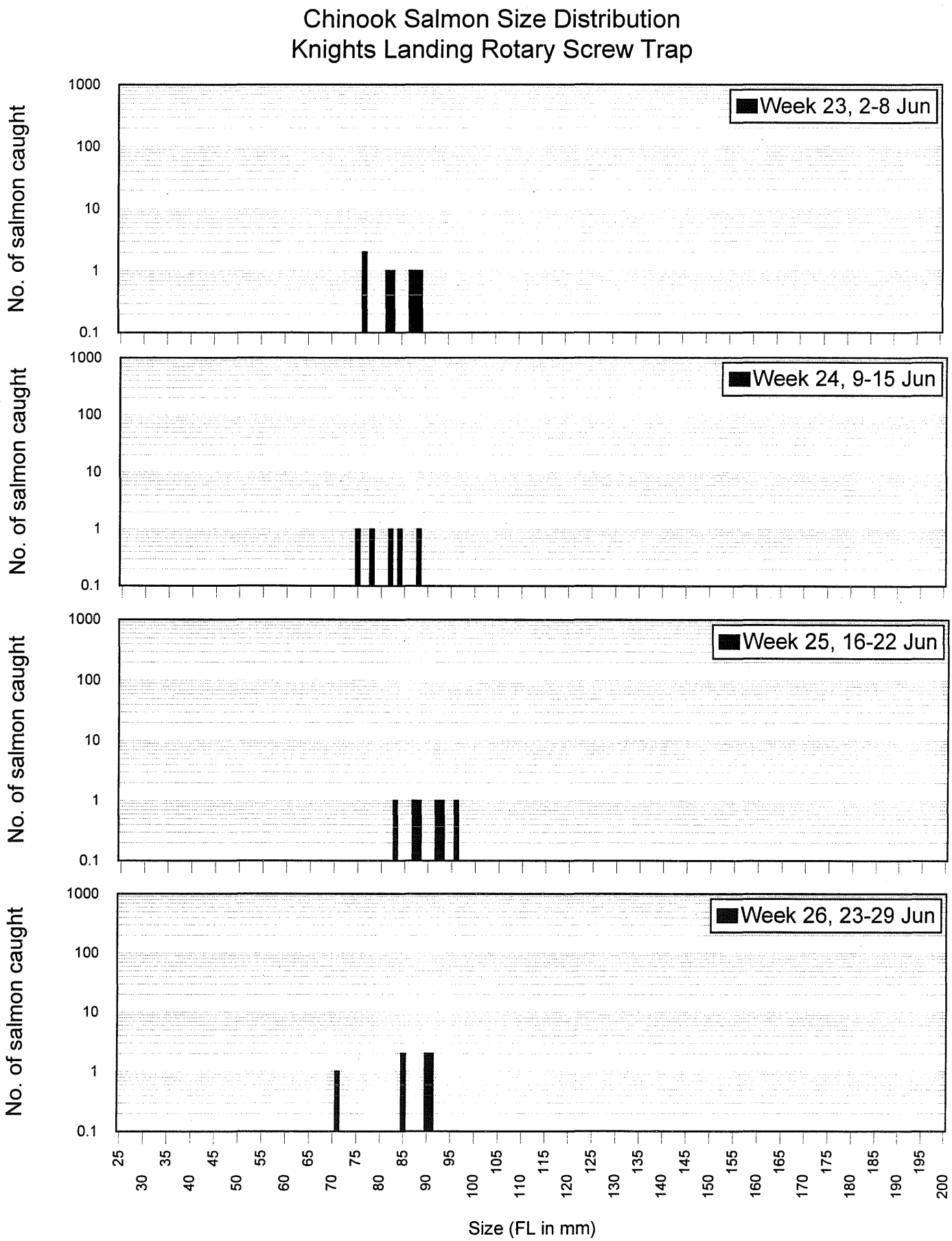
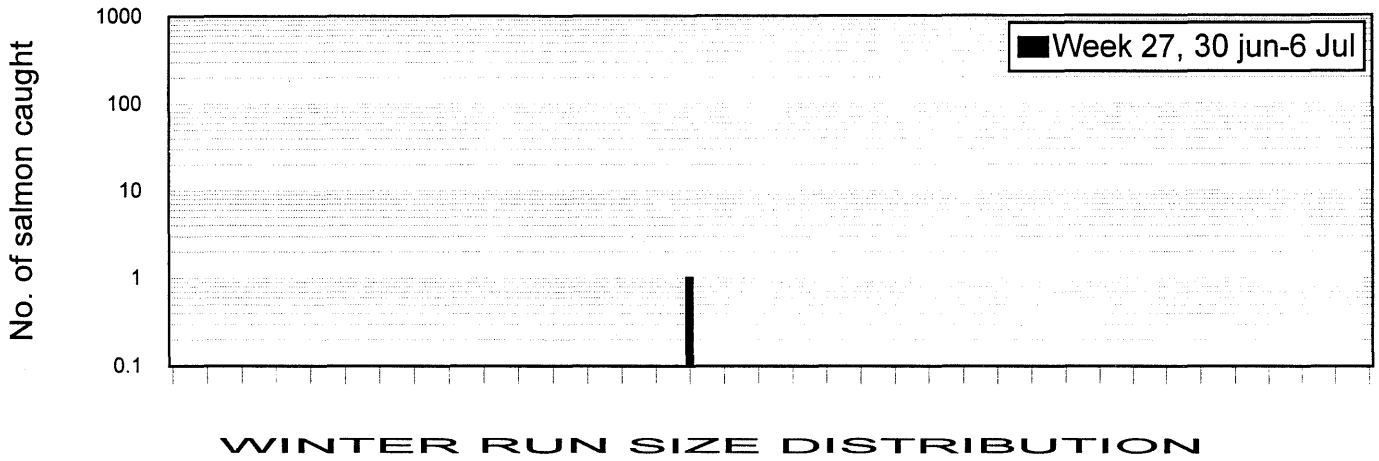


Figure 15. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 02 through 29 June 1996.

Chinook Salmon Size Distribution
Knights Landing Rotary Screw Trap



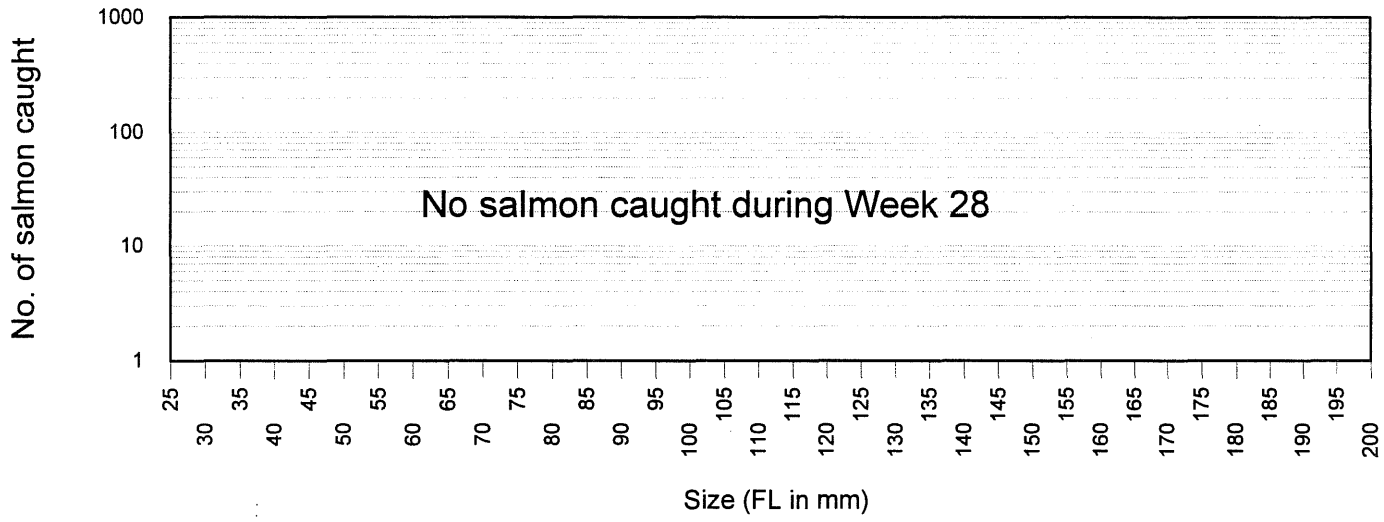


Figure 16. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 30 June through 13 July 1996.

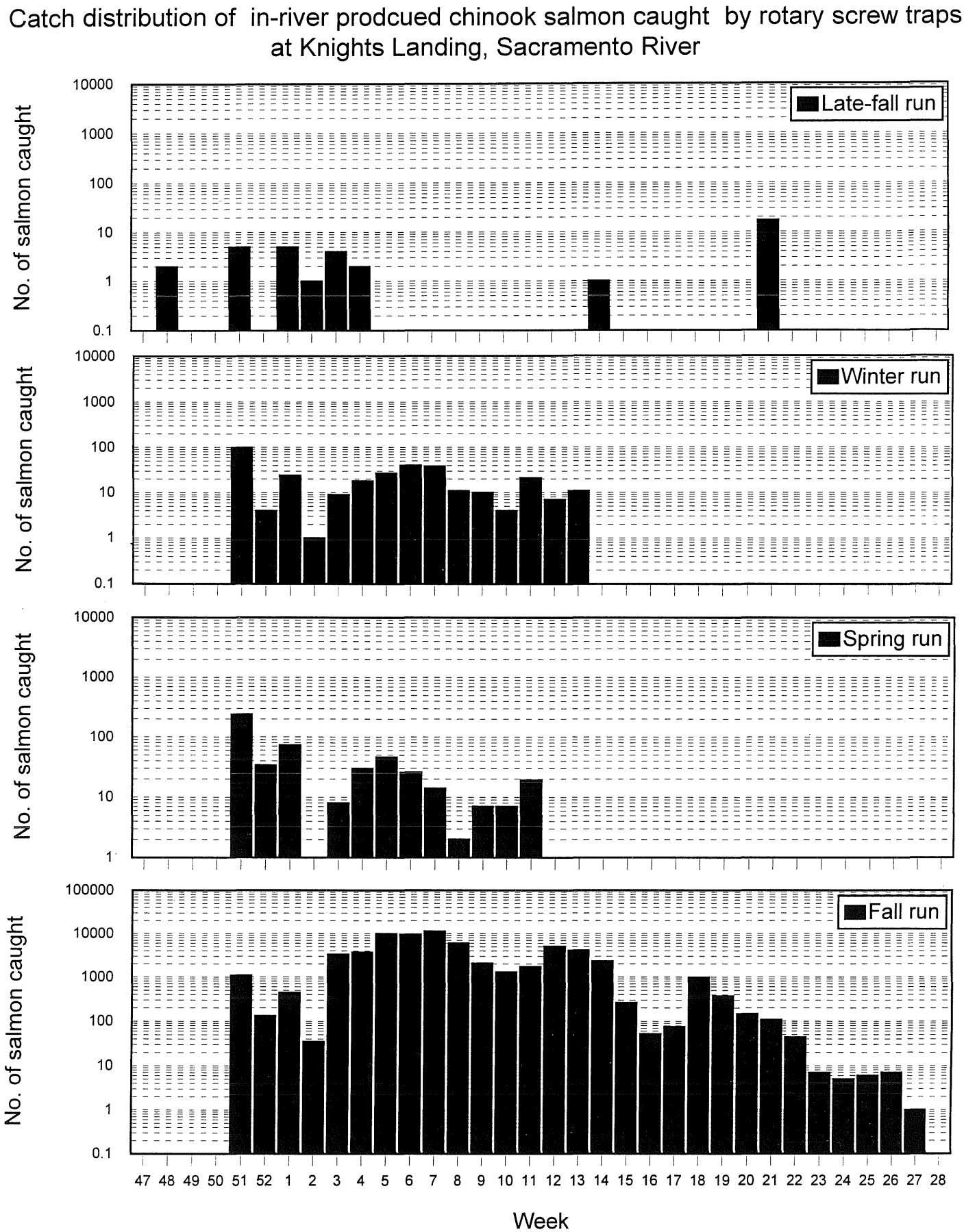


Figure 17. Catch distribution of in-river produced chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 21 November 1995 through 13 July 1996. (Note that all unmarked, spring-run sized chinook salmon caught after Week 11 were combined with fall run)

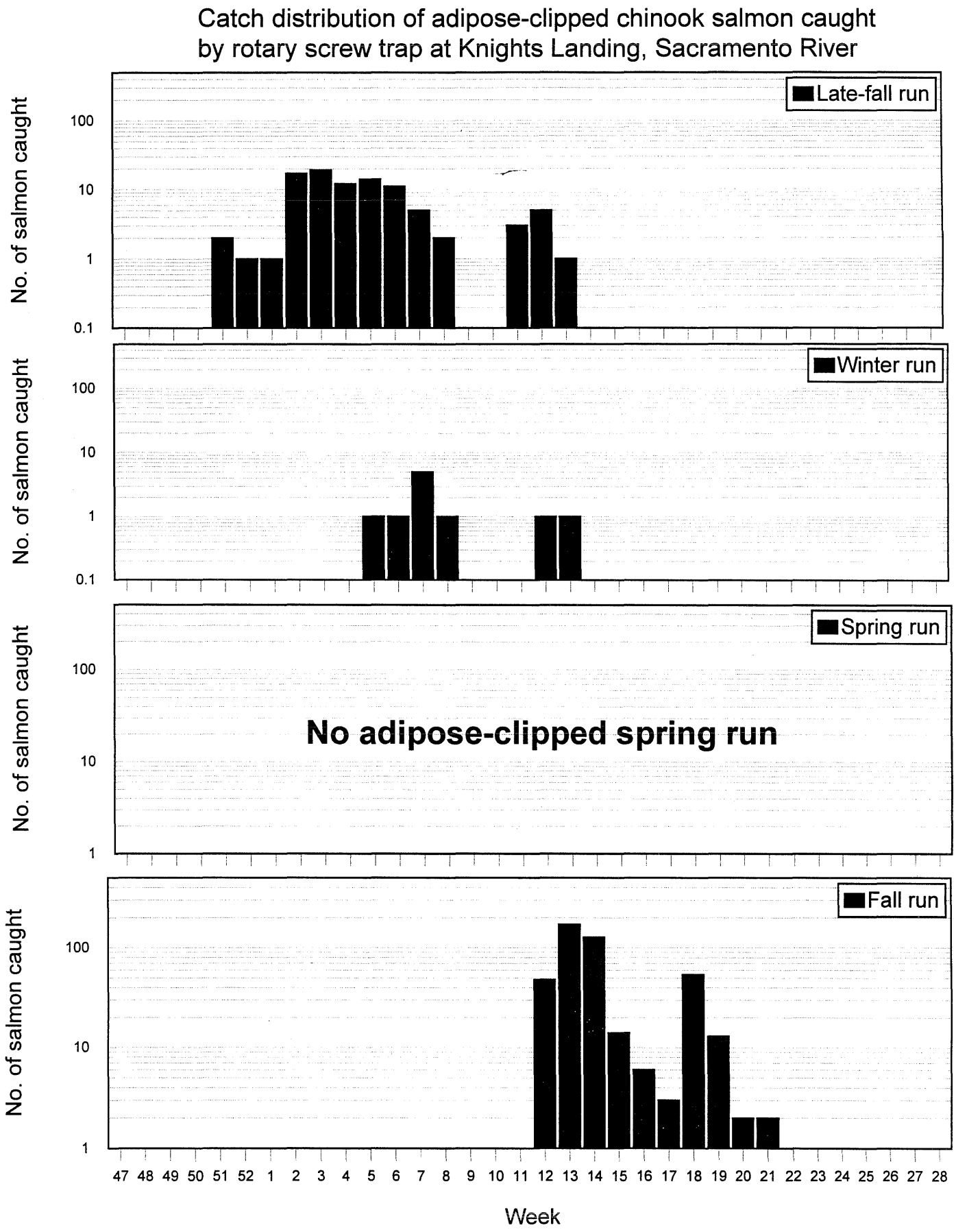


Figure 18. Catch distribution of adipose-clipped chinook salmon caught by rotary screw traps at Knights Landing, Sacramento River, 21 November 1995 through 13 July 1996.

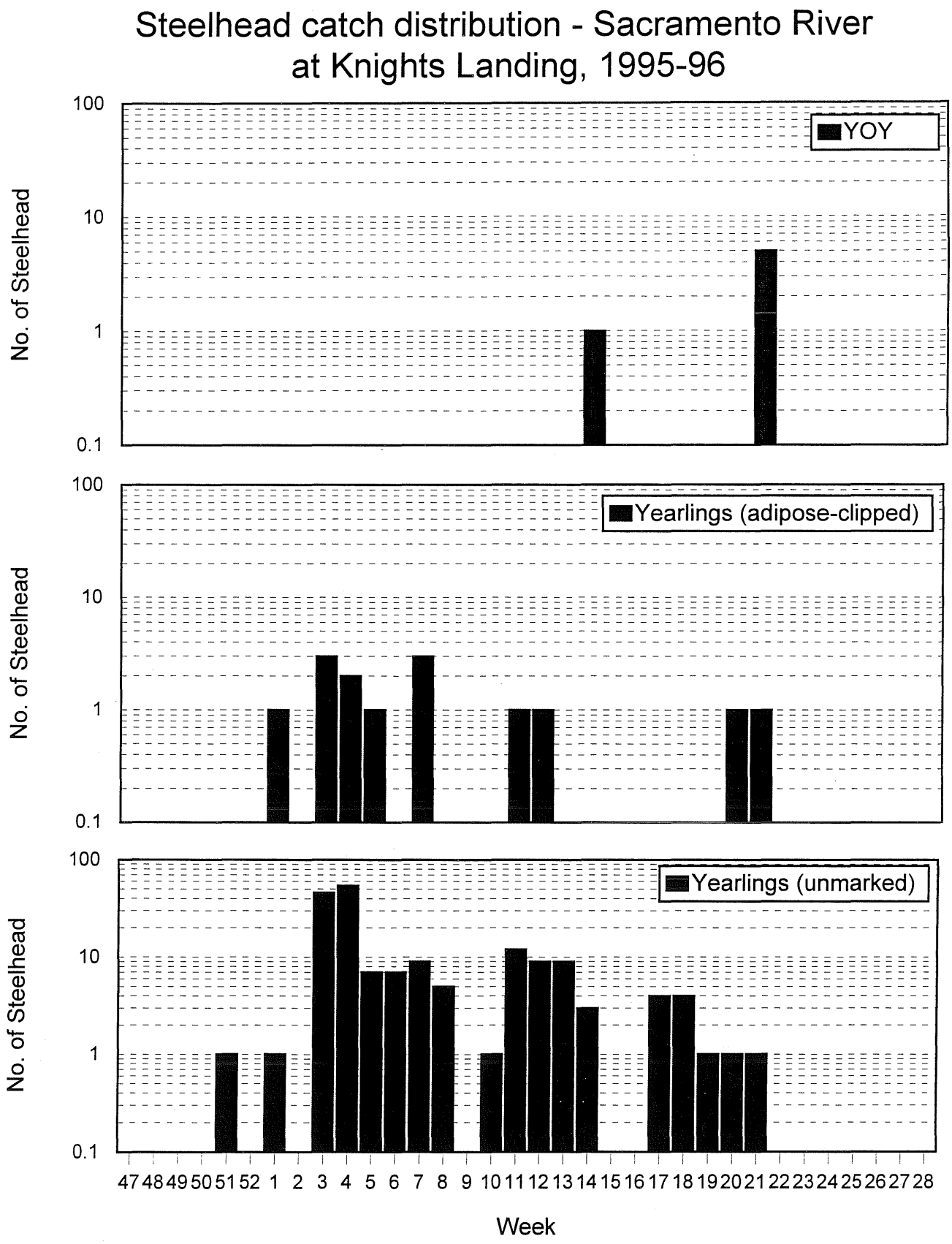


Figure 19. Catch distribution of young-of-year and yearling steelhead trout collected from the Sacramento River near Knights Landing by rotary screw trap, November 1995 - July 1996.

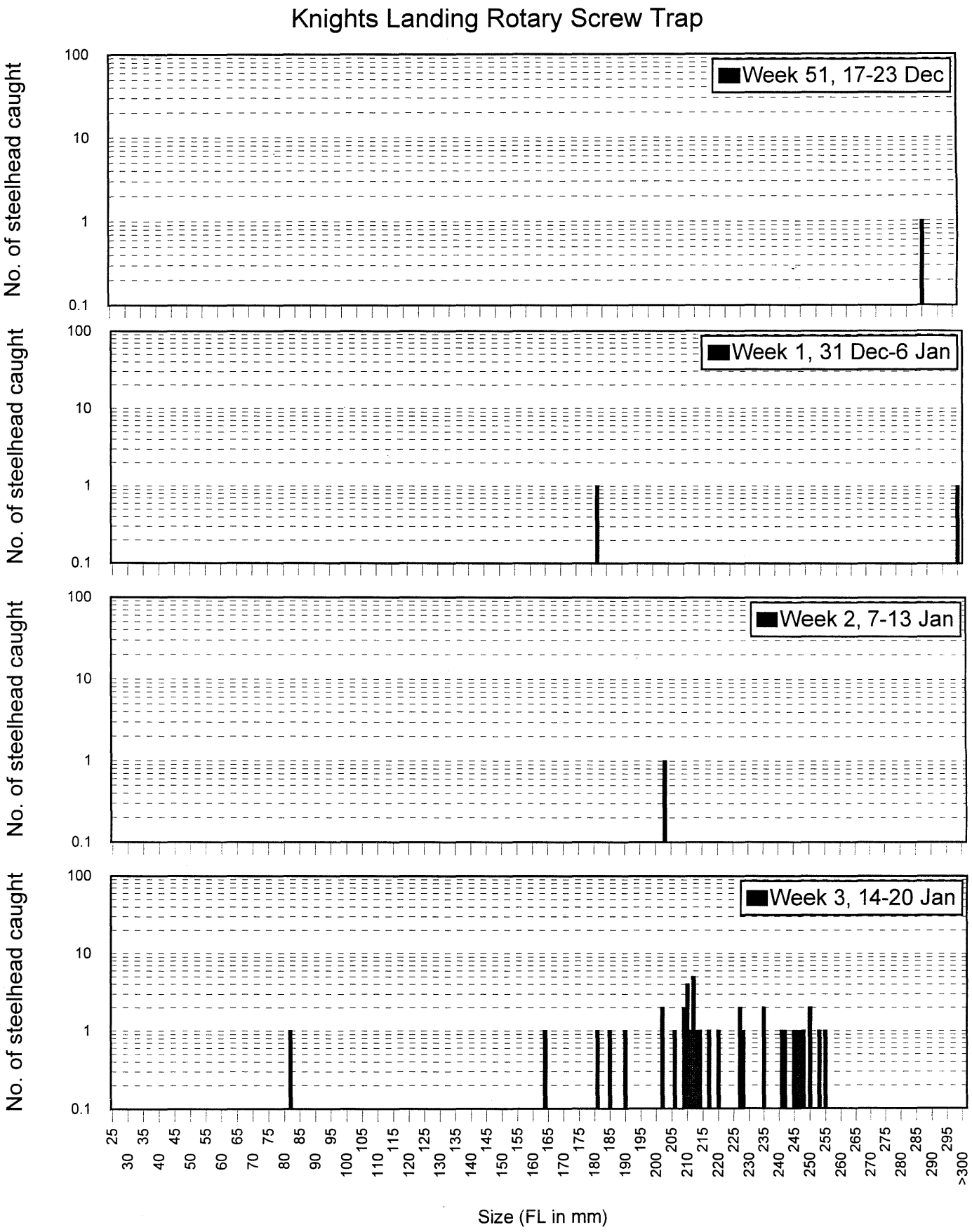


Figure 20. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 17 December 1995 - 20 January 1996.

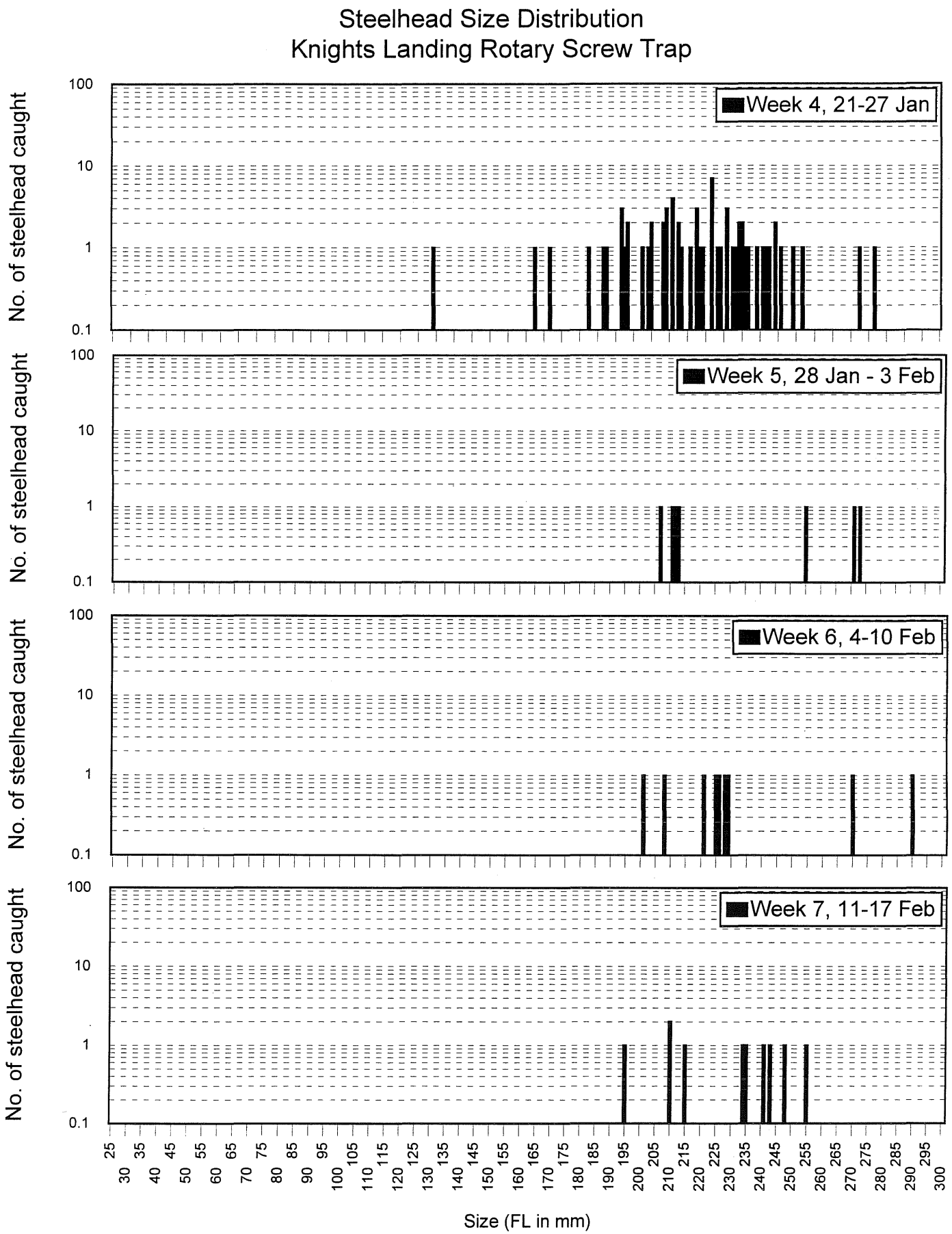


Figure 21. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 21 January - 17 February 1996.

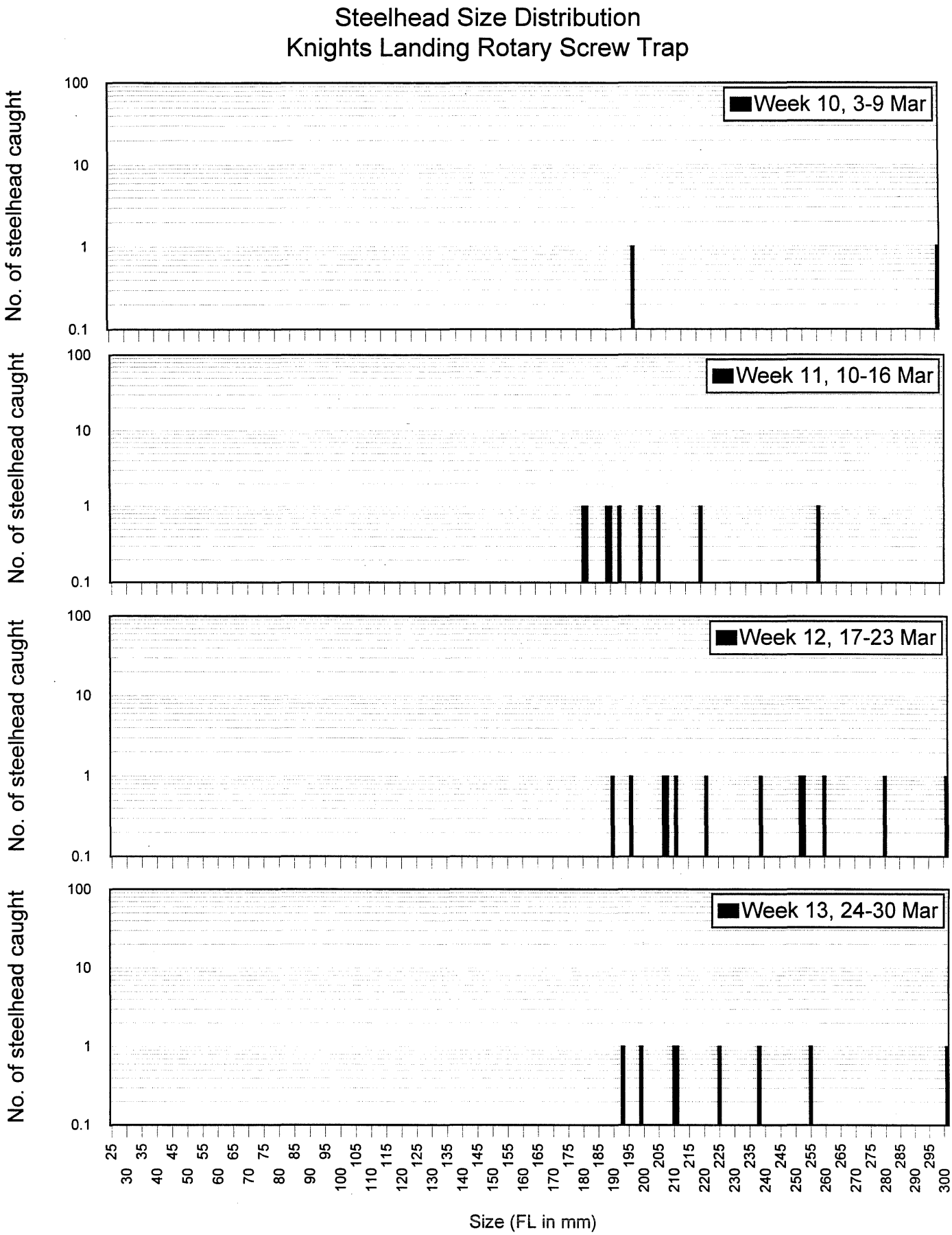


Figure 22. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 3-30 March 1996.

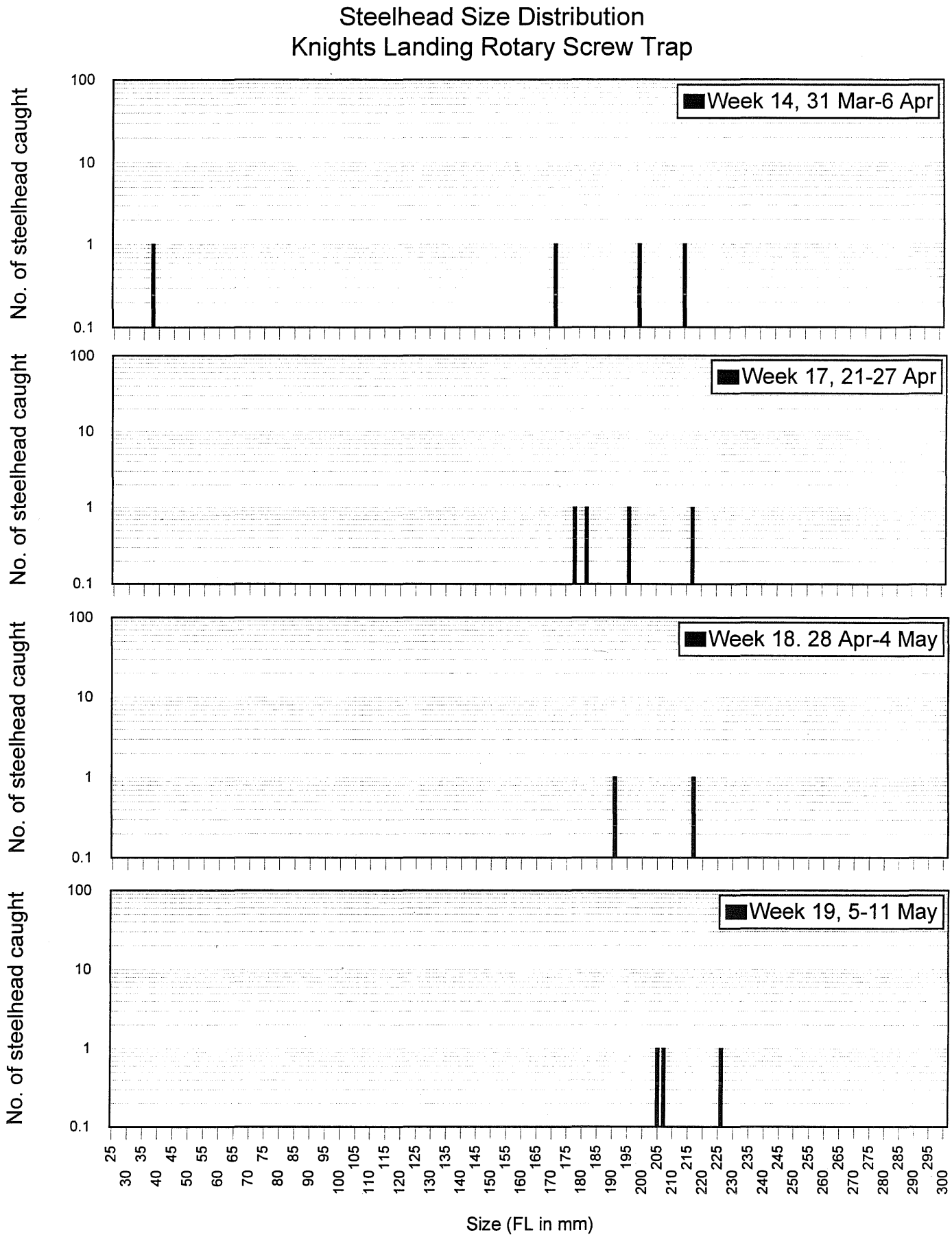


Figure 23. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 31 March- 11 May 1996.

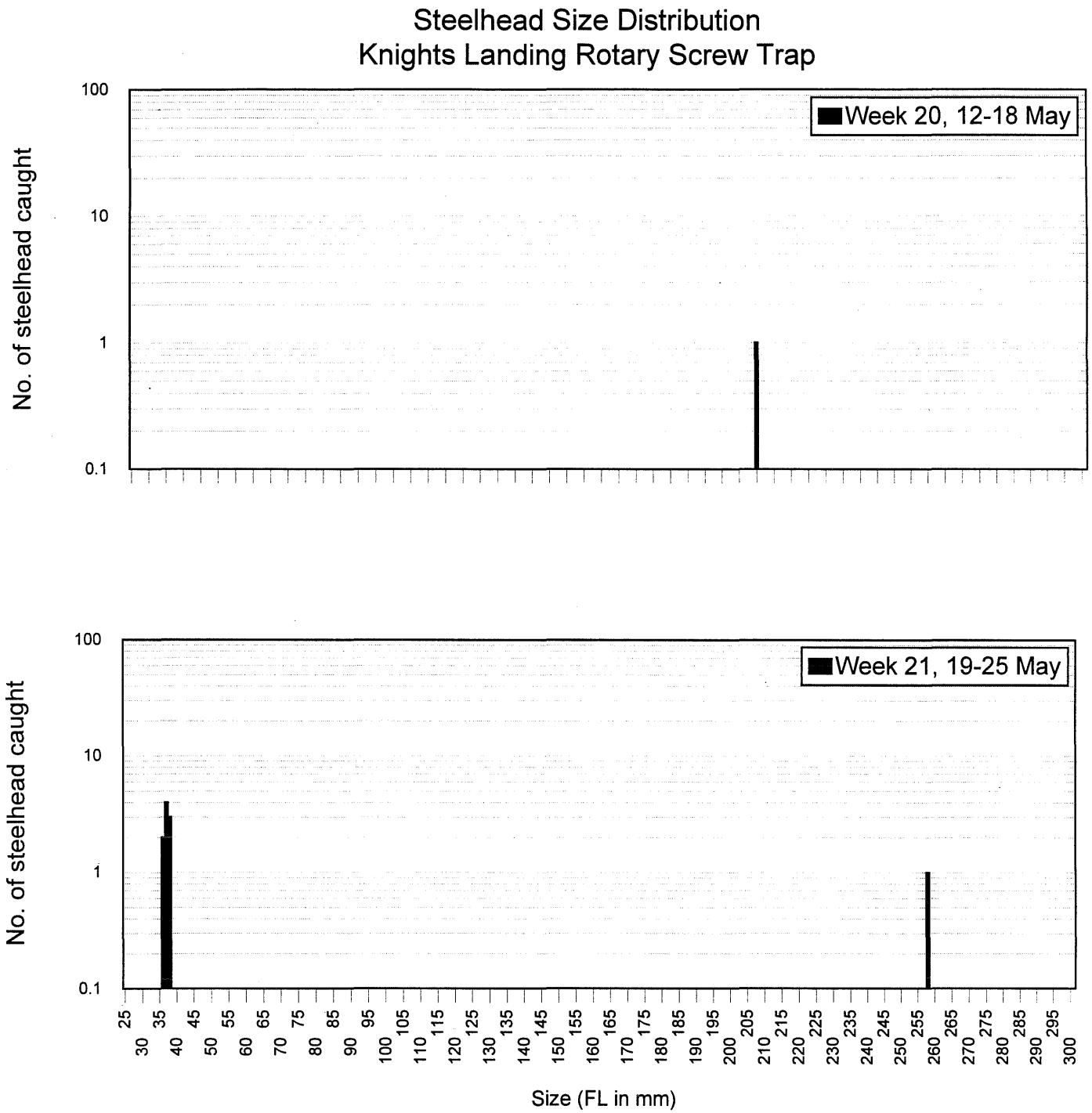


Figure 24. Size distribution of steelhead caught by rotary screw traps at Knights Landing, Sacramento River, 12-25 May 1996.

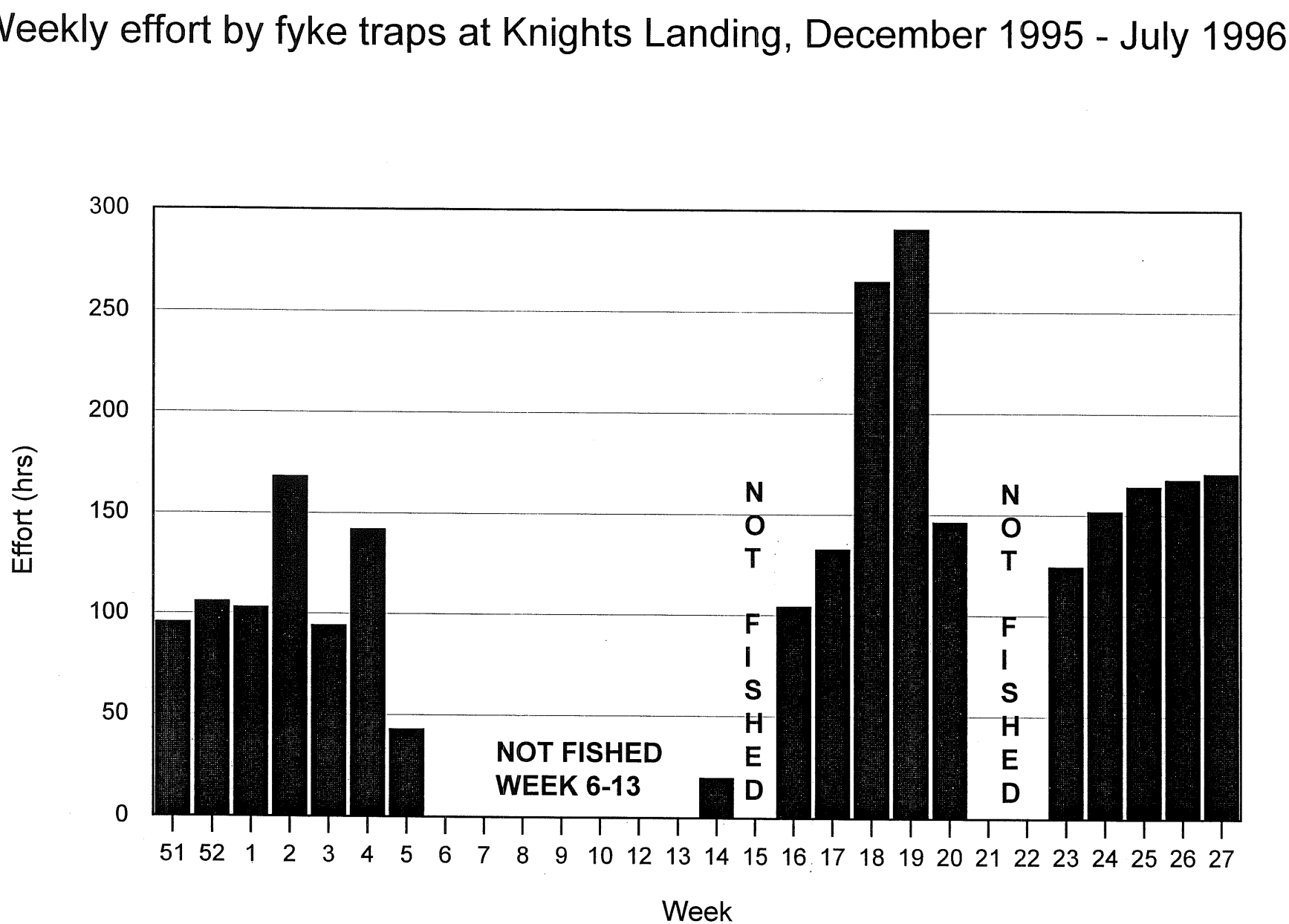


Figure 25. Weekly effort by fyke traps at Knights Landing, Sacramento River, December 1995 - July 1996.

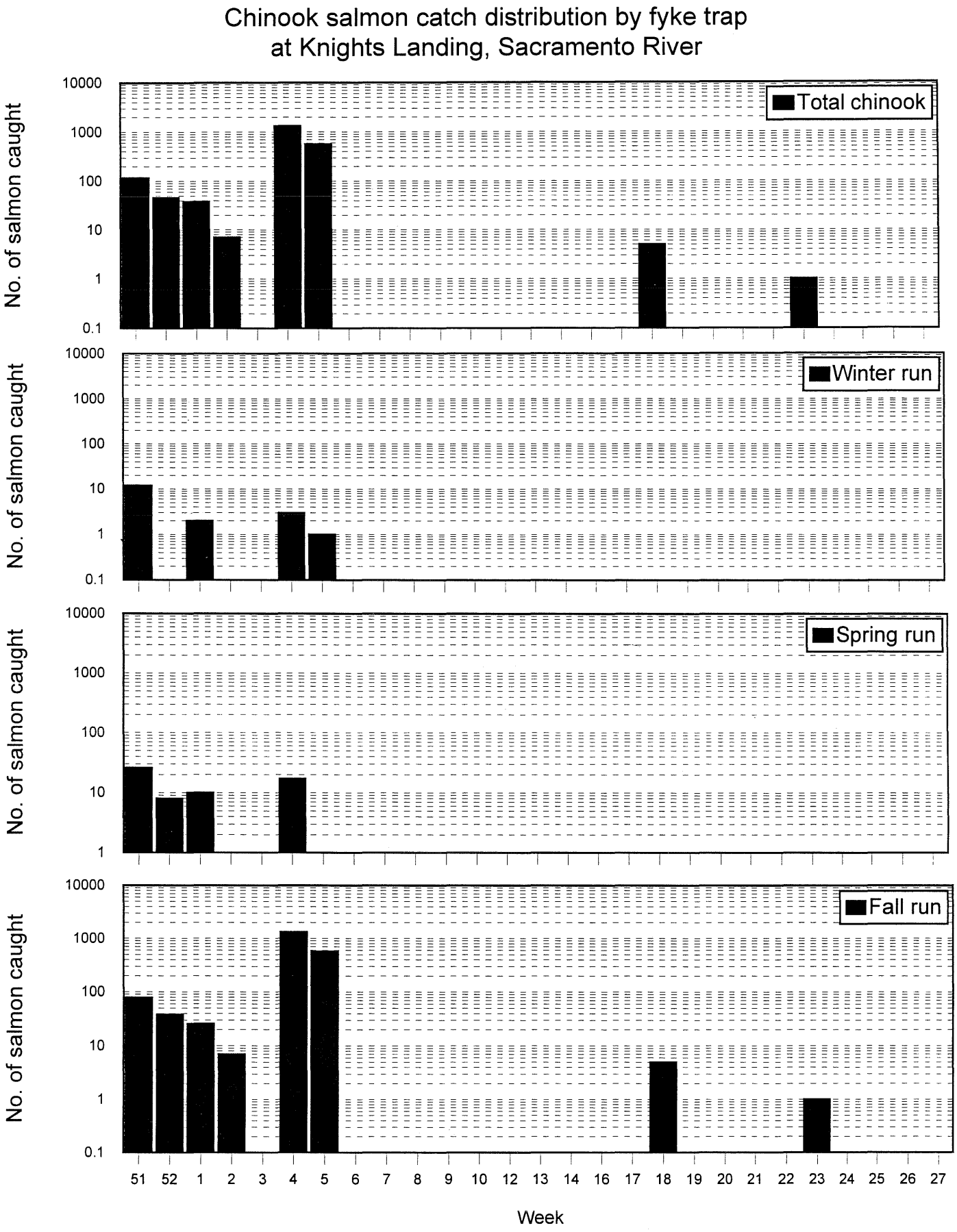


Figure 26. Catch distribution of chinook salmon caught by fyke traps at Knights Landing, Sacramento River, December 1995 - July 1996.

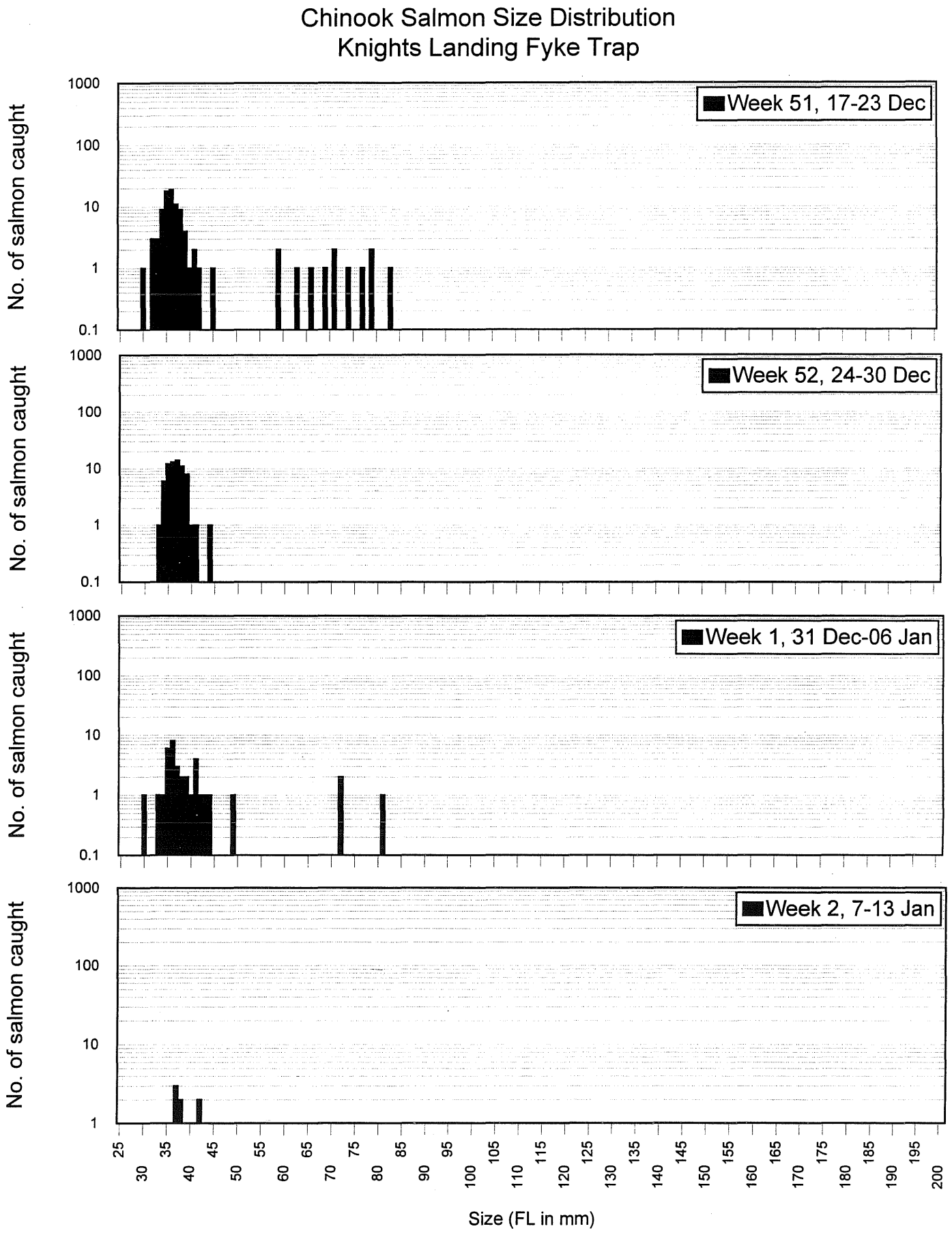


Figure 27. Size distribution of chinook salmon caught by fyke traps at Knights Landing, Sacramento River, 17 December 1995 - 13 January 1996.

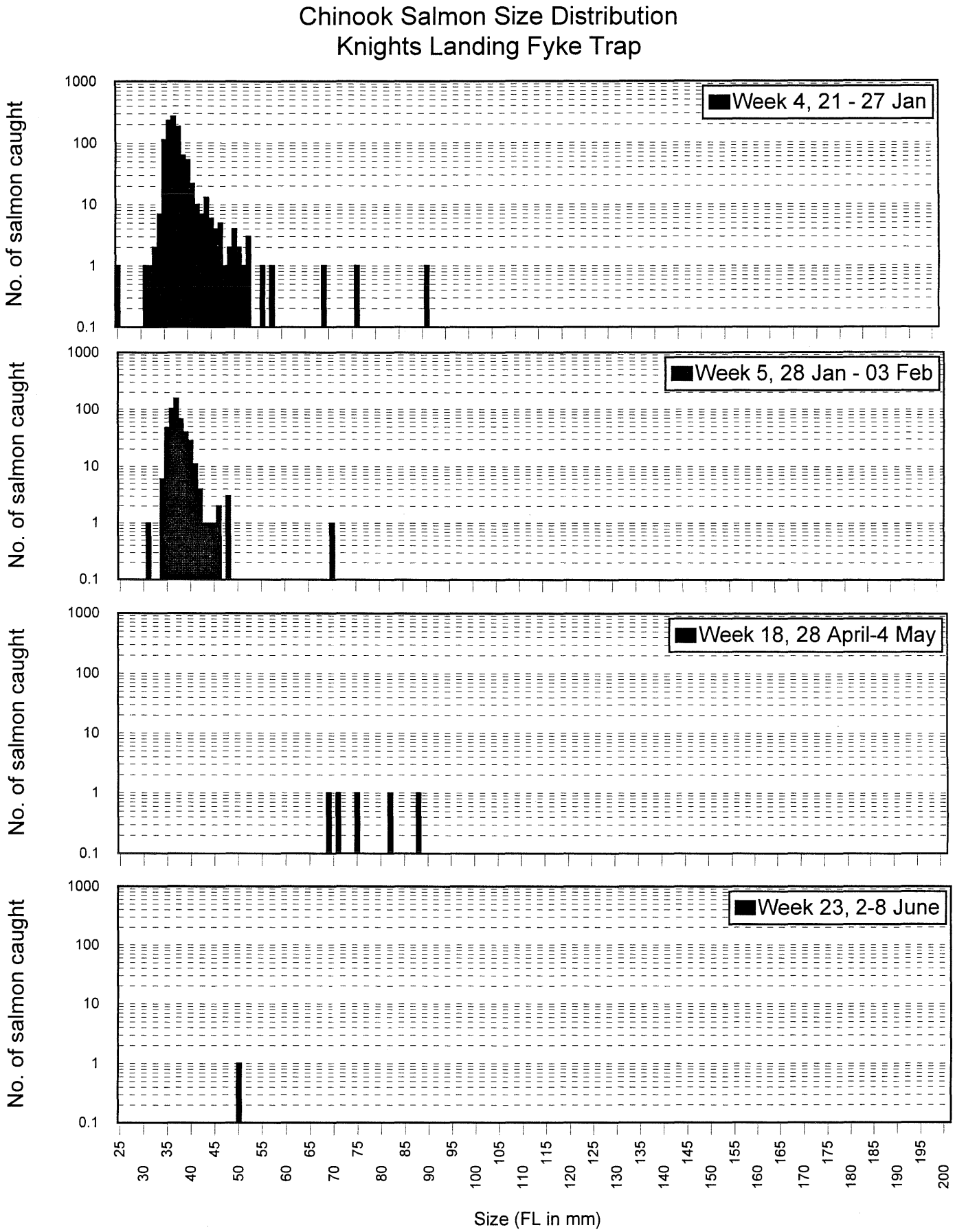


Figure 28. Size distribution of chinook salmon caught by fyke traps at Knights Landing, Sacramento River, 21 January - 8 June 1996.

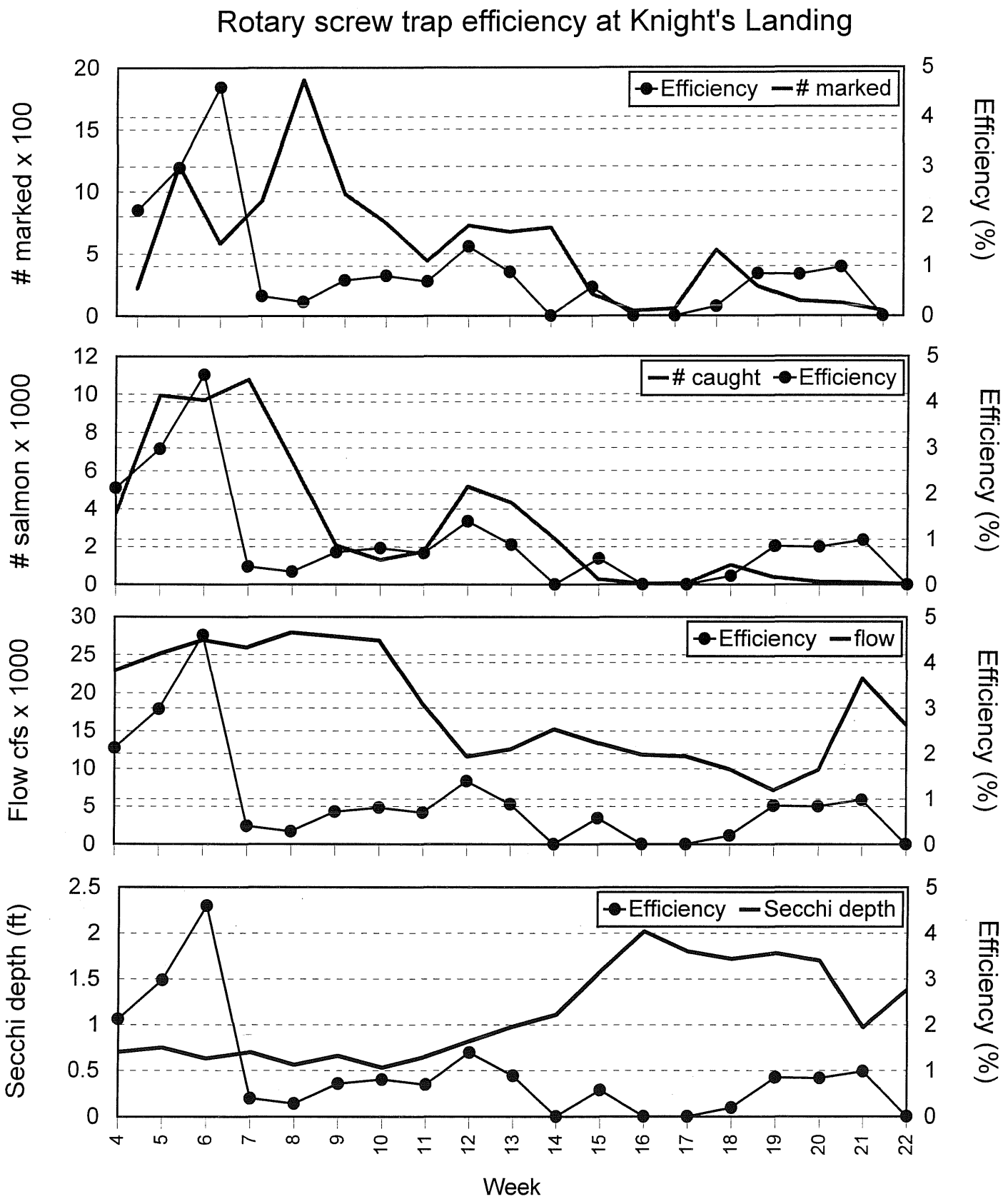


Figure 29. Trap efficiency compared with weekly mean flow, visibility, number of salmon caught and number of salmon marked during the Sacramento River emigration evaluation at Knight's Landing, November 1995 - July 1996.

Chinook salmon size distribution - rotary screw trap versus fyke trap at Knights Landing

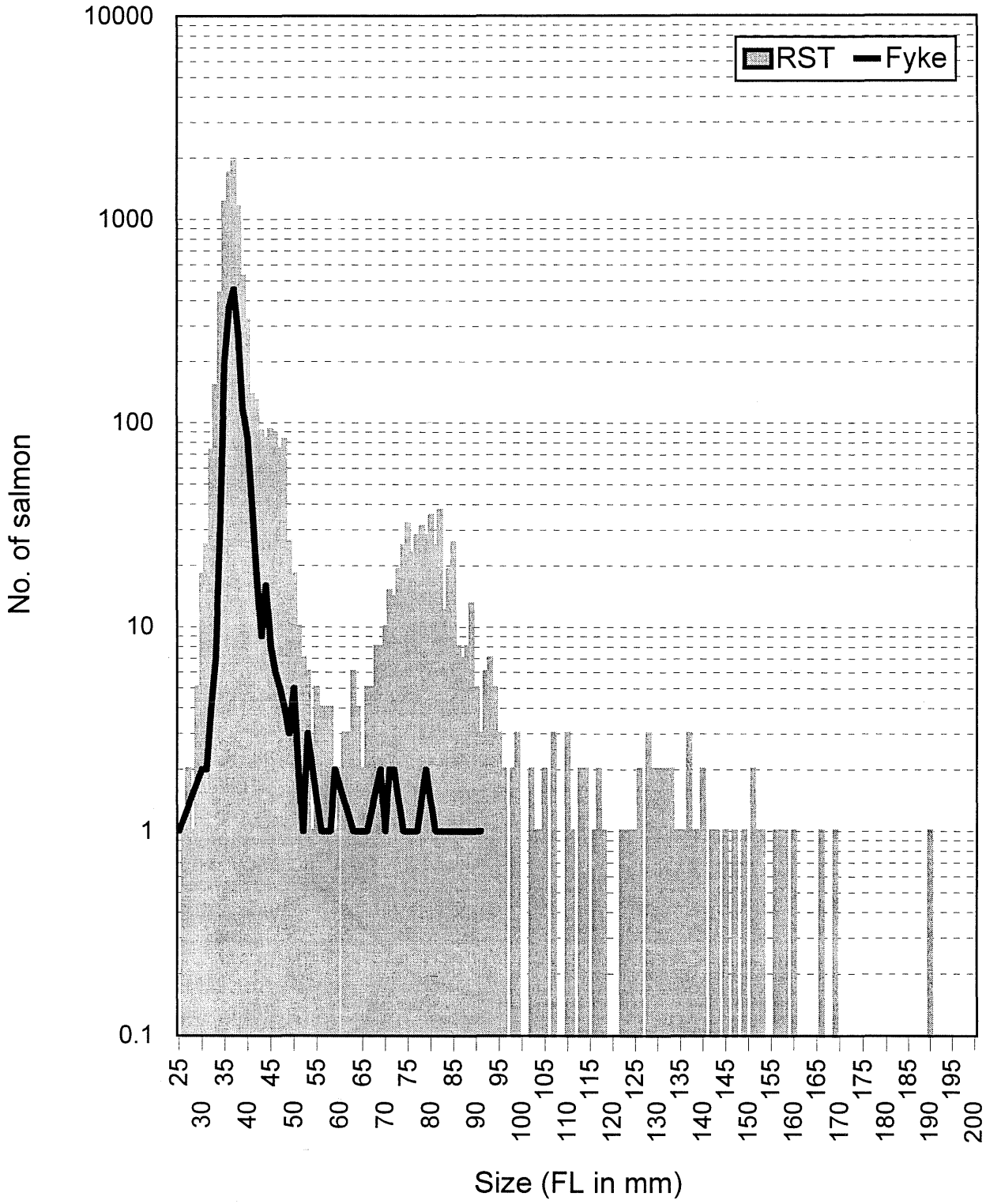


Figure 30. Comparison of size distributions for chinook salmon caught by rotary screw traps versus fyke traps in the Sacramento River at Knight's Landing, during concurrent sampling periods (17 December 1995 - 13 July 1996)

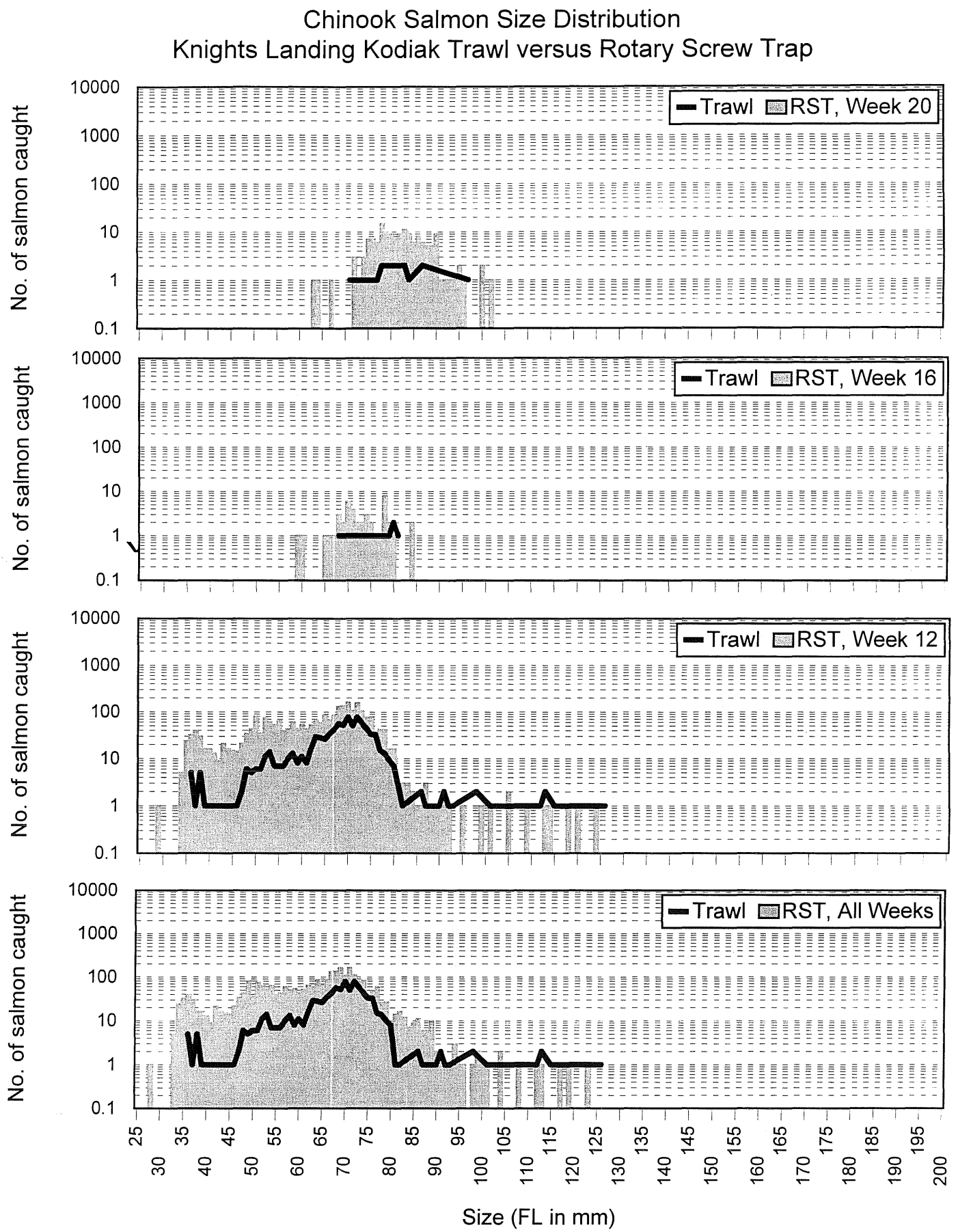


Figure 31. Size distribution of chinook salmon caught by Kodiak trawl versus rotary screw traps at Knights Landing, Sacramento River, 10 March - 06 April 1996.

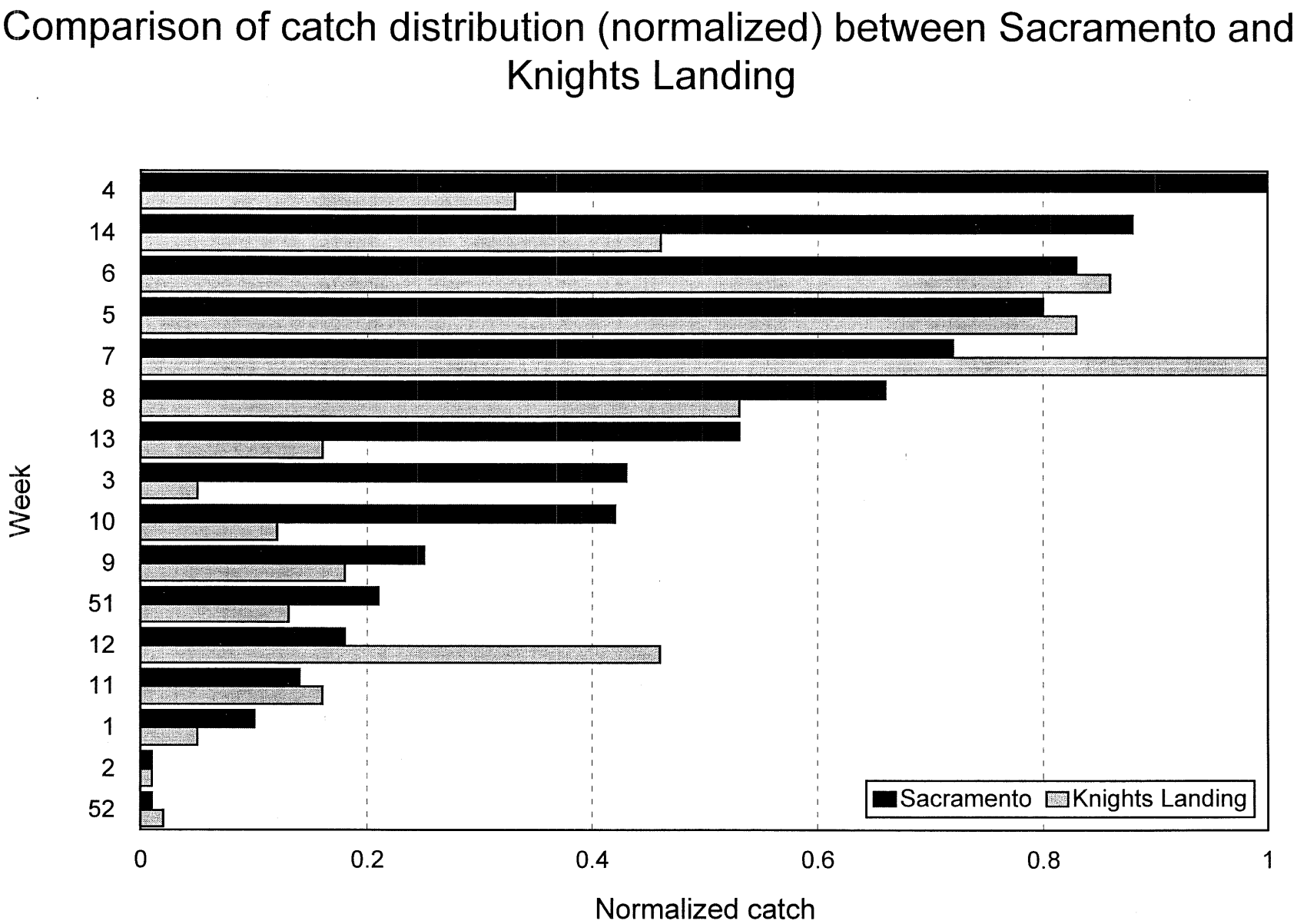


Figure 32. Comparison of normalized catch distributions at Sacramento (Kodiak trawl) and Knights Landing (rotary screw trap) for concurrently sampled weeks, December 1995 - March 1996.

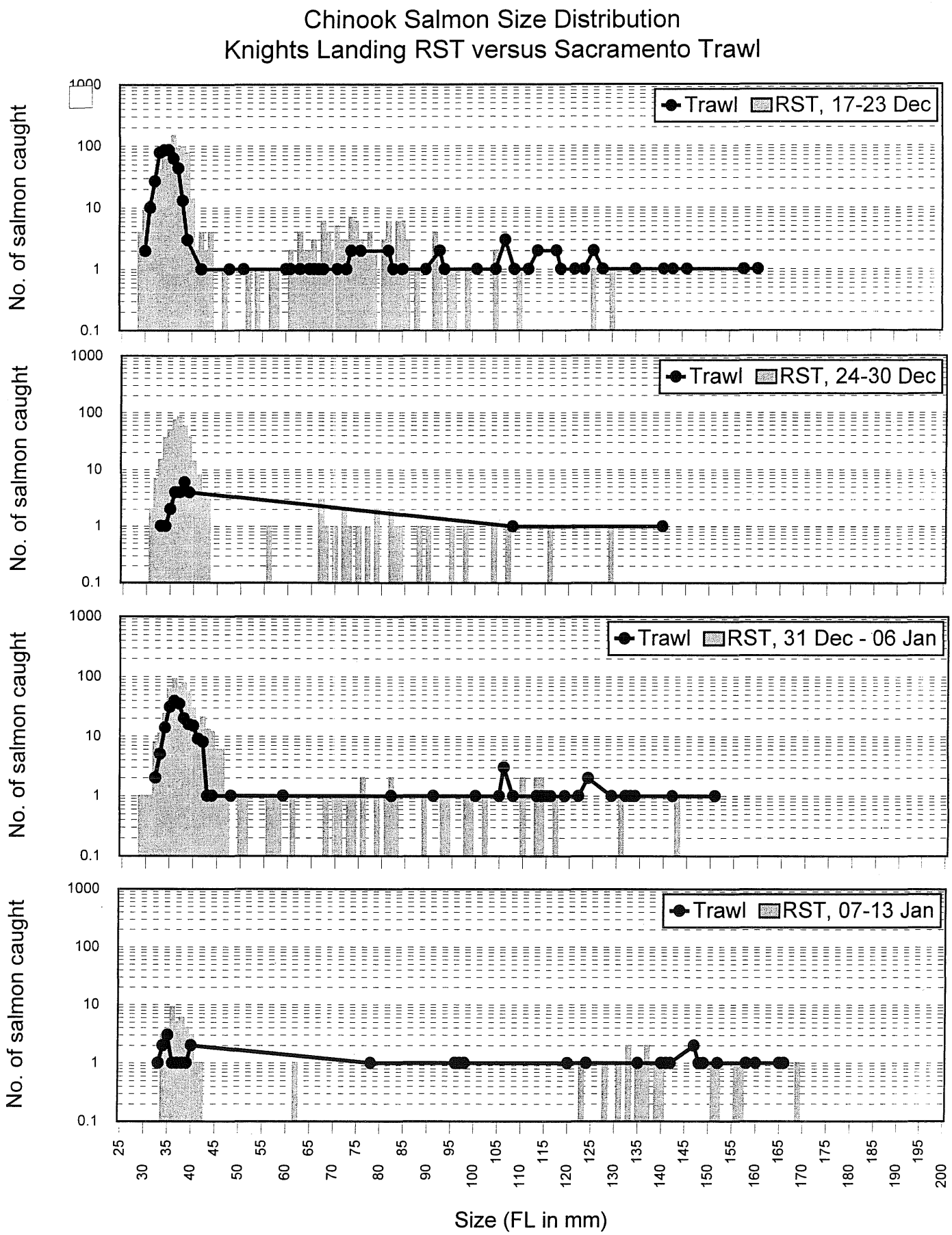


Figure 33. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing versus Kodiak trawl at Sacramento, 17 December 1995 - 13 January 1996.

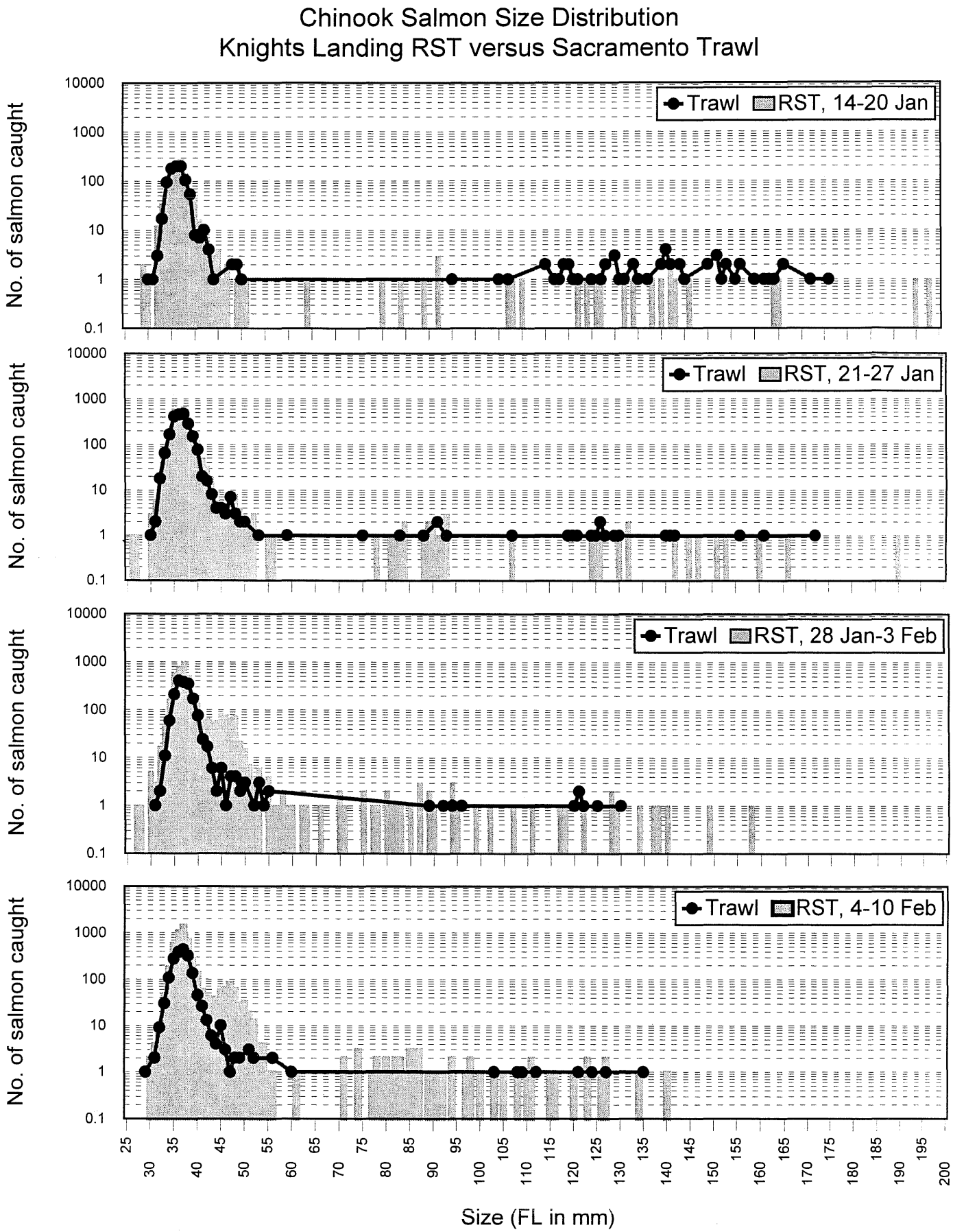


Figure 34. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing versus Kodiak trawl at Sacramento, 14 January - 10 February 1996.

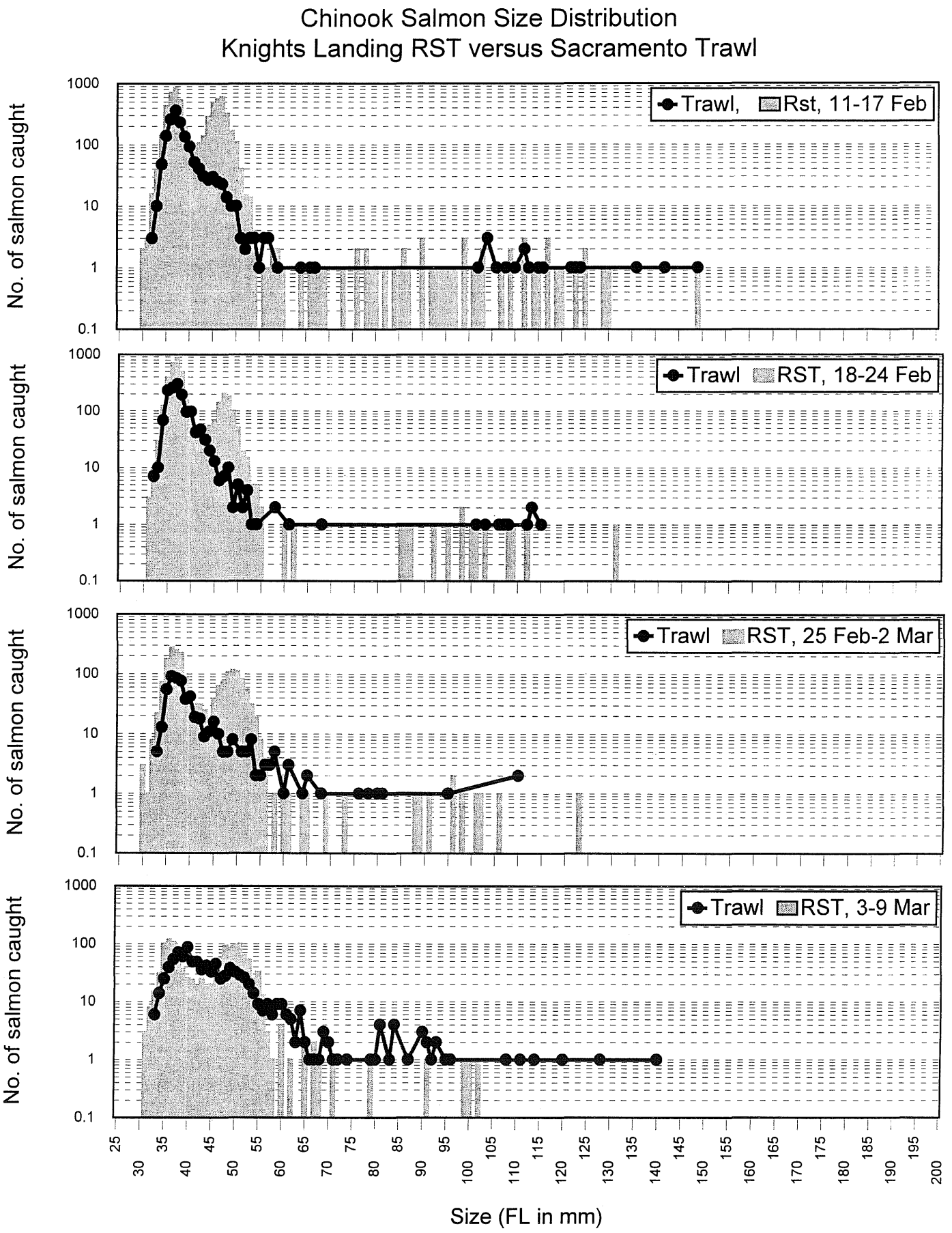


Figure 35. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing versus Kodiak trawl at Sacramento, 11 February - 09 March 1996.

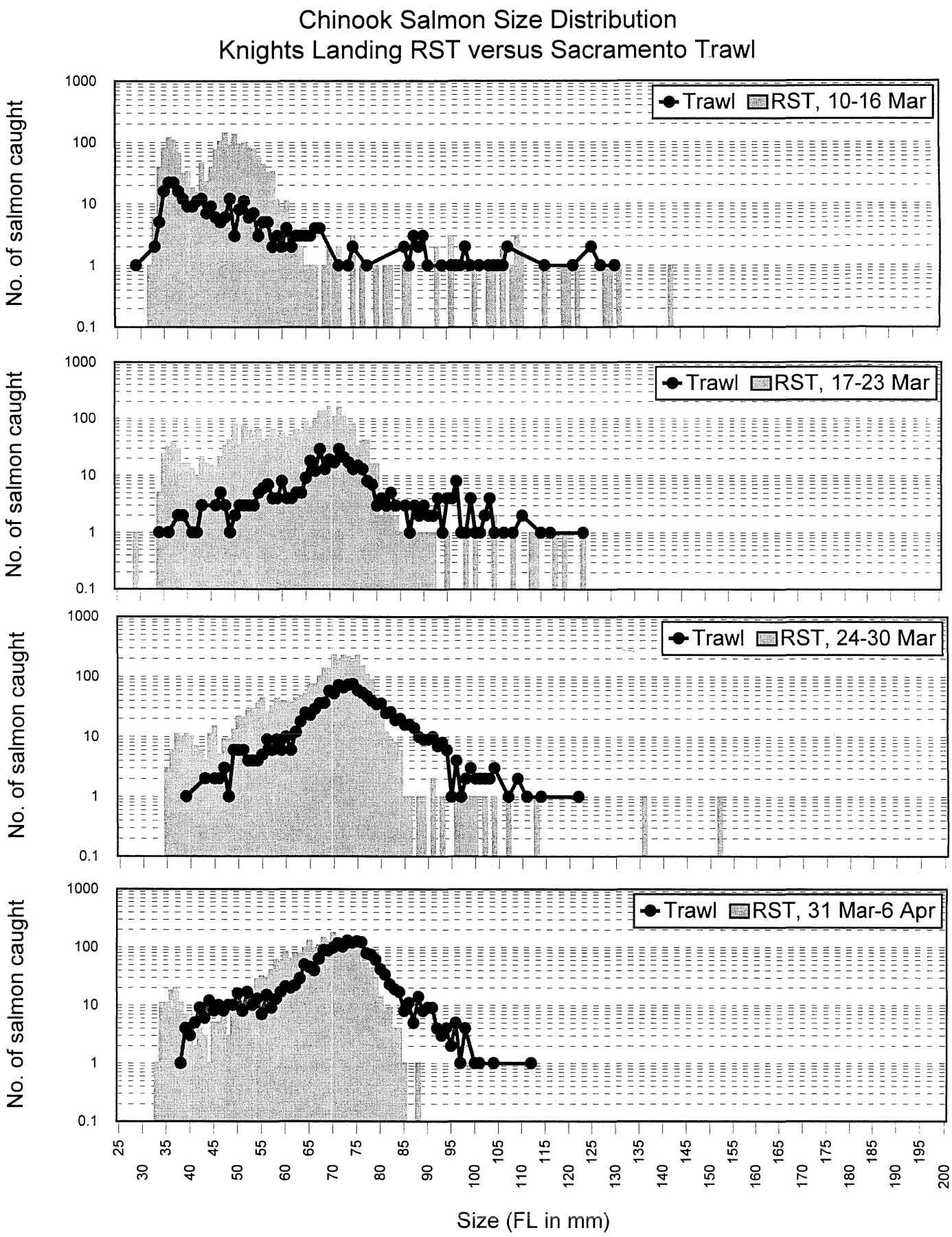
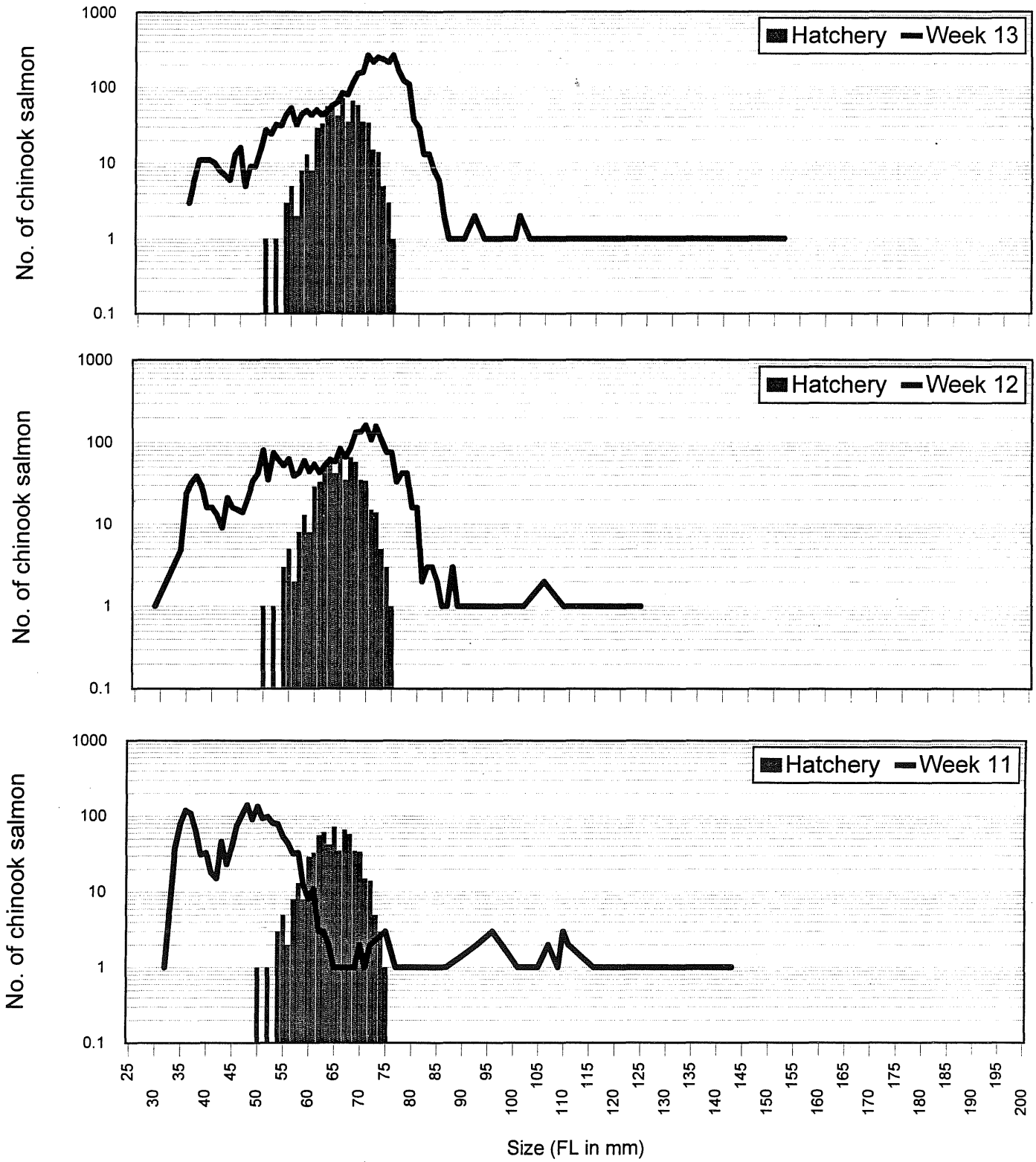


Figure 36. Size distribution of chinook salmon caught by rotary screw traps at Knights Landing versus Kodiak trawl at Sacramento, 10 March - 06 April 1996.

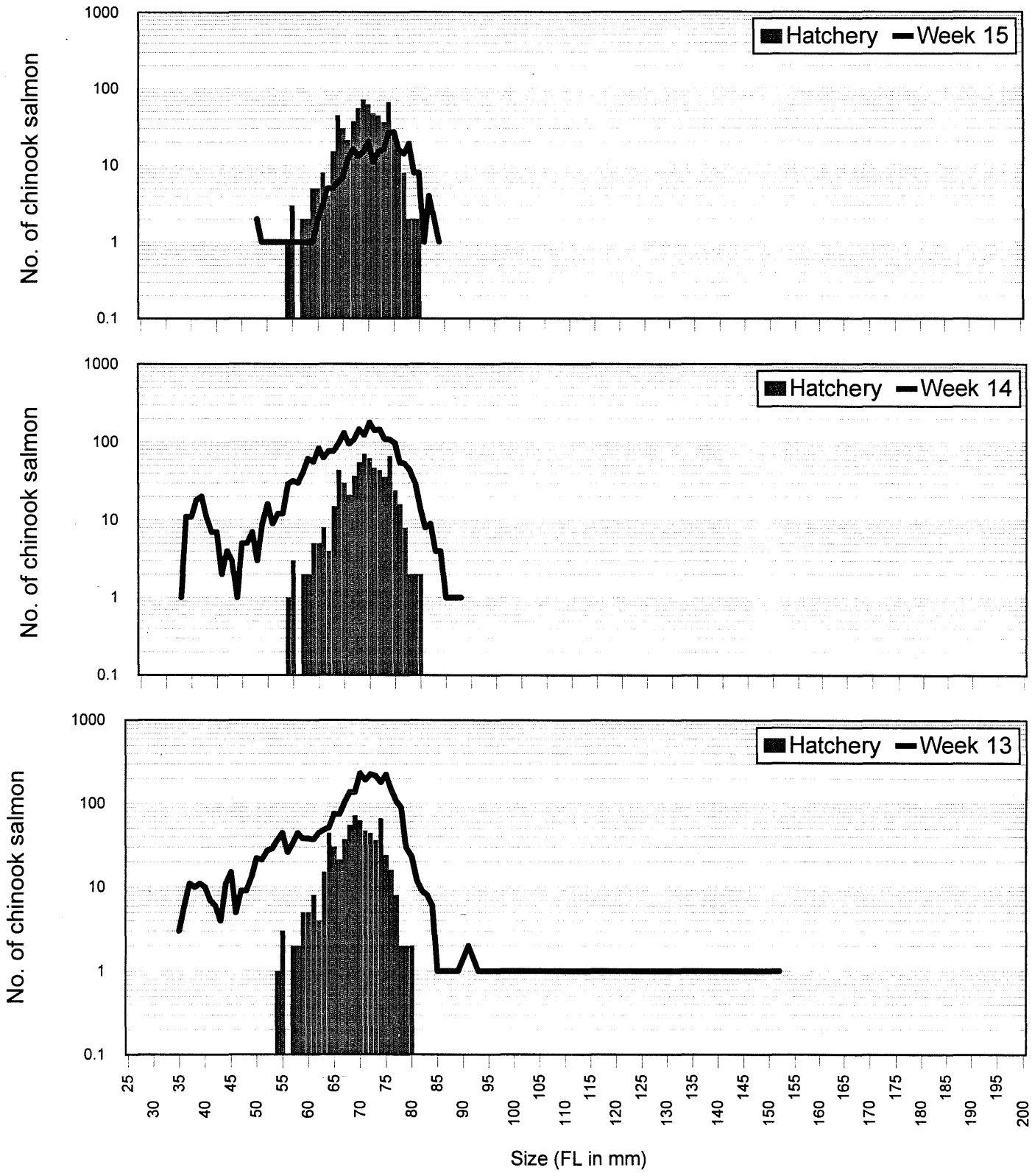
APPENDIX

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

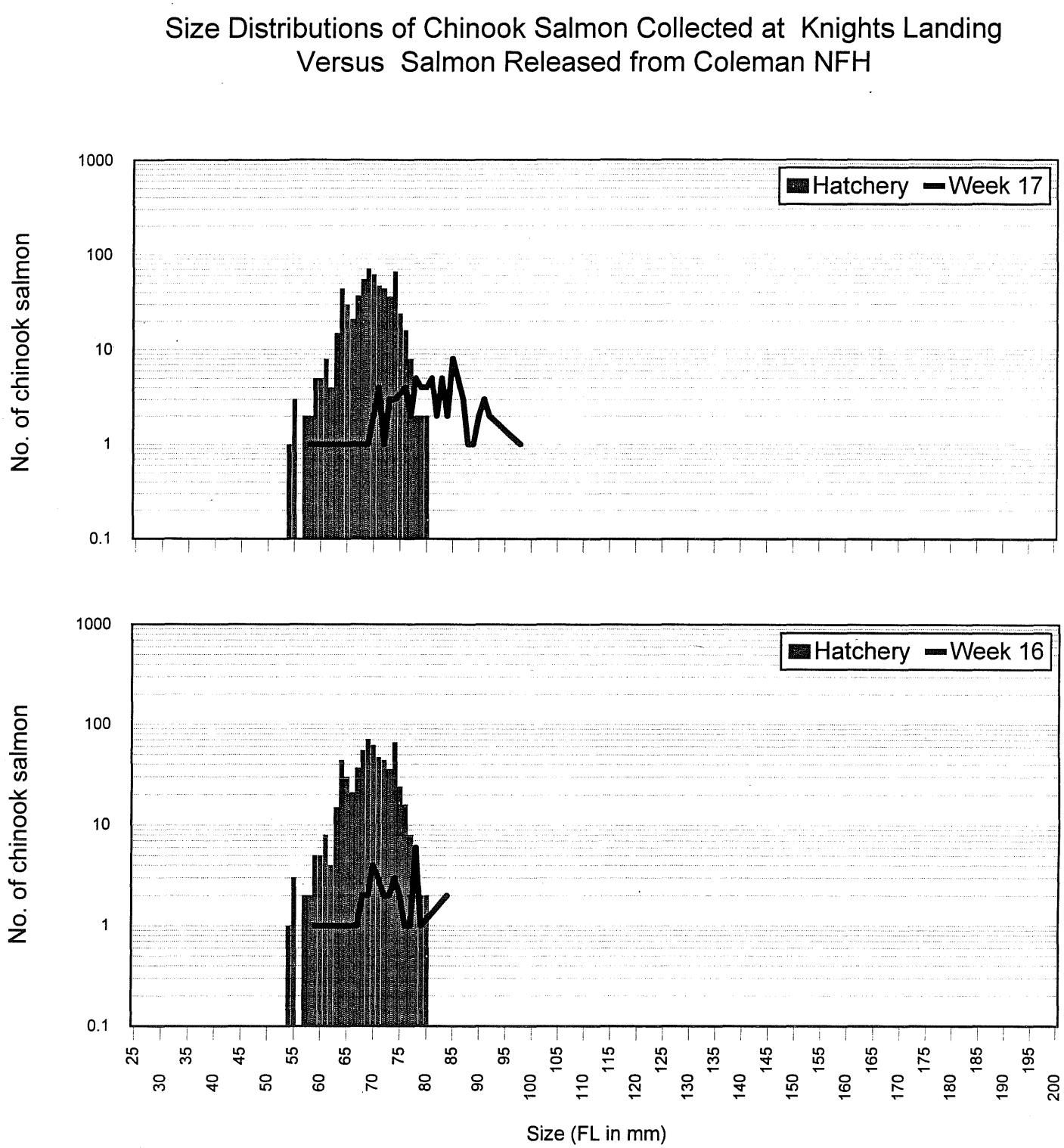


Appendix Figure 1. Size distribution of chinook salmon collected in the Sacramento River near Knights Landing compared with size distribution of Coleman NFH salmon released 13 March 1996.

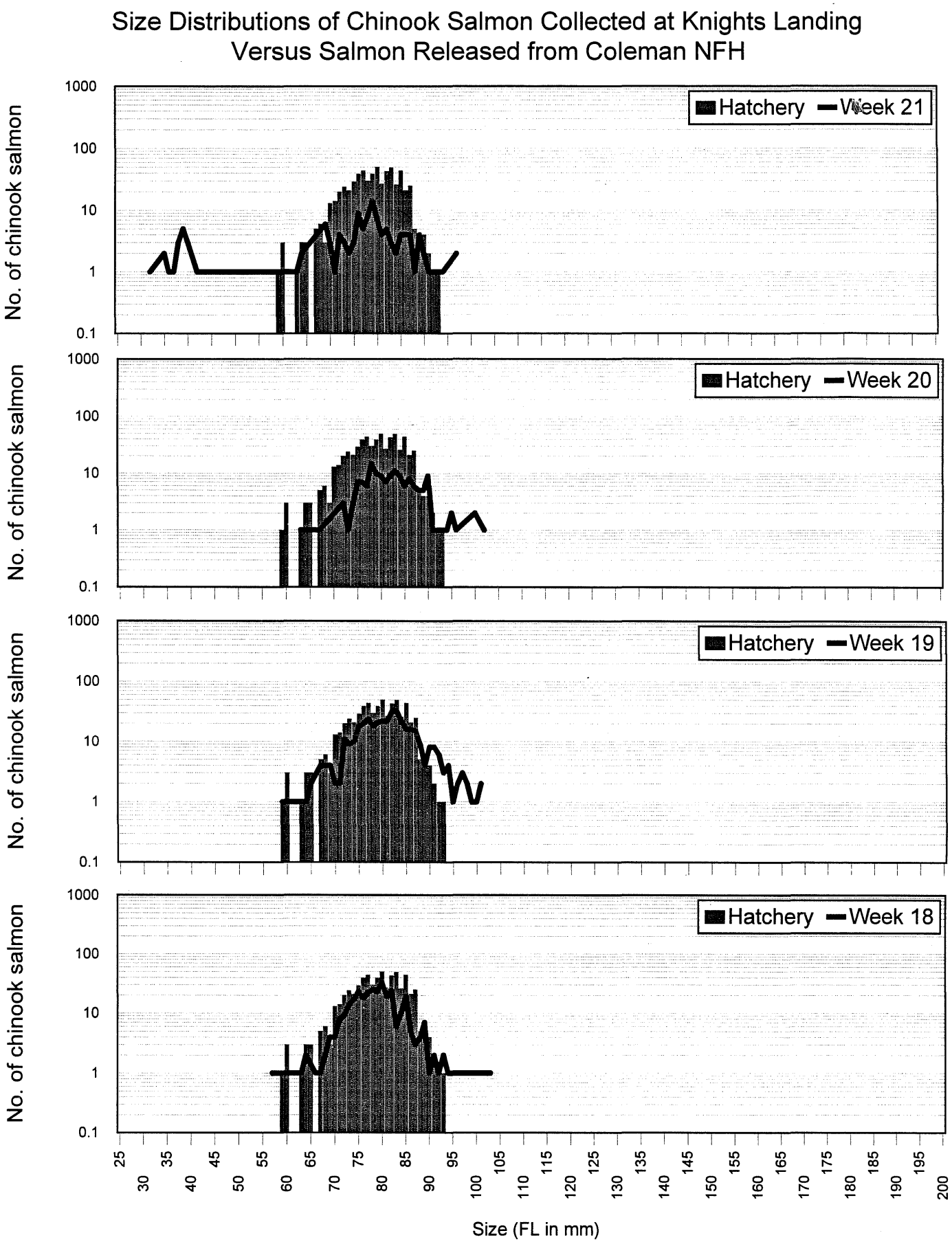
Size Distribution of Chinook Salmon Collected at Knights Landing Versus Samon Released from Coleman NFH



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 29 March 1996.



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 29 March 1996.



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 23 April 1996.