PASSAGE TIMING AND SIZE OF NATURALLY PRODUCED JUVENILE COHO SALMON EMIGRATING FROM THE KLAMATH RIVER

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INTRODUCTION

The effects of flow regulation and other environmental factors on the migratory behavior and smolt production of coho salmon (*Oncorhynchus kisutch*) in the Klamath River are not well understood. Following recent declines and subsequent listing of coho populations within the Southern Oregon Northern California (SONC) Evolutionary Significant Unit (ESU) as threatened under the Endangered Species Act (ESA) in 1997, increased efforts have been made to restore and monitor salmon populations in the Klamath Basin. Identifying the factors that influence the migratory behavior and size of juvenile coho salmon in the Klamath River is an important step in development of a sound recovery strategy.

During the freshwater phase of their life history, juvenile coho salmon require sufficient stream flows and cool temperatures to rear and survive prior to and during migration to the ocean. Water storage reservoirs like the Iron Gate Dam have altered the natural stream hydrograph and have reduced the volume and velocity of water in the Klamath River. The effects of reduced flow on salmonid populations in large river systems like the Klamath basin are complex and studies addressing this problem have produced mixed results. In an extensive review of the effects of water velocity on survival of downstream migrating juvenile salmonids in the Columbia River Basin, Cada et al. (1997) concluded that reductions in stream flows can result in delayed migration of salmonid smolts and decreased fish survival by increasing their exposure to predation and disease. On the other hand, Shapovalov and Taft (1954) found that reduced flows typically coincided with warmer stream temperatures and earlier emigration of juvenile coho. Reduced spring flows may also alter the osmoregulatory ability of downstream migrants entering the marine environment (Berggren and Filardo 1993). In a radiotelemetry study of juvenile coho salmon migration through the Klamath River, Stutzer et al. (2006) found that flow was positively correlated with migration rate, but this pattern was not consistent across all study reaches.

Stream temperature likely plays an influential role in regulating the migratory behavior of juvenile coho salmon in the Klamath River. The effect of increased temperature in triggering downstream migration has been well documented (Jonsson 1991; Wallace and Collins 1997). Downstream migration may also be delayed (Giannico and Healey 1998) or even stopped (Solomon 1978) when temperatures fall below a certain threshold. Stream temperature may also influence migratory behavior indirectly by altering fish growth and causing physiological changes related to smoltification.

The objectives of this analysis were to (1) describe general spatial and temporal patterns in migration timing and size of juvenile coho salmon emigrating from the Klamath River Basin during the period from 1998 through 2005, and (2) Identify potential effects of stream discharge and temperature on migratory behavior and fish size. It was intended that this analysis will provide a thorough summary of the current information available about the migratory characteristics of juvenile coho salmon in the Klamath River and will facilitate the development of a comprehensive life-cycle model capable of predicting coho production under differing flow regimes in the Klamath River downstream of Iron Gate Dam.

METHODS

Monitoring of juvenile coho salmon emigrants in the mainstem Klamath River and various tributaries including the Trinity River, Salmon River, Elk Creek, Seiad Creek, and Horse Creek was conducted by the Arcata office of the US Fish and Wildlife service during the spring of 1997 through 2005. Additional monitoring of juvenile salmonid emigrants on the Scott and Shasta rivers was conducted by the California Department of Fish and Game from 2000-2005. Fish were captured using rotary screw traps and frame traps located in various positions within the Klamath River basin (Figure 1).

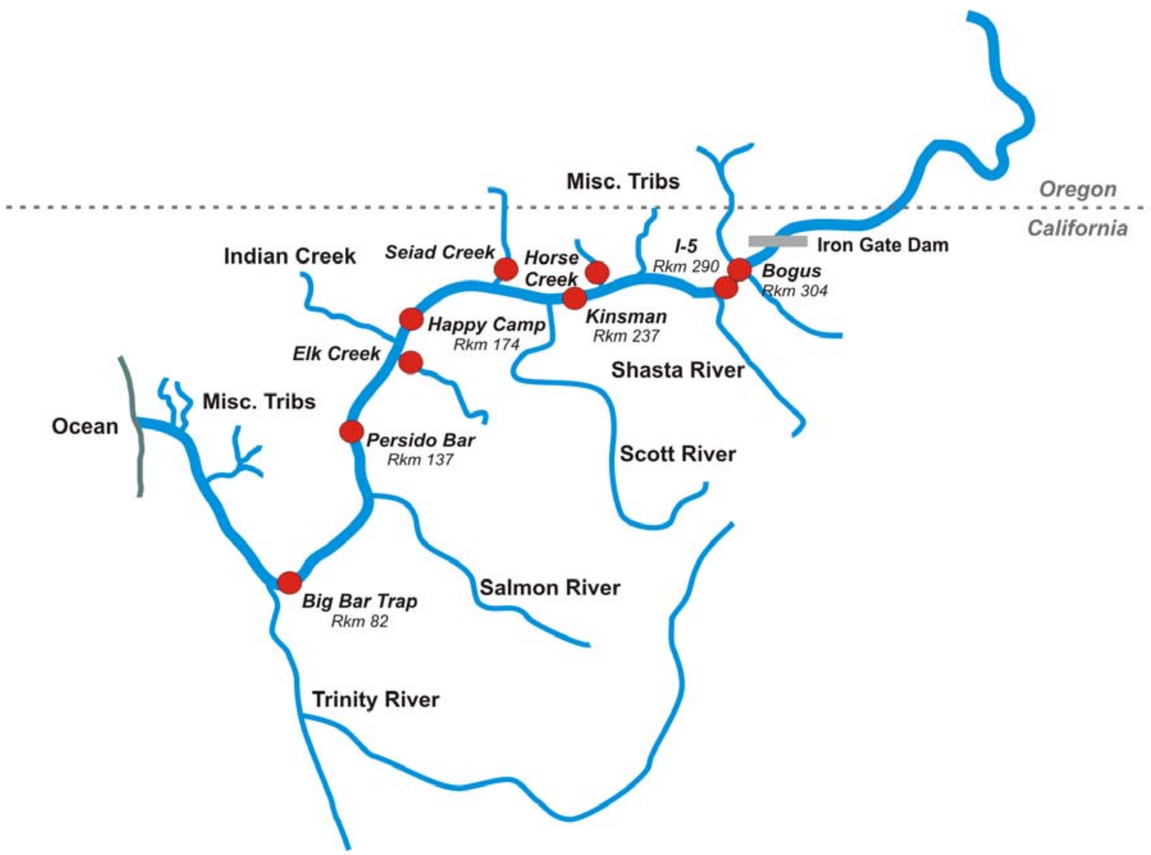


Figure 1. Map of the Klamath River and Trinity River study area indicating locations of juvenile salmonid trapping sites and distances from the river mouth in kilometers (Rkm).

Operational dates varied for each trap site, with the Klamath River Big Bar and Trinity River Willow Creek sites having the longest consecutive periods of operation (Table 1). Most traps were operated during the spring months (March-July) to correspond with typical peak migration timing of salmonid smolts, however, several of the traps including those located on the Klamath River at Big Bar, Trinity River at Willow Creek, and the Salmon River at Somes Bar were fished well into late fall (October-December). Traps were fished between 5 and 7 days per week throughout the trapping season except during rare periods when trapping was halted due to high flows or excessive debris accumulation. Traps were typically checked and cleaned 1-2 times per day and sometimes more frequently during peak migration times to reduce stress to the fish.

Daily catch data was organized by Julian week (JW; Table 2) for consistency and ease of comparison with previous reports by the Arcata Fish and Wildlife Office (AFWO). Daily flow data was obtained from the USGS National Water Information System Web Site (NWISWeb). Flow data from the nearest gauging station was used for each trapping location and was reported as weekly average flow (cfs). Temperature data was provided by the AFWO (Personal communication) and was reported as the weekly average maximum temperature (˚C). More specifically, we calculated the maximum daily temperature from the hourly temperature readings, and then averaged those values for each Julian week. Continuous temperature data was not available for all trap locations and years.

All captured juvenile coho salmon were examined for fin clips and were classified as either Age 0 or Age 1; the latter were considerably larger in size, silvery, and lacked distinct parr marks. A subsample of up to 30 fish was randomly selected from the daily catch and these individuals were anesthetized with tricaine methanesulfonate (MS-222), measured to the nearest mm fork length, and weighed by volumetric displacement or a digital balance. This analysis was limited to naturally produced coho salmon, and data from hatchery fish was not included.

We established modest criteria for each trap site and year to determine if the duration and timing of trap operation was sufficient to capture the majority of emigrating coho fry and smolts. At a given trap site and year, if the proportion of fish captured during the first seven trapping days exceeded 5 % of the total catch, then the start date for that trap was considered too late. Similarly, if the proportion of fish captured during the last 7 trapping days exceeded 5 % of the total catch, then the trapping duration was considered too short. Although we utilized data from some of the traps that failed to meet these criteria in this analysis, the conclusions concerning passage timing based on these data should be considered tentative.

We calculated an index of abundance for each Julian week by weighting the number of fish captured each week by the average weekly flow (cfs):

$$Index_i = Catch_i * Q_i.$$

Where: $Catch_i$ = Total catch on Julian Week i;

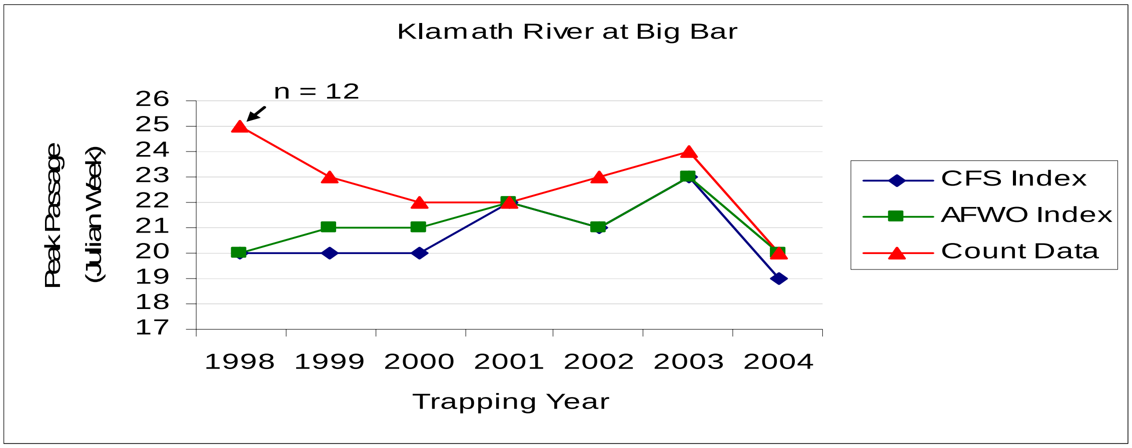
Q_i = Average stream discharge on Julian Week i.

This abundance index is similar to the method used by the AFWO in which the total daily catch is divided by the proportion of flow sampled (USFWS 2001). Because we did not have estimates of flow sampled at most of the trap sites, it was not possible to use the AFWO method.

In order to determine how the abundance index we calculated compared with the AFWO abundance index and to basic count data with respect to peak passage timing, we compared the three different estimates of peak passage week of age 0 fry between 1998 and 2004 at two of the trapping sites for which we had AFWO abundance index data (Figure 2). Peak passage timing estimated from abundance index data was generally earlier than that from raw count data. This trend is not surprising given that the highest peaks in flow tended to occur early in the year. While the estimated peak passage date was generally similar (within 1-2 weeks) between the two abundance index methods, the estimates of peak passage timing using the raw count data produced large differences in some years compared with the abundance index data. In 1998, the peak passage week estimated from count data was 5 and 11 weeks later than that estimated from the abundance index data at Klamath River at Big Bar and Trinity River at Willow Creek trap sites respectively. This large discrepancy was likely due to the small number of coho fry captured in 1998 and considerably higher mean flows in 1998 relative to 1999-2004 (n = 12 at Big Bar, n = 21 at Willow Creek).

The abundance index relies on the assumption that trap efficiency is inversely proportional to flow. While the relationship between trap efficiency and flow is probably not linear and may by complicated by other factors such as fish size and turbidity, the general negative relationship between trap efficiency and flow is commonly observed in downstream migrant studies (Demko et al. 2000) and the expanded abundance indices likely provide a more realistic estimate of migration timing than simple count data. It should be noted that these abundance indices were not meant to reflect true population estimates, and were used only to examine patterns in migration timing.

True abundance estimates of emigrating juvenile coho salmon in the Scott and Shasta Rivers were conducted by the California Department of Fish and Game using mark-recapture techniques in 2003-2005. However, very few marked fish were recaptured in 2003 and 2004, resulting in unreliable abundance estimates in those years. Therefore, analyses of fish passage timing in 2003 and 2004 utilized flow-based abundance indices instead of the mark-recapture abundance estimates. However, analysis of passage timing in the Scott and Shasta Rivers in 2005 was based on true abundance estimates because mark-recapture estimates were assumed to be more accurate than the flow expansion indices.



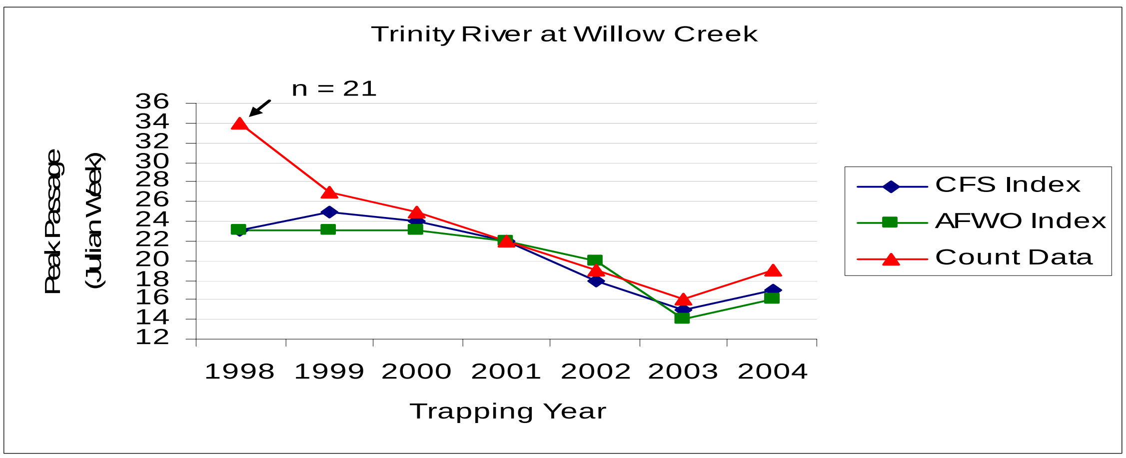


Figure 2. Comparison of peak passage timing of age 0 coho salmon passing the Klamath River at Big Bar and Trinity River at Willow Creek trap sites estimated from raw count data, abundance index data based on proportion of flow sampled (AFWO index), and abundance index data based on direct proportionality to flow (CFS Index).

Table 1. Description of trapping locations and operational dates in the Klamath and Trinity River basins, 1998 – 2005.

River	Trap location	Trap ID	Rkm	Trapping method	Operational Dates							
					1998	1999	2000	2001	2002	2003	2004	2005
Trinity R.	Willow Cr.	TRWC1	34	Frame	-	-	-	-	-	05/15-07/12	06/30-07/10	-
Trinity R.	Willow Cr.	TRWC1	34	RST	4/16-11/20	3/18-9/30	5/16-10/6	4/10-11/6	03/19-11/21	04/15-11/21	03/24-10/15	03/06-09/02
Trinity R.	Willow Cr.	TRWCY	34	RST	-	-	-	-	03/14-11/07	03/05-11/19	03/19-10/19	06/05-06/06
Klamath R.	Big Bar	KRBB1	82	RST	4/30-8/15	4/11-8/10	4/6-7/19	4/10-7/25	03/05-08/22	04/24-12/03	03/24-06/23	-
Klamath R.	Big Bar	KRBB2	82	RST	-	-	-	-	-	09/24-11/24	04/08-07/30	-
Klamath R.	Persido Bar	KRPB1	132	Frame	-	-	-	-	-	-	04/07-06/23	-
Klamath R.	Persido Bar	KRPB1	132	RST	-	-	-	-	-	-	03/03-07/19	-
Klamath R.	Happy Camp	KRHC1	174	Frame	-	-	-	-	-	-	03/30-07/09	-
Klamath R.	Happy Camp	KRHC1	174	RST	-	-	-	-	-	-	03/05-07/14	-
Klamath R.	Kinsman Cr.	KRKIL	235	Frame	-	-	-	-	-	-	-	03/10-06/29
Klamath R.	Kinsman Cr.	KRKIR	235	Frame	-	-	-	-	03/20-05/23	03/05-06/12	03/10-06/28	03/09-06/03
Klamath R.	Kinsman Cr.	KRKIL	235	RST	-	-	-	-	-	-	-	03/31-07/07
Klamath R.	Kinsman Cr.	KRKIR	235	RST	-	-	-	-	03/14-05/29	03/05-06/26	03/10-07/03	-
Klamath R.	I-5	KRI5L	290	Frame	-	-	-	-	03/27-03/27	-	-	03/16-05/04
Klamath R.	I-5	KRI5R	290	Frame	-	-	-	-	03/13-05/08	03/06-05/30	03/11-05/06	03/11-05/04
Klamath R.	I-5	KRI5R	290	RST	-	-	-	-	03/14-05/08	04/02-05/30	03/10-04/21	-
Klamath R.	Bogus Cr.	KRBOL	304	Frame	-	-	-	-	-	-	-	03/09-05/04
Klamath R.	Bogus Cr.	KRBOR	304	Frame	-	-	-	-	03/28-05/08	03/11-05/29	03/10-05/13	03/02-05/04
Klamath R.	Bogus Cr.	KRBOR	304	RST	-	-	-	-	03/26-05/08	-	03/10-05/05	-
Salmon R.	Somes Bar	SASB1	1.5	RST	-	-	-	-	04/15-11/04	02/27-11/19	04/06-10/17	-
Elk Cr.	Elk Cr.	KREL1	0.2	RST	-	-	-	-	-	-	03/31-06/03	-
Elk Cr.	Elk Cr.	KREL1	1.6	Frame	-	-	-	-	-	-	05/29-07/25	-
Seiad Cr.	Seiad Valley	SESV1	0.2	Frame	-	-	-	-	-	-	03/03-07/03	-
Scott R.	Scott R.	SCOTT	8.1	RST	-	-	03/19-07/18	02/26-06/07	02/26-07/13	02/18-07/17	02/12-07/08	02/12-07/15
Horse Cr.	Horse Cr.	HRHR1	2.6	Frame	-	-	-	-	-	-	02/26-07/03	-
Shasta R.	Shasta R.	SHASTA	0.4	RST	-	-	02/26-07/16	01/11-07/07	02/25-07/06	02/12-07/22	02/12-07/15	02/12-07/15

Note 1. Although smolt trapping was conducted on the Shasta River from 2000 through 2005, we were only able to acquire data from the 2005 trapping season.

Table 2. Julian weeks and corresponding start dates for standard Gregorian calendar weeks.

Julian week	Gregorian week beginning	Julian week	Gregorian week beginning	Julian week	Gregorian week beginning
1	1/1	19	5/7	37	9/10
2	1/8	20	5/14	38	9/17
3	1/15	21	5/21	39	9/24
4	1/22	22	5/28	40	10/1
5	1/29	23	6/4	41	10/8
6	2/5	24	6/11	42	10/15
7	2/12	25	6/18	43	10/22
8	2/19	26	6/25	44	10/29
9	2/26	27	7/2	45	11/5
10	3/5	28	7/9	46	11/12
11	3/12	29	7/16	47	11/19
12	3/19	30	7/23	48	11/26
13	3/26	31	7/30	49	12/3
14	4/2	32	8/6	50	12/10
15	4/9	33	8/13	51	12/17
16	4/16	34	8/20	52	12/24
17	4/23	35	8/27		
18	4/30	36	9/3		

RESULTS AND DISCUSSION

The total number of coho salmon fry and smolts captured during each trapping season and at each trap site is given in Tables 3 and 4. These data indicate a large amount of interannual variability in total catch of downstream migrants. Extremely low numbers of fish captured in some years, particularly between 1998 and 2001, limited our ability to make clear inferences about patterns in passage timing and size of emigrating juvenile coho. At some locations, less than 5 coho smolts were captured during an entire trapping season. In addition, a large proportion of the traps were not in operation during the entire period of downstream migration, resulting in reduced precision in our estimates of peak passage timing.

Spatial Variation in Passage Timing

The variation in peak passage timing of coho smolts and fry at different trapping locations within the mainstem Klamath River generally followed a predictable pattern with respect to the longitudinal distance from the river mouth. As would be expected, smolt and fry passage generally peaked much earlier at locations furthest upstream, and peaked later as the fish proceeded downstream (Figure 3 & 4). The time gap between median passage dates at different locations varied considerably between years. In addition, the amount of time required for approximately 75 % of the emigrant population to pass by each trap (i.e. denoted by gray bars in Figure 3) varied widely between trap sites and years. This variation was reflective of potential differences in migration rates and rearing behavior of coho smolts in the mainstem. Long delays in passage of coho fry and smolts may indicate that substantial rearing was occurring upstream of a given trapping location. A radio telemetry study of the migratory behavior of juvenile coho salmon in the Klamath River confirmed that coho smolts utilize the mainstem Klamath River for rearing in spring and early summer, prior to emigration to the estuary (Stutzer et al. 2006). One anomalous result occurred at the Happy Camp trap location (KRHC1) in 2004, where peak passage occurred several weeks earlier than two upstream trap locations. This seemingly spurious result probably resulted from small sample size (n = 17).

Peak passage timing of coho smolts and fry at each trap site within the mainstem Klamath River generally occurred within 0-3 weeks of one another, and no consistent patterns were observed between the two life stages. Previous studies have shown that coho smolts tend to emigrate before fry (Irvine and Ward 1989), a pattern likely reflective of the need for fry to obtain sufficient size to maximize their survival probability prior to downstream dispersal. Small sample sizes for coho smolts at mainstem Klamath trapping locations likely precluded our ability to detect such a pattern even if it did exist. In addition, the mixing of numerous subpopulations of smolts and fry from different tributaries within the Klamath watershed might also obscure any patterns in passage timing related to the size or age of downstream migrants.

In contrast to the mainstem trapping locations, peak migration of coho smolts from Klamath River tributaries in 2004 was consistently earlier than that of coho fry by a margin of approximately 5-8 weeks (Figure 5). The majority of coho smolts emigrated from Klamath tributaries between Julian weeks 10 and 17 (March 5 - April 23) while the majority of coho fry emigrated between Julian weeks 14 and 25 (April 2 – June 18). No convincing relationships were apparent between passage timing and the location or size of tributary streams. Comparisons among tributaries were restricted to data from 2004 because of limited data from other years.

Table 3. Total number of wild age-0 coho captured at each trap site by year.

River	Trap ID	Rkm	1998	1999	2000	2001	2002	2003	2004	2005
Trinity R.	TRWC1	34	21	212	30	150	451	114[ab]	46[ab]	661[b]
Trinity R.	TRWCY	34	-	-	-	-	934	590[a]	94[ab]	-
Klamath R.	KRBB1	82	12[a]	47	44	14	269	143	103	-
Klamath R.	KRBB2	82	-	-	-	-	-	-	104	-
Klamath R.	KRPB1	132	-	-	-	-	-	-	64	-
Klamath R.	KRHC1	174	-	-	-	-	-	-	43	-
Klamath R.	KRKIL	235	-	-	-	-	-	-	-	812[a]
Klamath R.	KRKIR	235	-	-	-	-	2,376	338	316	474[ab]
Klamath R.	KRI5L	290	-	-	-	-	-	-	-	86[a]
Klamath R.	KRI5R	290	-	-	-	-	760[b]	639	349	154[b]
Klamath R.	KRBOL	304	-	-	-	-	-	-	-	1,187[b]
Klamath R.	KRBOR	304	-	-	-	-	1,405[ab]	184	1,288[b]	1,765[b]
Salmon R.	SASB1	1.5	-	-	-	-	44[a]	38	30	-
Elk Cr.	KREL	0.2	-	-	-	-	-	-	163	-
Seiad Cr.	SESV1	0.2	-	-	-	-	-	-	416[b]	-
Scott R.	SCOTT	8.1	-	-	38	164	1,900	228	58	13,729
Horse Cr.	HRHR1	2.6	-	-	-	-	-	-	836	-
Shasta R.	SHASTA	0.4	-	-	-	-	-	-	-	3,167

[a]Denotes years and locations where > 5% of the total catch was captured during the first 7 trapping days.

[b]Denotes years and locations where > 5% of the total catch was captured during the last 7 trapping days.

Table 4. Total number of wild age-1 coho captured at each trap site by year.

River	Trap ID	Rkm	1998	1999	2000	2001	2002	2003	2004	2005
Trinity R.	TRWC1	34	32[a]	77	48[a]	54[a]	160	55	46[a]	33
Trinity R.	TRWCY	34	-	-	-	-	414	24[a]	19[a]	-
Klamath R.	KRBB1	82	1	3	9	9[a]	26	8	6	-
Klamath R.	KRBB2	82	-	-	-	-	-	-	10	-
Klamath R.	KRPB1	132	-	-	-	-	-	-	3	-
Klamath R.	KRHC1	174	-	-	-	-	-	-	17[a]	-
Klamath R.	KRKIL	235	-	-	-	-	-	-	-	17
Klamath R.	KRKIR	235	-	-	-	-	8[a]	64	12	18
Klamath R.	KRI5L	290	-	-	-	-	-	-	-	4
Klamath R.	KRI5R	290	-	-	-	-	15[b]	2	4	0
Klamath R.	KRBOL	304	-	-	-	-	-	-	-	4
Klamath R.	KRBOR	304	-	-	-	-	1	6	35	2
Salmon R.	SASB1	1.5	-	-	-	-	0	2	0	-
Elk Cr.	KREL	0.2	-	-	-	-	-	-	2	-
Seiad Cr.	SESV1	0.2	-	-	-	-	-	-	65	-
Scott R.	SCOTT	8.1	-	-	832	19	11	1,473	93	248
Horse Cr.	HRHR1	2.6	-	-	-	-	-	-	88	-
Shasta R.	SHASTA	0.4	-	-	-	-	-	-	-	409

[a]Denotes years and locations where > 5% of the total catch was captured during the first 7 trapping days.

[b]Denotes years and locations where > 5% of the total catch was captured during the last 7 trapping.

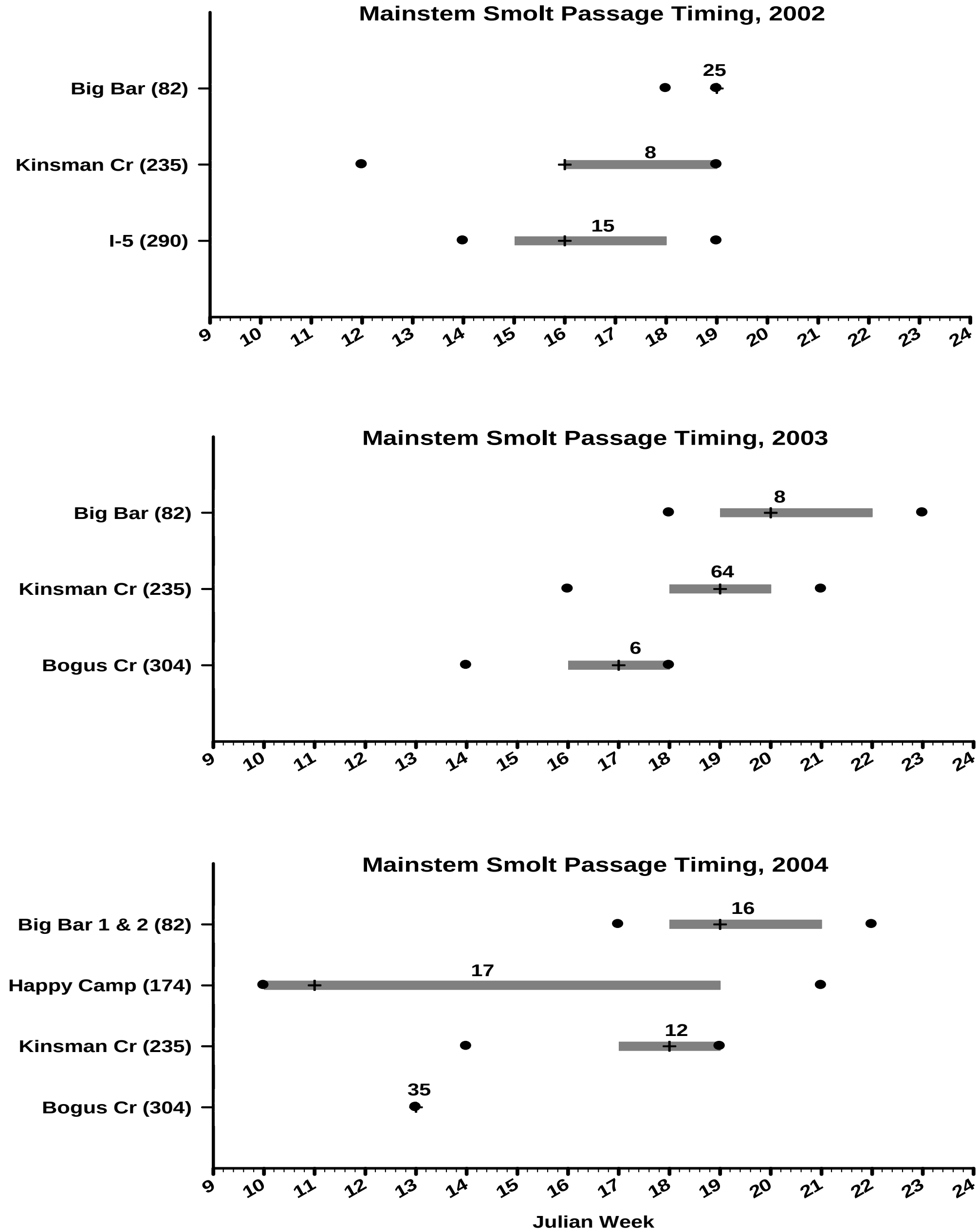


Figure 3. Passage timing of coho salmon smolts at different trapping locations in the mainstem Klamath River based on expanded abundance indices. Numbers in parentheses represent distance from the river mouth to each trapping location (km). Grey bars indicate the distribution of data within the 25th and 75th percentiles, black dots denote 10th and 90th percentiles, and plus symbols denote the median. Numbers above each bar represent the total number of fish captured during the trapping season. Data from 2005 was not shown due to low numbers of captured smolts.

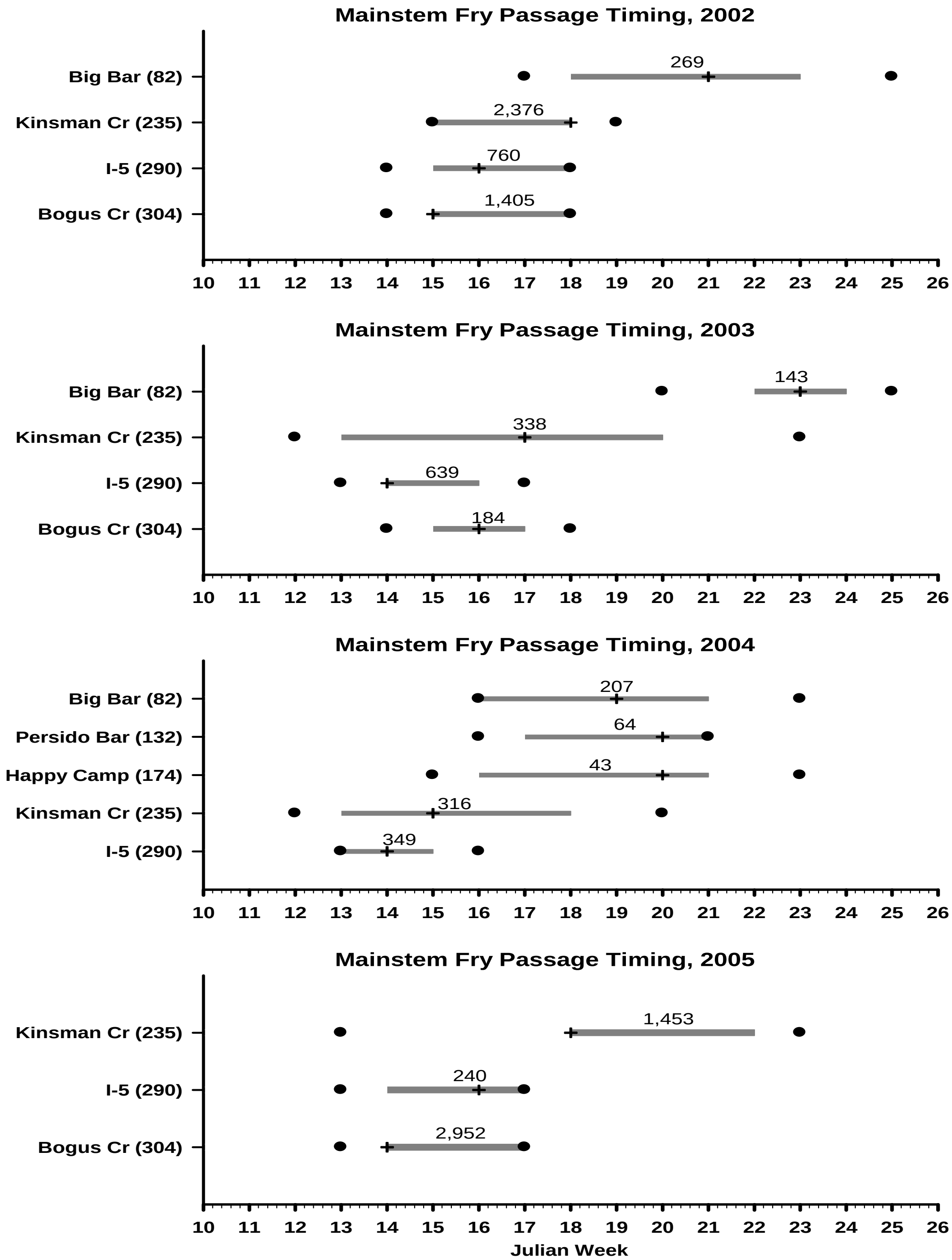


Figure 4. Passage timing of coho salmon fry at different trapping locations in the mainstem Klamath River based on expanded abundance indices. Numbers in parentheses represent distance from the river mouth to each trapping location (km). Grey bars indicate the distribution of data within the 25th and 75th percentiles, black dots denote 10th and 90th percentiles, and plus symbols denote the median. Numbers above each bar represent the total number of fish captured during the trapping season.

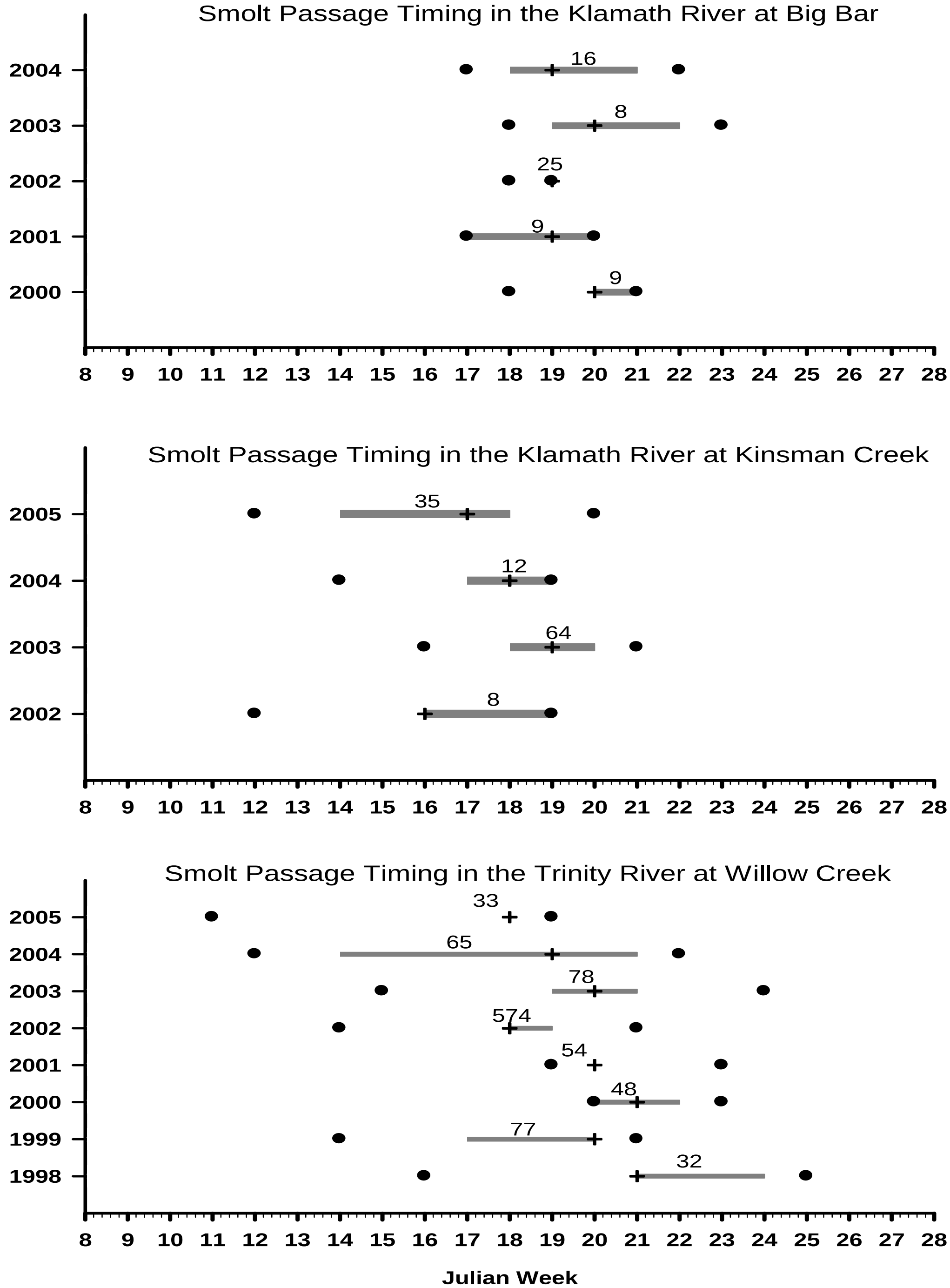


Figure 5. Passage timing of juvenile coho salmon at various tributaries to the Klamath River based on expanded abundance indices. Numbers in parentheses represent distance from the tributary mouth to each trapping location (km). Grey bars indicate the distribution of data within the 25th and 75th percentiles, black dots denote 10th and 90th percentiles, and plus symbols denote the median. Numbers above each bar represent the total number of fish captured during the trapping season.

Interannual Variation in Passage Timing

Peak passage timing of coho smolts in the mainstem Klamath River at Big Bar and Kinsman Creek and in the Trinity River at Willow Creek varied considerably across years (Figure 6). The difference in median passage date among years ranged from 0-4 weeks at all three trap sites and was most consistent at Big Bar (range = 0 – 1 week). No consistent trends in peak passage timing of smolts among years were apparent at any of the trap locations. However, migration patterns of coho fry in the Trinity River indicated a potential shift toward earlier migration after 2001 (Figure 7). This apparent early departure of coho fry did not appear to be related to stream temperature or flow. In fact, the most rapid increases in flow and temperature during the period of peak emigration occurred in 1998 and 2001 respectively; years in which peak fry migration occurred later in the trapping season (Figures 8 & 9). Therefore, the apparent shift toward earlier emigration of fry in recent years may simply reflect a high degree of interannual variability in peak passage timing, or other behavioral or environmental factors that were not examined.

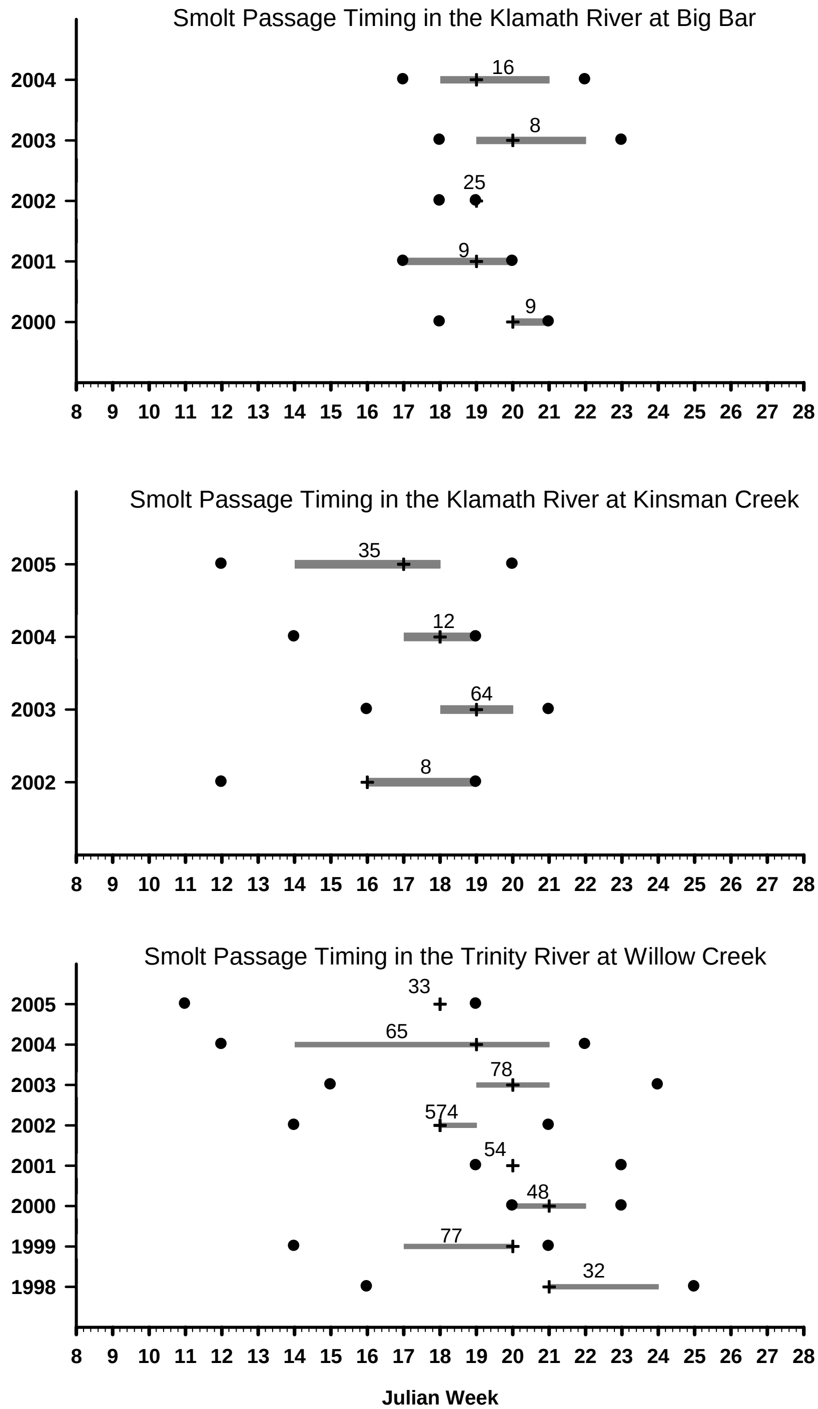


Figure 6. Annual variability in passage timing of coho salmon smolts at three different trap sites including the Klamath River at Big Bar, Klamath River at Kinsman Creek, and Trinity River at Willow Creek. Passage timing analyses were based on expanded abundance indices. Grey bars indicate the distribution of total counts within the 25th and 75th percentiles, black dots denote 10th and 90th percentiles, and plus symbols denote the median. Numbers above each bar represent the total number of fish captured during the trapping season.

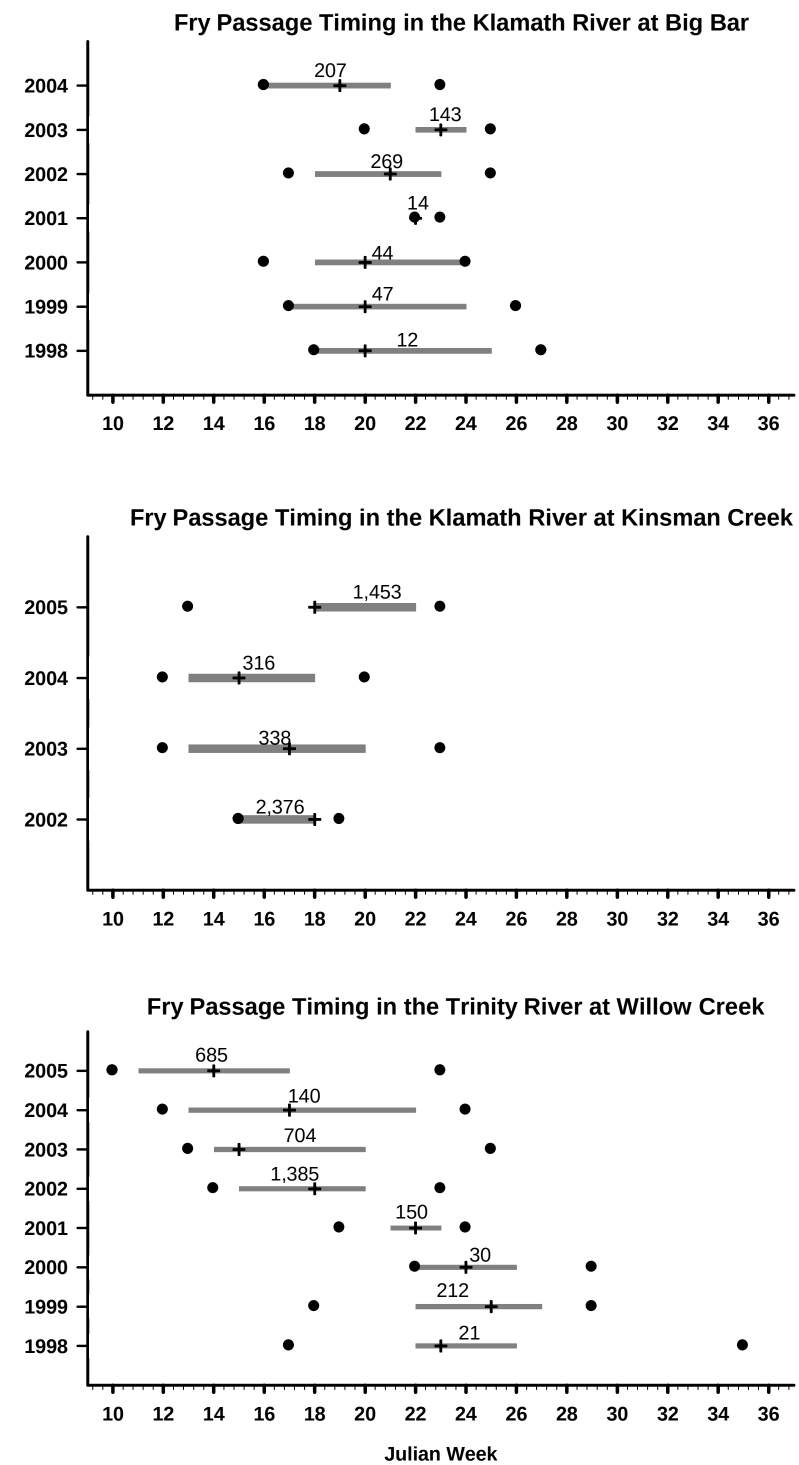


Figure 7. Annual variability in passage timing of coho salmon fry at three different trap sites including the Klamath River at Big Bar, Klamath River at Kinsman Creek, and Trinity River at Willow Creek. Grey bars indicate the distribution of total counts within the 25th and 75th percentiles, black dots denote 10th and 90th percentiles, and plus symbols denote the median. Numbers above each bar represent the total number of fish captured during the trapping season.

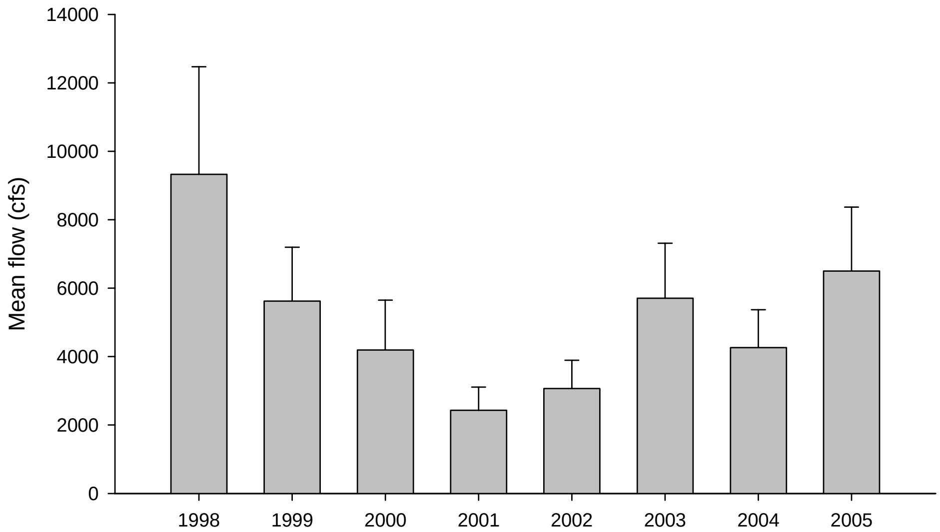


Figure 8. Mean stream discharge (cfs) in the Trinity River at Willow Creek from JW 10-34, 1998-2005. Error bars represent two standard errors.

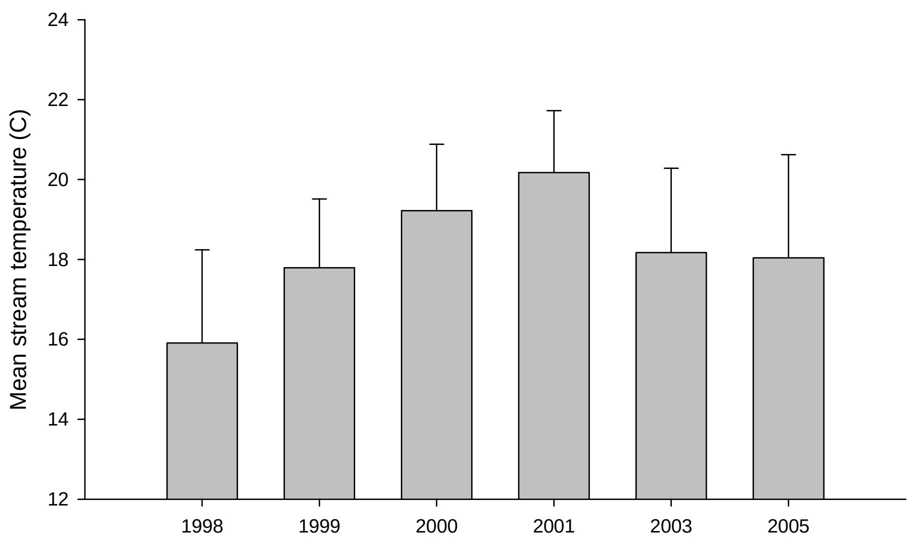


Figure 9. Mean stream temperature(˚C) in the Trinity River at Willow Creek from JW 21-31, 1998-2005. No data was available for 2002 or 2004. Error bars represent 2 standard errors.

Intraannual Variation in Passage Timing

Downstream migration of coho smolts and fry captured in the Klamath River at Big Bar appeared to coincide with elevated streamflows and rising stream temperatures with peak passage typically occurring on the downslope of the hydrograph (Figure 10). The majority of fish migrated past the trap before stream temperatures reached 22-23˚C. This finding is consistent with other studies in the Klamath Basin which have shown that juvenile coho seek cool water refugia when ambient stream temperatures reach approximately 22-23 ˚C (Belchik 2003; Sutton et al. 2006). Most coho fry and smolts passed the Big Bar trap during elevated flow conditions. However, there was no clear indication that within-year variations in streamflow influenced the downstream migration of juvenile coho salmon. For example, sharp peaks in flow occurring between Julian weeks 12-16 in 2002 and 2003 did not correspond with increased passage of coho fry or smolts.

Patterns in migration timing in the mainstem Klamath River at the Kinsman Creek trap site, located approximately 155 km upstream from Big Bar, were more variable across years compared with the Big Bar trap site, but still tended to coincide with increases in stream temperature and to a lesser extent, to elevated streamflow (Figure 11). The greater interannual variability in peak migration observed at the Kinsman Creek site is likely related to substantial fluctuations in the stream hydrograph from one year to the next. There is some evidence for a bimodal migration pattern for both coho fry and smolts in 2005. Steadily increasing temperatures and a sharp rise in stream flow between Julian weeks 17 and 22 may have triggered this secondary pulse of downstream migrants. However, the secondary peak of fry migration occurred approximately 2 weeks after a rapid rise in flow while the secondary peak of smolts occurred on the rising slope of the hydrograph, casting some doubt as to the direct effects of flow on this bimodal migration pattern. It is likely that some of the variation in passage timing of fish migrating past the Kinsman Creek trap site could be attributed to differences in physical habitat and geographic location of the fishes' natal spawning grounds. In most cases, migration of both age 0 and age 1 coho virtually ceased as temperatures reached 21-24 ˚C.

The majority of fish passed the Trinity River at Willow Creek prior to the onset of summer base flow conditions (Julian week 28-30), and termination of age 0 and age 1 emigration occurred when mean weekly average temperatures reached approximately 20-22 ˚C (Figure 12). Similar patterns between stream temperature and migration timing of coho fry and smolts in the Trinity River were observed in 1997-2000 (USFWS 2001). The influence of streamflow on downstream migration of coho salmon in the Trinity River was unclear. In 2002, peaks in streamflow occurring around Julian weeks 14 and 18 coincided with sharp increases in emigration of coho fry and smolts. On the other hand, large spikes in flow occurring between Julian weeks 16-20 in 2003 and Julian weeks 19-21 in 2005 did not appear to stimulate downstream migration.

Peak migration of coho smolts in the Scott River typically preceeded that of fry by approximately 2-10 weeks between 2000 and 2005. This pattern of earlier migration of smolts was consistent with migration patterns observed in other Klamath tributaries in 2004 (Figure 5). There was some evidence for a bimodal distribution in passage timing of fry in the Scott River (Figure 13). This pattern was most apparent in 2005, when the total number of fry captured at the trap exceeded previous years by a factor of approximately 10-360. The second peak in fry migration appeared to coincide with the downward slope of the hydrograph between Julian weeks 23 and 28. According to temperature data from 2005, this period also coincided with rapidly increasing stream temperatures which reached approximately 19˚C on Julian week 26. Tripp and McCart (1983) reported a similar bimodal pattern in juvenile coho migration in which the first peak in coho migration occurred during the time of maximum stream discharge and the second peak coincided with decreasing flows and increasing temperatures. There was no clear indication of a bimodal migration pattern for age 1 coho.

Peak migration of coho fry in the Shasta River in 2005 also occurred during the receding limb of the hydrograph while smolt migration peaked on the rising limb (Figure 14). Stream temperatures were approximately 4 ˚C warmer on average in the Shasta River compared with the Scott River, a factor which may have contributed to earlier emigration of fry from the Shasta River. The largest pulses of coho fry from both the Shasta and Scott Rivers occurred when the stream temperature reached between 19 and 20 ˚C.

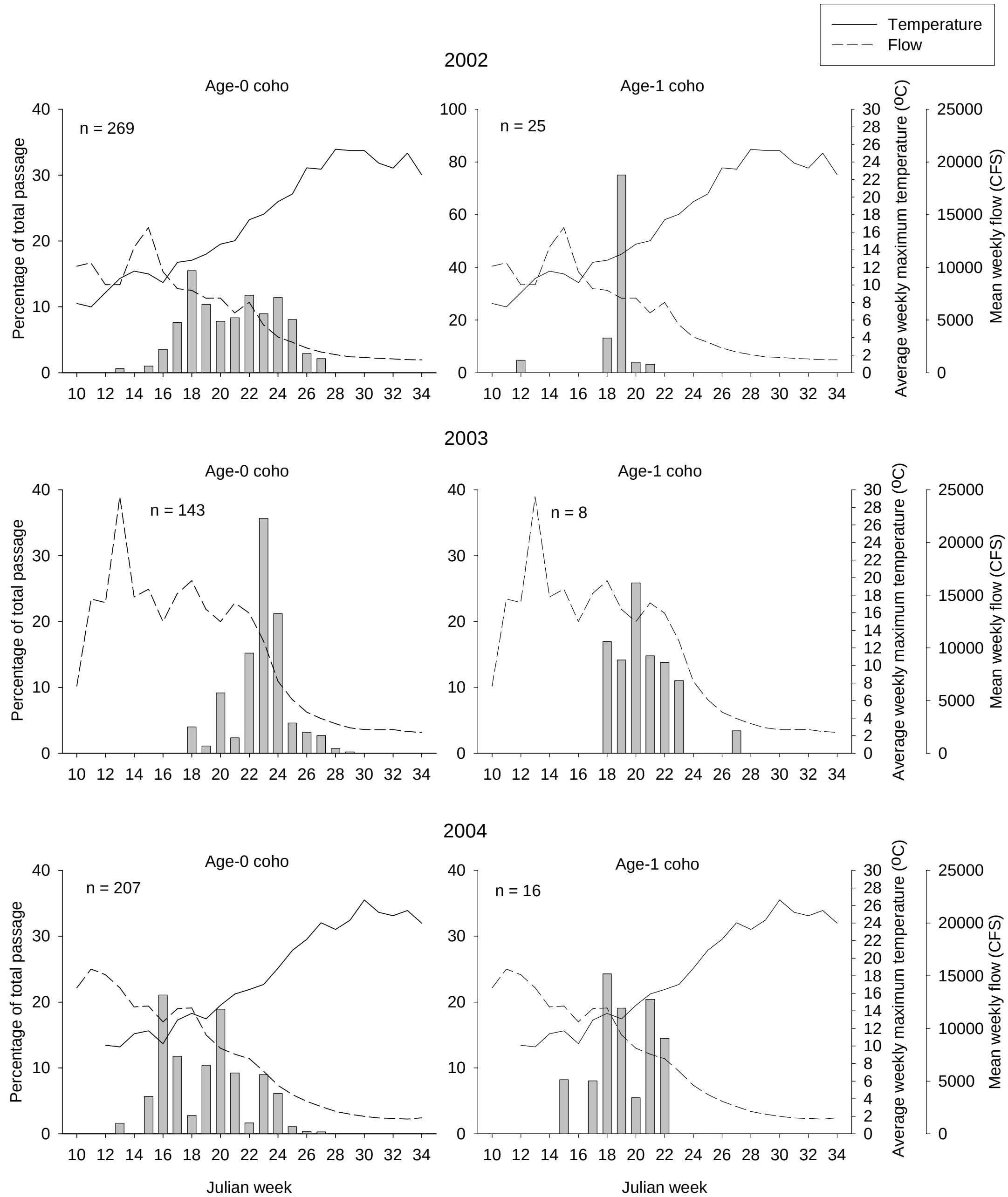


Figure 10. Passage timing of juvenile coho salmon in relation to mean weekly flow (cfs) and average weekly maximum temperature (˚C) in the mainstem Klamath River at Big Bar (Rkm = 82.0), 2002-2004. The total number of fish captured in each year is given in the upper left corner of each plot.

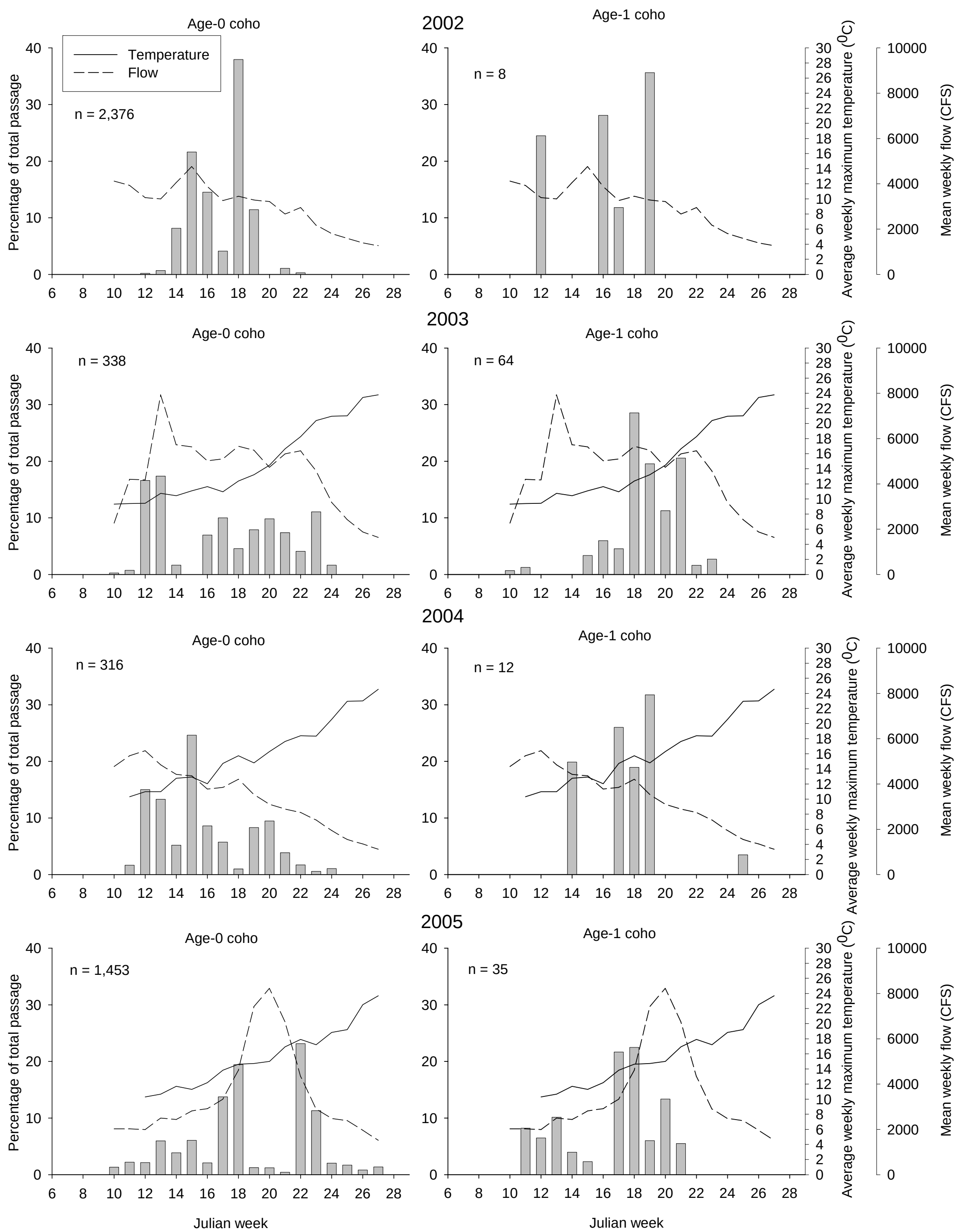


Figure 11. Passage timing of juvenile coho salmon in relation to mean weekly flow (cfs) and average weekly maximum temperature (˚C) in the mainstem Klamath River at Kinsman Creek (Rkm = 237.1), 2002-2005. The total number of fish captured in each year is given in the upper left corner of each plot.

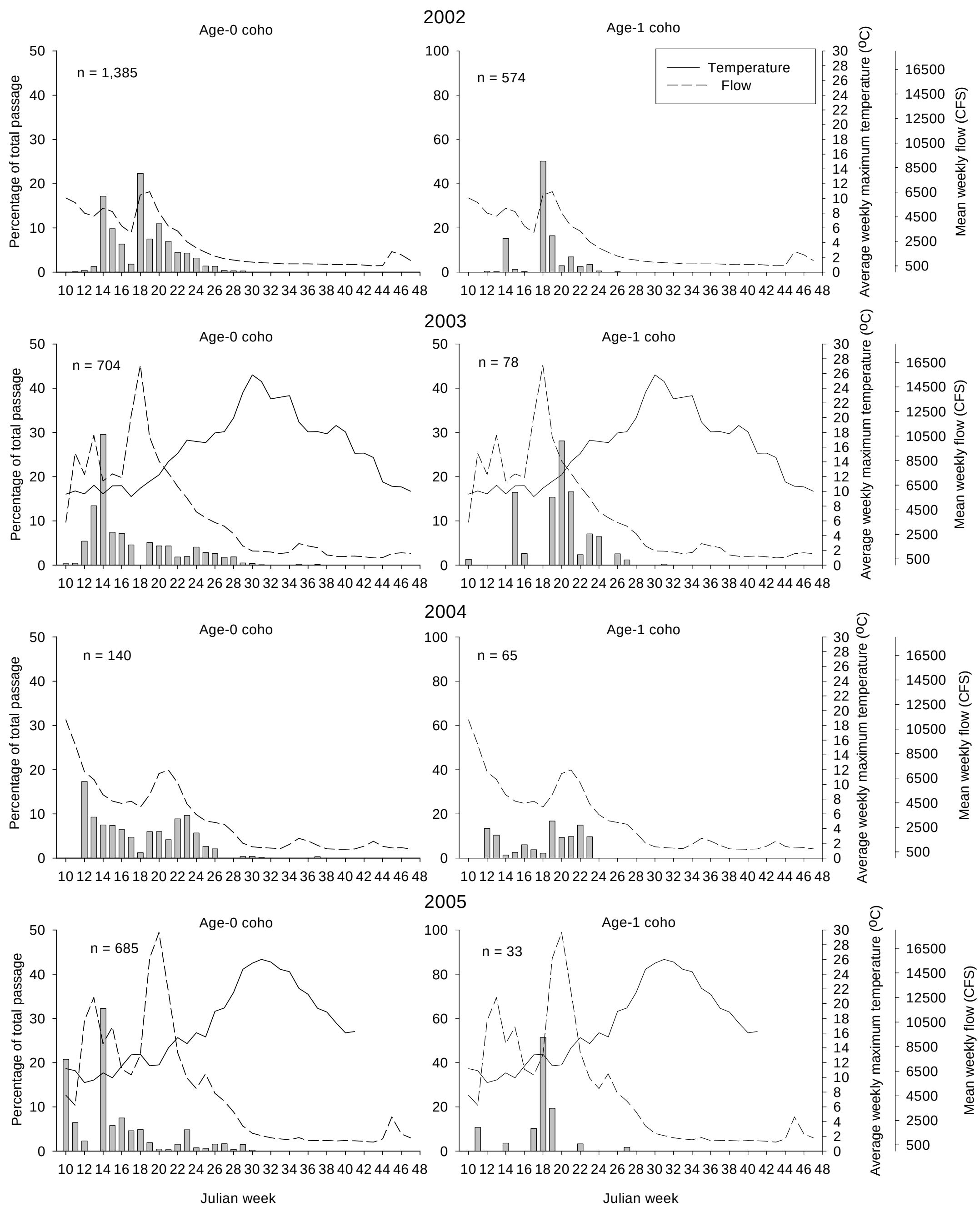


Figure 12. Passage timing of juvenile coho salmon in relation to mean weekly flow (cfs) and average weekly maximum temperature (˚C) in the mainstem Trinity River at Willow Creek (Rkm = 34.0), 2002-2005. The total number of fish captured in each year is given in the upper left corner of each plot.

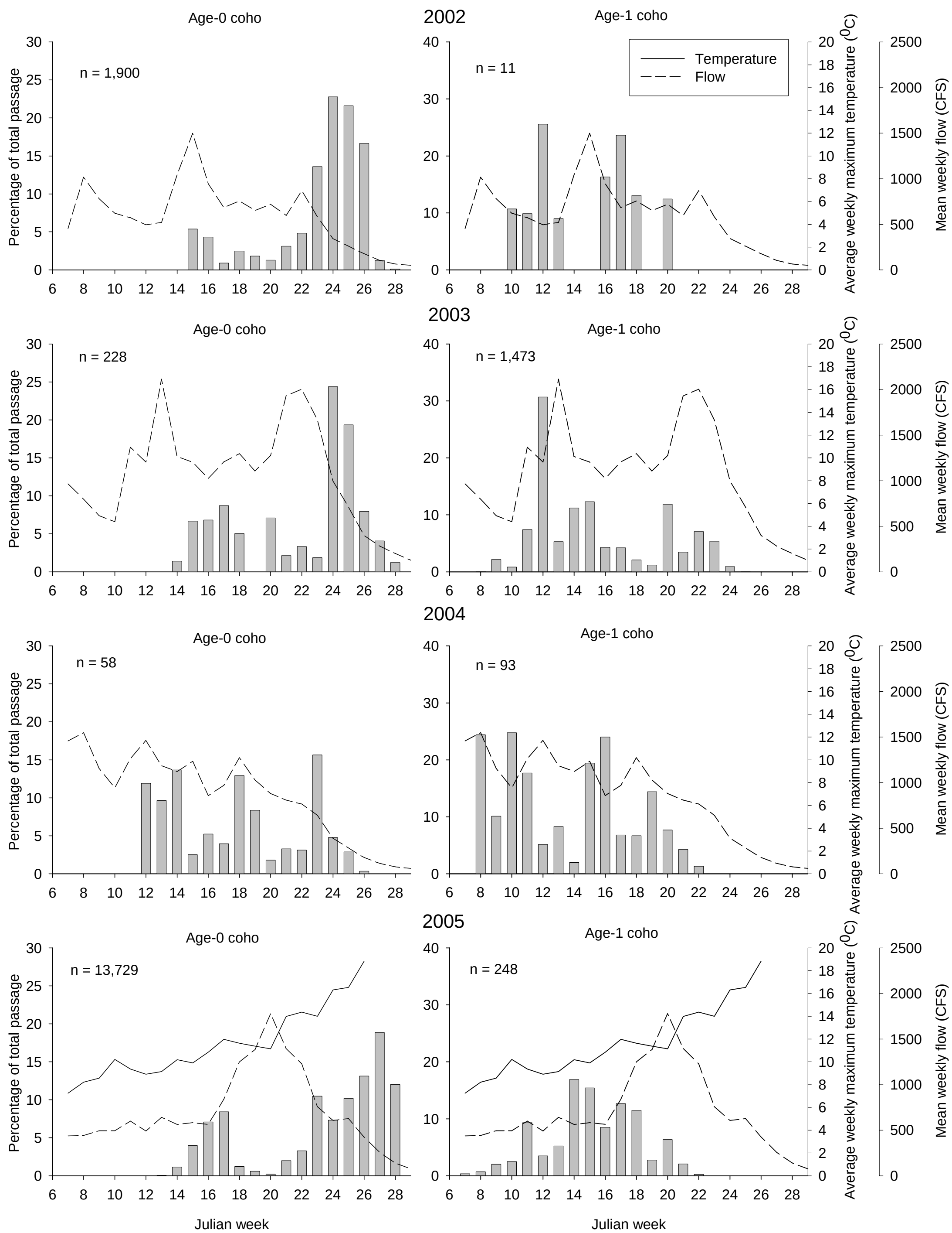


Figure 13. Passage timing of juvenile coho salmon in relation to mean weekly flow (cfs) and average weekly maximum temperature (˚C) in the Scott River (Rkm = 8.1), 2002-2005. The total number of fish captured in each year is given in the upper left corner of each plot.

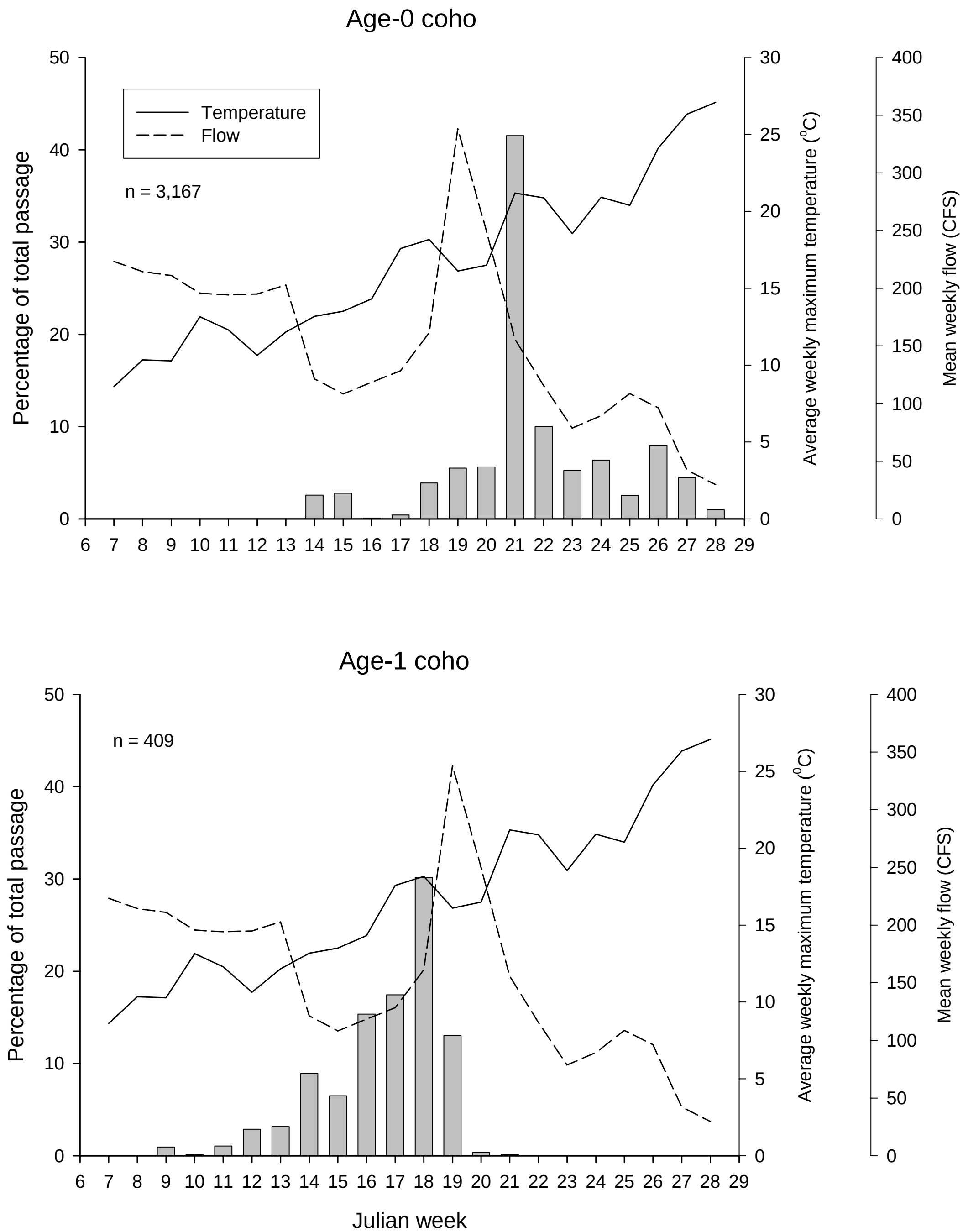


Figure 14. Passage timing of juvenile coho salmon in relation to mean weekly flow (cfs) and average weekly maximum temperature (˚C) in the Shasta River (Rkm = 0.4), 2002-2005. The total number of fish captured in each year is given in the upper left corner of each plot.

Fish Size

The weekly average length of coho fry captured in the mainstem Klamath River at Bogus Creek (Rkm = 307.1) was similar among years and ranged from approximately 34-48 mm (mean = 38 mm) for all years combined (Figure 15). The relatively consistent size range of coho fry passing the trap before about Julian week 16-19 suggest that fry emergence was continuing throughout this period. Slight increases in mean fish size (<14mm) occurred later in the trapping season (i.e. JW 16-22), indicating relatively slow growth of coho fry above Bogus Creek. Very few coho smolts were captured at the Bogus Creek trap site, making it difficult to make inferences about size-related patterns in passage timing. Weekly average smolt length ranged from 108-144 mm (mean = 121 mm) for all years combined.

Similar size ranges of coho fry and smolts were observed at the I-5 trap site (Rkm = 294.4), located approximately 12.7 km downstream from the Bogus Creek trap site (Figure 16). Weekly average size of coho fry ranged from 33-53 mm in length (mean = 38 mm) while mean smolt length ranged from 80-165 mm (mean = 127 mm) for all years combined. The similarity in fish size between the I-5 and Bogus Creek trap sites is not surprising considering the relatively close proximity of the two trapping locations. Migrating juvenile coho would have little opportunity to feed and grow in the short distance between traps. The consistent patterns in the size of coho fry at the I-5 and Bogus Creek trap site helps to confirm that emergence was occurring until about week 19.

Coho fry captured at the Kinsman Creek trap site (Rkm = 237.1) were slightly larger than those passing at upstream trapping locations with weekly average lengths ranging from 34-60 mm (mean = 42 mm) for all years combined (Figure 17). Weekly average fork lengths of coho smolts ranged from 99-182 mm (mean = 129 mm) for all years combined. Emergence continued until approximately week 16-19, at which growth commenced. Growth of coho fry following week 16-19 was generally slow with maximum increases in weekly average fork length throughout the trapping season averaging 20 mm across years.

The average weekly fork length of coho fry captured at the Big Bar trap site (Rkm = 81.9) gradually increased from Julian week 13 to about 20-21, and then leveled off for the remainder of the trapping season in years 2002 and 2003 (Figure 18). In 2004, growth of coho fry continued until week 26. Mean weekly lengths of coho fry ranged from 38-81 mm (mean = 59 mm) for all years combined. The average change in length throughout the trapping season averaged 33 mm across years. In contrast with upstream mainstem trapping locations, it appeared that few emergent fry were captured at Big Bar. The weekly average length of coho smolts ranged from 102-165 mm (mean = 134 mm) for all years combined.

The most substantial increases in mean length of coho fry occurred between the Kinsman Creek and Big Bar trap sites (Figure 19). This result is not surprising considering the relatively long distance between these two locations (Rkm = 155.2) and the corresponding increased capacity for rearing throughout this section of the river. Due to potential confounding factors such as size-dependent survival and capture probabilities and variable locations of natal spawning areas, it is difficult to determine if the differences in fish length observed between Kinsman Creek and Big Bar were actually reflective of growth. However, recent radio telemetry studies have provided strong evidence for coho rearing in the mainstem Klamath (Stutzer et al. 2006), suggesting that some of the size increases we observed were likely due to growth. Small sample sizes resulted in highly variable size distributions and reduced our ability to make inferences about spatial or temporal trends in smolt size (Figure 20).

Mean weekly lengths of coho fry and smolts captured in the Trinity River at Willow Creek (Rkm 34.0) ranged from 33-86 mm (mean = 55 mm) and 90-175 mm (mean = 121 mm) respectively. Coho fry lengths remained steady from about Julian week 10-17, increased gradually through week 25-26, and then leveled off for the remainder of the trapping season. Maximum weekly average temperatures ranged from 14-17 ˚C during the growth period from week 18-26. The cessation of growth after week 26 likely resulted from stream temperatures becoming too warm and is consistent with previous studies which have shown that juvenile coho growth stops when temperatures exceed approximately 19 ˚C (Armour 1991). Maximum size increases for coho fry averaged 43 mm from 2002-2005 (Figure 21). Coho smolt lengths at the Willow Creek trap site were highly variable and there was no compelling evidence for significant smolt growth throughout the migration period.

The mean weekly size of age 0 coho captured at the Shasta River trap site (Rkm 0.4) in 2005 ranged from 31-112 mm (mean = 66 mm). Fry length remained relatively constant from Julian week 10-16, averaging approximately 36 mm during this period followed by a relatively rapid increase in mean size through JW 24 (Figure 22). This increase in fish size corresponded with a large peak in spring flows (JW 18-21) coupled with an increase in mean weekly maximum temperature from 15-20˚C (Figure 13). The reason for the subsequent decline in mean fry size in JW 27-28 is unclear, but may reflect emigration of smaller fish triggered by high temperatures during those weeks (> 25˚C) or simply movement of fry from a different subbasin within the Shasta basin.

Mean weekly smolt length at the Shasta River trap site ranged from 107-160 mm (mean = 137 mm). Mean smolt size increased rapidly from approximately 107 mm to 160 mm from JW 8-13, and then steadily declined to 131 mm in JW 20 (Figure 22). The fact that emigration of smaller smolts preceeded that of larger fish is inconsistent with previous studies examining migratory behavior of juvenile coho salmon (Washington 1982; Irvine and Ward 1989). This trend may have been reflective of small sample sizes during JW 8-13, or high variability in fish sizes resulting from mixing of smolt populations from various subbasins within the Shasta watershed. It should be noted that the average size of both smolts and fry exceed that of all other locations within the Klamath basin, highlighting the high productive capacity of the Shasta river.

Coho fry and smolts emigrating from the Scott River in 2005 ranged in size from approximately 33-74 mm (mean = 52 mm) and 102-154 mm (mean = 119 mm) respectively. The size of fry captured throughout the migration period followed a fairly clear pattern in which smaller emergent fry (mean fork length = 37 mm) emigrated between JW 9-18, followed by a period of substantial size increase between JW 19-21 (Figure 22). After JW 21, the size of coho fry passing the trap remained relatively steady (mean fork length = 67 mm). The size of coho smolts gradually increased throughout the trapping season. This pattern may reflect substantial growth during the migration season, but is likely complicated by other factors such as variability in spawning timing and habitat characteristics within different subbasins of the Scott River.

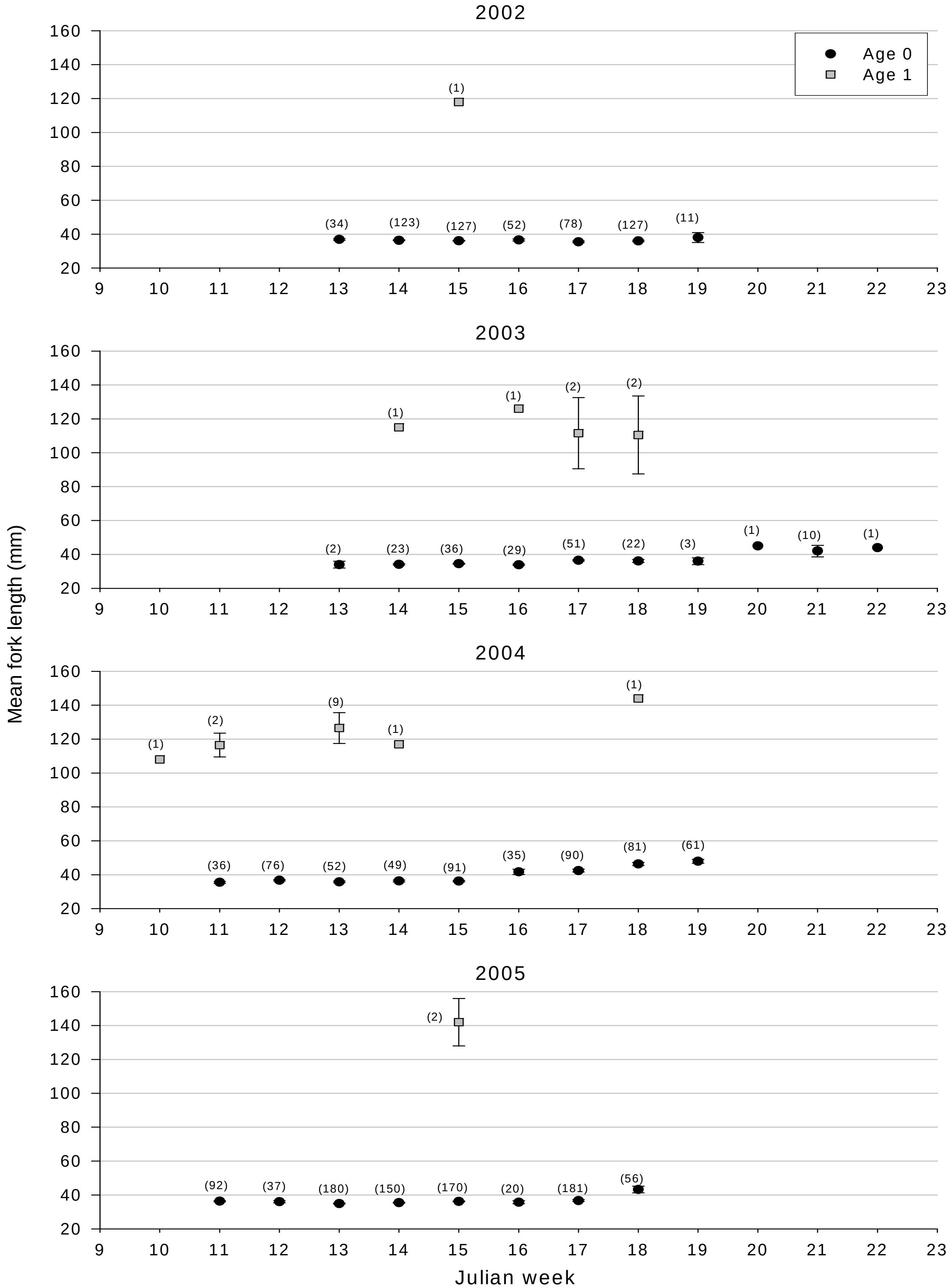


Figure 15. Mean fork lengths (mm) juvenile coho salmon emigrants by Julian week at the Klamath River Bogus Creek trap site (Rkm = 304), 2002-2005. Error bars represent 2 standard errors and sample sizes are given in parentheses.

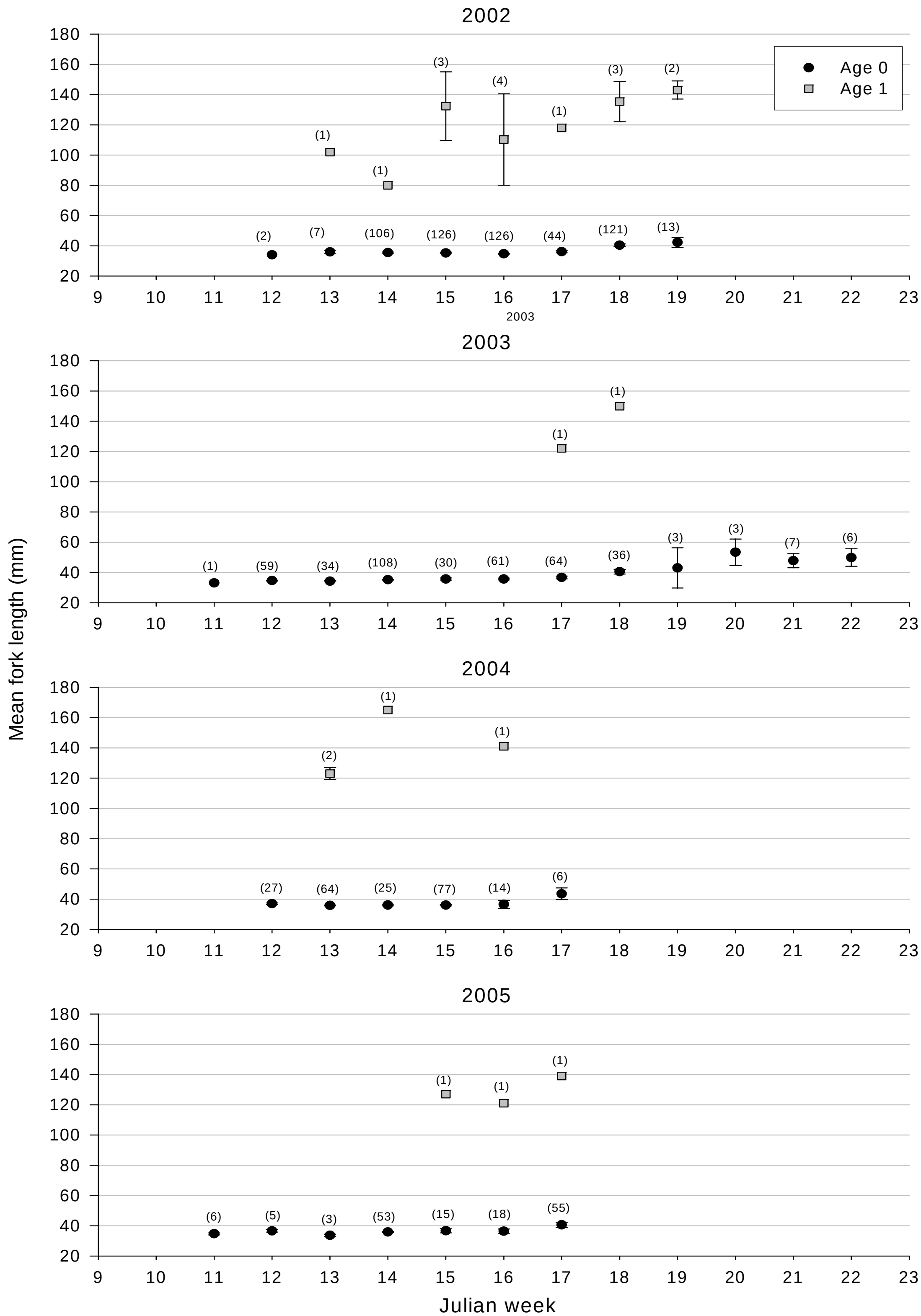


Figure 16. Mean fork lengths (mm) juvenile coho salmon emigrants by Julian week at the Klamath River I-5 trap site (Rkm = 290), 2002-2005. Error bars represent 2 standard errors and sample sizes are given in parentheses.

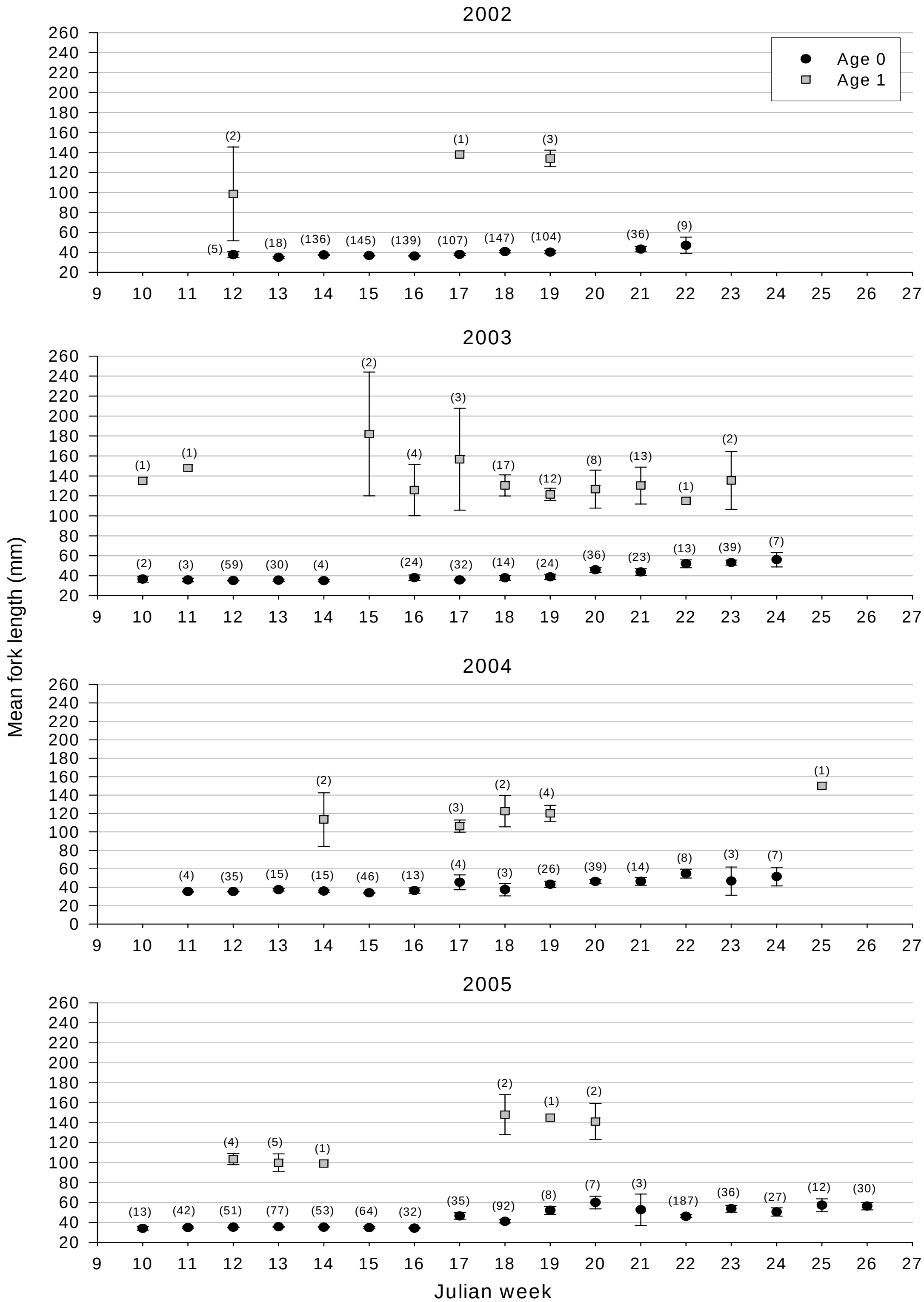


Figure 17. Mean fork lengths (mm) juvenile coho salmon emigrants by Julian week at the Klamath River Kinsman Creek trap site (Rkm = 235), 2002-2005. Error bars represent 2 standard errors and sample sizes are given in parentheses.

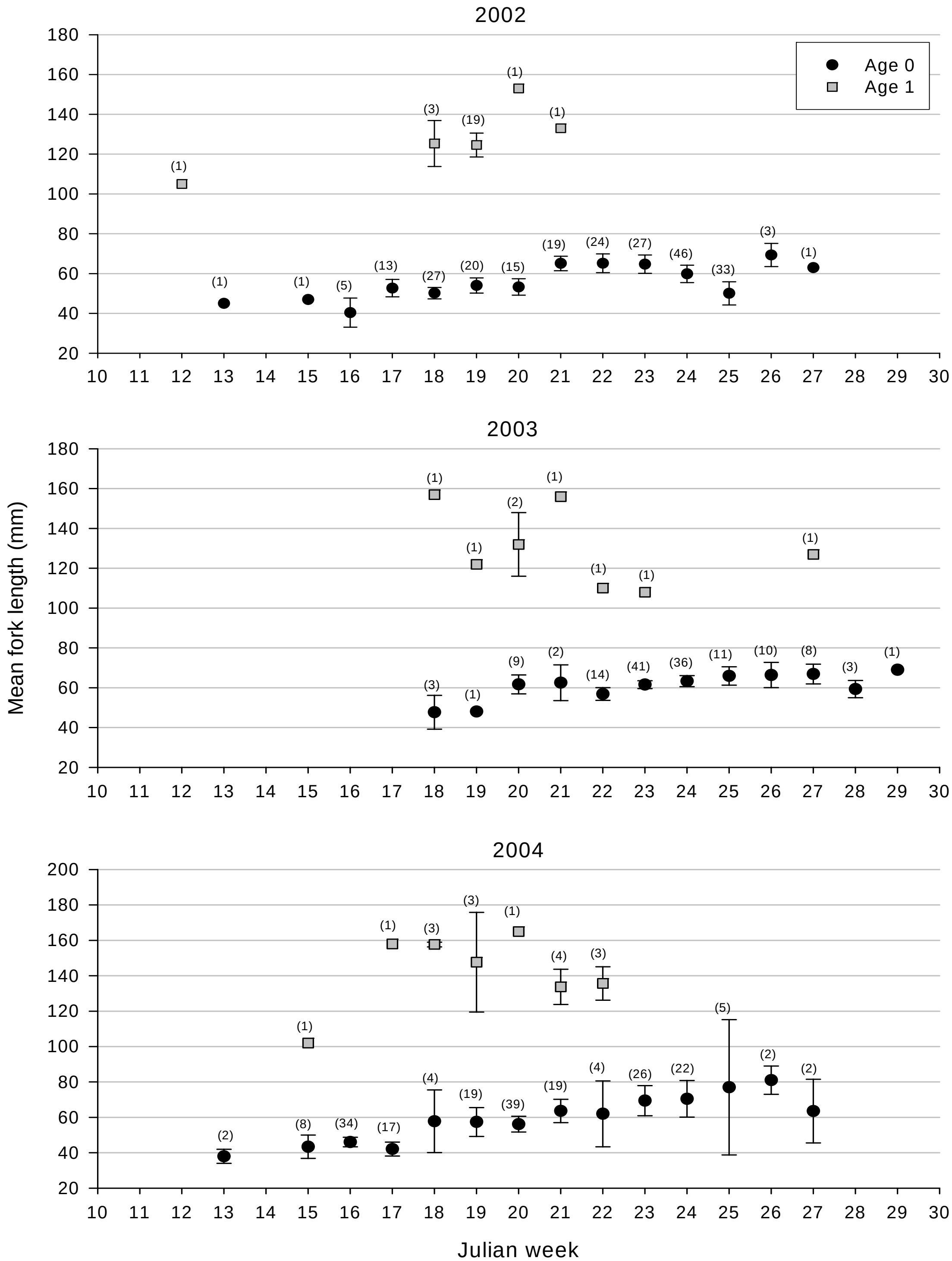


Figure 18. Mean fork lengths (mm) juvenile coho salmon emigrants by Julian week at the Klamath River Big Bar trap site (Rkm = 82), 2002-2004. Error bars represent 2 standard errors and sample sizes are given in parentheses.

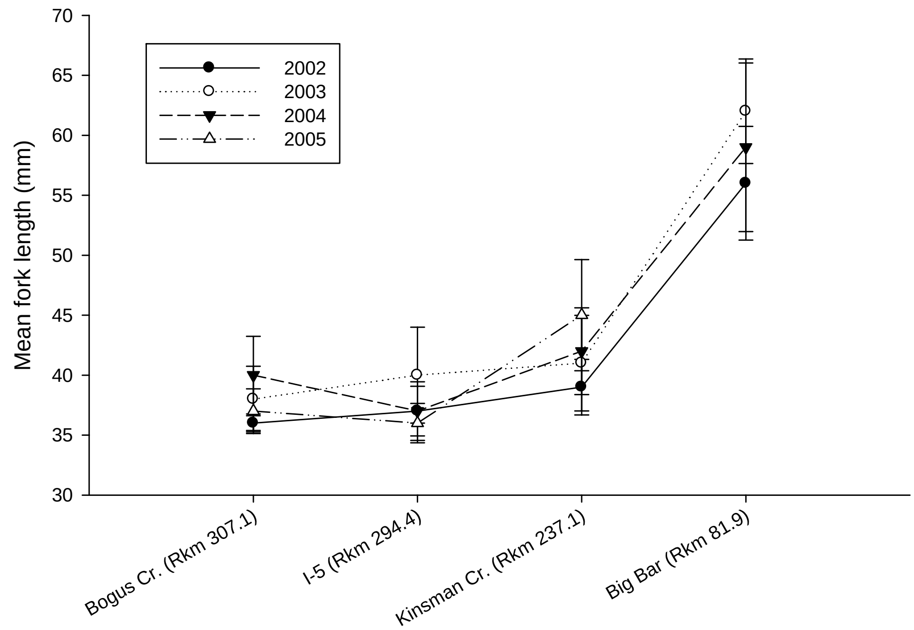


Figure 19. Average fork length (mm) of coho fry captured at four trapping locations on the mainstem Klamath River, 2002-2005. Error bars represent two standard errors.

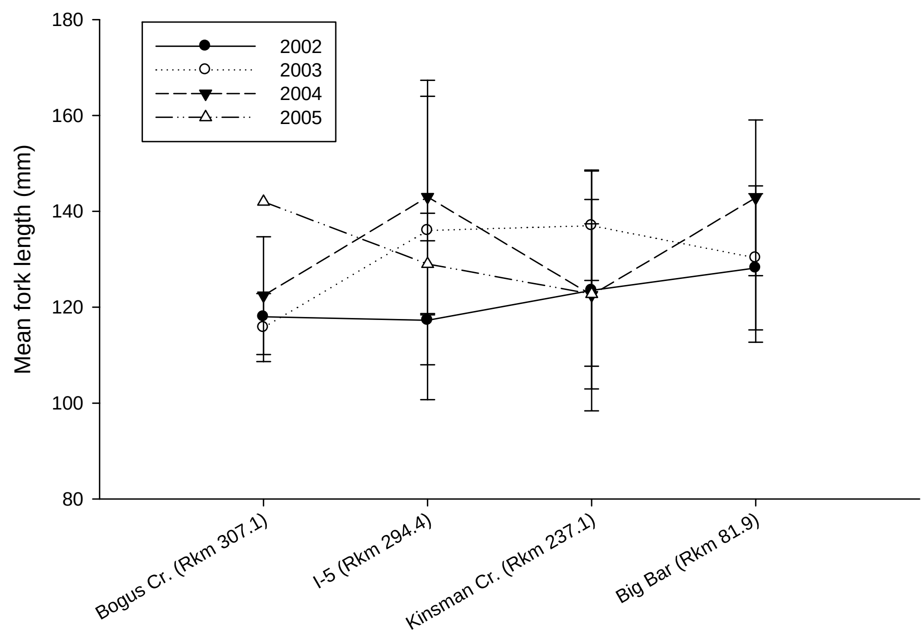


Figure 20. Average fork length (mm) of coho smolts captured at four trapping locations on the mainstem Klamath River, 2002-2005. Error bars represent two standard errors.

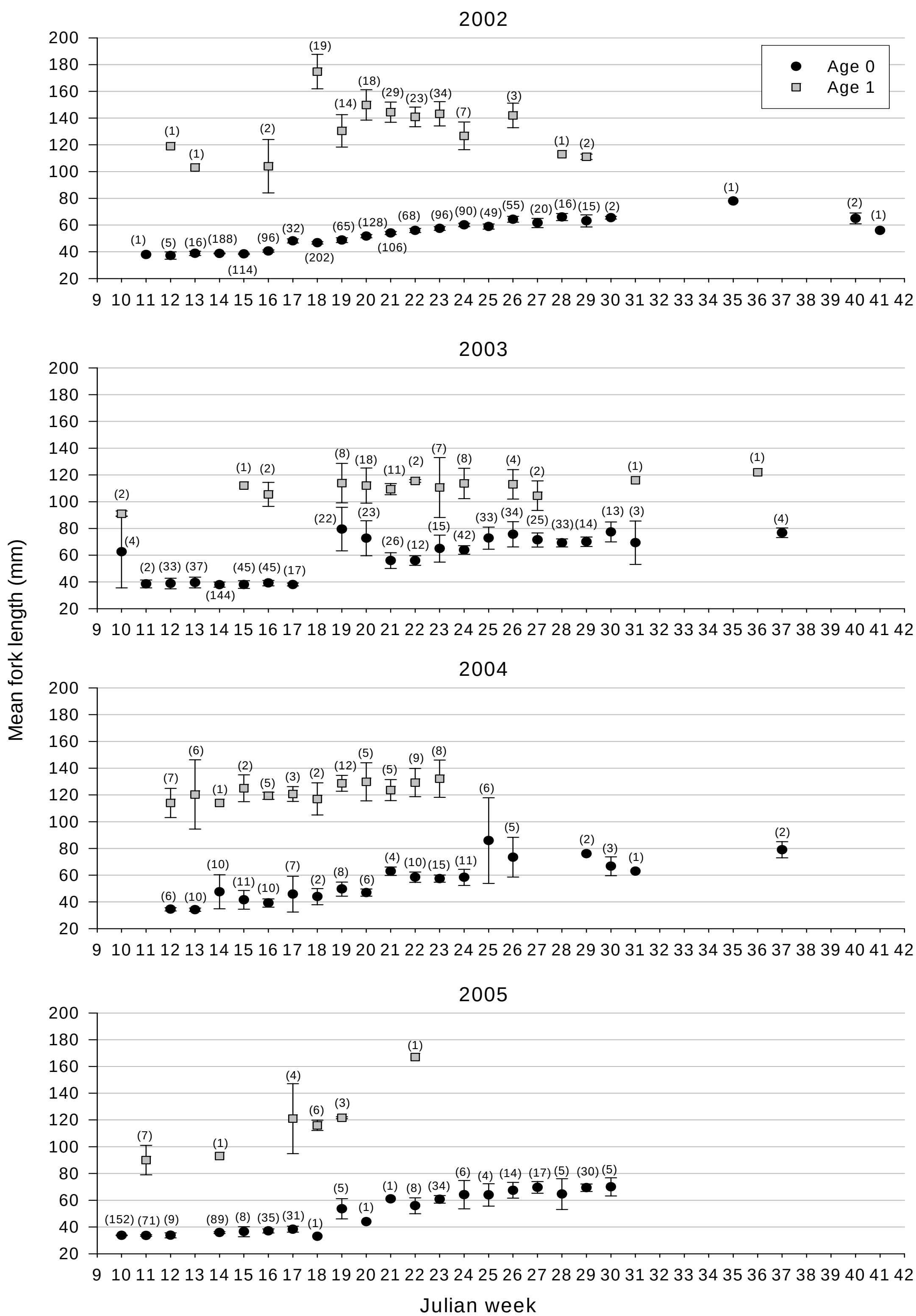


Figure 21. Mean fork lengths (mm) juvenile coho salmon emigrants by Julian week at the Trinity River Willow Creek trap site (Rkm = 34), 2002-2005. Error bars represent 2 standard errors and sample sizes are given in parentheses.

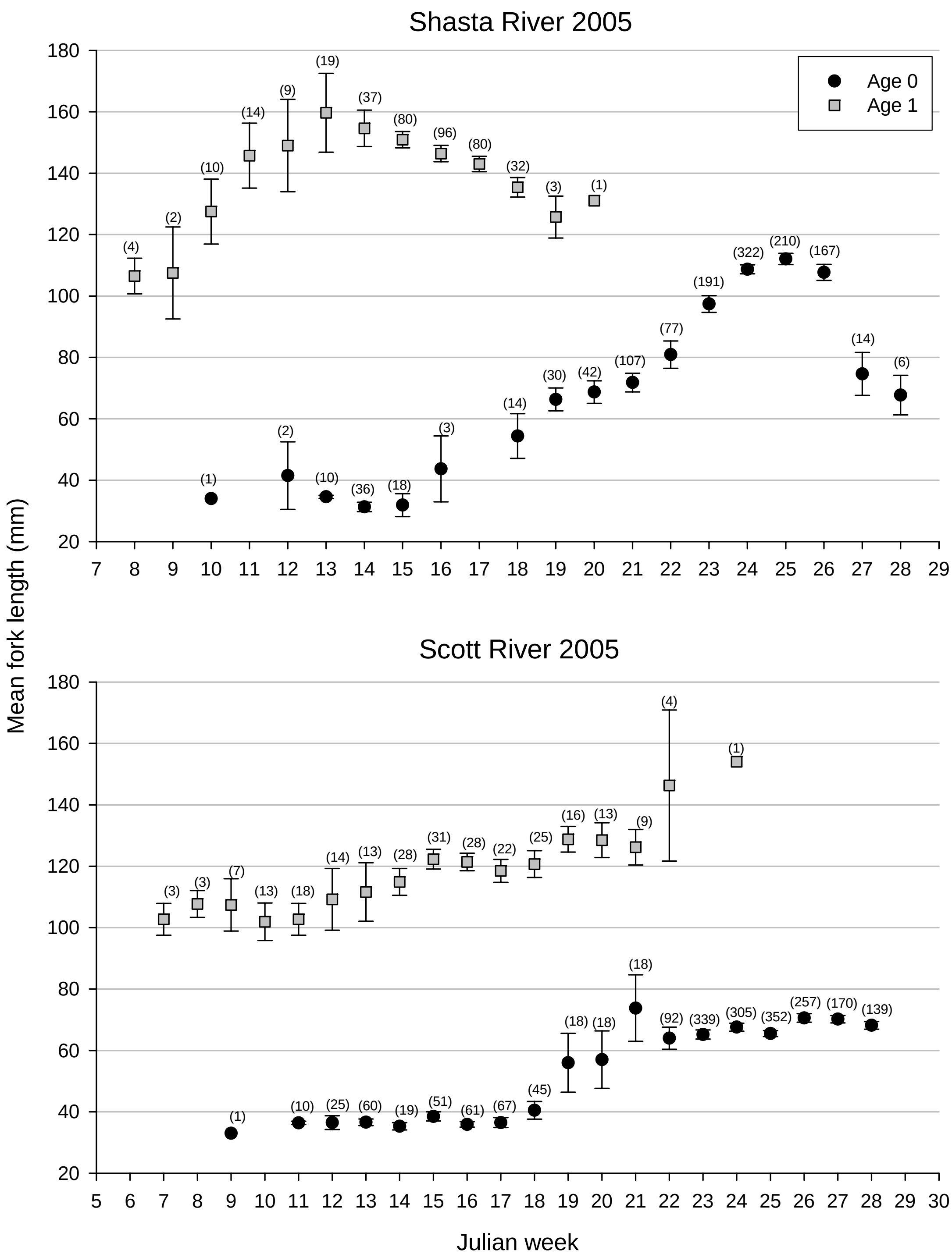


Figure 22. Mean fork lengths (mm) juvenile coho salmon emigrants by Julian week at the Shasta River (Rkm = 0.4) and Scott River (Rkm = 8.1) trap sites 2005. Error bars represent 2 standard errors and sample sizes are given in parentheses.

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