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Use of Passive Integrated Transponder (PIT) Tags to Monitor Migration Timing of Snake River Chinook Salmon Smolts

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Abstract.—Before 1989, there was little detailed knowledge of the migrational timing of wild smolts of Snake River spring and summer chinook salmon *Oncorhynchus tshawytscha* from individual streams. With the development of the passive integrated transponder (PIT) tag and methods for collecting and tagging parr, acquisition of information on migrational timing became feasible. We PIT-tagged wild chinook salmon parr in several streams in Idaho and Oregon each summer from 1988 through 1990. Each subsequent spring and summer, we detected surviving smolts on their migration through Lower Granite Dam. We also PIT-tagged hatchery-reared parr during fall or late winter and compared their migrations with those of wild fish. Migrational timing of wild smolts through Lower Granite Dam varied for fish from different streams and also differed from hatchery-reared fish. Generally, wild spring chinook salmon migrated later and over a more protracted period than their hatchery-reared counterparts. Wild summer chinook salmon migrated earlier than their hatchery-reared counterparts but also over a protracted period. This study demonstrated that PIT tag technology can be used successfully to monitor migrations of wild and hatchery chinook salmon smolt stocks during their journey to the ocean.

Smolt migrations of spring and summer chinook salmon *Oncorhynchus tshawytscha* have been monitored in the Snake River drainage in most years since Ice Harbor Dam was constructed in 1962. These monitoring programs became more complex as the number of dams in the lower Snake River increased from one to four between 1962 and 1975. Until the mid-1980s, freeze brands were usually used to mark juvenile migrants (Mighell 1969). Fish were branded at hatcheries prior to release, after collection at scoop traps on the Salmon River, and in selected streams in Idaho and Oregon in 1966 and 1967 (Raymond 1979). Smolts were also marked after collection from turbine intake gatewells at dams (Bentley and Raymond 1968) or in the bypass systems installed at some dams (Ebel 1980). Recovery of branded fish downstream from release sites provided data for estimating survival, migrational timing, and travel time.

Development of the passive integrated transponder (PIT) tag (Prentice et al. 1990b), which permitted identification of individual marked fish, allowed acquisition of precise information on migrational timing and juvenile salmonid behavior. In 1988, we began to collect and PIT-tag wild spring and summer chinook salmon parr from several streams in the Snake River basin. In this paper, we provide information on the collection and PIT tagging of wild and hatchery spring and summer chinook salmon parr as well as data on the detection and migration timing of the smolts as they migrated through Lower Granite Dam on the Snake River each spring and summer from 1989 through 1991.

Methods

Collection and tagging of wild fish.—During August and September from 1988 through 1990, we collected and PIT-tagged wild spring and summer chinook salmon parr in 15 streams in Idaho and 4 streams in Oregon (Figure 1). Fish from the Secesh River, Lake Creek, South Fork Salmon River, Imnaha River, and McCall Hatchery were considered summer chinook salmon; all other fish that were tagged were considered spring chinook salmon during this study.[1] Fish were collected, tagged, and released in selected reaches of each stream. Before collections, areas of high parr concentration were located by snorkeling.

To collect wild fish for tagging, electrofishing

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[1] In June 1991, the National Marine Fisheries Service (NMFS) Northwest Region Biological Review Team concluded that the Snake River spring and summer chinook salmon are a single evolutionarily significant unit and should be termed "spring/summer chinook salmon" (NMFS, unpublished). Because most of the data in this paper were generated and analyzed prior to this conclusion, we compared timing of spring and summer chinook salmon populations separately in this paper. We will refer to these populations collectively as "spring/summer chinook salmon" in all future documents.

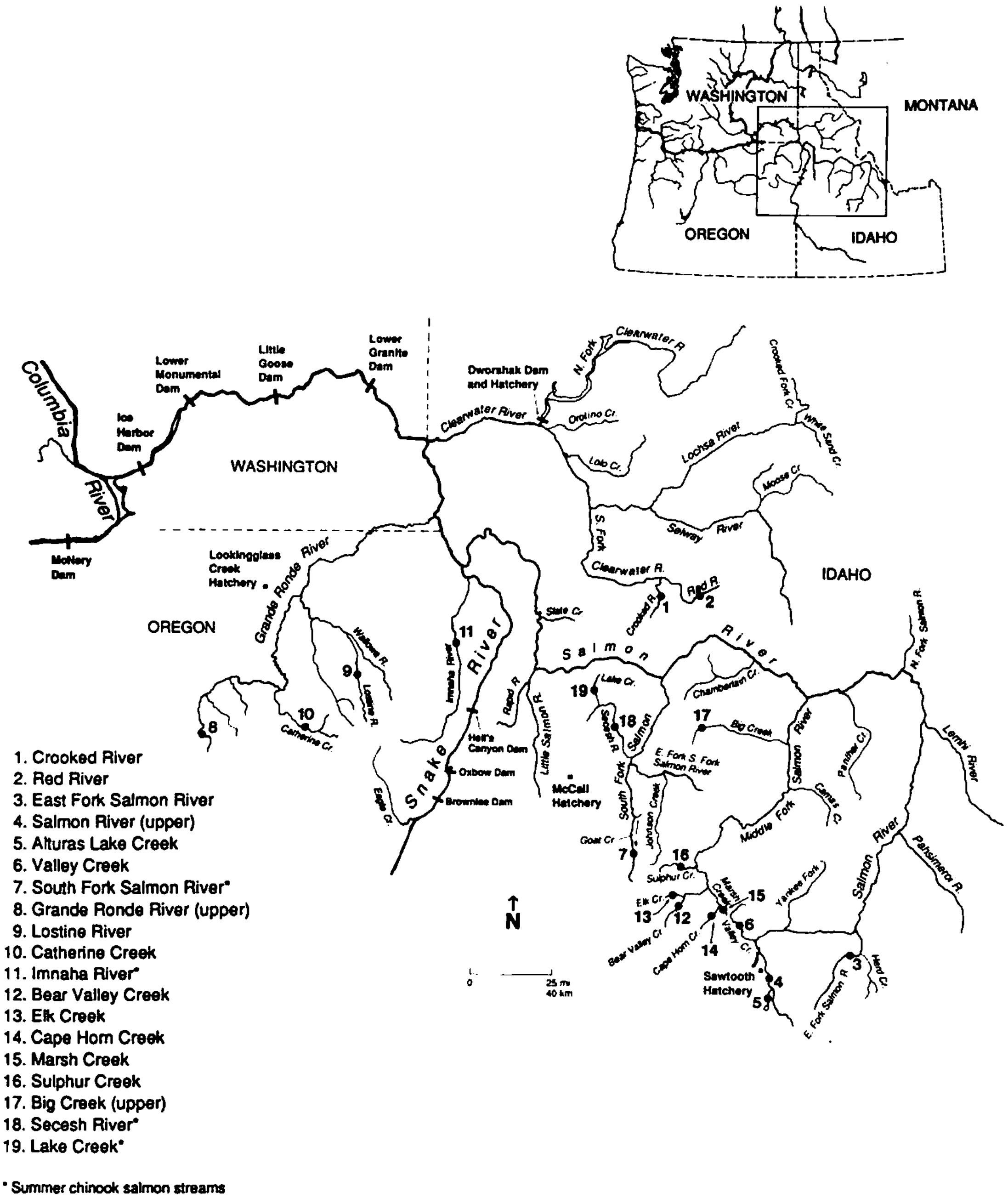

FIGURE 1.—Study area where wild and hatchery-reared spring and summer chinook salmon parr were PIT-tagged. Streams are numbered with associated tagging areas. PIT-tagged smolts were subsequently monitored as they passed Lower Granite Dam each spring and summer from 1989 through 1991.

and a seining method developed specifically for this application were used. The seining method, which was used when fish densities were high, was the principal collecting method in 1988 and 1989. One seine was positioned securely across the lower end of a run or pool, and a second seine was stretched across the stream approximately 10–30 m upstream from the lower seine. The second seine, which was usually shorter, was moved quickly downstream, crowding fish toward the

TABLE 1.—Numbers of wild and hatchery-reared spring and summer chinook salmon collected, PIT-tagged, and released in Idaho and Oregon, and their mean fork lengths and weights, 1988 through early 1991.

Tagging location or statistic	Number of fish collected	PIT-tagged and released fish		
		Number	Mean length (mm)	Mean weight (g)
Idaho wild chinook salmon, 1988–1989				
Crooked River	2,479	2,464	69	3.8
Red River	3,602	2,532	75	5.0
East Fork Salmon River	745	724	74	5.6
Upper Salmon River	2,789	2,720	75	5.1
Alturas Lake Creek	415	415	83	7.0
Valley Creek	2,521	2,251	66	3.5
Secesh River	2,349	2,178	69	4.1
Lake Creek	678	664	66	3.6
South Fork Salmon River	2,968	2,184	63	3.4
Total or mean	18,546	16,150	70	4.3
Oregon wild chinook salmon, 1988–1989				
Upper Grande Ronde River	3,044	2,984	68	3.6
Imnaha River	1,339	1,207	70	3.4
Total or mean	4,383	4,191	69	3.5
Hatchery-reared chinook salmon, 1988–1989				
Lookingglass Creek Hatchery		10,012	127	
Sawtooth Hatchery				
Fall release		2,054		
Spring release		10,073	117	
McCall Hatchery		2,411		
Total or mean		24,550	122	
Idaho wild chinook salmon, 1989–1990				
Sulphur Creek	2,599	2,509	70	3.8
Elk Creek	16	16	73	4.2
Marsh Creek	2,810	2,496	67	3.6
Bear Valley Creek	1,610	1,557	68	4.2
Valley Creek	3,342	2,498	66	3.7
Alturas Lake Creek	1,107[a]	1,036	77	5.7
Upper Big Creek	2,456	2,026	65	3.7
Secesh River	2,542	2,359	66	3.1
Total or mean	16,482	14,497	68	3.7
Oregon wild chinook salmon, 1989–1990				
Lostine River	84	84	70	4.8
Imnaha River	2,106	1,986	73	3.8
Total or mean	2,190	2,070	73	3.8
Hatchery-reared chinook salmon, 1989–1990				
Dworshak Hatchery		6,629	113	19.5
Sawtooth Hatchery		9,943	120	20.3
Total or mean		16,572	117	20.0
Idaho wild chinook salmon, 1990–1991				
Bear Valley Creek	358	352	69	4.7
Elk Creek	257	247	76	6.1
Valley Creek	1,089	1,023	68	4.3
Cape Horn Creek	175	164	69	4.6
Marsh Creek	889	861	71	4.9
East Fork Salmon River	573	532	78	6.3
South Fork Salmon River	1,024	986	65	3.4
Upper Big Creek	749	724	67	4.2
Secesh River	1,131	1,016	61	2.9
Total or mean	6,245	5,905	68	4.2
Oregon wild chinook salmon, 1990–1991				
Catherine Creek	1,018	1,012	80	6.3
Lostine River	1,019	1,006	77	4.8
Imnaha River	346	327	69	3.9
Total or mean	2,383	2,345	77	4.2[b]

TABLE 1.—Continued.

Tagging location or statistic	Number of fish collected	PIT-tagged and released fish		
		Number	Mean length (mm)	Mean weight (g)
Hatchery-reared chinook salmon, 1990–1991				
Dworshak Hatchery		6,741	116	19.2
Sawtooth Hatchery		7,085	114	18.2
McCall Hatchery		400		
Total or mean		14,226	115	18.7

[a] Most of these fish were probably hatchery parr.
[b] Only 6.9% of tagged fish were weighed.

lower seine. As the lead line of the upstream seine crossed the lead line of the downstream seine, the lower seine was pulled up out of the water, trapping the fish. A box trap was used to collect fish in only one stream, the Imnaha River in Oregon.

Captured fish were maintained in water and transferred in a watertight sanctuary dip net (Matthews et al. 1986) to a 20-L bucket. They were held in live cages prior to tagging. All activities stopped when water temperatures reached 16°C or when any other observations suggested fish stress.

We used electrofishing to collect fish only when absolutely necessary, such as in difficult terrain or when parr densities were low. We used Smith-Root[2] model 12 units and the techniques and settings recommended by the manufacturer. Stunned fish were collected from the river with standard dip nets and placed in buckets for transfer to live cages.

Prentice et al. (1990c) described in detail the components and setup of a PIT tagging station. For this study, tagging operations were conducted with portable PIT tagging stations designed for field use beside streams. Components of each station included an electronic balance, digitizer, tag detector, and automatic tag injector. A multiport controller electronically directed the flow of information between the computer and other components of the station. A 12-V battery powered the entire station, except the balance, which was powered by a small external battery. The automatic tag injector used a pushrod system, activated by high-pressure carbon dioxide, to inject tags into the fish. Each injector was fed by clips containing approximately 150 PIT tags each.

To prepare the system to mark fish, a program and a data diskette were inserted into the computer, and the file name was designated to receive data. Header information at the beginning of each file included file name, creation date and time, tagger, species, run, rearing type, brood year, migratory year, tag site, raceway or transect, capture method, water temperatures at tagging and release, tagging method, agency, coordinator identification, comments, release date and time, release location, and release river kilometer.

Fish were anesthetized in tricaine (MS-222, about 40 mg/L). Anesthetized fish of other species and chinook salmon parr that were injured, descaled, or less than 55 mm fork length were sorted and rejected. Each remaining chinook salmon parr was injected with a PIT tag according to the technique described by Prentice et al. (1990c). Tagged fish were then passed through the detector loop, which entered the tag code into the computer, and placed on the electronic balance; the weight in grams was automatically entered into the computer. Finally, we placed the fish on the digitizing board, activated an electronic stylus at the fork of the tail, and recorded the length in millimeters in the computer. The digitizer assembly included a grid or menu of individual comments or commands that could be activated by the stylus for any fish. Using the computer keyboard, we could add other comments to the data sets of individual fish.

Tagged fish were allowed to recover in a bucket of freshwater, transferred back to a live cage in the stream, and held for a minimum of 0.5 h before they were released back into the stream. Tagged fish were released as close as possible to the location from which they had been collected. To evaluate tag loss and delayed mortality, about 10% of the tagged fish from most streams were held in live cages for 24 h. We chose that time period because of scheduling restrictions and container holding size.

Tagging of hatchery fish.—To develop comparable data on hatchery-reared fish, we PIT-tagged spring chinook salmon parr at Sawtooth Fish

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[2] Reference to trade names does not imply endorsement by the National Marine Fisheries Service.

Hatchery in Idaho for all three migration years, Dworshak National Fish Hatchery in Idaho for the 1990 and 1991 migration years, and Lookingglass Creek Fish Hatchery in Oregon for the 1989 migration (Figure 1). Smolts were released from Sawtooth Hatchery on 13 March 1989, 17 March 1990, and 21 March 1991; from Dworshak Hatchery on 4 April 1990 and 3 April 1991; and from Lookingglass Creek Hatchery on 3 April 1989. Fish tagged at Dworshak and Sawtooth hatcheries for the 1990 and 1991 migrations were tagged by the National Marine Fisheries Service (NMFS) for a U.S. Fish and Wildlife Service (USFW) pilot study on bacterial kidney disease (BKD) (Pascho et al. 1991, 1993). The Idaho Department of Fish and Game (IDFG) PIT-tagged another group of spring chinook salmon parr at Sawtooth Hatchery and released them on 6 October 1988. Groups of summer chinook salmon at McCall Hatchery in Idaho (Figure 1) were released with normal production fish in the South Fork Salmon River on 21 March 1989 and 18 March 1991 by the IDFG. We were permitted to use the IDFG and the BKD pilot-study releases in our migration study.

At the hatcheries, fish for tagging were obtained from normal production lots, except for the BKD pilot study in which segregated production lots were tagged. Fish were crowded in raceways and removed with standard dip nets. Otherwise, all tagging and data storage procedures were similar to those previously described for wild fish. All fish that died before release were scanned, and those with PIT tags were deleted from the release files.

Interrogation of PIT tags at the dam.—At Lower Granite Dam, smolts that were guided from turbine intakes into the juvenile bypass system were interrogated for PIT tags as described by Prentice et al. (1990a). Dates and time of passage were automatically recorded. All detection data were transferred once each day to a mainframe computer operated by NMFS in Seattle, Washington, or to a mainframe computer operated by the Pacific States Marine Fisheries Commission in Portland, Oregon. Detections of PIT-tagged fish at dams below Lower Granite Dam are not presented in this paper.

Results

Fish Collection and Tagging

We released 45,158 PIT-tagged wild spring and summer chinook salmon parr in Idaho and Oregon streams during the study (Table 1). To provide comparable data, 55,348 hatchery-reared chinook salmon smolts were also PIT-tagged and released in Idaho and Oregon.

Average fork lengths and weights of wild fish were less than those of hatchery-reared fish and varied over the three tagging years. Average fork length and weight of Secesh River fish declined; Valley Creek fish measurements were virtually identical in the first 2 years, then increased in the third year. In streams of the Middle Fork Salmon River, parr were generally larger during the third year of the study than during the second year. Density-dependent factors may have contributed to these size differences, because wild chinook salmon parr densities were much lower in both Valley Creek and streams of the Middle Fork Salmon River during the third year. Variability in average fork length and weight of hatchery fish was minimal.

Mortality and tag loss were low in all 3 years (Table 2). The slight increase in collection mortality in Idaho in 1990 was probably due to electrofishing. In 1988 and 1989, parr densities were high enough in most streams for us to collect sufficient numbers of fish by seining. Overall mortality from tagging declined over the course of the study as our fish-handling and tagging techniques improved. We held 4,977 fish (10.9% of the total tagged) for 24 h in the streams to document delayed mortality and tag loss. Delayed mortality was 1.3%, and tag loss was 0.1%. Overall mortality from collection, tagging, and 24-h delayed mortality tests combined was 1.0%.

Detections at the Dam

Altogether, 10,880 PIT tags were detected at Lower Granite Dam (Table 3). Of these, 2,542 originated from wild releases, 5.6% of the total number of wild fish released and 0.4–15.2% for individual streams over the years. The remaining 8,338 fish originated from hatcheries, constituting 15.1% of all hatchery fish released (annual range, 3.1–29.3%). The overall percentage of released wild fish detected at the dam was lowest in 1989. In part, this was because fish from a few streams (Crooked and Red rivers) in which large numbers of fish were tagged were detected in very low numbers. We did not tag fish in these streams in subsequent years; however, we added streams from the Middle Fork Salmon River. The percentage of released fish detected at the dam varied among streams and hatcheries within years. Overall detection rates (and timing) for both wild and hatchery fish may not be directly comparable between years due to the different stocks and numbers

TABLE 2.—Mortality and tag loss for wild spring and summer chinook salmon collected and PIT-tagged in Idaho and Oregon, summers of 1988–1990.

Tagging location or statistic	Mortality (%) Collection	Tagging	24-h	Overall	24-h tag loss (%)
Idaho, 1988					
Crooked River	0.0	0.4	1.4	0.6	0.3
Red River	1.0	1.5	1.0	2.1	0.0
East Fork Salmon River	2.9	0.4	1.0	3.4	0.0
Upper Salmon River	0.0	0.1	0.0	0.1	0.0
Alturas Lake Creek	0.0	0.0		0.0	
Valley Creek	0.1	0.7	2.6	0.9	0.0
Secesh River	0.3	0.8	1.9	1.5	0.2
Lake Creek	0.1	0.2		0.3	
South Fork Salmon River	0.7	1.7	2.6	2.2	0.0
Mean	0.5	0.8	1.5	1.3	0.1
Oregon, 1988					
Upper Grande Ronde River	0.1	0.3	0.0	0.4	0.4
Imnaha River		0.7		0.7	
Mean	0.1	0.5	0.0	0.5	0.4
Idaho, 1989					
Sulphur Creek	0.2	0.3	0.9	0.6	0.0
Elk Creek	0.0	0.0		0.0	
Marsh Creek	0.1	0.2	5.6	0.8	0.0
Bear Valley Creek	0.1	0.1	0.0	0.2	0.0
Valley Creek	0.1	0.4	2.4	0.6	0.0
Alturas Lake Creek	0.3	0.8		1.0	
Upper Big Creek	0.4	0.3	0.9	0.7	0.5
Secesh River	0.0	0.3	5.1	0.6	0.0
Mean	0.1	0.3	2.4	0.6	0.1
Oregon, 1989					
Lostine River	0.0	0.0		0.0	
Imnaha River		1.1		1.1	
Mean	0.0	1.1		1.0	
Idaho, 1990					
Bear Valley Creek	1.1	0.0	0.0	1.1	0.0
Elk Creek	1.2	0.0		1.2	
Valley Creek	1.1	0.7	0.0	1.7	0.0
Cape Horn Creek	3.4	0.0	0.0	3.4	0.0
Marsh Creek	1.2	0.0	0.0	1.2	0.0
East Fork Salmon River	6.3	0.0	0.6	6.5	0.0
South Fork Salmon River	1.0	0.4	0.0	1.4	0.0
Upper Big Creek	1.0	0.3	0.0	1.2	0.0
Secesh River	0.4	0.1	1.0	0.6	0.0
Mean	1.5	0.2	0.2	1.8	0.0
Oregon, 1990					
Catherine Creek	0.5	0.0	0.6	0.6	0.0
Lostine River	0.1	0.8	1.1	1.2	0.0
Imnaha River		2.1		2.0	
Mean	0.3	0.6	0.9	1.0	0.0

tagged over the years, as well as other factors beyond our control.

During the three smolt migration years, we also tested an apparatus that detected and diverted PIT-tagged fish as they passed through the juvenile bypass and collection system at Lower Granite Dam. In 1990 and 1991, diverted fish were scanned for PIT tags, weighed, and measured. This allowed us to collect information on fork length and weight gains for wild fish from time of tagging until recovery at the dam (Figure 2). In 1990, over an average of 241.5 d, the average gain in fork length was 36.7 mm, and the average gain in weight was 8.3 g. In 1991, over an average of 267.9 d, the average gain in fork length was 38.5 mm, and the average gain in weight was 10.2 g. Using two-

TABLE 3.—Numbers and percentages of released spring and summer chinook salmon smolts that were detected at Lower Granite Dam, 1989–1991. See Table 1 for numbers released.

	1989		1990		1991	
Tagging location or statistic	Number of fish	%	Number of fish	%	Number of fish	%
Wild chinook salmon						
South Fork Clearwater Drainage						
Crooked River	44	1.8				
Red River	21	0.8				
Upper Salmon River Drainage						
East Fork Salmon River	57	7.7			18	3.4
Upper Salmon River	69	2.5				
Alturas Lake Creek	20	4.8	4	0.4		
Valley Creek	65	2.9	76	3.0	41	4.0
Middle Fork Salmon River Drainage						
Sulphur Creek			166	6.6		
Elk Creek			1	6.2	32	13.0
Marsh Creek			178	7.1	59	6.9
Bear Valley Creek			91	5.8	44	12.5
Cape Horn Creek					25	15.2
Upper Big Creek			145	7.2	67	9.3
South Fork Salmon River Drainage						
Secesh River	191	8.8	155	6.6	71	7.0
Lake Creek	51	7.7				
South Fork Salmon River	85	3.9			98	9.9
Northeast Oregon						
Upper Grande Ronde River	242	8.1				
Lostine River			8	9.5	90	8.9
Catherine Creek					77	7.6
Imnaha River	73	6.0	160	8.1	18	5.5
Total or mean	918	4.5	984	5.9	640	7.8
Hatchery-reared chinook salmon						
Lookingglass Creek Hatchery	1,917	19.1				
Sawtooth Hatchery						
Fall release	64	3.1				
Spring release	1,058	10.5	793	8.0	307	4.3
Dworshak Hatchery			1,941	29.3	1,632	24.2
McCall Hatchery	529	21.9			97	24.2
Total or mean	3,568	14.5	2,734	16.5	2,036	14.3

sample *t*-tests, we found no significant differences in overall pooled fork length or weight gains between the 2 years ($P > 0.05$).

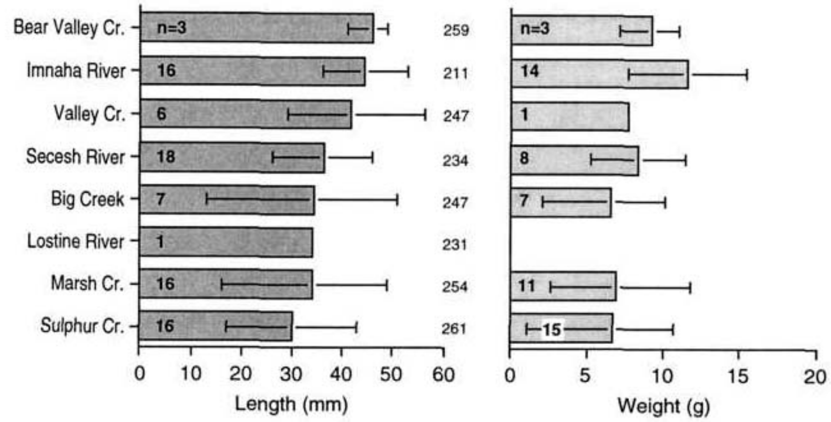
Migration Timing at the Dam

Migration timing at Lower Granite Dam was calculated for combined populations by totaling the detections of groups in 3-d intervals and dividing by the total detected during the season for the same groups. Average river flows were plotted for the same time intervals (Figure 3).

Although the migration of wild spring and summer chinook salmon from individual streams occurred between 4 April and 22 July during the 3 years, patterns were evident from PIT tag detections at the dam. Stocks of wild summer chinook salmon tended to arrive in abundance at the dam earlier than their hatchery-reared counterparts in 1989 and 1991 (no hatchery summer chinook salmon were PIT-tagged for the 1990 migration) (Table 4). Wild summer chinook salmon from the Imnaha River tended to arrive at the dam earlier than any other fish. In all 3 years, peak migration for the combined populations of wild summer chinook salmon occurred in April, coincidental with moderate to low river flows (Figure 3).

Arrival timing of wild spring chinook salmon at Lower Granite Dam varied for fish from different streams and was generally protracted, while that of their hatchery-reared counterparts was compressed and consistent in all three study years (Table 4). Hatchery-reared spring chinook salmon were abundant early, and few were detected at the dam after mid-May. Peak passage occurred during the same 3-d period (22–24 April) in all 3 years, even though river flows varied considerably (Figure 3). By contrast, their wild counterparts were more abundant later in all 3 years, and peak pas-

1990 (April-May)



1991 (April-July)

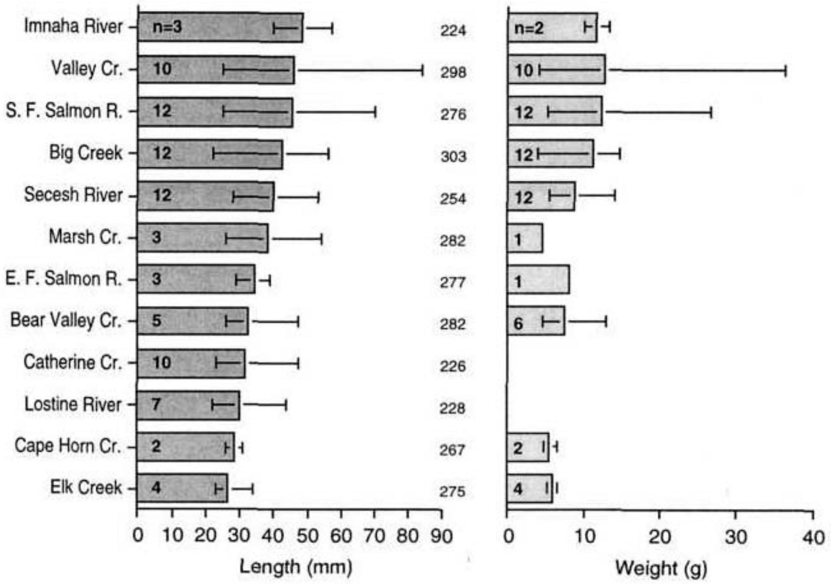


FIGURE 2.—Mean increases in lengths and weights of wild spring and summer chinook salmon from time of tagging in the summers of 1989 and 1990 to time of recovery at Lower Granite Dam in the springs of 1990 and 1991. The number within each bar (n) is sample size, the number at the right of each bar is the average number of days between measurements, and horizontal lines denote ranges.

sage periods generally coincided with periods of peak river flow at the dam (Figure 3). Wild spring chinook salmon from the East Fork Salmon River tended to arrive early, while fish from upper Big Creek were the last to arrive at the dam.

Discussion

Before 1989, knowledge of smolt migration timing of individual populations of wild yearling chinook salmon as they passed through the lower Snake River on their way to the sea was limited. Comparisons with historical migration timing are limited to data reported by Raymond (1979) for individual populations in 1966 and 1967 at Ice Harbor Dam. Raymond's general observations concerning annual variations in peak migration and protracted timing of the migrations of wild fish are similar to ours.

In this study, we cannot offer any conclusions as to why migrational timings differed among

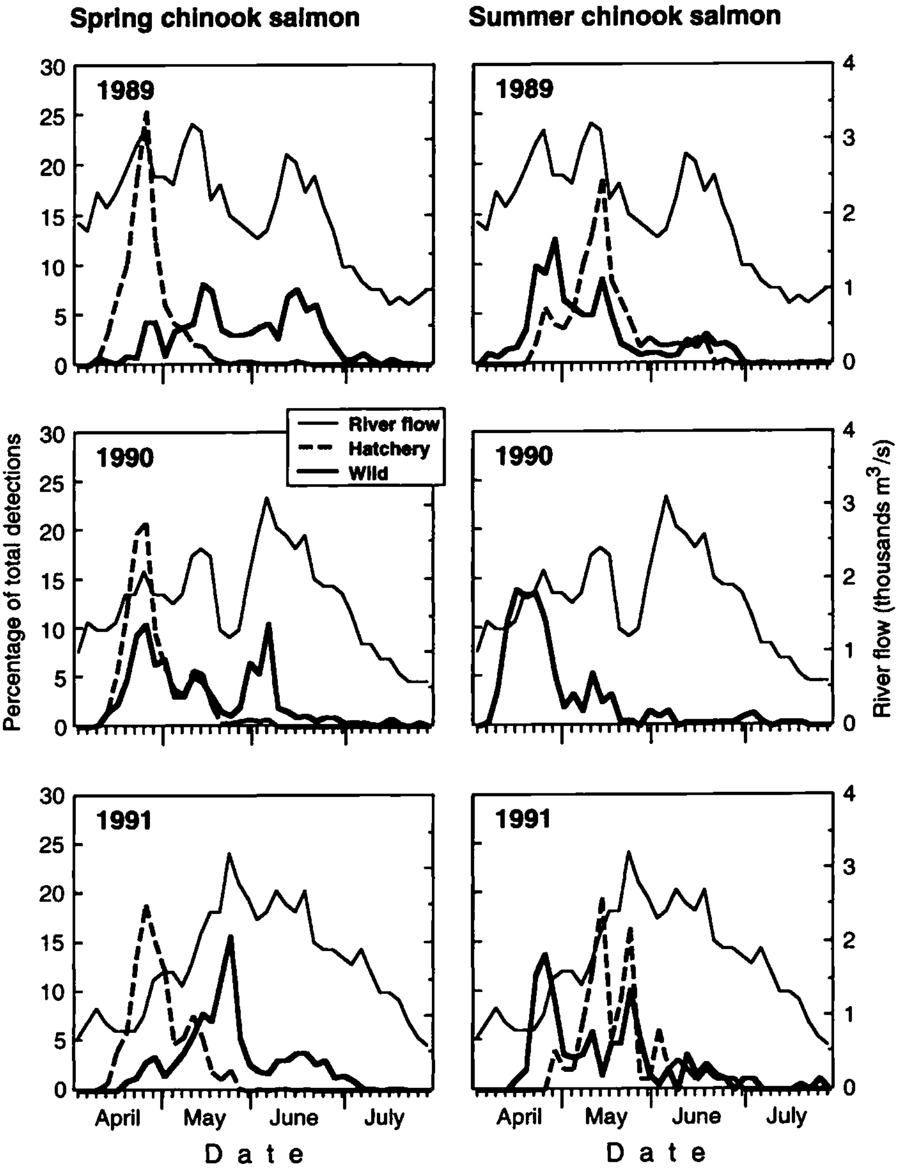


FIGURE 3.—The migration timing of wild and hatchery-reared spring and summer chinook salmon smolts through Lower Granite Dam compared with river flow, 1989–1991. Wild fish and hatchery fish have each been combined in the tag detection plots. The percentages of total detections and river flows are plotted for 3-d periods.

years. We suspect, however, that environmental conditions during the 3 years of our study contributed to the variability observed in the migration timing of wild fish. A late, cold winter and spring and reduced spring water temperatures may have delayed the migrations in 1989 and 1991, even though flows were close to normal in 1989. In 1990, late winter and early spring were mild, and spring water temperatures were warmer than normal. This may have contributed to an earlier migration, even though flows were lower than normal. Raymond (1979) cited water temperature as one of the most important factors that trigger the downstream movement of hatchery-reared and wild chinook salmon smolts in spring.

Because peak passage of wild and hatchery-reared spring and summer chinook salmon coincided with highly variable flows before mid-May in this study, river flow may not be the most important factor affecting migration timing of these

TABLE 4.—Migrational timing of spring and summer chinook salmon smolts from individual Idaho and Oregon streams and hatcheries arriving at Lower Granite Dam, 1989–1991.

Tagging location	Dates at Lower Granite Dam for:			
	50% passage	Peak passage	90% passage	Passage range
Wild spring chinook salmon, 1989				
Crooked River	9 Jun	11, 30 Jun	30 Jun	11 Apr–15 Jul
Red River	26 May	3 May	20 Jun	9 Apr–30 Jun
East Fork Salmon River	3 May	23, 24 Apr	18 May	7 Apr–8 Jun
Upper Salmon River	9 May	26 Apr; 4, 10, 13 May	4 Jun	9 Apr–17 Jun
Alturas Lake Creek	16 May	10, 16 May	6 Jun	24 Apr–8 Jun
Valley Creek	14 May	24 Apr; 3 May; 12 Jun	12 Jun	9 Apr–17 Jun
Upper Grande Ronde River	6 Jun	9 Jun	19 Jun	27 Apr–22 Jul
Hatchery-reared spring chinook salmon, 1989				
Lookingglass Hatchery	21 Apr	22 Apr	29 Apr	8 Apr–3 Jun
Sawtooth Hatchery				
Fall release	25 Apr	22 Apr	11 May	26 Mar–8 Jun
Spring release	25 Apr	22 Apr	11 May	6 Apr–17 Jun
Wild summer chinook salmon, 1989				
Secesh River	27 Apr	21, 25 Apr	9 Jun	9 Apr–19 Jul
Lake Creek	2 May	1 May	16 Jun	12 Apr–1 Jul
South Fork Salmon River	13 May	13 May; 12 Jun	14 Jun	16 Apr–20 Jun
Imnaha River	30 Apr	14, 17 Apr; 4 May	11 May	4 Apr–5 Jun
Hatchery-reared summer chinook salmon, 1989				
McCall Hatchery	10 May	10 May	1 Jun	18 Apr–20 Jun
Wild spring chinook salmon, 1990				
Sulphur Creek	30 Apr	23 Apr	31 May	11 Apr–27 Jun
Marsh Creek	29 Apr	23 Apr	31 May	9 Apr–1 Jul
Bear Valley and Elk creeks	2 May	20, 22, 26 Apr; 31 May	31 May	11 Apr–18 Jul
Valley Creek	8 May	19 Apr; 31 May	5 Jun	12 Apr–29 Jun
Alturas Lake Creek	[a]			20 Apr–30 May
Upper Big Creek	30 May	31 May	22 Jun	17 Apr–18 Jul
Lostine River	[a]			30 Apr–31 May
Hatchery-reared spring chinook salmon, 1990				
Dworshak Hatchery	24 Apr	20 Apr	11 May	9 Apr–2 Jun
Sawtooth Hatchery	22 Apr	22 Apr	28 Apr	7 Apr–31 May
Wild summer chinook salmon, 1990				
Secesh River	22 Apr	14, 19, 20 Apr	7 Jun	10 Apr–13 Jul
Imnaha River	18 Apr	12 Apr	9 May	5 Apr–27 May
Wild spring chinook salmon, 1991				
Bear Valley Creek	20 May	21 May	12 Jun	18 Apr–23 Jun
Elk Creek	20 May	21 May	16 Jun	25 Apr–24 Jun
Valley Creek	20 May	20 May	20 Jun	21 Apr–13 Jul
Cape Horn Creek	16 May	17 May	28 May	19 Apr–6 Jun
Marsh Creek	20 May	20 May	9 Jun	17 Apr–18 Jun
East Fork Salmon River	9 May	23 Apr; 11 May	26 May	16 Apr–20 Jun
Upper Big Creek	10 Jun	14 Jun	26 Jun	26 Apr–1 Jul
Lostine River	14 May	13 May	26 May	20 Apr–9 Jul
Catherine Creek	14 May	12, 20 May	8 Jun	17 Apr–23 Jun
Hatchery-reared spring chinook salmon, 1991				
Dworshak Hatchery	25 Apr	24 Apr	9 May	9 Apr–23 May
Sawtooth Hatchery	3 May	24 Apr	17 May	14 Apr–12 Jun
Wild summer chinook salmon, 1991				
South Fork Salmon River	16 May	20 Apr; 22 May	10 Jun	17 Apr–13 Jul
Secesh River	27 Apr	24 Apr	14 Jun	13 Apr–20 Jul
Imnaha River	1 May	8 May	13 May	14 Apr–15 May
Hatchery-reared summer chinook salmon, 1991				
McCall Hatchery	14 May	12 May	4 Jun	26 Apr–22 Jun

[a] Insufficient numbers detected to estimate timing.

fish before mid-May. However, peak migration periods for wild spring and summer chinook salmon coincided with peak river flows after mid-May, although most migration peaks of wild summer chinook salmon smolts occurred before this time. This suggests that water reserved[3] for migrating fish may be more beneficial to wild chinook salmon smolts if it is released after mid-May in most years, especially years with low streamflows.

We suspect that unusually low overwinter survival, caused by a succession of extreme environmental conditions, contributed to low detections of fish in 1989. Back-to-back droughts resulted in low river discharge in the study streams during summer, fall, and winter 1988. Normally, large numbers of parr migrate downstream out of the upper tributaries in fall (Edmundson et al. 1968; Bjornn 1971; Raymond 1979). The magnitudes of these migrations differ annually and can result in many fish moving far downstream into the larger tributaries, where quality overwintering habitat is more abundant. Factors such as stream discharge, temperature, turbidity, and habitat availability affect the migrations (Bjornn 1971). Low stream discharge may have impeded the fall migrations. Thus, more fish than normal may have remained upstream in the tributaries where quality overwinter habitat was limited.

Little snow fell in most areas of the Snake River watershed in the winter of (1988–1989), and temperatures were very low in midwinter. These conditions, coupled with low stream discharge, probably resulted in ice forming deep into the substrate (anchor ice) and large amounts of ice crystals (frazzle ice) suspended in the water column. These conditions may have hindered the survival of salmon parr burrowed into the substrate during winter (Edmundson et al. 1968).

The winters of 1989–1990 and 1990–1991 were less severe than the winter of 1988–1989. Overall detection rate for wild fish in 1990 is not comparable to the previous year because many streams from the Middle Fork Salmon River were added for the 1990 migration year. Of fish groups from streams tagged in both 1988 and 1989, two had lower and two had higher detection rates at the dam in 1990 than in 1989. In 1991, we documented substantial increases in detections at the dam for fish from most streams in the Middle Fork Salmon River in which we tagged fish in both years. For fish tagged in the remaining four streams, those in two streams had higher and those in two streams had lower detections at the dam than in 1990.

Prior to 1992, decisions on dam operations and the use of stored water in the Snake River basin relied upon recoveries of branded hatchery fish, index counts at traps and dams, and flow patterns at the dams. Since 1992, a more complete approach has included PIT tag detections of several wild spring and summer chinook salmon stocks at Lower Granite Dam. This study provided initial data on the migration timing of some stocks of wild fish and laid the foundation for a long-term study specifically designed to monitor run timing of wild spring and summer chinook salmon smolts at dams on the Snake and Columbia rivers. This extended research will determine if consistent patterns exist and will measure the effects of various environmental factors on migration timing. Information gained in these studies will provide the basis for sound management decisions in the future.

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[3] In recent years, more emphasis has been placed on conserving water in Snake River basin storage reservoirs in advance of the annual smolt migrations. The stored water is then released during the smolt migrations to help move fish through the main-stem hydropower system.

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