Effects of Dams on Redband Trout Life History in the Upper Klamath River: A Summary and Synthesis of Past and Recent Studies

Steven J. Starcevich and Steven E. Jacobs
Native Fish Investigation Project
Oregon Department of Fish and Wildlife
Corvallis, Oregon 97333

William Tinniswood
Klamath Watershed District
Oregon Department of Fish and Wildlife
Klamath Falls, Oregon 97601

December 2006

Abstract

The physical and ecological environment of redband trout in the Upper Klamath River has been altered by hydroelectric dams. Four dams and five distinct river reaches are currently present in the 48-mile section between the outflow of Upper Klamath Lake and the Oregon-California Border. Spencer Creek, which enters the Klamath River just upstream of J.C. Boyle Dam, is an important spawning area and source of juvenile recruitment for redband trout in the upper Klamath River. In 1959, the year after J.C. Boyle Dam was completed, fish ladder trap counts showed adult redband trout migrated upstream in the Klamath River in large numbers to spawn in Spencer Creek. By 1962, trap counts had declined by at least 90%. Despite this decline, studies conducted in the late 1980s showed that a significant spawning run and juvenile outmigration persisted in Spencer Creek. These findings left questions about the extant adult and juvenile life history of Spencer Creek spawning population. We used radio telemetry and PIT-tag technology to address these questions. Our results suggest that, since the construction of J. C. Boyle Dam, upstream movement of adult redband trout to Spencer Creek is uncommon and movement of juveniles from Spencer Creek downstream past the dam may be restricted largely to periods when spill occurs. We also found that the Keno Reach of the Klamath River is the main source of spawning adults in Spencer Creek. In total, these results suggest that diversity of life histories displayed by Spencer Creek spawners has been constricted by the construction of J.C. Boyle Dam. This reduction in life history diversity has likely reduced trout abundance downstream of the dam. These results also show that the extant adult life history is composed largely of a downstream spawning migration in Klamath River to Spencer Creek and a substantial juvenile upstream migration to the Keno Reach.

Introduction

Redband trout in the Upper Klamath basin support diverse life histories. Life histories present in the basin range from headwater populations that complete their life cycle within a few kilometers of their natal stream to fluvial and adfluvial populations that migrate extensively over their life cycle to use riverine and lake habitats for rearing (Benhke 1992, Buchanan et al. 1994). Diverse life histories are important to the stability and persistence of trout populations because

they provide a means of buffering against environmental stochasticity. Alteration of environmental conditions that result in persistent and directional changes in habitat characteristics can reduce life history diversity. The net effect of a reduction in life history diversity can lead to losses of productivity and ultimately reduced viability of populations.

The establishment of impoundments and operations associated with hydroelectric production and irrigation has modified the environment of native redband trout in the Upper Klamath River (Hecht and Kamman 1996, IMST 2003, PacifiCorp 2004a). These modifications include fragmentation of habitats, obstruction of upstream and downstream passage, alteration of stream flow and water quality, and increased competition from introduced species associated with habitat changes. An improved understanding of the life history of these trout populations is needed to address management concerns and guide dam operation protocols that minimize detrimental impacts to these populations. Studies addressing these issues were initiated in the early 1960s and have continued sporadically since then. Most recently, radio telemetry and PIT-tag technology was used to monitor movement patterns of adult and juvenile redband trout. In this paper we summarize findings of past studies, present the results of new research and attempt to synthesize these findings to describe life history features of these redband trout populations and assess how operations of hydro facilities have influenced this life history.

Study Area

The study area encompasses the Klamath River basin between Link River dam (RM 254.3), which is the outlet of Upper Klamath Lake, and Shovel Creek (RM 206.5), which is a tributary of the Klamath River near the Oregon-California border (Figure 1). Within this 48-mile stretch of river, there are three dams, two reservoirs, two important tributaries, and several distinct river reaches. Starting at Link River dam and moving downstream, Link River flows 1.2 miles (1.9 km) to the head of Lake Ewauna, which is now part of the 19.9-mile long reservoir created by Keno dam (RM 231.5). The Keno Reach of the Klamath River flows through a canyon downstream of Keno Dam. The channel is generally broad with rapids, riffles and pocket water among cobble, boulders and bedrock. Flow in the Keno reach is seasonally variable ranging form a few hundred to near 8,000 cfs, depending on natural runoff patterns and irrigation diversion.

The Keno reach ends at the head of Topsy Reservoir (RM 227), which is a 4-mile long impoundment of J. C. Boyle dam (RM 225). Spencer Creek, an important spawning tributary, flows southeasterly from the Cascade Mountains for 18 miles and enters the Klamath River near the head of Topsy Reservoir. There are two channels from J.C. Boyle dam to the power house (RM 219). The Bypass Reach occupies the natural channel of the Klamath River and consists of a series of rapids, runs, and pools flowing through a canyon. Bypass reach discharge is generally about 100 cfs (20 cfs from the fish bypass facility and 80 cfs from the fish ladder and attractor) except for infrequent and short periods of spill, when Klamath River flow exceeds 3,000 cfs. Cool groundwater springs augment flow in this 4-mile reach so that discharge is about 350 cfs

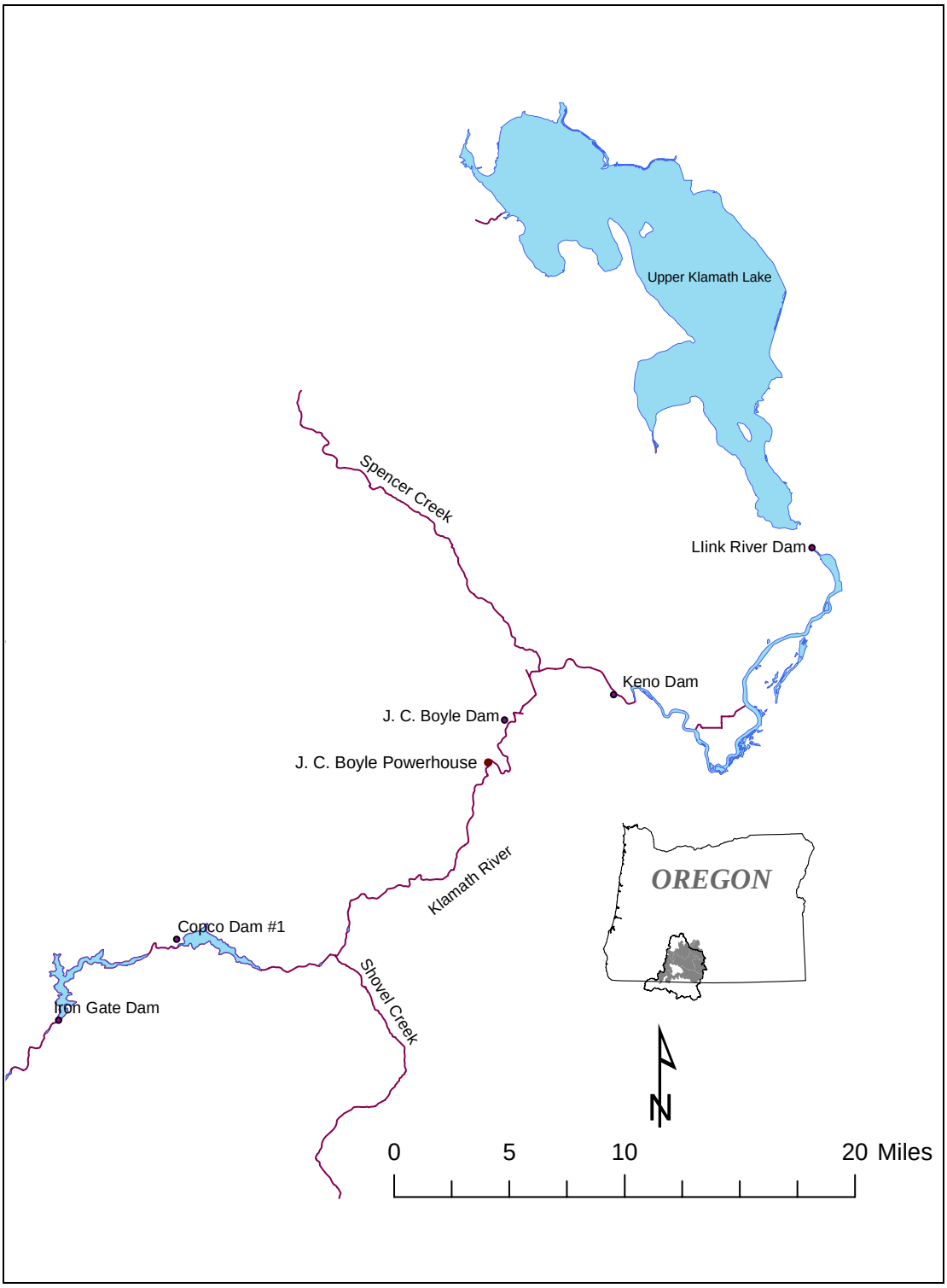

Figure 1. Upper Klamath River showing locations of important spawning tributaries for redband trout and locations of dams and associated hydroelectric facilities. The reach of the Klamath River between J. C. Boyle Dam and J. C. Boyle Powerhouse is referred to as the Bypass Reach and the reach of the river between the J. C. Boyle Powerhouse and the mouth of Shovel Creek is referred to as the Peaking Reach.

when it reunites with the powerhouse outflow. Most of the Klamath River flow is stored at J.C. Boyle Dam and then released through the concrete power diversion canal for peak power production. The volume and duration of flow in the power diversion canal is dependent on the amount of water flowing into and being stored at J.C. Boyle Dam and the hours of peak electrical demand. A typical summer flow scenario is 750 to 1,500 cfs for a few daylight hours for peak power production. The Peaking Reach extends from the J.C. Boyle power house outlet (RM 220.4) to the upper end of Copco Reservoir (RM 203.1) in California. Peaking reach discharge fluctuates daily from about 350 cfs, when there is no power production, up to 1850 cfs during peak power production. Shovel Creek, another important tributary, enters the southern bank of the Klamath River at about RM 206 in California. Since its construction in 1917, Copco Dam has prevented upstream fish passage. Upstream passage at all other dams described in this study is provided by fish ladders.

Spawning Areas and Sources of Juvenile Recruitment

In the study area, redband trout spawning has been documented in Spencer Creek (ODFW unpublished data), Klamath River Bypass Reach (PacifiCorp 2004), and Shovel Creek (Beyer 1984). Based on redd counts and weir trap catches of adult fish moving upstream and juveniles moving downstream, Spencer Creek is considered an important stream for spawning and recruitment of redband trout in the upper Klamath River basin. For example, in 1988, 348 redds were counted in an 8.5 mile reach of Spencer Creek during spawning surveys in April and May (ODFW unpublished data). Similarly, 132 and 113 redds were observed in a 5.4 mile reach of Spencer Creek on a single day during peak spawning in 2003 and 2004, respectively. Because spawning in Spencer Creek is thought to occur from February through June and peak in April and May, these counts probably represent only a fraction of the total annual number of redds.

In 1989-91, ODFW used weir traps in Spencer Creek (0.8 km from the confluence with the Klamath River) to capture upstream and downstream migrant redband trout (Buchanan et al. 1989, 1990, 1991, Hemmingsen et al. 1988, 1992). In 1989, only 42 redband trout were caught in the upstream migrant weir trap; however, high water events and debris in March and April damaged the weir and allowed fish passage around the traps during peak upstream movement of adults and the juvenile outmigration. In 1990, the trap was installed 6 March, operated continuously until 21 May, and captured 926 redband trout (Table 1). In 1991, the trap was installed 21 February (one week after ice left the creek), operated continuously through 21 June, and captured 1,813 redband trout (Table 1). Totals from both years are minimum estimated numbers of redband trout that migrated into Spencer Creek because some fish likely migrated before the weir was installed and traps were damaged periodically by high flows during March and April. Analysis of scales from 99 redband trout captured during April of both years suggested most had migrated from Spencer Creek at ages 1 and 2 (range, 0 to 3), then returned to spawn for the first time at age 3 (range, 2 to 4). Ages of spawning fish ranged from 2 to 8 years (Borgerson 1992).

Table 1. Numbers and lengths of upstream migrant redband trout captured by weir trap in Spencer Creek, 1990 and 1991.

		Fork Length (mm)		
Month	N	Min	Max	Mean
		1990		
March	478	137	590	260
April	438	127	568	332
May	10	283	502	354
Total	926	127	590	295
		1991		
February	9	156	233	199
March	396	150	589	257
April	1,222	152	560	291
May	186	172	530	339
Total	1,813	150	589	283

Downstream migrant juvenile redband trout were captured in 1989-91 by a weir trap installed in Spencer Creek about 50 m upstream from the upstream-migrant trap described above. In 1989, this trap was not installed until June, missing peak flows, and only caught 573 juvenile trout (estimated to be ages 1 to 3, based on size) by the end of the trapping period on 30 September. Seven trout fry (age-0) were caught immediately after trap installation in June. The number of trout fry caught appeared to peak in August (1,425 fry), which was similar to the trap results in 1990-91. In 1990-91, the downstream migrant trap was installed in late March and captured juvenile redband trout the first night of operation. The number of outmigrating juveniles peaked in May when the trap captured nearly 6,000 fish in 1990 and 17,000 in 1991 (Table 2). Catches of juveniles decreased throughout June and July. Catch of age-0 redband trout began in June, peaked in August 1991, and continued until trapping ended in November. In all years, numbers of captured juvenile redband were not adjusted for trapping effort.

Table 2. Monthly trap effort and number of downstream migrant fry (age 0) and juvenile (age 1+) redband trout captured by weir trap in Spencer Creek. In 1990, trapping occurred continuously from 23 March to 28 November, except when a rain-on-snow event disabled the trap from 24 to 30 March. In 1991, trapping began on 22 March and ended on 30 November. In both years, numbers of captured juvenile redband trout were not adjusted for trapping effort and trap efficiency was not estimated.

	1990			1991		
	Trap effort	Number of rainbow trout		Trap effort	Number of rainbow trout	
Month	(hours)	Fry	Juveniles	(hours)	Fry	Juveniles
March	32	0	786	214	0	187
April	701	0	773	673	0	3,198
May	524	0	5,751	725	0	16,996
June	130	18	1,295	678	99	4,723
July	71	54	8	550	534	231
August	66	32	0	716	2,263	54
September	78	184	1	672	883	35
October	118	169	39	522	438	486
November	174	270	156	382	337	119
Total	1,893	727	8,809	5,132	4,554	26,029

Shovel Creek is the only other known spawning tributary of the Klamath River within this study area. Based on the spawning survey and weir trap results of Beyer (1984), Shovel Creek is also important to reproduction of redband trout in the upper Klamath River basin. Only the first 3.2 km are accessible to migrating adult redband trout because of a barrier falls, and spawning mainly occurred in the first 2.4 km (Beyer 1984). In spawning surveys conducted from April through June 1982, 79 redband trout redds were counted (Beyer 1984). Weir traps on Shovel Creek were installed on 31 March and were operated through October 1982. However, the weir was inoperative from 10 to 19 April because of high flows. Upstream migrating fish were caught immediately after traps were installed and the adipose fin was clipped from each fish caught. The run peaked once in late April, again in mid-May, and ended in mid-June. In the upstream migrant trap, 226 adult trout were caught and the male to female ratio did not differ significantly from a 1:1 ratio. In the downstream migrant weir trap, 67 spawned out adults (kelts) were captured and only 12 fish had adipose clips. Based on these data, Beyer estimated the adult migratory population to be 1,187 fish. This population estimate is near the magnitude of historical population estimates of 1,100 fish in 1892 and 1,776 in 1893 trapped at egg taking stations on Shovel Creek (California State Board Fish Commission 1892, 1894). The discrepancy between the relatively low number of redds counted in 1984 and the much larger estimated spawning population may have been caused by high flows and redd superimposition obliterating earlier redds or an inaccurate population estimate (Beyer 1984).

The downstream weir trap in Shovel Creek was operated April through October and captured 104 juvenile redband trout and 2,750 trout fry (Beyer 1984). Similar to Spencer Creek, the outmigration of juveniles (age-1+ and 2+) occurred from April to mid-June and the fry (age-0+) outmigrated peaked in late summer. Unlike Spencer Creek, fry were more abundant than juvenile fish in Shovel Creek and most redband trout appeared to migrate out of Shovel Creek at age-0+ (Beyer 1984). Based on electrofishing 6 segments (15 to 45 m long) or the stream in July and September, over 30,000 trout fry and only 174 juveniles were estimated to reside in Shovel Creek (Beyer 1984).

Redband trout spawning on the mainstem Klamath River is difficult to detect because turbid conditions prevent examining the river bottom except in the shallower stream margins. However, spawning has been documented in the bypass reach of the Klamath River (PacifiCorp 2004). During snorkel and bank surveys on 30 April 2003, 56 redds were counted between RM 221.2 and 222.5 of the Bypass Reach. This was considered a minimum estimate of the total number of redds because turbidity limited observations to the stream margins and the survey occurred on a single day of the spawning period (PacifiCorp 2004b).

Adult Life History

Adult redband life history in the upper Klamath River has been investigated by mark-recapture of fish caught ascending the fish ladder of Link River, Keno, and J.C. Boyle dams, and by using radio telemetry to track movements in several reaches of the upper Klamath River. In 1988 through 1991, fyke traps were installed in the fish ladders of Link River, Keno, and J.C. Boyle dams to capture fish moving upstream (Hemmingsen et al. 1988, 1992; Buchanan et al. 1989, 1990, 1991). Traps were installed in February 1988 and removed in December 1991. They were operated Monday through Friday except during periods when no fish were caught when the traps were operated at least one day each week. All captured trout were measured for fork length, sampled for scales. Fish > 15 cm were marked externally with numbered floy tags.

Link River Dam

At Link River Dam, less than eight redband trout were estimated to ascend annually the fish ladder to enter Upper Klamath Lake in 1988, 1990, and 1991 (Figure 2, Table 3). In 1989, however, 147 fish were estimated to pass upstream over the dam, 94% of which were captured from April to June. Floy tags were inserted in 104 trout over the study period (Table 3) and only 6 were recaptured, all from fish tagged in 1989. Four floy-tagged fish were caught by anglers in Upper Klamath Lake; one was recaptured in December 1990 near spawning areas at Kirk Springs on the Williamson River, a tributary at the north end of Upper Klamath Lake; and another was recaptured in April 1991 in the upstream migrant weir trap of Spencer Creek. No fish floy-tagged at J.C. Boyle Dam, Spencer Creek or Keno Dam were captured at Link River Dam.

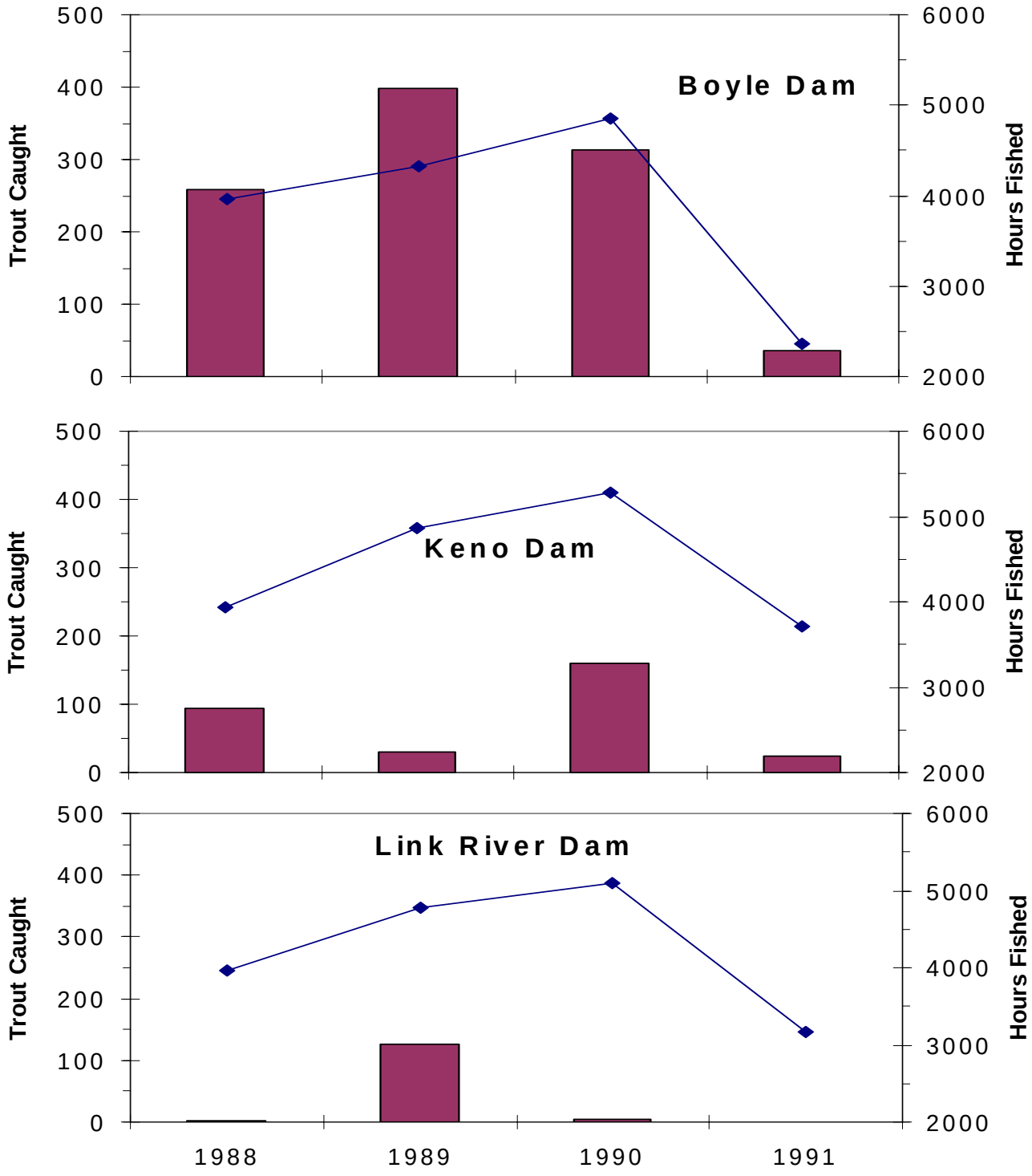

Figure 2. Catch of adult redband trout migrating upstream through the fish ladders of dams in the Upper Klamath River, 1988-91. Also shown is the trapping effort expressed as cumulative hours each trap was operated each year.

Although limited in scope, these results suggest that connectivity between redband trout populations in the Link River Reach of the Upper Klamath River and Tributaries of Upper Klamath Lake is sporadic and represents only a small fraction of the adults produced downstream of Upper Klamath Lake.

Table 3. Estimated number of redband trout captured moving upstream in a fish ladder fyke trap, and total number floy-tagged, at Link River Dam and Keno Dam in 1988-91. Estimates were based on actual catch number expanded for monthly trapping effort.

	Link River Dam		Keno Dam	
Year	Trout (N)	Floy-tagged (N)	Trout (N)	Floy-tagged (N)
1988	6	3	187	86
1989	147	99	54	28
1990	7	1	215	159
1991	2	1	67	30

Keno Dam

At Keno Dam, the estimated number of redband trout ascending the fish ladder alternated from about 200 fish in 1988 and 1990 to 60 fish in 1989 and 1991 (Table 3). Over all years of trap operation, 12% of the estimated number of fish passing over Keno Dam were captured in March and April and 77% were captured in October and November. Over the study period, three of the 303 fish floy-tagged at the Keno Dam trap were subsequently recaptured; one by an angler 200 m downstream of Keno Dam in April 1989, and two others at the downstream migrant trap in Spencer Creek in May 1991. There is no historical information on adult redband trout life history that precedes the construction of Keno Dam so no comparison with recent life history information can be made. Movement timing and the recapture of fish marked at the fish ladder trap at Keno Dam suggest that a substantial number of fish appear to be overwintering between Keno Dam and Link River Dam and returning to Spencer Creek to spawn in spring. Although a small percentage of fish (12%) caught in the Keno Dam trap showed movement timing that suggested spawning may be occurring above Keno Dam, Keno Reservoir has inundated any potential spawning habitat and redband trout spawning has never been observed in Link River.

Radio-tagging and PIT-tagging in the Keno Reach

In 2004-05, we used radio telemetry and half-duplex passive integrated transponder (PIT) technology to gain a better understanding of redband trout life history movements in the Keno Reach of the upper Klamath River. Fish were caught by fly-angling in mid-Keno Reach (RM 229.5) and near Keno Dam (RM 231.5). They were tagged on 26-27 September and 21-22 October 2004 and 14-15 March 2005 with interperitoneal radio transmitters (6 to 18 month battery life) or 23 mm half-duplex PIT-tags.

A total of 36 redband trout were tagged; of these, 23 received radio transmitters and 34 were given PIT-tags. By 17 March 2005, PIT-tag receiver stations were installed and functioning on Spencer Creek, located 30 m upstream from its confluence with the Klamath River (Topsy Reservoir), and in the Bypass Reach of the Klamath River, downstream 200 m from J.C. Boyle Dam. During the spawning period (February through July), radio-tagged fish were tracked an average of every 16 days, with the tracking interval ranging from 3 to 36 days. Through either mobile tracking of radio tags or detecting PIT Tags at the antenna array in Spencer Creek we could account for 17 of the 23 radio tagged fish and 16 of the 34 PIT tagged fish.

Tagged adult redband trout from the Keno Reach of the Klamath River were strongly associated with Spencer Creek during the spawning period and returned to, or near, their tagging location in the Keno Reach after spawning. Eighteen fish were successfully tracked throughout the spawning period or until they were observed in Spencer Creek. Through mobile radio-tracking or detection at the PIT-tag receiver station, 61% (11/18) were observed in Spencer Creek (Table 4). Based on the first and last observations recorded at the PIT-tag receiver station of five of these fish, spawning fish spent an average of 21 days (range, 10–39 days) in Spencer Creek. Another 28% (5/18) were radio-tracked into Topsy Reservoir near the mouth of Spencer Creek (Table 5). These fish entered the reservoir near the beginning of the spawning period, before the PIT-tag receiver station was installed in Spencer Creek, and when the interval (26 days) between tracking observations was greater than the average time spent spawning in Spencer Creek. It is therefore plausible that these fish may have also spawned in Spencer Creek. Only two radio-tagged fish remained in the Keno Reach during the tracking period (Table 4). Of the fish that were tracked to Spencer Creek or Topsy Reservoir during the spawning period, only eight survived spawning and had functioning radio transmitters at the end of the spawning period. All eight returned to the Keno Reach; more specifically, three returned to their tagging location, four were observed within 0.2 miles, and one was last observed 0.6 miles away.

Radio-tracking also showed that some adult redband trout spend part of winter in Keno Reservoir before spawning in Spencer Creek. Two radio-tagged fish climbed the Keno Dam fish ladder and spent at least part of winter in Keno Reservoir. One fish (Tag frequency 900, Table 4) ranged over 11 miles upstream of Keno Dam and was later detected at the PIT-tag reader moving in and out of Spencer Creek during the spawning period. The other fish was observed in Keno Reservoir in early March and not located again.

Table 4. Redband trout radio-tagged and PIT-tagged in the Keno Reach (RM 227-231.5) of the Klamath River in 2004-05 and observed in Spencer Creek. Observations were recorded by PIT-tag receiver station, located on Spencer Creek (<100 m from mouth), and by mobile radio-tracking. First and last observation dates approximate when fish entered and exited Spencer Creek. Two tagged fish remained in the Keno Reach during the spawning season.

Tagging		Frequency	PIT-tag	Length	Weight	Observations (Date, Time)	
Date	RM	(151 MHz)	code	(mm)	(g)	First	Last
			PIT-tag antenna				
9/27/04	229.5	580.34	26967298	495	NA	4/15/05 19:59	4/29/05 4:42
10/21/04	229.5	580.33	33230179	371	691	3/19/05 20:42	4/27/05 23:55
10/21/04	229.5	880	33230216	459	1341	4/17/05 20:50	NA
10/22/04	231.5	900	33230192	397	704	4/16/05 19:17	5/5/05 22:24
3/14/05	229.5	230	33230224	414	966	4/7/05 20:08	5/1/05 3:41
3/14/05	229.5	None	38074696	372	635	3/23/05 19:14	4/3/05 3:10
3/15/05	231.5	740	33230200	414	1010	NA	4/16/05 2:37
			Radio-tracking				
9/26/04	229.5	580.38	None	421	NA	4/14/05	6/6/05 Mort*
10/21/04	229.5	850	33230191	450	1221	3/24/05	NA
10/21/04	229.5	860	33230188	470	1482	5/6/05	6/05/05 Mort*
10/22/04	231.5	890	33230177	501	1553	3/24/05	5/1/05
9/26/04	229.5	580.37	None	422	NA	Remained in Keno Reach	
10/21/04	229.5	580.32	33230186	350	620	Remained in Keno Reach	

* *These fish were spawning mortalities and their carcasses were recovered.*

Table 5. Redband trout radio-tagged and PIT-tagged in the Keno Reach (RM 227-231.5) of the Klamath River in 2004-05 and observed in Topsy Reservoir near the mouth of Spencer Creek (RM 226). First and last observation dates approximate when fish entered and exited Topsy Reservoir and were based on mobile radio-tracking observations. The PIT-tag receiver station was not installed until 16 March 2005.

Tagging		Frequency	PIT-tag	Length	Weight	Observations (Date)	
Date	RM	(151 MHz)	code	(mm)	(g)	First	Last
9/27/04	229.5	580.31	26969603	350	NA	1/3/05	3/2/05
10/21/04	229.5	200	33230180	403	745	12/4/04	2/22/05
10/21/04	229.5	580.35	33230189	348	578	3/2/05	3/11/05
10/21/04	229.5	780	33230181	475	1518	2/3/05	3/11/05
10/22/04	231.5	960	33230214	378	783	12/3/05	3/11/05

J.C. Boyle Dam

There is no information about the abundance and life history of Klamath River redband trout in the Bypass Reach (RM 219-223) prior to the construction of J.C. Boyle Dam. From 1959 to 1963, a fyke trap was operated in the J.C. Boyle Dam fish ladder (Gerlach and Hanel 1964). The annual trap catch was expanded, based on trapping effort, to estimate the total

number of fish passing over the dam. In 1963, the trap was operated intermittently and annual abundance of migratory individuals was not estimated (Gerlach and Hanel 1964). All fish (>200 mm fork length) caught in the trap were marked with metal jaw tags. Trap catch in 1959 and mark-recapture results may represent the best estimate of historical abundance and life history of adult redband trout from the Bypass Reach prior to dam construction.

Trap counts at J.C. Boyle Dam fish ladder from 1959-1962 suggest that following dam construction there was a rapid decline in abundance of adult redband trout migrating upstream past the dam (Figure 3). In 1959, an estimated 5,529 redband trout used the fish ladder to pass over J.C. Boyle Dam. Within 3 years, the estimated number of migrating fish declined almost 60% (N=2,295). The extent of this decline may be underestimated because a significant portion of the run may have been missed in 1959. Trapping in 1959 began on 10 May and 82% of all fish handled in 1961 and 1962 were caught in March and April (Gerlach and Hanel 1964).

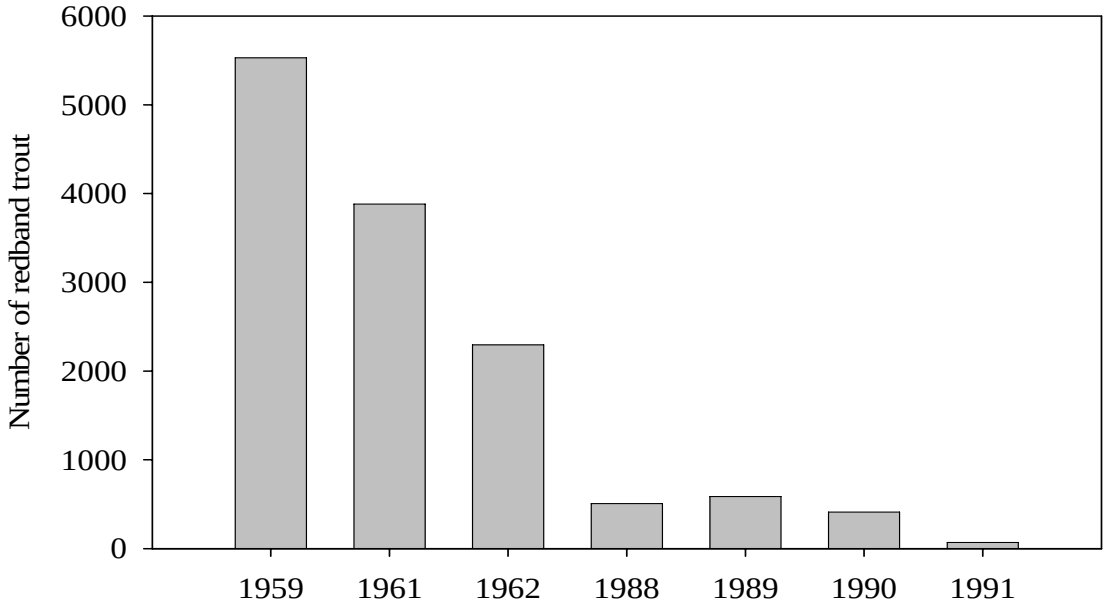

Figure 3. Estimated number, expanded for trap effort, of redband trout captured moving upstream in a fish ladder fyke trap at J.C. Boyle Dam. Construction of the dam was completed in 1958. From 1961 to 1962, and 1988 to 1991, trapping generally occurred from February to December. In 1959, trapping did not begin until 10 May.

Between 1960 and 1963, 866 redband trout were tagged and 12% (N=105) were recaptured by anglers fishing the Klamath River from the Peaking Reach near the Frain Ranch (RM 215) to Keno Dam (RM 231.5). Most of the angler recoveries (84%) were caught in the Bypass Reach (Gerlach and Hanel 1964). These results suggest that at least some of the fish migrating above J.C. Boyle Dam returned to reaches downstream of the dam after spawning, and were strongly associated with the Bypass Reach, however the location of tags recovered by angler harvest was likely influenced by access of fishing sites and therefore may not accurately reflect distribution of post spawning fish. By 1988, the contribution of adult fish from the Peaking Reach to the spawning population above J.C. Boyle Dam appeared to have disappeared.

In fall of 1988, 453 redband trout (>200 mm fork length) were floy-tagged in the Peaking Reach (City of Klamath Falls 1989). None of these fish was recaptured moving upstream in the J.C. Boyle fish ladder trap operated by the ODFW from March 1988 through 1991.

In two other studies in which fish were trapped moving upstream in the J.C. Boyle fish ladder, the results suggested further declines in numbers of redband trout moving upstream of J. C. Boyle Dam. In 1984, the fyke trap was operated, 5 days per week in the spring (April to June) and fall (late August to October, City of Klamath Falls 1990). Only eight trout were captured in the spring period and 130 in the fall period. Movement of redband trout upstream past J.C. Boyle Dam was monitored again using a fyke trap in the fish ladder from February 1988 through December 1991 (Hemmingsen et al. 1988, 1992; Buchanan et al. 1989, 1990, 1991). These totals were expanded to account for trap effort and showed low numbers relative to those in 1959 (Figure 3). Between 1988 and 1990, the estimated total of fish passing over the dam averaged 502 trout (range, 412 to 588), which was less than 10% of the estimated total in 1959. An estimated total of 70 redband trout passed over dam in 1991, which was less than 2% of the estimate in 1959.

In addition to the decline in abundance of upstream migrants following the construction of J. C. Boyle Dam, it appears that there was also a significant decline in fish size. The average length of redband trout captured from the ladder during March through May decreased from 30 cm in 1961 to 18-20 cm in 1989-91 (Figure 4).

Redband trout generally passed over J.C. Boyle Dam from February through November each year. Within each year there were two peaks in abundance of migratory fish, one occurring in April and one in either September or October. From 1988 to 1991, 765 redband trout captured in the trap at J.C. Boyle Dam were floy-tagged and only 4% (N=29) were recaptured. Among the recaptures, three movement patterns were observed. First, mature redband trout that moved past J.C. Boyle Dam in March-May (spring) were recaptured in the Spencer Creek trap 1 to 12 days later. Second, immature redband trout passing J.C. Boyle Dam in spring were recaptured in the Spencer Creek trap during the spawning period the following year, apparently spending summer and winter in Topsy Reservoir or in the Keno Reach of the Klamath River. Finally, 2 recaptured fish that migrated past J.C Boyle Dam in September-October (fall) entered Spencer Creek the following spring, presumably after overwintering in Topsy Reservoir or the Keno Reach. No redband trout tagged at J.C. Boyle Dam was recovered upstream of the Keno Reach of the Klamath River.

Radio-tagging downstream of J.C. Boyle Dam

Recent radio telemetry studies of adult redband trout in the Bypass Reach and Peaking Reach of the Klamath River add further evidence that adult life history connectivity above and below J.C. Boyle Dam has been reduced. PacifiCorp conducted a radio telemetry study in 2003 to gain a better understanding of adult redband trout spawning behavior and to assess passage effectiveness at J.C. Boyle fish ladder and powerhouse tailrace (PacifiCorp 2004b). In 2004, ODFW continued assessing adult redband life history below J.C. Boyle Dam using radio telemetry (ODFW, unpublished data).

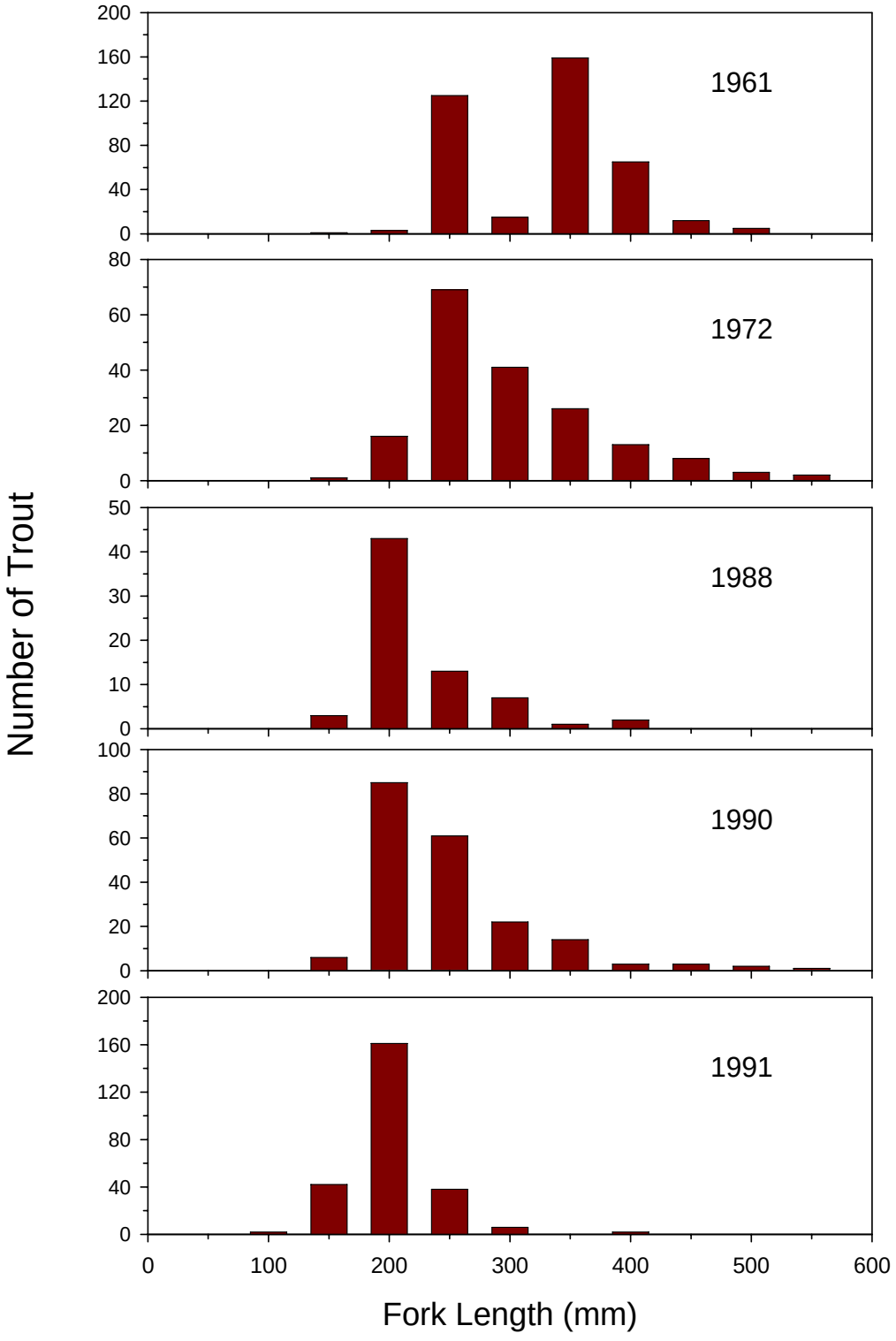

Figure 4. Length Frequencies of Trout captured in the fish ladder of J. C. Boyle Dam during 1961, 1972 and 1988-91.

Both studies showed that radio-tagged redband trout below J.C. Boyle Dam generally moved downstream to spawning grounds in the mainstem Klamath River or Shovel Creek and rarely moved upstream to spawn in Spencer Creek. In February 2003, PacifiCorp tagged 42 adult redband trout with interperitoneal transmitters with 199-day battery life. These were allocated equally to 3 reaches of the Klamath River below J.C. Boyle Dam and were tracked weekly from February through August (Table 6). In the Bypass Reach, 3 (21%) were lost through predation and transmitter failure, or ejection, and were not successfully tracked through the spawning period or to known spawning grounds. Only 1 (7%) fish tagged in the Bypass Reach moved upstream during the spawning period; this fish passed over J.C. Boyle Dam and spent most of April in Spencer Creek and presumably spawned there. Most fish moved downstream during the spawning period, 3 (21%) moved 1-3 miles downstream to known spawning areas in the lower Bypass Reach and 7 (50%) moved into the Peaking Reach (Figure 5).

Table 6. Klamath River reaches as defined by PacifiCorp (2004b), the number of fish tracked through the spawning period (through June) or to known spawning areas, and mean fork length of tagged fish, 2003.

Klamath River Reach	River mile	Number tagged (and tracked)	Mean fork length (range, mm)
Bypass	220-225	14 (12)	281 (254-312)
Upper Peaking	212-220	14 (8)	303 (250-356)
Lower Peaking	205-212	14 (14)	361 (298-429)

In the upper Peaking Reach, 5 transmitters were lost before the end of the spawning period. One was tracked to within 200 m of the J.C. Boyle fish ladder and was subsequently observed below a known heron nesting site alongside J.C. Boyle Reservoir. Two were observed within a mile of Shovel Creek when the transmitters were recovered or deemed ejected. Four fish tagged in the upper Peaking Reach were observed near known spawning areas: 2 (14%) fish were tracked moving downstream 11 miles to spawn in Shovel Creek, and 2 (14%) moved 1-3 miles into the lower Bypass Reach. For redband trout tagged in lower Peaking Reach, 11 (77%) were tracked into Shovel Creek during the spawning period. Based on tag recoveries and carcasses observed, at least 5 of the 13 Shovel Creek spawners were spawning mortalities. One other tagged redband trout moved 15 miles upstream and stopped just downstream of the J.C. Boyle powerhouse tailrace.

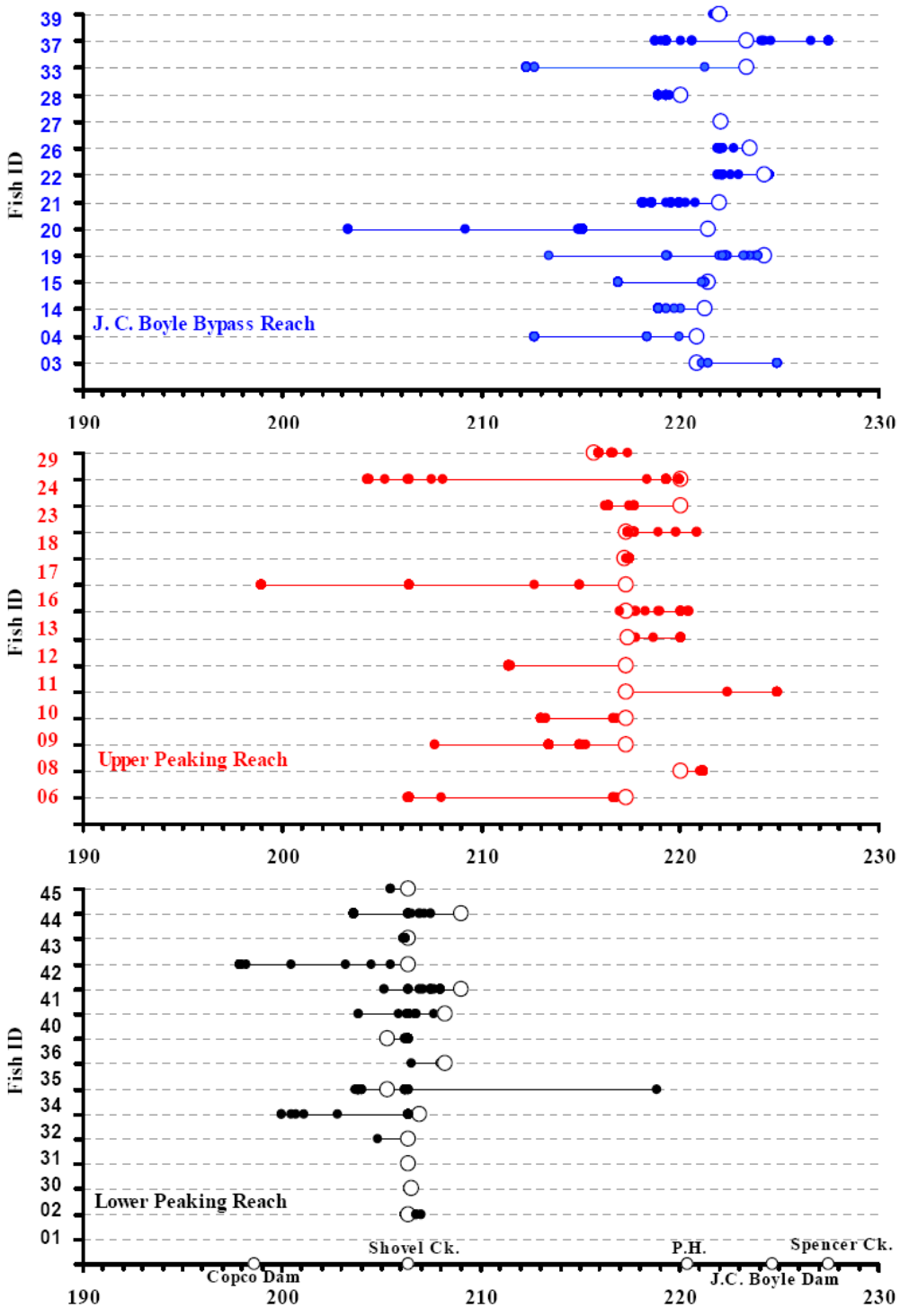

Figure 5. Results of the radio telemetry study conducted by PacifiCorp in 2003. Large open circles represent tag site locations. Small dark circles represent the locations (river mile) where fish were detected in the Klamath River. Figure from PacifiCorp 2004b.

A similar radio telemetry study was conducted by the ODFW in 2004 and produced similar results. From September 2003 to August 2004, seven adult redband trout were tagged in the Bypass Reach of the Klamath River and 65 were tagged in the Peaking Reach. Tagged fish ranged from 220 to 415 mm fork length and were tracked twice weekly until February 2005. This study experienced an unusually high percentage of fish mortality and tag ejection. In the Bypass Reach, only 2 fish were tracked through the spawning period or to known spawning areas. Both moved downstream about 1.5 miles to known spawning areas in the lower Bypass Reach. Two radio-tagged trout from the upper Bypass Reach (RM 221.5) showed upstream movement in fall; both fish were recorded at a fixed telemetry station 150 m below the J.C. Boyle fish ladder (RM 223) in early October and both fish appeared to be preyed upon before climbing fish ladder. One transmitter was recovered in November on the river bank next to a narrow (4-5 m wide) bedrock and boulder shelf that fish must ascend to access the J.C. Boyle fish ladder. The other transmitter was found on Topsy Reservoir shore (RM 225) and was not recorded by either of the two fixed telemetry stations monitoring the fish ladder.

In the Peaking Reach, 27 tagged trout were tracked throughout the spawning period or to known spawning areas (Table 7). Eighteen fish remained in mid Peaking Reach (RM 208-220) during the spawning period and were not observed near known spawning areas. One trout tagged at Frain Ranch (RM 215) moved 6 miles upstream to a lower Bypass Reach spawning area (RM 220) on 20 June, and two others moved 3.5 and 5 miles upstream near the J.C. Boyle powerhouse tailrace but did not move into the Bypass Reach. Tagged trout were also strongly associated with Shovel Creek during the spawning period; three were tracked into Shovel Creek between 9 April and 10 June. Three others were suspected of spawning in Shovel Creek because they were tracked near the mouth of Shovel Creek in early April, were not observed during April and May, then subsequently relocated upstream in mid Peaking Reach. Two others were tracked downstream into Copco Reservoir and may have also spawned in Shovel Creek.

Table 7. Location of radio-tagged trout (>200 mm fork length) during the spawning period. All fish were tagged in the mid-Peaking Reach (RM 214.4-216) and tracked at least once per week. Fish tracked to Copco Reservoir and the mouth of Shovel Creek were not observed for two or more weeks during the spawning period and may have spawned in Shovel Creek undetected by radio-tracking.

Location	River mile	Trout (N)
Copco Reservoir	200	2
Shovel Creek Mouth	206	3
Shovel Creek	206	3
Lower Peaking Reach	208-212	9
Mid Peaking Reach	213-217	7
Upper Peaking Reach	217-220	2
Bypass Reach	>220	1

Juvenile Life History in Spencer Creek

As redd counts and weir trap results have shown, Spencer Creek is a major source of recruitment to the redband trout population of the upper Klamath River (Buchanan et al. 1991; Hemmingsen et al. 1992). However, until recently, little was known about juvenile life history after young fish outmigrated from Spencer Creek. In 1991, over 25,000 juvenile (age-1+) redband trout were captured in the downstream-migrant weir trap and most of them were marked by a caudal clip and released. In order to estimate the magnitude of recruitment of juvenile trout into the Klamath River Bypass Reach, a rotary screw trap was installed in the Bypass Reach (200 m downstream of J.C. Boyle Dam) in April 1991 and operated through May 1992. Over this period, only 54 marked trout from Spencer Creek were recaptured in the screw trap (Table 8). Although these catches were not intended to estimate abundance, the researchers were surprised by the low numbers of juveniles that passed below the dam (Buchanan et al. 1991; Hemmingsen et al. 1992). These results suggested that the operation of J.C. Boyle Dam may impede recruitment of juvenile trout from Spencer Creek to downstream portions of the Klamath River.

Table 8. Number of marked and unmarked juvenile (age-1+) redband trout captured in a screw trap operating in the Bypass Reach of the Klamath River 200 m downstream of J.C. Boyle Dam. In 1991, about 25,000 juvenile trout were caught in a downstream migrant weir trap in Spencer Creek and most of them were marked by a caudal clip and released.

	Juvenile trout	
Date	Unmarked	Marked
	1991	
April	6	2
May	36	38
June	8	8
July	3	0
Aug-Oct	0	0
November	16	1
December	4	0
	1992	
February	3	0
March	4	0
April	14	5
May	4	0
Total	98	54

To gain a better understanding of juvenile redband trout dispersal from Spencer Creek and assess juvenile passage over J.C. Boyle Dam, in 2004 and 2005 we radio-tagged and PIT-tagged outmigrating juvenile trout captured in a weir trap near the mouth of Spencer Creek and tracked their movements. Fixed telemetry receiver stations were installed on J.C. Boyle Dam

and fish ladder, the Klamath River Bypass Reach, and the powerhouse diversion canal (Figure 5). Antennae at each station monitored distinct non-overlapping zones and were able to determine when radio-tagged juveniles entered Topsy Reservoir forebay and if they passed the dam via the juvenile bypass, the fish ladder, or the powerhouse diversion canal. In 2005, a solar powered receiver station was also installed at the upstream end of Topsy Reservoir to monitor fish movement into the first 500 m of the Keno Reach of the Klamath River. Radio-tagged fish were also tracked along a fixed route with a mobile receiver at weekly or shorter intervals from 10 May through 5 July in 2004 and from 7 April through 11 July in 2005. This route covered the Keno Reach of the Klamath River (to Keno Dam), Spencer Creek, Topsy Reservoir, and the Klamath River below of J. C. Boyle Dam downstream to Frain Ranch (RM 215). Additionally, to monitor movements of PIT-tagged fish in 2005, PIT-tag receiver stations (Oregon RFID, http://www.oregonrfid.com/index.html) were installed at the mouth of Spencer Creek and 300 m downstream of J.C. Boyle Dam in the Bypass Reach. Telemetry stations were tested at least monthly, PIT-tag antennae were tested twice weekly, and data obtained from all receiver stations were downloaded at least every week.

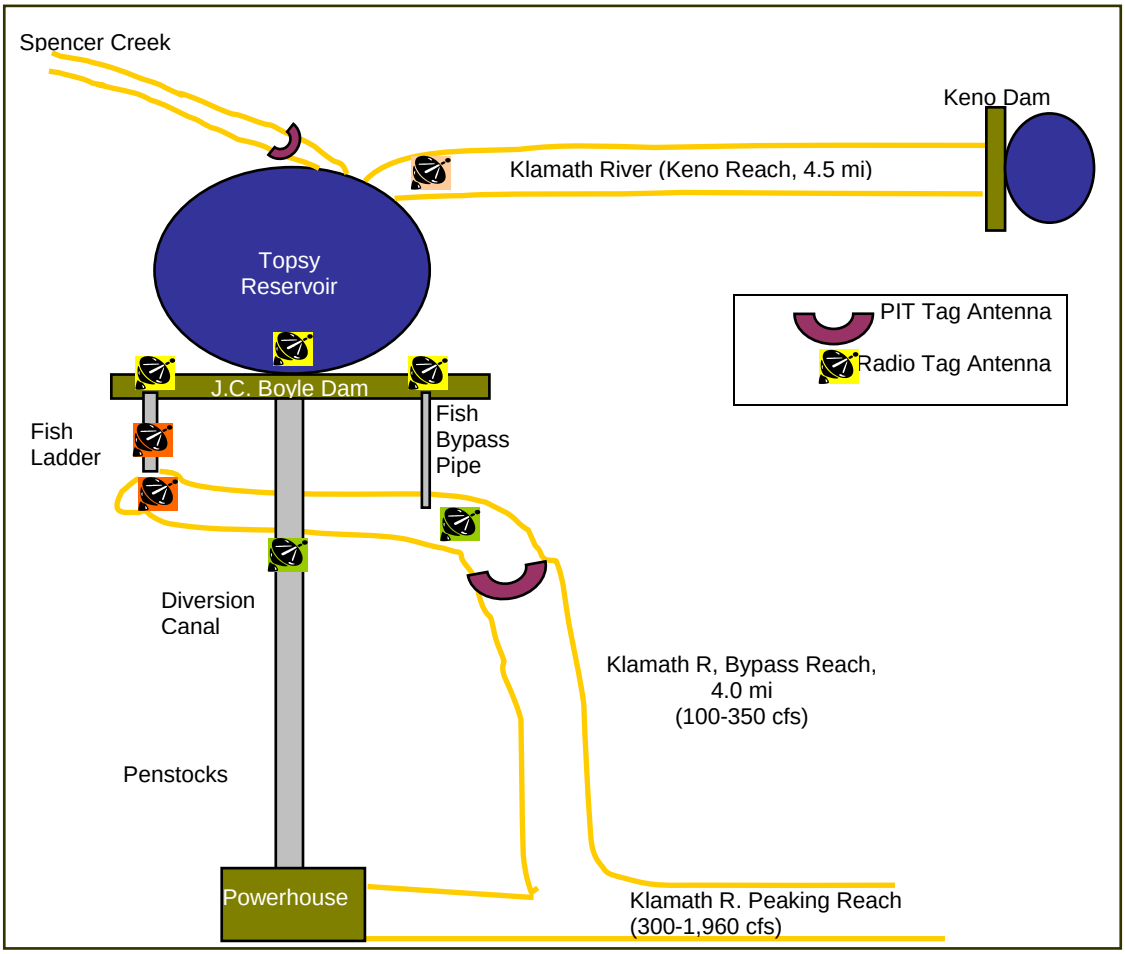

Figure 5. Schematic of fixed radio telemetry antennae and PIT tag antenna arrays used to track movements of juvenile redband trout tagged in Spencer Creek during 2004 and 2005.

The Spencer Creek weir trap was operated 21 April to 7 June 2004 and 24 March to 9 June 2005 and captured about 7,500 and 5,200 redband trout, respectively. Radio-tagging in 2004 began near peak discharge while tagging started a month earlier than peak discharge in 2005 so fish were tagged and tracked throughout a greater proportion of the spring freshet. In 2004, inter-peritoneal radio transmitters (43-day battery life, 1.1 g, Lotek, Inc.) were surgically implanted in 80 juvenile trout. Seventy-three radio-tagged juvenile were tracked for two or more weeks and battery life averaged about five weeks. The median fish fork length was 107 mm (range, 91-174 mm). In 2005, 75 juvenile trout (median fork length, 115 mm) were implanted with radio transmitters (74-day battery life, 1.1 g, Lotek, Inc.), and 307 fish (range, 85-170 mm) received PIT-tags (half-duplex, 23 mm). Radio-tagged trout in 2005 were significantly longer ($p<0.001$) than fish tagged in 2004. Of the radio-tagged trout in 2005, 65 were tracked for two weeks or more and transmitter battery life averaged about six weeks. Radio-tagged trout that were not re-located, or observed only once, after release were not included in the analysis.

In 2004, no radio-tagged juvenile trout from Spencer Creek moved to the Klamath River below J.C. Boyle Dam. By mid July, when all transmitter batteries had expired, 71% of radio-tagged trout remained in lower Spencer Creek and 25% in Topsy Reservoir (Figure 7). Summer growth and survival of juvenile redband trout in lower Spencer Creek and Topsy Reservoir is unknown; however, past studies have shown that the reservoir experiences unstratified water temperatures >25° C and low dissolved oxygen in summer that are stressful to redband trout (http://www.pacificorp.com/File/File16144.pdf). Further, the reservoir contains a high abundance of nonnative fishes relative to redband trout (Desjardins and Markle. 1999) and reservoir water levels fluctuate daily for peak electricity production. These conditions suggest that summer residence in the reservoir and lower Spencer Creek may adversely affect juvenile trout growth and survival. However, in 2004, only one radio-tagged fish was tracked below the dam, but this fish appeared to be preyed upon as the transmitter was not detected by the fixed receiver stations and was found near a known osprey nesting site; and only 11% of radio-tagged trout were observed in the upper reservoir or in the Keno Reach. It should be noted however that tracking methods used in 2004 may have missed fish that moved upstream into the Keno Reach.

Although a substantial proportion (69%) of radio-tagged trout remained in lower Spencer Creek and Topsy Reservoir in 2005, more fish moved upstream toward the Keno Reach after exiting Spencer Creek and recruitment downstream of J.C. Boyle Dam was observed. By mid-July 2005, 34% of radio-tagged trout remained in lower Spencer Creek, 31% (20/65) of the radio-tagged fish ended up in upper Topsy Reservoir or in the Keno Reach, and 17% (11/65) of radio-tagged trout were observed downstream of the dam (Figure 7). Telemetry receiver stations detected one fish moving downstream via the fish ladder, at least four through the fish bypass facility, two via the power diversion canal, and four may have passed over the dam through the spillway during peak discharge in May.

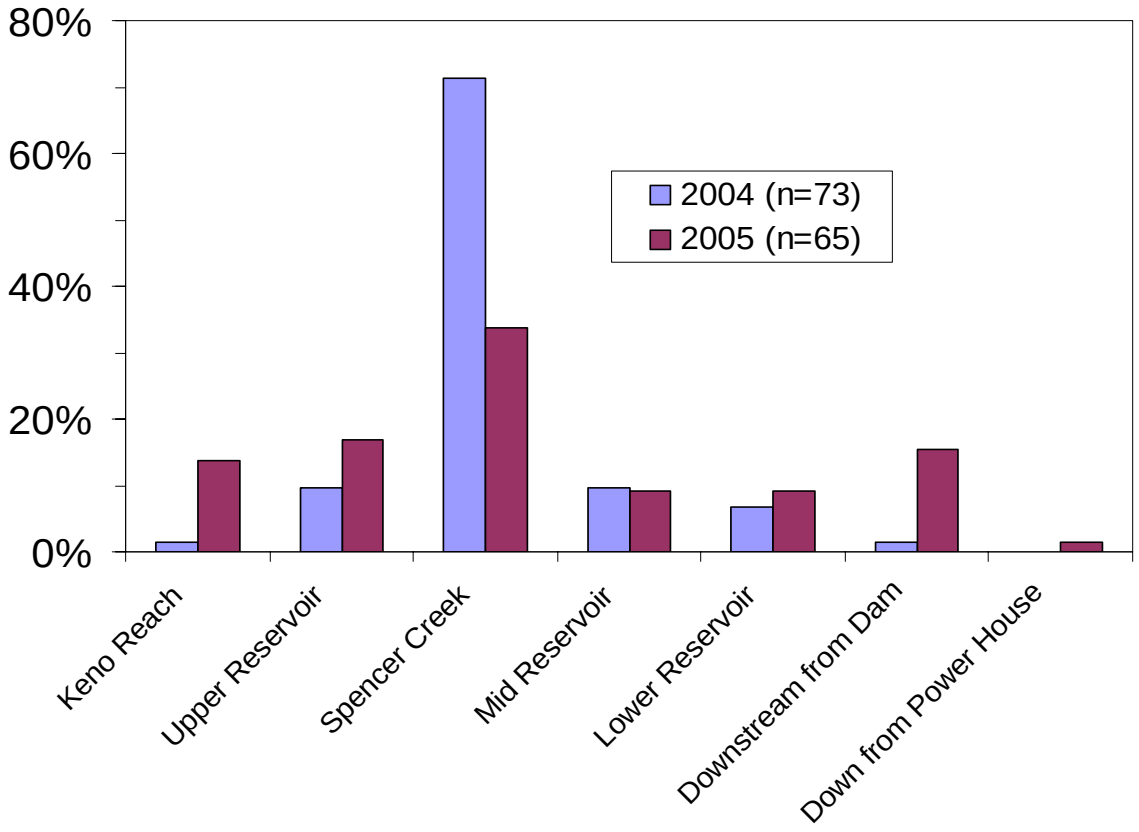

Figure 7. Location of juvenile redband trout, captured and radio-tagged on Spencer Creek, on the final tracking observation in 2004 and 2005.

Differences in juvenile dispersal between 2004 and 2005 appeared to be related to the dramatic differences in Klamath River discharge and operation of J.C. Boyle Dam. In 2005, mean daily discharge was above 3,000 cfs for most of May and peaked at 4,500 cfs. These high flows caused dam operators to open the spillway for two weeks in May and a week June, increasing discharge in the Bypass Reach from 150 cfs to almost 2,000 cfs. Over 70% (8/11) of the downstream passage of juvenile trout over the dam occurred when the dam spillway was open (Figure 8). In 2004, peak discharge on the Klamath River only reached 2,000 cfs and the spillway was not opened during the study period. These results suggest that inter-annual variability in discharge and dam operation affect juvenile fish passage over J.C. Boyle Dam and recruitment to the Bypass Reach of the Klamath River.

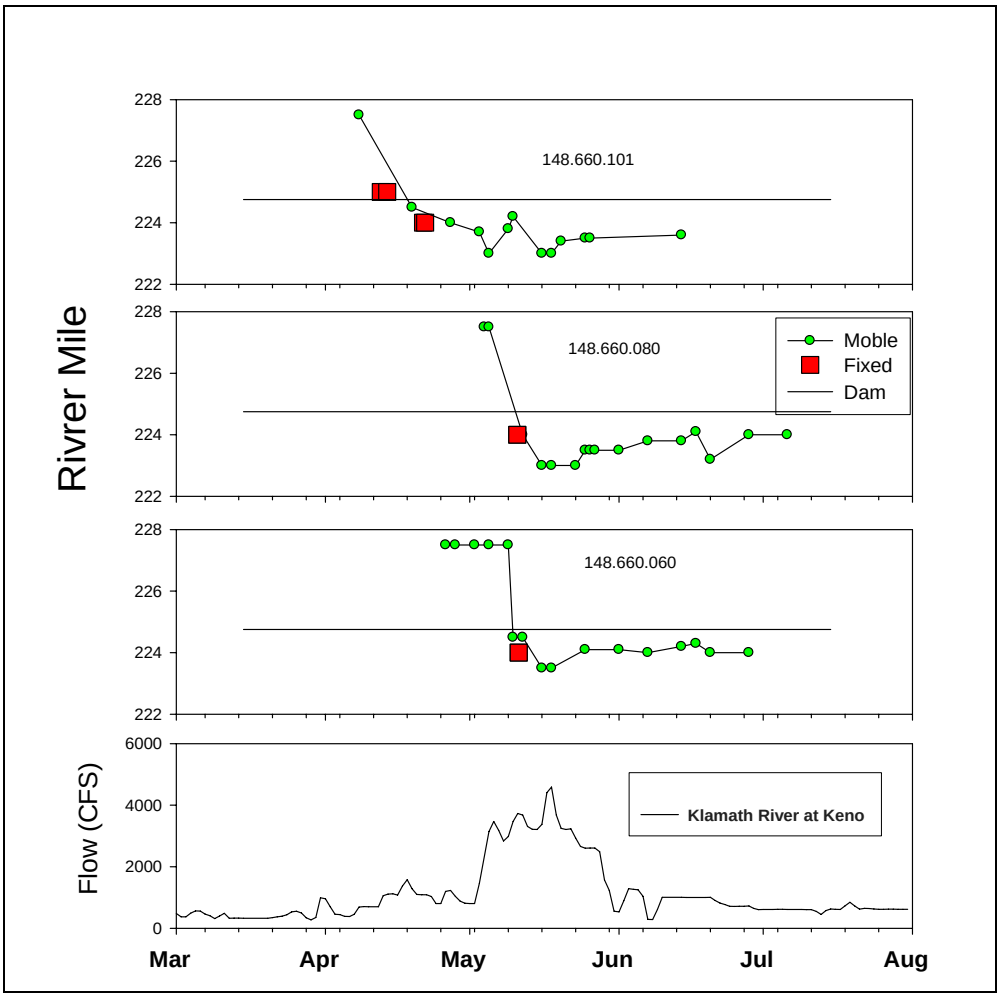

Figure 8. Relationship between passage below J. C. Boyle Dam of radio-tagged juvenile redband trout and Klamath River flow during the Spring of 2005.

Dam operators generally do not spill at J.C. Boyle until Klamath River discharge exceeds 3,000 cfs. Over the past 25 years, the Klamath River exceeded this threshold a median of 4.5 days per year (range, 0-61 days), and in 12 of these years flow did not exceed 3000 cfs (Figure 9). During the years when J.C. Boyle Dam does not spill, juvenile trout recruitment from Spencer Creek to the Klamath River Bypass Reach may be reduced or completely prevented. Recruitment to the Bypass Reach is further reduced by fish entrainment in the powerhouse diversion canal. In 2005, 18% (2/11) of radio-tagged juvenile trout that passed downstream over J.C. Boyle Dam were entrained in the powerhouse canal. One of these ended up as a shed tag in the tailrace of the J.C Boyle Powerhouse. One radio-tagged adult redband trout, 287 mm fork length, was entrained in the power canal, diverted past the Bypass Reach, and ended up residing in the Peaking Reach (PacifiCorp 2004). The intake for the powerhouse canal is screened to prevent fish entrainment, but based on the above observations and annual salvage efforts by PacifiCorp, the screen has not effectively excluded fish (Table 9). PacifiCorp crews drain the 2-mile canal for maintenance at least once per year and, using electrofishers, attempt to salvage redband trout and sucker species from the canal. These fish are counted and transferred to the Peaking Reach of the Klamath River.

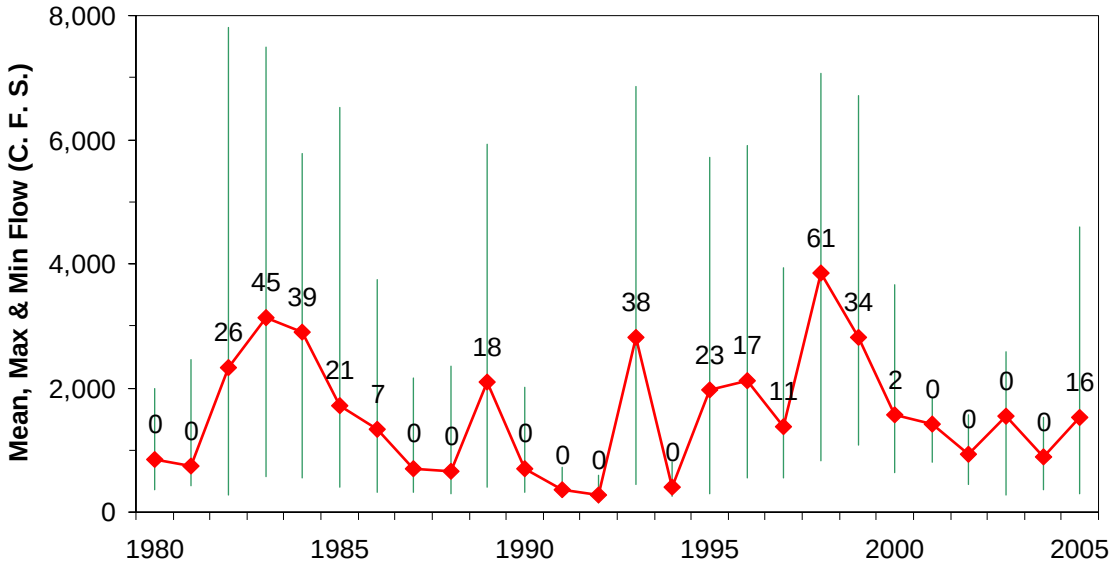

Figure 9. Mean (diamonds), minimum and maximum (vertical bars) flow of the Klamath River at Keno during April through June, 1980-2005. Also show are the total number of days during this period when flow exceeds 3,000 for each year. Flows exceeding 3,000 cfs generally coincide with spill over J. C. Boyle Dam.

In 2005, movement of PIT-tagged and radio-tagged fish in Spencer Creek was similar and suggested that radio-tagging did not adversely affect behavior relative to PIT-tagging. At least 60% (183/307) of the PIT-tagged trout and 65% of the radio-tagged fish outmigrated from Spencer Creek. There were three periods in which the PIT-tag datalogger was deactivated and none lasted more than three days. Of the PIT-tagged fish that outmigrated, over 50% exited one day after release, and 80% left within one week (Figure 10). About 65% of the outmigrating radio-tagged trout left within a week of release. It was not possible to compare PIT-tag and radio-tag results for the Bypass Reach because the PIT-tag antenna was disabled on two occasions when the J.C. Boyle spillway was opened during high flows in May and June.

Table 9. Number of redband trout salvaged from J.C. Boyle powerhouse diversion canal.

Year	Trout (N)
1996	81
1997	365
1998	63
1999	106
2000	NA
2001	78
2002	6
2003	88
2004	92
2005	750

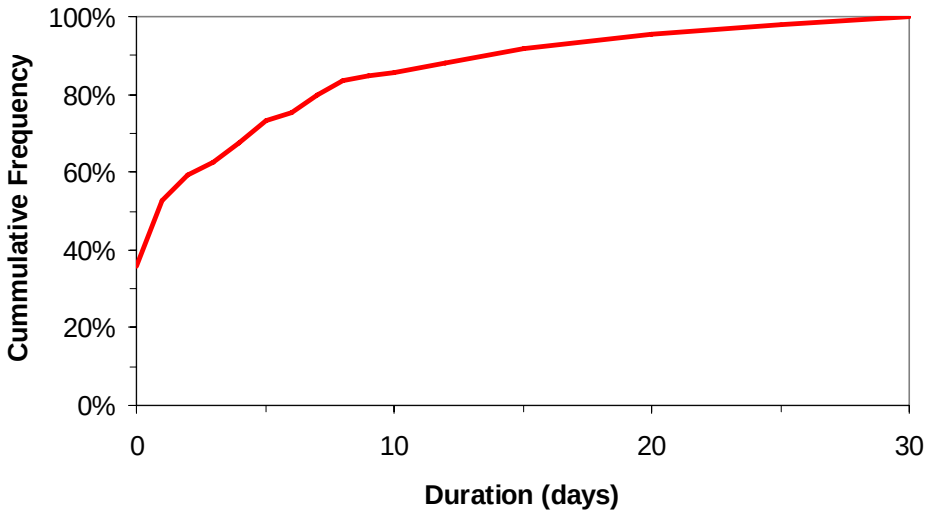

Figure 10. Cumulative frequency distribution of movement of PIT-tagged juvenile redband trout past the interrogation antenna in lower Spencer Creek, 2005.

Conclusions

The physical and ecological environment of redband trout in the Upper Klamath River has been altered by hydroelectric dams. These alterations have also affected redband trout life history and abundance. Recent and past studies of redband trout in this region provide important information on the current status and life history of redband trout, and highlight impacts since dams were constructed, that may aid in managing for long-term sustainability of these populations.

First, Spencer Creek is the only known spawning area and source of juvenile recruitment in the upper Klamath River basin upstream of J.C. Boyle Dam and Spencer Creek spawners had diverse life histories. Prior to the construction of Copco Dam in 1918, Spencer Creek likely served as a spawning site for steelhead as well as resident redband trout (Hamilton et al. 2005). In 1959, the year after J.C. Boyle Dam was completed, adult redband trout migrated from what are now known as the Peaking Reach and Bypass Reach of the Klamath River in large numbers to spawn in Spencer Creek and then returned to these reaches after spawning (Gerlach and Hanel 1964). Currently, the upstream migratory life history of the peaking reach population appears to be gone and the upstream migratory life history of the Bypass Reach population has been reduced to less than 10% of historical abundance and is composed of significantly smaller trout.

There appears to be multiple factors leading to the decline in abundance and size of adult redband trout migrating upstream over J.C. Boyle Dam. First, the dam is managed solely for hydroelectric power production and, during base flow conditions, at least 80% of the Klamath River discharge is stored in the reservoir and then diverted through the powerhouse diversion canal. Therefore, for most of the year, the Bypass Reach experiences less than 20% of the natural flow regime, this reduces habitat volume and carrying capacity in this reach. Second, dam operators generally only spill water when Klamath River discharge exceeds 3,000 cfs. This

flow threshold occurs infrequently, typically only a short period in spring of water years with high discharge. Short, unpredictable, and infrequent periods of spill at J.C. Boyle Dam appear to reduce recruitment of juvenile migrants from Spencer Creek to the Bypass Reach. A substantial proportion of juvenile trout dispersing downstream are also entrained in the powerhouse canal, which contributes to the reduction in juvenile recruitment to the Bypass Reach. Third, construction of the dam and powerhouse canal maintenance road along the Bypass Reach has improved angler access to this reach and may have increased angler harvest from this section of the river (Gerlach and Hanel 1964). Finally, construction of the dam and fish ladder has substantially restricted passage opportunities for upstream migrating. While the fish ladder appears to be passable for sub-adult and adult redband trout, it appears to have excluded other species and created a passage bottle-neck that may increase predation of redband trout attempting to enter ladder.

Adult redband trout from the Bypass Reach are now more strongly associated with spawning areas in the lower Bypass Reach and possibly locations in the Peaking Reach. Adult trout from the upper Peaking Reach downstream to near Copco Reservoir are strongly associated with Shovel Creek during the spawning period and the upper Peaking Reach contributes some fish to the spawning population in the lower Bypass Reach.

From 1988 to 1991, the observed numbers of adult redband trout that entered Spencer Creek were clearly larger than the estimated numbers that passed J.C. Boyle Dam in respective years. Redband trout from as far upstream as Upper Klamath Lake have been observed spawning in Spencer Creek. The Keno Reach of the Klamath River, in particular, appears to be the primary source of spawning adults for Spencer Creek. Substantial proportions of Keno Reach adults spend at least part of winter in Keno or Topsy Reservoirs and generally return to the Keno Reach shortly after spawning in Spencer Creek. Juvenile recruitment from Spencer Creek to the Keno Reach and the upstream end of Topsy Reservoir occurs in both low and high discharge years.

Acknowledgements

We wish to thank Trent Hartill, Alex Higgins, Randy Roe and Matt Weeber for assisting with the field studies conducted during 2003-05. Al Hemmingsen did the initial planning and preparation for the juvenile movement study and, along with Dave Buchannan and Rod French, conducted much of the initial research on Upper Klamath redband trout. This work was supported through funding obtained from the Sport Fish Restoration Program of the U. S. Fish and Wildlife service.

References

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society Monograph 6. American Fisheries Society, Bethesda, Maryland.

Beyer, J.M. 1984. Rainbow trout fishery and spawning stock in the upper Klamath River wild trout area, Copco, California. Master's thesis, Humboldt State University.

Borgerson, L. A. 1992. Scale Analysis. Oregon Department of Fish and Wildlife. Fish Research Project F-144-R-4, Annual Progress Report, Portland, Oregon.

Buchanan, D.V., A.R. Hemmingsen, D.L. Bottom, R.A. French, and K.P. Currens. 1989. Native Trout Project. Oregon Department of Fish and Wildlife. Fish Research Project F-136-R, Annual Progress Report, Portland, Oregon.

Buchanan, D.V., A.R. Hemmingsen, D.L. Bottom, R.A. French, and K.P. Currens. 1990. Native Trout Project. Oregon Department of Fish and Wildlife. Fish Research Project F-136-R, Annual Progress Report, Portland, Oregon.

Buchanan, D.V., A.R. Hemmingsen, D.L. Bottom, P.J Howell, R.A. French, and K.P. Currens. 1991. Native Trout Project. Oregon Department of Fish and Wildlife. Fish Research Project F-136-R, Annual Progress Report, Portland, Oregon.

Buchanan, D.V., A.R. Hemmingsen and K.P. Currens. 1994. Native trout project. Oregon Department of Fish and Wildlife, Fish Research Project F-136-R-07, Annual Progress Report, Portland, OR.

California State Board of Fish Commissioners. 1892. Biennial report for the years 1891- 1892. Sacramento, California. 65pp.

California State Board of Fish Commissioners. 1894. Thirteenth biennial report for the years 1893-1894. Sacramento, California. 143 pp.

Desjardins, M. and D.F. Markle. 1999. Distribution and Biology of Suckers in Lower Klamath Reservoirs. 1999 Final Report. Submitted to PacifiCorp by Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.

Gerlach, A.R., and C.J. Hanel. 1964. Klamath River flow study at J.C. Boyle Project. Oregon Game Commission and Pacific Power and Light Company.

Hamilton, J. B., G. L. Curtis, S. M. Snedaker, and D. K. White. 2005. Distribution of Anadromous Fishes in the Upper Klamath River Watershed Prior to Hydropower Dams-A Synthesis of the Historical Evidence. Fisheries 30:5-36.

Hecht, B. and G. R. Kamman. 1996. Initial assessment of pre- and post-Klamath project hydrology on the Klamath River and impacts of the project on instream flows and fishery habitat. Balance Hydrologies, Inc.

Hemmingsen, A.R., D.V. Buchanan, D.L. Bottom, R.A. French, K.P. Currens, and F.C. Shrier. 1988. Native Trout Project. Oregon Department of Fish and Wildlife. Fish Research Project F-136-R, Annual Progress Report, Portland, Oregon.

Hemmingsen, A.R., R.A. French, D.V. Buchanan, D.L. Bottom, and K.P. Currens. 1992. Native Trout Project. Oregon Department of Fish and Wildlife. Fish Research Project F-136-R, Annual Progress Report, Portland, Oregon.

Hemmingsen, A.R., and D.V. Buchanan. 1993. Native Trout Project. Oregon Department of Fish and Wildlife. Fish Research Project F-136-R-6, Annual Progress Report, Portland, Oregon.

IMST (Independent Multidisciplinary Science Team). 2003. Review of the USFWS and NMFS 2001 Biological Opinions on Management of the Klamath Reclamation Project and Related Reports. Technical Report 2003-1. Available at: http://www.fsl.orst.edu/imst/reports/klamath.html.

PacifiCorp. 2004a. Klamath Hydroelectric Project (FERC Project No. 2082) Water Resources. FINAL TECHNICAL REPORT. PacifiCorp Portland, Oregon. Available at: http://www.pacificorp.com/Article/Article28659.html.

PacifiCorp. 2004b. Adult rainbow trout movement study, Klamath River, 2003. PacifiCorp Portland, Oregon. Available at: http://www.pacificorp.com/Article/Article35478.html.

Zydlewski G., A. Haro, G. Whalen, D. McCormick. 2001. Performance of stationary and portable passive transponder detection systems for monitoring of fish movements. Journal of Fish Biology. 58:1471–1475