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

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Abstract

In the 77-km section of the Klamath River, between the outflow of Upper Klamath Lake and the Oregon-California Border, the physical and ecological environment of redband trout *Oncorhynchus mykiss newberrii* has been altered by four hydroelectric dams. 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 raised questions about the adult and juvenile life history of the Spencer Creek spawning population. We used radio telemetry and PIT-tag technology to address these questions. Our results show that upstream movement of adult redband trout over the dam to Spencer Creek is rare and suggest that the Keno Reach of the Klamath River is the main source of spawning adults in Spencer Creek. We also found that movement of juveniles from Spencer Creek downstream past the dam has been restricted to those infrequent periods when spill occurs. These findings suggest that the life history diversity displayed by Spencer Creek spawners has been constricted by J.C. Boyle Dam, likely reducing trout abundance and productivity downstream of the dam.

Introduction

Redband trout *Oncorhynchus mykiss newberrii* life histories 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 (Behnke 1992; Buchanan et al. 1994). Life history diversity is important to the stability and persistence of trout populations, because it provides the ability to exploit a diversity of available habitats and thus provides a means of buffering against environmental stochasticity. Alteration of the riverine environment that results in persistent changes in habitat can reduce life history diversity. The net effect of a reduction in life history diversity can lead to reduced population productivity and viability.

Dams and associated management for hydroelectric production and irrigation have modified the environment of native redband trout in the Upper Klamath River (Hecht and Kamman 1996; IMST 2003; PacifiCorp 2004a). These changes include habitat degradation, passage obstruction, dampened peak flows, poor water quality, and increased competition from introduced species.

An improved understanding of the life history of these trout populations is needed to address

management concerns and guide fish passage and dam operation protocols that minimize detrimental impacts. 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 Upper Klamath River redband trout populations. We also assess how operations of hydro facilities have influenced these life history patterns.

Study Area

The study area encompasses the Klamath River between Link River dam at river kilometer (RK) 406.9, which is the outlet of Upper Klamath Lake, and Shovel Creek (RK 330.4), which is near the Oregon-California border (Figure 1). Downriver of the dam, Link River flows 1.9 km to Lake Ewauna, which is now part of the 31.8-km long reservoir created by Keno dam (RK 370.4). Downriver of Keno Dam, the Keno Reach of the Klamath River flows through a canyon and consists of a wide channel with rapids, riffles and pocket water among cobble, boulders and bedrock. The Keno reach discharge depends on seasonal patterns and irrigation demands and ranges from summer base flows of <10 to >300 m^3/sec in spring. This reach ends at the head of Topsy Reservoir (RK 363.2), which is a 6.4-km long pool created by J. C. Boyle dam (RK 360.0). Spencer Creek, an important spawning tributary, flows 28.8 km from the Cascade Mountains and enters the Klamath River at Topsy Reservoir.

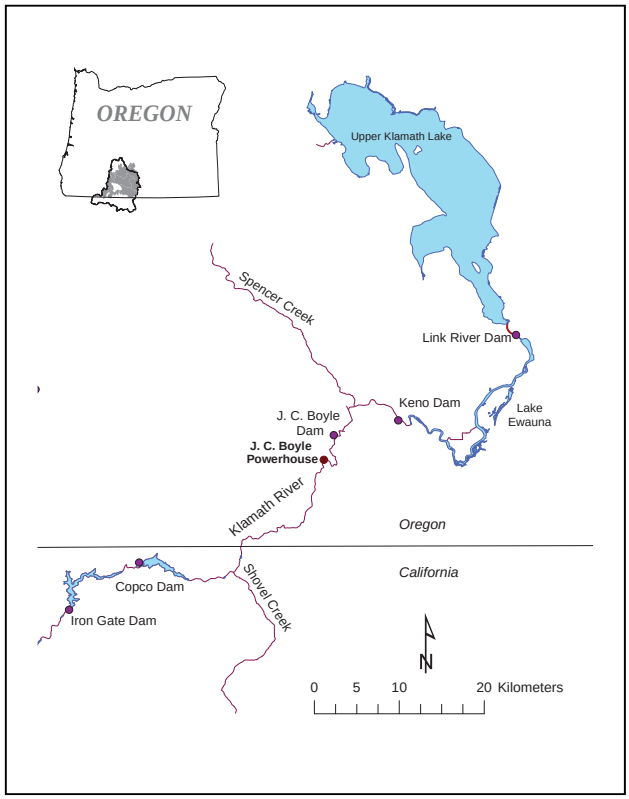

Figure 1. Upper Klamath River showing locations of important spawning tributaries for redband trout and locations of dams and associated hydroelectric facilities. The reach of the Klamath River between J. C. Boyle Dam and J. C. Boyle Powerhouse is referred to as the Bypass Reach and the reach of the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

From J. C. Boyle Dam to the powerhouse, the Klamath River Bypass Reach flows through a canyon at the minimum allowable discharge of 2.83 m^3/sec (0.57 m^3/sec from the screened fish bypass facility and 2.83 m^3/sec from the fish ladder and attractor) except for infrequent and short periods of spill. Cool groundwater springs augment flow in this 6.4-km reach so that discharge is about 9.91 m^3/sec when it reunites with the powerhouse outflow.

Most of the Klamath River flow is stored at J.C. Boyle Dam and then diverted through a concrete canal for power production. Typical summer canal discharge for peak power production ranges from 21.2 to 42.5 m^3/sec for a few hours during the day. The Klamath River Peaking Reach extends from the powerhouse outlet (RK 352.6) to Copco Reservoir (RK 325.0). Peaking Reach discharge fluctuates daily from about 9.91 m^3/sec, when there is no power production, to 80.7 m^3/sec during peak power production. Shovel Creek, another important spawning tributary, enters the Klamath River (RK 329.6) in California. Since its construction in 1917, Copco Dam has prevented upstream fish passage. Upstream passage at all other dams in the study area is provided by fish ladders.

Review of Past Studies

Redband trout life history in the upper Klamath River has been investigated by mark-recapture of

adult fish caught in fyke traps in the fish ladders of Link River, Keno, and J.C. Boyle dams and by trapping fish in weirs near the mouths of Spencer and Shovel creeks. Trap catches in the ladders of Link River and Keno dams during 1988-1991 (Hemmingsen et al. 1988 1992; Buchanan et al. 1989, 1990, 1991) showed some movement of adults from the Keno reach into Lake Ewana but very little movement of adult trout into Upper Klamath Lake. At Link River Dam, less than eight redband trout per year were estimated to ascend the fish ladder to enter Upper Klamath Lake in 1988, 1990, and 1991. In 1989 however, 147 fish were estimated to pass upstream over the dam, 94% of which were captured from April to June. At Keno Dam, the estimated number of redband trout ascending the fish ladder alternated from about 200 fish in 1988 and 1990 to about 60 fish in 1989 and 1991. Although limited in scope, these results suggest that connectivity between redband trout populations in 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.

Trap counts at J.C. Boyle Dam fish ladder from 1959 to 1962 suggest that, following dam construction in 1958, there was a rapid decline in abundance of adult redband trout migrating upstream past the dam. 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 by nearly 60%. Adult redband trout movement over J.C. Boyle Dam was monitored again from February 1988 through December 1991 (Hemmingsen et al. 1988, 1992; Buchanan et al. 1989, 1990, 1991). Between 1988 and 1990, the estimated total number of fish passing over the dam averaged 502 trout (range: 412-588), which was less than 10% of the estimated total in 1959. Only 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 the upstream migrants there was also a significant decline in fish size. The average length of redband trout captured from the ladder during March through May decreased significantly ($p<0.01$, one-way ANOVA) from 30 cm in 1961 to 18-20 cm in 1989-1991.

Despite the loss of adult migrants over J.C. Boyle Dam, Spencer Creek continues to be an important redband trout spawning stream and source of juvenile recruitment in the upper Klamath River basin. In 1988, 348 redds were counted in a 13.6-km reach in April and May (Oregon Department of Fish and Wildlife – ODFW, unpublished data). Similarly, 132 and 113 redds were observed in an 8.6-km 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 1989-1991, weir traps were installed near the mouth of Spencer Creek to capture upstream and downstream migrant redband trout (Buchanan et al. 1989, 1990, 1991; Hemmingsen et al. 1988, 1992). In 1989 high flows prevented efficient trapping. In the two latter years, the traps operated continuously through the migration period. Resulting abundance estimates totaled 1,032 and 1,830 adults and 41,681 and 26,247 juveniles for 1990 and 1991, respectively. Scale analysis of 99 adult redband trout suggested most migrated from Spencer Creek at ages 1 and 2 and returned to spawn for the first time at age 3. Ages of spawning fish ranged from 2 to 8 years (Borgerson 1992).

To estimate the magnitude of juvenile recruitment into the Klamath River Bypass Reach, over 25,000 juvenile trout outmigrating from Spencer Creek were fin-clipped and a rotary screw trap was operated 200 m downriver of J.C. Boyle Dam from April 1991 through May 1992. Over this period, only 54 marked trout from Spencer Creek were recaptured in the screw trap. 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.

Spawning survey and weir trap results of Beyer (1984) indicate that Shovel Creek is also important

to reproduction of redband trout in the upper Klamath River basin. Based on a mark-recapture study, Beyer estimated an adult migratory population of 1,187 fish during the spring of 1982. 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 RK 354 and 356 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).

These studies suggest that redband trout in the upper Klamath River function independently from populations inhabiting Klamath Lake tributaries. Further, it appears that the operation of J.C. Boyle Dam and has led to a sharp decline in the number of adult trout migrating upstream to spawn in Spencer Creek and may also impede juvenile trout dispersal from Spencer Creek to downriver sections of the Klamath River. Finally, the importance of spawning habitat in the main stem river and Shovel Creek is unclear. From 2003 to 2005, we used radio telemetry and half-duplex passive integrated transponder (PIT) technology to gain a better understanding of the movement of adult redband trout populations in the Keno, Bypass and Peaking reaches and juvenile dispersal from Spencer Creek.

Methods

To assess adult movement, large redband trout (220-501 mm fork length) were angled with flies and surgically implanted with radio transmitters (interperitoneal) or PIT tags (dorsal sinus). In the Keno Reach, fish were captured on 26-27 September and 21-22 October 2004 and 14-15 March 2005 and given 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. From September 2003 to August 2004, 7 adult redband trout were radio-tagged in the Bypass Reach and 65 were radio-tagged in the Peaking Reach.

To improve our understanding of juvenile redband trout dispersal from Spencer Creek and assess downstream passage over J.C. Boyle Dam, we radio-tagged and PIT-tagged outmigrating juvenile trout captured in a weir trap near the mouth of Spencer Creek in 2004 and 2005 and tracked their movements. Radio tagging in 2004 began near peak discharge, while tagging started a month earlier than peak discharge in 2005. Interperitoneal radio transmitters (43- to 74-d battery life, 1.1 g, Lotek, Inc.) were surgically implanted in 80 and 75 juvenile trout in 2004 and 2005, respectively, with a median fork length of 110 mm (range, 91-174 mm). Additionally, in 2005, 307 fish (range, 85-170 mm) received PIT tags (half-duplex, 23 mm). Only radio-tagged trout observed more than once after release were included in the analysis.

Radio-tagged fish were tracked via fixed telemetry stations, and mobile tracking (on foot, vehicle, and airplane). Telemetry stations were installed on J.C. Boyle Dam, the Klamath River Bypass Reach, and the powerhouse diversion canal and outlet. Antennae at each station monitored distinct non-overlapping zones and were able to determine when radio-tagged trout entered Topsy Reservoir forebay and whether they passed the dam via the juvenile bypass pipe, the fish ladder, or the powerhouse diversion canal. In 2005, a solar-powered telemetry station was installed at the upstream end of Topsy Reservoir to monitor fish movement into the first 500 m of the Keno Reach. Adult radio-tagged fish were tracked twice monthly and more frequently during the March-May peak spawning period. Radio-tagged juvenile trout were tracked at weekly or shorter intervals from 10 May through 5 July in 2004 and from 7 April through 11 July in 2005. The tracking route included the Keno Reach of the Klamath River (to Keno Dam), Spencer Creek, Topsy Reservoir, and the Klamath River Peaking Reach (to RK 344).

To monitor movements of PIT-tagged fish in 2005, PIT-tag receiver stations (Oregon RFID, Portland,

Oregon) 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.

Results

Adult Movement

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 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 (Figure 2). 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 d (range, 10–39 d) in Spencer Creek. Another 28% (5 of 18) were radio-tracked into Topsy Reservoir near the mouth of Spencer Creek (Figure 2).

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 between tracking observations (26 d) was greater than the average time spent spawning in Spencer Creek. It is therefore plausible that these fish also spawned in Spencer Creek but were missed by the trackers. Only two radio-tagged fish remained in the Keno Reach during the tracking period. 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 0.3 km, and one was last observed 1.0 km away.

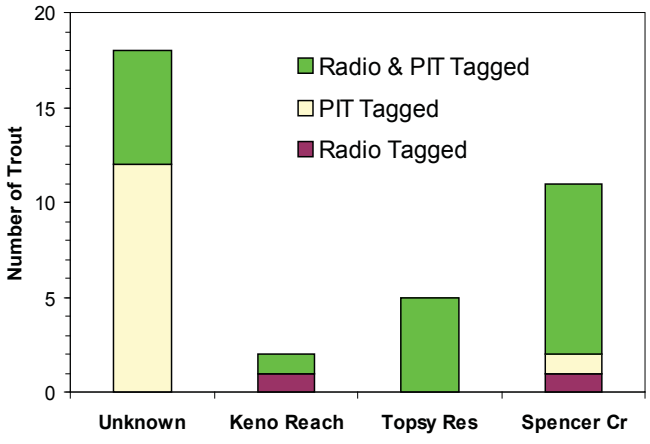

Figure 2. Location of adult redband trout during the spawning season that were radio and PIT tagged. All fish were captured in the Keno Reach during the fall of 2004 and early spring of 2005.

Fish tagged in the Bypass and Peaking reaches experienced unusually high rates of mortality and tag ejection. In the Bypass Reach, only two fish were tracked through the spawning period or to known spawning areas. Both moved downstream about 2.4 km to known spawning areas in the lower Bypass Reach. Two radio-tagged trout from the upper Bypass Reach (RK 354.4) showed upstream movement in fall; both fish were recorded at a fixed telemetry station 150 m below the J.C. Boyle fish ladder (RK 356.8) in early October and both fish appeared to be preyed upon before entering the 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 (RK 360) and was not recorded by either of the two fixed telemetry stations monitoring the fish ladder.

In the Peaking Reach, 27 radio-tagged trout were tracked throughout the spawning period or to known spawning areas (Table 1). Eighteen fish remained in mid Peaking Reach (RK 333-352) during the spawning period and were not observed near known spawning areas. One Peaking Reach fish (tagged at RK 344) moved 9.6 km upstream to a lower Bypass Reach spawning area (RK 352) on 20 June, and two others moved 5.6 and 8.0 km upstream near the J.C. Boyle powerhouse tailrace but did not move into the Bypass Reach. Tagged trout were also strongly associated with Shovel

Table 1. Radio-tagged trout (>200 mm fork length) locations during the spawning period. All fish were tagged in the mid-Peaking Reach (RK 343-346) and tracked at least once per week.

Location	River Kilometer	Trout (N)
Copco Reservoir	320	2
Shovel Creek Mouth	330	3
Shovel Creek	330	3
Lower Peaking Reach	333-339	9
Mid Peaking Reach	340-347	7
Upper Peaking Reach	348-352	2
Bypass Reach	>352	1

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, and then were subsequently relocated upstream in mid Peaking Reach. Two others were tracked downstream into Copco Reservoir and may have also spawned in Shovel Creek.

Movement of Juveniles

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 3). 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 does not stratify with 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. 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% were found in upper Topsy Reservoir or in the Keno Reach, and 17% were observed downstream of the dam (Figure 3). 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.

Differences in juvenile dispersal between 2004 and 2005 seemed 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 85 m^3/sec for most of May and peaked at 127 m^3/sec. These high flows caused dam operators to open the spillway for 2 weeks in May and a week in June, increasing discharge

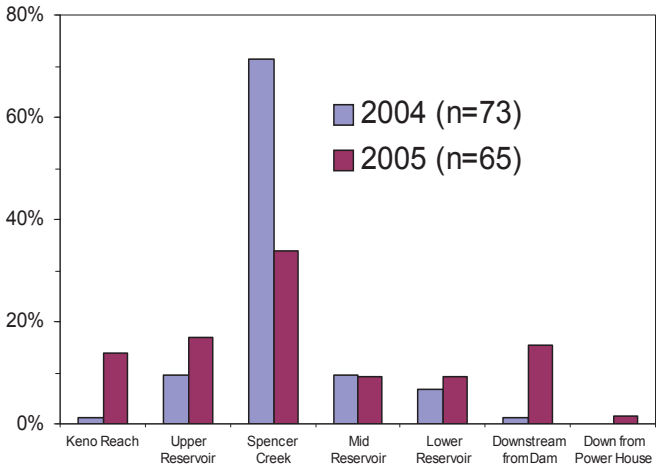

Figure 3. Location of juvenile redband trout, captured and radio-tagged on Spencer Creek, on the final tracking observation in 2004 and 2005.

in the Bypass Reach from 4 m^3/sec to almost 57 m3/sec. Over 70% of the downstream passage of juvenile trout over the dam occurred when the dam spillway was open. In 2004, peak discharge of the Klamath River only reached 57 m^3/sec 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.

Dam operators generally do not spill water at J.C. Boyle Dam until Klamath River discharge exceeds 85 m^3/sec. Over the past 25 years, the Klamath River exceeded this threshold a median of 4.5 d per year (range, 0-61 d), and in 12 of these years flow did not exceed 85 m^3/sec. During the years when J.C. Boyle Dam does not spill water, 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% of radio-tagged juvenile trout that passed downstream over J.C. Boyle Dam were entrained in the powerhouse canal. One of these fish shed its tag in the tailrace of the J.C. Boyle Powerhouse. 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.

In 2005, movement of PIT-tagged and radio-tagged fish in Spencer Creek was similar, suggesting that radio tagging did not adversely affect behavior relative to PIT tagging. At least 60% of the PIT-tagged trout and 65% of the radio-tagged fish outmigrated from Spencer Creek. Of the PIT-tagged fish that outmigrated, over 50% exited 1 d after release, and 80% left within 1 week. 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.

Discussion

The physical and ecological environment of redband trout in the Upper Klamath River has been altered by dam construction and operation. 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.

Reasons for the lack of connectivity among Upper Klamath River redband trout and redband trout inhabiting the Upper Klamath Lake basin are unclear. Passage may be impaired because of restrictions associated with the design of the fish ladders of Link River and Keno dams; however, prior to the construction of Link River Dam, a natural falls existed at the outlet of Upper Klamath Lake (Hamilton et al. 2005). The degree this falls influenced connectivity among these trout populations is unknown, but recent analysis shows Upper Klamath River redband trout to be genetically distinct from populations collected from lake tributaries (Pearse 2007).

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. Historically, these fish had diverse life histories. Prior to the construction of Copco Dam in 1918, Spencer Creek likely served as a spawning site for steelhead Oncorhynchus mykiss 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 lost 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.

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 recent years. 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 thank Alex Higgins, Trent Hartill, Randy Roe and Matt Weeber for field assistance in 2003-05. Al Hemmingsen did much of the initial planning and preparation for the juvenile movement study and, with Dave Buchannan and Rod French, conducted the initial research on Upper Klamath redband trout. This work was funded in part by the Sport Fish Restoration Program of the U. S. Fish and Wildlife Service.

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