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Movements, Habitat Use, and Mortality of Adult Fluvial Bull Trout Isolated by Seasonal Subsurface Flow in the Twisp River, WA

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MOVEMENTS, HABITAT USE, AND MORTALITY OF ADULT FLUVIAL BULL TROUT ISOLATED BY SEASONAL SUBSURFACE FLOW IN THE TWISP RIVER, WA

Final Report
Mid-Columbia River Tributary Bull Trout
Radio-Telemetry Project
FONS Project # 2001-002

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Abstract. – The Mid-Columbia River Fishery Resource Office used radio-telemetry to track the movements of eight adult fluvial bull trout tagged by the Chelan, Douglas, and Grant Public Utility Districts at mid-Columbia River hydroelectric projects in 2002. The bull trout migrated from the Columbia River into the Twisp River, where six radio-tagged bull trout, along with the majority of the adult fluvial population, became isolated in the upper Twisp River by a seasonal reach of subsurface flow near Poplar Flats Campground (rkm 35.2 to 38.1). Bull trout spawning, movements, habitat use, and response to isolation were monitored from September 9 to November 26, 2002. Most spawning activity occurred from September 12 to October 4, in the vicinity of North Creek (rkm 42). Post-spawning adults migrated 3 km downstream, encountered the de-watered barrier, and utilized pool habitat in the vicinity of South Creek (rkm 39.3). Bull trout habitat use was significantly different in the spawning and post-spawning areas: spawning habitat units contained significantly higher percentages of riffle and gravel, and more pieces of large woody debris, while post-spawning habitat units had significantly higher percentages of pool and boulder. Four radio tags were recovered during or shortly after spawning, and one tagged bull trout died when stranded and frozen in low water at the upper edge of the dry reach. Another tagged bull trout was stranded in a shallow pool, but was rescued, transported, and released downstream in the lower river. Two tagged bull trout remained isolated in the post-spawning area, but it appears they did not survive over winter. The Twisp River upstream of the dry reach is a critical area of habitats for adult fluvial bull trout migrating from the Columbia River. Potential impacts of isolation are discussed, and management and research options are recommended.

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Introduction

Bull trout *Salvelinus confluentus* were listed as threatened within the Columbia River basin on June 10, 1998 (50 CFR 63 (111)) and as threatened throughout the coterminous United States on November 1, 1999 (50 CFR 64 (210)). The Draft Bull Trout Recovery Plan identifies the delineation of migratory habitat in recovery units and in the main-stem Columbia River as a priority research project (USFWS 2002). The recovery unit in the mid-Columbia basin has been designated the Upper Columbia River Unit and includes the mid-Columbia's major tributaries, the Wenatchee, Entiat, and Methow River watersheds.

Fluvial bull trout distribution, migration patterns, and habitat use are relatively unknown in the Upper Columbia Recovery Unit, and radio-telemetry studies have been implemented to address this lack of knowledge. In 2000, the U.S. Fish and Wildlife Service (USFWS) began a study examining adult bull trout movements in the Wenatchee River system (Kelly-Ringel and DeLaVergne 2001, 2002). In 2001, the Mid-Columbia Public Utility Districts (PUDs), which includes Chelan, Douglas, and Grant County PUDs, began a multi-year study assessing the effects of mid-Columbia dams on the movement patterns of adult fluvial bull trout in the mid-Columbia River and its major tributaries (BioAnalysts 2002, 2003, 2004).

Most of what is known about fluvial bull trout in tributaries of the major watersheds in the mid-Columbia basin is limited to bull trout spawning ground surveys (e.g. USFS 2001, 2002), and more information is necessary for the USFWS to aid recovery of populations. Studies in other large river systems indicate that most fluvial bull trout undertake seasonal long distance migrations between spawning habitat in small tributaries and deep pool habitat in larger rivers (Elle et al. 1994, Schill et al. 1994, Swanberg 1997). However, preliminary analysis by the PUDs of fixed site and aerial telemetry data indicated that some tagged adult fluvial bull trout appeared to over-winter in small tributaries and did not migrate to the Columbia River in 2001 (BioAnalysts 2002). Because the PUDs' study was not designed to examine habitat use or survival in tributaries, it is not known if the tagged bull trout were alive, dead, or expelled their tags (BioAnalysts 2003). Also, it is not known what stream habitats the tagged bull trout used in the tributaries, or if river conditions prevented their return to the Columbia River. Therefore, in 2002, the USFWS Mid-Columbia River Fishery Resource Office (MCRFRO) initiated a study of fluvial bull trout that were radio-tagged by the PUDs at mid-Columbia River dams and migrated into the Twisp River. The objectives of this study were: 1) locate tagged bull trout and describe movements in the Twisp River; 2) identify and describe critical areas of habitat used by adult fluvial bull trout in the Twisp River during fall; 3) locate and describe barriers to bull trout migration; and 4) provide information on the tagged bull trout to the PUDs. This study was funded under the Mid-Columbia River Tributary Bull Trout Radio-Telemetry Project, FONS # 2001-002.

Study Area

The Twisp River is a tributary of the Methow River at river kilometer (rkm) 64.7 (Figure 1). It is a 4th order stream, draining an area of 634.5 square kilometers. Mean daily stream flow at the mouth ranges from 1.2 m^3/s (42.6 ft^3/s) on September 22 to 32.1 m^3/s (1136 ft^3/s) on June 4 (Appendix A, USGS 2003). During the irrigation season, approximately 2 m^3/s (70+ ft^3/s) is diverted from the Twisp River above the USGS gage station (USFS 1995), or about 40-65% of the total discharge during August and September (PWI 2003). The valley bottom contains appreciable groundwater and glacial deposits and alluvial sediments cover bedrock along the entire river (Mullan et al. 1992). Above rkm 27 the river is mostly within public lands managed by the US Forest Service.

During late summer, the Twisp River usually begins to flow subsurface in the vicinity of Poplar Flats Campground, from rkm 35.2 to rkm 38.1 (Mullan et al. 1992), except in years when precipitation is above normal (USFS 1995). Winter rain on snow events are unusual in the Twisp River watershed (USFS 1995) so surface flows are usually not restored until snow melt in the spring (D. Hopkins, USFS, personal communication). There is a 4.6 meter barrier falls at the confluence of the North and South Forks at rkm 45.4. Bull trout are not known to be present above this barrier (Mullan et al. 1992).

Methods

We used bull trout tagged by PUDs at Mid-Columbia River hydroelectric dams in 2002 (tagging described in BioAnalysts 2003) to gather information on bull trout fall habitat use and response to isolation by subsurface flows in the Twisp River. Length and weight were recorded and scale samples were taken when the fish were tagged. The scale samples were analyzed by the Washington Department of Fish and Wildlife (WDFW 2002). The tags were Lotek model MCFT-3A, transmitting at frequency 148.580, with an expected battery life of 761 days. We used a Lotek SRX _400 Telemetry Receiver and a collapsible Yagi-type antenna to locate the tagged fish.

We used aerial-tracking flight maps provided by PUDs to determine the general locations of tagged fish in the Twisp River. We took bearings from the Twisp River Road and Forest Roads 44 and 4435 before walking in to get exact locations. Team tracking techniques allowed us to get precise locations and minimized harassment of bull trout. One biologist interpreted radio signal strength to maintain an adequate distance from tagged fish while the other biologist looked for and counted untagged fish. To avoid disturbing the tagged fish, we marked the location with plastic flagging and habitat data was recorded the following week. We immediately collected habitat data if the fish was disturbed and moved from the location.

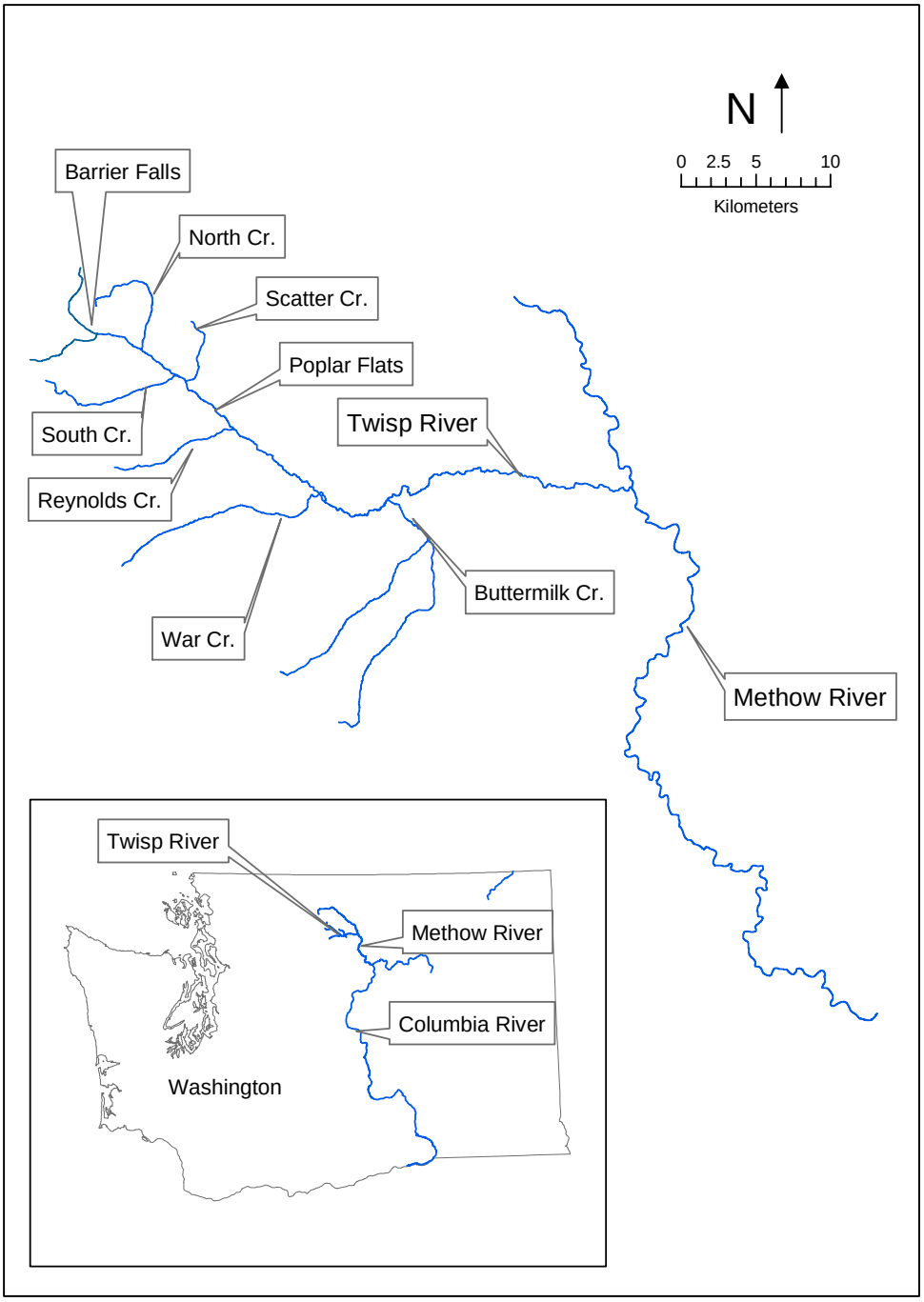

Figure 1. Map of the bull trout study area in the Twisp River.

The habitat variables we collected were adapted from the bull trout snorkeling protocols (Peterson et al 2001). The exact location of the fish was the center of a 50 m unit and measurements of width, maximum depth and average depth were taken along transects at the top, center, and bottom of the unit. We recorded length of pool, length of riffle, stream gradient, large woody debris (LWD), substrate composition (estimated percent cover of boulder, cobble, gravel), and water temperature within the sample unit. We used the non-parametric two-tailed Whitney-Mann Test (alpha = 0.05) to statistically compare habitat data between the spawning and post-spawning areas. We controlled for multiple comparisons using the Bonferroni method of multiplying each p-value by the total number of tests performed on the data. To avoid pseudo-replication, only one visit of repeated visits to the same habitat unit by an individual fish was included in the analysis.

We snorkeled to observe the behavior of tagged fish and check the condition of surgical wounds, and untagged bull trout and other salmonids were noted. We used small, fine-mesh aquarium nets to capture and identify juvenile salmonids. We incorporated redd count data collected by the U.S. Forest Service (USFS) Methow Ranger District (USFS 2002) and supplemented with our observations during radio-tracking.

Locations of the fish were recorded on quadrangle maps and a drawing detailing the site was recorded on the back of the habitat form. Field notes were recorded in an all-weather notebook. We used a Trimble GeoExplorer3 global positioning system (GPS) unit to record the latitude and longitude coordinates of tracked fish and to monitor the upstream dry edge of the subsurface flow area, but the downstream resurface wet edge was not monitored. Maps of radiolocations were produced in MapTech Terrain Navigator. Photographs were taken with film and digital cameras.

Results

Twisp River flows. During the study, daily flows at the mouth of the Twisp ranged from 3.8 m^3/s (135 ft^3/s) on August 1, 2002 to 0.76 m^3/s (27 ft^3/s) on September 30, 2002 and were below the median flows of the last 16 years of record (Figure 2 and Appendix A). On about August 15, the Twisp River began to flow subsurface at approximately rkm 35.2 (D. Hopkins, USFS, personal communication). From September 25 to November 26, 2002, we monitored the upstream dry edge of the subsurface flow area and recorded the expansion and contraction of the dry reach (Figure 3 and Appendix B). The highest upstream expansion was recorded on October 22 at rkm 37.8, downstream of Scatter Creek. Within the dry reach, we observed several isolated pools that completely dried up during expansion. Rains re-watered part of the dry bed in early November, but had not reconnected the river by November 26, 2002.

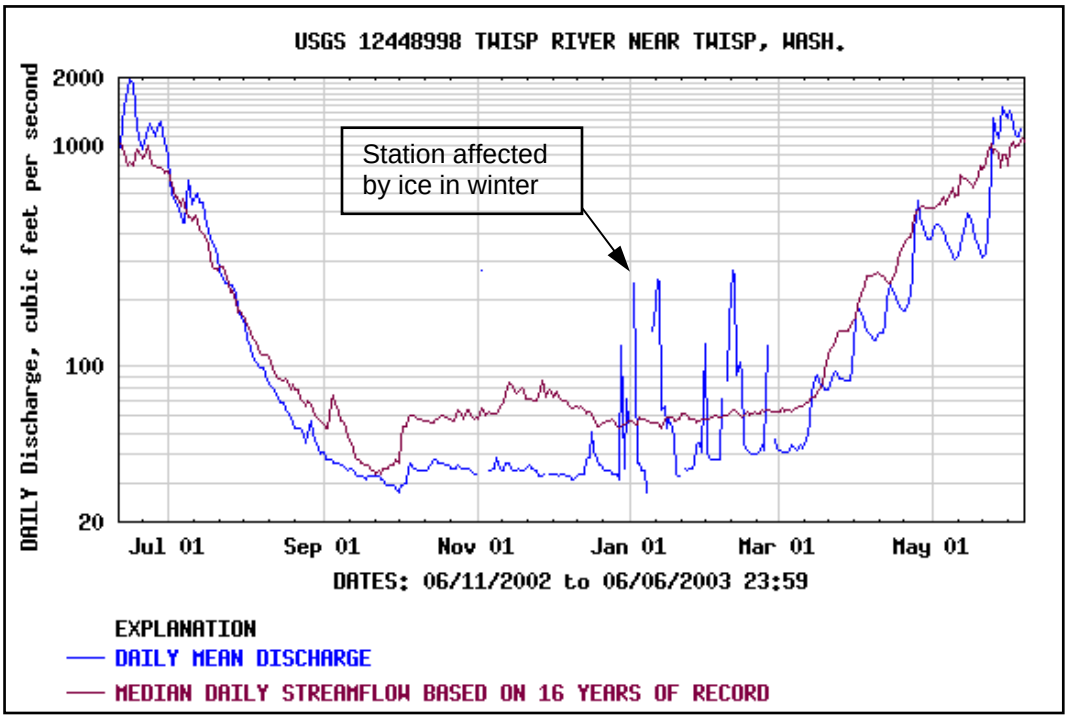

Figure 2. Twisp River discharge at mouth from 6/11/2002 to 6/6/2003 (USGS 3003).

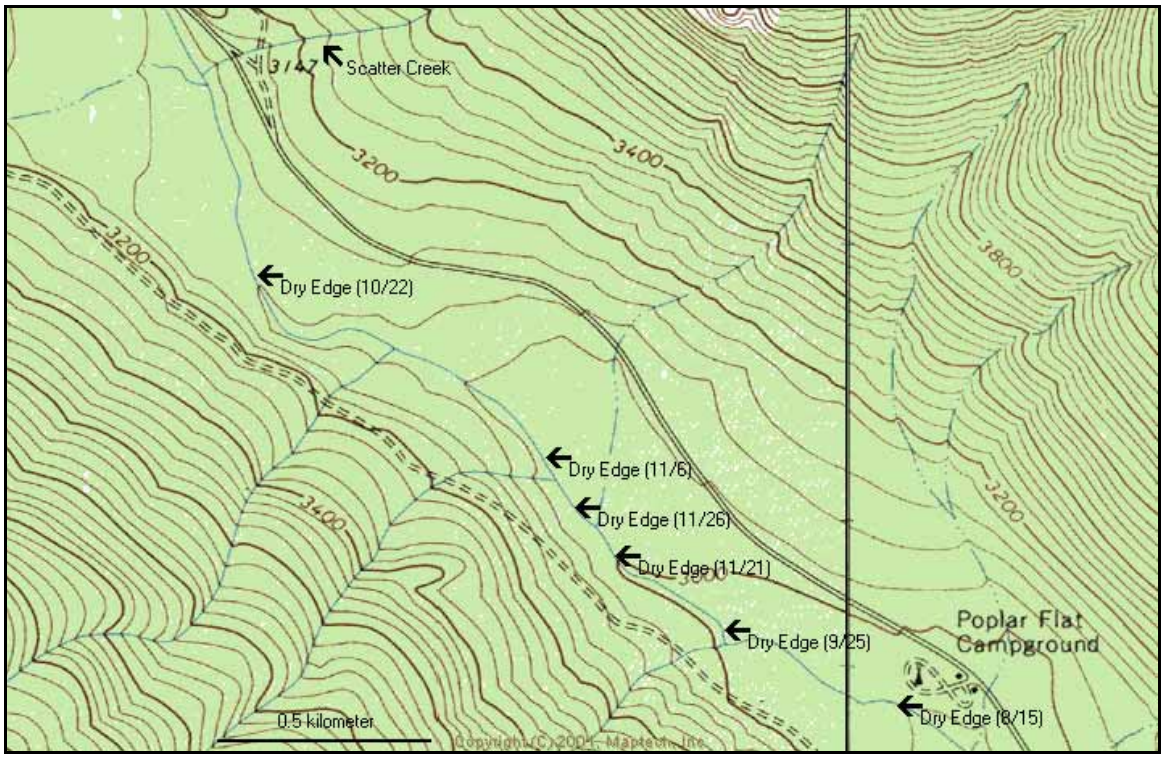

Figure 3. Locations of upstream dry edge of subsurface flow area in the Twisp River, Fall 2002. The date is in parentheses.

Tagged bull trout. Eight of 40 bull trout radio-tagged by PUDs in 2002 moved into the Twisp River. Of these, 5 were captured and tagged at Wells Dam and 3 at Rocky Reach in May and June 2002 (BioAnalysts 2003). Lengths ranged from 52.0 to 63.5 cm and weights from 1.40 to 2.95 kg (Table 1). The fish were 5 and 6 years old; age analysis of scales showed no indications of previous spawning (WDFW 2002).

Table 1. Bull trout captured and tagged by PUDs at mid-Columbia River dams that migrated into the Twisp River in 2002.

Date tagged	Time	Location	Transmitter code	Length (cm)	Weight (kg)	Age (years)
21-May	1737	Rocky Reach	89	63.0	2.95	5
28-May	1510	Wells	93	54.5	1.80	6
03-Jun	1310	Rocky Reach	108	62.0	2.35	5
03-Jun	915	Wells	107	60.5	2.30	5
03-Jun	1650	Wells	96	56.0	1.85	6
04-Jun	912	Wells	102	63.5	2.90	5
10-Jun	1656	Rocky Reach	116	60.8	2.85	5
12-Jun	1535	Wells	117	52.0	1.40	5

Radio-tracking. Seven of the fish were in the Methow River and 1 in the lower Twisp River during the July 1, 2002 aerial survey; all 8 were in the upper Twisp by the August 1 flight (BioAnalysts 2003). On September 12, based on triangulation from several locations on Twisp River Road and Forest Roads 44 and 4435, two tagged bull trout were located downstream and six bull trout were upstream of the dry reach. All of the foot-based radio-tracking effort was focused on the bull trout isolated upstream of the dry reach (codes 89, 102, 107, 108, 116, 117) during 10 visits from September 19 to November 26, 2002 (Appendix B). No tagged fish were located above the barrier falls at the confluence of the North and South Forks (rkm 45.4).

Spawning area. Some spawning activity was observed in the area of North Creek (rkm 42) during a reconnaissance visit on September 12. Spawning neared peak activity on September 19 and numbers of new redds were decreasing by October 4. All spawning activity was completed prior to October 21, when the all the tagged bull trout were located 3 km downstream in the vicinity of South Creek (rkm 39.3). None of the fish were tracked moving back upstream on subsequent visits. Thus, the tagged bull trout used two separately defined areas of the Twisp River above the subsurface flow area: a spawning area and a post-spawning holding area (Figure 4).

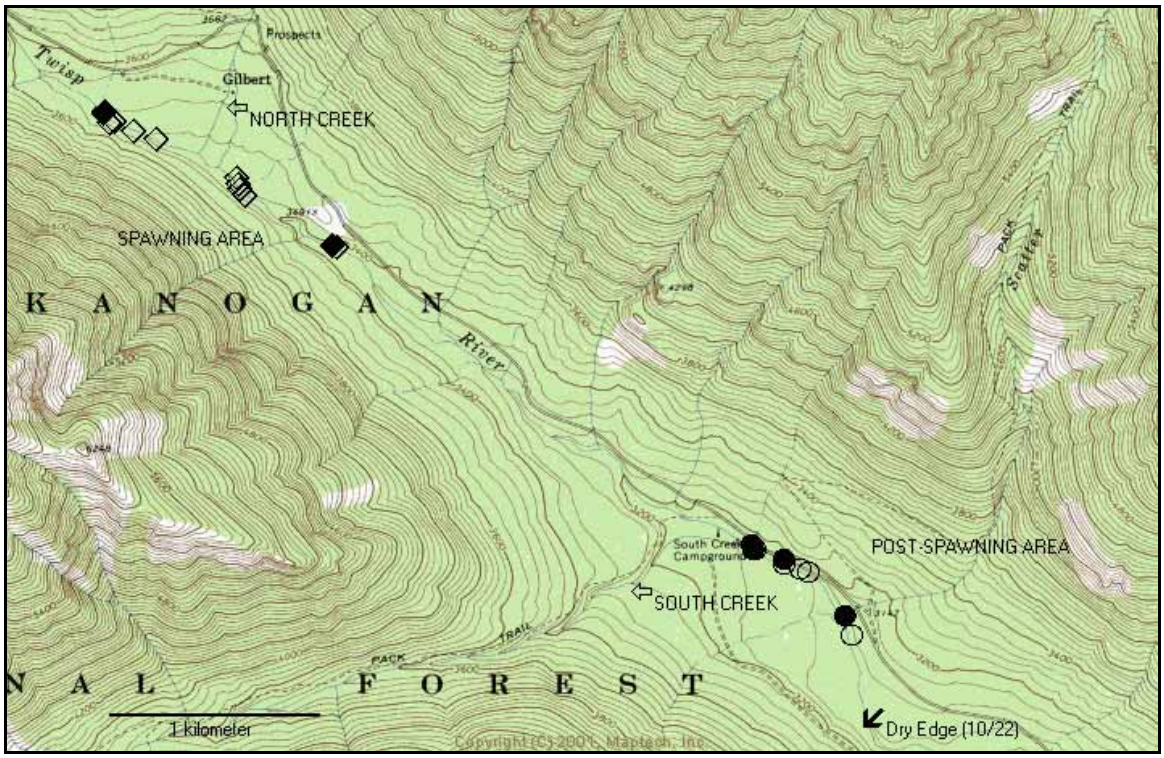

Figure 4. Bull trout spawning and post-spawning areas above dry reach of Twisp River, as defined by radio-telemetry during Fall 2002. *Diamonds* (◊) denote individual fish locations during spawning and *circles* (○) denote locations post spawning. A solid symbol indicates that the same bull trout was located at that position on more than one date.

The spawning area contained most of the bull trout redds observed by the USFS during the 2002 spawning ground survey. Of the 69 redds counted above the dry reach, 67 were upstream of South Creek, with the majority in the vicinity of North Creek. Only 2 redds were located in the post-spawning area downstream of South Creek. Eleven redds were found downstream of the dry reach.

Several redds were associated with LWD dams. For example, 10 of the 69 redds (14.5%) were located within 25 meters of one big dam: 2 were under logs, 3 were in a side channel, and 5 were in the pool above the dam (Figures 5 and 6).

Figure 5. A large woody debris (LWD) dam located in the spawning reach of the Twisp River. Two bull trout redds were constructed under the large logs and 3 more in small side channel not seen in left of picture.

Figure 6. Shallow pool with spawning gravel created by LWD dam shown in Figure 5. Five bull trout redds were constructed in this pool.

Post-spawning area. The post-spawning area contained several pools where the bull trout congregated in groups of varying sizes. Two pools were used most often (Figure 7). The primary pool at the mouth of South Creek (Figure 8) held between 22-30 bull trout on various visits. This pool was 0.75 m deep and 7.0 m wide, with vegetation overhanging from an undercut bank (Figure 9). Thirty adult fluvial bull trout and 1 brook trout (150mm) were counted while snorkeling on October 22. The secondary pool, located 200 m downstream of South Creek, held 8-15 bull trout at a time (Figure 10). This pool was 1.0 m deep and 10.0 m wide, and contained a large log the bull trout used for cover. A dispersed campsite was located on the bank adjacent to the pool (Figure 11).

The highest number of adult fluvial bull trout observed and counted in the post-spawning area was 48 on November 6.

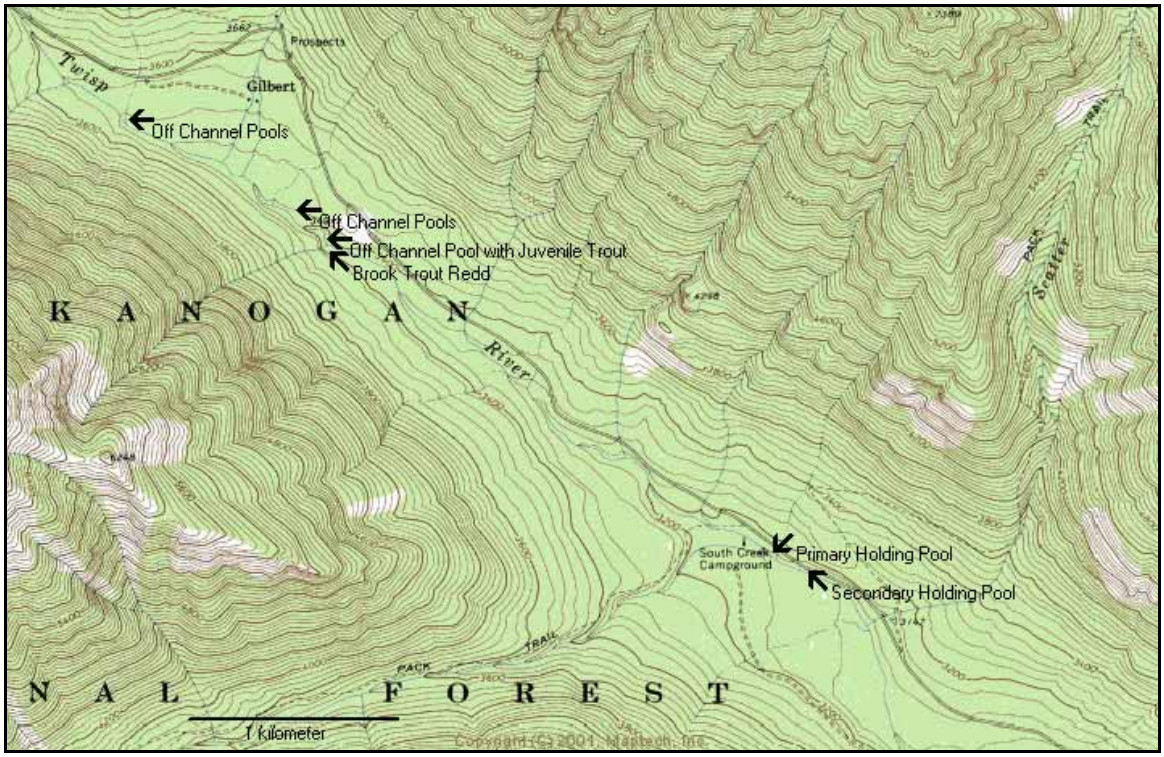

Figure 7. Locations of post-spawning bull trout holding pools, brook trout redd, and off channel pool with juvenile trout.

Figure 8. Primary post-spawning bull trout holding area in pool at mouth of South Creek. View is looking downstream with frozen South Creek at right.

Figure 9. Undercut bank and overhanging vegetation (visible on left bank in Figure 8) of pool at mouth of South Creek. Note group of fluvial bull trout holding in pool.

Figure 10. Secondary post-spawning bull trout holding area in pool downstream of South Creek.

Figure 11. Dispersed campsite on bank next to secondary holding pool in Figure 10. Note same log in both pictures.

Habitat descriptions. The spawning and post-spawning areas differed in several important habitat variables (Table 2). Spawning habitat units contained significantly higher percentages of riffle (Mann-Whitney test, $Z = -4.63$, $p < 0.001$) and gravel ($Z = -3.38$, $p < 0.005$), and more pieces of large woody debris ($Z = -2.53$, $p < 0.05$). Although not significant, the gradient was lower in spawning units. Post-spawning habitat units had significantly higher percentages of pool ($Z = -4.63$, $p < 0.001$) and boulder ($Z = -5.87$, $p < 0.0001$). Bull trout were located in deeper water in the post-spawning habitat units than in spawning units (transect2 in Table 3), but the difference wasn't significant ($Z = -1.65$, $p = 0.5$).

The morphology of the river channel in the sampled habitat units differed in the spawning and post-spawning areas. In spawning units, the downstream transects within a unit decreased in width and depth (Table 3), indicating the fish usually were in the tail-out riffle of a shallow pool or glide. In the post-spawning units, the downstream transects within a unit increased in width and the middle transect was deepest (Table 3), indicating the fish usually held near the head or middle of the pool.

In late fall, when the river started to freeze, bull trout were observed using surface ice as hiding cover.

Table 2. Mean habitat variables in bull trout habitat units in the spawning and post-spawning areas of upper Twisp River, Fall 2002.

Area Type	# of Units	Unit Length (m)	Pool (%)	Riffle (%)	Gradient (%)	LWD	Boulder (%)	Cobble (%)	Gravel (%)	H2O T (°C)
Spawning	9	50	32	68	1.3	13.0	1.8	49.3	46.1	7.3
Post-spawning	7	50	56	44	1.6	2.3	41.1	39.7	19.0	2.1

Table 3. Mean width and depth of water at transects in bull trout habitat units in spawning and post-spawning areas of upper Twisp River, Fall 2002.

Area Type	Transect1 width (m)	Transect2 width (m)	Transect3 width (m)	Unit avg width (m)	Transect1 depth (m)	Transect2 depth (m)	Transect3 depth (m)	Unit avg depth (m)
Spawning	7.54	6.92	6.64	7.03	0.21	0.29	0.25	.25
Post-spawning	7.96	7.47	10.80	8.74	0.25	0.46	0.27	.33

Brook trout. During the study, several adult brook trout were observed and one brook trout redd was found. On October 21, at water temperature of 5° C, a 180 mm female was observed actively spawning with a 250 mm male in the bull trout spawning area (Figure 7). On October 22, one 250 mm brook trout was observed with several fluvial bull trout in the primary holding pool at the mouth of South Creek.

Juvenile salmonids. There are several small off-channel pools in the vicinity of North Creek (Figure 7). On October 21, five 50 mm and one 100 mm juvenile brook trout were captured, identified, and released in one small off-channel pool, along with one 40 mm juvenile bull trout and one 50 mm juvenile steelhead/rainbow trout. The other off-channel pools were not examined for the presence of juvenile salmonids.

Salmonid fry were observed in isolated pools within the dry reach in the vicinity of Poplar Flats Campground during mid-September. These pools dried up before we were able to identify and count the juveniles. While direct mortality was not observed, we assumed these juveniles did not survive.

Stranding mortality. At times, there were noticeable differences in the behavior of the bull trout isolated in the post-spawning area. While most held in the deeper pools, others appeared to be constantly moving and occasionally were found in shallow riffle areas. In mid-November, rains increased river flow and re-watered part of the dry reach, and all the bull trout dispersed downstream from the main holding pools. Several were observed lying on the bottom in the shallows at the margins of small pools and rocky riffles. On November 21, 2 tagged and at least 1 untagged bull trout were found in low water immediately upstream of the dry edge of the subsurface reach (Figure 12). Bull trout #116 appeared to be dead, as ¾ of the fish was out of the water with only the head submerged (Figure 13), but when we attempted to collect it, it startled and swam back upstream 50 m to a small pool. We did not disturb bull trout #107 and the untagged fish as they were completely submerged in approximately 30 cm of water.

On November 26, lower flows and cold air temperature re-expanded the dry reach (Figure 12), resulting in the death of bull trout #107 and the untagged bull trout by de-watering and freezing (Figure 14). Bull trout #116 was found alive, 400 m up the streambed, and 200 m upstream of the new dry edge. It was totally hidden under a boulder in a small pool, where it was prevented from swimming further upstream at this low water discharge by an impassable cobble shelf (Figure 15). We determined it was trapped and would die, so we captured and examined it. The surgical scar was completely healed, but the area surrounding the antennae appeared reddish and slightly opened. We transported bull trout #116 in a large cooler filled with cold river water (Figure 16), and released it approximately 3 km downstream of the dry reach. During the aerial surveys on February 19 and June 17, 2003 it was located in the main-stem Methow River at rkm 56.3. During the aerial survey on October 2, 2003, it was found in the West Fork of Buttermilk Cr, a tributary of the Twisp River at rkm 20.4.

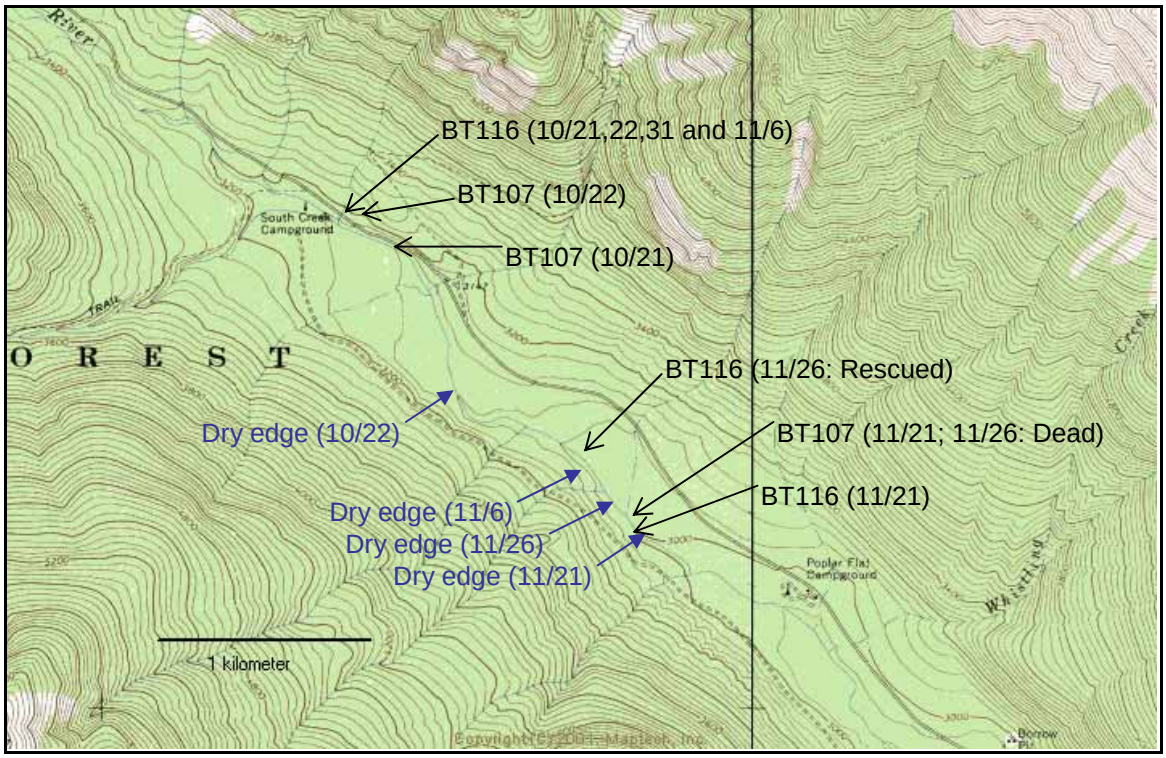

Figure 12. Movements of bull trout #107 and #116 before and during stranding event, Twisp River, fall 2002. Date of location is in parentheses.

Figure 13. Bull trout #116 stranded in low water at dry edge of subsurface flow on Nov. 21, 2002. This fish moved upstream and was rescued on Nov. 26, 2002.

Figure 14. Recovery of dead bull trout #107 on November 26, 2002. Note ice and high water line on small boulder.

Figure 15. Location of bull trout #116 on November 26, 2002. View is looking downstream, and fish is in isolated small pool indicated by arrow. Note line of cobble shelf extending across streambed on upstream side of small pool.

Figure 16. Transporting bull trout #116 to below the dry reach.

Two fish (codes #89 and #108) remained isolated above the dry reach and were still alive when located on November 26. They were located there on the February 19, 2003 aerial survey, but their status was unknown. If these bull trout had survived the winter, we would have expected them to move downstream when the river was re-watered by runoff in the spring. However, their signals were still in the same locations during the aerial survey on June 17, 2003. Both radio tags were recovered by PUDs on September 12, 2003. Tag #108 was found downstream of the Scatter Creek trailhead (rkm 38.3), near what was the upstream edge of the dry reach in 2002. Tag #89 was found just downstream of Poplar Flats (rkm 35.2), in an area that was dry in the fall of 2002 (D. Snyder, BioAnalysts, Inc., personal communication).

Mortality/tag recoveries. Five of the 8 tagged bull trout appeared to have died during the study and two others apparently did not survive the winter (Table 4). Only one of the carcasses was recovered. We recovered two tags (#93 and #96) downstream of the subsurface flow area. They were not observed when alive, but did not move from their triangulated positions from October 4 through October 31. Tag #93 was recovered at rkm 25, on a gravel bar in the area of the lower river open to fishing. Tag #96 was recovered in mid-stream at rkm 32.5.

Two fish were observed alive in the spawning area and later died. When bull trout #117 was observed in a small pool in the spawning area on September 25, it was dark in color, appeared listless and was riding high in the water. On October 22, only the tag was recovered under a log jam in the post-spawning area, where it had been since October 4. Bull trout #102 was observed near redds pictured in Figure 5. It never left the spawning area and on all subsequent visits the tag was still located near the LWD dam pictured in

Figure 4. In 2003, the tag was recovered on a gravel bar in this vicinity (D. Snyder, BioAnalysts, Inc., personal communication). As described above, bull trout #107 died when stranded near the edge of the subsurface flow reach. That carcass and all recovered tags were returned to PUDs for postmortem examination.

Table 4. Fate of PUD tagged bull trout that entered the Twisp River, as of October, 2003.

Tag code	Fate	Cause of Death	Tag Recovery
89	Over-wintered above subsurface area; location unchanged on 2/19 and 6/17/03 flights	Unknown; probably stranding related	9/12/03
93	Tag recovered on gravel bar in area open to fishing	Unknown; possibly angling related	10/31/02
108	Over-wintered above subsurface area location unchanged on 2/19 and 6/17/03 flights	Unknown; probably stranding related	9/12/03
107	dead	Stranded; dewatered and frozen	11/26/02
96	Tag recovered mid-stream downstream of dry reach	Unknown; probably spawning related	10/31/02
102	Tag in log jam in spawning area near several redds	Unknown; probably spawning related	9/12/03
116	Captured and relocated; located in main-stem Methow R. on 2/19 and 6/17/03 flights. Located in West Fork Buttermilk Cr. on 10/02/03 flight.	alive	n/a
117	Tag recovered in log jam in post-spawning area	Unknown; probably spawning related	10/22/02

Discussion

Tag recoveries and mortality. During the study, 7 of 8 (87.5%) radio tags were recovered. With the exception of the stranded bull trout, no carcasses or body parts were found with the tags, so it is difficult to determine whether a recovered tag represents expulsion of the tag or mortality of the fish. Tag expulsion has been documented in other bull trout studies, with expulsion rates ranging from 3% to 28% (Elle et al. 1994, Swanberg 1997, Clayton 2001, BioAnalysts 2003, Mendel et al. 2003). However, since tag expulsion did not positively bias spawning mortality estimates in the Rapid River, Idaho (Elle et al. 1994), and carcasses are rarely recovered in bull trout radio-telemetry studies (see Elle et al. 1994, Schill et al. 1994, BioAnalysts 2003), tag recoveries are assumed to represent mortality in this paper.

Four of 8 (50%) tagged bull trout died during or immediately after spawning in the Twisp River, but this may not be unusual or unnaturally high mortality. Based on reported salmonid annual mortality values of 30% - 70%, Reiman and McIntyre (1993) modeled bull trout population structure with an annual mortality of 40%. A telemetry study of bull trout in the Rapid River, Idaho recorded annual spawning mortality from 18% to 67 % over 4 years (Schill et al. 1994, Elle et al. 1994, Elle 1998), with the majority occurring in periods of downstream movement during or immediately after spawning. The evidence suggests that at least three mortalities (37.5%) in the Twisp River are related to spawning. Two bull trout were observed alive on the spawning grounds in close proximity to redds. One fish never moved from the area after we first observed it, and the other appeared to be weak; its tag was recovered from the post-spawning area a short time later. The third bull trout was never observed, but the tag was recovered one kilometer downstream of the 11 bull trout redds constructed below the dry reach.

One of the mortalities in the Twisp River may have been angling related, as the tag was recovered on a gravel bar in the open fishing zone. The tag was found out of the water above the seasonal high water level, so it is unlikely the carcass or tag would have settled onto the gravel bar. There were no bite marks on the tag or the antenna as sometimes occurs when a tagged fish is depredated or scavenged by a mammal.

Three mortalities were related to isolation by subsurface flow. One tagged bull trout died after stranding in low water and freezing, and circumstances suggest the other two met a similar fate and did not survive the prolonged isolation over winter. The only bull trout known to have survived isolation was the tagged bull trout that was rescued and released downstream of the dry reach.

No bull trout mortalities were documented by PUDs in 2001, but in 2002 several tags were recovered in other Columbia River tributaries in addition to the Twisp River (BioAnalysts 2003, 2004). However, the apparently higher mortality rate in 2002 may be an artifact of the PUDs' study design. In 2001, there was no foot-based tracking or observation of tagged fish and the battery life of the tags was only 1 year. Some bull trout that were thought to over-winter in tributaries may not have been alive, and the batteries died before verification was possible. Based on our observations, it appears that few

Columbia River fluvial bull trout voluntarily over-winter in the Twisp River. Further investigation is required to determine if this is also true for other small tributaries in the Mid-Columbia Basin.

Interpretation of aerial tracking data to determine the status of a tagged bull trout can be deceptive, due to relatively large position errors of radio locations from factors such as signal strength, overhead cover, water depth, and altitude and flight pattern of the plane. Using test radio transmitters in the Entiat River, Chelan PUD determined the accuracy of aerial surveys to be plus or minus 300 meters (BioAnalysts 2004). Thus, interpretation of radio locations from successive flights can result in the perception that the fish is still alive because it appeared to have moved, when in fact it had not. In addition, stream currents can also move a radio tag or carcass considerable distance, and again give the false impression that the fish is still alive. Without on-the-ground verification, a major fish movement, or a mortality switch in the tag, it is difficult to determine if a tagged fish is still alive. If we had not closely followed the isolated bull trout nor recovered the radio tags, but instead relied solely on aerial tracking, it would have been reasonable to assume the bull trout were alive, particularly since fluvial bull trout are known to move only short distances once they have selected their over-winter pool habitat in a large river (Elle et al. 1994, Schill et al. 1994, Swanberg 1997). Standard methods for verifying conclusions based on aerial telemetry data should be developed.

Habitat. A complex mix of habitats is needed to provide suitable fall and winter habitat for bull trout (Fraley and Shepard 1989, Swanberg 1997, Jakober et al. 1998), and accordingly, the habitats used by the isolated bull trout in the spawning and post-spawning areas in the Twisp River were significantly different, even though these areas are located in relatively close proximity. As in other studies, spawning habitat was characterized by lower gradient, more riffles, and more gravel in the substrate (Fraley and Shepard 1989, Reiser et al. 1997), and contained significantly more pieces of large woody debris (LWD), which trapped gravel to create spawning areas (MacPhail and Baxter 1996, Swanberg 1997). However, during the 1960s and 1970s, LWD was removed from the entire Twisp River channel from the mouth to North Creek (including part of the spawning area and all of the post spawning area), and LWD levels are still below pre-cleanout conditions (USFS 1995, WSCC 2000).

Similar to other studies, bull trout in the post-spawning area used pools for post-spawning habitat (Elle et al. 1994, Schill et al. 1994, Swanberg 1997, Jakober et al. 1998). Normally, fluvial bull trout undertake seasonal long distance migrations between spawning habitat in small tributaries and deep pool habitat in larger rivers (Elle et al. 1994, Schill et al. 1994, Swanberg 1997), but in the Twisp River, the post-spawning bull trout were prevented from leaving the upper tributary by the subsurface flow barrier, and moved only a short distance downstream into the holding pools, presumably to wait until the barrier subsided. The short movements, habitat selection of shallow pools, and use of ice as cover by the isolated fluvial bull trout more closely resembled behavior of resident bull trout (Jakober et al. 1998). An important difference, however, is that the isolated fluvial bull trout were forced to utilize a very restricted range of habitat. Pool quality and quantity downstream of South Creek have been judged to be below expected levels for

low gradient rivers such as the Twisp River (USFS 1995, WSCC 2000). The post-spawning reach may not contain enough optimal pool habitats for these large bull trout to survive prolonged isolation over winter.

The entire upper Twisp River upstream of the dry reach to the barrier falls appears to be a critical area of habitats for the adult fluvial bull trout population. The majority of spawning habitat used by this population is upstream of the dry reach, mostly in the vicinity of North Creek. The area from South Creek downstream to the dry reach is where the majority of post-spawning fluvial bull trout hold while waiting for the migration barrier to subside. Although the number and depth of these holding pools may not be optimal, it is all that is available to the isolated bull trout, and it may be desirable to attempt to improve the quality and quantity of pool habitat in this area.

Subsurface flow. While seasonal low flows in this area of the Twisp River are a natural occurrence, the causes of de-watering and possible solutions require further investigation. It is known that the Twisp River channel is aggraded at Poplar Flats, and the accumulated bed load has raised the elevation of the stream channel in this reach, causing the stream to go subsurface at base flows (PWI 2003). Although the cause of the aggradation is not known, a technical advisory group judged the subsurface flow as natural, based on seasonal low flows, no sizeable diversions above the reach, and the fact that the upper Twisp River valley floor is surrounded by wilderness (WSCC 2000). However, no assessment has been made of past disturbances which may affect the reach, although this section of the river is rated as having a high sensitivity to land use disturbance (PWI 2003). Disturbance events in the upper watershed include past logging practices in the flood plain and hill slopes, wildfires, debris slides, and construction of roads and campgrounds (USFS 1995, PWI 2003). Events which occurred directly within the stream bed include placer and hydraulic mining in the vicinity of North Creek (USFS 1995, PWI 2003) and the removal of all large woody debris (USFS 1995). Following the spring 1972 flood, large equipment was used within the stream bed to push and pull LWD from the channel from War Cr. (rkm 26.2) to North Cr. (rkm 42), and the amount of LWD and the pool to riffle ratios are still far below levels that were present historically (USFS 1995, WSCC 2000, PWI 2003).

It is not known how long the dry reach has been occurring or at what base flows de-watering develops. A similar, though larger, seasonally de-watered reach between Mazama and Weeman Bridge in the upper Methow River has been documented since at least 1942 (Milhous et al. 1976), while the earliest known records of the subsurface flow in the Twisp River are only from 1987 (Kohn 1987, Rhodus 1988). The dry reach is not mentioned in reviews of past Chinook salmon spawning areas in the Columbia River Basin (USFWS 1950, 1960, 1965, 1968), nor in the few historical water records available for the Twisp River watershed (Walters and Nassar 1974).

Impacts of isolation. The upper Twisp River is the one of the most important known spawning areas in the Methow Basin for fluvial bull trout migrating from the Columbia River. Based on aerial survey data, seventy-five percent of PUD tagged fish that entered the Methow in 2002 migrated up the Twisp River, and a similar pattern was observed in

2001 (BioAnalysts 2002, 2003, 2004). In 2002, most of the post-spawning bull trout were observed to be isolated from the Methow and Columbia Rivers due to the dry reach, and apparently the same isolation occurred in 2001 (USFS 2001). Thus, a seasonal occurrence of subsurface flow in the upper Twisp River could have several impacts on the fluvial bull trout population. Most of the fluvial bull trout in the Twisp River spawn upstream of the dry reach (USFS 2001, 2002), so the timing of the development of the dry reach is critical. If de-watering were to occur earlier in the summer, fluvial bull trout could be prevented from migrating to the upper spawning grounds. Because much of the coldest water available in late summer is located upstream of the dry reach (Watershed Sciences 2002), fluvial bull trout may also be prevented from accessing thermal refuges.

Redds constructed in the reach while surface water is still flowing may later be dewatered; this has occurred with bull trout redds (USFS 2001) and spring Chinook salmon redds (Meekin 1993) in the Twisp River. Juvenile bull trout mortality may increase if trapped in isolated pools that dewater within the dry reach (Meyer 2002), although young-of-the-year bull trout have been documented living within subsurface flow (Boag and Hvenengaard 1997).

The isolated post-spawning bull trout appear vulnerable to stochastic events such as stranding and freezing in shallow water. The survival rate of the isolated adult bull trout is unknown, but the fact that none of the tagged fish survived indicates that isolated post-spawning bull trout may not survive over winter. Thus, in years following de-watering and low flow, repeat spawning of Twisp River fluvial bull trout may be rare. For example, none of the tagged bull trout that migrated to the Twisp showed evidence of previous spawning (WDFW 2002), but 5 tagged fish in the larger PUD study that did previously spawn migrated to rivers not subject to de-watering (see tracking maps in BioAnalysts 2003).

The high visibility of the congregated bull trout in low, clear water and their close proximity to campgrounds increases the vulnerability of the isolated fish to disturbance and illegal harvest. During spawning, the USFS temporarily closes Forest Road 4440 at spur 460, about one kilometer from the road's end. However, the majority of spawning and all of the post-spawning habitat use occurs downstream of the gate. In particular, bull trout are very susceptible to disturbance in the two major holding pools, and the South Creek Campground and the dispersed campsite downstream of South Creek could pose a distinct threat to these fish.

Research opportunities. Because the majority of the adult fluvial bull trout appear to be at risk of isolation by dewatering, a large segment of the breeding cohorts of this population is vulnerable to catastrophic loss. More information on the response and survival of the isolated bull trout in the Twisp River is needed in order to use metapopulation theory to aid recovery of bull trout in the Upper Columbia Unit. The isolated fish should be monitored, and appropriate responses to stranding should be developed by the U.S. Fish and Wildlife Service. If deemed necessary, the isolated bull trout could be captured from the post-spawning holding areas and transported downstream. The combination of low

flow, schooling behavior, easy access, and low water temperature would simplify the task and reduce risk to the bull trout.

Research studies could be implemented to determine if relocation of isolated fish increases the number of repeat-spawn adults or the size of the spawning area in following years. It should also be determined if relocation changes migratory behavior. For example, after being rescued, bull trout #116 over wintered in the Methow River instead of the Columbia River and then migrated up Buttermilk Creek instead of returning to the upper Twisp River. These different migratory movements may be related to the fish seeking spawning grounds in one year and thermal refuge the other. Alternatively, the change may be a result of capturing and relocating that fish; the PUDs noted in their study that tributary selection by tagged bull trout appeared to be influenced by release location at the dams (BioAnalysts 2004).

Currently, redd counts are expanded to estimate the effective population size of adult bull trout in a recovery unit (USFWS 2002), but the number of adults per redd varies among populations (McPhail and Baxter 1996), and the ratio is not known in the Upper Columbia Recovery Unit. The isolated bull trout in the Twisp River offer an opportunity to increase the accuracy of abundance estimates. Migrating bull trout could be captured and marked at the Twisp River temporary weir operated by Washington Department of Fish and Wildlife (WDFW) and PUDs. The U.S. Forest Service counts bull trout redds during annual spawning ground surveys, and as bull trout spawning above the dry reach are effectively a closed population, the USFWS could snorkel and count marked and unmarked bull trout to estimate the adult population and determine the number of adults per redd.

Introduced non-native brook trout pose a threat to bull trout in the Upper Columbia Recovery Unit (USFWS 2002). Brook trout were not reported in the main-stem Twisp River during intensive sampling periods from 1982-1990, but a few were found in War Creek (rkm 26.2) during surveys in 1989-1990 (Mullan et al. 1992). We found evidence of brook trout actively spawning and rearing in the bull trout spawning reach, 14.5 km upstream of War Creek. The USFS recently documented an increase in the numbers and distribution of brook trout in the lower river (D. Hopkins, USFS, personal communication). Further studies on brook trout distribution, reproduction, hybridization, and competition with bull trout in the Twisp River are warranted.

Recommendations

The following bull trout related issues should be investigated in the Twisp River:

1.) Use of Forest Road 4440, South Creek Campground, and dispersed campsites should be evaluated for potential impacts to isolated post-spawning bull trout.
2.) A monitoring plan and intervention policy in response to isolated and stranded bull trout should be considered, and the effects and risks/benefits of rescuing isolated bull trout should be examined.
3.) Causes of the de-watering and possible solutions should be investigated, and the feasibility of improving pool habitat upstream of the dry reach should be explored.
4.) Accuracy of extrapolating redd count data to bull trout population estimates should be measured.
5.) Distribution of brook trout, and their interaction and hybridization with bull trout in the Twisp River should be monitored.

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Appendix A. Twisp River discharge: mean of daily mean values for this day for 16 years of record, in ft^3/s (USGS 2003).

Day of month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	75.8	63.7	82.7	199	524	1087	647	174	61.5	54.6	67.6	154
2	75.0	64.5	82.7	214	560	1103	631	166	59.9	59.6	67.8	137
3	75.0	65.8	82.1	228	587	1110	646	159	60.0	60.7	67.5	128
4	74.8	65.1	82.1	235	598	1136	642	158	59.2	65.4	72.5	125
5	73.0	64.9	82.0	238	612	1115	638	152	56.1	66.4	70.9	148
6	71.7	64.3	81.9	239	644	1091	627	144	55.6	64.3	70.8	135
7	69.9	65.9	83.3	248	677	1038	613	154	53.7	62.3	71.6	128
8	70.2	69.0	82.8	270	696	999	598	146	52.5	61.3	85.2	118
9	70.2	68.8	84.1	293	716	941	590	133	50.4	62.6	98.4	115
10	69.6	69.5	84.9	306	750	937	552	124	51.7	62.4	119	114
11	70.3	69.4	86.3	308	773	929	516	115	51.0	62.8	121	109
12	69.4	69.1	87.5	305	821	960	485	108	47.9	61.8	121	105
13	69.0	67.7	89.9	305	890	935	465	102	45.5	61.4	137	101
14	70.0	66.1	94.1	302	945	909	432	98.5	44.8	61.3	135	97.8
15	72.0	67.4	102	301	955	949	393	94.3	45.3	61.6	126	95.2
16	71.6	68.5	107	310	952	975	372	92.2	44.5	62.9	117	95.4
17	71.3	69.2	110	325	923	944	354	90.3	44.9	65.5	110	92.3
18	66.6	70.6	113	337	932	928	332	89.6	44.5	67.8	106	89.7
19	67.4	74.7	120	358	976	886	307	90.1	43.2	67.2	101	85.9
20	67.3	80.5	130	377	954	873	296	84.5	43.5	66.2	97.1	82.0
21	67.2	83.3	133	392	929	888	298	86.0	42.9	66.6	94.5	80.0
22	66.3	83.1	139	404	924	856	283	81.4	42.6	66.5	94.5	80.4
23	65.9	81.8	147	416	912	812	272	76.2	43.8	67.1	97.3	80.4
24	65.9	81.6	150	443	935	787	267	72.9	44.6	68.8	165	80.2
25	66.0	81.3	152	457	993	759	259	74.2	45.2	67.1	162	78.8
26	65.3	81.6	158	465	1000	698	240	72.5	44.9	67.6	141	77.1
27	64.3	81.8	163	463	980	658	229	68.8	45.4	69.6	125	77.6
28	63.9	81.9	167	477	969	650	216	65.7	45.5	68.1	123	79.2
29	63.3	110	172	489	978	704	210	64.6	44.4	68.1	191	77.4
30	62.4		179	514	995	694	202	63.6	45.2	68.7	201	76.1
31	62.9		188		1008		186	63.8		69.1		75.9

Appendix B. Radio-tagged bull trout and dry edge locations (in decimal degrees, NAD27) in the Twisp River, Fall 2002.

Latitude	Longitude	Tag #	Date
48.4503826	-120.554535	108	9/19/2002
48.4502889	-120.554173	117	9/19/2002
48.452765	-120.5604258	89	9/25/2002
48.4559921	-120.5691284	102	9/25/2002
48.4560715	-120.5691094	107	9/25/2002
48.4556537	-120.5684146	108	9/25/2002
48.4532854	-120.5606413	116	9/25/2002
48.4549051	-120.5657356	117	9/25/2002
48.4225169	-120.5046977	Dry Edge	9/25/2002
48.4502848	-120.554234	89	10/2/2002
48.4529615	-120.5604617	108	10/2/2002
48.4524931	-120.5601251	116	10/2/2002
48.4368821	-120.5253917	89	10/4/2002
48.4560715	-120.5691094	107	10/4/2002
48.4344739	-120.5215117	117	10/4/2002
48.4375023	-120.5275073	89	10/21/2002
48.4556132	-120.5687671	102	10/21/2002
48.4367423	-120.5254528	107	10/21/2002
48.4372644	-120.5273599	116	10/21/2002
48.4375023	-120.5275073	89	10/22/2002
48.4373626	-120.5273104	107	10/22/2002
48.4372644	-120.5273599	116	10/22/2002
48.4344739	-120.5215117	117	10/22/2002
48.4301096	-120.5196434	Dry Edge	10/22/2002
48.4375023	-120.5275073	89	10/31/2002
48.4372644	-120.5273599	116	10/31/2002
48.4375023	-120.5275073	89	11/6/2002
48.4372644	-120.5273599	116	11/6/2002
48.4262016	-120.5104644	Dry Edge	11/6/2002
48.4368821	-120.5253917	89	11/21/2002
48.4244817	-120.5085038	107	11/21/2002
48.4337056	-120.5210421	108	11/21/2002
48.4246985	-120.5089264	116	11/21/2002
48.424103	-120.5081949	Dry Edge	11/21/2002
48.4363652	-120.5238953	89	11/26/2002
48.4248604	-120.5088128	107	11/26/2002
48.4364962	-120.5243961	108	11/26/2002
48.4272121	-120.5116556	116	11/26/2002
48.4252105	-120.5091074	Dry Edge	11/26/2002

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