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Migration Patterns of Adult Bull Trout in the Wenatchee River, Washington 2000-2004

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Mark C. Nelson

U.S. Fish and Wildlife Service
Leavenworth, Washington

***On the cover**: Two lacustrine-adfluvial adult male bull trout competing to spawn with a female adult (in the middle) in the White River drainage. USFWS photograph by Barbara M. Kelly Ringel.*

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MIGRATION PATTERNS OF ADULT BULL TROUT IN THE WENATCHEE RIVER, WASHINGTON 2000-2004

Barbara M. Kelly Ringel, Judy Neibauer, Kathleen Fulmer, and Mark C. Nelson

Abstract– Movements of 62 adult migratory bull trout captured at five locations in the Wenatchee River basin were monitored with radio telemetry during 2000–2004. Objectives were to describe adult bull trout seasonal movements, migration timing, movements past obstacles, and to identify spawning, overwintering, and other areas used. Bull trout from four local populations were tracked to four different overwintering areas, and several distinct migration patterns were documented. Most of the bull trout overwintered in Lake Wenatchee, and four of these spawned in its tributary the White River, but the most common migration pattern (32 bull trout) was downstream from the lake 9.4 km then upstream in the Chiwawa River to spawning areas in its upper main stem and tributaries. Almost half of the Chiwawa bull trout also made forage/refuge movements into another stream (White River, Little Wenatchee River, and Nason Creek). Two bull trout that spawned in the Chiwawa River basin overwintered in the upper Wenatchee River while two others migrated downstream 77.8 km to overwinter in the Columbia River. One bull trout that spawned in Nason Creek also overwintered in the Columbia River, a 130 km migration. Three bull trout spawned in Chiwaukum Creek, overwintered downstream in the middle Wenatchee River, and seasonally used lower Icicle Creek. Thus several complex migration patterns are exhibited by Wenatchee Core Area bull trout, including the unique allacustrine-adfluvial migrations between Lake Wenatchee downstream into the Chiwawa River and the lacustrine-adfluvial upstream movement of the White River population. The adfluvial-fluvial migration pattern was expressed primarily in the Chiwaukum and Nason Creek populations, although a few Chiwawa fish adopted this strategy and also moved downstream to larger riverine habitats. The complexity and connectivity of these migrations may increase the likelihood of population persistence. Most of the bull trout (80%) only spawned once, but of those alive the year after first spawning, 50% (7 of 14) spawned again. Bull trout showed fidelity to spawning streams and in other streams they visited were only found downstream of bull trout spawning areas. Spawning migrations began as early as April and lasted into September, but the majority moved in June and July during declining flows at 3 to 5 weeks after peak discharge. Bull trout migrating later in the season often moved when daily water temperatures exceeded 16º C. Several bull trout held downstream of the Chiwawa River weir and did not pass until the weir was down or entered the trap after a few days. Bull trout generally slowly moved upstream in tributaries and entered spawning areas within 2 to 7 weeks. Median dates to move into spawning areas for four streams were between July 23 and August 1. After spawning, most bull trout quickly migrated downstream out of tributaries. In the Wenatchee River bull trout moved slowly through the reach downstream of Tumwater Dam for at least one month before entering overwintering areas. The results of this study provide migration information that will assist in recovery actions including consultation, fisheries management and stream restoration. Potential research and management considerations are discussed.

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Introduction

Bull trout *Salvelinus confluentus* are a potamodromous species of char that require cold clean water and complex habitats. Bull trout express several life history strategies ranging from resident fish that spend their entire life in a small area of a stream to large migrants that move long distances from spawning areas in cooler headwaters to overwintering areas downstream (Fraley and Shepard 1989; Rieman and McIntyre 1993; Brown 1994; Swanberg 1997). Bull trout that migrate within stream systems have been categorized as fluvial and those that migrate between a lake and rivers as adfluvial (USFWS 2002a). Although primarily a freshwater species, some coastal populations may exhibit anadromous behavior (Brenkman and Corbett 2005).

Juvenile migratory bull trout rear for one to four years in tributaries before migrating to a larger stream or lake where the subadults grow until reaching sexual maturity between four and seven years of age (Fraley and Shepard 1989; Brown 1992; Downs et al. 2006; Al-Chokhachy and Budy 2008). Adults initiate spawning migration in the spring or early summer and spawn in the fall with timing of migration also related to water temperature and discharge (Swanberg 1997; Brenkman et al. 2001; Salow 2004; Nelson and Nelle 2008; Howell et al. 2010). Bull trout are iteroparous and annual or alternate year spawning patterns may occur (Fraley and Shepard 1989; Downs et al. 1996; Bahr and Shrimpton 2004; Hogen and Scarnecchia 2006). Bull trout exhibit patchy distribution within stream networks and require connectivity in migration corridors to promote gene flow for the long-term persistence of local populations (Rieman and McIntyre 1993; Rieman and Dunham 2000; Dunham et al. 2002). Habitat degradation and fragmentation, migration barriers, historic fisheries management actions that included introduction of non-native species of char, and overfishing have caused significant declines in bull trout abundance and distribution (USFWS 2002a). As a result the species is listed as threatened under the Endangered Species Act throughout its range in the United States (USDI 1998; USDI 1999).

For recovery planning and implementation, bull trout populations are currently grouped by geographic areas into recovery units containing core areas of local populations (USFWS 2002a). The draft Mid-Columbia Recovery Unit includes the Wenatchee, Entiat, and Methow Core Areas connected by the Columbia River (Figure 1) (USDI 2010). In the draft recovery plan the U.S. Fish and Wildlife Service (USFWS) identified seven local populations in the Wenatchee Core Area: Peshastin Creek, Icicle Creek, Chiwaukum Creek, Chiwawa River, Nason Creek, Little Wenatchee River, and White River (Figure 2) (USFWS 2002b; USFWS 2004).

Several types of surveys have helped to define bull trout population distribution and abundance. Spawning ground surveys in the Wenatchee River basin were initiated in 1989 (Brown 1992) and indicate that three of the local populations contain the majority of the migratory bull trout in the Wenatchee Core Area. The Chiwawa River has the healthiest population (mean annual index count of 306 redds), followed by the White River (67 redds), and Chiwaukum Creek (29 redds),

while the other four populations each average fewer than 10 redds (Kelly Ringel 2012). Most of the spawning reaches of migratory bull trout in the core area end at impassable waterfalls (USDI 2010).

During preparation of the 2002 draft bull trout recovery plan it was determined that more information was needed to guide management and recovery. Radio telemetry was identified as the primary method to gain detailed information on adult bull trout movements. Since then several telemetry studies of migratory bull trout have been completed in the upper Mid-Columbia Recovery Unit, including in the Columbia River (BioAnalysts 2004; LGL and DCPUD 2008; Stevenson et al. 2009), Entiat River (Nelson and Nelle 2008), Methow River (Nelson et al. 2006; Nelson et al. 2007; Nelson and Johnsen 2012), and Icicle Creek and lower Wenatchee River (Nelson et al. 2009; 2011; 2012). These studies documented migration timing, identified factors affecting populations, confirmed that the mid-Columbia River and its main tributaries are functional migratory corridors for long distance movements from spawning areas to foraging/overwintering areas, and that most bull trout exhibited fidelity to their local population.

Since the listing of bull trout, efforts have focused on identifying the mechanisms for decline or for persistence of bull trout populations. The Wenatchee Core Area has several attributes that provide an opportunity for elucidating some of those factors. Two of the bull trout local populations have relatively high numbers while other nearby populations have low numbers and are barely persisting. The Wenatchee River watershed has diverse habitat with a large undammed lake, connected by a large river to the Columbia River, several tributaries supporting bull trout, and mostly intact migration corridors. Lake Wenatchee is the largest natural lake with bull trout and anadromous salmon and without non-native lake trout (Fredenberg 2003). Ten races of seven native salmonid species are present in the Wenatchee River drainage, one of the highest native fish diversities in the interior Columbia River Basin (Thurow et al. 1997). Understanding movement patterns of the local populations in this large landscape could help local recovery efforts and contribute to understanding how bull trout function in a large connected system (Rieman and Dunham 2000; Dunham et al. 2008).

The objectives of this radio-telemetry study were to describe adult bull trout seasonal movements, including migration timing and movements past obstacles, and to identify spawning, overwintering, and other seasonal habitat use in the Wenatchee River Core Area.

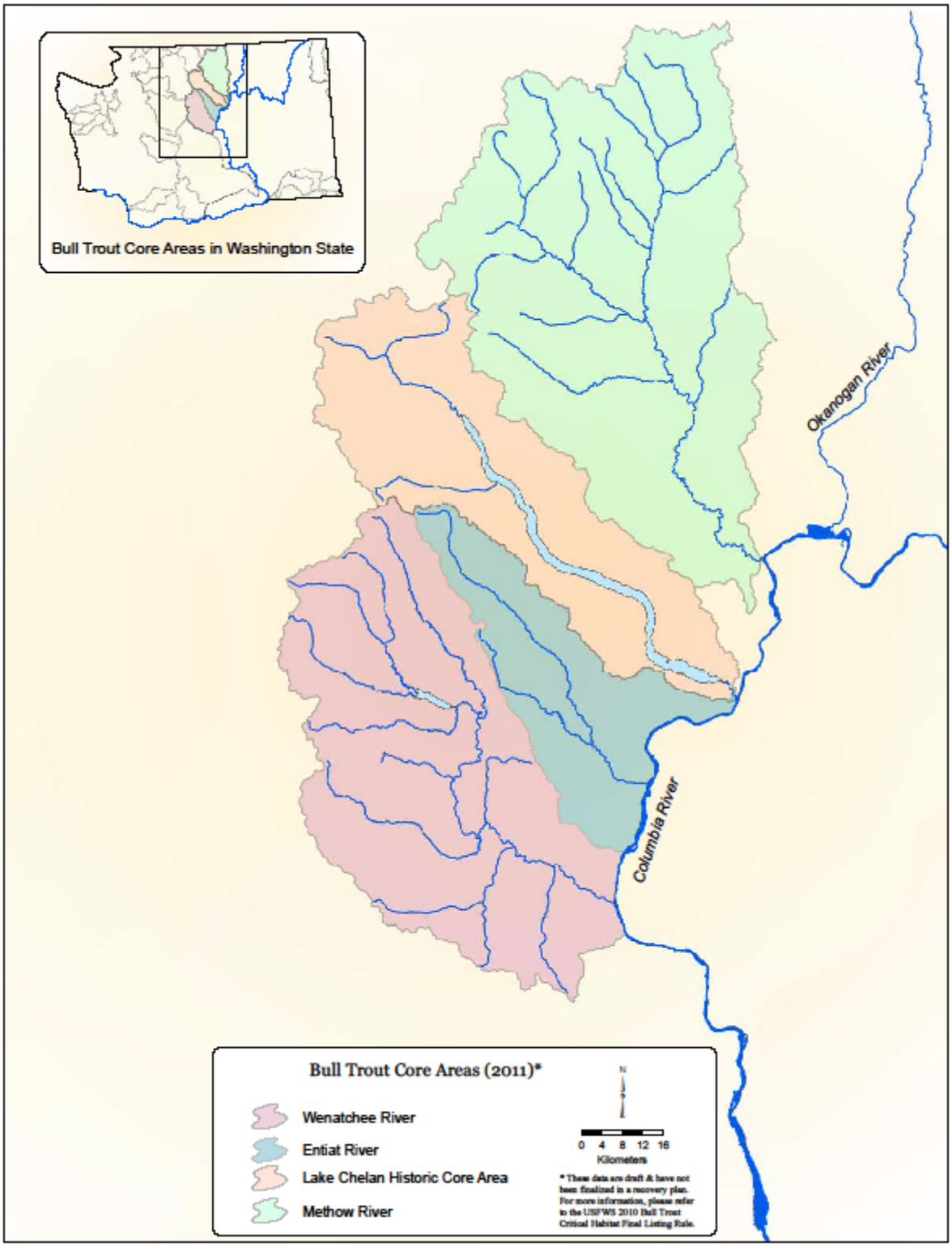

Figure 1. Map of Wenatchee, Entiat, and Methow Core Areas in the upper Mid-Columbia Bull Trout Recovery Unit.

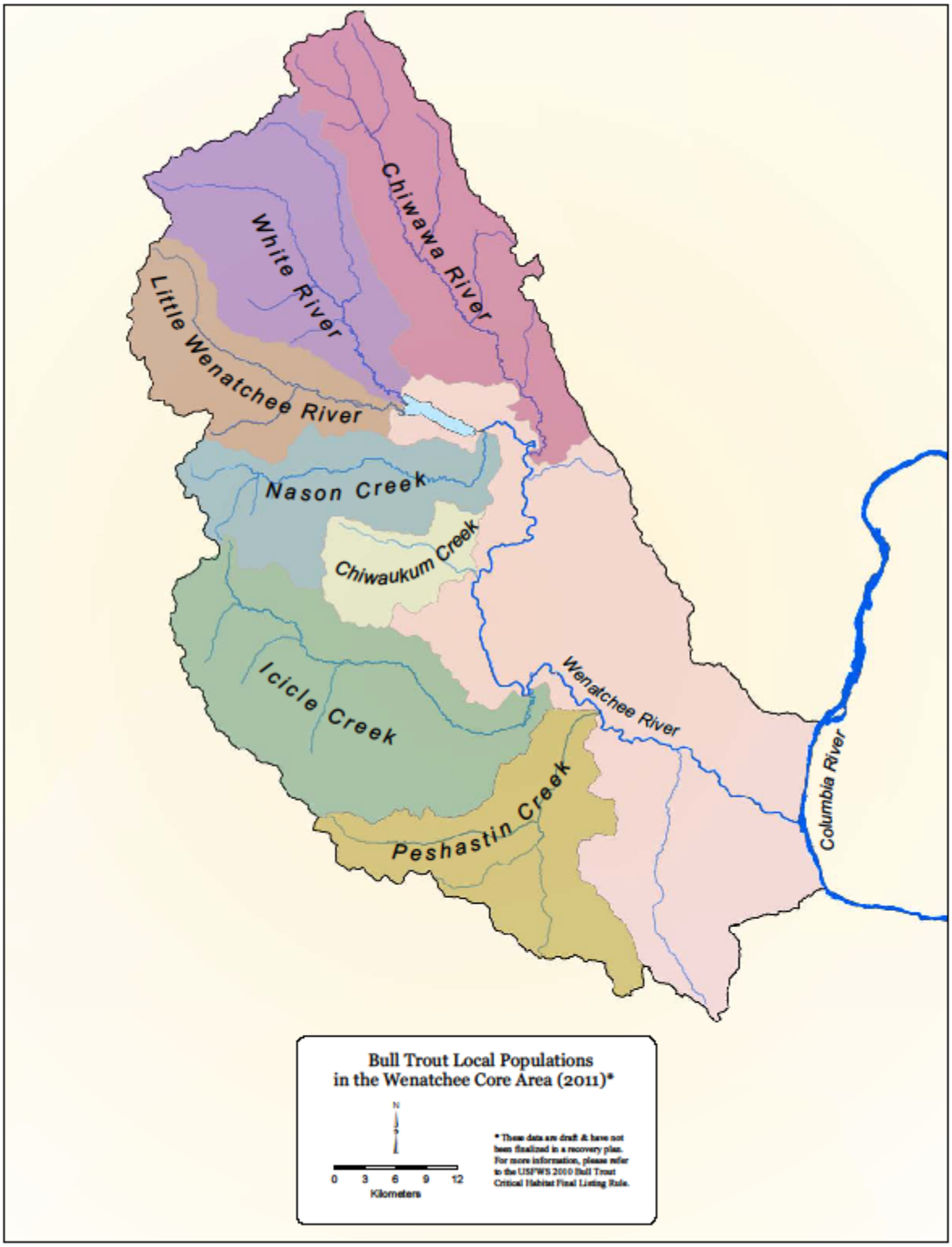

Figure 2. Map of seven bull trout local population areas in the Wenatchee Core Area.

Study Area

Watershed Overview

The Wenatchee River watershed is on the east slopes of the Cascade Mountains and drains an area of 3,437 km^2 in Chelan County, Washington (Figure 3). Elevations range from 2,870 m at Mount Stuart to 186 m at the confluence with the Columbia River. Snowmelt is the principal water source and the mean annual flow is 97 m^3/s (USGS 2012). Precipitation varies from 380 cm along the Cascade crest to just over 20 cm on the breaks of the Columbia River (Hindes 1994). Upstream of the City of Leavenworth (rkm 43; mouth of Tumwater Canyon) the upper river basin is mountainous and heavily forested, whereas downstream in the lower river basin the vegetation consisting primarily of Ponderosa pine *Pinus ponderosa*, sagebrush Artemisia spp., and pinegrass *Calamagrostis rubescens* reflect the drier climate. Downstream of Leavenworth, the river valley is broader and supports irrigated fruit orchards along with rural and urban development. Approximately 90% of land in the Wenatchee River basin is in public ownership, and most of the private lands are located in the valley bottoms.

The Wenatchee River originates at Lake Wenatchee, an oligotrophic glacial lake with a surface area of 990 hectares and a mean depth of 55 m (Mullan et al. 1992). The White River and Little Wenatchee River are the major tributaries to Lake Wenatchee and flow through mostly U.S. Forest Service (USFS) forest lands before entering the lake at the west end. The White River (22.4 m^3/s: WDOE 2012) is a glacial fed stream with cooler water temperatures while the Little Wenatchee River (11.7 m^3/s) is in a lower elevation basin without glaciers and thus has warmer water temperatures (Watershed Sciences 2002). The Wenatchee River flows from the eastern end of the lake (rkm 87.2) in a southeasterly direction to the confluence with the Columbia River (rkm 753.7) near the City of Wenatchee. Nason Creek (rkm 86.2; 10.4 m^3/s) enters the Wenatchee River just downstream from Lake Wenatchee. Supplied by snowmelt, Nason Creek is the most human impacted of the upper tributaries, with State Route 207, U.S. Highway 2, and the Great Northern Railroad traversing its valley to the headwaters at Stevens Pass. The Chiwawa River (rkm 77.8; 14.2 m^3/s) is a glacial stream that lies mostly within USFS forest and provides the majority of the bull trout spawning and rearing habitat in the Wenatchee Core Area. These four upper basin streams provide over 60% of the discharge for the entire watershed. Chiwaukum Creek (rkm 57.8; 2.9 m^3/s) enters upstream of Tumwater Canyon, is fed by one glacier and lies mostly within the Alpine Lakes Wilderness Area. Tributaries in the lower river downstream of Tumwater Canyon include Icicle Creek (rkm 41.2) and Peshastin Creek (rkm 28.8). Icicle Creek (18.9 m^3/s) is glacial fed with several high elevation lakes in the Alpine Lakes Wilderness Area; the upper river cascades through USFS forest but downstream of Leavenworth National Fish Hatchery (rkm 4.3) the lower river is a meandering stream through private lands developed for single family homes with some agriculture. Peshastin Creek (5.3 m^3/s) is paralleled by Highway 97 for most of its length, with USFS forest in the upper reaches and homes and orchards in its lower valley.

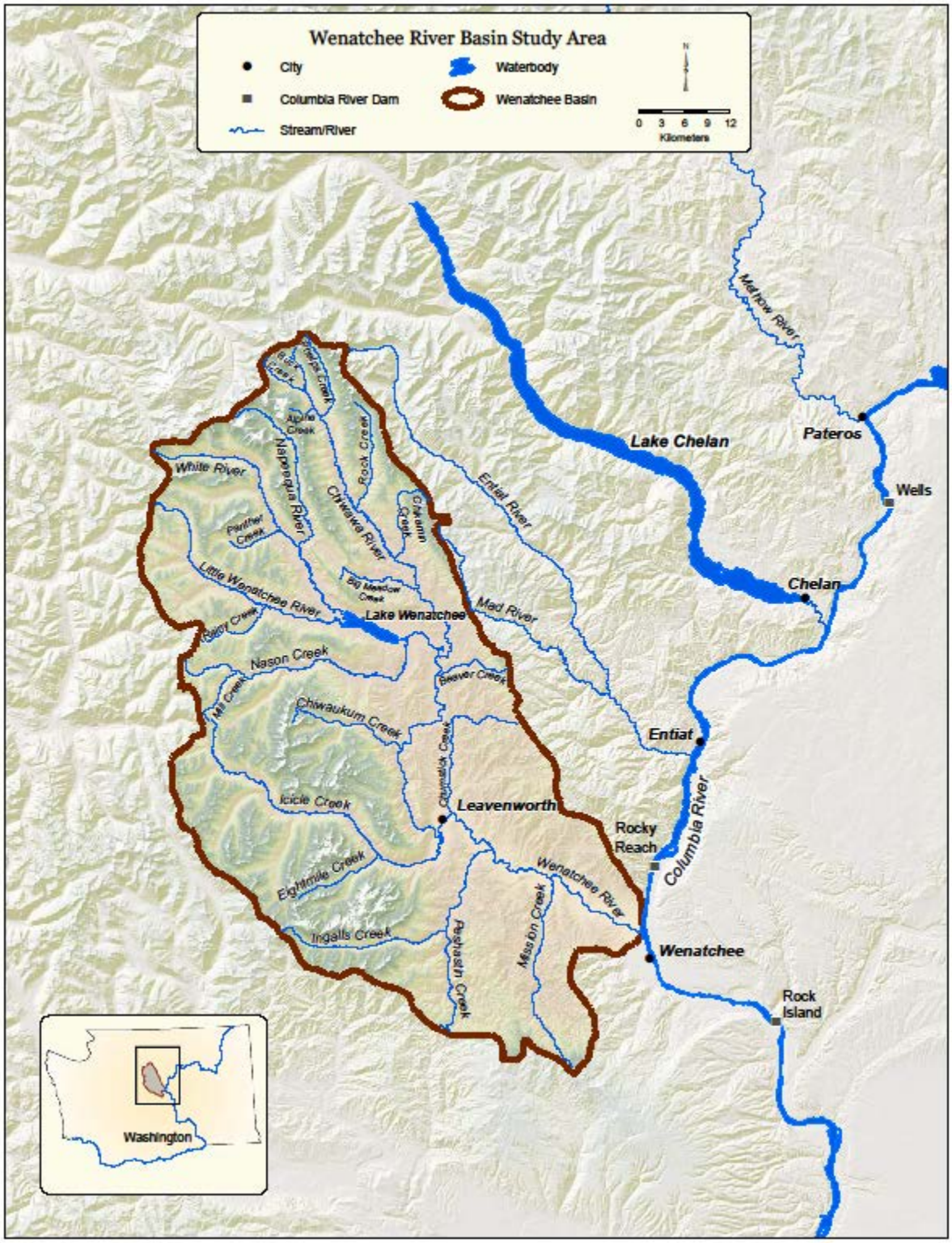

Figure 3. Map of the Wenatchee River Basin study area.

Artificial Obstructions

Migration corridors for fish are mostly intact in the Wenatchee River basin. There are two non-storage dams (Dryden Dam and Tumwater Dam) on the mainstem Wenatchee River. Several other smaller water diversion structures, weirs, and culverts are located throughout the basin (Andonaegui 2001).

Dryden Dam- Dryden Dam (rkm 28.3) was constructed in 1908 and diverts water into the Dryden Irrigation Canal on the left bank. The fishway was reconstructed with vertical slot fish ladders to improve fish passage in 1986 (OTT 1984; Mullan et al. 1992). Fish can migrate past Dryden Dam in the ladders on both sides of the river or mid-channel over natural boulder substrate incorporated into the dam. Dryden Dam has fish trapping facilities on both right and left banks that are periodically operated passively with a V-trap weir at the top of the fish ladders that divert fish into holding areas that are checked daily (Ferguson 2011). A retractable water-filled bladder can be expanded on top of the dam at the right bank to divert migrating fish and improve trapping efficiency at that fishway (Ferguson 2011).

Tumwater Dam- Tumwater Dam (rkm 49.7) was built in 1909 for hydropower, but the power plant was decommissioned in 1956, and water is no longer diverted. In 1986 the fishway was reconstructed with a vertical slot fish ladder to improve fish passage (OTT 1984; Mullan et al. 1992). Upstream movement past Tumwater Dam only occurs via one fish ladder on the left bank. This ladder is equipped with a viewing window and video recorder to provide a complete count of upstream passage. In 2001 a trapping system was constructed along the ladder at Tumwater Dam (Murdoch et al 2006). From 2001–2003 the trap was periodically operated by Washington Department of Fish and Wildlife (WDFW) during the daytime for hatchery broodstock collection and fisheries management objectives. In 2004 the trap was operated seasonally to capture all migrating adult spring Chinook salmon, and the trap was closed at night and sometimes during the day to allow time to process fish (Murdoch et al. 2006; Chelan PUD 2011).

Chiwawa River weir and trap- The Chiwawa River Salmon Rearing and Acclimation Facility (rkm 1.5) has a diffuser weir operated by hydraulic rams and a fish trap operated seasonally since 1990 (typically mid-May through early September) for collection of spring Chinook salmon hatchery broodstock by WDFW (Bugert 1998). The weir is typically operated in the upright position four consecutive days each week and fish moving upstream can be captured in the box trap on the right bank. The weir is lowered the other three days and fish can swim past the site. During the study the weir and trap were operated Sunday morning through Thursday morning, and the trap checked daily at 0830. Bull trout captured in the trap Monday, Tuesday, and Wednesday mornings were transported by WDFW and released 13.3 km upstream in the Chiwawa River at the Meadow Creek Campground (rkm 14.8). Thursday morning captures were released just upstream of the weir, which was lowered and remained down for the next three days, allowing migratory fish to move upstream naturally and unimpeded.

Leavenworth National Fish Hatchery- The artificial structures in Icicle Creek associated with Leavenworth National Fish Hatchery (LNFH) include a seasonal brood stock collection weir (rkm 4.4) and a headgate structure (rkm 6.1) that diverts water into either the historic channel or the flood control canal (USFWS 2006; Nelson et al. 2011). The outfall of the hatchery flows into the spillway pool at the base of the flood control canal (rkm 4.3). Operations of LNFH structures periodically blocked upstream fish movement but were not monitored for passage during this study.

Fish Species Diversity

Native salmonid species present in the Wenatchee River basin include spring and summer Chinook salmon *Oncorhynchus tshawytscha*, sockeye salmon and kokanee *O. nerka*, steelhead and redband rainbow trout *O. mykiss gairdneri*, coho salmon *O. kisutch* (reintroduced- first adult returns in 2000), westslope cutthroat trout *O. clarkii lewisi*, mountain whitefish *Prosopium williamsoni* and bull trout *Salvelinus confluentus* (Mullan et al. 1992; Proebstel et al. 1998; Wydoski and Whitney 2003; Sholz and McLellan 2009). Native non-salmonid species include Pacific lamprey *Entosphenus tridentatus*, redside shiner *Richardsonius balteatus*, longnose dace *Rhinichthys cataractae*, speckled dace *R. osculus*, leopard dace *R. falcatus*, threespine stickleback *Gasterosteus aculeatus*, peamouth *Mylocheilus caurinus*, chiselmouth *Acrocheilus alutaceus*, northern pikeminnow *Ptychocheilus oregonensis*, bridgelip sucker *Catostomus columbianus*, largescale sucker *Catostomus macrocheilus*, longnose sucker *C. catostomus*, prickly sculpin *Cottus asper*, mottled sculpin *C. bairdii*, Paiute sculpin *C. beldingi*, shorthead sculpin *C. confusus*, and torrent sculpin *C. rhotheus* (Mullan et al. 1992; Wydoski and Whitney 2003; Sholz and McLellan 2009).

Introduced species of fish in the basin include eastern brook trout *Salvelinus fontinalis*, lake trout *S. namayacush* (planted in Eightmile Lake and Chiwaukum Lake), brown trout *Salmo trutta*, coastal rainbow trout *Oncorhynchus mykiss irideus*, golden trout *O. mykiss aguabonita*, Yellowstone cutthroat trout *O. clarkii bouvieri*, yellow perch *Perca flavescens*, and common carp *Cyprinus carpio* (Sholz and McLellan 2009).

Methods

Capture and tagging

Capture- Bull trout were captured at five locations in the Wenatchee River watershed: Lake Wenatchee, Chiwawa River, Icicle Creek, and in the Wenatchee River at Tumwater Dam and Dryden Dam. In Lake Wenatchee and Icicle Creek bull trout were caught by angling with artificial lures, single barbless hooks, and knotless nets. Lake Wenatchee was angled in the west end including from the sockeye salmon floating net pens during a few selected days from May to August. In Icicle Creek the spillway pool at Leavenworth National Fish Hatchery (rkm 4.3) was angled during August and September to capture bull trout that seasonally use that area.

Migratory bull trout were captured in traps operated by WDFW for salmon hatchery broodstock collection on the Chiwawa River and at Tumwater and Dryden dams on the Wenatchee River. At the Chiwawa River weir trap bull trout were tagged on a range of dates selected after stationary telemetry sites were installed. At Tumwater and Dryden dams, bull trout that were captured during intermittent or limited trapping operations in 2001, 2002, and 2003 were tagged. Lake Wenatchee and Icicle Creek fishing dates and numbers of fish tagged each day depended on staff schedules, available transmitters, and sizes of fish caught.

Radio transmitters- Two sizes of coded radio transmitters (Lotek Wireless Inc™, Ontario, Canada) operating at radio frequencies 148.480 and 148.520 MHz, code set 1994, with a 5 s burst rate were used. The larger model MCFT-3A transmitter measured 16 x 46 mm, weighed 16.0 g in air, and estimated battery life was 761 d. The smaller model MCFT-3BM transmitter measured 11 x 43 mm, weighed 7.7 g in air, and estimated battery life was 278 d. To meet the recommendation that radio transmitters not exceed 2% of the fish's weight (Winter 1996), bull trout greater than 800 g were targeted for tagging with the large transmitter. Because bull trout were not weighed on capture, a minimum estimated length of 375 mm was used for the target criteria.

Transmitter implantation- Bull trout were surgically implanted with radio transmitters placed in the abdominal cavity using methods described by Summerfelt and Smith (1990). Surgical equipment and tags were sanitized in chlorhexidine diacetate solution (Nolvason®) and rinsed in 0.1% saline-distilled water solution. Surgeons washed their hands in chlorhexidine solution and rinsed with distilled water. Bull trout were anesthetized with tricaine methanesulfonate (Finquel®) at 80 mg/L of water solution buffered with sodium bicarbonate to match the pH of the lake or river water (Wedemeyer 1970; Summerfelt and Smith 1990). Ice packs were used in the anesthetic bath if needed to cool the water to less than 15^{o}C. When the fish lost equilibrium it was placed in a nylon duffel bag and weighed on a spring scale (± 50 g). Total length (TL, ± 5 mm) was measured, and a genetic tissue sample was taken from the lower caudal fin. (In 2002, the leading one or two rays from the left pelvic fin were excised from a subset of tagged bull trout- see Appendix D). When the bull trout exhibited loss of reflex reactivity, usually after 6–10 minutes in the bath, it was placed on a foam-lined cradle lubricated with a protective slime coat (PolyAqua®). The fish's gills were perfused with a maintenance dose of buffered anesthetic (40 mg/L) using a large bulb syringe. The incision site was rinsed with a saline-distilled water solution or lightly swabbed with povidine-iodine solution (Betadine®) (Wagner et al. 1999). A scalpel was used to make a 3-4 cm long incision into the abdominal cavity approximately 1 cm lateral of the midventral line and 1 cm anterior of the pelvic girdle. A catheter needle was inserted through the body wall to make an antenna exit hole dorsal and anterior of the pelvic fin. The antenna was threaded through the catheter, transmitter inserted, catheter removed, and the antenna lightly pulled to seat the tag posteriorly in the abdominal cavity. The incision was closed

with three to four simple interrupted sutures with external knots. Cyanoacrylate adhesive (Vetbond®) was applied to the knots and incision and allowed to dry 30 s before placing the fish into a perforated PVC tube in freshwater for recovery.

Archival temperature and depth tags- Archival temperature and pressure data loggers (model LTD1100, Lotek Wireless) were externally attached to ten radio-tagged fish. Archival tags measured 8 x 16 x 27 mm, weighed 5.0 g in air, and estimated tag life was three years. The tags recorded water temperature and pressure, with pressure converted to depth when the tag was recovered. Archival tags needed to be removed from the recaptured fish to retrieve data. See Appendix B for more information on the archival tags including attachment methods.

Transport and release- Tagged bull trout were held in PVC tubes for at least 15 min to recover and acclimate. Bull trout caught by angling in Lake Wenatchee and Icicle Creek were released at or near their capture site. Bull trout captured at Dryden Dam and Tumwater Dam were released 0.2–0.8 km upstream of the dams. Bull trout tagged at the Chiwawa River weir were transported 13.3 km upstream to a site near Meadow Creek (rkm 14.8). Tagged bull trout subsequently recaptured at the weir were transported to rkm 14.8 unless trapped the last (fourth) day of the capture week, and those were released just upstream of the lowered weir. Bull trout were transported by truck in perforated PVC holding tubes placed in in a large water tank equipped with bottled oxygen.

Recaptures

Bull trout trapped at the Chiwawa weir were checked by WDFW for presence of radio and archival tags. Recaptured bull trout were held until the crew arrived, and then were lightly anesthetized (tricaine, 80 mg/l), weighed, and measured. Archival tags were removed by clipping the stainless steel threads.

Monitoring of radio tagged bull trout

Movements of tagged bull trout were monitored by fixed receiver telemetry stations, aerial surveys, and ground tracking. Bull trout were detected with data logging telemetry receivers (Lotek™ SRX-400A model with W7, W16 or W31CG firmware). Locations were recorded with global positioning system units (Garmin™ GPSmap 76) or hand placed on maps. Location coordinates and other information was compiled in a geographic information system (ESRI ArcGIS™). River kilometers were designated from a river mile index (CBIC 1964), a stream catalog (Mullan et al. 1992), or digitally calculated in mapping software (MapTech™ Terrain Navigator). All river kilometer designations are approximate and may not agree with designations used by other agencies or in other reports.

Fixed stations- Fixed telemetry stations had multiple six-element Yagi antennas positioned to determine direction of movement. Line amplifiers and attenuators were used to boost and

balance signal strength. Antenna switching units (Lotek™ ASP 8 or Grant Engineering™ Hydra) were used and SRX-400A receivers sequentially scanned two channels for 6 s each. Sites were powered by a 12-volt battery charged by AC power or a 60 watt solar panel. Sites were periodically visited to download receiver data onto a laptop computer, replace batteries, and check the system using test transmitters.

There were twelve fixed telemetry stations, designated by a three letter code, including three on the Wenatchee River and nine in tributaries (Table 1, Figure 4). Tributary stations were located near confluences with two exceptions: The WHI station (White River rkm 10.2) was shared with a sockeye salmon project and was just downstream of sockeye salmon spawning areas, and the NAS station (Nason Creek, rkm 5.6) was selected because AC power was available. Three sites detected movements in two streams: The ROC station monitored Rock Creek and the Chiwawa River, and the WLK station on the Wenatchee River (1.0 km downstream of Lake Wenatchee and 0.2 km downstream of Nason Creek) was used to assess movements in and out of Lake Wenatchee and Nason Creek. In 2003 the PHE site on Phelps Creek was replaced with the CHP site on the Chiwawa River at the mouth of Phelps Creek that monitored movements in both streams. Stations with AC power were operated year-round and stations relying on solar power typically were operated from early summer to late fall.

Table 1. Wenatchee River watershed fixed telemetry stations: name, river monitored, river kilometer (rkm), location, and year and season operated.

Name	River	Rkm	Location	Years	Season
DRY	Wenatchee	28.3	Dryden Dam	2000-2004	year-round
TUM	Wenatchee	49.7	Tumwater Dam	2000-2004	year-round
WLK	Wenatchee	86.2	Hwy 207 bridge	2000-2004	year-round
ICI	Icicle	4.3	LNFH spillway pool	2002-2003	fall-spring
CHI	Chiwawa	1.5	WDFW weir	2000-2004	year-round
CHK	Chikamin	1.0	FS Road 62 bridge	2000-2004	summer-fall
ROC	Rock & Chiwawa	0.1 & 34.4	confluence	2000-2004	summer-fall
PHE	Phelps	0.5	FS Road 62 bridge	2000-2002	summer-fall
CHP	Chiwawa	48.6	Phelps confluence	2003-2004	summer-fall
NAS	Nason	5.6	USFS weigh station	2000-2004	year-round
WHI	White	10.2	Sears Cr. Rd. bridge	2000-2004	summer-fall
LTW	Little Wenatchee	1.9	old weir site	2000-2004	summer-fall

Aerial surveys- Fixed-wing airplanes with strut-mounted 2- or 3-element Yagi antennas were used for aerial surveys. Each antenna was connected to one or two receivers set to monitor one or two frequencies at a 6 s scan rate. Low elevation aerial surveys were flown 100–200 m above the river. One or two biologists operated the receivers, took notes, watched for hazards, and recorded transmitter signal locations with a handheld GPS unit and marked positions on a map.

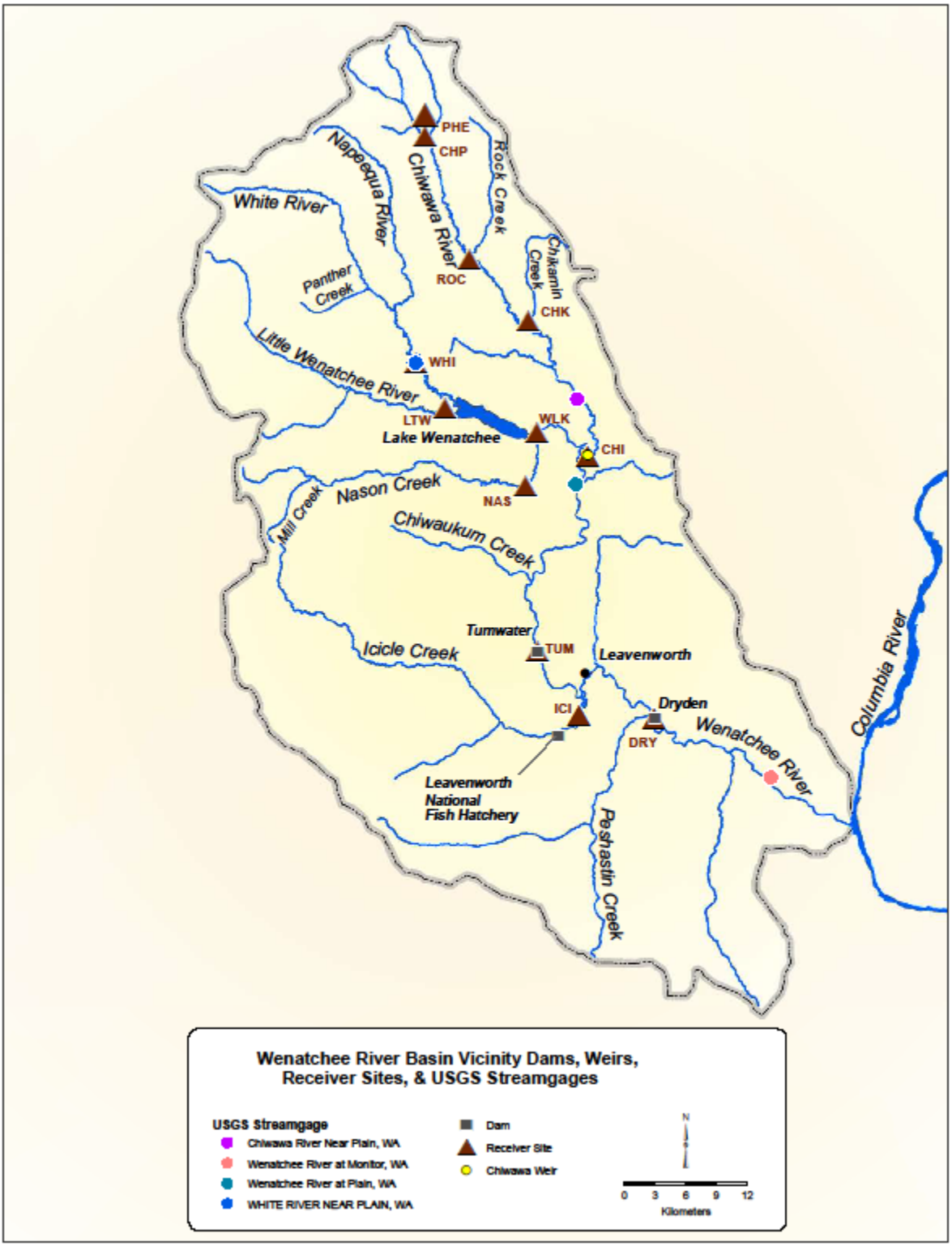

Figure 4. Map of fixed telemetry stations, dams and obstacles, and gage stations in the Wenatchee River study area.

During later flights a SRX-400A W31CG receiver interfaced with a GPS unit was used to automatically record the location. The coordinates taken from the plane at the time of the strongest transmitter signal were used to denote position of the fish.

There were 26 aerial surveys during five years (Table 2). Flight routes were planned to cover areas that tagged bull trout would likely be found, often based on fixed station data. In addition to the Wenatchee River watershed, most surveys included flying over the Columbia River between Rock Island Dam (rkm 731) and Rocky Reach Dam (rkm 762), and some flights extended to McNary Dam (rkm 470) and Chief Joseph Dam (rkm 877). Flights were scheduled during movement periods and to identify spawning and overwintering areas, but the frequency and dates of flights were dependent on annual budgets.

Table 2. Aerial telemetry survey dates for Wenatchee River watershed and Columbia River, 2000-2004.

2000	2001	2002	2003	2004
Aug 31	May 14	Feb 25	Jun 17	May 13
Sep 13	Aug 2	May 13	Jul 28	Jul 15
Sep 25	Nov 2	Jun 20	Aug 12	Aug 31
Nov 2		July 24	Sep 17	
		Sep 13	Oct 2	
		Sep 27	Oct 23	
		Nov 25	Nov 3	
			Nov 24	
			Dec 18	

Ground surveys- Tagged bull trout were periodically tracked by vehicle along roads, on foot in the stream, or by boat using a receiver and a hand-held 3-element Yagi antenna. The perimeter of Lake Wenatchee was ground-surveyed periodically by truck and on a few occasions by boat focusing on shallower areas since radio tags in deeper water cannot be detected due to signal attenuation.

Discharge, temperature, and fish passage data

At the Chiwawa weir and Tumwater Dam, the dates that pre-spawn migrating bull trout passed were compared to stream discharge and water temperature. Stream discharge data were obtained from the U.S. Geological Survey website (USGS 2012) for Chiwawa River near Plain and Wenatchee River at Plain, and from the Washington Department of Ecology website (WDOE 2012) for White, Little Wenatchee, Nason, Chiwaukum, Icicle, and Peshastin rivers (Figure 4). Bull trout trapping data and daily water temperature for the Chiwawa River weir were recorded and provided by WDFW (WDFW 2004a and 2004b). Temperature data for the Wenatchee River at Tumwater Canyon were obtained for 2001 and 2004 (WDOE 2005). Daily bull trout passage data for Tumwater Dam and Dryden Dam were recorded by WDFW and provided by Chelan County Public Utility District (WDFW 2005).

Data analysis

Tracking- The number of years tracked is defined as the number of years a tagged bull trout made at least one migratory movement after tagging and included the following overwintering period. If a transmitter remained in the same location over one or two migratory periods, the fish was assumed to have died or shed the tag (in some cases there was evidence about possible causes of mortality) and the last location and season was included in the movement analysis. Some transmitter signals weakened and batteries expired during the third year; if they were actively migrating but their signal was lost, we assumed the fish reached their spawning or overwintering locations.

Movement Categories- Movements were categorized as spawning migrations or forage/refuge migrations. Spawning migrations were movements between spawning areas and overwintering areas. Forage/refuge migrations are defined as non-spawning migrations to feeding habitat or refuge migrations to survival habitat (Northcote 1997). Bull trout were assumed to have spawned if they were within a known spawning area during the spawning period but actual reproductive activity was not witnessed. Bull trout were considered to be non-spawning during a year they were alive if they made forage/refuge migrations or remained in overwintering areas rather than migrating to a spawning area.

Spawning migrations were partitioned into four time periods defined as: (a) **pre-spawning**- migrations from overwintering area to spawning area, which included movements in migratory corridors prior to entering a tributary as well as movements in the tributary up to the spawning area; (b) **spawning**- located within known spawning reaches, usually from early September through middle October; (c) **post-spawning**- migrations from spawning area to overwintering area, which included movements downstream from spawning areas in tributaries and movements in migratory corridors after exiting the tributary; and (d) **overwintering**- defined as the location where a tagged bull trout stopped post-spawn (or fall) movement and remained prior to migration the following spring or summer.

Assignments to local population- Bull trout were assigned to local populations based on movement patterns during this study. Tagged bull trout that migrated to known or expected spawning areas were assigned to that tributary's local population (i.e. White, Chiwawa). If a tagged bull trout did not migrate to a spawning area, it was not assigned and was categorized as unknown. Subsequent genetic analysis of tissue samples from a subset of tagged bull trout confirmed that their population assignments during the telemetry study were correct (DeHaan and Neibauer 2012) and validated the use of spawning migrations to make those determinations.

Spawning frequency- In the year that bull trout were tagged, the size at tagging of those that spawned and those that did not spawn were compared with Student's t-test. The number of times

that individual bull trout spawned was tallied, and those fish tracked for two or three years were used to calculate spawning frequency and identify patterns.

Migration rate- Travel times between fixed telemetry stations were calculated using the last detection at one station and the first detection at the next station. Migration rate was calculated as distance between fixed stations divided by travel time between the stations (km/d). Migration rates for tagged bull trout transported 13.3 km from the Chiwawa weir to the Meadow Creek release site were adjusted for transport distance.

Time to pass structures- The passage times for tagged bull trout at Dryden Dam, Tumwater Dam, and the Chiwawa weir were calculated as the difference between the time of first and last detection recorded at the fixed telemetry station at each site. Passage time was calculated for both upstream and downstream movements. Number of days and migration rate of bull trout that passed the Chiwawa weir naturally were compared to those transported upstream 13.3 km using Student's t-test.

Diel movement- Diel movements at each stationary site were evaluated using a sunrise/sunset calendar (http://www.sunrisesunset.com) referenced to Leavenworth, Washington. Movements were considered to occur during daytime if they were between sunrise and sunset, at night if between sunset and sunrise, and both if times a bull trout arrived and left a station included both day and night times. Diel movements were tallied separately for pre-spawning and post-spawning migration periods.

Mapping- Geographic information system (GIS) software (ESRI ArcGIS 10.1™) was used to develop maps. Locations recorded during aerial and ground surveys were used to determine spawning locations, overwinter locations, and migration patterns, with the more accurate ground locations preferentially used. Location points were categorized into movement periods based on dates and areas of detection. Local population movement maps used locations for individual fish most instructive to illustrate migrations including furthest upstream locations during spawning, overwintering locations, and forage/refuge locations furthest upstream in tributaries and in areas of summer use in non-spawning years. Points were labeled with transmitter code numbers and dates as needed.

Statistics- Data were entered in spreadsheet software (Microsoft Excel™ 2010, Microsoft Corp.) that was used to calculate descriptive statistics. A statistical software package (STATGRAPHICS™ Plus for Windows 2.0, Statistical Graphics Corp. 1996) was used for calculation of Student's t-test (alpha = 0.05).

Results

Bull Trout Capture Data

Capture, tagging, and tracking

Tagging locations and dates- Sixty-two bull trout were radio tagged during the study, including 30 in 2000, 10 in 2001, 20 in 2002, and 2 in 2003 (Table 3). Most were captured during July and August, and 80% were tagged in the upper basin, with 27 bull trout tagged at Lake Wenatchee and 23 at the Chiwawa weir. Bull trout caught by angling that were too small or not fit to tag were released, including 21 in Lake Wenatchee and 2 in Icicle Creek (See Appendix C). Sixty bull trout were tagged with large transmitters (761 d) and two with small transmitters (278 d). Tagged fish were tracked through 2004.

Table 3. Bull trout tagging location, capture method, tagging dates, capture effort (days), and number tagged by year, 2000-2003.

Location	Method	Year	Dates	*n* Days	*n* Tagged
Lake Wenatchee	angling	2000	Jul 24 – Aug 10	4	14
Lake Wenatchee	angling	2001	Jul 24	1	4
Lake Wenatchee	angling	2002	May 29–30	2	9
Chiwawa Weir	trap	2000	Jul 20 – Aug 14	9	16
Chiwawa Weir	trap	2002	Jul 30 – Sep 10	3	7
Tumwater Dam	trap	2001	Jul 18	1	1
Tumwater Dam	trap	2002	Jul 30	1	2
Tumwater Dam	trap	2003	Jun 18–23	2	2
Icicle Creek	angling	2001	Sep 25 – Sep 26	2	4
Icicle Creek	angling	2002	Aug 26 – Sep 12	2	2
Dryden Dam	trap	2001	Jul 6	1	1

Sizes of tagged bull trout- The total lengths (TL) of radio tagged bull ranged from 390 to 725 mm (mean = 565 mm, SD = 68), and weight ranged from 640 to 3,810 g (mean = 1,616 g, SD = 571 g) (Table 4; see Appendix A). The tag burden was 0.4%–2.4% of the mass of the fish (mean = 1.2%, SD = 0.4) and only exceeded 2% in one fish (code 105).

Lengths and weights of the tagged bull trout were variable and differed by capture location. Bull trout trapped while moving upstream at the Chiwawa weir and Tumwater Dam (mean 588 mm, 1,878 g, n = 28) were significantly larger than fish caught by angling in Lake Wenatchee and Icicle Creek (mean 543 mm, 1,394 g, n = 33) in both length (one-way Student's t-test, t = 1.67, df = 59, $P = 0.004$) and weight (t = 1.67, df = 59, $P = 0.0003$) (Table 4; Figure 5).

Table 4. Total length (range, mean, and SD) of tagged bull trout by capture/tagging location in the Wenatchee River watershed, 2000-2003.

Tag location	*n*	Lengths (mm)	Mean length (mm)	SD (mm)
Lake Wenatchee	27	475–670	558	62
Chiwawa weir	23	520–680	587	50
Tumwater Dam	5	470–725	592	96
Icicle Creek	6	390–540	473	64
Dryden Dam	1	*no data*	-	-

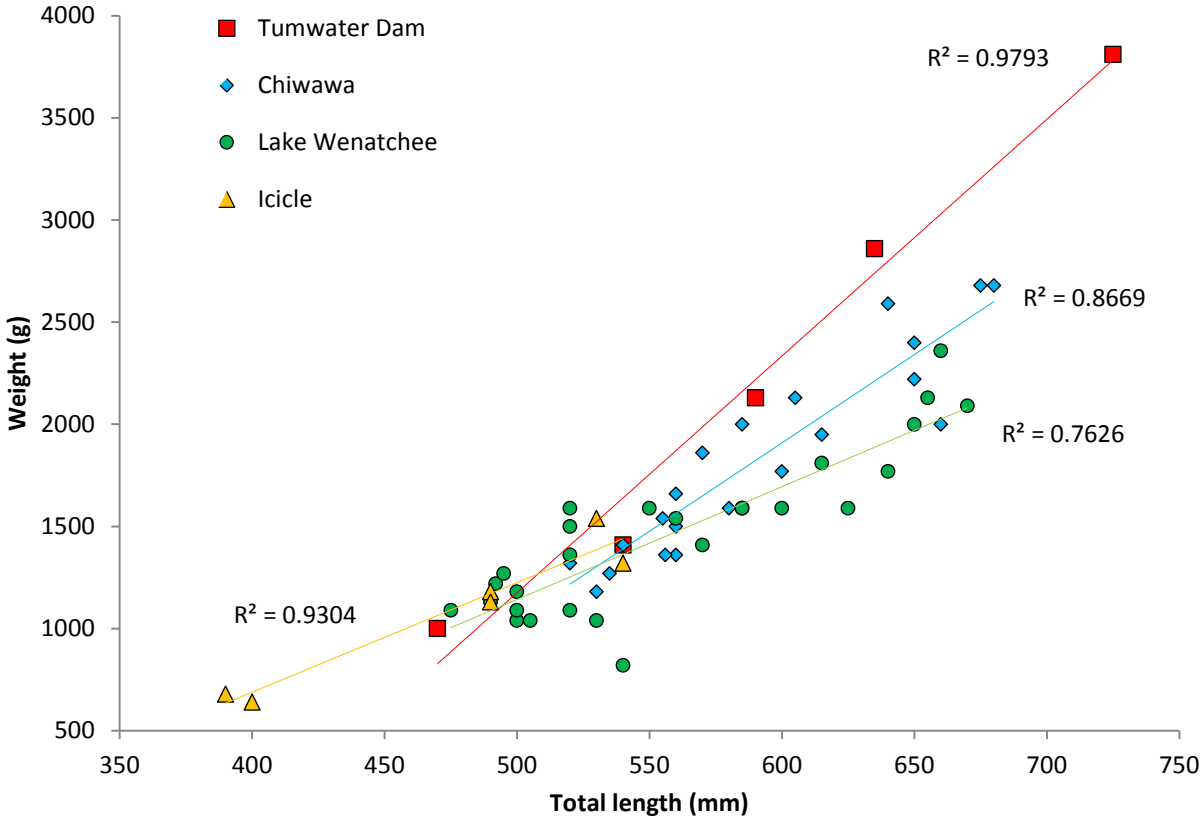

Figure 5. Plot of total lengths and weights of tagged bull trout trapped in the Wenatchee River at Tumwater Dam and at the Chiwawa River weir and captured by angling in Lake Wenatchee and Icicle Creek.

Archival tags- Ten radio-tagged bull trout were also externally tagged with archival temperature and depth tags. Only one archival tag (bull trout code 111) was recovered, 56 days after it was tagged. At least four of the bull trout lost their archival tags within a year. See Appendix B for more information on the archival tags.

Numbers of bull trout tracked- Movements of 59 bull trout were tracked including 29 individuals during one year, 18 during two years, and 12 during three years. Three bull trout tagged in Lake Wenatchee were never detected moving. Eleven bull trout died or shed the transmitter and were not tracked to spawning areas but provided some movement information (Appendix E).

Size of spawning and non-spawning bull trout

Mean total length of bull trout that spawned during the year they were tagged was 580 mm and for those that did not spawn 519 mm (Table 5). The difference between the two groups was significant (one-way Student's t-test, t = 3.36, df = 44, $P = 0.0008$). Only 50% (14 of 28) of the bull trout between 475 mm and 575 mm spawned in the year tagged, but 90% of the fish larger than 575 mm spawned (Figure 6). The two smallest bull trout that spawned were 490 mm (code 110) and 500 mm (code 72). The smallest bull trout trapped during migration was 470 mm and 1000 g (code 122) when tagged at Tumwater Dam on July 30 and it is uncertain if it spawned. (The transmitter was recovered 4 km upstream on September 13 and it could have expelled its tag or died.)

Table 5. Total length (range, mean, and SD) for bull trout that spawned or did not spawn during the year they were tagged.

Activity in 1st year tagged	*n*	Lengths (mm)	Mean length (mm)	SD (mm)
Spawn	28	490–680	580	59
No spawn	18	390–650	519	62

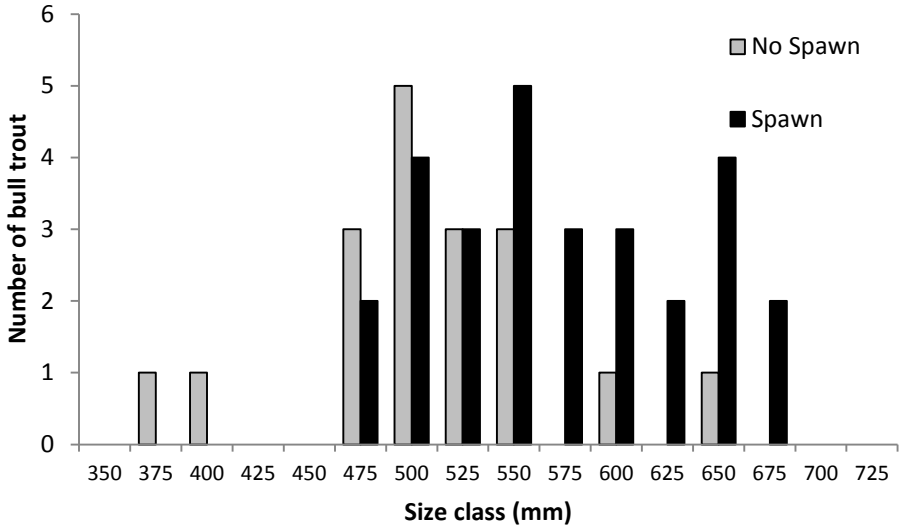

Figure 6. Numbers of bull trout by total length (25mm size classes) that spawned or did not spawn in the year they were tagged.

There was overlap in lengths and weights of spawners and non-spawners, but those with lower weights at the smaller lengths tended to be the individuals that did not spawn (Figure 7).

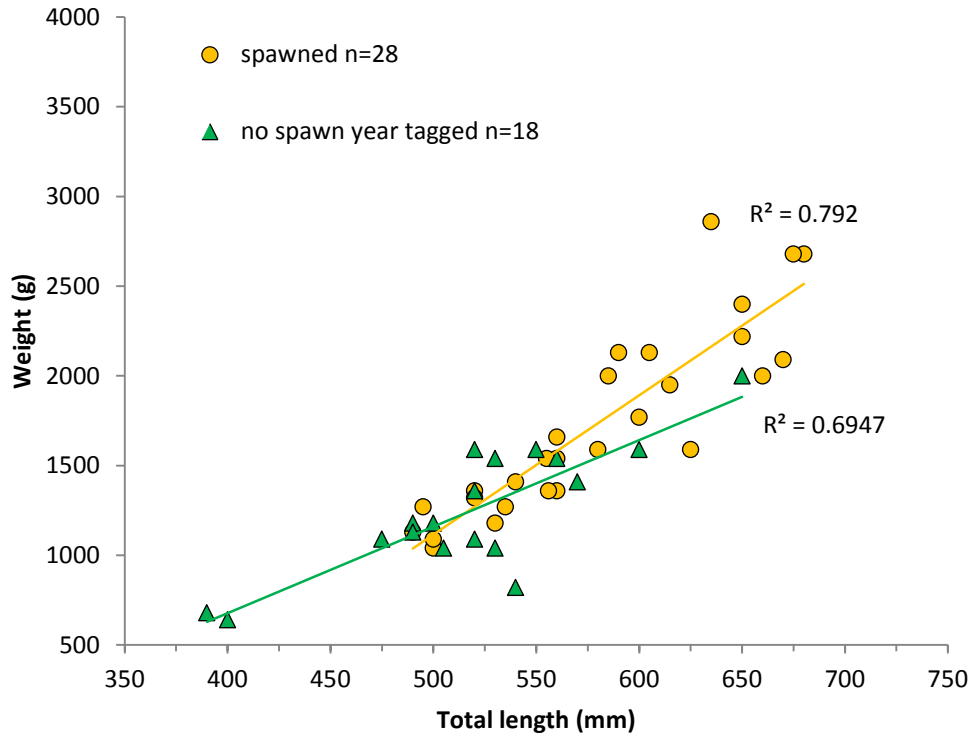

Figure 7. Plot of total lengths and weights at tagging of 28 bull trout that spawned in the year tagged, and 18 that did not spawn in the year tagged during the study.

Sex may have influenced size at spawning but could not be reliably determined when tagged. The lowest condition fish (540 mm and 820 g, code 103) tagged in Lake Wenatchee migrated to spawn during its third year tracked, thus allowing two more years of growth. The two largest bull trout not to spawn were 600 mm (code 81) and 650 mm (code 71) and had lower weights than most other bull trout that spawned in the higher length range (Figure 7). It was not known if these or others spawned in the year before they were tagged.

Eight bull trout did not spawn until the second year tracked and five bull trout did not spawn until their third year tracked. The lengths of the second and third year spawners were not significantly different (Table 6; one-way Student's t-test, t = 1.8, df = 11, *P* = 0.209). It was not known if any of these bull trout had spawned in previous years or if were immature when tagged.

Table 6. Total length, range, mean, and SD of bull trout at tagging that spawned in the second or third year tracked during the study.

First spawn	n	Lengths (mm)	Mean length (mm)	SD (mm)	Weight (g)	Mean weight (g)	SD (g)
Second year	8	490–650	538	51	1040–2000	1360	335
Third year	5	390–570	510	70	680–1540	1108	369

Growth of recaptured bull trout

Four bull trout tagged in Lake Wenatchee were recaptured at the Chiwawa weir 342 to 410 days after tagging. Growth rates ranged from 0.04 to 0.18 mm/d and 0.35 to 1.87 g/d (Table 7). The only bull trout that did not spawn between tagging and recapture (code 115) had the highest growth rate in length.

Table 7. Recaptured bull trout: radio code, size (mm and g) at tagging, number of days between captures, growth, and average daily growth rates (mm/d and g/d).

Code	Size at tagging		Days between	Growth		Growth rate	
	mm	g	captures	mm	g	(mm/d)	(g/d)
110	490	1130	398	55	140	0.14	0.35
115	500	1180	392	70	140	0.18	0.36
116	495	1270	410	55	410	0.13	1.00
118	650	2400	342	15	640	0.04	1.87

Spawning Frequency

Of the 59 bull trout tracked during the study, 41 were judged to have spawned and 34 of those spawned only once. Of 30 bull trout tracked for one year, 16 spawned once, 2 did not spawn, and 12 died or were not tracked (Table 8). Of 17 bull trout tracked during two years, 2 spawned twice, 13 spawned once including two that initiated a pre-spawning migration the second year (code 116 died pre-spawning and code 131 migrated downstream before spawning commenced), and 2 did not spawn (Table 9). Of 12 bull trout tracked for three years, 2 spawned three times, 3 twice, 5 once, and 2 (code 81 and 107) may have spawned once but were not located during spawning in one of the years (Table 9).

Fourteen bull trout spawned one year that were tracked the next year and 50% spawned again during the second year (Table 9). The other 7 bull trout moved the second year and 5 made forage/refuge migrations to non-spawning areas, one died pre-spawning, and one (code 131) migrated downstream from a spawning area before spawning began. The consecutive year spawners overwintered in the Columbia River (2 of 3 overwintering there, 66%), Lake Wenatchee (4 of 29, 14%), and the middle Wenatchee River near Icicle Creek (1 of 4, 25%).

Table 8. Bull trout tracked in only one year that spawned: number, radio codes, spawning location, and overwintering location.

n	Codes	Spawn location	Overwinter location
10	72, 84, 89, 90, 96, 98, 99, 109, 127, 129	Chiwawa	Lake Wenatchee
1	87	Chiwawa	Wenatchee River
3	91, 95, 97	Chiwawa	Unknown
2	73, 80	White	Lake Wenatchee

Table 9. Spawning frequency of tagged bull trout tracked during multiple years: number of years spawned, spawning location, and overwintering location.

Code	Years tracked	Years spawned	Year tracked 1-spawn 0-no spawn			Spawn location	Overwintering location
			1st	2nd	3rd		
86	3	3	1	1	1	Chiwawa	Columbia River
118	3	3	1	1	1	Chiwawa	Lake Wenatchee
76	3	2	0	1	1	Chiwawa	Lake Wenatchee
83	3	2	0	1	1	Chiwawa	Lake Wenatchee
130	3	2	0	1	1	Chiwaukum	Icicle Creek, Wen River
115	3	1	0	1	0	Chiwawa	Lake Wenatchee
82	3	1	0	0	1	Chiwawa	Wenatchee River
103	3	1	0	0	1	Chiwawa	Lake Wenatchee
104	3	1	0	0	1	White	Lake Wenatchee
105	3	1	0	0	1	Chiwaukum	Icicle Creek, Wen River
81	3	unk	0	unk [a]	0	unknown	Wenatchee River
107	3	unk	0	0	unk [a]	unknown	Icicle, Wen R, Columbia R
85	2	2	1	1		Chiwawa	Columbia River
110	2	2	1	1		Chiwawa	Lake Wenatchee
116	2	1	1	0	0 [b]	Chiwawa	Lake Wenatchee
131	2	1	1	0 [c]		Nason	Columbia River
88	2	1	1	0		Chiwawa	Lake Wenatchee
92	2	1	1	0		Chiwawa	Lake Wenatchee
93	2	1	1	0		Chiwawa	Lake Wenatchee
94	2	1	1	0		Chiwawa	Lake Wenatchee
124	2	1	1	0		Chiwawa	Lake Wenatchee
132	2	1	1	0		Chiwaukum	Wenatchee River
71	2	1	0	1		Chiwawa	Lake Wenatchee
77	2	1	0	1		Chiwawa	Lake Wenatchee
101	2	1	0	1		Chiwawa	Lake Wenatchee
113	2	1	0	1		Chiwawa	Lake Wenatchee
112	2	1	0	1		White	Lake Wenatchee
70	2	0	0	0		unknown	Lake Wenatchee, Wen River
108	2	0	0	0		unknown	Lake Wenatchee

[a] Codes 81 and 107 were not found during the spawning period so unknown if spawned. [b] Code 116 in its third year migrated into the Chiwawa River but died during pre-spawning migration. [c] Code 131 migrated in second year to the same area it spawned its first year but migrated downstream before spawning began.

Seasonal Movements

During the study radio-tagged bull trout migrated to known spawning areas in the Chiwawa River (including its tributaries Rock Creek and Phelps Creek), White River, Nason Creek (and its tributary Mill Creek), and Chiwaukum Creek. Tagged bull trout also made forage/refuge migration to use non-spawning areas in the White River, Little Wenatchee River, Nason Creek, and Icicle Creek. Overwinter areas and migration corridors used by tagged bull trout included Lake Wenatchee, the Wenatchee River, and the Columbia River.

Chiwawa River bull trout

Tracking summary- Thirty-five bull trout migrated into the Chiwawa River, including 20 tagged at the Chiwawa weir and 15 in Lake Wenatchee (Table 10). Thus 81% (35 of 43) of the bull trout in the study that were tracked to spawning areas migrated into the Chiwawa River. Chiwawa River bull trout overwintered in Lake Wenatchee (80%), the Wenatchee River upstream of the Chiwawa River (6%), the Columbia River (6%), and unknown locations (8%) (Table 10). Fifteen of the bull trout (43%) made forage/refuge migrations into other streams.

Table 10. Chiwawa River bull trout tracking summary: radio code, tagging location, number of years tracked, spawning location, number of years spawned, overwinter locations, number of years found at overwintering location, and other tributaries used.

Code	Tagging location	Years tracked	Spawn location	Years spawned	Overwinter location	*n* Winters	Use of other tributaries
85	Chiwawa	2	Rock	2	Columbia R	2	-
86	Chiwawa	3	Chiwawa	3	Columbia R	3	-
82	Lake Wen	3	Chiwawa	1	Wen River	2	White, Little Wen
87	Chiwawa	1	Rock	1	Wen River	1	-
72	Lake Wen	1	Rock	1	Lake Wen	1	-
94	Chiwawa	2	Rock	1	Lake Wen	2	Little Wenatchee
99	Chiwawa	1	Rock	1	Lake Wen	1	White
109	Lake Wen	1	Rock	1	Lake Wen	1	-
129	Chiwawa	1	Rock	1	Lake Wen	1	-
110	Lake Wen	2	Phelps	2	Lake Wen	2	-
113	Lake Wen	2	Phelps	2	Lake Wen	2	-
127	Chiwawa	1	Phelps	1	Lake Wen	1	-
71	Lake Wen	2	Chiwawa	1	Lake Wen	2	White
76	Lake Wen	3	Chiwawa	2	Lake Wen	3	White
77	Lake Wen	2	Chiwawa	1	Lake Wen	2	White
83	Lake Wen	3	Chiwawa	2	Lake Wen	3	White
84	Chiwawa	1	Chiwawa	1	Lake Wen	1	-
88	Chiwawa	2	Chiwawa	1	Lake Wen	2	Little Wenatchee
89	Chiwawa	1	Chiwawa	1	Lake Wen	1	-
90	Chiwawa	1	Chiwawa	1	Lake Wen	1	-
92	Chiwawa	2	Chiwawa	1	Lake Wen	2	Little Wenatchee
93	Chiwawa	2	Chiwawa	1	Lake Wen	2	Little Wenatchee
96	Chiwawa	1	Chiwawa	1	Lake Wen	1	-

98	Chiwawa	1	Chiwawa	1	Lake Wen	1	-
101	Lake Wen	2	Chiwawa	1	Lake Wen	2	Nason Creek
103	Lake Wen	3	Chiwawa	1	Lake Wen	3	-
111	Lake Wen	1	Chiwawa	0	Lake Wen	0	-
114	Lake Wen	1	Chiwawa	0	Lake Wen	0	-
115	Lake Wen	3	Chiwawa	1	Lake Wen	1	Little Wenatchee
116	Lake Wen	2	Chiwawa	1	Lake Wen	1	Little Wenatchee
118	Chiwawa	3	Chiwawa	3	Lake Wen	3	White, Little Wen
124	Chiwawa	2	Chiwawa	1	Lake Wen	2	White, Little Wen
91	Chiwawa	1	Chiwawa	1	Unknown	0	-
97	Chiwawa	1	Chiwawa	1	Unknown	0	-
95	Chiwawa	1	Chiwawa	1	Unknown	0	-

Pre-spawning migration- Bull trout migrated downstream from Lake Wenatchee to the Chiwawa River and passed the WLK station between April 21 and August 19 (Table 11). Six bull trout held in the Wenatchee River (rkm 77.8–86.2) for 4 to 43 d. Most moved downstream in the Wenatchee River relatively fast, with a median elapsed time of 1.0 d to travel 9.9 rkm from the WLK station to the CHI station (Table 12). Bull trout entered the Chiwawa River and passed the CHI station between June 2 and September 10 (Table 11), with two tagged fish from the Columbia River entering between June 28 and July 22. Bull trout migrated upstream in the Chiwawa River for 5 to 46 d before they passed the ROC station from July 7 to September 20, and then either entered Rock Creek spawning areas or continued upstream to spawning areas in the mainstem or Phelps Creek (Table 11, Figures 8 – 12). Five bull trout in 2003 took an additional 9 to 33 d to reach the CHP station near the mouth of Phelps Creek, arriving July 22 to September 3 (mean = 45 d from CHI to CHP).

Table 11. First and last dates that radio-tagged bull trout passed fixed receiver stations during pre-spawning migrations downstream from Lake Wenatchee then upstream in the Chiwawa River, 2000–2004.

Fixed station	Direction	First date	Last date	Median date	*n*
WLK (rkm 86.2)	down	Apr 21	Aug 19	Jul 7	20
CHI (rkm 1.5)	up	Jun 2	Sep 10	Jul 28	45
ROC (rkm 34.2)	up	Jul 7	Sep 20	Aug 17	38
CHP (rkm 48.6)	up	Jul 22	Sep 3	Jul 31	5

Table 12. Bull trout pre-spawning migration rates (km/d) between Lake Wenatchee and Chiwawa River (WLK to CHI stations) and upstream in the Chiwawa River (CHI to ROC and ROC to PHE stations), 2000-2004.

Reach	Direction	Distance (km)	Median (d)	Range (d)	Mean km/d (SD)	*n*
WLK–CHI	down-up	9.9	1.0	0.2–76	14.6 (19.4)	17
CHI–ROC	up	19.4[a]–32.7	22.5	5–46	1.2 (1.1)	28
ROC–CHP	up	14.4	16	9–33	1.0 (0.5)	5

[a] Distance traveled after bull trout transported to release site.

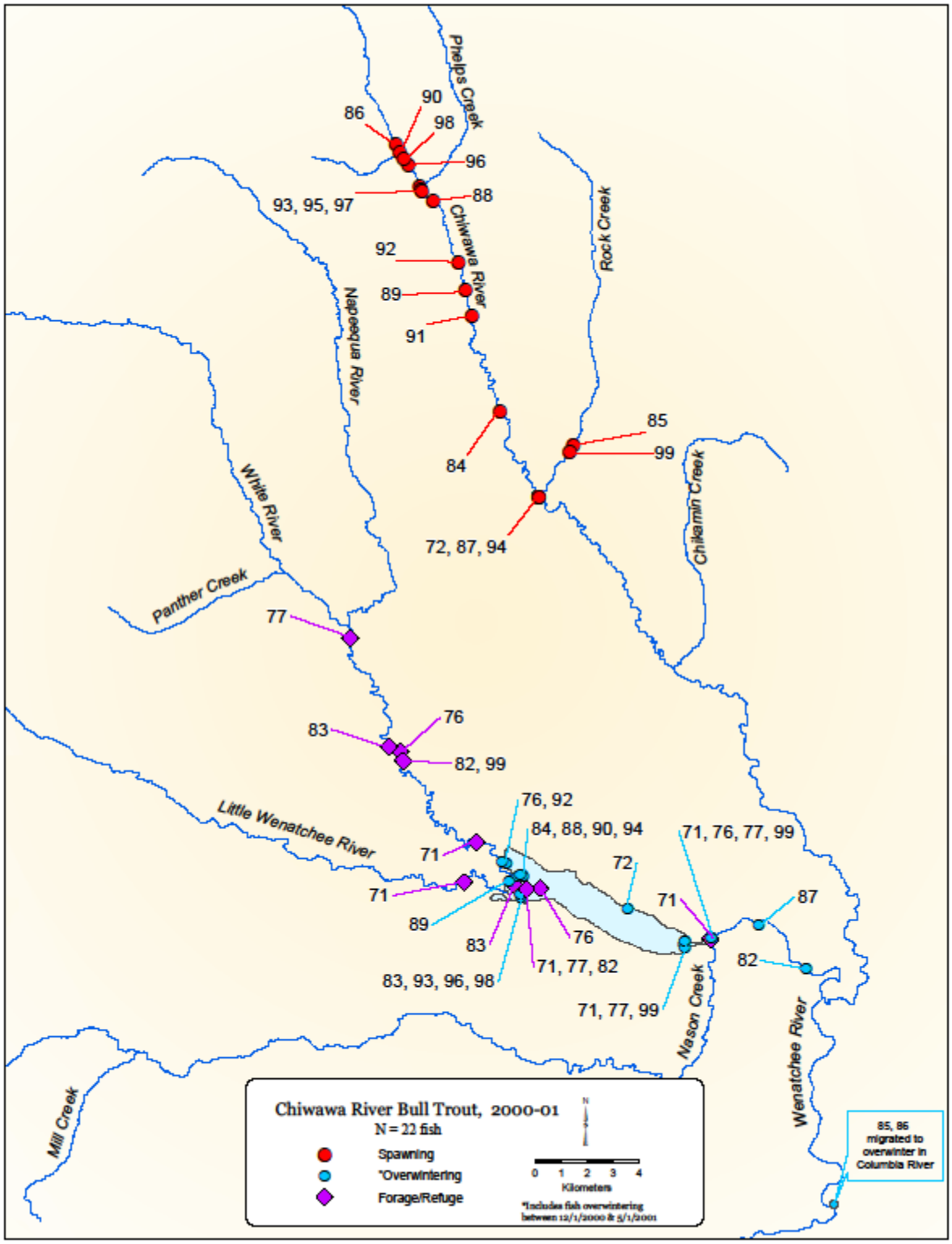

Figure 8. Map of Chiwawa River local population bull trout showing spawning, overwintering, and forage/refuge locations, 2000/2001.

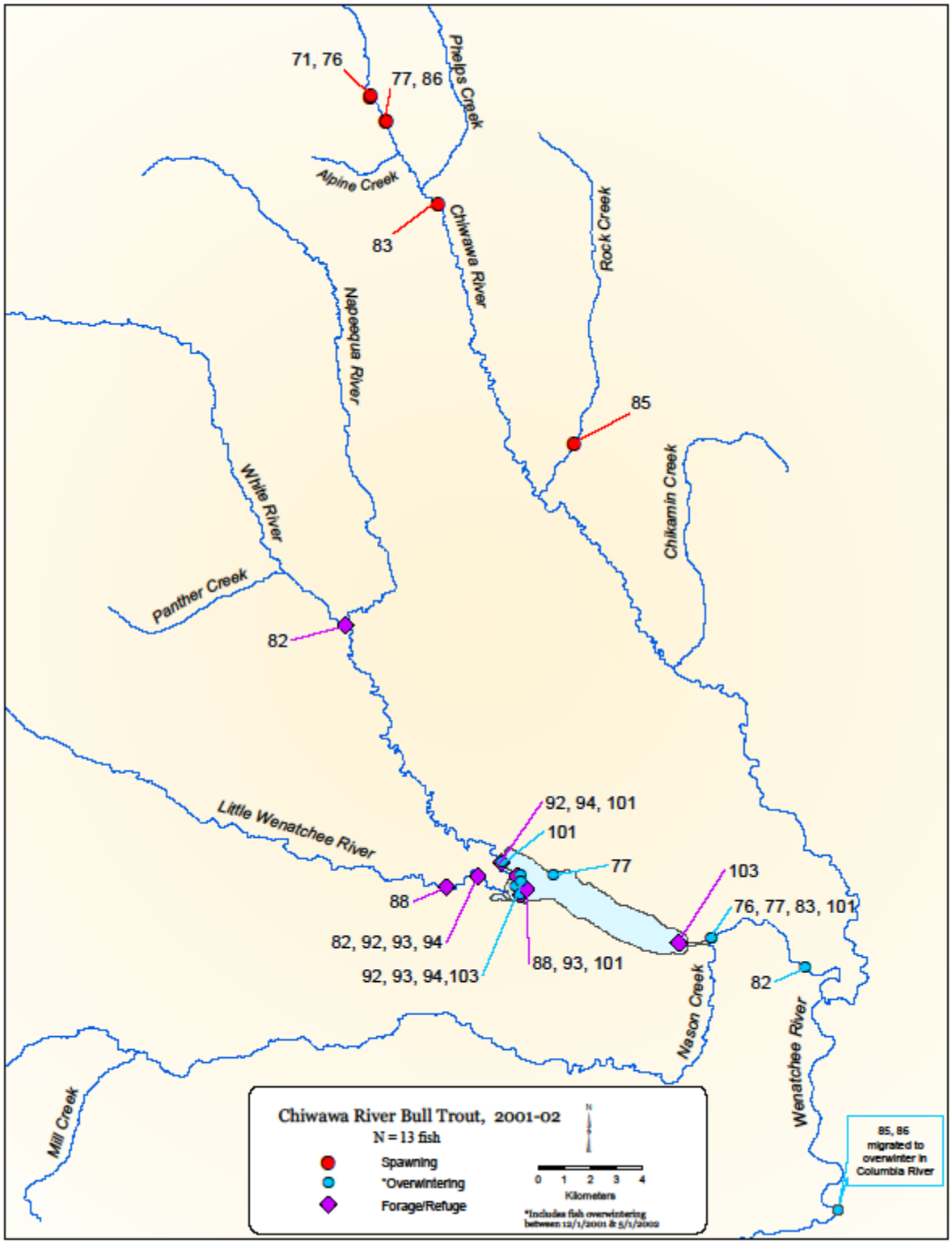

Figure 9. Map of Chiwawa River local population bull trout showing spawning, overwintering, and forage/refuge locations, 2001/2002.

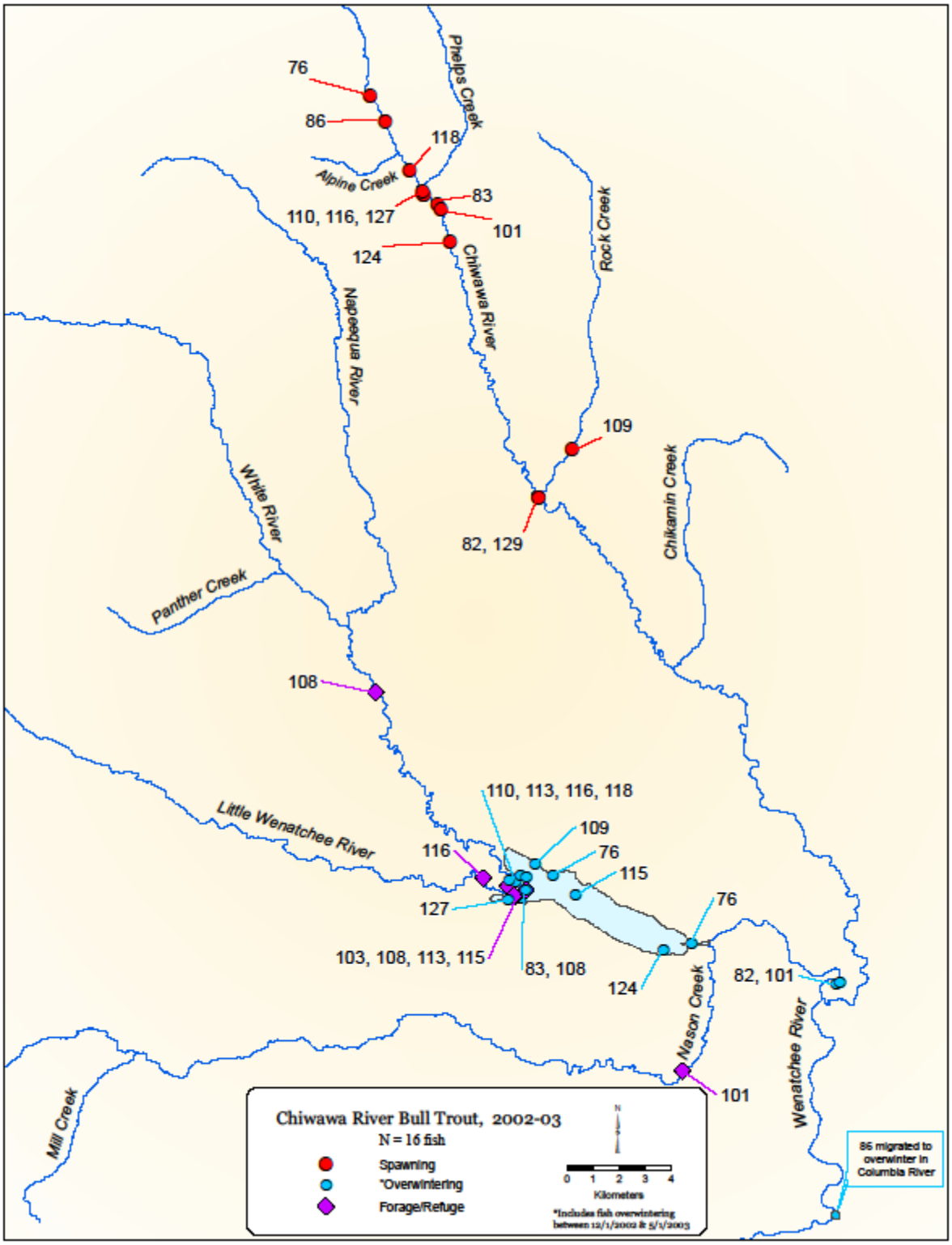

Figure 10. Map of Chiwawa River local population bull trout showing spawning, overwintering and forage/refuge locations, 2002/2003.

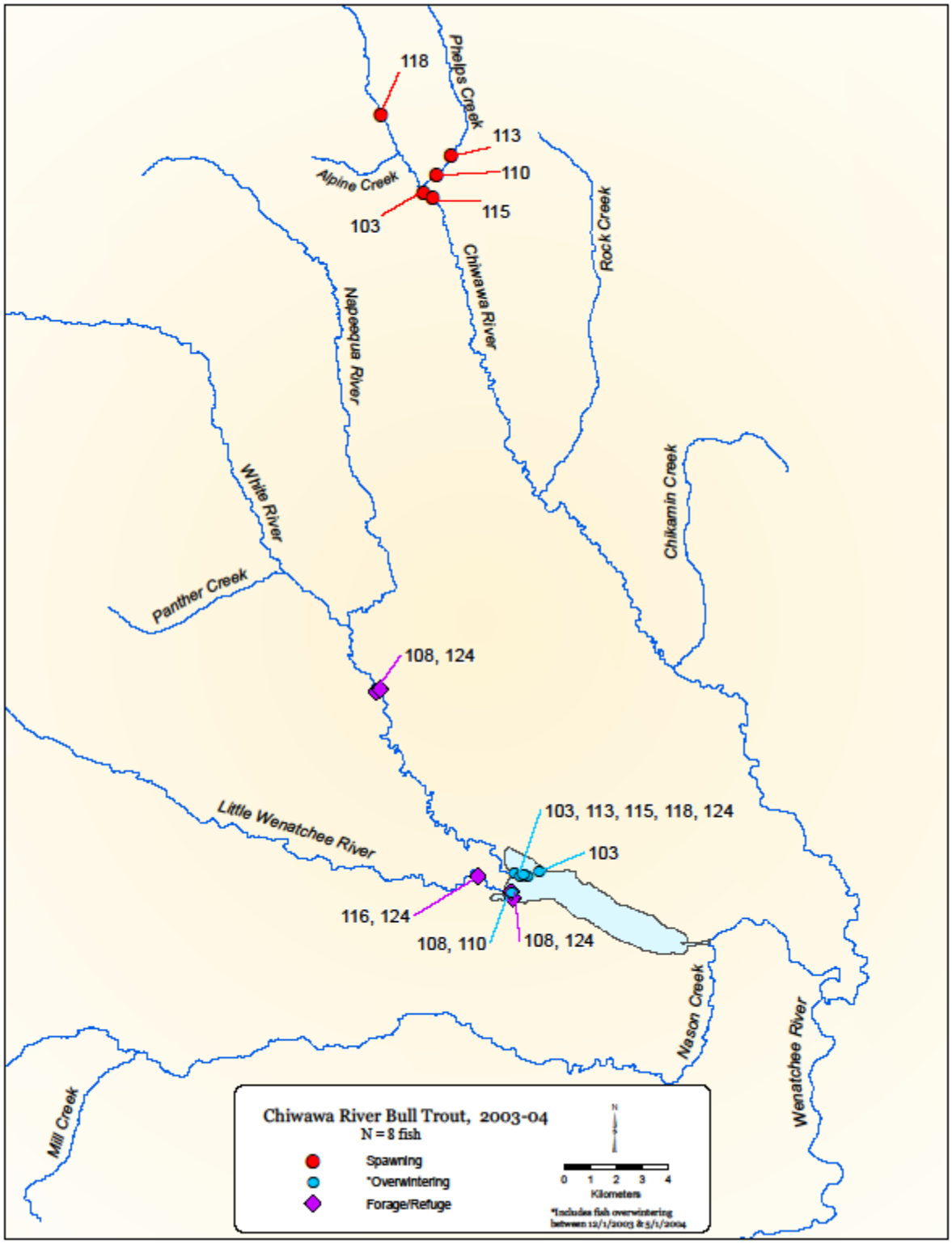

Figure 11. Map of Chiwawa River local population bull trout showing spawning, overwintering, and forage/refuge locations, 2003/2004.

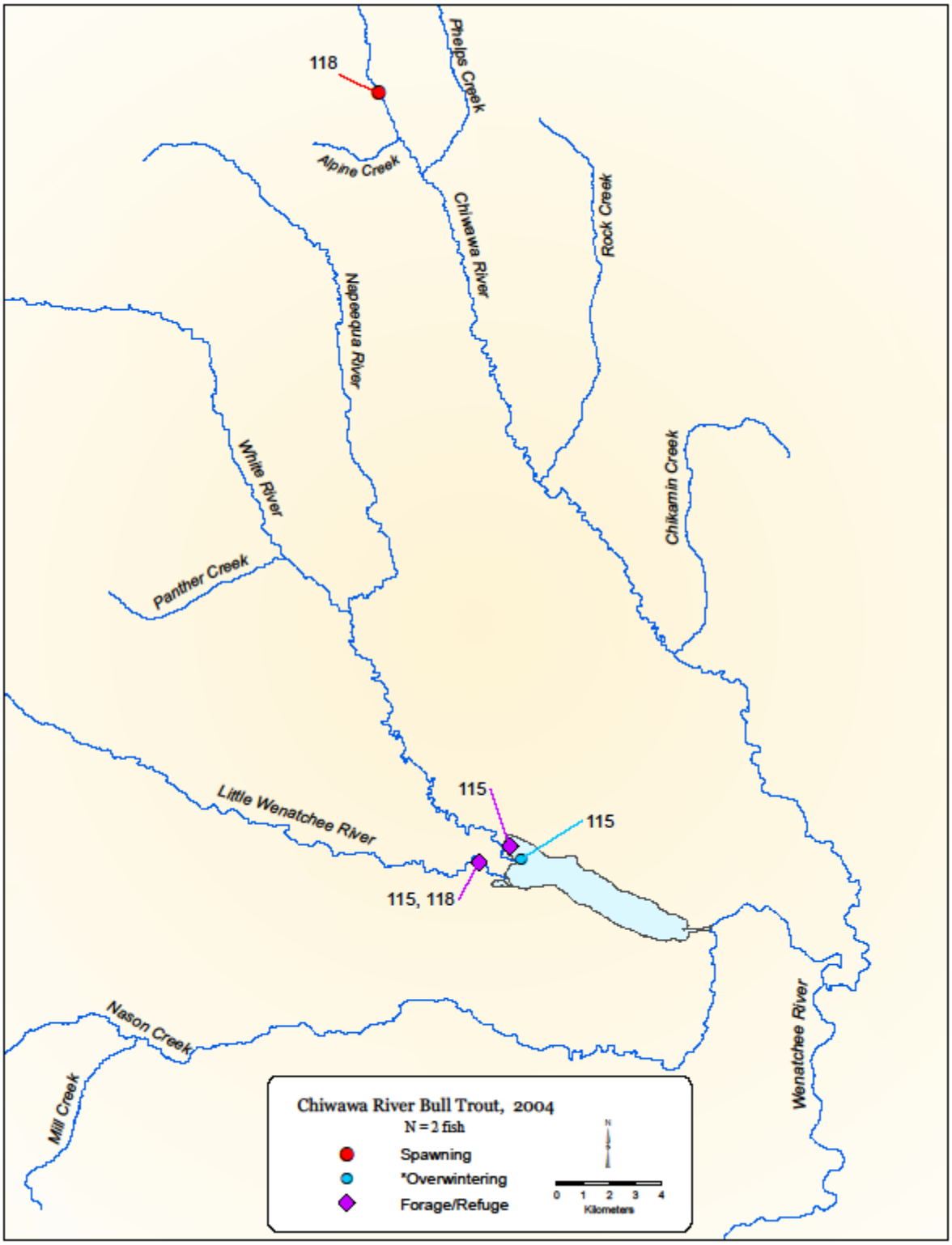

Figure 12. Map of Chiwawa River local population bull trout showing spawning, overwintering, and forage/refuge locations, 2004.

The range of dates that bull trout migrated into the Chiwawa River were influenced by stream flows and water temperatures as indicated by both telemetry data and trap counts at the weir (212 to 501 bull trout trapped per year during 2000–2003). Chiwawa River discharge ranged from 3 to 67 m^3/s during pre-spawning migrations, but the majority of bull trout did not enter the river until flows declined to less than 45 m^3/s and most passage occurred at less than 30 m^3/s (Figures 13-14). In 2001 and 2003 when the spring runoff was lower or peaked earlier, most of the bull trout entered and passed the weir in June through mid-July. By contrast in 2000 and 2002 when the peak flows were higher and later, the majority of bull trout passed the weir in July and early August (Figures 13-14). Maximum daily water temperatures ranged from 6.1 to 19.4ºC during pre-spawning migrations and 90% of all bull trout entered the river when maximum daily water temperatures ranged from 8ºC to 16ºC (Figures 13-14).

Spawning- Thirty-two bull trout migrated into known spawning areas in the Chiwawa River. Twenty-two (69%) spawned in the upper mainstem Chiwawa River, 7 (22%) spawned in Rock Creek, and 3 (9%) spawned in Phelps Creek (Figures 8-12). No tagged bull trout were detected in known spawning areas in Chikamin Creek or Buck Creek. Bull trout were in spawning reaches from July 7 to October 9 for a duration of 15 to 77 d (mean = 42 d) (Table 11 and Table 13).

Post-spawning migration- After spawning most of the tagged bull trout moved downstream relatively quickly in the Chiwawa River. They traveled from the ROC station to the CHI station between September 11 and October 10 (Table 13) at a mean rate of 18.1 km/d (Table 14). The exception was code 76, which was located between the ROC and CHI stations for 92 d (located at rkm 22.7 on November 2) and exited the Chiwawa River on December 19. Tagged bull trout spent between 31 and 189 d in the Chiwawa River basin (mean = 71 d). After migrating out of the Chiwawa River the majority migrated upstream in the Wenatchee River to Lake Wenatchee and entered the lake between September 15 and December 21 (Table 13). Most took less than 1 d to migrate from the Chiwawa River into Lake Wenatchee (Table 14). Two bull trout (code 85 in two years and 86 in three years) migrated in the Wenatchee River to the Columbia River.

Table 13. First, last, and median dates that Chiwawa River tagged bull trout moved past telemetry stations (ROC, CHI, WLK) during post-spawning migrations, 2000-2004.

Station (rkm)	Direction	First date	Last date	Median date	*n*
ROC (34.2)	downstream	Sep 11	Oct 9	Sep 27	35
CHI (1.5)	downstream	Sep 13	Dec 19	Sep 28	35
WLK (86.2)	upstream	Sep 15	Dec 21	Sep 28	28

Table 14. Migration distances (km) and rate (km/d) of Chiwawa River tagged bull trout during post-spawning migrations, 2000-2004.

Reach	Direction	Distance (km)	Median (d)	Range (d)	Mean km/d (SD)	*n*
ROC–CHI	downstream	32.7	1.6	0.5–92	21.3 (10.1)	28
CHI–WLK	down-upstream	9.9	0.8	0.2–12	18.1 (13.5)	27

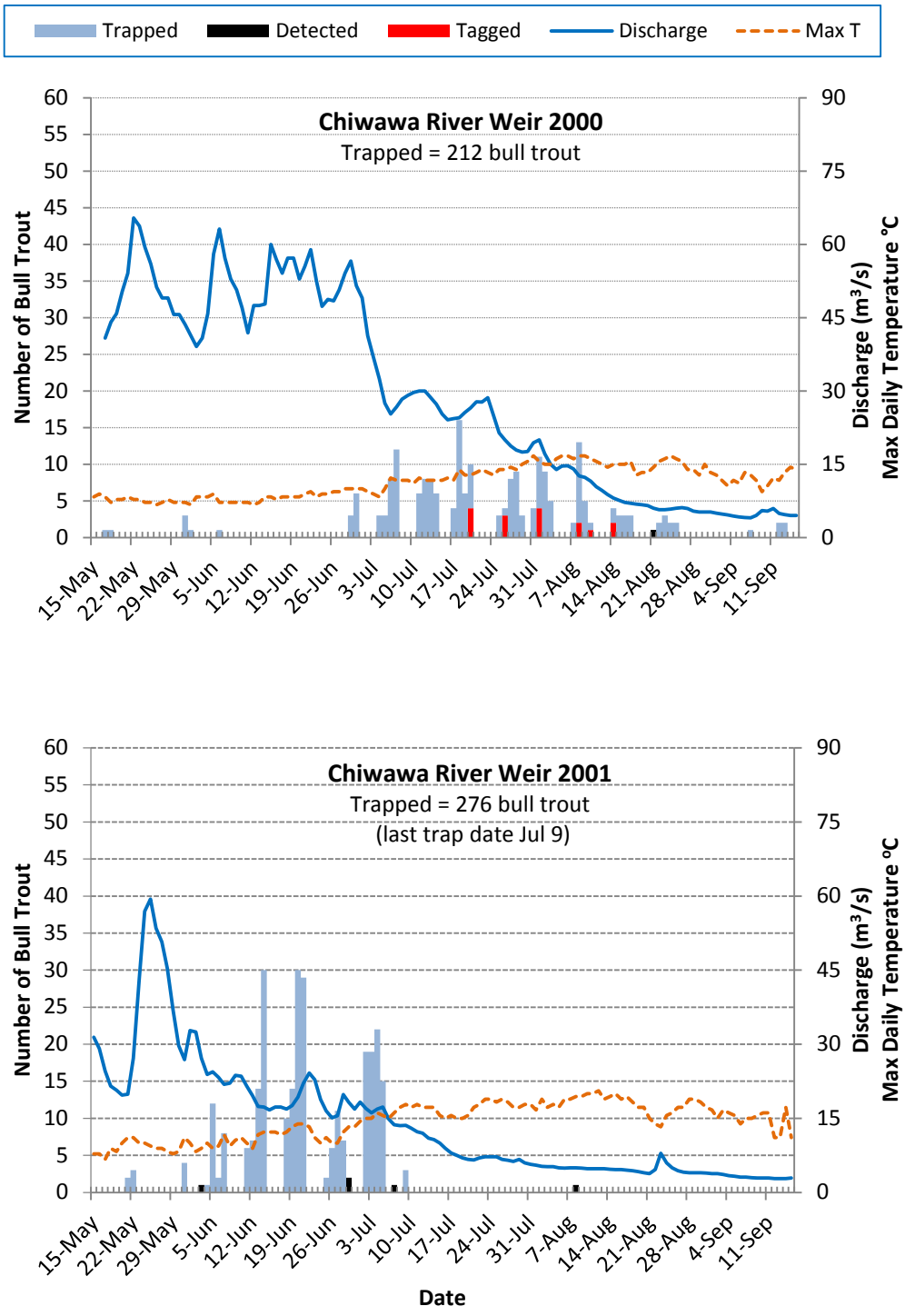

Figure 13. Daily bull trout passage at the Chiwawa River weir (rkm 1.5) in relation to stream discharge (m^3/s) and maximum daily temperature (°C), 2000-2001.

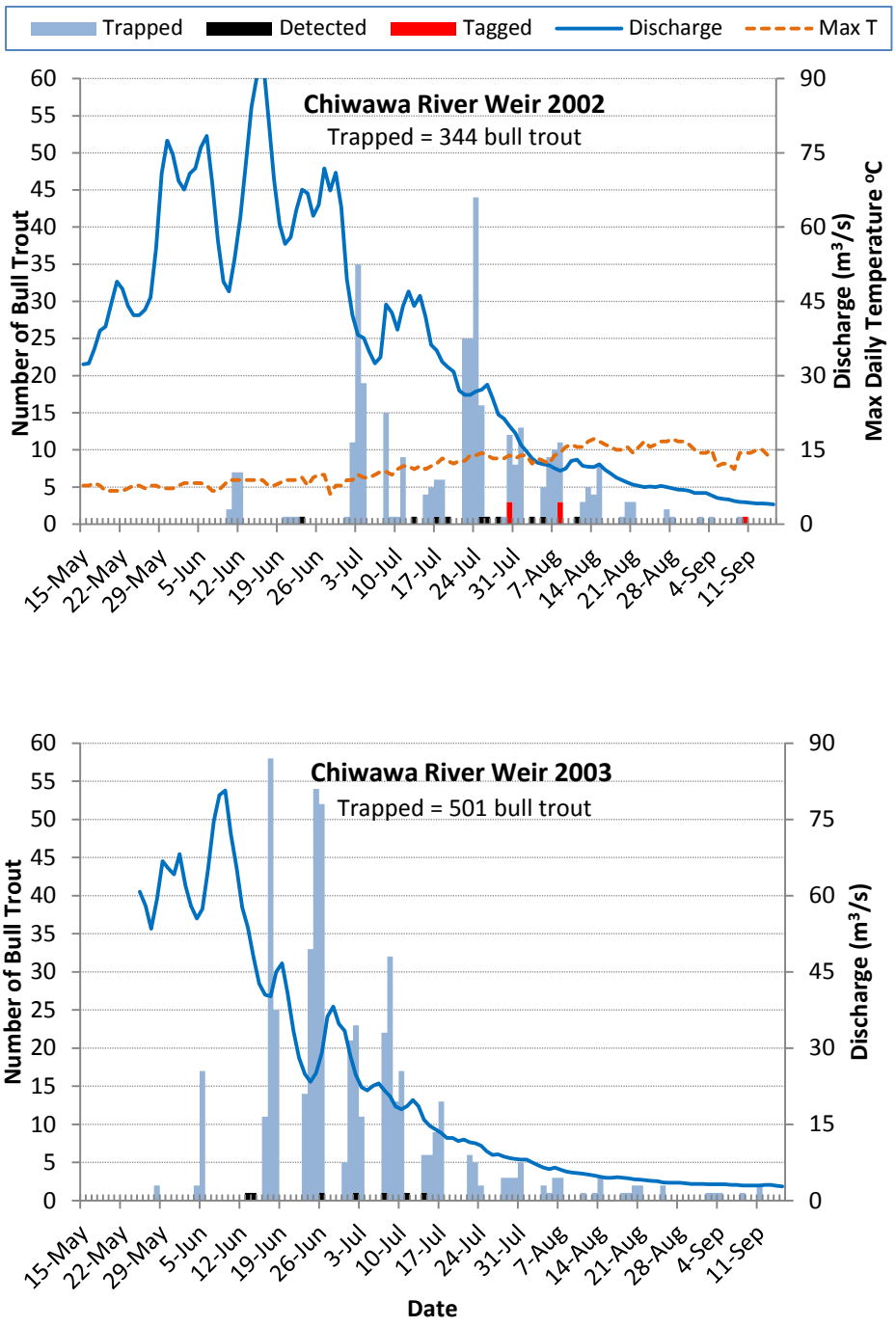

Figure 14. Daily bull trout passage at the Chiwawa River weir (rkm 1.5) in relation to stream discharge (m^3/s) and maximum daily temperature (°C), 2002-2003.

Overwintering- Twenty-nine Chiwawa River bull trout overwintered in Lake Wenatchee, 88% of the 33 fish tracked to or from overwintering areas. Tagged bull trout migrated upstream into Lake Wenatchee on a median date of September 28 (Table 13). See the *Lake Wenatchee* section for more details on use of the lake. Two Chiwawa River bull trout were thought to have overwintered in the Wenatchee River upstream of the Chiwawa River, including one (code 87) located near rkm 84 that later died, and one that moved downstream from Lake Wenatchee during October in two years (code 82) (Figures 8-10). Two bull trout (codes 85 and 86) migrated from the Chiwawa River downstream in the Wenatchee River and overwintered in the Columbia River at unknown locations. Code 85 migrated to spawn twice and code 86 three times, each time making the migration back downstream to overwinter in the Columbia River. They were in the Columbia River for 229 to 234 d before re-entering the Wenatchee River the following spring.

Use of other tributaries- Fifteen Chiwawa River bull trout made forage/refuge migrations into non-spawning reaches of other tributaries outside of the Chiwawa River, apparently for non-reproductive activities. Before their pre-spawning migrations two bull trout (codes 116 and 118) moved from Lake Wenatchee into the Little Wenatchee River and one bull trout (code 101) moved downstream and into Nason Creek before proceeding into the Chiwawa River (Figures 8-12; Table 15). Two post-spawning bull trout moved into the White River. In non-spawning years eight bull trout used the White River or Little Wenatchee River and three used both. Code 82 used both lake tributaries during the first two years it was tracked and migrated to spawn in the Chiwawa River its third year. Code 118 spawned in the Chiwawa River in three years and in the first two years used the White River after spawning but in the third year used the Little Wenatchee River before spawning. During a non-spawning year, code 124 was in the White River from July 28 through October 4 and then was in the Little Wenatchee River on October 5.

Table 15. Dates that Chiwawa River bull trout were detected in the White River, Little Wenatchee River, and Nason Creek during forage/refuge movements, 2000-2004.

Tributary	When used	Dates detected	*n* Bull trout
Little Wenatchee	pre-spawn	Jun 23 – Jul 24	3
Nason	pre-spawn	May 21 – Aug 4	1
White	post-spawn	Sep 27 – Oct 16	3
Little Wenatchee	post-spawn	Oct 5	1
White	non-spawn year	Jul 28 – Oct 11	7
Little Wenatchee	non-spawn year	Jun 23 – Oct 9	7

White River bull trout

Tracking summary- Four bull trout tagged in Lake Wenatchee spawned in the White River and wintered in Lake Wenatchee (Table 16; Figure 15). One of these also used the lower Little Wenatchee River for forage/refuge. Twelve bull trout from other local populations used the White River downstream of bull trout spawning areas for forage/refuge.

Table 16. White River bull trout tracking summary: radio code, tagging locations, number of years tracked, number of years spawned, overwintering locations, and number of winters tracked.

Code	Tagging location	Years tracked	Spawn location	Years spawned	Overwintering location	*n* Winters	Use of other streams
73	Lake Wen	1	White	1	Lake Wenatchee	1	
80	Lake Wen	1	White	1	Lake Wenatchee	1	Little Wen R
104	Lake Wen	3	White	1	Lake Wenatchee	3	
112	Lake Wen	2	White	1	Lake Wenatchee	2	

Pre-spawning migration- Four White River bull trout migrated from Lake Wenatchee upstream into the White River and passed the WHI station (rkm 10.2) between July 16 and August 9 (Table 17). Codes 73 and 80 migrated to spawn their first year, code 104 stayed in Lake Wenatchee its first two years and migrated into the White River the third year, code 112 migrated into the White River in two years, but only migrated into spawning areas during its second year. In 2003 two tagged bull trout were detected at the WHI station after discharge declined to less than 20 m^3/s, and the mean daily water temperature had increased to 11.1–13.4°C (Figure 16).

Spawning- Two bull trout (codes 104 and 112) were observed with a group of 26 bull trout in a glide pool at rkm 20 within the known spawning reach on September 18. During the next survey both were in the same area near completed redds. The other two bull trout (codes 73, 80) were in the White River during the spawning period, although code 80 was not located after it moved upstream of the WHI station, and code 73 was located downstream of the known spawning index reach, but in an area where bull trout redds have been observed (Figure 15); both were assumed to have spawned. Code 112 was in the White River in a non-spawning area downstream of the Napeequa River through early October its first year tracked, and it was assumed it did not spawn.

Table 17. Detection histories of White River bull trout at the WHI station (rkm 10.2): date of upstream movement, farthest upstream location, date of downstream movement and minimum number of days spent in the White River, 2000-2003.

Code	Year	Date up WHI	Farthest upstream rkm	Date farthest upstream	Date down WHI	*n* Days up of WHI
73	2000	Aug 9	16.8	Sep 13	Sep 30	53
80	2000	Aug 7	*unknown*	*unknown*	Sep 29	54
104	2003	Jul 16	19.0	Sep 25	Oct 9	86
112	2002	<Aug 27	13.6	Sep 20	Oct 5–17	39–51+
112	2003	Jul 29	20.5	Sep 17–Dec 18	*unknown*	143+

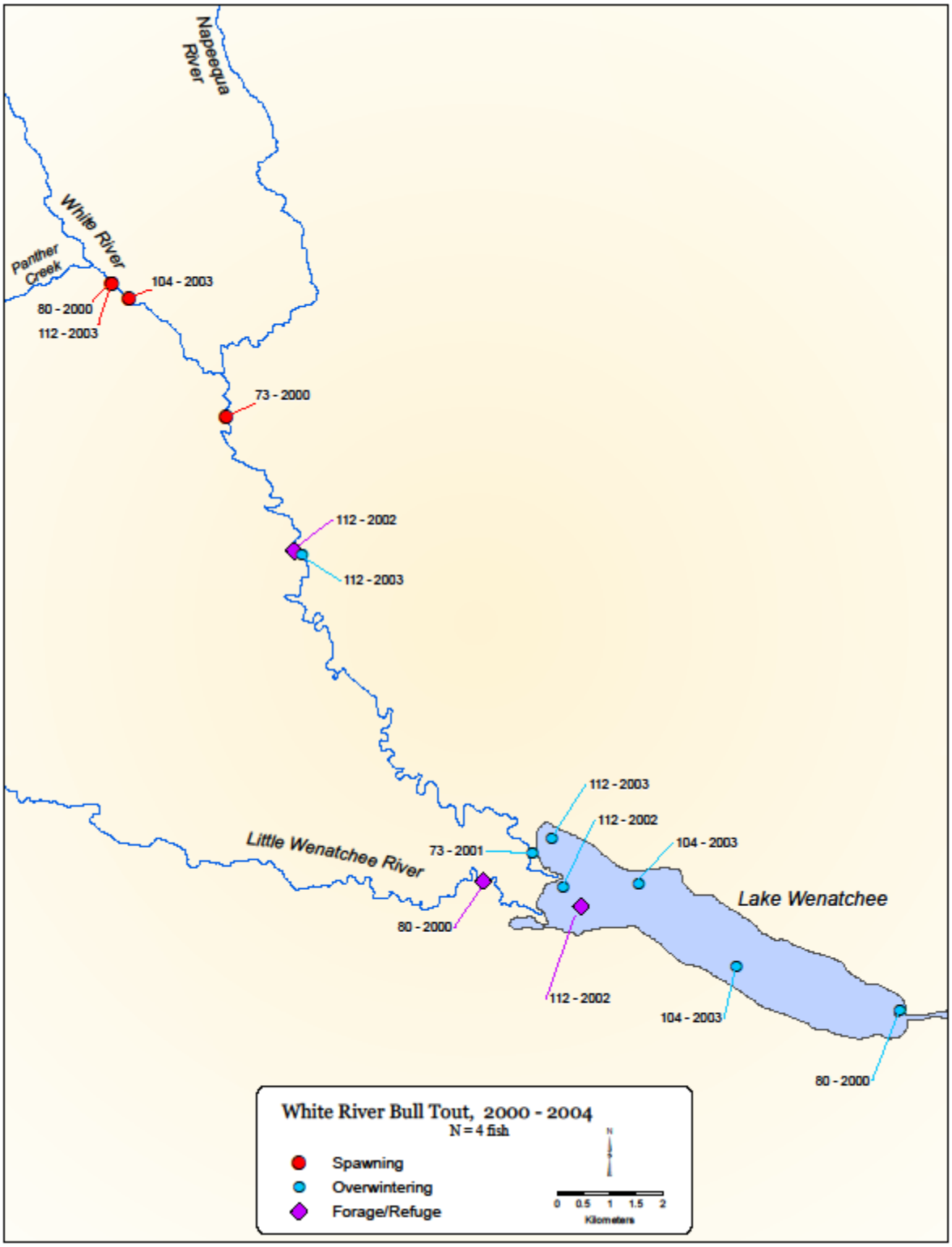

Figure 15. Map of White River local population bull trout showing spawning, overwintering, and forage/refuge locations, 2000–2004.

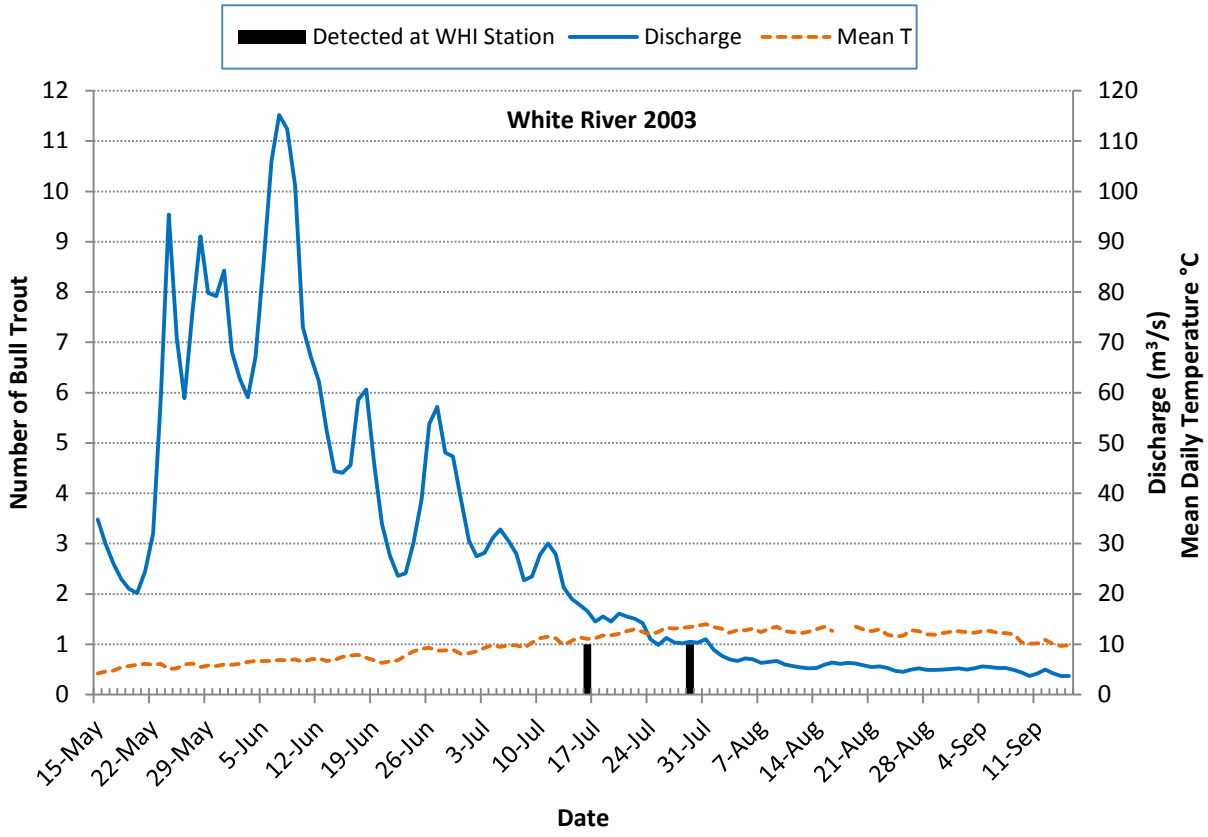

Figure 16. Pre-spawning migration dates of radio-tagged bull trout at the WHI station (rkm 10.2) in the White River in relation to stream discharge and mean daily water temperatures during 2003.

Post-spawning migration- The four White River bull trout were detected moving downstream past the WHI station from September 29 to October 17. Code 112 was last detected between rkm 11.7 and 14.1 between October 1 and December 18, 2003 (after the WHI station was removed) and it was later located in Lake Wenatchee.

Use of other tributaries- After spawning in the White River, code 80 moved into the Little Wenatchee River and was detected at the LTW station (rkm 1.9) on September 30 before returning to Lake Wenatchee.

Overwintering- All four bull trout that spawned in the White River overwintered in Lake Wenatchee. They entered Lake Wenatchee between September 29 and late December. See *Lake Wenatchee* section for more detail.

Forage/refuge use of the White River- During the study 9 bull trout from the Chiwawa River local population and 2 bull trout from an unknown population made forage/refuge movements into the White River (Figure 17). The 11 bull trout were detected in the White River between

rkm 0.4 and rkm 17.8 and were downstream of known spawning areas. Bull trout using the White River for forage/refuge were detected between July 28 and October 16 and from 1 d to more than 80 d (Table 18). Three of these fish migrated to spawn in the Chiwawa River in the same year that they used the White River. Three of the bull trout (codes 82, 118, 124) also made forage/refuge movements into the Little Wenatchee River. Code 108 moved upstream to rkm 14.9 in two years; the first year it was upstream of rkm 10.2 during August 28 to September 28 and the next year it was upstream of rkm 10.2 during September 2 to October 7. Since code 108 was downstream of known spawning areas in both years, it was assumed it did not spawn.

Table 18. Use of the White River by bull trout from other local populations: year, migration period, date detected at the WHI station (rkm 10.2), farthest upstream location and date detected, and number of days spent upstream of WHI station.

Code	Year	Local population	Migration category	Date up WHI	Date down WHI	Days above WHI	Farthest upstream rkm	Date
70	2000	Chiwawa	forage/refuge	-	-	-	1.6	Aug 31
71	2000	Chiwawa	forage/refuge	-	-	-	2.0	Aug 31
76	2000	Chiwawa	forage/refuge	Sep 22	Sep 25	3	10.5	Sep 25
77	2000	Chiwawa	forage/refuge	Aug 26	Oct 4	40	17.1	Sep 13
82	2000	Chiwawa	forage/refuge	Sep 16	Oct 11	28	10.2	Sep 16
82	2001	Chiwawa	forage/refuge	<Jul 31	>Sep 17	48–63	17.8	Aug 2
83	2000	Chiwawa	forage/refuge	-	-	-	10.0	Aug 31
124	2003	Chiwawa	forage/refuge	<Jul 16	Oct 4	>80	15.3	Jul 28
99	2000	Chiwawa	post-spawn	Oct 16	Oct 16	1	10.2	Oct 16
118	2002	Chiwawa	post-spawn	Sep 27	Oct 5-7	1-11	10.2	Sep 27
118	2003	Chiwawa	post-spawn	Sep 27	Oct 2	6	14.4	Oct 1
78	2000	unknown	unknown	Aug 8	Died	-	16.7	Sep 13
108	2002	unknown	forage/refuge	Aug 28	Sep 28	32	14.8	Sep 13
108	2003	unknown	forage/refuge	Sep 2	Oct 7	36	14.9	Sep 16

Little Wenatchee River

Tracking summary- No tagged bull trout from this study spawned in the Little Wenatchee River, however, ten bull trout used the Little Wenatchee River during other periods of the year for forage/refuge.

Forage/refuge use of the Little Wenatchee River- Nine Chiwawa River local population and one White River local population bull trout made forage/refuge migrations into the Little Wenatchee River. Bull trout were detected in the Little Wenatchee River up to rkm 3.2 on dates between June 23 and October 9 and spent from 2 to 20 d in the lower river (Figure 17; Table 19). Three Chiwawa River bull trout (codes 82, 118, 124) also used the White River before or after visiting the Little Wenatchee River.

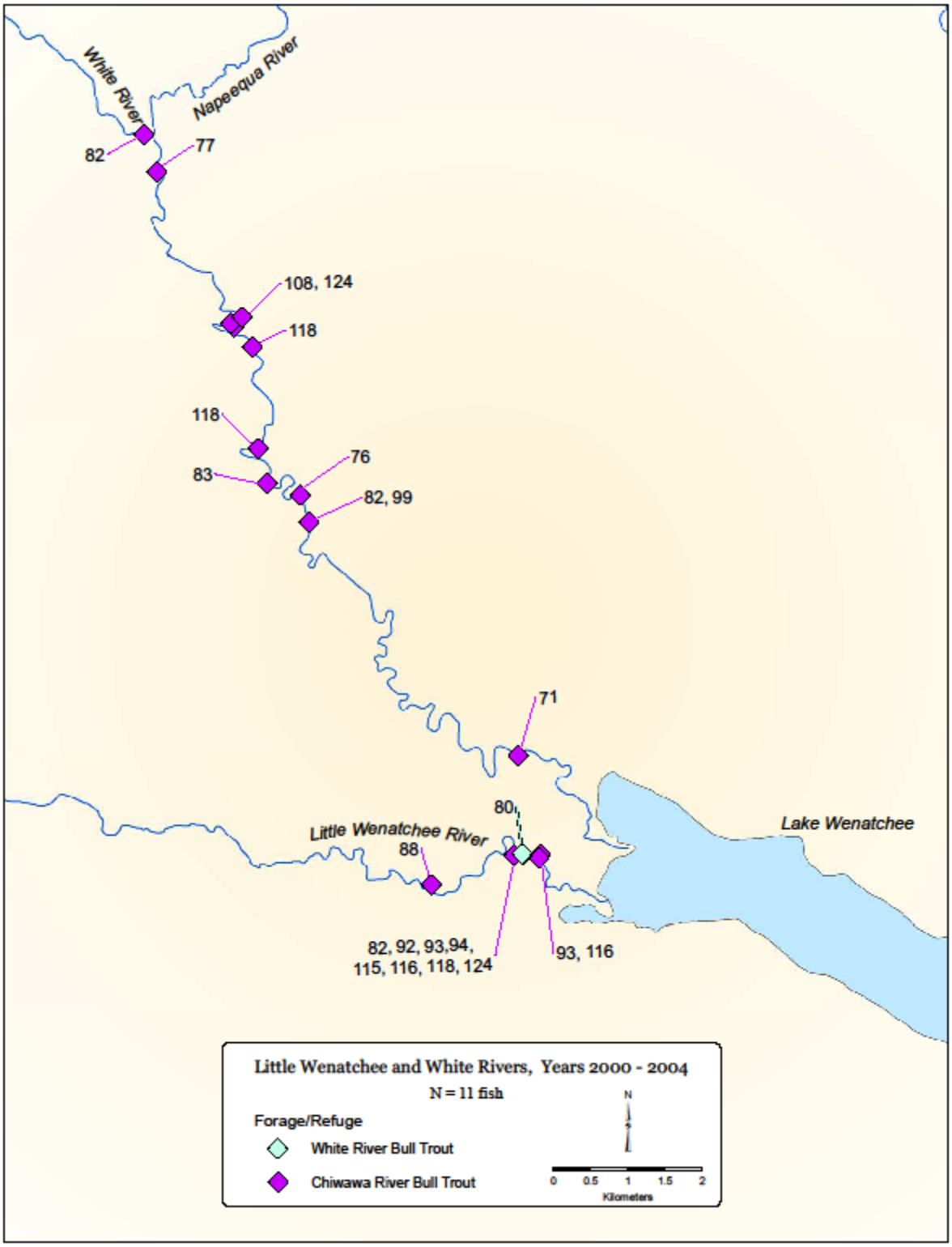

Figure 17. Map of Little Wenatchee River and White River showing use of the tributaries for forage/refuge movements by tagged bull trout from the White River and Chiwawa River local populations.

Table 19. Use of the Little Wenatchee River by bull trout from other local populations: year, migration period, dates detected at the LTW station (rkm 3.2), farthest upstream location and date detected, and number of days spent upstream of the LTW station.

Code	Year	Local population	Migration category	Date up LTW	Date down LTW	Days up LTW	Farthest upstream rkm	Date farthest up
80	2000	White	post-spawn	Sep 30	Sep 30	0	3.2	Sep 30
82	2000	Chiwawa	forage/refuge	Sep 9	Sep 9	0	3.2	Sep 9
82	2001	Chiwawa	forage/refuge	Oct 9	Oct 9	1	3.2	Oct 9
88	2001	Chiwawa	forage/refuge	<Jul 30	-	died	3.2	Aug 2
92	2001	Chiwawa	forage/refuge	Oct 6	Oct 9	4	3.2	Oct 9
93	2001	Chiwawa	forage/refuge	Sep 17	Sep 18	2	1.5	Aug 2
94	2001	Chiwawa	forage/refuge	Sep 17	Sep 18	2	3.2	Sep 18
115	2004	Chiwawa	forage/refuge	Jun 23	Jul 13	20	1.0	May 13
116	2002	Chiwawa	pre-spawn	-	-	-	1.1	Jul 24
116	2003	Chiwawa	pre-spawn	-	Jul 10	unknown	3.2	Jul 10
118	2004	Chiwawa	pre-spawn	Jun 23	Jul 12	19	3.2	Jul 12
124	2003	Chiwawa	post-spawn	Oct 5	Oct 5	1	3.2	Oct 5

Nason Creek bull trout

Tracking summary- One bull trout (tagged at Tumwater Dam) migrated into spawning areas in Nason Creek in two years (Table 20). Another bull trout visited lower Nason Creek during its pre-spawning migration to the Chiwawa River.

Table 20. Nason Creek bull trout tracking summary: radio code, tagging location, number of years tracked, spawning location, number of years spawned, overwintering location, and number of years found at overwintering location.

Code	Tagging location	Years tracked	Spawn location	Years spawned	Overwinter location	*n* Winters
131	Tumwater	2	Mill Creek	1	Columbia R	1

Pre-spawning migration- Code 131 migrated into Nason Creek in two years (Figure 18). Code 131 was tagged at Tumwater Dam on June 18, 2003 and migrated upstream in the Wenatchee River past the WLK station 25 d later, entering Nason Creek on July 13. By July 31 it was in a known spawning reach in Mill Creek. In 2004 code 131 migrated upstream in the Wenatchee River and entered Nason Creek on July 11 (Table 21). It was detected 3.5 d later in Nason Creek near Mill Creek (rkm 43) for a migration rate of 9.4 km/d. Code 131 was located from July 15 to August 3 in Nason Creek where it was observed in a large pool with 30 adult bull trout.

Spawning- In 2003 code 131 was assumed to have spawned in Mill Creek near rkm 1.0 where three redds were found during the spawning ground survey. In 2004 code 131 was in a known spawning area in Nason Creek near rkm 43 (last located on August 3). However code 131 left prior to the onset of the spawning season and passed the WLK station (Wenatchee River rkm

Table 21. Detection histories of Nason Creek bull trout at the WLK station on the Wenatchee River (rkm 86.2): first (up) and last (down) dates at station, dates and river kilometer of first and last mobile detections in Nason Creek, and number of days spent in Nason Creek, 2003-2004.

Code	Year	Up WLK	First mobile Nason	Rkm	Last mobile Nason	Rkm	Down WLK	Days in Nason
131	2003	Jul 13	Jul 31	0.4	Sep 4	0.8	Sep 17	65
131	2004	Jul 11	Jul 15	35.0	Aug 3	35.0	Sep 3	54

77.8) on September 3, 2004. It was assumed it did not spawn as no bull trout redds were found during a September 8 survey of Mill Creek and Nason Creek upstream of Mill Creek.

Post-spawning migration- Code 131 moved downstream into the Wenatchee River past WLK (rkm 77.8) on September 17, 2003 and September 3, 2004 (Table 21). In 2003 it passed the DRY station on November 19 (see *Wenatchee River* section for more details).

Overwintering- In 2003 code 131 moved downstream of rkm 28.3 on the Wenatchee River on November 19. It was not detected during several aerial surveys and was assumed to have overwintered in the Columbia River. Code 131 migrated at least 139 km from its spawning location to the Columbia River and was one of the longest migrations documented during the study. In the spring of 2004 it was first detected in the Wenatchee River (at DRY station) on June 1 after about 200 d in its overwintering area.

Forage/Refuge use of Nason Creek- One Chiwawa River bull trout (code 101) was located in lower Nason Creek between May 21 and August 4 before migrating to the Chiwawa River to spawn in 2002 (Figure 10; see the *Chiwawa River* section for details).

Chiwaukum Creek bull trout

Tracking summary- Three tagged bull trout migrated into Chiwaukum Creek during the study. Two fish (codes 105, 130) were tagged in September in Icicle Creek and were tracked during three years (Table 22). Code 132 was tagged in June at Tumwater Dam and was tracked during two years. The three Chiwaukum Creek bull trout overwintered in the Wenatchee River and two also were in Icicle Creek during part of the winter.

Table 22. Chiwaukum Creek bull trout tracking summary: radio code, tagging location, number of years tracked, number of years spawned, overwintering location, number of years at overwintering location, and use of other tributaries.

Code	Tagging location	Years tracked	Spawn location	Years spawned	Overwinter location	*n* Winters	Use of other tributaries
105	Icicle	3	Chiwaukum	1	Icicle/Wen R	2	Icicle
130	Icicle	3	Chiwaukum	2	Icicle/ Wen R	3	Icicle
132	Tumwater	2	Chiwaukum	1	Wen R	1	-

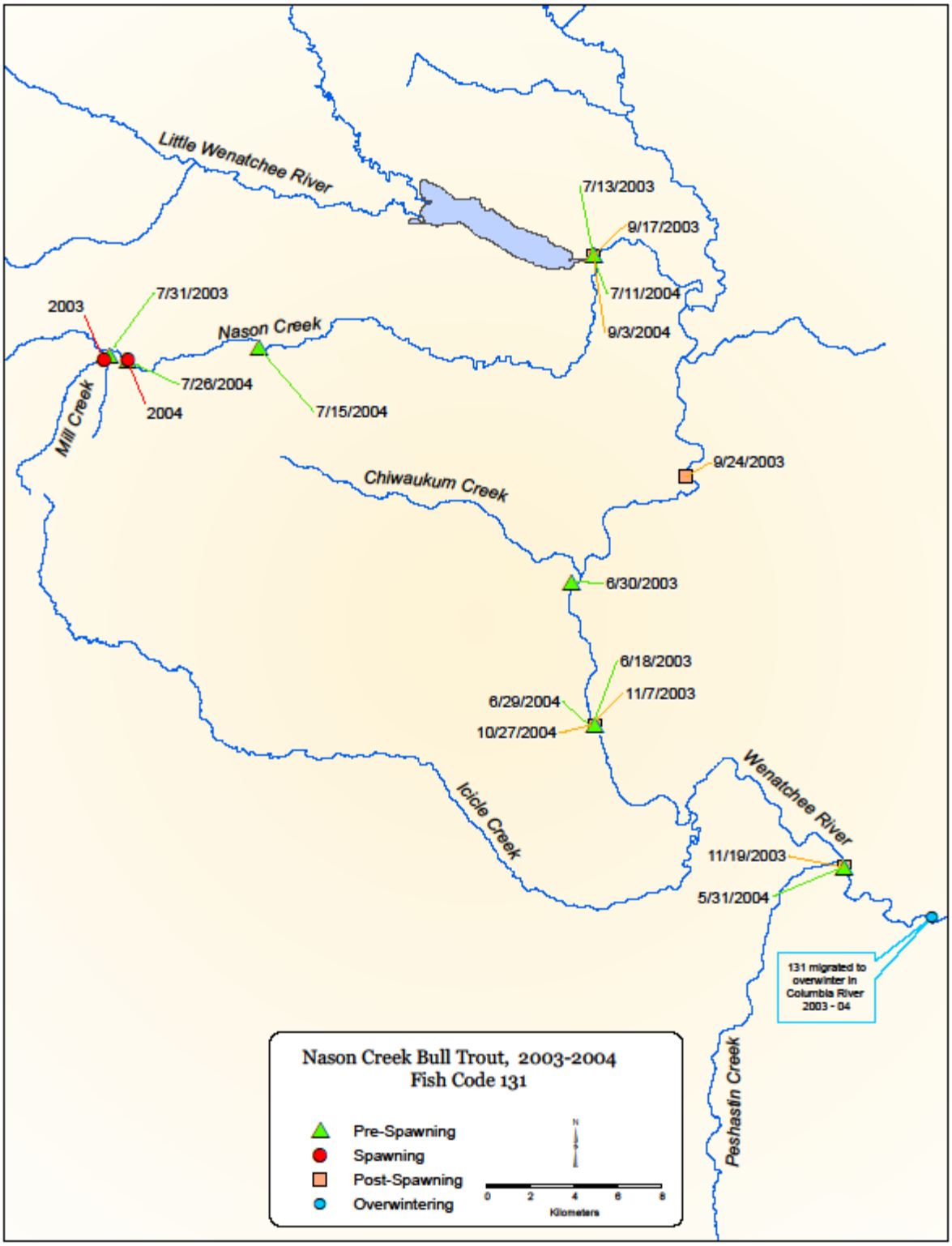

Figure 18. Map of Nason Creek bull trout code 131 showing pre-spawning, spawning, post-spawning, and overwintering locations, 2003–2004.

Pre-spawning migration- Code 105 did not migrate to Chiwaukum Creek until the third year tracked. Code 130 migrated into Chiwaukum Creek its second year tracked. In the year they spawned both codes 105 and 130 were located in Icicle Creek between April 2 and June 3 before they moved into the Wenatchee River (Figure 19). They passed the TUM station (rkm 49.7) at Tumwater Dam between June 19 and July 8 (Table 23). Code 132 was tagged at Tumwater Dam on June 23 and was detected in Chiwaukum Creek at rkm 0.1 on June 29. During its second year tracked code 132 did not migrate into Chiwaukum Creek.

Table 23. Detection histories of Chiwaukum Creek bull trout during pre- and post-spawning migrations: radio code, year, first (up) and last (down) dates at the TUM station in the Wenatchee River (rkm 49.7), first and last dates of mobile detection in Chiwaukum Creek, and number of days upstream of the TUM station, 2003-2004.

Code	Year	Up TUM	First Chiwaukum	Last Chiwaukum	Down TUM	Days above TUM
132	2003	Jun 23	Jun 29	Sep 17	Sep 26	98
105	2003	Jul 7	Jul 14	Aug 12	Tag expired	Unknown
130	2003	Jul 8	Jul 15	Sep 23	Oct 21	106
130	2004	Jun 19	Jul 15	Aug 31	Sep 17	90

Spawning- During their spawning migration the three bull trout moved upstream of rkm 3 in Chiwaukum Creek by mid-July to mid-August. All three were located in the known spawning reach between rkm 3.8 and 7.5 during the spawning period (Figure 19).

Post-spawning migration- After spawning, tagged bull trout moved out of Chiwaukum Creek and into the Wenatchee River by September 29. They spent an estimated 84 to 92 days in Chiwaukum Creek, as inferred by number of days upstream of the TUM station or from mobile detections in the Wenatchee River upstream of the dam (Table 23).

Overwintering- The three Chiwaukum Creek bull trout spent the winter in the Wenatchee River downstream of Tumwater Dam between rkm 25 and 49 (Figure 19). They arrived at their overwintering locations as early as September 26 and stayed as late as July 8. Code 130 used different overwintering areas located 12 km apart in the Wenatchee River during the three winters it was tracked. Code 132 overwintered downstream of Dryden Dam. Code 105 overwintered in the Wenatchee River at the same location during both years (Figure 19).

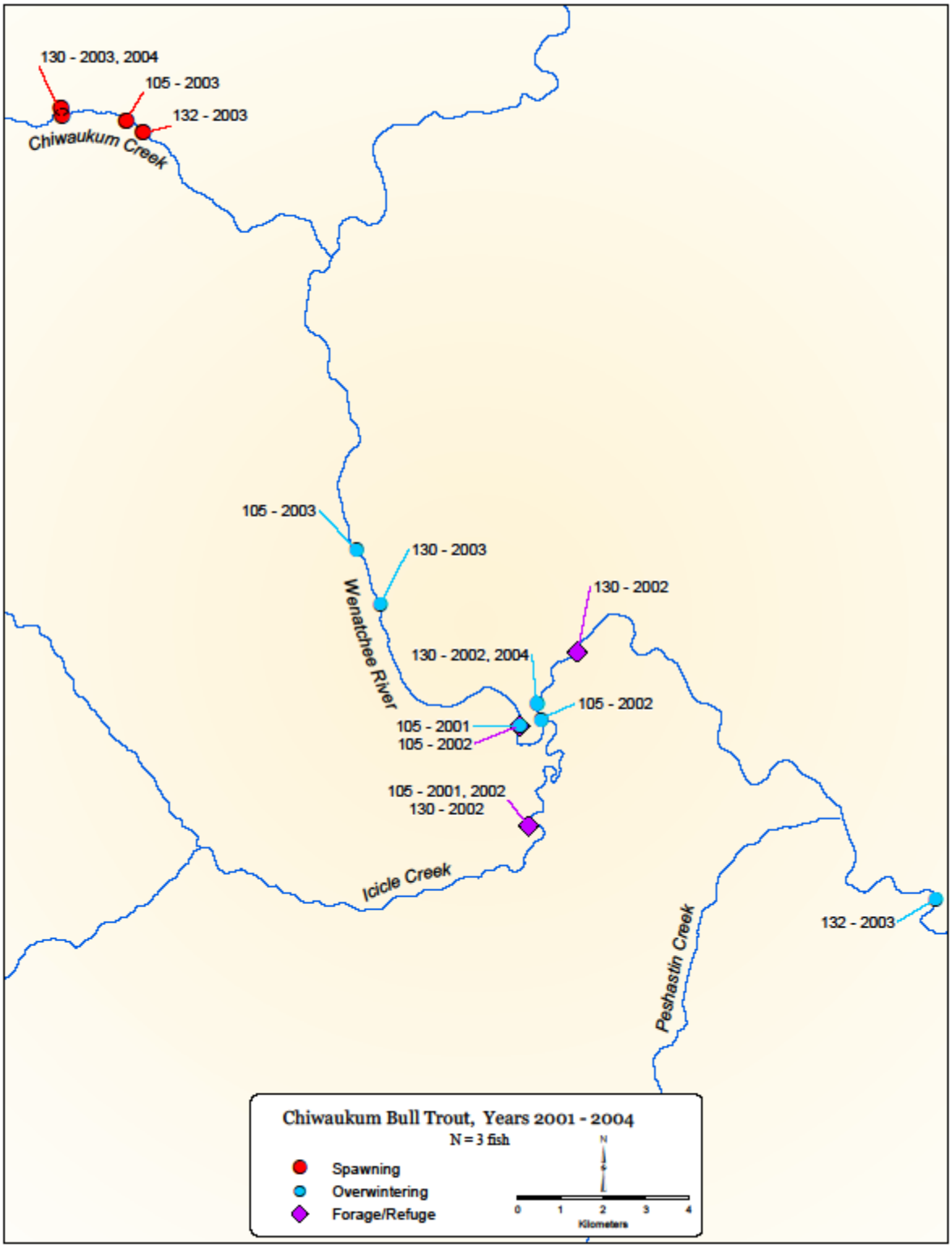

Figure 19. Map of Chiwaukum Creek bull trout showing spawning, overwintering, and forage/refuge locations, 2001-2004.

Lake Wenatchee

Overwintering- Lake Wenatchee was the primary overwintering area for the majority of bull trout in this study. Thirty-four tagged bull trout overwintered in the lake, including 28 bull trout from the Chiwawa population, 4 from the White, and 2 from unknown populations. There were another 7 bull trout tagged in Lake Wenatchee that died during the year tagged and could not be assigned to a local population. Most bull trout were detected in the west end of the lake within 1 km of the two tributaries (Figure 20). Several were also found at the east end near the outlet with some using the upper kilometer of the Wenatchee River (Figure 20). Few bull trout were located in the mid-section of the lake and many of the detections were near the shoreline, but this may be because the radio signals of bull trout in deeper water are attenuated and likely too weak to be detected. Also, during aerial surveys the GPS unit recorded the location of the airplane instead of the fish; thus the indicated location may not have been the actual position of the fish in the lake.

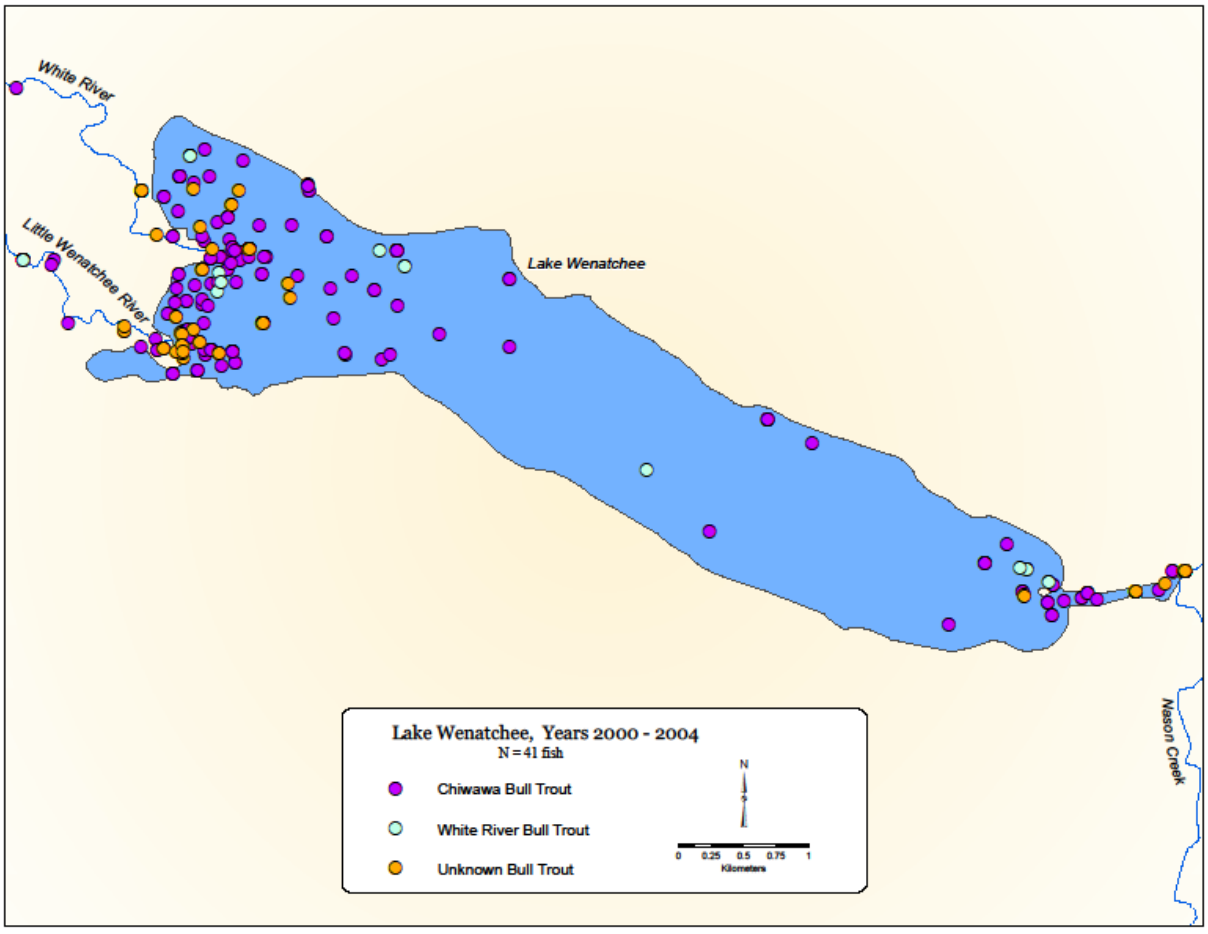

Figure 20. Map of Lake Wenatchee showing overwintering locations of bull trout assigned to local populations from the Chiwawa River, White River, and unknown areas, 2000–2004.

Tagged bull trout that overwintered in Lake Wenatchee entered the lake from September 13 to December 21 (median October 2) and exited from June 6 to October 6 (median July 14) (Table 24). Fish that spawned in consecutive years overwintered in Lake Wenatchee between spawning migrations for 199 to 310 d (55-85% of the year). Those that spawned then overwintered in Lake Wenatchee before leaving on a forage/refuge migration spent 299 to 369 d in the lake. Bull trout tagged in Lake Wenatchee that waited to spawn their second year tracked were in the lake 200 to 328 d and those that waited to spawn their third year were in the lake 684 to 722 d.

Table 24. Bull trout use of Lake Wenatchee: dates of entry into and exit from the lake, number of days between consecutive spawning migrations or between spawning migrations and other movements out of the lake, and percentage of the year spent in the lake.

Code	Date into lake	Pre lake migration	Date out of lake	Post lake migration	Days in lake	% of year in lake
76	21-Dec-01	Spawn	7-Jul-02	Spawn	199	55
83	13-Oct-01	Spawn	9-Aug-02	Spawn	300	82
110	2-Oct-02	Spawn	29-Jun-03	Spawn	270	74
116	5-Oct-02	Spawn	13-Jul-03	Spawn	281	77
118	27-Sep-02	Spawn	4-Jul-03	Spawn	280	77
118	2-Oct-03	Spawn	8-Aug-04	Spawn	310	85
94	15-Sep-00	Spawn	17-Sep-01	Non-spawn	367	101
93	29-Sep-00	Spawn	2-Aug-01	Non-spawn	307	84
92	2-Oct-00	Spawn	6-Oct-01	Non-spawn	369	101
88	5-Oct-00	Spawn	2-Aug-01	Non-spawn	301	82
124	2-Oct-02	Spawn	28-Jun-03	Non-spawn	299	82
83	13-Sep-00	Non-spawn	7-Aug-01	Spawn	328	90
77	3-Oct-00	Non-spawn	21-Apr-01	Spawn	200	55
76	15-Oct-00	Non-spawn	13-Jun-01	Spawn	241	66
112	3-Oct-02	Non-spawn	28-Jul-03	Spawn	288	79
103	24-Jul-01	Tagged	8-Jun-03	Spawn	684	187
104	24-Jul-01	Tagged	16-Jul-03	Spawn	722	198
108	30-May-02	Tagged	28-Aug-02	Non-spawn	90	-
108	28-Sep-02	Non-spawn	2-Sep-03	Non-spawn	339	93

Lake Wenatchee was used by some bull trout as a migration corridor. Several post-spawning Chiwawa River bull trout moved through Lake Wenatchee to make forage/refuge migrations into the White and Little Wenatchee rivers. Some movements through Lake Wenatchee were relatively fast as illustrated by code 82: In October 2000, it migrated past the WHI station (rkm 10.2), out of the White River, through Lake Wenatchee, and into the Wenatchee River (WLK station) in 2.6 days; in October 2001, it took only 1.7 days to move from LTW station (rkm 1.9) out of the Little Wenatchee River, through Lake Wenatchee and then into the Wenatchee River (WLK station).

Use of the Lake Wenatchee outlet- Six tagged bull trout in Lake Wenatchee moved into the upper 1 km of the Wenatchee River where they were detected frequently for short periods (typically measured in hours) by the WLK station. Most use of the outlet occurred during overwintering and there was a peak in March and April (Figure 21). Some bull trout used the outlet almost daily during high use periods. One bull trout used the outlet in three winters (code 76), one in two years (code 70) and the others during one year (codes 71, 77, 99, 101). Ninety-five percent of all detections at the outlet were recorded during the night.

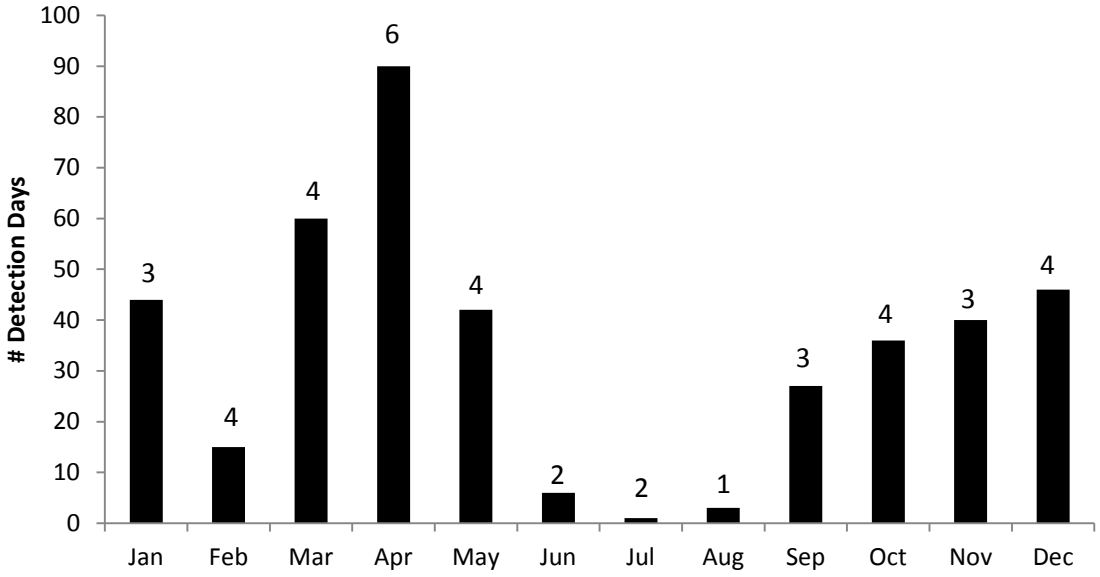

Figure 21. Seasonal use of the upper Wenatchee River between Lake Wenatchee (rkm 87.2) and the WLK station (rkm 86.2) as indicated by the number of detection days that tagged bull trout were recorded by the station during each month (number of individual bull trout shown above the bars), 2000–2004.

Lower Icicle Creek

Forage/refuge use of Icicle Creek and migrations to other streams- Six bull trout were captured and tagged in Icicle Creek at the LNFH spillway pool (rkm 4.3). Two of these bull trout (codes 105, 130) were tracked to spawning areas in Chiwaukum Creek (see Chiwaukum Creek section for more information). The other four bull trout were not located in spawning areas or were only tracked for limited periods and a local population could not be assigned based on their movements.

Bull trout were tagged in Icicle Creek between August 26 and September 26. Most stayed in the LNFH spillway pool into October and November, and the last one moved downstream of the pool on November 26. In 2001, codes 105 and 141 were last detected in the spillway pool on November 5 and increased flows from heavy rains starting that day may have influenced their movements. After tagging they were in Icicle Creek for 1 to 126 d before moving to the

Wenatchee River, with January 28 the latest exit date. Three bull trout (codes 105, 107, 130) returned to lower Icicle Creek during another year and two (codes 105, 107) revisited the LNFH spillway pool (Table 25; Figure 22).

Code 128, a female with eggs, was tagged on August 26. On August 29 it exited Icicle Creek, moved downstream in the Wenatchee River and was detected at the DRY station on September 1. On September 19 its transmitter and carcass were retrieved in Peshastin Creek at rkm 0.1.

Code 107 exhibited some relatively unusual movements during its tracking history. It was tagged in Icicle Creek on September 26, 2001 and was in Icicle Creek or the Wenatchee River through two winters (Figure 23). On June 2, 2003 it moved downstream in the Wenatchee River past the DRY station. During an aerial survey on December 11, 2003 it was detected in the Columbia River near the mouth of the Methow River, 135 km from its tagging location. It returned to the Wenatchee River in 2004 and was detected at the DRY station from April 15 to May 28. It was not located again and its transmitter battery probably expired. Spots were noted in the dorsal fin when code 107 was captured and may have indicated hybridization with brook trout. (Genetic analysis has not yet been conducted to determine if it was a pure bull trout or to identify its local population.)

Overwintering- Two bull trout used Icicle Creek at least into November (code 107) and as late as January 28 (code 105) (Figure 23). They also used the Wenatchee River part of the winter. Two bull trout (codes 105, 130) used Icicle Creek in the spring between April 2 and June 3. As described above, code 107 overwintered in the Icicle Creek/Wenatchee River area during two winters. Code 106 migrated downstream of DRY station in November and likely overwintered in the Columbia River.

Table 25. Detection histories of non-spawning bull trout in lower Icicle Creek: first and last dates detected in the LNFH spillway pool (rkm 4.6), other locations and dates detected in Icicle Creek, and minimum number of days in Icicle Creek.

Code	Year	First date rkm 4.6	Last date rkm 4.6	Other location (rkm)	Date	Days
105	2001	Sep 25[a]	Nov 5	-	-	41
105	2002	May 13	May 13	-	-	1
105	2002	Sep 24	Nov 22	3.1	Jan 28	126
105	2003	Jun 3	Jun 3	2.4	Apr 2, 9	62
106	2001	Sep 25[a]	Oct 12	1.4	Nov 2	38
107	2001	Sep 26[a]	Oct 15	4.1	Nov 5	40
107	2002	Sep 13	Nov 26	3.0	Dec 9	87
128	2002	Aug 26[a]	Aug 29	-	-	3
130	2002	Sep 12[a]	Sep 27	-	-	15
130	2003	-	-	0.6	May 27–Jun 3	7
141	2001	Sep 25[a]	Nov 5	-	-	41

Note: a- date tagged in Icicle Creek

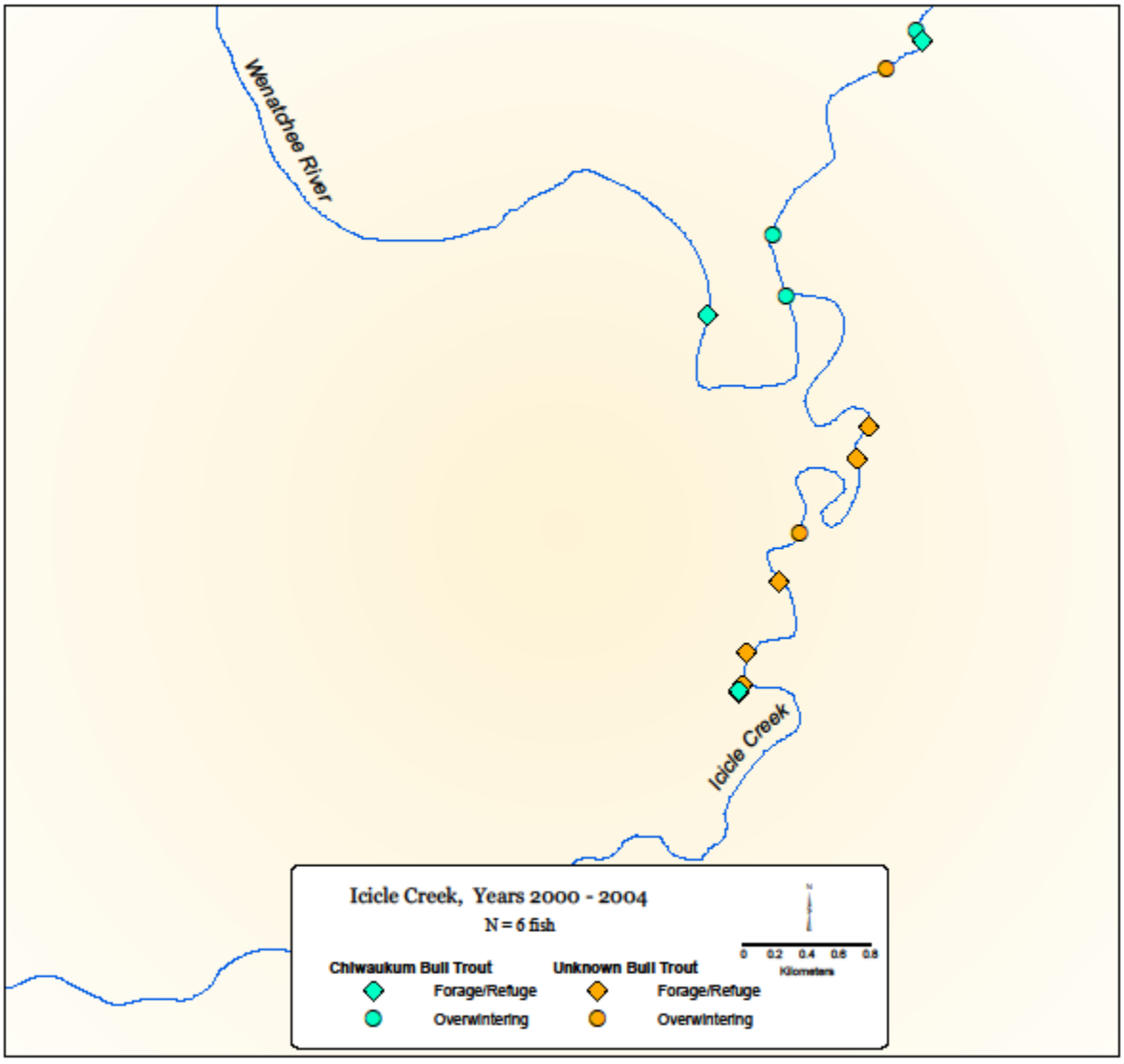

Figure 22. Map of Icicle Creek showing overwintering and forage/refuge locations of tagged bull trout from Chiwaukum Creek and unknown local populations, 2000-2004.

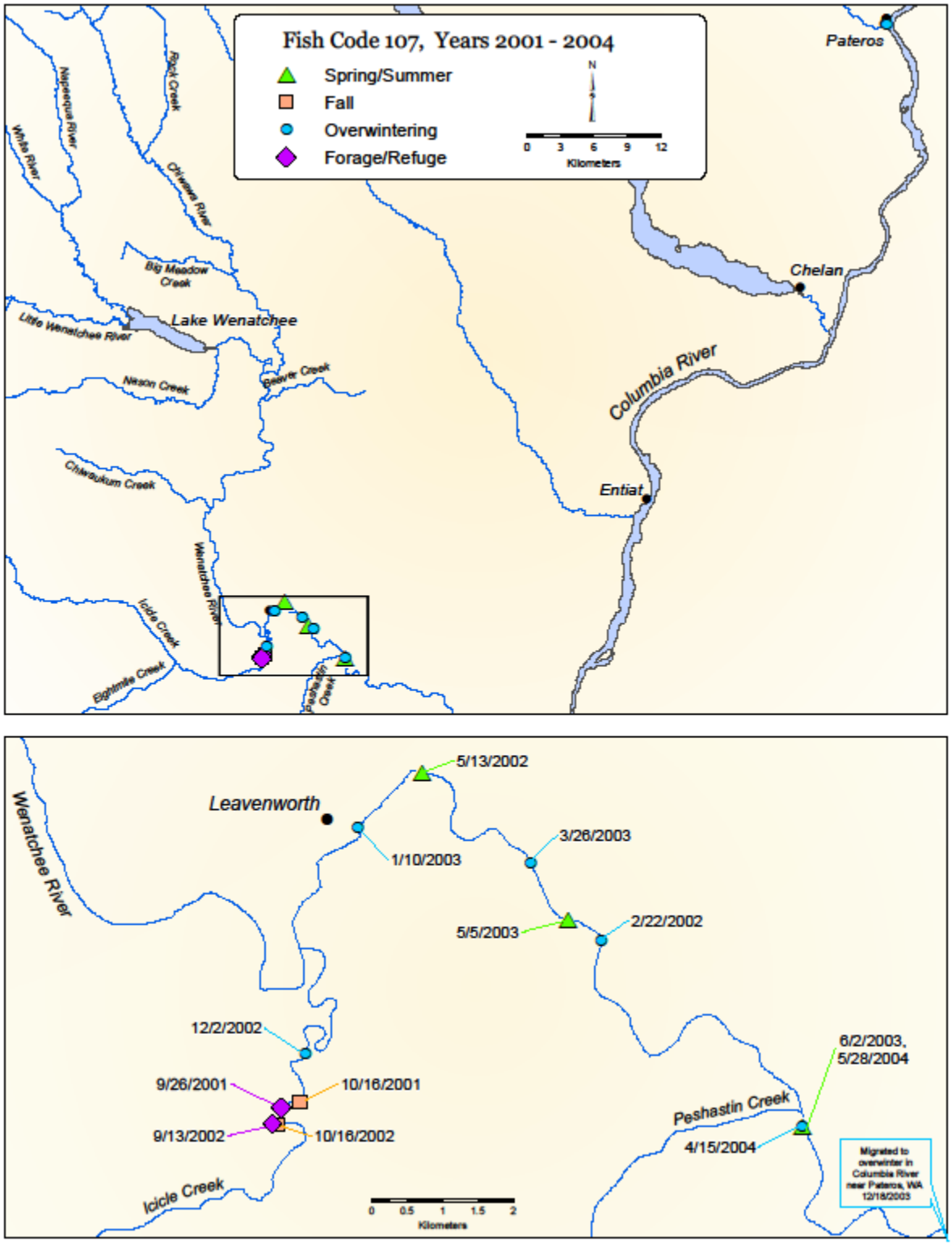

Figure 23. Map of locations of bull trout code 107 during September 26, 2001 to May 28, 2004.

Wenatchee River

Tracking summary- The Wenatchee River was used by most of the tagged bull trout, representing three of the four local populations tracked (Figure 24). Thirty-two bull trout migrated in the upper Wenatchee River between Lake Wenatchee and the Chiwawa River during pre- and post-spawning migrations, and three fish apparently overwintered in that reach (see *Chiwawa River* section). Six tagged bull trout overwintering in Lake Wenatchee frequently used the outlet and upper 1 km of the Wenatchee River mostly during winter (Figure 20, see *Lake Wenatchee* section). Four bull trout overwintered in the Wenatchee River between rkm 49 (downstream of Tumwater Dam) amd rkm 25 (downstream of Dryden Dam). Three bull trout migrated in the Wenatchee River between their spawning tributaries (Chiwawa River and Nason Creek) and their overwintering areas in the Columbia River. Bull trout that used Icicle Creek also migrated in the Wenatchee River downstream to the Columbia River. (See also the *Chiwawa River, Nason Creek, and Icicle Creek* sections.)

Pre-spawning migrations- Tagged bull trout were detected migrating past the DRY station (rkm 28.3) from April 15 to July 4 and moved upstream of Dryden Dam in 0.5 to 23 hours (Table 26). Tagged bull trout were between the DRY and TUM stations from June 1 through July 8 and were first detected at Tumwater Dam from June 13 through July 3 (Table 27). Overall the migration rates were lowest between Dryden Dam and Tumwater Dam (Table 28) and were likely influenced by the higher stream discharge during the times they were moving in that reach. Bull trout mostly passed Tumwater Dam 3 to 5 weeks after peak discharge and except in 2002, the majority were not detected or counted by WDFW until flows declined to less than 100 m^3/s (Figures 25 and 26).

Table 26. Detection histories of tagged bull trout moving past the DRY telemetry station at Dryden Dam (rkm 28.3) during pre-spawning migrations in the Wenatchee River, 2001-2004.

Code	Year	Population	DRY first		DRY last		Hours at
			Date	Time	Date	Time	DRY
85	2001	Chiwawa	Jun 6	2201	Jun 7	2103	23.0
86	2001	Chiwawa	Jun 21	0039	Jun 22	0107	0.5
86	2002	Chiwawa	Jul 4	0139	Jul 4	2156	20.8
107	2004	unknown	Apr 15	0809	Apr 15	1323	5.2
131	2003	Nason	May 31	1547	Jun 1	1719	1.5
132	2003	Chiwaukum	Jun 9	0418	Jun 9	2059	16.7

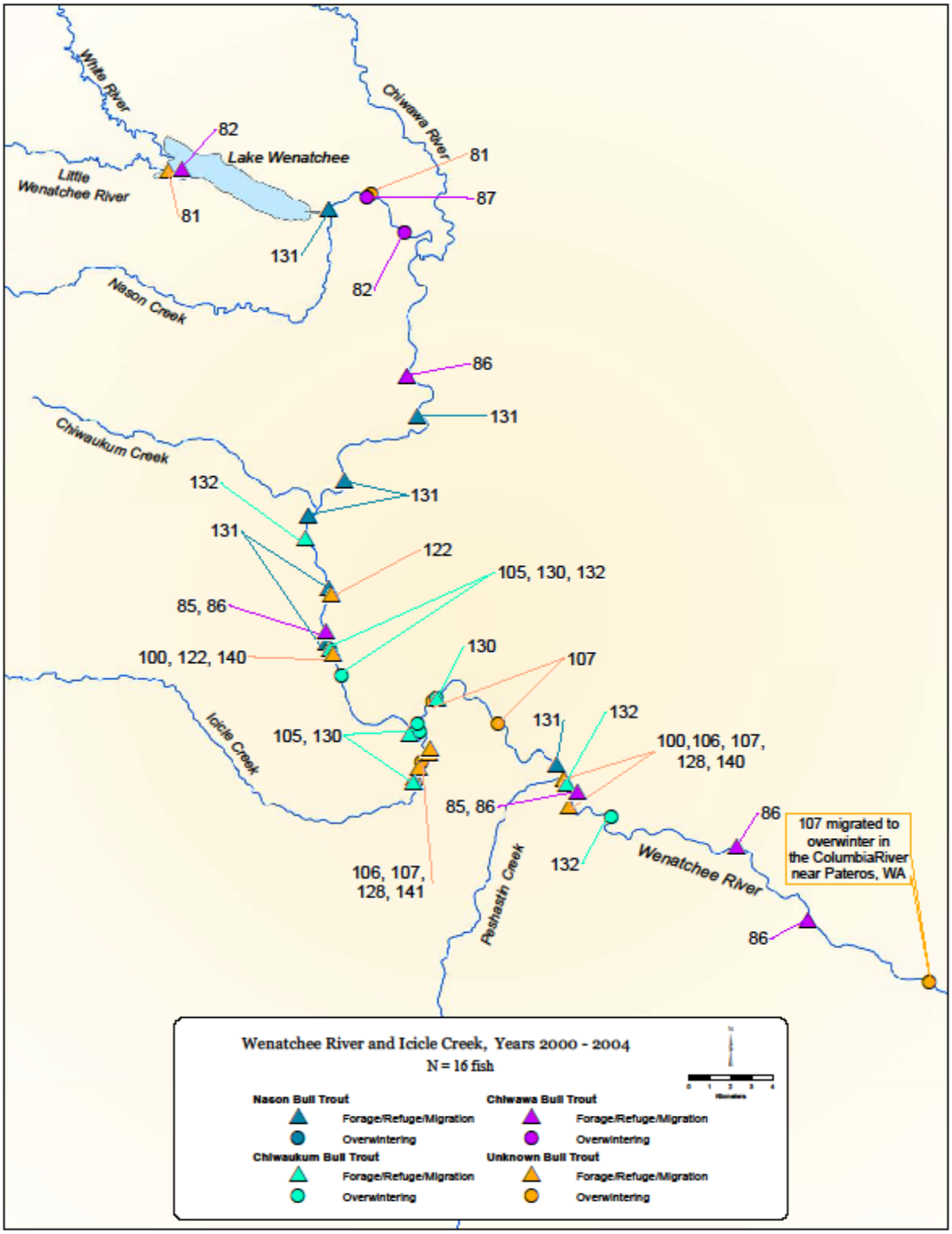

Figure 24. Map of the Wenatchee River showing foraging, migrating, and overwintering locations of tagged bull trout from Chiwawa River, Chiwaukum Creek, Nason Creek and unknown local populations, 2000-2004.

Table 27. Detection histories of bull trout at the TUM station (rkm 49.7) during pre-spawning migrations in the Wenatchee River and entrance date into spawning tributary, 2001-2004.

Code	Year	Tributary population	TUM First		TUM Last		Days at TUM	Date in tributary	Days to tributary
			Date	Time	Date	Time			
85	2001	Chiwawa	Jun 21	1206	Jun 22	0919	1.3	Jun 28	6
86	2001	Chiwawa	Jun 28	0651	Jun 28	1530	0.1	Jul 4	6
131	2003	Nason	*tagged*		Jun 18	1536	-	Jul 13	24
132	2003	Chiwaukum	*tagged*		Jun 23	2205	-	Jun 29	5
105	2003	Chiwaukum	Jul 7	1413	Jul 7	2205	0.3	Jul 14	6
130	2003	Chiwaukum	Jul 7	1646	Jul 8	0841	0.7	Jul 15	7
130	2004	Chiwaukum	Jun 15	1407	Jun 19	0051	3.5	Jul 15	26
131	2004	Nason	Jun 29	1553	Jul 2	0946	2.8	Jul 11	9

Table 28. Migration rates (km/d) of tagged bull trout during pre-spawning migrations between fixed telemetry stations in the Wenatchee River (DRY, TUM, WLK stations) and the Chiwawa River (CHI station), 2001-2004.

Station to Station	Distance (km)	Median (d)	Range (d)	Median (km/d)	Mean (km/d)	Range (km/d)	*n*
DRY–TUM	24.3	14	6–33	1.7	2.0	0.7–4.0	5
TUM–CHI	26.0	7	6–9	3.7	4.6	2.9–4.3	3
TUM–WLK	33.6	17	9–25	2.0	2.0	1.3–3.7	2

Maximum daily water temperatures while bull trout were passing Tumwater Dam ranged from 9.5°C to 23.1°C (data for 2001 and 2004, Figure 27). In 2001, the majority (72%) of bull trout passed Tumwater Dam on days when maximum water temperature was less than 15°C. In 2004, the bull trout run was larger with more fish passing in the later weeks, and only 30% passed on days the maximum water temperature was less than 15°C, 55% passed when maximums were between 15°C and 18°C, and 15% passed when maximum daily water temperatures exceeded 20°C. Stream flows in these years were similar; in 2001 the peak was 237 m^3/s on May 25 and in 2004 the peak was 165 m^3/s on May 21 (Figures 25 and 26). In 2001, 50% of the bull trout count had passed by June 21, and in 2004 the median passage date was July 1.

Bull trout were detected at the TUM station from June 13 through July 8 and took from 0.1 to 3.45 d to pass Tumwater Dam, with the longest passage times in 2004 when WDFW conducted intensive trapping in the fishway (Table 27). After passing Tumwater Dam, bull trout entered their spawning tributaries between June 28 and July 15. Overall migration in the Wenatchee River between the DRY station at Dryden Dam and the Chiwawa River or Nason Creek took 12 to 53 days with a mean migration rate of 2.5 km/d.

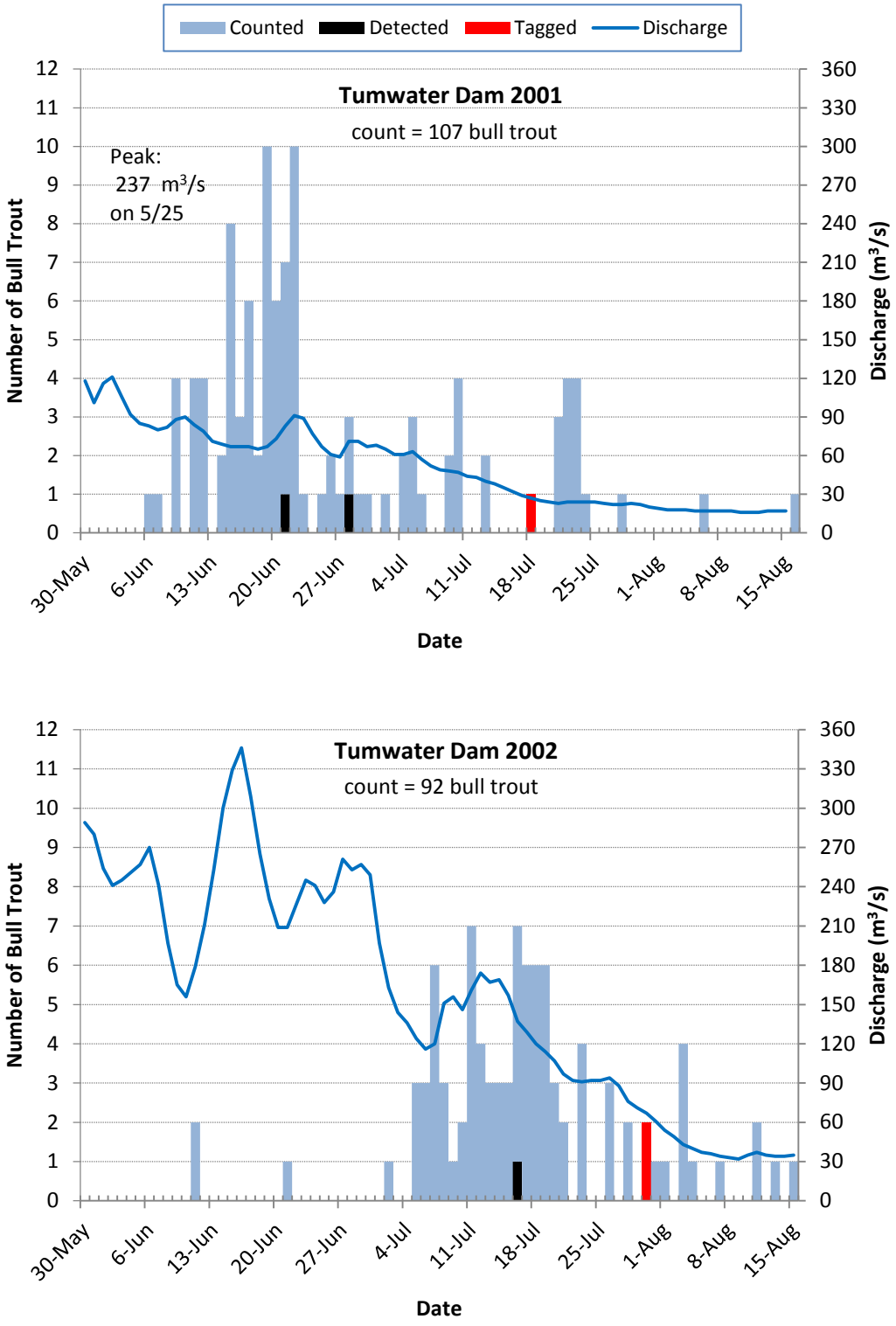

Figure 25. Daily bull trout passage at Tumwater Dam on the Wenatchee River (rkm 49.7) in relation to stream discharge (m^3/s), 2001-2002.

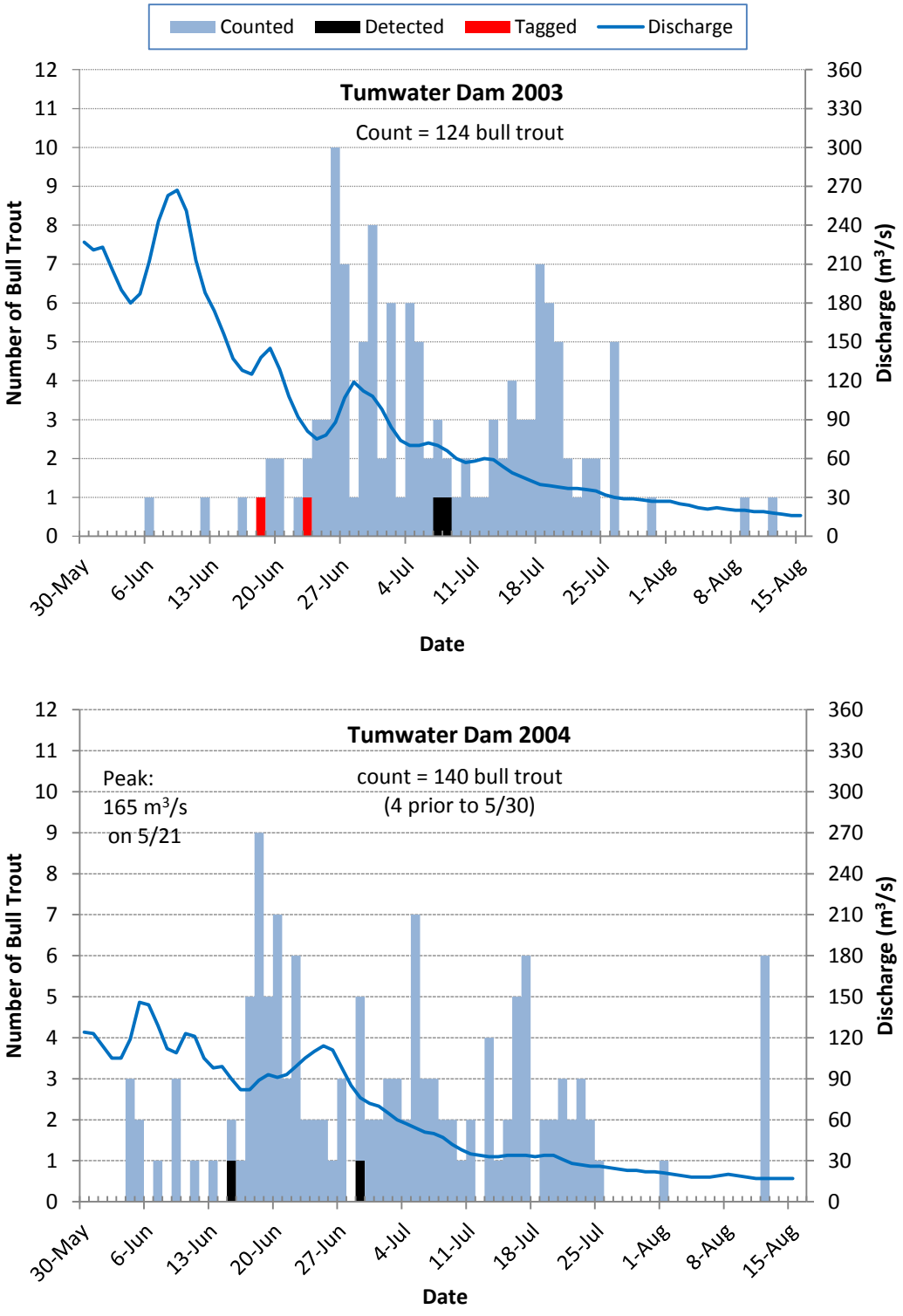

Figure 26. Daily bull trout passage at Tumwater Dam on the Wenatchee River (rkm 49.7) in relation to stream discharge (m^3/s), 2003-2004.

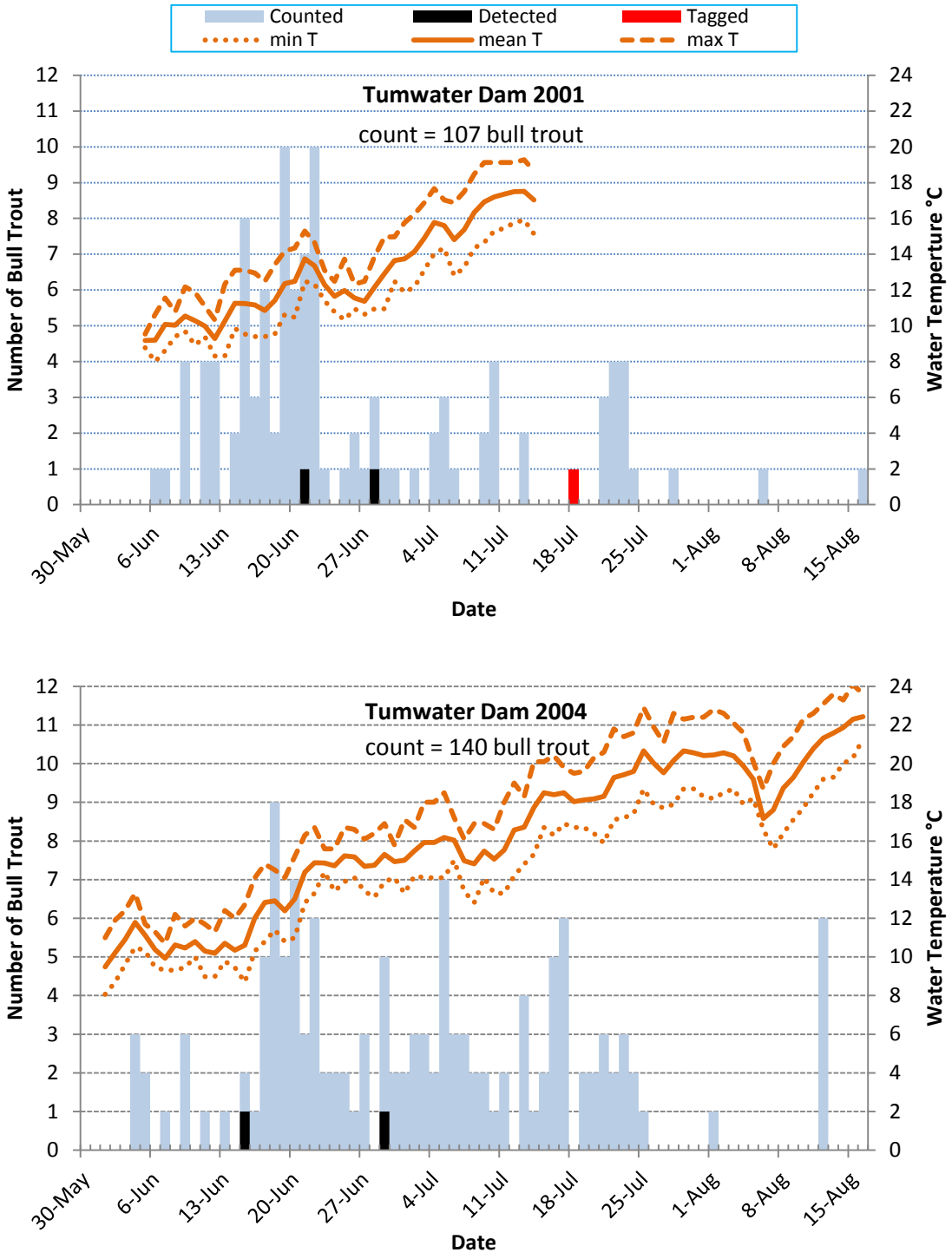

Figure 27. Bull trout daily passage at Tumwater Dam on the Wenatchee River (rkm 49.7) in relation to maximum, mean, and minimum daily stream temperatures (°C), 2001 and 2004.

Post-spawning migrations- After spawning in the upper Wenatchee River tributaries, bull trout moved into the Wenatchee River and most of the Chiwawa River population migrated upstream into Lake Wenatchee (see *Chiwawa River* section). The downstream migrants exited the Chiwawa River (codes 85 and 86) or Nason Creek (code 131) between September 3 and 28 but the dates tagged bull trout exited Chiwaukum Creek were not monitored. Tagged bull trout passed the TUM station at Tumwater Dam from September 17 to November 3 (Table 29). The time to pass downstream of Tumwater Dam ranged from 0.2 to 118 hours (Table 29). The two slowest times to pass were recorded by code 130, which after exiting Chiwaukum Creek slowly moved downstream or stopped at various locations before it arrived Tumwater Dam and then overwintered in the middle Wenatchee River (just downstream of Tumwater Dam in 2003).

Table 29. Detection histories of tagged bull trout at the TUM station at Tumwater Dam (rkm 49.7) during post-spawning migrations in the Wenatchee River, 2001-2004.

			TUM First Detection		TUM Last Detection		Time at
Code	Year	Population	Date	Time	Date	Time	TUM (hr)
86	2000	Chiwawa	Sep 29	1938	Sep 30	0255	7.3
85	2000	Chiwawa	Oct 4	0219	Oct 4	0229	0.2
85	2001	Chiwawa	Sep 24	0611	Sep 24	1823	12.2
86	2001	Chiwawa	Oct 2	1903	Oct 2	1929	0.4
86	2002	Chiwawa	Oct 1	1907	Oct 2	0257	7.8
132	2003	Chiwaukum	Sep 29	0202	Sep 29	0746	5.7
130	2003	Chiwaukum	Oct 21	0210	Oct 25	2354	117.7
131	2003	Nason	Nov 2	1602	Nov 3	1953	27.9
130	2004	Chiwaukum	Sep 17	0825	Sep 19	1224	52

Most of the bull trout were in the reach between the TUM and DRY stations for long periods, up to 34 d, and most migrated downstream slowly at a median rate of 0.9 km/d (Table 30). Tagged bull trout were detected migrating past the DRY station from September 25 through November 19 and took 0.1 to 7.3 hours to pass Dryden Dam (Table 31).

Table 30. Migration rates (km/d) of tagged bull trout during post-spawning migrations between telemetry stations in the Chiwawa River (CHI station) and the Wenatchee River (WLK, TUM, DRY stations), 2000-2004.

Station to Station	Distance (km)	Median (d)	Range (d)	Median (km/d)	Mean (km/d)	Range (km/d)	*n*
WLK-TUM	33.6	41	39–43	0.8	0.8	0.8–0.9	2
CHI-TUM	26.0	6	1.6–8	4.3	4.9	3.2–13	5
TUM-DRY	24.3	26	0.4–34	0.9	9.7	0.7–61	7

Table 31. Detection histories of tagged bull trout at the DRY station (rkm 49.7) during post-spawning migrations in the Wenatchee River, 2001-2004.

Code	Year	Population	DRY First Detection		DRY Last Detection		Time at DRY (hr)
			Date	Time	Date	Time	
86	2000	Chiwawa	Sep 29	1938	Sep 30	0255	7.3
85	2000	Chiwawa	Oct 20	2316	Oct 20	2321	0.1
85	2001	Chiwawa	Sep 25	0350	Sep 25	0456	1.1
86	2001	Chiwawa	Oct 28	2008	Oct 29	0325	7.3
106	2001	Unknown	Nov 17	1808	Nov 17	1816	0.1
86	2002	Chiwawa	Oct 31	0219	Oct 31	0445	2.4
132	2003	Chiwaukum	Nov 2	1832	2-Nov	2049	2.3
131	2003	Nason	Nov 19	1740	19-Nov	1831	0.9

Overwintering- Tagged bull trout used overwintering areas in the Wenatchee River upstream of the Chiwawa River and near Tumwater Dam to downstream of Dryden Dam (Figure 24). Bull trout from several local populations overwintered in the Wenatchee River and are described in the *Chiwawa River, Chiwaukum Creek, and Icicle Creek* sections. One bull trout (code 81) used the Wenatchee River upstream of the Chiwawa River, but was not tracked to a spawning area in the three years it was tracked; tagged in Lake Wenatchee on August 10, 2000 it migrated downstream of the WLK station on September 10 to the Wenatchee River, where it was located between rkms 83.3 to 85.3 during three winters (Figure 24).

Columbia River

Five bull trout migrated to overwinter in the Columbia River: one (code 131) from the Nason local population, two (codes 85, 86) from the Chiwawa local population, and two (codes 106, 107) from unknown populations that were tagged in Icicle Creek. Four then returned during the pre-spawning period to the Wenatchee River. Codes 85 and 131 overwintered one year and migrated back to spawning areas the second year and code 86 overwintered two years and spawned in three consecutive years. Estimated periods of overwintering in the Columbia River (using dates of detections at the DRY station at rkm 28.3 or downstream in the Wenatchee River) ranged from 192 d to 317 d (mean = 241 d or 66% of the year), with dates in the Columbia River (or Wenatchee River downstream of rkm 28.3) beginning October 20 and ending June 21 (Table 32). In contrast to the other bull trout, code 107 exited in the spring. It migrated downstream past the DRY station on June 2, entered the Columbia River, and was located at the mouth of the Methow River in December; it later returned to the Wenatchee River and passed the DRY station on April 15. Code 107 was the only tagged individual that was actually detected in the Columbia River and the others were likely in water too deep water for the signals to be detected during aerial surveys.

Table 32. Number of days tagged bull trout overwintered in the Columbia River as determined by detection dates at the DRY telemetry station on the Wenatchee River (rkm 28.3) or by last known location downstream of the station.

Code	Winter	Post-spawning migration Date at DRY	Pre-spawning migration Date at DRY	Max *n* days in Columbia R.	% of year in Columbia R.
85	2000-01	Oct 20	Jun 6	229	63
85	2001-02	Sep 25	-	-	-
86	2000-01	Nov 2 (rkm 10.3)	Jun 21	231	63
86	2001-02	Oct 29	Jun 20 (rkm16)	234	64
86	2002-03	Oct 31	-	-	-
131	2003-04	Nov 19	May 31	192	53
107	2003-04	Jun 2	Apr 15	317	87

Diel movement patterns

Overall, most movements past telemetry stations occurred at night (88%, n = 244) and few occurred either during the day (7%, n = 18) or both day and night (5%, n = 11). Almost all movements at the ROC, WHI, and WLK stations occurred at night during both pre- and post-spawning migrations (Figure 28). The TUM station at Tumwater Dam was the only site with predominantly daytime movement, with 100% during the day or both day and night during pre-spawning migration and 25% during post-spawning migrations (Figure 28). At the DRY station at Dryden Dam half of the upstream movements were either during the day or both day and night. At the CHI station on the Chiwawa River, 13% (3 of 24) of upstream movements were during the day or both day and night (Figure 28); all three bull trout were trapped but only one approached the weir during the day. The other site with some daytime movement was the LTW station on the Little Wenatchee River, with 4 tagged bull trout (27%) moving during the day or both day and night; however three of these did not move further upstream and appeared to have held near the stationary site. Interestingly, several tagged bull trout that did move during daylight died soon after: Code 75 moved upstream of the WHI station in the White River during the day and shortly after appeared to have been depredated (transmitter on shore with a mangled antenna); code 87 moved downstream of the ROC station during the day then moved upstream in the Wenatchee River and apparently died later; during pre-spawning migrations codes 114, 119 and 123 changed direction and moved downstream of the CHI station during the day and died a short time later.

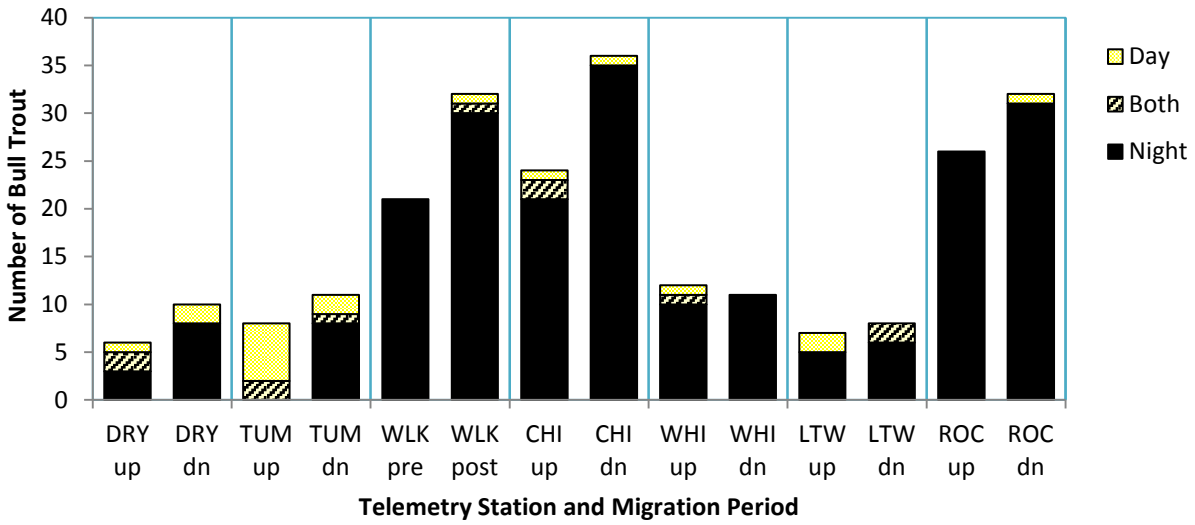

Figure 28. Diel periods of movement (day, night, or both) at telemetry stations during upstream and downstream (pre- and post-spawning) movements of tagged bull trout in the Wenatchee River basin, 2000-2004.

Chiwawa weir – During WDFW salmon broodstock collection the Chiwawa River weir was operated Sunday through Thursday morning (57% of the week). Overall, during pre-spawning migrations 23 tagged bull trout were detected at the weir site during annual trapping seasons (Table 33). Eleven bull trout approached the site when the weir was down and ten passed naturally in one to two nights with a mean time of 4.6 hours recorded at the site. (Code 115 approached when the weir was down but was subsequently trapped- see below.) Twelve bull trout first approached when the weir was up and eight were trapped, mostly on the first or second night. Passage times ranged from 6.0 to 16.3 hours (mean 11.4 hours) for six fish that entered the trap the first night, 32.9 hours for one that entered the second night, and 83.8 hours for one that entered the fourth night (Table 33). (Note that the trap was checked at 0830 and some tagged bull trout were held a few extra hours to be checked by a biologist, thus holding time influenced total passage time.)

Code 115 went through the weir site twice and took the longest total time (18 d) to pass (Table 33). It first approached the site at 0433 on June 22, a Sunday morning when the weir was down, and held downstream when the weir was put up later that morning. It entered the trap on the fourth night. The crew anesthetized, measured, and weighed the fish then released it at the site after the weir was lowered. Code 115 moved downstream and stayed below the weir the next two weeks, even though the weir was down for three consecutive nights each week. It did not pass until July 10 at 1107, soon after the weir was lowered at the end of a trapping cycle.

Twenty-six percent of the tagged bull trout (6 of 23) held below the trap for three to five nights and were considered to be delayed (Table 33). Four bull trout first approached the weir while it was up but did not pass until it was down and were at the site during three to five nights (70.5 to

96.1 hours); three of these passed the first night the weir was down and the fourth passed the second night it was down. The other two bull trout were trapped the fourth night they were at the site and the passage delay times were 83.8 and 101.3 hours.

The difference in passage time of bull trout that approached when the weir was down (mean = 4.6 hr, SD = 6.7, n = 10) was significantly less (one-way Student's t-test, t = 1.72, df = 21, *P* = 0.001) than the time to pass if the site was approached when the weir was up (mean = 49.3 hr, SD= 40.3, n = 13). (Note the time used for code 115 was only for the first passage during 2003.)

Table 33. Passage timing of naturally passed or trapped radio-tagged bull trout at the Chiwawa River weir (rkm 1.5) during pre-spawning migrations, 2001-2004.

Code	Year	First Date Approach	Time of Day	Weir Position during 1st Approach	Passage Movement	n Nights	Elapsed Time (hrs)
83	2001	Aug 8	0343	down	natural	1	0.2
83	2002	Aug 11	0116	down	natural	1	0.2
85	2001	Jun 28	2317	down	natural	1	0.9
103	2003	Jun 13	0102	down	natural	1	0.9
113	2003	Jun 13	2210	down	natural	1	0.3
110	2002	Jul 19	0253	down	natural	1	0.8
109	2002	Aug 2	2159	down	natural	1	2.4
77	2001	Jun 2	2232	down	natural	1	3.8
82	2002	Jun 22	0148	down	natural	2	16.3
116	2002	Jul 28	0413	down	natural	2	17.3
76	2002	Jul 8	2240	up	natural	5	95.8
86	2001	Jul 4	0207	up	natural	3	70.5
86	2002	Jul 22	0103	up	natural	4	92.5
71	2001	Jun 24	2329	up	natural	5	96.1
101	2002	Aug 4	2207	up	trapped	1	10.6
72	2000	Aug 20	2053	up	trapped	1	11.6
118	2003	Jul 6	2158	up	trapped	1	14.2
118	2004	Aug 8	1612	up	trapped	1	16.3
110	2003	Jun 30	0111	up	trapped	2	32.9
114	2002	Jul 17	0502	up	trapped	1	6:0
116	2003	Jul 14	0159	up	trapped	1	9.8
111	2002	Jul 21	2155	up	trapped	4	83.8
115	2003	Jun 22	0433	down	trapped	4	101.3
115[a]	*2003*	*Jun 26*	*0952*	*down*	*natural*	*14*	*337.3*

Note: a- passage during second approach after first trapped and released on June 26.

Three bull trout that were trapped at the weir died soon after and all had other factors that may have contributed to their death, including handling, transport, and archival tags. Code 114 was trapped, its externally attached archival tag was left on, and it was released at rkm 14.8. It moved downstream to the weir site 11 d later and held upstream of the weir four nights and passed the first night the weir was down. Code 114 then moved 3 km downstream to Beaver Creek where it died. Code 111 was trapped during the fourth night at the weir, lightly anesthetized, measured, the archival tag removed, and then released just upstream of the weir site. It moved downstream and its transmitter was recovered in the Wenatchee River, 32 km downstream of the Chiwawa River. The archival tags had caused open wounds and abrasions on both of these bull trout (see Appendix B). Code 116 was trapped, lightly anesthetized, measured, transported, and released upstream at rkm 14.8. It moved downstream and its carcass was retrieved from the weir ten days later. A necropsy conducted by a USFWS veterinarian could not identify the cause of the mortality of code 116 (Mumford 2003).

The migration of tagged bull trout trapped and transported from the weir was compared to tagged bull trout that passed naturally or were released at the weir. The migration distance between the CHI and ROC stations is 33.4 km but only 19.4 km between the Meadow Creek release site and the ROC station. The average rate of movement to the ROC station was slower for transported bull trout (mean = 2.1 km/d for natural and 0.9 km/d for transported) and significantly different (two-way Student's t-test, t = 2.06, df = 26, $P = 0.032$).

Discussion

Before bull trout were listed as threatened, relatively little information on their movements was available. Numerous studies have since revealed the complexities of life history forms and the often surprising variations expressed by bull trout in different core areas and local populations (USFWS 2008a). During our telemetry study of migratory bull trout in the Wenatchee Core Area, we gained insights into movement patterns that may have important applications across the range of the species and will be useful for bull trout management, conservation, and recovery. This discussion highlights some of the most significant findings, including complexity of migration patterns; use of forage, migration, and overwintering areas; timing and frequency of spawning and migration; potential effects of in-stream structures; and metapopulation function.

Migration patterns

Bull trout in the Wenatchee Core Area expressed several migration patterns including some unusual movements not found in other areas. The large lake and river system connected to the Columbia River allowed bull trout to move to a wide range of habitats for migrating, spawning, rearing, foraging, refuge, and overwintering. The complex movements of bull trout in this core area illustrate the need for concise terminology beyond the simple dichotomy of "fluvial" and "adfluvial" usually used to describe migrations in freshwater. Although migration terminologies are somewhat artificial constructs and differ among authors, they are useful in succinctly describing and classifying patterns (Varley and Greswell 1988; Fraley and Shepard 1989; Northcote 1978; Meka et al. 2003). Therefore, in this discussion we use the classifications developed for migratory freshwater fish (Northcote 1997) and specifically cutthroat trout (Varley and Gresswell 1988) to discuss the complexity of bull trout movements documented during the study. Those terms for the spawning movements are: ***fluvial***- migrations within a single river; ***fluvial-adfluvial***- from river into tributary; ***lacustrine-adfluvial***- upstream from lake into tributary; and ***allacustrine***- downstream from lake into the outlet stream. We coin the term ***allacustrine-adfluvial*** to describe movement from a lake downstream in the outlet stream and then upstream into a tributary to spawn. Some of these specific terms have received limited use in the bull trout literature (e.g. Brenkman et al. 2001; DuPont et al. 2007) and we suggest that they also be adopted for use in recovery planning and consultation documents.

The four local populations of the upper Wenatchee basin migrated varying distances between several different overwintering and spawning areas. Most bull trout in the study were allacustrine-adfluvial (70% overall and 88% of the tagged bull trout in the lake) and thus migrated downstream from Lake Wenatchee then upstream to spawning areas in the Chiwawa River, a migration of 40 to 73 km. Two Chiwawa River bull trout (7% of the tagged bull trout from that local population) were fluvial-adfluvial and traveled downstream for 100 to 130 km to overwinter in the Columbia River. The White River population made the shortest average migrations, traveling upstream from Lake Wenatchee to enter the spawning area beginning at rkm 17 of the White River. This lacustrine-adfluvial pattern was made by 12% (4 of 34) of the

tagged bull trout that overwintered in Lake Wenatchee. Only the fluvial-adfluvial pattern was documented in the Nason Creek and Chiwaukum Creek local populations. The Nason bull trout made the longest migration (139 km) to overwinter in the Columbia River. Chiwaukum bull trout overwintered in the Wenatchee River or partly in Icicle Creek for migration distances ranging from 13 to 41km from their spawning reach, but individuals from this population are known to also migrate to overwinter in the Columbia River (Nelson et al. 2013).

The allacustrine-adfluvial migration of bull trout between Lake Wenatchee and the Chiwawa River is a unique movement that provides access to a large watershed with more than 20 km of spawning and juvenile rearing habitat. Without this pattern, bull trout that use the lake would have access to only about 5 km for spawning and rearing in the two west end tributaries. A relatively rare migration pattern, allacustrine-adfluvial migrations in bull trout are also found in Lake Pend Oreille, Idaho (DuPont et al. 2007) and Bull Lake, Montana (USDI 2002d). Interestingly, an allacustrine-adfluvial migration developed after a small lake was created by mining activities upstream of a bull trout spawning tributary in the Salmon River basin of Idaho (Hogen and Scarnecchia 2006). Allacustrine-adfluvial migration may have historically been more common across the range of bull trout but many lakes and reservoirs were dammed at their outlet (Fredenberg 2003) and likely blocked or impeded migrations. Building a dam at the outlet of Lake Wenatchee to increase storage capacity has been proposed several times, most recently in 2003 (MWH 2003). Our study indicates a dam could have severe impacts on bull trout that use Lake Wenatchee, particularly on the Chiwawa River population because it consists primarily of the allacustrine-adfluvial form.

The Chiwawa local population is unusual in having both allacustrine-adfluvial and fluvial-adfluvial migrations, with overwintering and foraging areas in Lake Wenatchee, the upper Wenatchee River, and the Columbia River. Thus, subadult bull trout during their first out-migration from the Chiwawa River can either move upstream to Lake Wenatchee or downstream towards the Columbia River and this decision could have a genetic component (Kaya 1989). It may also be random or influenced by olfactory attraction or other cues. The allacustrine-adfluvial life history was predominant over the fluvial-adfluvial life history, and it is unknown if proportional numbers of out-migrating subadults initially migrate to these areas or if there is a survival difference in Lake Wenatchee compared to the Wenatchee and Columbia rivers. Some individuals from other bull trout populations with fluvial-adfluvial migrations may also have upstream movements from spawning tributaries to overwinter in a river reach, as documented in the Grande Ronde River (Hemmingsen et al. 2001), the Salmon River (Hogen and Scarnecchia 2006), the Entiat River and Columbia River (Nelson and Nelle 2008), and the Methow River (Nelson and Johnsen 2012). However, in these rivers most of the bull trout migrated downstream to overwintering locations.

Across the range of bull trout, only a single migratory form is present in 69% of core areas, with lacustrine-adfluvial the dominant pattern in 48% of core areas and fluvial-adfluvial in 40% (Fredenberg et al. 2005). Only 25% of core areas contain both, indicating that multiple migratory patterns within a single local population are relatively rare. In the upper Mid-Columbia Recovery Unit only the fluvial-adfluvial migration pattern is found in 13 of 18 local populations (BioAnalysts 2004; Nelson et al. 2007; Nelson and Nelle 2008; Nelson and Johnsen 2012), including Nason and Chiwaukum. It is surprising however, that allacustrine-adfluvial migration was not documented in either of the latter populations, particularly in Nason Creek since the confluence is only 0.8 km downstream of Lake Wenatchee. Because the Nason Creek population is small there was a lower probability of encountering a Nason bull trout during our tagging efforts in the lake and may explain why the allacustrine-adfluvial pattern was not found during the study. It may also be that there are issues within Nason Creek, such as marginal spawning and juvenile rearing habitat that limits the population, that warrant further investigation. Although Chiwaukum Creek is farthest downstream from Lake Wenatchee, this population could conceivably have allacustrine-adfluvial migrations, as bull trout in Lake Pend Oreille are known to move 36 km downstream before entering and moving upstream in the Priest River as they migrate to their spawning area (DuPont et al. 2007). However, redd counts and information from PIT-tagging at Tumwater Dam (WDFW unpublished data) indicates that most Chiwaukum bull trout are fluvial-adfluvial and adults returning to spawn migrate upstream through Tumwater Canyon.

Lacustrine-adfluvial migration was the only pattern for White River bull trout documented by radio-telemetry. Interestingly, a bull trout captured at Tumwater Dam was genetically assigned to the White River local population (DeHaan and Neibauer 2012), indicating fluvial-adfluvial migration can also occur in this lake tributary population. Whether this migration pattern is common or the chance result of the random movement of a displaced adult or subadult is unknown. The Little Wenatchee River is thought to have lacustrine-adfluvial bull trout (USFWS 2002b), although none were found during our study and very few redds have been counted during spawning ground surveys (Kelly Ringel 2012). A waterfall at rkm 12.4 in the Little Wenatchee River limits available spawning and rearing habitat and maximum water temperatures can exceed 17^{o} C throughout this reach (Watershed Sciences 2002), increasing vulnerability to climate change. Further investigations are needed to evaluate the status and threats to this local population. Genetic stock identification of bull trout in Lake Wenatchee may provide additional information on migration patterns of fish that use the lake.

Foraging, migrating, and overwintering

Bull trout from several local populations overlapped in their use of foraging, migrating, and overwintering (FMO) areas, including in Lake Wenatchee, White River, Little Wenatchee River, Wenatchee River, Icicle Creek, and Columbia River. Local populations in the Entiat and Methow rivers can also overlap in FMO habitats in those core areas and the Columbia River (BioAnalysts

2004; Nelson et al. 2007; Nelson and Nelle 2008; Stevenson et al. 2009; Nelson and Johnsen 2012).

Lake Wenatchee was a key foraging and overwintering area and also used year-round by subadult and non-reproductive adult bull trout. Thus, the lake is important for the continued expression of several different life history stages and migration patterns of several populations. Most of the Chiwawa River and all of the White River population returned to Lake Wenatchee to overwinter. Bull trout overwintering in the lake had access to forage/refuge areas in the White, Little Wenatchee, and upper Wenatchee rivers. Although not documented during our study, Lake Wenatchee is also thought to be used by Nason and Little Wenatchee local populations (USFWS 2002b). Management actions affecting Lake Wenatchee need to consider potential impacts to all four local populations that may use the lake.

The Wenatchee River functions as a migratory corridor, foraging area, or overwintering habitat for bull trout from most of the local populations. Several tagged bull trout used the Wenatchee River for long periods during spawning migrations, especially post-spawning. Some individuals from the Chiwawa and Nason local populations made long distance migrations in the Wenatchee River to reach overwintering areas in the Columbia River. Other studies have shown that bull trout from Chiwaukum, Nason, and Peshastin Creek populations also migrate to overwinter in the Columbia River (BioAnalysts 2004; Nelson et al. 2013). Tagged bull trout from the Chiwaukum population, as well as others that could not be assigned to a local population during our study, overwintered in the Wenatchee River mostly between Tumwater Dam and Dryden Dam.

Lower Icicle Creek appears to be a uniquely important forage/refuge area for bull trout from a wide range of areas, including from local populations of Chiwaukum Creek (this study; Nelson et al. 2011), Nason Creek (Nelson et al. 2011), Etienne Creek in the Peshastin Creek drainage (Nelson et al. 2012), the Chiwawa River (WDFW, unpublished PTAGIS data), the upper Entiat River (Nelson and Nelle 2008, Nelson et al. 2011), and possibly the Methow River (code 107-this study). Operations of Leavenworth NFH, including late summer release of cold water from deep wells and a regulated high elevation lake, likely provide a seasonal cool water refuge for bull trout in Icicle Creek (Nelson et al. 2011). Some bull trout forage in lower Icicle Creek throughout much of the year (Nelson et al. 2010) and spring Chinook salmon and coho salmon smolts released from the hatchery may attract additional bull trout during the spring.

Most of the tagged bull trout exhibited movement activities throughout the watershed that were thought to be related to foraging. Almost half of the study fish from the Chiwawa local population made forage/refuge migrations into the White River and Little Wenatchee River, including several in September and October when they stayed in areas where sockeye salmon were spawning. In the Wenatchee River, bull trout had slow post-spawning movements and held

for longer periods in spawning reaches of summer Chinook salmon. Use of these areas likely provided forage opportunities, including on drifting eggs, dislodged benthos, insects attracted to carcasses, or smaller fish also attracted to the spawning activity (Denton et al. 2009). Similar movements of bull trout to non-spawning tributaries for foraging have been observed in the Koocanusa Reservoir of the upper Kootenay River in Canada (Westover and Heidt 2004). Movements in Lake Wenatchee may also increase foraging success on seasonal or ephemeral resources, as indicated by the diet of earthworms in some of the bull trout tagged during late May at the west end near the tributaries (See Appendix C). Seasonal concentrations of bull trout near the outlet may be timed to forage on out-migrating sockeye salmon and spring Chinook salmon smolts. Bull trout increased foraging on hatchery sockeye salmon juveniles when large releases occurred in the lake during previous stocking programs (Thompson and Tufts 1967). A recent study found that sculpins are a primary prey item during the spring while juvenile salmon are more common during the fall in diets of both adult and subadult bull trout in the lake (D. Beauchamp, USGS, unpublished data). All of these seasonal foraging behaviors in Lake Wenatchee are probably necessary in order to gain fitness for reproductive success in this oligotrophic system.

Spawning

Bull trout size and condition likely influence maturation, spawning migrations, spawning success, and post-spawning survival. Brown (1992) found that the majority of Lake Wenatchee females spawn for the first time during ages 5 to 7 and were larger than 510 mm and males showed a similar pattern but with mature fish at age 5 likely to be smaller. In our study, bull trout that spawned during the year they were tagged averaged 580 mm (range 490 to 650 mm) while those that did not spawn averaged 519 mm (range 390 to 570 mm). In the Boise River, radio-tagged bull trout tracked to spawning areas averaged 571 mm (range 449 to 610 mm) and those that did not migrate to spawning areas averaged 507 mm (range 341 to 576 mm) (Salow and Hottstettler 2004). Other studies have found a similar range of sizes of bull trout that migrated to spawn within large river systems: 440 to 790 mm in the Twisp River (Nelson 2012); greater than 480 mm in the Wigwam River (Baxter and Westover 2000); and larger than 500 mm in the Salmo River (Prince 2010). Thus, we suggest migratory bull trout less than 450 mm (and not undertaking spawning migrations) should be considered subadults in the upper Mid-Columbia Recovery Unit. This classification is consistent with the studies on migratory bull trout that show in large river and lake systems subadults are considerably larger than they are in small river systems. For example, subadults range up to 450 mm in the Metolius River/Lake Billy Chinook system of Oregon, the Flathead Lake and River system of Montana, and the Salmo River of Canada (Fraley and Shepard 1989; Ratliff et al. 1996; Muhlfeld and Marotz 2005; Prince 2010) but in the small system of the upper Walla Walla River of Oregon, most subadults are less than 300 mm (Homel and Budy 2008). While it is possible our classification criteria may misclassify a few individuals as adults, identifying subadult bull trout will allow us to learn more about their specific requirements. Information on all life history stages is needed in order to aid recovery of

this threatened species (USFWS 2008b). Accurately determining size at maturity will help understand bull trout population dynamics and guide appropriate management strategies in the upper Mid-Columbia Recovery Unit.

Only half (7 of 14) of the bull trout that spawned one year and were alive the next year repeated spawning, and two of these spawned in three consecutive years. Six of the seven that did not spawn the next year made forage/refuge migrations, likely to regain condition, and suggests an alternate year spawning strategy. The other one migrated to spawn in Nason Creek but moved downstream before spawning commenced. Sex and spawning success of tagged fish was not documented but it may be that competition between males results in some not spawning or leaving early. Several of the bull trout that were smaller when tagged did not spawn until their second or third year tracked, allowing more growth before reproductive maturation. In this study most of the tagged bull trout (80% of those tracked during at least one spawning period) spawned only one time. Similar survival and spawning ratios have been noted in other telemetry studies in the upper Mid-Columbia Recovery Unit (BioAnalysts 2004; Nelson and Nelle 2008; Nelson et al. 2007; Nelson et al. 2009; Nelson and Johnsen 2012). Gaining adequate condition to mature likely limits size at first spawning, which in this study was 490 mm and only half of the fish at sizes 475–575 mm spawned. Subsequent spawning is likely constrained by fish condition as well.

Delayed age of first spawning, alternate year spawning or spawning only a single time may be a result of the low productivity of Lake Wenatchee. In contrast to the Lake Wenatchee fish, the three bull trout that migrated from the Chiwawa River or Nason Creek to overwinter in the Columbia River all migrated to spawn more than once, and this may have been a benefit of the longer migration to presumably more profitable resources and moderate temperatures. Limited recapture data indicates that growth and condition of bull trout that use the Columbia River may be greater than for some of the tributaries (BioAnalysts 2004; Nelson and Nelle 2008, Nelson and Johnsen 2012).

Movements of tagged bull trout indicated fidelity to spawning areas and their local population in the Wenatchee Core Area. Spawning site fidelity has been observed in other bull trout telemetry studies (McPhail and Baxter 1996; Bahr and Shrimpton 2004), including the Entiat and Methow core areas (Nelson and Nelle 2008; Nelson and Johnsen 2012). Fidelity is also supported by genetic differences between nearby local populations (Leary et al. 1993; Spruell et al. 1999; Spruell et al 2003; Ardren et al. 2011; DeHaan and Neibauer 2012).

Migration timing

Pre-spawning migrations occurred over several months, with some beginning as early as April and a few lasting into September. Discharge and water temperature influenced initiation of migration with most movements occurring after peak discharge as water temperatures increased.

Similar patterns have been observed for bull trout in the Entiat and Methow core areas (Nelson and Nelle 2008; Nelson and Johnsen 2012). Bull trout are one of the most water temperature sensitive salmonids and adults are rarely found in water temperatures warmer than 18 or 19^{o} C (McPhail and Baxter 1996; Howell et al. 2010). Although the majority of our tagged bull trout migrated upstream when maximum daily temperatures ranged from 10 to 18°C, in low water years several fish migrated during temperatures greater than 18°C. Other recent studies documented some adult bull trout migrating through or using habitats with similar warm water (Nelson and Nelle 2008; Howell et al. 2010).

Bull trout may migrate later and tolerate warmer water because there could be some benefit to not arriving too early in spawning areas. In small spawning streams there may be limited secure holding areas and adult bull trout may be more vulnerable to mammalian predators than when they are in a larger river with more cover (Ogg and Stutsman 2002; Salow and Hostettler 2004; Prince 2010). A need for secure holding habitat until the time of spawning may result in longer migration times if there is more holding cover in a migratory corridor and shorter times if not. A comparison between migration timing of two local populations in this study illustrates this conjecture: In the Chiwawa River- a relatively pristine system with large pools and many log jams- tagged bull trout took at least 22 days and as many as 65 days to move to spawning areas upstream of rkm 34.2. In contrast, in Nason Creek- more heavily impacted in the lower reaches with simplified channel morphology and fewer log jams- during two years code 131 migrated in less than 3.5 days to rkm 43. It was then found in secure habitat: one year under a log complex in Mill Creek and the next year in a large pool in the spawning reach of Nason Creek.

Diel behavior of predominantly nighttime movements observed in this study may have several advantages. Water temperatures are cooler at night and could provide bioenergetic advantages for bull trout to move at that time (Mesa et al. 2013). During the nighttime, exposure to avian and other predators is eliminated or reduced, and bull trout may be more successful preying on other fish (Cerri 1983; Railsback et al. 2005). Several other studies report mostly nighttime movements (Fraley and Shepard 1989; Swanberg 1997; Salow and Hostettler 2004; Downs et al. 2006), but within large river systems diel patterns are influenced by several factors including time of year, location within the system, water depth, turbulence, and in-stream cover such as boulders that can favor daytime movement (Nelson and Nelle 2008; Nelson and Johnsen 2012). Bull trout typically have been found to pass natural obstacles such waterfalls and rapids during the day (Brown 1994; Nelson and Nelle 2008) and it may be that visual cues increase successful passage of manmade obstacles such as dams as well. Upstream passage at Tumwater Dam was predominantly during the daytime for tagged or video-recorded bull trout in the fish ladder (WDFW data, 2000-2003). Tumwater Canyon has several rapids with boulders, turbulence, and deep pools that provide cover. Bull trout moved through these areas during the daytime as first detections at the TUM station were all during daylight. This suggests that at structures that may

present passage problems for bull trout, the approaches to fishways and fish ladder entrances should be evaluated to determine if there is adequate cover for bull trout to quickly pass.

Effects of artificial structures

Although this study was not specifically designed to measure the effects of structures on bull trout movements, telemetry information from stationary sites warrants some discussion of Dryden Dam, Tumwater Dam, and the Chiwawa River weir.

Dryden Dam- Based on the few tagged individuals that migrated through the lower Wenatchee River, it appears that bull trout moving upstream or downstream of Dryden Dam are not significantly delayed by the structure. Although the upstream passage routes at the dam were not documented, it may be that most bull trout pass at the mid-channel natural rock area as the number of bull trout observed in the ladders at Dryden Dam is much lower than expected when compared to counts at Tumwater Dam.

Tumwater Dam- Tagged bull trout from three local populations (Chiwaukum, Nason, and Chiwawa) migrated past Tumwater Dam. Upstream migration passage times at the dam were slower when the fish trap in the ladder was in operation. During 2001 through 2003, tagged bull trout bull trout passed in less than 2 days, but in 2004, when the fish trap began continuous operation by WDFW for salmon management and research, it took from 3 to 4 days for tagged bull trout to pass the dam. During a USFWS telemetry study in 2008 to 2010, tagged bull trout were significantly delayed at Tumwater Dam during salmon trapping, including one fish that took 23 days to pass (Nelson et al. 2011, 2012). The delays could have been caused by avoidance of the trap structure or because passage was blocked each night and then periodically during the day to process the backlog of captured salmon. Delays later in the pre-spawn migration when water temperatures are warmer may have more impact on survival and spawning success and would likely have greater effects on the Chiwaukum and Nason populations, which mostly migrate from overwintering areas downstream of the dam. Trapping also significantly affected migrating salmon (Fryer et al. 2010) and in 2011 operations were modified to reduce delay of sockeye and Chinook salmon (Chelan PUD 2011). Some form of monitoring such as PIT tagging is needed to determine if the modifications were effective for bull trout as well. It is imperative to minimize delay and ensure bull trout pass upstream relatively unimpeded by fisheries management activities.

Most tagged bull trout moved quickly downstream over Tumwater Dam. Two study fish during post-spawning migrations held for 3 to 5 days upstream of Tumwater Dam, but the dam pool provides good holding areas and the bull trout had been moving slowly before they arrived and after passing, they overwintered just a few kilometers downstream of the dam.

Chiwawa Weir- Because the Chiwawa River contains the healthiest local population, operation of the weir has the potential to impact a large number of bull trout. Over a quarter of the tagged bull trout were delayed by the weir, most for 3 to 5 days. One was delayed for 18 days – it was trapped on the fourth night at the weir, released at the site (the weir was down) where it remained downstream of the weir for 14 days including through two 3-day cycles when the weir was down and two 4-day cycles when it was up. Since this bull trout had just been trapped it may have learned to avoid the trap, but it is unknown why it did not pass when the weir was down. The rest of the tagged bull trout passed in less than 1 or 2 days, either when the weir was down or they were trapped during their first night at the weir. A few bull trout seemed to avoid entering the trap and waited downstream until the weir was down before moving upstream. This behavior may reflect an individual or learned behavior, as demonstrated by one tagged bull trout that during both years it was tracked held for 3 to 4 nights before the weir was lowered and then passed.

The pre-spawning migration into the Chiwawa River occurs over one to three months (dependent on stream discharge) and on average took 22 days to reach upstream areas so delays of up to four days at the weir may have little consequence in migration timing to spawning areas. However later in the migration, with warmer water and closer to spawning, it is possible that delays at the weir could affect individual reproductive success. Daily water temperatures exceeded 15^{o}C during several weeks of trapping, and the long term impact of prolonged warm water exposure on fitness and survival is unknown.

Transport and release of bull trout 13.3 km upstream of the weir may have effects on the fish, as indicated by the significantly slower migration rate to Rock Creek compared to un-transported fish. The transported fish may have spent time recovering or acclimating at the release site before resuming migration, but a few of the tagged bull trout that were transported moved downstream and died. These may have been affected by the trapping and transport, but other factors such as archival tags or warm temperatures may also have contributed to their deaths. Interestingly, one bull trout waited upstream of the weir while it was up for four days before continuing downstream after the weir was lowered and soon thereafter died. One reason for transport is to prevent bull trout from becoming impinged on the weir, but this apparently unhealthy or injured bull trout was able to hold upstream of the weir.

Wenatchee Core Area Metapopulation

The Wenatchee River Core Area, with seven local populations and a diversity of migration patterns, may provide a practical example of the dynamics of a bull trout metapopulation. Metapopulation theory implies that collections of local populations may persist in large connected habitat through dispersal (Hanski and Simberloff 1996; Rieman and Dunham 2000). Several populations in the Wenatchee Core Area share the same connections to habitat, however some are healthy (i.e. Chiwawa, White, and Chiwaukum) and others are not (Nason, Little

Wenatchee). For example, the Nason Creek population has access to the same wintering and foraging areas as the Chiwawa population, but has more human impact and less spawning and rearing habitat. Nason Creek was historically a robust population with a successful fishery (Brown 1992), but has declined to low numbers, often less than 10 redds per year (Kelly Ringel 2012). Under metapopulation dynamics, the Nason population could be "rescued" or re-founded by the Chiwawa population, but on the shorter time scale Nason still faces the very real threat of extirpation. In addition, if the causes of the decline are not identified and corrected, any recolonization by fish from the Chiwawa or other local populations is unlikely to succeed.

The current status and migration patterns of some populations in the Wenatchee Core Area may reflect historic changes in migration routes. In the Wenatchee River, Dryden Dam and Tumwater Dam were major historical obstructions to migrations due to seasonal withdrawals that mostly dewatered downstream stretches of the river from 1908 until 1956 and by inefficient fish ladders until modernized in 1986 (Foster and Hanavan 1945; Mullan et al. 1992). A local population like the Chiwawa River that had two or more migration patterns and different wintering areas may have been more likely to maintain itself despite critical changes in the migration corridors. Other populations with only one migration pattern that used the corridor, such as Nason or Peshastin, may have suffered greater impacts.

Successful recovery of bull trout is contingent on understanding and conserving key processes such as migration, linkages between landscapes, and life history diversity (Reiman and Dunham 2000). This study adds to the baseline of bull trout information previously gathered in the Mid-Columbia Recovery Unit and will be useful in the identification of mechanisms for persistence of populations (Dunham et al. 2008). The following research and management actions are recommended to aid recovery of bull trout in the Wenatchee Core Area.

Recommendations

Research recommendations:

1. Identify additional movement patterns in the Wenatchee Core Area and further evaluate the status of some of the small populations, in particular Nason, Little Wenatchee, Peshastin, and Icicle local populations.
2. Implement studies on subadult bull trout migrations, habitat use, and factors influencing size and age at maturation. Refine a practical definition of subadults, which we suggest in the Wenatchee Core Area should be migratory bull trout downstream of spawning/rearing areas that are less than 450 mm and do not exhibit signs of sexual maturity.
3. Rigorous studies of the ecology of Lake Wenatchee are needed to understand the complexities of bull trout growth and survival in a low nutrient environment. Lake Wenatchee is a popular recreation area, has private development along much of the

shoreline, and supports several sport fisheries. Additional information is needed to guide successful management of the lake.

4. Studies on the potential impacts of climate change on local populations of bull trout in the draft Mid-Columbia Recovery Unit are needed.

Management recommendations:

1. Evaluate impacts of current operations of Tumwater Dam and the Chiwawa weir on bull trout especially during warmer periods. Monitor the effects of transport on bull trout captured at the Chiwawa weir. Stream restoration projects to improve release habitat near the weir should be considered.
2. Maintain and improve migratory connectivity within the watershed. Weirs, dams, and traps that are used and maintained for fisheries management should be designed and managed to minimize effects to all non-target species, including bull trout and Pacific lamprey.
3. Prioritize conservation of the native fish assemblage in the Wenatchee River basin. Develop a comprehensive plan to prevent introductions of non-native fish or aquatic nuisance species and educate public users of Lake Wenatchee.
4. Projects in the Wenatchee River Basin should be evaluated with consideration of the biology and migration patterns of the various local populations of bull trout. Identify if projects or management activities affect reproductive success and prioritize actions that improve it.
5. Focus on restoration and protection of areas that provide holding cover, spawning, and rearing habitat in migratory corridors and spawning reaches.

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Appendices

The following appendices are contained in a separate document titled:
Appendices for the Report: Migration Patterns of Adult Bull Trout in the Wenatchee River, Washington 2000-2004.

Appendix A: Tagging Information
Appendix B: Archival Temperature and Depth Tags
Appendix C: Angling in Lake Wenatchee and Icicle Creek
Appendix D: Bull Trout Pelvic Fin Ray Removal
Appendix E: Movement Summaries of Individual Bull Trout (available on request)

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