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Seasonal Movements of Adult Fluvial Bull Trout in the Entiat River, WA 2003 - 2006

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***On the cover**: A pair of adult fluvial bull trout downstream of their redd at the Dolly Holes in the Mad River. The radio-tagged male (code 80, in foreground) is attending the female during a break in redd construction. USFWS photograph by Jenn Jones.*

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Final Report

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Abstract- The seasonal movements of adult fluvial bull trout from the Entiat River Core Area of the Upper Columbia Recovery Unit were monitored with radio-telemetry during 2003 – 2006. The objectives were to define migration timing, movement barriers, spawning locations, factors affecting populations, and seasonal movements of adult fluvial bull trout. A total of 92 bull trout were tracked, including 35 tagged in the Entiat River and Mad River by the USFWS Mid-Columbia River Fishery Resource Office and 57 tagged at Columbia River hydroelectric dams by Chelan and Douglas County Public Utility Districts. Analysis of movements confirmed that bull trout from the Mad River and upper Entiat River are separate local populations. Both populations exhibited fidelity to the separate spawning areas, used the lower Entiat River as a migratory corridor, and over-wintered in the Columbia River alongside bull trout from the Wenatchee Core Area and the Methow Core Area. During spring migration in 2004, USFWS tagged bull trout took 0.45 to 4.26 days (mean 2.01 days) to pass upstream of Rocky Reach Dam in the Columbia River. After arriving at the mouth of the Entiat River, tagged bull trout staged for 1 – 22 days before entering the river on the declining hydrograph at 13 – 18 days after peak discharge, as mean daily water temperature increased to > 8 °C. Upstream migration mean speeds ranged from 0.34 – 4.34 km/day, varied by stream reach, and were significantly slower in the Mad River. Bull trout were delayed in Box Canyon for 23 – 38 days until stream discharge declined to < 200 ft^3/sec, and then migration continued to the upper Entiat River spawning grounds. Due to a debris obstacle, the percentage of bull trout that passed Box Canyon declined from 67% during 2003 – 2005 to 24 % in 2006, and the redd count declined from 50 to 21 redds. Until 2006, Mad River bull trout were prevented from reaching the majority of the optimal spawning and rearing habitat by a log and debris jam at rkm 22.8, and the redd count declined from 52 to 7 redds. Mortality of adult bull trout was significantly higher in the Mad River than in the upper Entiat River. Mean speed during downstream migration ranged from 0.6 – 38.9 km/day, varied by stream reach, and were significantly slower in the Mad River. In 2004, adult bull trout from the Mad River spent significantly more time (mean 168.9 days) in the Entiat Core Area upstream of rkm 5.1 than did upper Entiat River bull trout (mean 130.3 days). Migration distances between spawning reaches and over-wintering sites in the Columbia River ranged from 36.4 – 91.9 km. Mad River bull trout were more likely to use the Rocky Reach Reservoir while upper Entiat River bull trout were more likely to use the Rock Island Reservoir. Several tagged bull trout were documented successfully passing downstream through Rocky Reach and Rock Island dams. Natural factors such as log jams and migration obstacles to optimal spawning areas appeared to play a major role in the distribution and survival of adult bull trout in the Entiat Core Area.

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Introduction

The U. S. Fish and Wildlife Service (USFWS) listed bull trout *Salvelinus confluentus* within the Columbia River basin District Population Segment as threatened under the Endangered Species Act (ESA) on June 10, 1998 (USDOI 1998). On November 1, 1999 bull trout were listed throughout the coterminous United States as threatened under the ESA (USDOI 1999). Declining bull trout populations are thought to be the result of habitat degradation and fragmentation, blockage of migratory routes, reduced water quality, and introduction of nonnative species.

The mid-Columbia River basin has been designated the Upper Columbia River Recovery Unit (USFWS 2002 and 2004) and includes the Wenatchee, Entiat, and Methow River watersheds as core population areas (Figure 1). Bull trout in core areas with less than five local populations may be at increased risk of local extinction when dealing with deterministic and stochastic events, a result of the inability to spread risk among a larger collection of local populations (Rieman and McIntyre 1993). Bull trout in the Entiat River Core Area are considered to be especially sensitive to local extinctions because only two local populations of fluvial bull trout are thought to exist in the Entiat River watershed: the Mad River population and the upper Entiat River population (USFWS 2002 and 2004).

Some of the first recorded observations of bull trout in the Entiat Core Area were made in the Mad River, where bull trout were found at river kilometer (rkm) 12.9 – 16 and rkm 21 – 22.5, in "areas where there are log jams and deep pools" (Holtby 1972). In the upper Entiat River, bull trout are thought to mainly occur in a zone from rkm 36 – 54 (USFS 1996). Bull trout distributions and spawning areas in the Mad and Entiat rivers were delineated during surveys in the late 1980s and early 1990s (Brown1992). Using the methods and areas described by Brown (1992), the U.S. Forest Service (USFS) has conducted bull trout redd surveys in the Mad River since 1989 (Archibald and Johnson 2005a). The USFS has also conducted limited surveys in the upper Entiat River in a small index reach downstream of Entiat Falls (rkm 54.1 – 54.5) since 2002 (Archibald and Johnson 2005a). In addition, incidental observations of presumed bull trout redds have been recorded in the Chinook salmon spawning index reaches (rkm 26 to 45) by USFWS since 1994 (Hamstreet and Carie 2004). The relationship of these redd counts to the true number of spawning bull trout has not been examined.

Bull trout movement patterns within the Columbia River were investigated by the Mid-Columbia Public Utility Districts (PUDs) of Chelan, Douglas, and Grant Counties in an effort to address issues related to bull trout, dam operation, and re-licensing of the Mid-Columbia River dams (BioAnalysts 2004). During 2001 – 2002, the PUDs radio tagged bull trout at Rock Island Dam, Rocky Reach Dam, and Wells Dam and monitored their movements at the dams and reservoirs until 2004. Tagged bull trout were also recorded entering all 3 core areas of the recovery unit and migrated onto spawning grounds in several tributaries. Radio-tracking of tagged bull trout did not reveal any significant impacts of hydroelectric operations on adult bull trout movements and survival (BioAnalysts 2004). Although aerial surveys to locate bull trout in the tributaries were

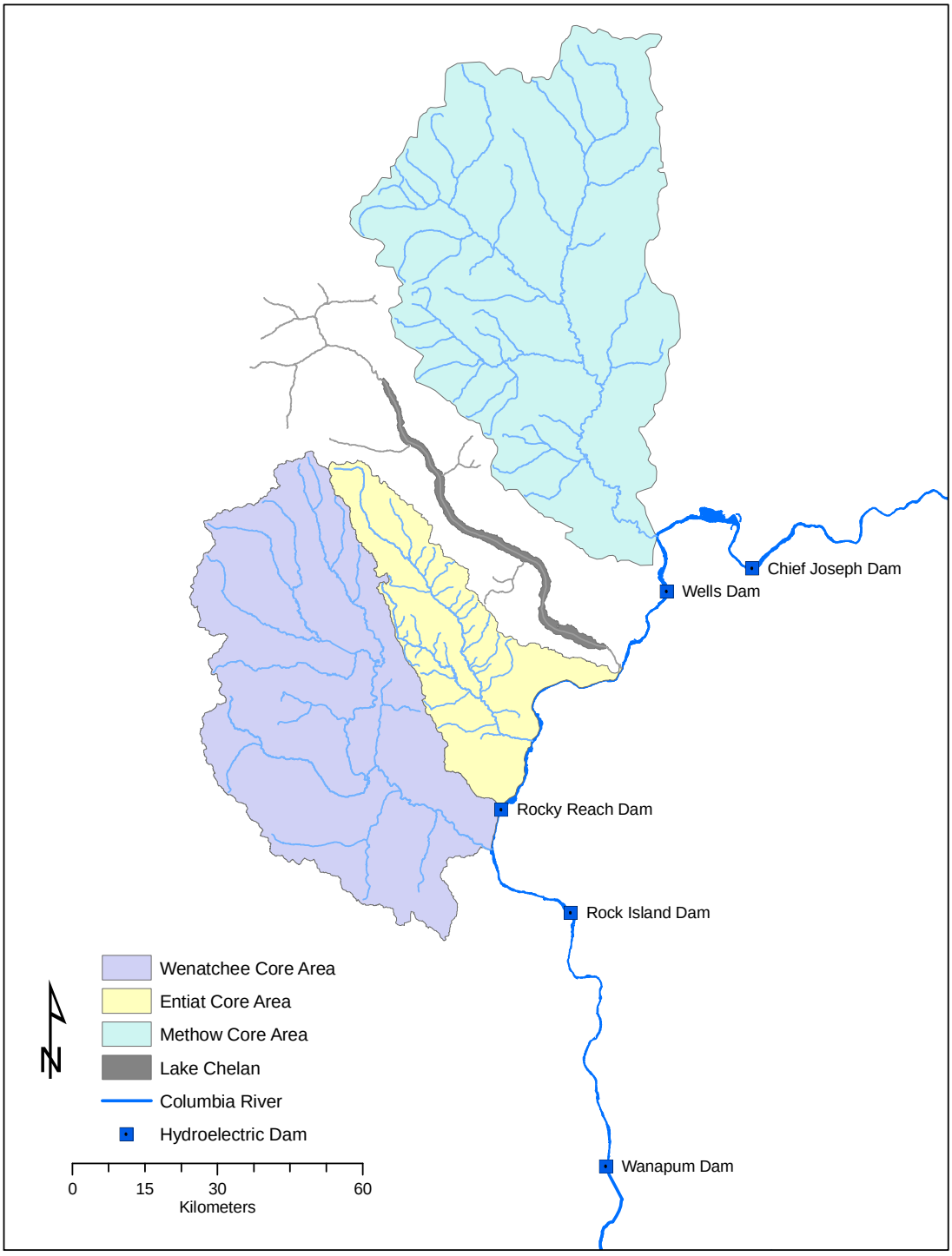

Figure 1. Map of the Upper Columbia Bull Trout Recovery Unit.

flown, limited on the ground monitoring of these fish was conducted by PUDs. To gain additional information on bull trout movements and habitat use, USFWS monitored the bull trout that migrated to the Twisp River of the Methow Core Area (Nelson 2004).

In 2005, both Chelan County PUD and Douglas County PUD implemented additional bull trout radio tagging projects to monitor the passage and incidental take of adult bull trout at their Columbia River hydroelectric projects (CPUD 2005, LGL 2006). By verbal agreement, USFWS tracked those tagged bull trout that left the Columbia River and entered the Methow Core Area (Nelson and Nelle 2007a, Nelson et al. 2007).

The Draft Bull Trout Recovery Plan identified a need for research associated with bull trout migratory patterns and habitat use in the Entiat River watershed (USFWS 2002 and 2004). A better understanding of the life history of bull trout in the Entiat River watershed will provide managers with information related to critical habitat, migratory corridors, movement barriers, and migratory timing. This information will be crucial in refining the draft bull trout recovery plan, guiding stream restoration efforts, and aiding the recovery of bull trout.

The objectives of this radio telemetry study were to define migration timing, movement barriers, spawning locations, factors affecting populations, and seasonal movements of adult fluvial bull trout in the Entiat River Core Area. These objectives were accomplished by tracking bull trout tagged in the Entiat Core Area by USFWS as well as those bull trout tagged in the Columbia River by PUDs that entered the Entiat Core Area.

Study Area

The Entiat River watershed is in Chelan County, Washington and is bordered by the Chelan Mountains to the north and the Entiat Mountains to the south. The Entiat River flows approximately 84 kilometers (km) in a southwesterly direction from its headwaters in a glaciated valley on the east side of the Cascade Range to where it enters the Columbia River at river kilometer (rkm) 779 (Figure 2). The elevation at the basin headwaters is 1,338 meters, drainage area is 1,085 km^2, and average precipitation is 114 cm (Mullan et al. 1992). The major tributaries of the Entiat River are the Mad River (rkm 16.7) and North Fork Entiat River (rkm 55). Mean annual stream discharge for the Entiat River is 509 ft^3/s, mean low discharge is 266 ft^3/s and flood discharge is 10,800 ft^3/s (Mullan et al. 1992). In the Mad River, mean annual discharge is 69 ft^3/s and mean minimum discharge is 17 ft^3/s (Mullan et al. 1992). (See Appendix 1 for hydrographs of stream discharge in the Entiat River and Mad River during the study).

Pleistocene glaciers carved a U-shaped valley from the Entiat River headwaters to a terminal moraine at Potato Creek (rkm 25). Downstream of the terminal moraine the river forms a V-shaped river valley down to the confluence with the Columbia River. Based on geomorphic characteristics, the Entiat River can be divided into three major areas: the Transportation, Transition, and Deposition zones (USFS 1996). The Transportation Zone runs from the Entiat River headwaters to Entiat Falls (rkm 54- the upstream limit of anadromous migrations) and is marked by high sub-surface water storage capacity and

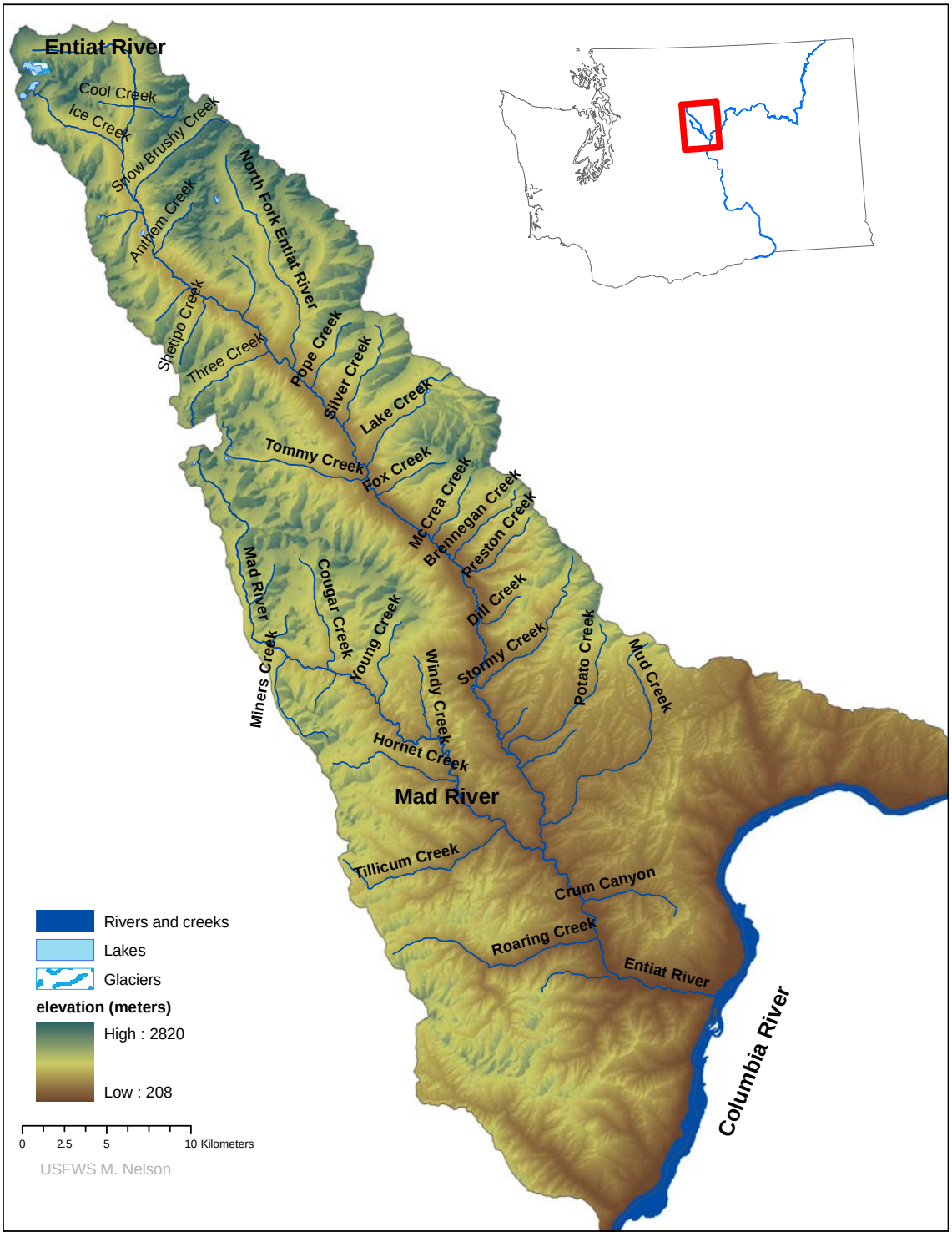

Figure 2. Map of the Entiat River watershed.

large amounts of woody debris. The Transitional Zone runs from Entiat Falls to McCrea Creek (rkm 40.4), and contains the highest amount of fish habitat. The Depositional Zone runs from McCrea Creek to the confluence with the Columbia River, and upstream of the Potato Creek Moraine contains a depositional reach known locally as the "stillwater" area where glacial alluvium has accumulated, resulting in a low gradient, meandering river channel (CCCD 2004). Sediment deposition is the dominant process in this zone, periodic floods are a significant transport mechanism, and a cycle of fill and scour occurs along low gradient reaches (CCCD 2004).

The upper Entiat River descends in a series of steps carved by glaciers. From Entiat Falls to Box Canyon (rkm 47), stream gradient averages 2 %, and then increases to 4.3% between Box Canyon and Fox Creek (rkm 44.7). Gradient is less than 0.3 % in the stillwater area upstream of the Potato Creek moraine, while downstream of the moraine to the mouth it averages about 1 % per mile, and the stream lacks pools in this reach (Mullan et al. 1992).

The Mad River flows for approximately 39 kilometers from Mad Lake to its mouth at rkm 16.7 of the Entiat River. A terminal moraine lies near Maverick Saddle at rkm 27 and downstream the river lies in a narrow steep canyon. The Mad River has a steep gradient and cascades over small falls for much of its course. From the mouth to Pine Flats Campground (rkm 6.4) it averages a 2 % gradient and from Pine Flats to river kilometer 35 it averages 4 % (Holtby 1972). Stream gradient at the falls below Cougar Creek (rkm 22.4) is 6-7 %, and there are several places in this vicinity where the gradient exceeds 7.5 % (Holtby 1972).

Dry forest of ponderosa pine *Pinus ponderos*a, Douglas fir *Psuedotsuga menziesii*, and grand fir *Abies grandis* is the major forest type at elevations below 1200 m in the Entiat River watershed. Historically, low intensity wildfire maintained dry forests that were dominated by widely spaced, large trees with little underbrush. Previous management practices of fire suppression, timber harvest, and livestock grazing have altered the forest ecology, increased tree density and underbrush, and changed the fire regime to high intensity, stand replacement, large wildfires (USFS 2000). As a result, much of the Entiat River watershed has periodically burned in large fires. In 1888, wildfires burned over most of the Mad River drainage (Holtby 1972). From 1970 to 1994, over 60% of the watershed was affected by large stand replacing wildfires, and in 1994 alone, the Tyee Wildfire burned 33 % of the watershed (Andonaegui 1999)

Salmonids known to inhabit the Entiat River are bull trout *Salvelinus confluentus,* brook trout *S. fontinalis,* westslope cutthroat *Oncorhynchus clarki lewisi*, rainbow trout and steelhead *O. mykiss*, spring and summer Chinook salmon *O. tshawytscha*, sockeye salmon *O. nerka,* coho salmon *O. kisutch,* and mountain whitefish *Prosopium williamsoni.* Non-salmonid species include Pacific lamprey *Lampetra tridentatus,* redside shiner *Richardsonius balteatus,* three spine stickleback *Gasterosteus aculeatus,* northern pikeminnow *Ptychocheilus oregonensis,* various sculpin *Cottus spp*., various sucker species *Catostomus spp*., longnose dace *Rhinicthys cataractae,* and chisel mouth *Acrocheilus alutaceus*.

Methods

Tagging

Capture- Adult bull trout were captured by angling with hook and line. Spinning rods and reels, rigged with 8 lb test monofilament line and a lead jig with a rubber minnow body and a single barbless hook, were used to angle in pools downstream of obstructions and barriers. All hooked bull trout were landed with a knotless hand net and placed in perforated PVC holding tubes until implantation surgery. Each capture site was geo-referenced using a hand held Garmin Map76™ global positioning (GPS) unit and the positions were mapped using ESRI® ArcMap™ version 9.2 software.

Tags- The radio tags implanted in adult bull trout were Lotek Engineering model MCFT-3A and MCFT-3FM coded microprocessor transmitters, operating on RF frequency 148.580 MHz, channel 214 and code set year 2000. The MCFT-3A tag measured 16 mm x 46 mm, weighed 16 g in air and had an expected life of 761 days. The MCFT-3FM tag measured 11 mm x 59 mm, weighed 10 g in air and had an expected life of 560 days.

Tag implantation procedure- Prior to tagging bull trout, surgeons and assistants practiced surgical techniques and procedures on at least 10 spring Chinook salmon jacks and/or rainbow trout obtained from the Leavenworth National Fish Hatchery. All practice fish were held in recovery tanks and observed for at least 2 hours, and several were held for up to 3 weeks. All practice fish were sacrificed and autopsied for evaluation of the implantation.

Radio transmitters were surgically implanted in bull trout following the methods described by Summerfelt and Smith (1990). All surgeries were performed streamside using a portable surgery kit developed for use in remote locations (Figures 3 - 4). Surgery equipment, transmitters, and the surgeon's hands were sanitized with 3 % solution of chlorhexidine and rinsed with 3 % solution of sodium chloride before each surgery. Water used in the sanitizing and rinsing solutions was filtered through a 0.3 micron Katadyn backpacking filter. Each fish was anesthetized for 8 – 10 minutes in a bath using a solution of 80 mg of tricaine methanesulfonate (Tricaine-S (MS-222), Western Chemical, Inc.) per L of H_2O and buffered with sodium bicarbonate to match the pH of the river water (Wedemeyer 1970). Total and fork lengths (mm), weight (g), and a genetic tissue sample were collected from each bull trout. While still in the bath, anesthetized bull trout were floated onto a foam cradle designed to support the weight of the fish and prevent injury to the ribs and backbone during transport to and from the surgery table (Figure 5). The bull trout was oriented dorsal side down in the cradle while the gills were irrigated with a buffered solution of 40 mg of MS-222/L H_2O during surgery. The ventral body surface of the bull trout was rinsed with river water and a 30-40 mm incision was made immediately anterior to the pelvic girdle and approximately 10 mm lateral of the mid-ventral line, and gender was determined if eggs or testes were visible. Using a modified shield-needle method (Ross and Kleiner 1982), the side wall of the fish was punctured with a hollow needle posterior to the incision. The whip antenna end was threaded into the hollow needle and extended through the body wall, and the transmitter was inserted into the abdominal cavity. The incision was closed using an

Figure 3. Portable stream-side surgery kit on freighter pack.

Figure 4. Radio tag implantation surgery at Fish Tail Falls (rkm 47), Entiat River, Aug 15, 2003.

Figure 5. Surgery cradle used to transport anesthetized bull trout to recovery tube.

interrupted pattern of three to four absorbable sutures, and Vetbond® was applied to the knotted sutures and incision area to ensure closure.

The bull trout were allowed to recover from the anesthetic in a holding tube for at least 15 minutes and were released in an area of reduced water velocity and cover near the capture site.

Radio-telemetry

Bull trout locations were recorded using five monitoring methods: fixed receiver telemetry stations, truck surveys, boat surveys, foot ground surveys, and aerial surveys. Location coordinates were recorded with a Garmin GPSmap76 unit or placed by hand on 7.5 minute USGS topographic maps. GPS waypoints were downloaded into MapTech® Terrain Navigator and the marker files were exported into ESRI® ArcMap™ 9.2 for creation of maps. The river mile (rm) of a location was determined by one or more methods: interpolation from river mile markers on USGS 1:24000 topographic maps; from a table of river miles created in GIS by USFS, estimation by linear distance and map scale, or from the stream catalog in Mullan et al. (1992). These methods may result in a river mile designation of a landmark that deviate from designations in other sources. The river mile was then converted to river kilometers (rkm).

Equipment- The telemetry receivers used were Lotek model SRX400 W7 or W31 units. Lotek ASP 8 or Grant Engineering Hydra antenna switching units, Grant Engineering 4 element model 4LYVT yagi-type antennas, and 12 V batteries powered by 60 watt solar panels were used at fixed stations (Figure 6).

Figure 6. Fixed station in the burned-over area at Camp Nine (rkm 15.9) on the Mad River.

Fixed stations- Fixed receiver telemetry stations were set up at 7 locations in the Entiat River watershed (Table 1, Figure 7). Each station was designated by a two letter site code referencing its location or other information (Table 1). Hence, ***ER*** refers to the station upstream of the mouth of the Entiat River (operated by Chelan PUD), ***EF*** to the Entiat Fish Hatchery, ***MD*** to the confluence of the Mad River, ***SH*** to the station located on Shorty Long's property, ***DB*** to downstream of Box Canyon, ***BC*** to upstream of Box Canyon, ***CN*** to Camp Nine, ***LB*** to lower footbridge downstream of Alma Creek.

Other fixed stations were maintained during concurrent studies in the Wenatchee River and Methow River watersheds, and the Chelan and Douglas PUDs maintained telemetry stations at mid-Columbia River hydropower dams and tributary entrances (Table 1, Figure 8). For descriptions of these systems, see BioAnalysts (2004), Stevenson et al. (2006), LGL and DPUD (2006), and Nelson et al. (2007).

Table 1. Name, river location, and years of operation of fixed telemetry stations in the Entiat Core Area.

Receiver Station	River	River km	Years	Notes
ER	Entiat	5.1	2003-2006	At Whitehall property, CPUD site
EF	Entiat	10.9	Spring 2005	At Entiat National Fish Hatchery
MD	Entiat	16.7	2003-2006	At confluence of Mad River
SH	Entiat	26.0	2004-2005	At Shorty Long's, start of "stillwater"
DB	Entiat	46.7	2005, 2006	Downstream of Box Canyon
BC	Entiat	47.0	2004-2006	Upstream of Box Cyn and Fishtail Falls
CN	Mad	15.9	2004-2005	At Camp Nine
LB	Mad	22.4	2004-2005	At footbridge downstream of Alma Creek
WR	Wenatchee	12.5	2003-2006	At Wenatchee R. Co. Park, CPUD site
RR	Columbia	762.3	2003-2006	At Rocky Reach Dam, CPUD site
RI	Columbia	729.7	2003-2006	At Rock Island Dam, CPUD site
WL	Columbia	830.1	2003-2006	At Wells Dam, DPUD site

Mobile surveys- A Lotek SRX400 telemetry receiver and mobile telemetry techniques were used to locate the fish. The size of the watershed precluded a single survey of the entire core area and different areas may have been covered during each survey session. Surveys were conducted by truck with hitch mounted and amplified dual yagi 4-element antennas (Nelson 2006), and by boat with dual yagi antennas. Boat surveys were conducted in the Columbia River from Wanapum Dam to Wells Dam; each reservoir was surveyed on a separate day in both upstream and downstream directions.

Team tracking techniques were used while tracking on foot to avoid disturbing or changing the behavior of tagged bull trout (Nelson 2004). The exact location of the fish was recorded, and notes were taken describing the general habitat features in the immediate vicinity. When possible, snorkeling was conducted to ascertain the condition and status of tagged bull trout.

Aerial surveys- A fixed wing aircraft, equipped with dual yagi antennas and Lotek receivers interfaced with GPS units, was used to record tagged bull trout locations in tributaries and the Columbia River. Aerial surveys were flown by USFWS and Chelan PUD, and the information was shared with all cooperating agencies.

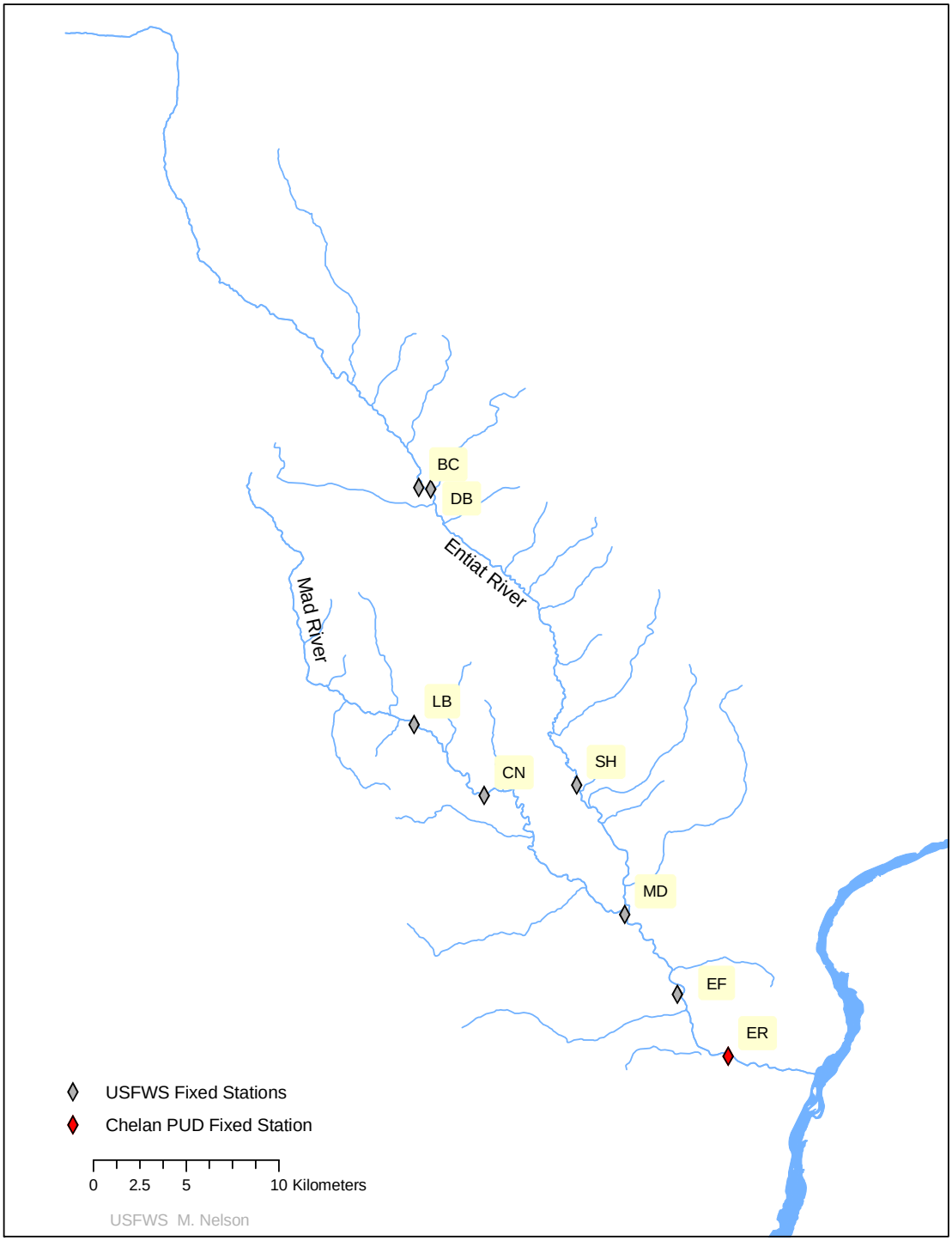

Figure 7. Map of fixed telemetry stations in the Entiat Core Area.

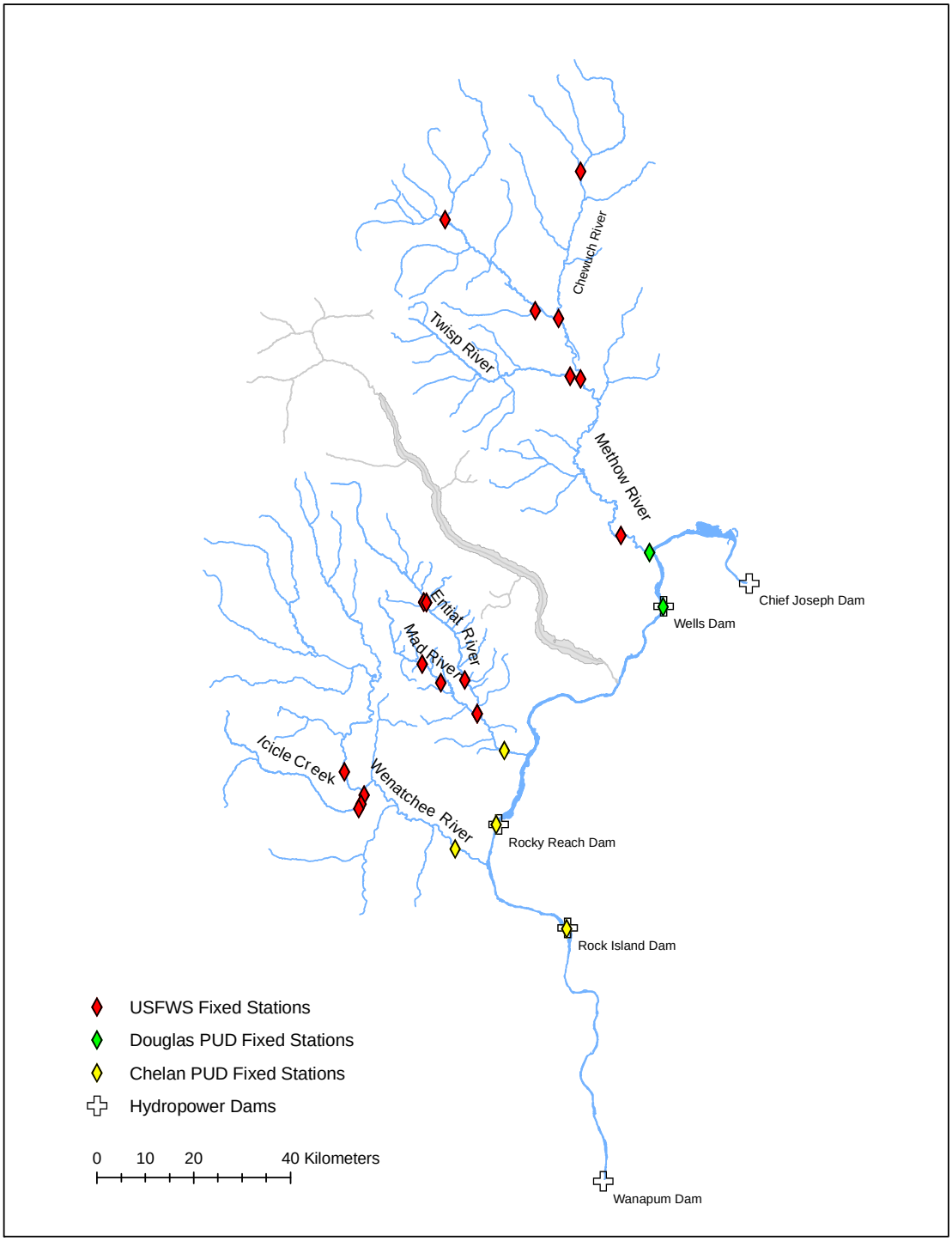

Figure 8. Map of all fixed telemetry stations in the Upper Columbia Recovery Unit.

Spawning ground surveys

Bull trout spawning surveys were conducted by USFWS and USFS in several index reaches in the Entiat Core Area (Figure 9). The USFS has conducted surveys in the Mad River in 3 index reaches (rkm 19.8 – 31.9) since 1989 and in a 0.4 km reach (rkm 54.1 – 54.5) downstream of Entiat Falls in the upper Entiat River since 2002 (Archibald and Johnson 2005a). In 2004, during this telemetry study, USFWS added 2 index reaches in the upper Entiat River (rkm 47.3 – 54.1). Each index reach was surveyed 3 times, with visits scheduled to coincide with the beginning, peak, and completion of the bull trout spawning period. Surveys were conducted by a team of two surveyors, with at least one experienced observer present for all surveys. Redds were categorized as definite, probable, or possible, with only definite and probable redds included in the final count (Bonar et al. 1997). Redd dimensions were measured with a graduated wading rod and the coordinates geo-referenced with Garmin Map76® GPS units or other methods (Archibald and Johnson 2005, Nelson and Nelle 2007b).

Stream discharge data

Stream discharge data were obtained from gage stations operated by United States Geological Survey and Washington Department of Ecology (USGS 2007, WDOE 2007). These included USGS stations 12452990 (Entiat River near Entiat), 12452890 (Mad River at Ardenvoir), 12452800 (Entiat River near Ardenvoir) and WDOE stations 46A160 (Entiat River below Entiat Falls), and 46C100 (Mad River above Camp Nine) (Figure 10). Stream discharge data is presented in ft^3/s.

Temperature data

Stream temperatures were monitored at several locations in the Entiat River watershed (Figure 10). Automated temperature loggers (Onset Tidbit® and Stowaway® models) were deployed and maintained during long-term monitoring by the USFS Entiat Ranger District (Archibald and Johnson 2003, Archibald and Johnson 2007), and temperature data was recorded by WDOE at gaging stations in their stream monitoring network (WDOE 2007). The daily mean, minimum, maximum temperatures and the running 7 day average daily maximums (7DADMax) were calculated. The largest value of the running 7DADMax indicates the maximum weekly maximum temperature (MWMT), defined as the mean of daily maximum water temperatures measured over the warmest 7 day consecutive period during a given year (Hillman and Essig 1998). The running 7DADMax was graphed and MWMT was compared to the temperature standard of 13 °C MWMT thought to be fully protective of juvenile bull trout rearing during June, July, and August (Essig et al. 2003). In some analyses of temperature data, delta T, the difference between the daily minimum and maximum temperatures was calculated.

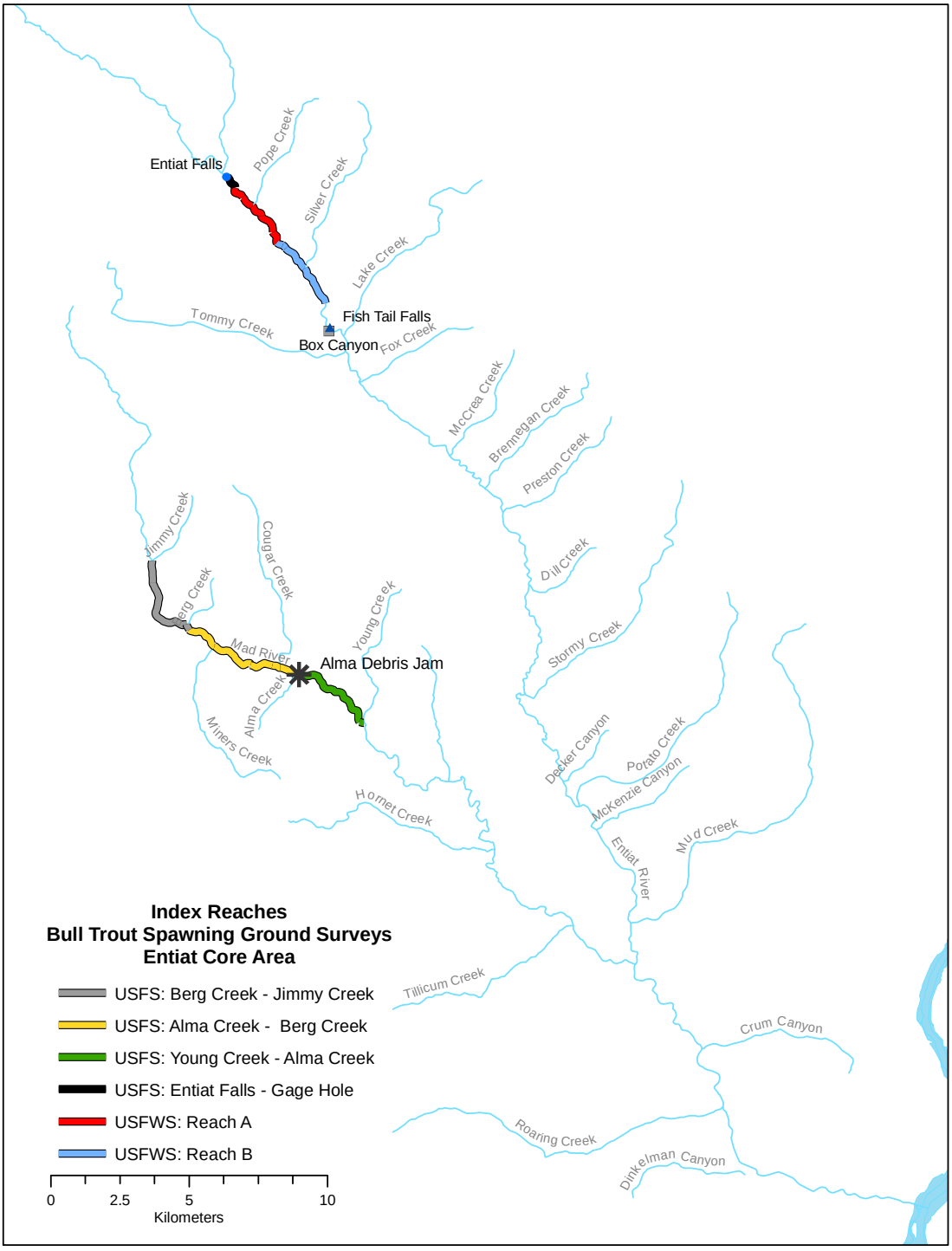

Figure 9. Map of bull trout spawning ground survey index reaches in the Mad River and upper Entiat River.

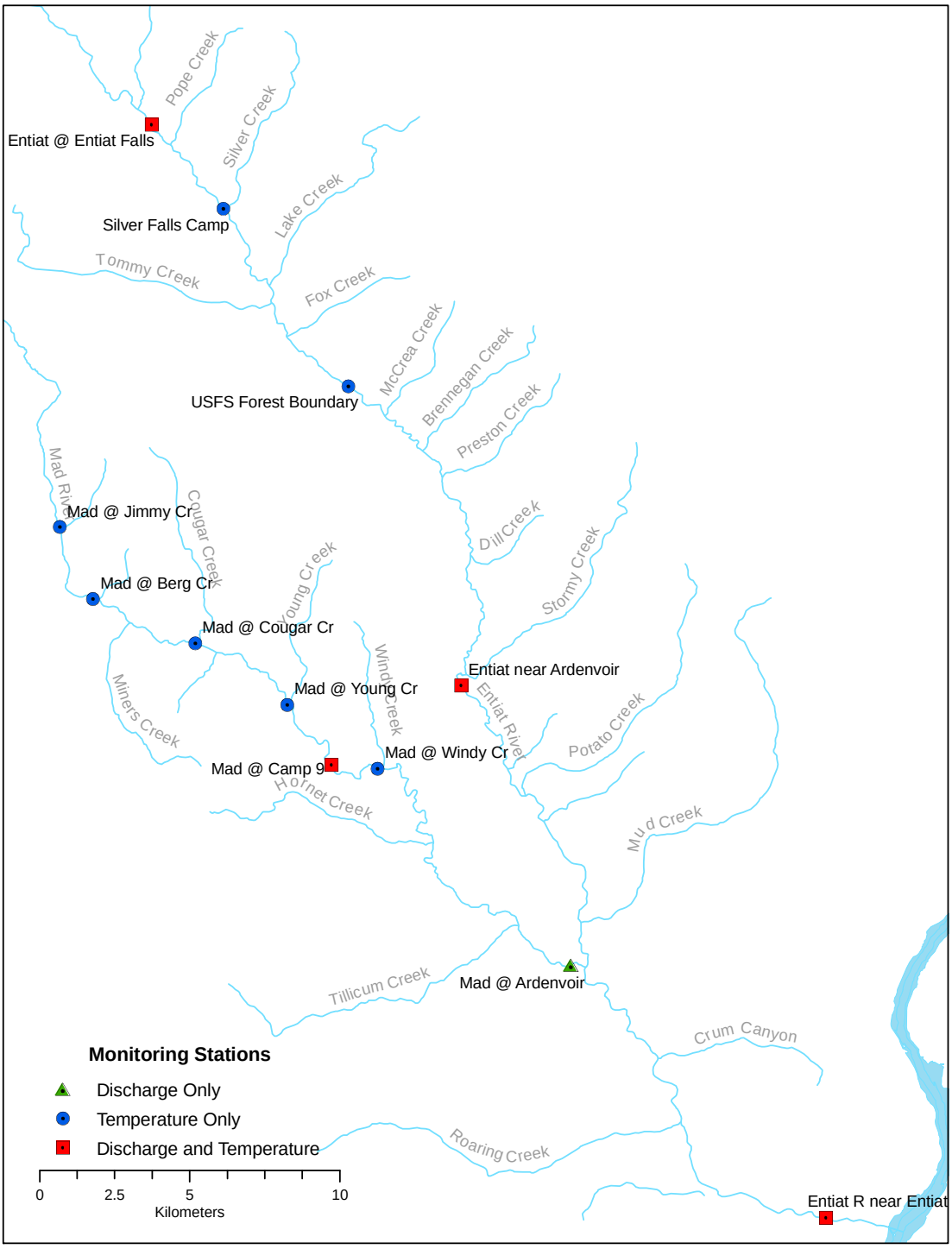

Figure 10. Map of temperature and discharge gage stations in the Entiat Core Area.

Data analysis

Assignment of daily movement periods- In the analysis of daily movements recorded at fixed stations during migrations, the movement was assigned to day or night periods. Day is defined as after sunrise and before sunset and night is after sunset and before sunrise. A sunrise/sunset calculator (www.sunrisesunset.com), set for the City of Entiat, was used to determine during which period tagged bull trout passed fixed sites. The times a tagged bull trout arrived at and left a fixed station was used to assign the period of movement. If both times were before sunset, the period was recorded as day. If both were after sunset, the period was recorded as night. If the fish came into the station during the day and left at night (or vice versa), the period was recorded as both. When the fish was at a fixed site for an extended period, the time in and time out were still used to assign the period, i.e. if the fish came in at night, stayed for 48 hours and left at night, it was assigned to night, or if it came in at night, stayed for 60 hours and then left in the daytime, it was recorded as both.

Ranking of order of arrival at fixed stations- To determine if migration occurs as an orderly procession or if bull trout pass each other as they move upstream, the arrival date and time at fixed stations was examined for each tagged fish. Thus, if migration is viewed as a race between individual bull trout to the spawning grounds and then back to the Columbia River, a race ranking was assigned to each bull trout in the order it passed each station. These rankings were then compiled into a table for each migration year.

Tests of statistical significance- The statistical software STATGRAPHICS Plus for Windows 2.0 (Statistical Graphics Corp. 1996) was used for statistical analysis of data. Two-way ANOVA was used to compare means and test for differences in length of adult bull trout in the Mad and Entiat rivers by year. Student's t-test was used to compare means and test for differences in migration speed and time spent in the Mad and Entiat rivers. The chi-square test was used to test for difference between expected and observed distribution of radio-tagged adult Entiat River bull trout over-wintering in each reservoir of the Mid-Columbia River hydro-electric dams, with the expected values derived from the distribution of radio-tagged adult Mad River bull trout. Significance levels were set at alpha = 0.05.

Presentation of results

The results of this multi-year study are presented as a summary of seasonal migratory patterns, rather than a chronological list of movements organized by each year. Migrations were partitioned into four periods: upstream migration, spawning, downstream migration, and over-wintering. Most bull trout followed this general pattern, but others exhibited movements not so neatly defined and these exceptions are presented as such. This report includes analysis and discussion of bull trout tagged by USFWS and PUD for separate studies, so in some analyses it was appropriate to include only USFWS-tagged fish or both USFWS and PUD-tagged fish and those instances are identified in the text. For information on movements of the PUD-tagged bull trout in the Columbia River, see Stevenson et al. (2006, 2007).

Results

Radio-tagging

Number of bull trout tagged by USFWS- Radio transmitters were implanted in 35 adult bull trout captured at 3 locations in the Entiat River watershed (Figure 11). In the Mad River, 15 bull trout were tagged in 2003 and 6 in 2004, and in the Entiat River, 10 were tagged in 2003 and 4 in 2004 (Appendix 2). In the Mad River, all the bull trout were tagged in a step pool/cascade area downstream of Alma Creek known locally as the "Dolly Holes" (rkms 22.7 – 22.8). In the Entiat River, 13 of the bull trout were tagged in Box Canyon (rkm 47) and 1 was tagged at Entiat Falls (rkm 54.5).

Number of bull trout tagged by PUDs- During the study, 57 bull trout tagged at 3 Columbia River hydroelectric projects by Mid-Columbia Public Utility Districts (PUDs) were also tracked within the Entiat River watershed (see BioAnalysts 2004, Stevenson et al. 2006, 2007; DPUD and LGL 2006, 2007). Ten of these bull trout were tagged in 2002, 24 in 2005, and 20 in 2006 by Chelan County PUD at Rocky Reach and Rock Island Dams, and 3 were tagged in 2006 by Douglas County PUD at Wells Dam (Appendix 3).

Total number of bull trout tracked- In total, 92 bull trout were radio-tagged and tracked from 2003 to 2006, and the number monitored each year ranged from 26 to 35. During 2003 and 2004, the majority of the monitored bull trout were those tagged by USFWS in the Entiat Core Area. As the study proceeded and fish or tags died, the majority of the fish that were tracked were those tagged by PUDs in the Columbia River. By 2006, all the bull trout in the study were PUD fish, and 74 % were tagged in that year (Table 2).

Table 2. Total number of radio-tagged bull trout tracked in the Entiat Core Area each year during 2003 - 2006.

Year	Total # tagged bull trout tracked	USFWS tags	PUD tags	New tags	Tags from previous years
2003	35	25	10	25	10
2004	26	20	6	10	16
2005	31	5	26	24	7
2006	31	0	31	23	8

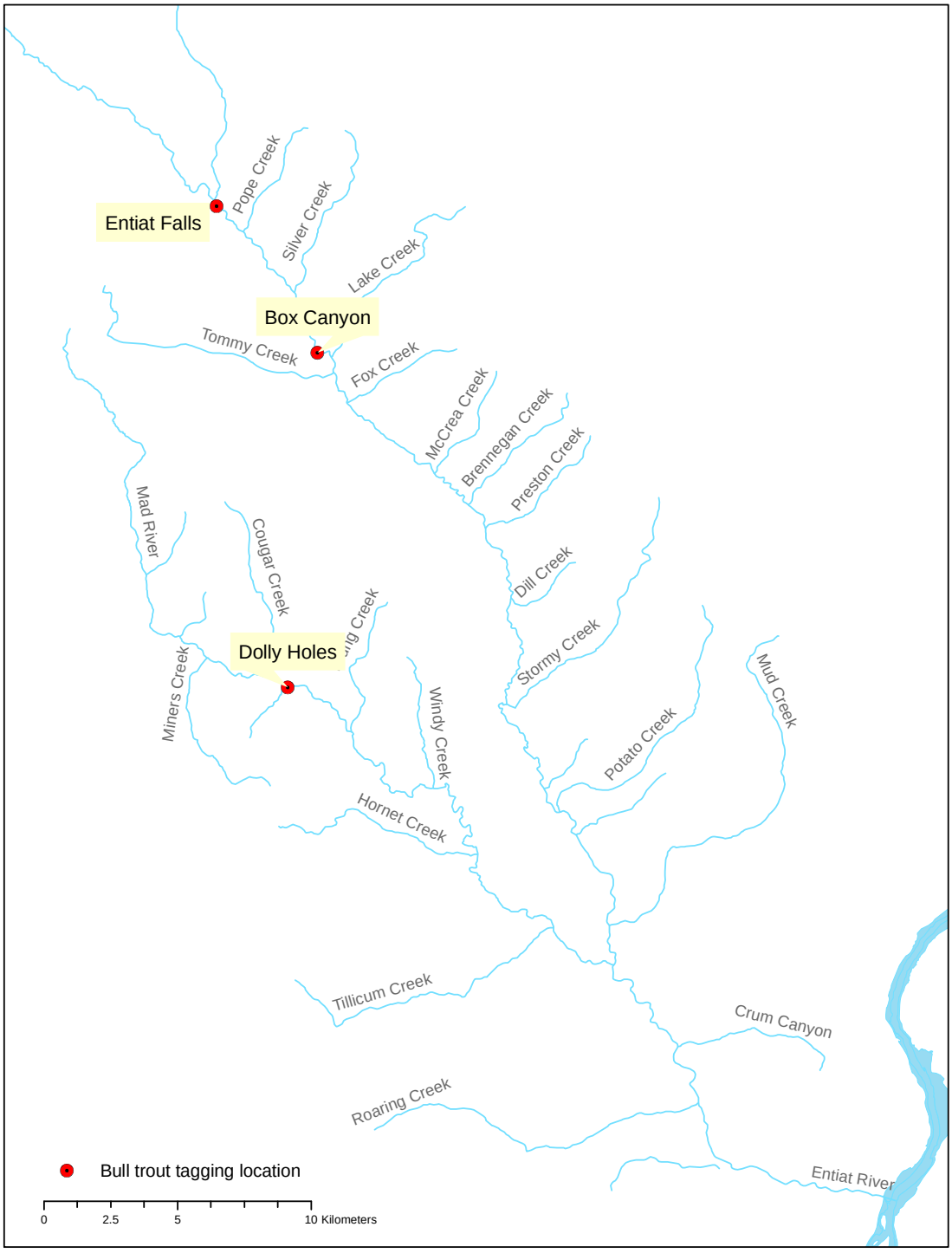

Figure 11. Map of bull trout tagging locations in the Entiat Core Area.

Morphometric data of USFWS tagged bull trout- Fork length of tagged bull trout ranged from 375 to 656 mm (Figure 12) and weight ranged from 550 to 3100 g (Appendix 2). Bull trout tagged in the Mad River were significantly smaller in length than bull trout tagged in the Entiat River (Table 3; 2-Way ANOVA, df = 34, F = 6.50, p = 0.016).

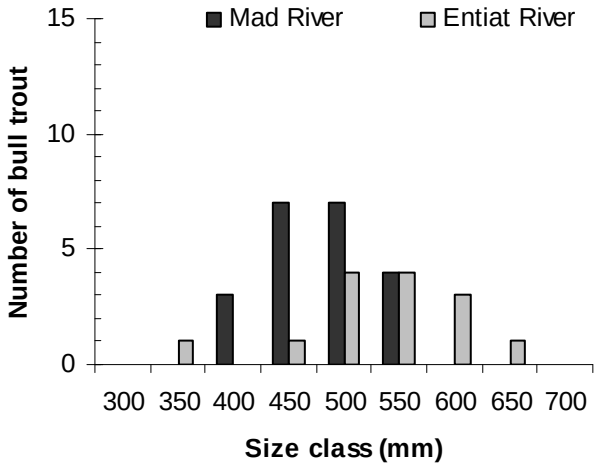

Figure 12. Size classes of bull trout tagged in the Mad River and Entiat River by USFWS in 2003 and 2004.

Table 3. Fork length (FL) of Mad River and Entiat River bull trout tagged by USFWS, 2003 - 2004.

River	n bull trout	Range FL (mm)	mean FL (mm)
Mad	21	408 - 570	501.25
Entiat	14	375 - 656	553.75

Morphometric data of PUD tagged bull trout- Fork length of bull trout tagged by PUDs at mid-Columbia River dams during 2002, 2005, and 2006 that entered the Entiat River watershed ranged from 404 to 720 mm (Figure 13) and weight ranged from 650 to 5160 g (Appendix 3). Tagged bull trout that migrated into the Mad River were significantly smaller in length than bull trout that migrated into the upper Entiat River (Table 4; 2-Way ANOVA, df = 57, F = 18.25, p = 0.0001).

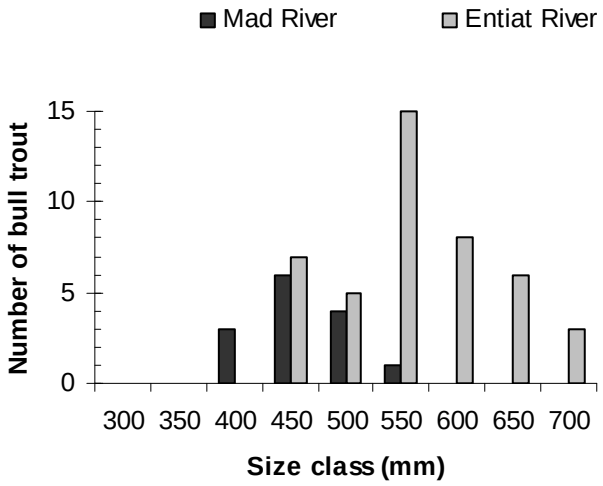

Figure 13. Size classes of bull trout tagged in Columbia River by PUDs in 2002, 2005, and 2006 that utilized the Mad River and Entiat River.

Table 4. Fork length (FL) of Mad River and Entiat River bull trout radio-tagged by PUDs in the Columbia River, 2002, 2005 and 2006.

River	n bull trout	Range FL (mm)	mean FL (mm)
Mad	14	404 - 550	487.5
Entiat	44	455 - 720	578.6

Population trends

The number of fluvial bull trout counted by Chelan PUD at Rocky Reach Dam on the Columbia River declined each year of the study (Figure 14). In 2003, 248 bull trout were counted ascending the Rocky Reach Dam fish ladder, but only 122 bull trout were counted in 2006. The proportion of tagged bull trout utilizing the Mad River declined each year- in 2003, 70% of bull trout tagged in the Columbia River by Chelan PUD that entered the Entiat River watershed migrated into the Mad River; in 2006, only 10% entered the Mad River (Figure 15).

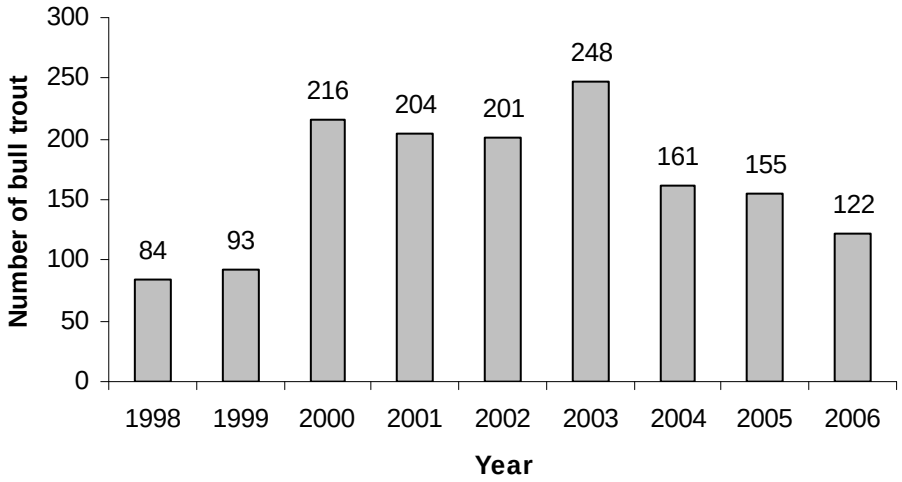

Figure 14. Number of bull trout counted in the fish ladder at Rocky Reach Dam, 1998 - 2006.

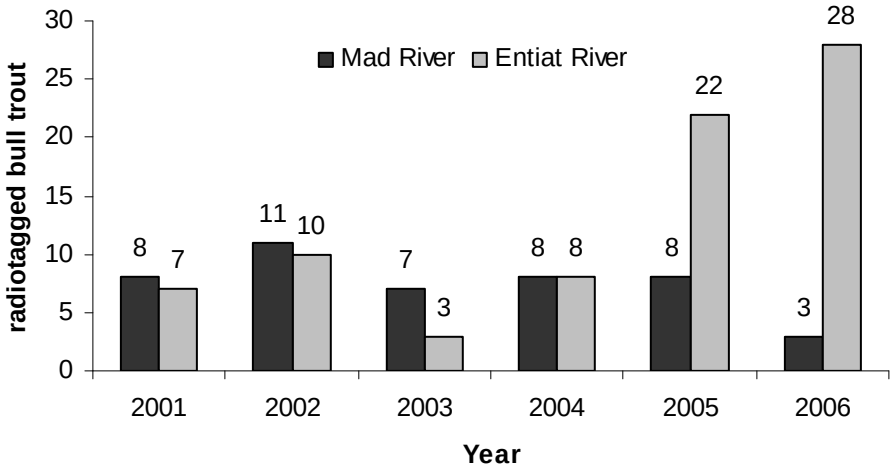

Figure 15. Number of radio-tagged adult fluvial bull trout that entered the Mad River and Entiat River, 2001 – 2006.

Upstream migrations

Columbia River- In the spring of 2004, seven bull trout tagged by USFWS during 2003 were detected at the telemetry systems operated by Chelan PUD at Rock Island and Rocky Reach dams on the Columbia River (Table 5). Between May 10 and May 30, 2 bull trout migrated upstream through both dams, and an additional 5 were recorded at Rocky Reach Dam.

In 2004, the elapsed time migrating bull trout took to pass the dams (calculated from the first detection at the telemetry stations downstream of the tailraces to detection at the exit of the fish ladders) ranged from 0.45 to 4.26 days, with a mean of 2.01 days at Rocky Reach (Table 5). At Rock Island Dam, bull trout code 72 was detected during boat surveys in the tailrace at the base of the dam, where it spent the winter and early spring before migrating upstream. Because it was upstream of the tailrace detection array and was not detected at that station, the elapsed time to pass the dam could not be calculated.

In 2005, two USFWS tagged bull trout were detected migrating upstream through Rocky Reach Dam, and the elapsed time ranged from 1.47 – 4.96 days, with a mean of 3.21 days.

Table 5. Elapsed time of upstream passage for USFWS radio-tagged bull trout at Rock Island Dam (RI) and Rocky Reach Dam (RR) in the Columbia River, 2004.

Code	RR tailrace 1st date time	RR fish ladder exit date time	elapsed time (days)
69	5/9/04 2:36	5/10/04 12:11	1.40
67	5/14/04 6:03	5/18/04 0:22	4.26
63	5/17/04 5:32	5/19/04 12:53	2.31
72	5/20/04 3:43	5/20/04 14:36	0.45
53	5/27/04 4:15	5/28/04 19:07	1.62
55	5/28/04 15:43	5/30/04 16:20	2.03
54	5/28/04 4:41	5/30/04 5:25	2.03
			mean = 2.01

Code	RI tailrace 1st date time	RI fish ladder exit date time	elapsed time (days)
55	5/25/04 19:07	5/27/04 14:51	1.82

In 2004, the travel time from Rock Island Dam to Rocky Reach Dam ranged from 1.0 to 1.5 days (mean (SD) = 1.3 (0.3), median = 1.3). The travel time from Rocky Reach Dam to the Entiat River (ER fixed station at rkm 5.1) ranged from 3.2 to 14.4 days (mean (SD) = 8.5 (5.1), median = 7.5).

Staging at the Entiat River confluence- During each spring migration, radio-tagged bull trout were detected staging in the Columbia River before entering the Entiat River. Eight tagged bull trout in 2004, 7 in 2005, and 14 in 2006 staged for up to 3 weeks before entering the tributary. In 2004, bull trout were detected staging on May 26 and four fish had already entered the Entiat River. In 2005, staging was first detected on May 19 during boat surveys and the minimum known days of staging ranged from 1 – 6 days (mean (SD) = 2.8 (1.8)). In 2004 and 2005, early arrivals staged and then moved slowly up the lower river while those arriving after June 1 usually did not stage and instead moved quickly up the lower Entiat River. In 2006, most bull trout arrived later at the Entiat River, with the first bull trout detected off the mouth on May 18, followed by 2 detected on May 25, then 14 on June 10 and 8 on June 16. The minimum known duration of staging was greater in 2006 than in 2005, ranging from 6 – 22 days (mean (SD) = 10.3 (7.9)).

Into the Entiat River- Tagged bull trout migrated into the Entiat River after peak discharge, as stream flow declined and water temperature increased. In 2004, limited mobile tracking indicated that bull trout took between 1 and 10 days to travel the 5.1 river kilometers to the ER fixed station. In 2005 and 2006, intensive mobile tracking was implemented and indicated that tagged bull trout took 0.4 – 7.1 days (mean (SD) = 2.8 (2.2)) during 2005 and 3.1 – 16.7 days (mean (SD) = 8.2 (3.9)) during 2006 to travel the lower river before detection at the fixed station.

ER fixed station (rkm 5.1) - Bull trout first migrated past the ER station at 13 – 18 days after peak discharge (Figure 16). In 2004, discharge peaked on May 4 at 1750 ft^3/s, and tagged bull trout were recorded from May 20 to June 5 (Tables 6 – 7) as flows declined from 1490 to 1360 ft^3/s (Figure 16). In 2005, peak flows occurred on May 11 at 1820 ft^3/s, and bull trout were recorded from May 28 to July 2 (Tables 6 – 7) as flows declined from 776 to 317 ft^3/s (Figure 16). In 2006, peak flows occurred on May 19 at 4510 ft^3/s, and most bull trout were recorded from May 31 to July 3 (Tables 6 – 7) as discharge declined from 1620 to 1250 ft^3/s (Figure 16), but 1 tagged bull trout entered on July 30, when flows were 299 ft^3/s.

During in-migration past the ER station, mean daily stream temperatures ranged from 8.7 – 12.7 °C in 2004 and 8.9 – 16.7 °C in 2005 (Figure 17). The grand mean water temperature during in-migration was 9.7 °C in 2004 and 12.9 °C in 2005.

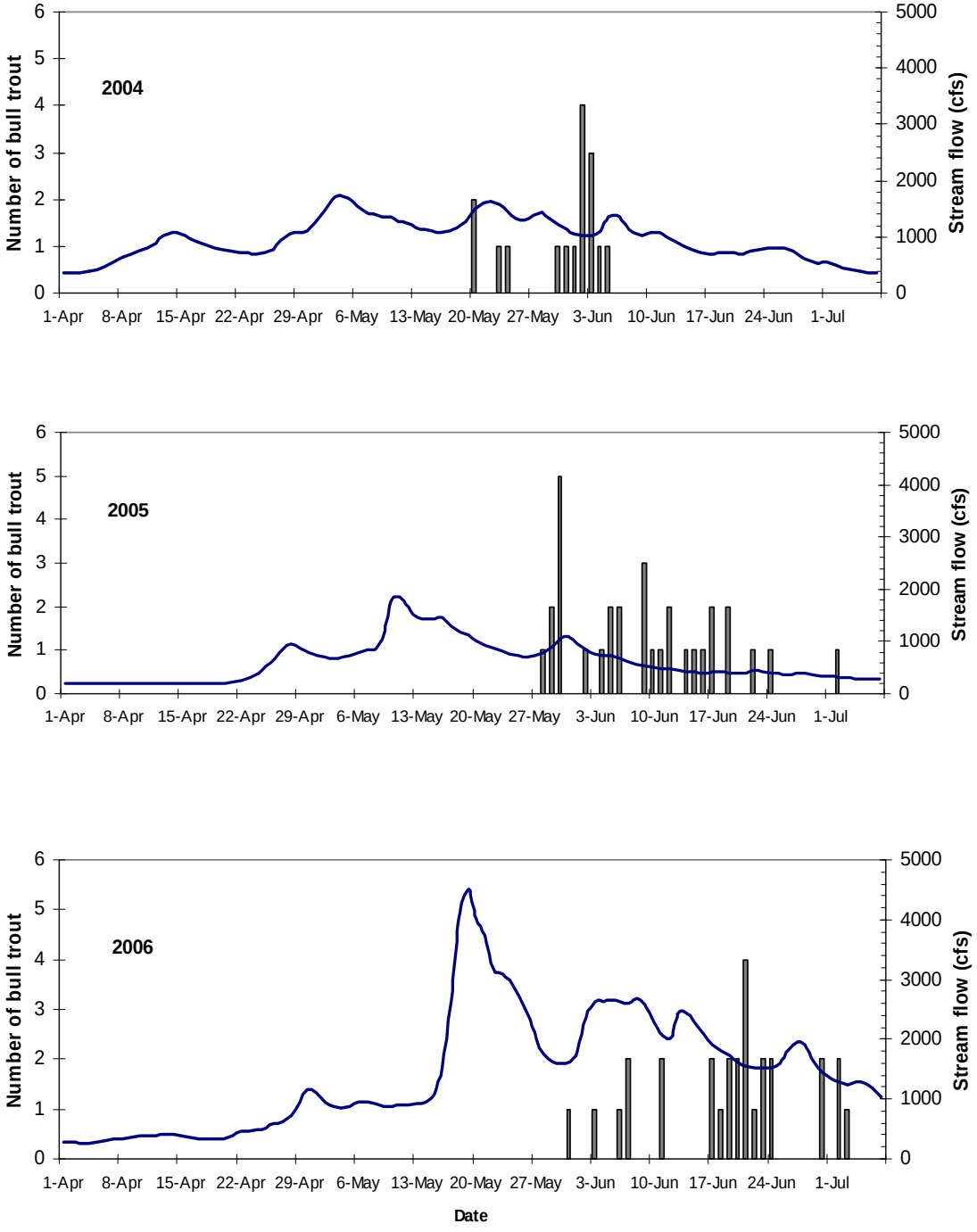

Figure 16. Entiat River discharge (USGS gage near Entiat at rkm 2.5) and dates when radio-tagged bull trout migrated upstream past the ER fixed station (rkm 5.1), 2004 - 2006.

Table 6. Dates that radio tagged Entiat River bull trout migrated upstream past fixed receiver stations in the Entiat River, 2004 - 2006.

	ER (rkm 5.1)	MD (rkm 16.7)	SH (rkm 26.0)	DB (rkm 46.7)	BC (rkm 47.0)
2004	20-May to 5-Jun	1-Jun to 18-Jun	3-Jun to 22 Jun	22-Jun [3]	14-Jul to 12-Aug
2005	29-May to 2-Jul [1]	3-Jun to 7-Jul	5-Jun to 10-Jul	12-Jun to 6-Jul	12-Jul to 30-Jul
2006	31-May to 30-Jul [2]	16-Jun to 2-Aug	not monitored	5-Jul [4]	11-Aug to 29-Aug

Notes: 1- data from Chelan PUD (Stevenson et al. 2006); 2- data from Chelan PUD (Stevenson et al. 2007); 3- date of first mobile detection; 4- date first bull trout arrived, receiver was then moved to BC station so final date not recorded.

Table 7. Dates that radio tagged Mad River bull trout migrated upstream past fixed receiver stations in the Entiat River and Mad River, 2004-2006.

	ER (rkm 5.1)	MD (rkm 16.7)	CN (Mad rkm 15.9)	LB (Mad rkm 22.4)
2004	20-May to 3-Jun	6-Jun to 22-Jun	26-Jun to 25-Jul	17-Jul to 31-Jul
2005	28-May to 19-Jun [1]	7-Jun to 22-Jun	30-Jun to 8-Aug	9-Jul to 12-Jul
2006	23-Jun to 3-Jul [2]	1-Jul to 9-Jul	not monitored	not monitored

Notes: 1- data from Chelan PUD (Stevenson et al. 2006); 2- data from Chelan PUD (Stevenson et al. 2007).

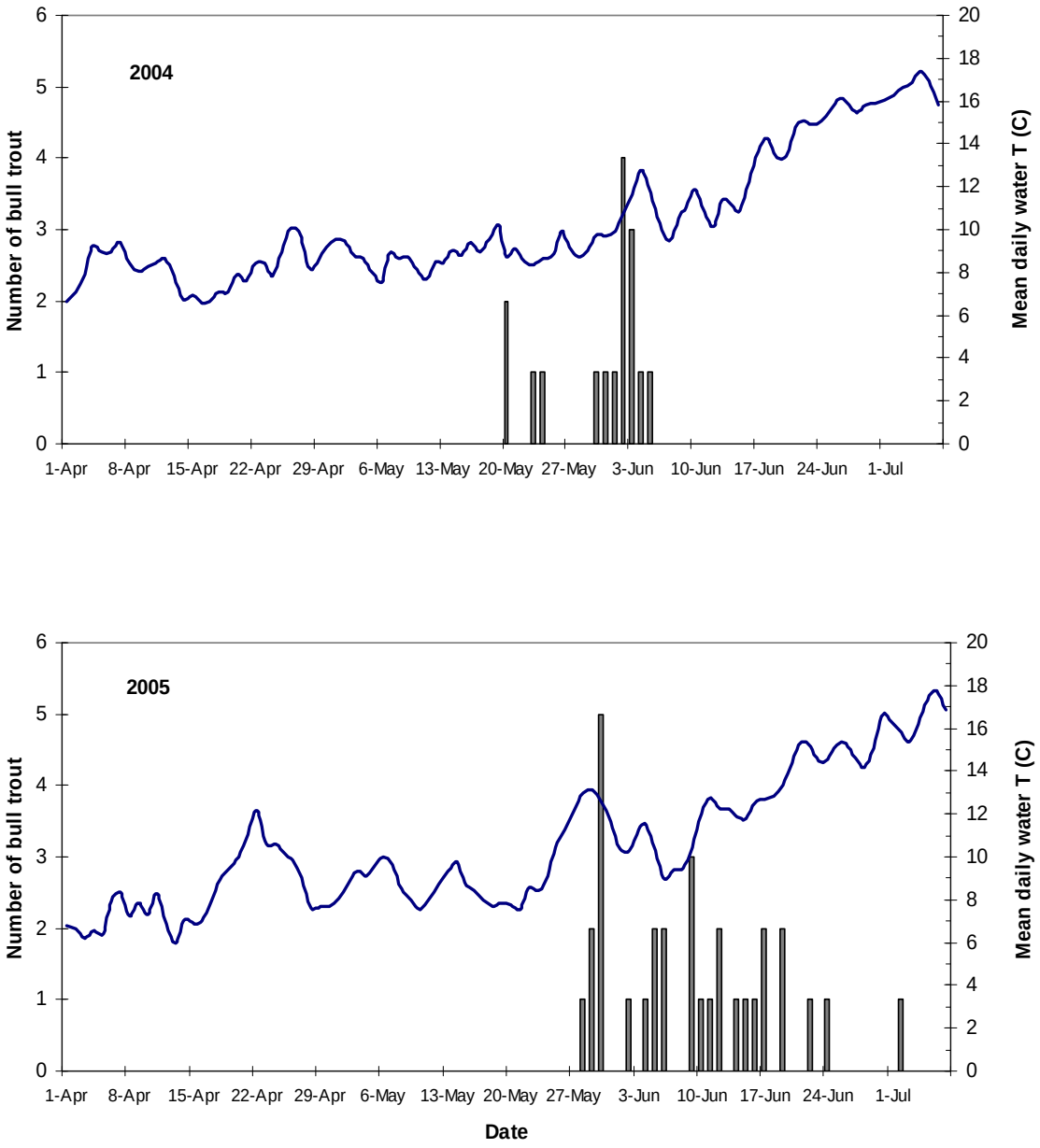

Figure 17. Mean daily water temperatures (USFS temperature logger at rkm 2.5) and dates when radio-tagged bull trout migrated upstream past the ER fixed station (rkm 5.1), 2004 - 2005.

EF fixed station (rkm 10.9)- During the upstream migration period in 2005, a portable receiver station was temporarily operated on the lower Entiat River at the Entiat National Fish Hatchery (rkm 10.9). Tagged bull trout passed the hatchery from June 1 to July 5. Thus in 2005, tagged bull trout were present in the Entiat River downstream of the hatchery from May 19 to July 5. During 2004, tagged bull trout were detected downstream of the hatchery from May 20 to June 22.

MD fixed station (rkm 16.7)- Bull trout arrived at the confluence of the Mad River (rkm 16.7) between June 1 and July 11 (Tables 6 – 7, Figure 18). The median arrival dates in 2004 were similar for Mad River and upper Entiat River bull trout: June 9 and 10, respectively. In 2005, the median arrival date for Mad River bull trout was 6 days later than for the upper Entiat River bull trout: June 18 and June 12, respectively.

In all years, tagged bull trout returning to the Mad River directly entered the Mad River and never continued up the Entiat River past the confluence, while tagged bull trout returning to the upper Entiat River never entered the Mad River.

Upstream migrations in the upper Entiat River

SH fixed station (rkm 26.0)-This fixed telemetry station, located at the downstream end of the still water section of the Entiat River, was operated in 2004 and 2005. Bull trout began to migrate past the station the first week of June (Table 6). In 2004, tagged bull trout passed from June 3 to 22, while in 2005, the passage was from June 5 to July 10. Stream discharge during migration in this reach of the river was higher in 2004 than in 2005 (Figure 19).

DB fixed station (rkm 46.7)- In 2004, mobile tracking detected the first tagged bull trout to enter Box Canyon on June 22. In 2005, the DB station was established at the downstream end of Box Canyon (rkm 46.7) in order to quantify the amount of time bull trout spent in Box Canyon before jumping Fish Tail Falls (rkm 47). Tagged bull trout arrived at Box Canyon from June 12 to July 6, 2005 (Table 6). In 2006, the first bull trout arrived on July 5, and the station was then moved to the BC site (rkm 47) so the final arrival date was not recorded. In 2005, tagged bull trout arrived at Box Canyon after stream flow declined from 350 ft^3/s to 200 ft^3/s (Figure 20)

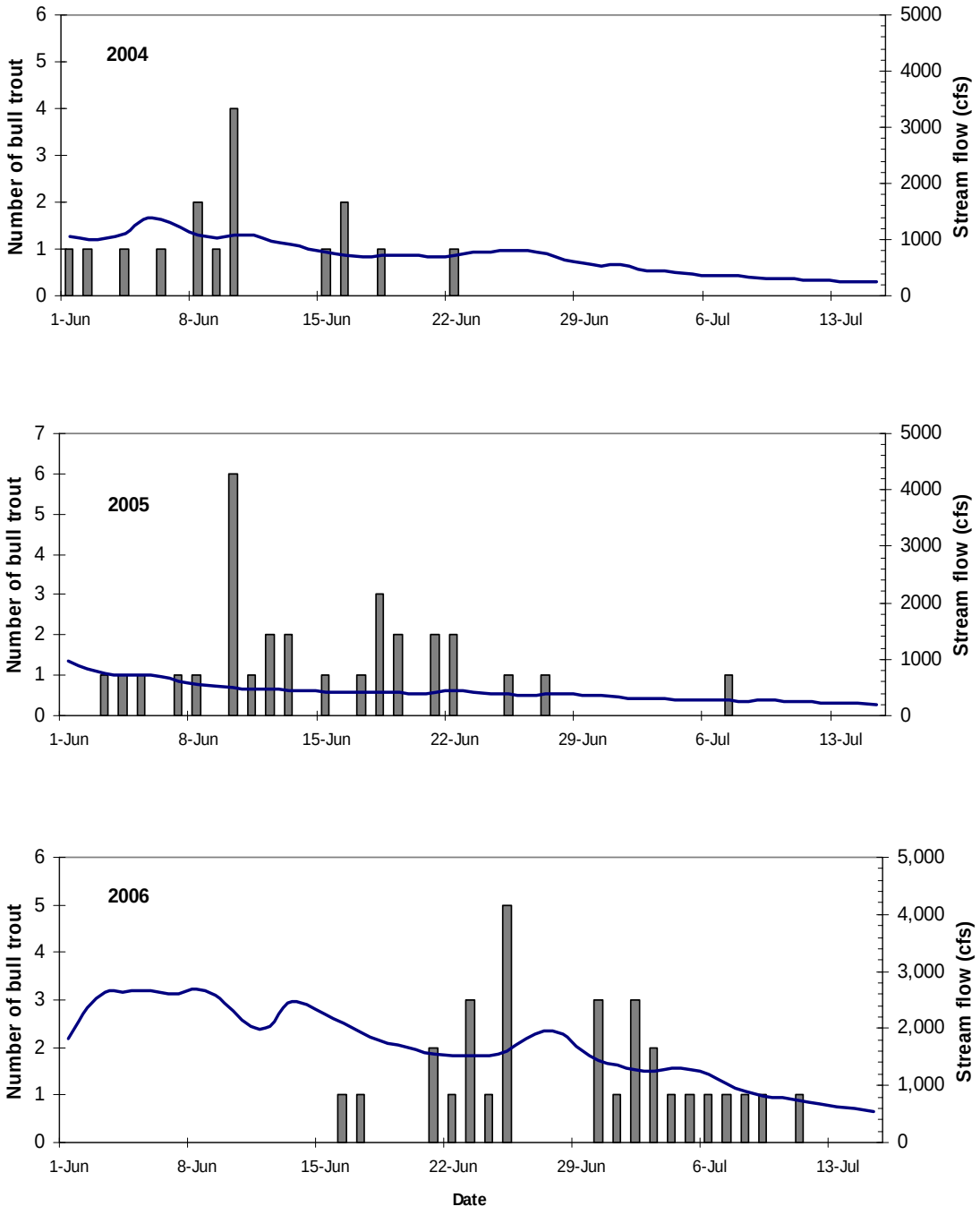

Figure 18. Entiat River discharge (USGS gage near Entiat at rkm 2.5) and dates when all radio-tagged bull trout migrated upstream past the MD fixed station (rkm 16.7), 2004-2006.

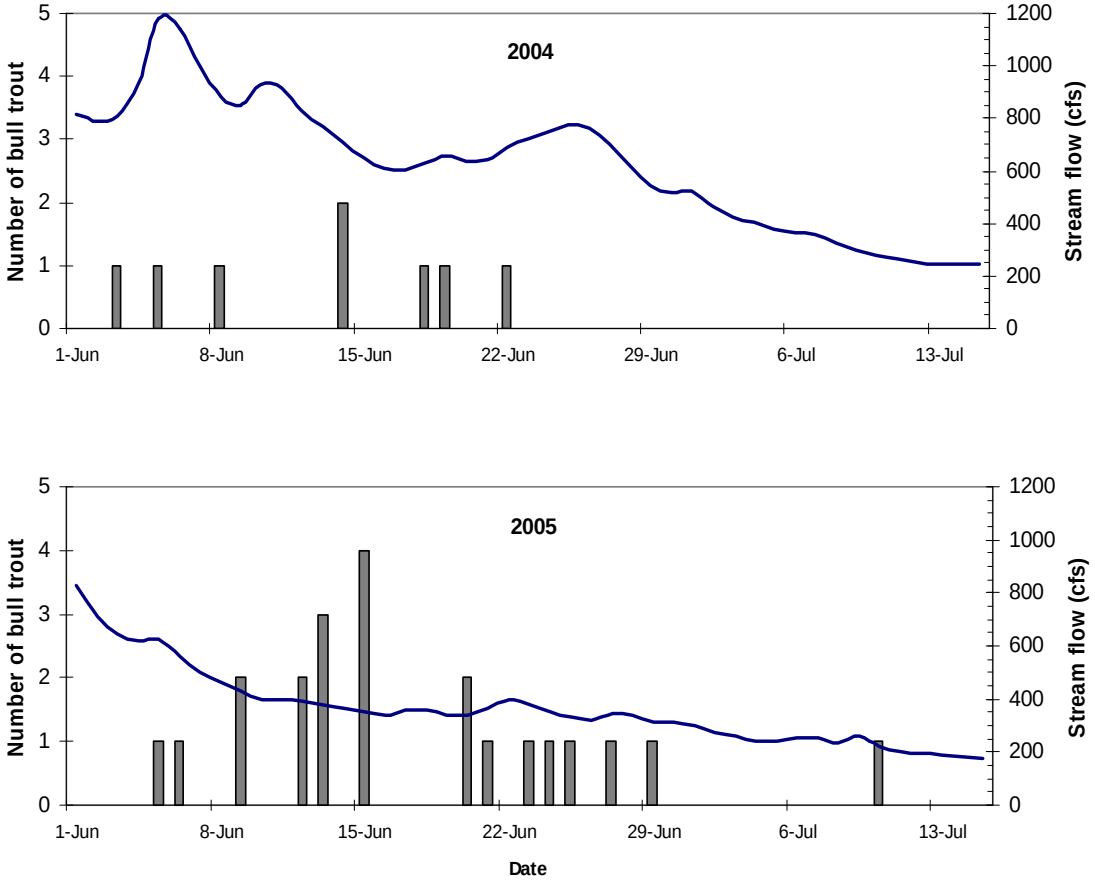

Figure 19. Entiat River discharge (USGS gage near Ardenvoir at rkm 29) and dates when radio-tagged bull trout migrated upstream past the SH fixed station (rkm 26), 2004 - 2005.

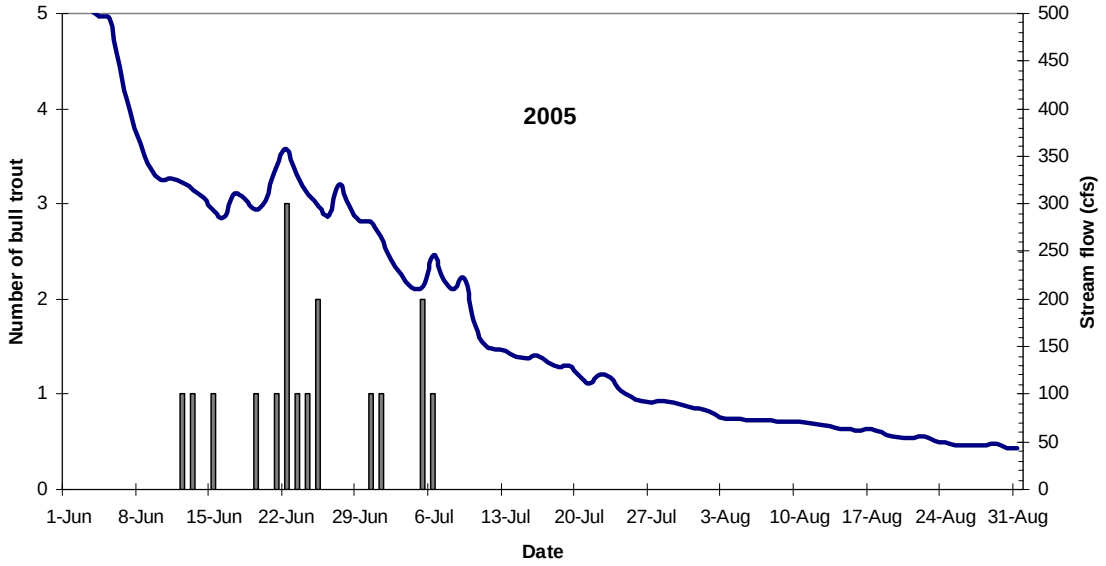

Figure 20. Entiat River discharge (WDOE gage below Entiat Falls at rkm 54.1) and dates when radio-tagged bull trout migrated upstream past the DB fixed station (rkm 46.7), 2005.

BC fixed station (rkm 47.0)-This station was set up upstream of Fish Tail Falls at the upper end of Box Canyon in order to determine the migration passage windows through these obstacles (Figures 21 - 23). Tagged bull trout migrated past the station from July 14 - August 12, 2004, July 12 - 30, 2005, and August 11- 29, 2006 (Table 6). Thus, tagged bull trout were present in pools in Box Canyon for a minimum of 23 days in 2004, 31 days in 2005, and 38 days in 2006 before the first tagged bull trout passed the falls. In 2005, based on entry and exit times at the DB and BC stations, individual bull trout spent an average of 26.7 days (SD 8.1, range 12 – 44) in Box Canyon before passing Fish Tail Falls. Most bull trout were observed congregating in the 2nd pool downstream of Fish Tail Falls (the "Slot" pool- Figure 22) and were visible from the public viewing platform above on the canyon wall (Figure 23).

During all years, tagged bull trout were unable to pass through Box Canyon and jump Fish Tail Falls until stream flows declined to < 200 ft^3/s, as measured at the Entiat Falls gage station at rkm 54.1 (Figure 24). During 2003 – 2005, an average of 67 % of the tagged bull trout passed Box Canyon and completed their migration to the spawning grounds (Table 8). In 2006, only 24 % of the tagged bull trout passed, apparently due to sustained higher flows but also to a blockage caused by logs and debris lodged in the fish passage slot between the Fish Tail Falls pool and the "Slot" pool (Figures 25 - 26). In 2006, tagged bull trout were present in Box Canyon from July 5 to October 3, a period of 90 days, before migrating downstream.

Figure 21. Bull trout jumping Fish Tail Falls (rkm 47), when flow was 85 ft^3/sec on August 15, 2003.

Figure 22. Fish Tail Falls pool (upper) and Slot Pool (lower) in Box Canyon on the Entiat River, as seen from the public viewing platform, August 5, 2005.

Figure 23. View (looking downstream) from the Slot Pool in Box Canyon on the Entiat River, showing logs and boulders in stream bed. Note public viewing platform on upper left canyon wall.

Table 8. Percentage of radio-tagged bull trout that passed Box Canyon and Fish Tail Falls in the upper Entiat River, 2003 - 2006.

year	total tagged bull trout in Box Canyon	n tagged bull trout that passed to spawning grounds	% tagged bull trout that passed
2003	13	8	61.5%
2004	13	9	69.2%
2005	21	15	71.4%
2006	25	6	24.0%

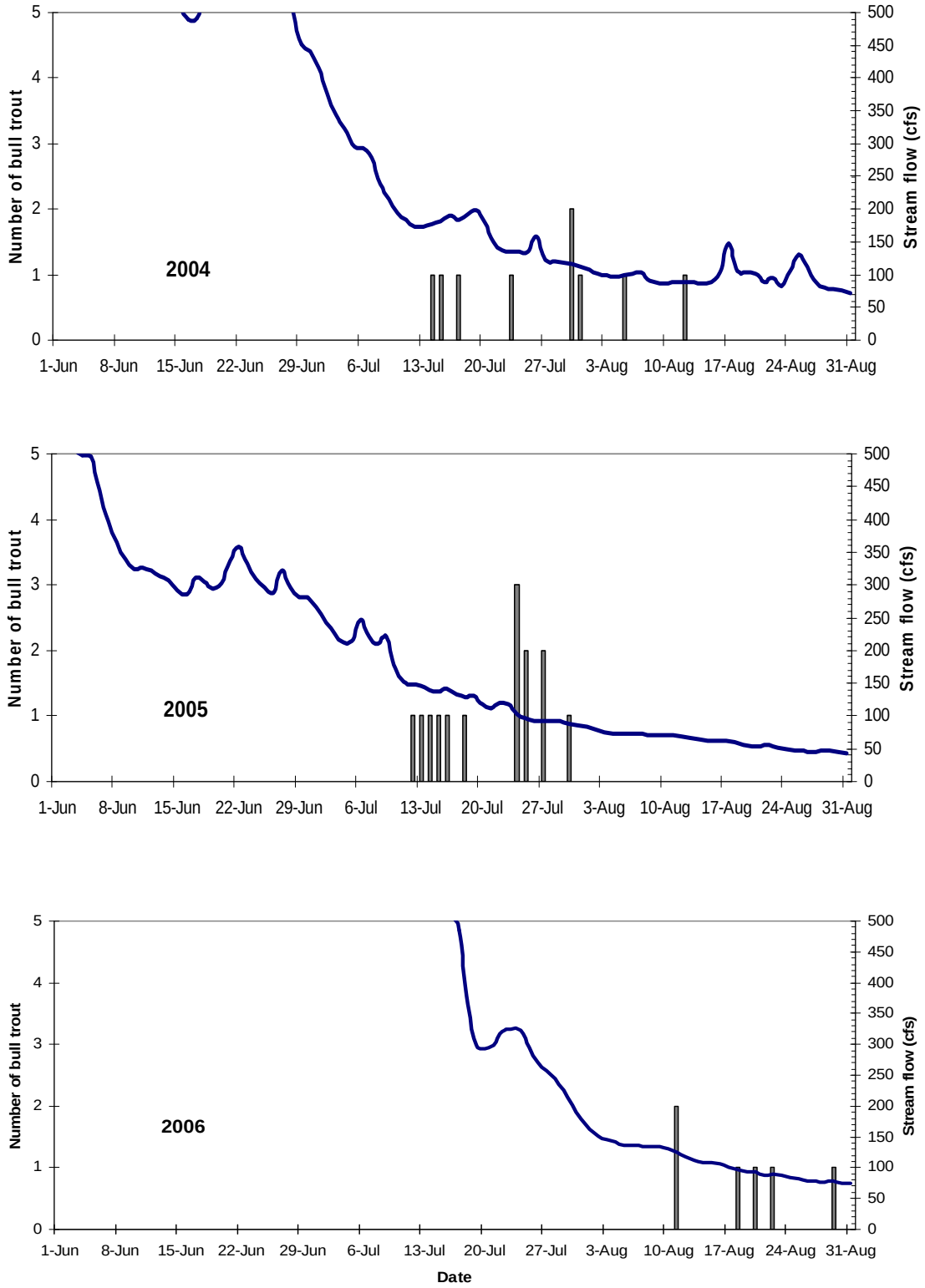

Figure 24. Entiat River discharge (WDOE gage below Entiat Falls at rkm 54.1) and dates when radio-tagged bull trout migrated upstream past the BC fixed station (rkm 47), 2004 - 2006.

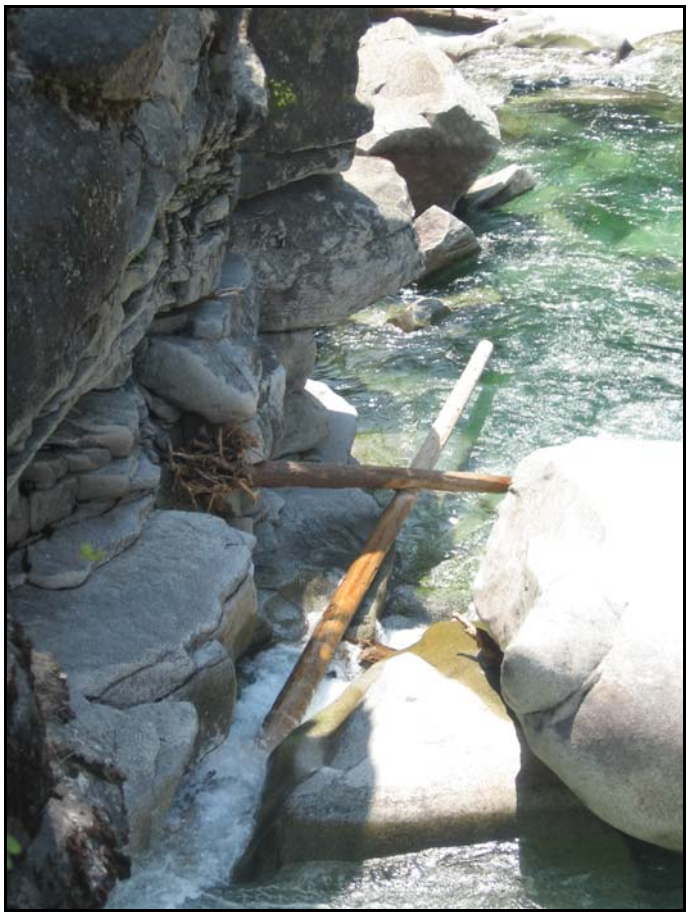

Figure 25. Log in fish passage slot between the Slot Pool (top right of photo) and Fish Tail Pool in Box Canyon (picture taken from above and view is looking downstream, river left).

Figure 26. View of log and debris in fish passage slot at low water.

In 2005, for fish tagged in that year, the mean length of bull trout that did pass the Box Canyon obstacles was significantly greater than for those that did not (Table 9). In contrast, for bull trout tagged in 2006, there was no significant difference in the length of fish that passed the obstacles in 2006 versus those that did not pass (Table 9).

Table 9. Mean lengths of radio-tagged bull trout that passed or did not pass Box Canyon and Fish Tail Falls, 2005 - 2006.

	Passed obstacles:		Did not pass obstacles:		
Year	Length (mean ± 1SD)	n	Length (mean ± 1SD)	n	t-test p-value
2005	576.9 ± 63.9	13	499.2 ± 49.4	6	0.018
2006	608.7 ± 66.0	4	624.5 ± 65.4	12	0.687

Note: Lengths are known only for bull trout tagged in that year

Upstream terminus of migration in the upper Entiat River (rkm 54.5)- Tagged bull trout were tracked to the pool at Entiat Falls at rkm 54.5 of the Entiat River. During August each year of the study, adult fluvial bull trout were observed repeatedly jumping at the base of the falls, but no bull trout were tracked upstream of this barrier (Figure 27).

Figure 27. Entiat Falls (rkm 54.5), the upstream terminus of migration in the Entiat River.

Upstream migrations in the Mad River

As the study progressed, fewer tagged bull trout entered the Mad River than the upper Entiat River. The percentage declined from 50% in 2004, to 27% in 2005, and by 2006 only 10% of bull trout tagged in the Columbia River migrated into the Mad River (Figure 15). Bull trout entered the Mad River June 6 – 22, 2004, June 7 – 22, 2005, and July 1 - 9, 2006 (Table 7). Stream discharge at the mouth of the Mad River varied during the migration period each year, and bull trout entered the river as flows declined to < 250 ft^3/s (Figure 28).

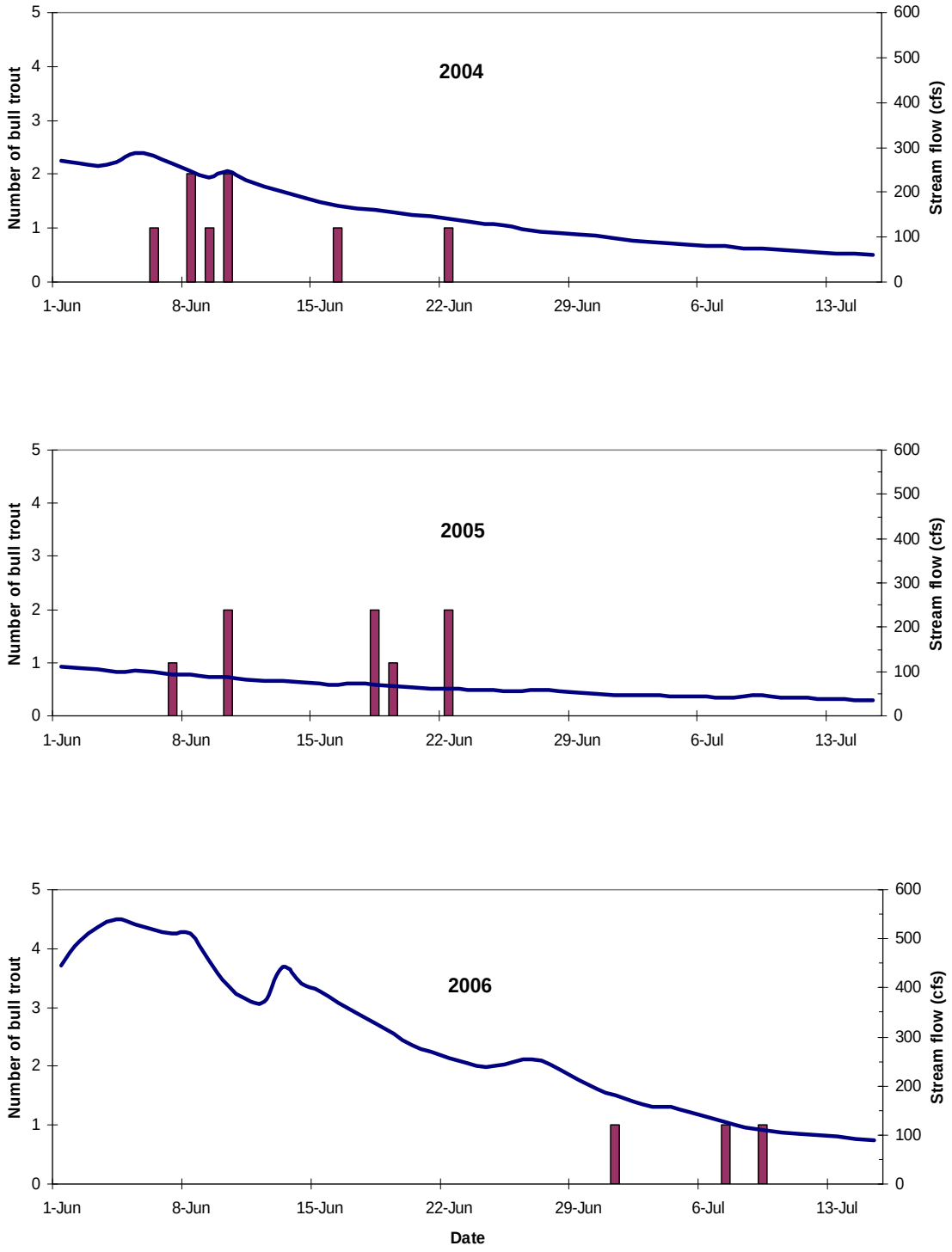

Figure 28. Mad River discharge (USGS gage Mad River at Ardenvoir) and dates when radio-tagged bull trout migrated into the Mad River, 2004 - 2006.

Cascade at Pine Flats Campground (Mad rkm 6.6)- A cascade near Pine Flats Campground (rkm 6.6) was observed to be an obstacle to migration. Six tagged bull trout were tracked to the area on June 14, 2004 and were observed congregating and jumping at the cascades until discharge velocity dropped and the fish could pass.

CN fixed station (Mad rkm 15.9)- Tagged bull trout migrated upstream past Camp Nine from June 26 – July 25, 2004 and June 30 – August 8, 2005 (Table 7). Mad River discharge declined to base flows in both years during these periods of migration (Figure 29). A large log jam at Camp Nine (Figure 30) delayed upstream migration of tagged bull trout for 1 – 40 days, and each year, 1 tagged bull trout did not pass and spent the summer and fall downstream of the obstacle. In 2004, bull trout code 72 remained downstream of the jam and an Onset® automated temperature data logger was deployed in the stream within 20 m of its location. Maximum water temperature was 20 °C, maximum delta daily T was -7.5 (Figure 31), and the MWMT was 17.8. The bull trout appeared healthy when observed during August and September, and it successfully migrated downstream into the Columbia River.

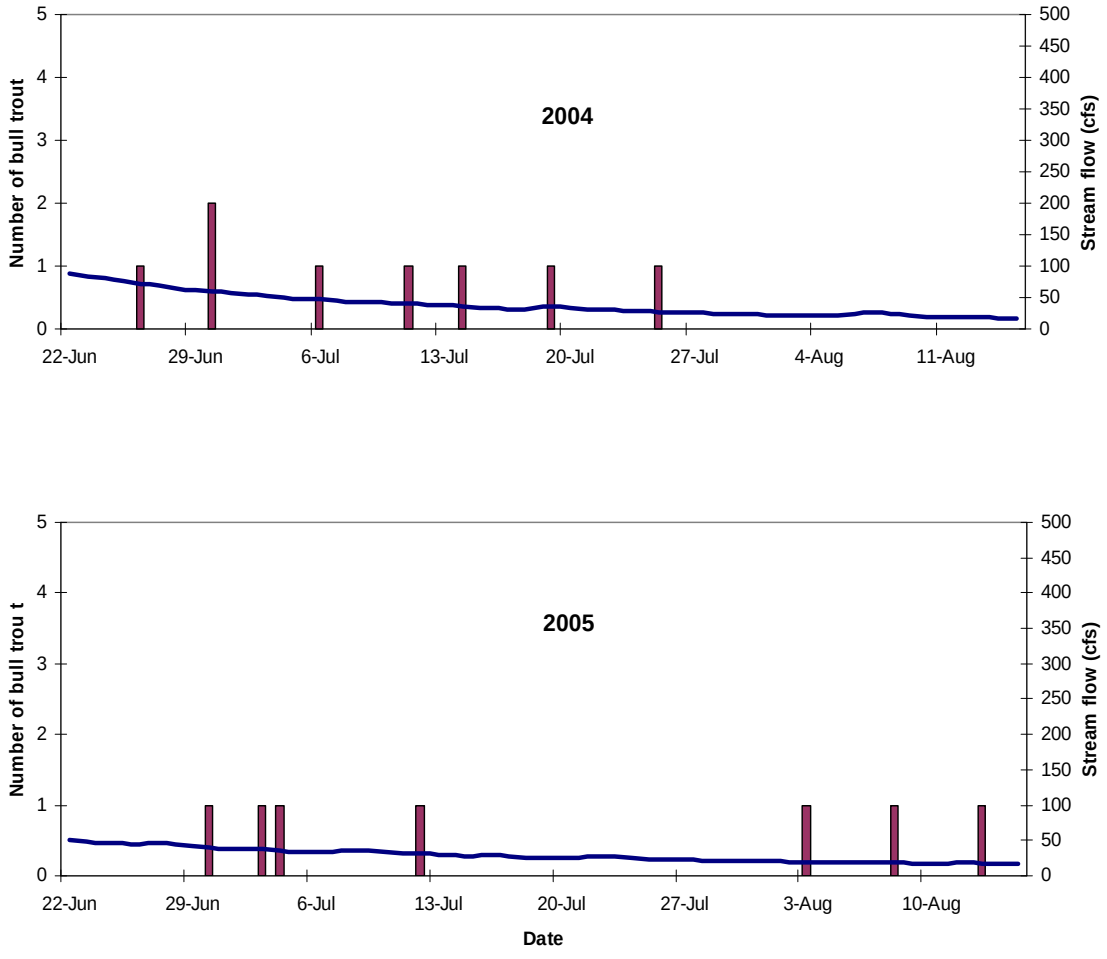

Figure 29. Mad River dischare (WDOE gage above Camp Nine) and dates when radio-tagged bull trout migrated upstream past the CN fixed station (rkm 15.9).

Figure 30. Log and debris jam at Camp Nine (rkm 15.9) on the Mad River, August 18, 2004.

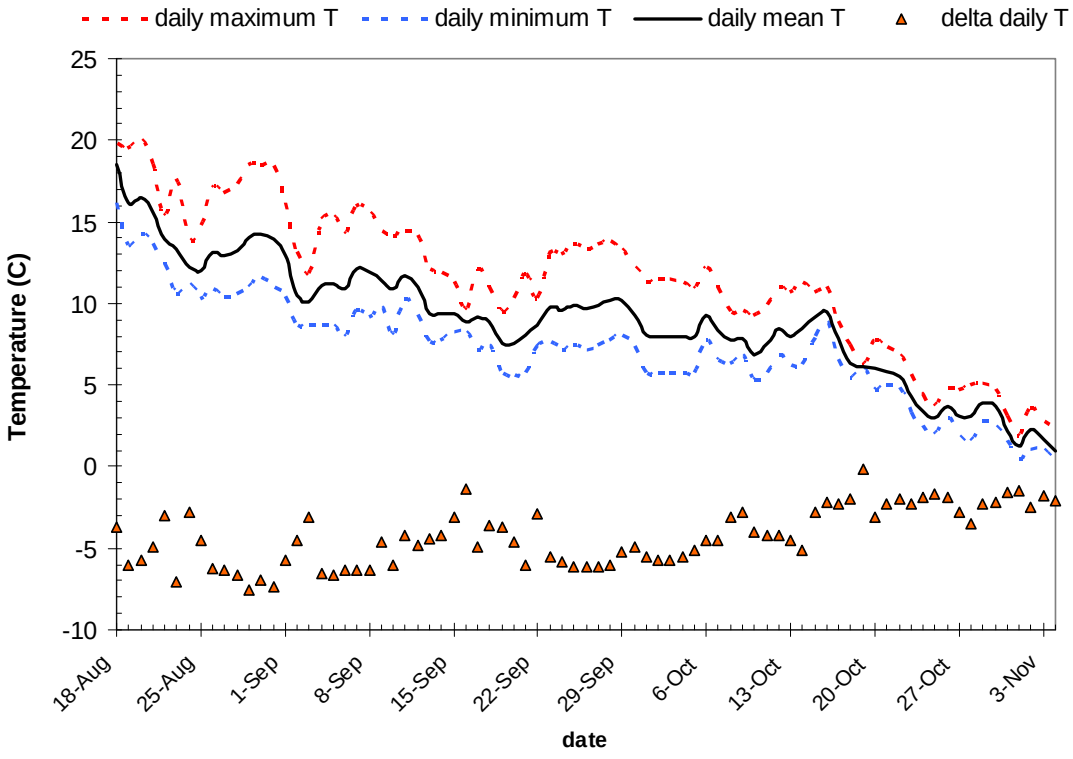

Figure 31. Temperature profile (daily max, min, mean and delta T) of Mad River in the immediate vicinity of bull trout code 72 downstream of the debris jam at Camp Nine (rkm 15.9), August 18 - November 5, 2004.

LB fixed station (Mad rkm 22.4)- Tagged bull trout migrated upstream past this station from July 17 – 31, 2004 and July 9 – 12, 2005 (Table 7). In 2004, 4 of 8 (50%) of the tagged bull trout that migrated upstream of Camp Nine migrated past the LB site. In 2005, only 2 of 7 (28%) reached this area.

Debris jam barrier downstream of Alma Creek (Mad rkm 22.8)- A log and debris jam on a small falls at a nick point downstream of Alma Creek (Figure 32) was a barrier to all tagged bull trout in 2003, 2004, and 2005. In 2006, conditions in the debris jam changed, and 2 of 3 tagged bull trout in the Mad River were tracked upstream of the former barrier.

Figure 32. Photograph of the Alma Creek debris jam in the Mad River (rkm 22.8), August 5, 2004.

Upstream migration speed- The upstream migration speed of tagged bull trout varied during the study. In 2004 and 2006, the average migration speed of all tagged bull trout traveling the 11. 6 km between the ER and MD stations was slower than in 2005 (Table 10). In general, tagged bull trout migrated faster at lower stream discharges as they moved upstream in the lower river (Figure 33).

Table 10. Upstream migration speed (km/day) of all tagged bull trout moving between the ER and MD stations in the lower Entiat River, 2004 - 2006.

Year	n bull trout	mean speed (km/day)
2004	16	1.28
2005	28	2.29
2006	28	1.46

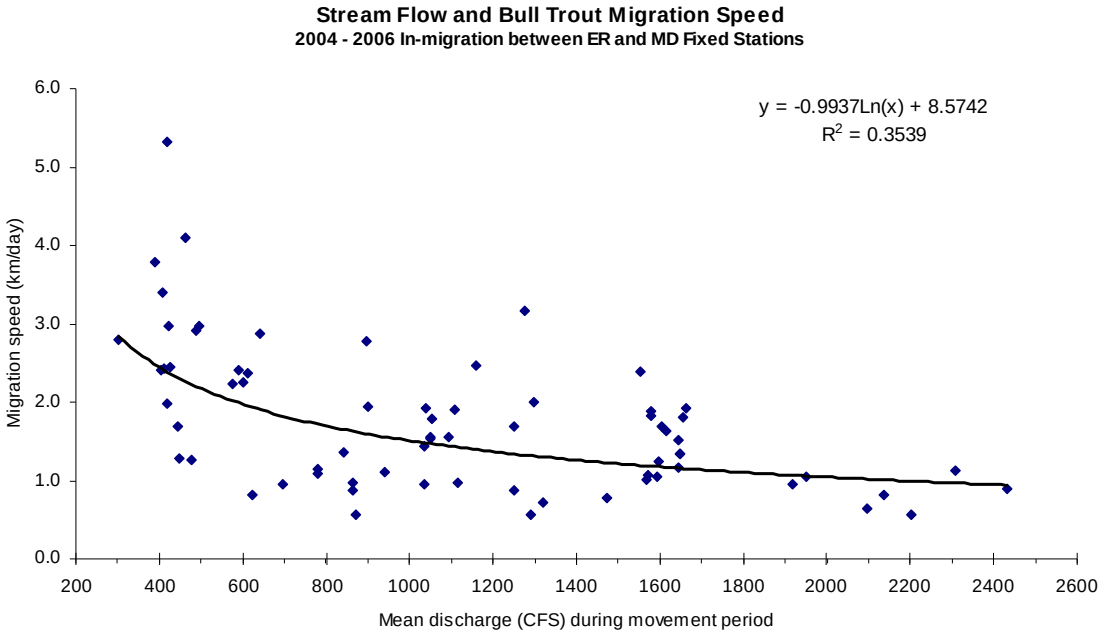

Figure 33. Relationship of mean Entiat River discharge (calculated as the mean of the discharges at USGS gages near Entiat and Ardenvoir during individual bull trout movement periods between telemetry stations) and bull trout migration speed between the ER and MD fixed stations, 2004 - 2006.

During upstream migration, there was no significant difference in migration speeds of upper Entiat River and Mad River tagged bull trout between the ER and MD fixed stations in the lower Entiat River (Tables 11 - 12). However, migration speeds were different between fixed stations after tagged bull trout entered the Mad River or continued to the upper Entiat River. In 2004 and 2005, Mad River tagged bull trout migrated significantly slower in river segments between stations in the Mad River than Entiat River tagged bull trout migrated between stations in the middle and upper Entiat River (Tables 11 - 12). In 2004, the total migration speed to the spawning grounds was significantly faster in the upper Entiat River (MD to BC stations) than in the Mad River (MD to LB stations), but in 2005, there was no difference in total migration speed (Tables 11 - 12) The fastest upstream migration speeds were recorded by upper Entiat River bull trout moving between the MD and SH stations during both 2004 and 2005 (Figure 34).

Table 11. Comparison of upstream migrations speed (km/day) of upper Entiat River vs. Mad River tagged bull trout moving upstream between fixed stations, 2004.

Local population	Segments compared	Distance (km)	n bull trout	Mean speed (km/day)	Range (km/day)	2004 p-value [1]
Entiat	ER-MD	11.6	8	1.37	0.88 – 2.46	
Mad	ER-MD	11.6	8	1.19	0.56 – 1.92	p = 0.5
Entiat	MD-SH	9.3	8	2.65	1.93 – 4.31	
Mad	MD-CN	15.9	7	0.60	0.40 – 0.90	p < 0.001
Entiat	SH-BC	21.0	6	0.53	0.49 – 0.58	
Mad	CN-LB	6.5	3	0.34	0.30 – 0.36	p < 0.001
Entiat	MD-BC	30.3	6	0.69	0.65 – 0.73	
Mad	MD-LB	22.4	3	0.52	0.49 – 0.58	p < 0.001

Note: 1- p value of 2-tailed Student's t test.

Table 12. Comparison of upstream migration speed (km/day) of upper Entiat River vs. Mad River tagged bull trout moving between fixed stations, 2005.

Local population	Segments compared	Distance (km)	n bull trout	Mean speed (km/day)	Range (km/day)	2005 p-value [1]
Entiat	ER-MD	11.6	20	2.48	0.82 – 4.10	
Mad	ER-MD	11.6	8	2.10	1.08 – 5.32	p = 0.39
Entiat	MD-SH	9.3	21	4.34	1.87 – 7.37	
Mad	MD-CN	15.9	7	0.74	0.27 – 1.38	p < 0.001
Entiat	MD-DB	30	19	2.71	1.37 – 5.74	
Mad	MD-CN	15.9	7	0.74	0.27 – 1.38	p < 0.001
Entiat	SH-BC	20.7	14	0.61	0.45 – 1.02	
Mad	CN-LB [2]	6.5	2	0.71	0.71 – 0.71	p = 0.39
Entiat	SH-DB	20.7	19	2.36	1.12 – 5.38	
Mad	CN-LB [2]	6.5	2	0.71	0.71 – 0.71	p < 0.01
Entiat	MD-BC	30.3	14	0.81	0.61 – 1.33	
Mad	MD-LB [2]	22.4	2	1.08	1.08 – 1.09	p = 0.08

Notes: 1- p value of 2-tailed Student's t test. 2- only 2 of the 7 Mad River bull trout migrated past the LB station.

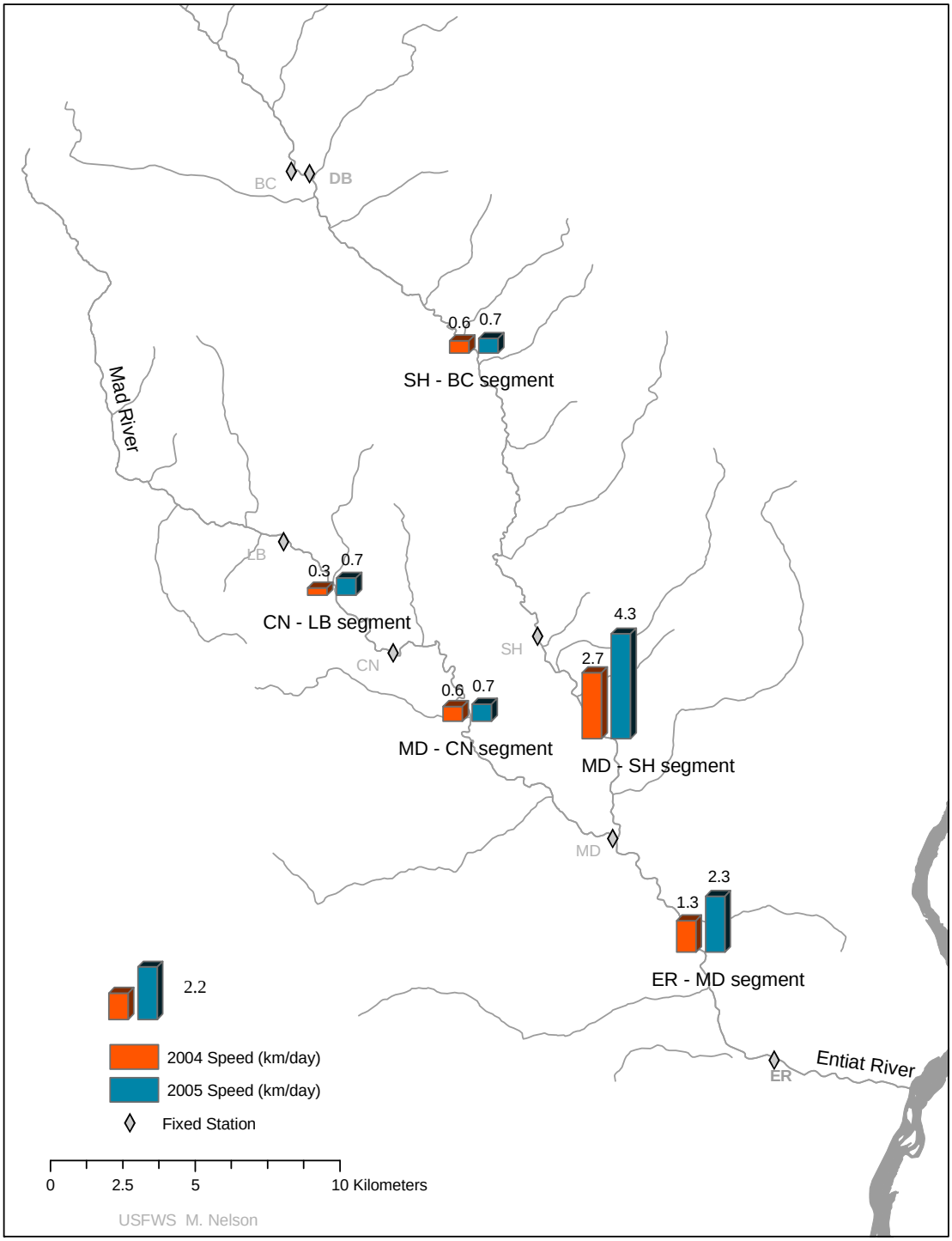

Figure 34. Mean upstream migration speed (km/day) of tagged bull trout in river segments between fixed telemetry stations during in-migration in the Mad River and Entiat River, 2004 - 2005.

Early outmigration
Each year, prior to the spawning season, at least one tagged bull trout migrated out of the Entiat Core Area into the Columbia River. In 2004, after tagging at Box Canyon, code 81 moved downstream, exited the Entiat River on August 30, and migrated downstream of Rocky Reach Dam to rkm 756. It over-wintered at that location, then moved into the Wenatchee River and Peshastin Creek in the spring before it migrated back into the upper Entiat River spawning reach in 2005 (see section below on movements to other core areas).

In 2005, two bull trout migrated into the core area but exited the Entiat River before the spawning season. Code 84 left on June 25 and moved into the Columbia River downstream of the Wenatchee River confluence, where it was detected at rkm 752 during autumn. Code 34 migrated out on July 15, moved upstream in the Columbia River and was detected near the outfall of the Chelan Fish Hatchery (rkm 811) until late October.

In 2006, two tagged bull trout migrated out of the Entiat River before spawning and then moved to the lower 4 km of the Wenatchee River. Code 182 migrated into the Entiat River on July 30, left on August 7, and spent the autumn in the lower Wenatchee River. Code 151 migrated in on June 20 and out on August 25, and was detected in the lower Wenatchee River on September 25, 2006. It migrated back into the Entiat River in 2007.

Spawning
Presence of bull trout on spawning grounds- The percentage of upper Entiat River bull trout that were able to migrate through Box Canyon to the upper spawning grounds ranged between 24 – 71% from 2003 – 2006 (Table 8, Figures 35 – 38). In the Mad River, the percentage of tagged bull trout that migrated into the river and were recorded on the spawning area downstream of the Alma Creek debris jam ranged from 43 – 88 % (Table 13, Figures 36 – 39). In 2006, 2 of 3 radio tagged bull trout were able to pass the debris jam and migrated to the optimal spawning habitat upstream of Cougar Creek.

The movement behaviors of tagged bull trout that did not reach the spawning grounds differed between the local populations. In the upper Entiat River, all the bull trout were recorded at or immediately downstream of Box Canyon during mobile surveys and then moved back downstream. In the Mad River, the tagged bull trout that did not reach the spawning grounds were recorded far downstream during mobile surveys, including several that did not pass log jam obstacles.

Table 13. Percentage of tagged bull trout on the Mad River spawning grounds, 2003 - 2006.

year	n tagged bull trout entered Mad River [1]	n tagged bull trout on spawning grounds	% tagged bull trout on spawning grounds
2003	7	5	71 %
2004	8	6	75 %
2005	7	3	43 %
2006	3	2	66 %

Note: 1- does not include bull trout tagged on the spawning grounds in that year

Tagged bull trout observed on redds- During the study, several tagged bull trout were observed actively spawning in both the Mad and Entiat rivers. No abnormal effects due to tagging were observed.

In 2003, four tagged bull trout were observed on redds and an additional nine tagged bull trout were radio-tracked in the immediate vicinity of established redds. Bull trout code 63 was observed in the Young – Alma index reach of the Mad River on a redd with a digging female on Sept 17, 2003. Two other redds were observed nearby. On September 25, code 63 was again observed attending a digging female on a new redd in the same area and an additional four new redds were in the immediate vicinity. Also on September 25, bull trout code 62 (female) was observed with a small untagged bull trout (estimated 400 mm) and bull trout code 92 was observed with 2 untagged bull trout (estimated 300 and 450 mm) on redds in the tail-outs of small pools at the Dolly Holes in the Young – Alma index reach,. On October 2, 2003, bull trout code 378 was observed with a large male on a redd in the tail-out of a cascade pool in lower Box Canyon, downstream of the Entiat River bull trout spawning index reaches.

In 2004, two tagged bull trout were observed on redds and an additional five bull trout were radio-tracked in the immediate vicinity of established redds. On September 28, bull trout code 71 was observed spawning with an untagged female bull trout in Reach A of the upper Entiat River. On October 6, bull trout code 80 was observed and photographed spawning in the Mad River at the Dolly Holes in the Young Creek – Alma Creek index reach (see cover photo).

In 2005, bull trout code 81 was observed actively digging and fanning on a redd in Reach A in the upper Entiat River on September 29, and 3 other tagged bull trout were observed near redds.

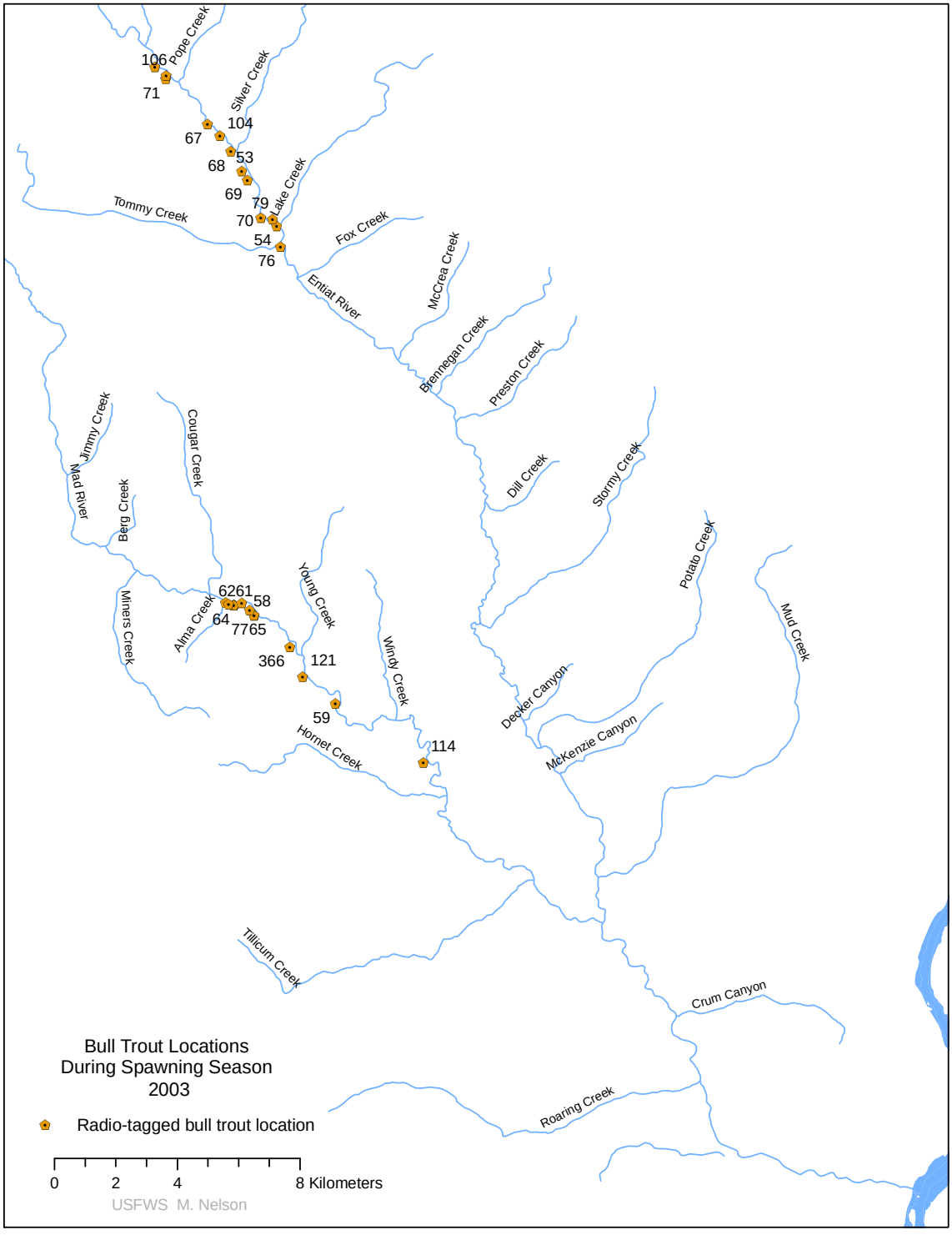

Figure 35. Locations of radio-tagged bull trout during the bull trout spawning season in the Entiat Core Area, 2003.

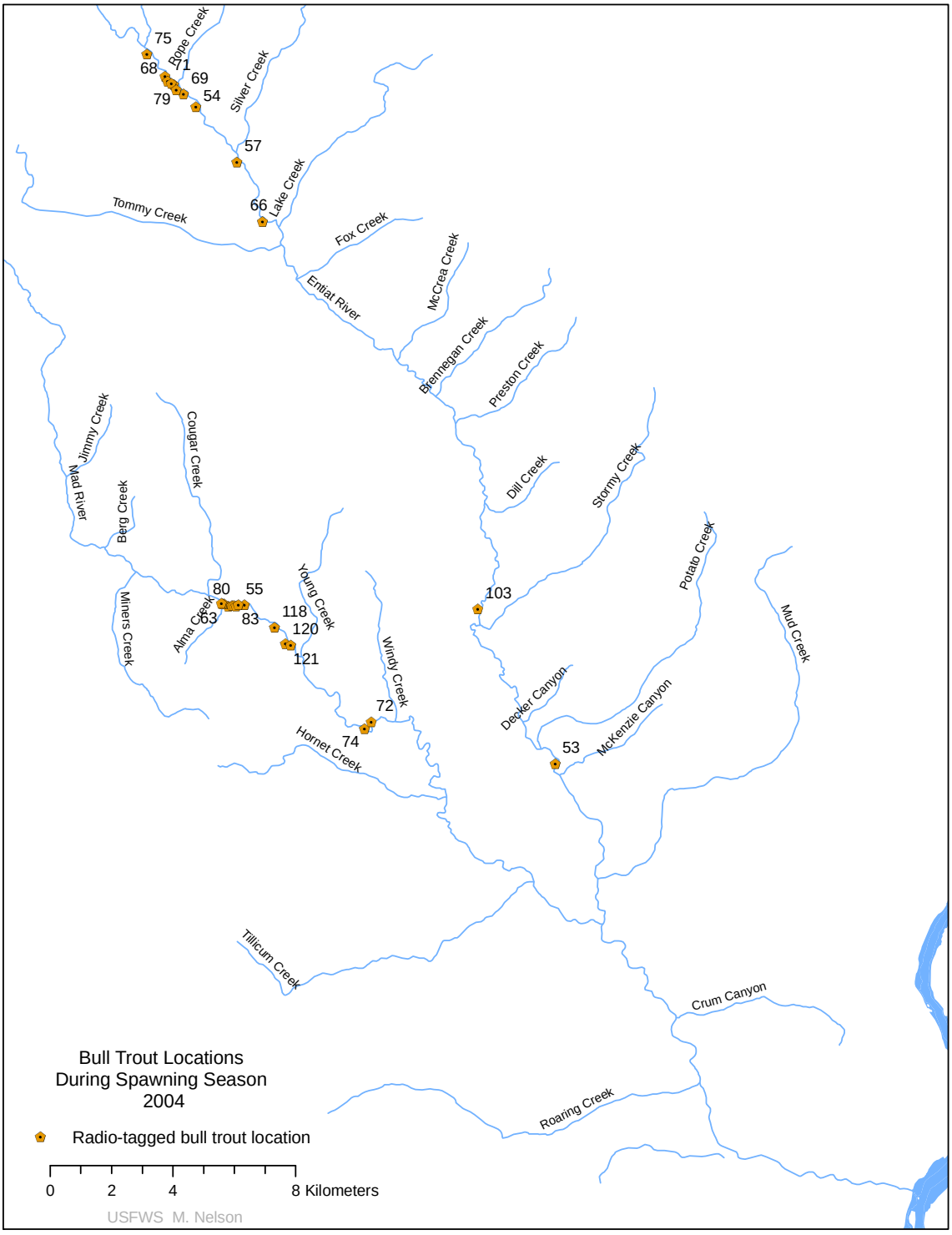

Figure 36. Locations of radio-tagged bull trout during the bull trout spawning season in the Entiat Core Area, 2004.

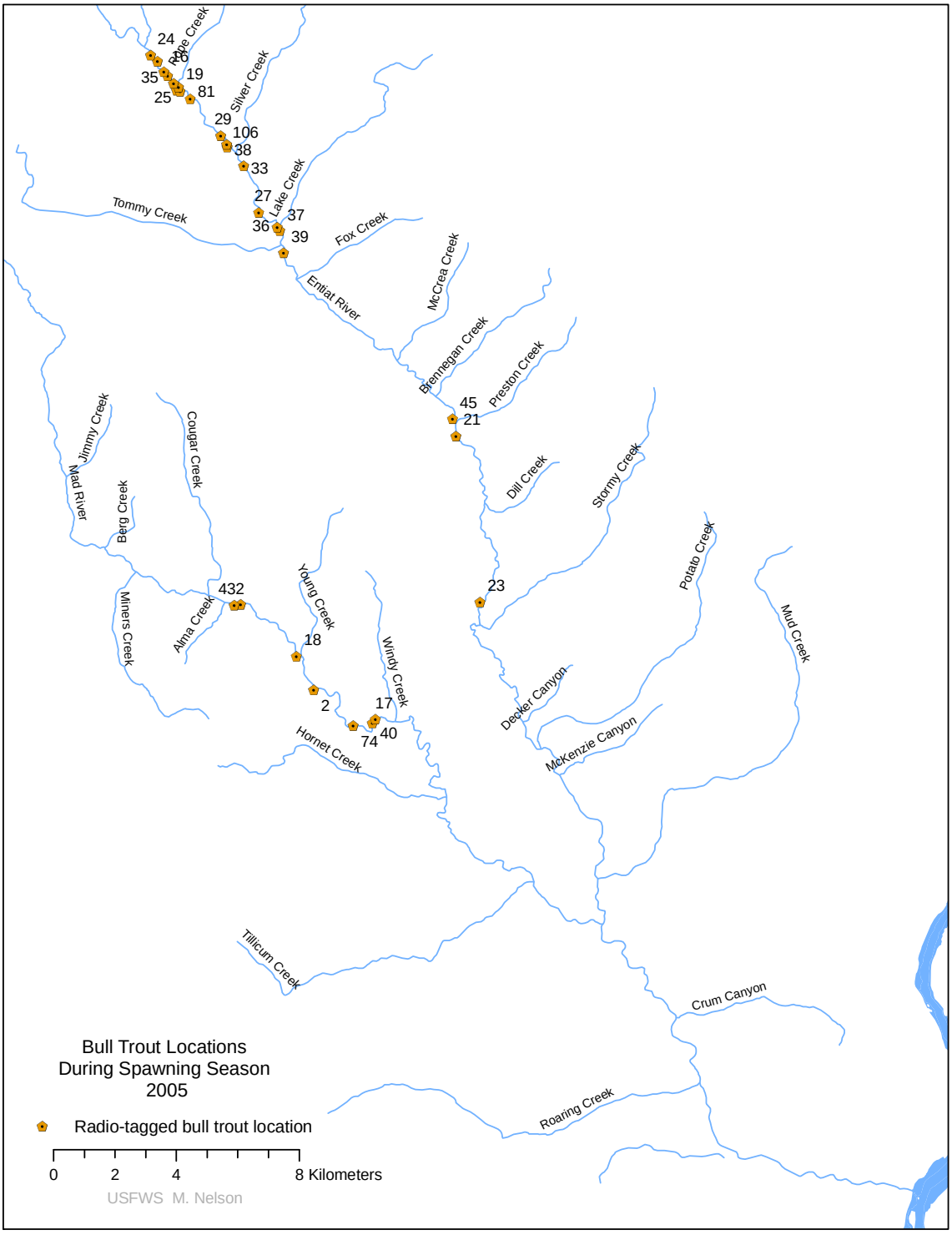

Figure 37. Locations of radio-tagged bull trout during the bull trout spawning season in the Entiat Core Area, 2005.

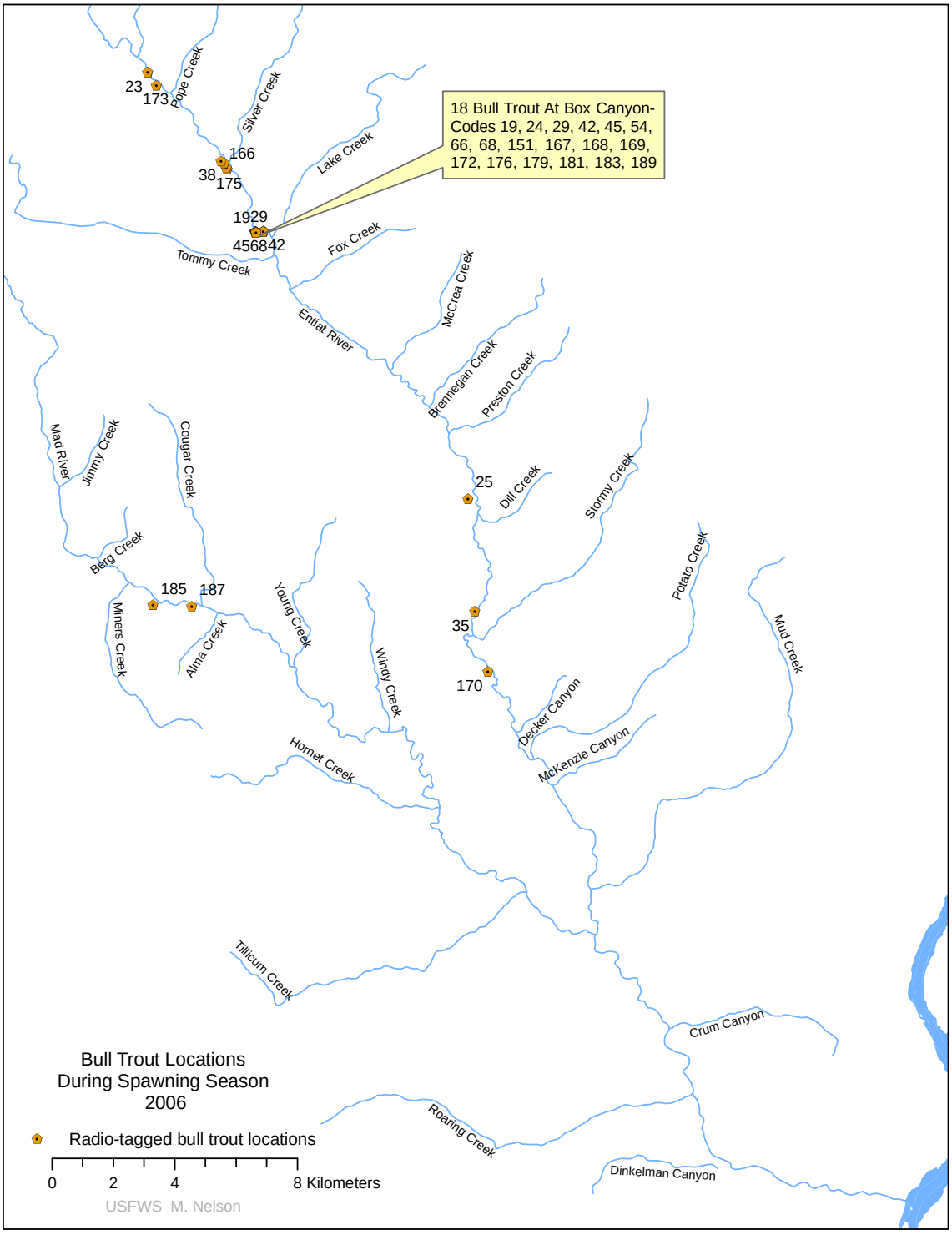

Figure 38. Locations of radio-tagged bull trout during the bull trout spawning season in the Entiat Corea Area, 2006.

Number of redds observed-

Mad River spawning grounds- In the Mad River, bull trout redds counted by USFS during the study ranged from a high of 52 in 2003 to a low of 7 in 2006 (Table 14). In 2006, bull trout were able to pass the Alma Creek debris jam for the first time since 1999, and 86 % of the redds were observed in the Alma Creek to Berg Creek reach, upstream of the former barrier (Table 14).

Table 14. Number of bull trout redds counted by USFS in each spawning index reach in the Mad River, 2003 - 2006.

reach	2003	2004	2005	2006	mean (*SD*)
Young Cr – Alma Cr	52	37	36	1	31.5 (*21.6*)
Alma Cr – Berg Cr	0	0	1	6	1.8 (*2.9*)
Berg Cr – Jimmy Cr	0	0	0	0	0 (*0*)
Totals	52	37	37	7	33.2 (*18.9*)

Note: redd count data from Archibald and Johnson (2006)

Entiat River spawning grounds- From 2004 – 2006, the total number of redds counted each year in the upper Entiat River index reaches ranged from 21 – 50 redds (Table 15). In 2004 and 2005, redds were distributed evenly between Reach A and Reach B (Table 15, Maps A – C in Figure 39). In 2006, when a total of only 21 redds were counted, 57 % were in Reach A, and the vicinity of Pope Creek appeared to be the preferred spawning area that year (Map C in Figure 39). The low total count in 2006 was directly related to the restricted passage of bull trout at Box Canyon when only 6 of 25 tagged bull trout reached the spawning index reaches.

Table 15. Number of bull trout redds counted by USFS and USFWS in spawning index reaches (rkm 47.3 – 54.5) in the upper Entiat River, 2004 - 2006.

reach	2004	2005	2006	mean (*SD*)
Reach A	20	16	12	16.0 (*4.0*)
Reach B	20	18	6	14.7 (*7.6*)
USFS Index	6	16	3	8.3 (*6.8*)
Totals	46	50	21	39.0 (*15.7*)

The USFS index reach (rkm 54.1 – 54.5) between Entiat Falls and the pool at the WDOE gage station may be the most important spawning area. Although this reach contains only 5 % of the total area in the upper spawning reaches, the percentage of bull trout redds in the USFS index reach was 15 % of the total count in 2004, 32 % in 2005, and 14 % in 2006.

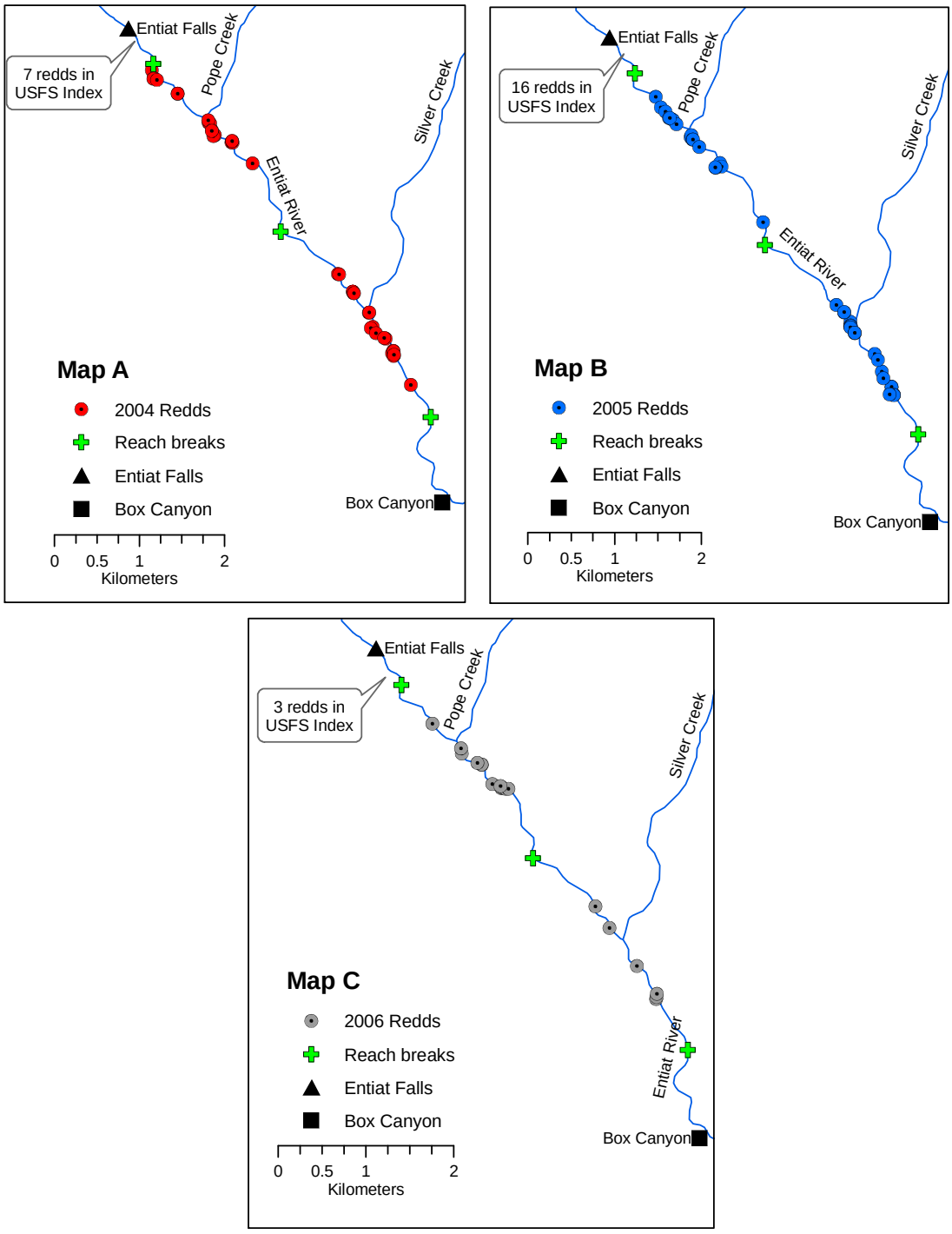

Figure 39. Maps of bull trout redd locations in the upper Entiat River, 2004 - 2006. Map A shows redd locations in 2004, Map B shows redd locations in 2005, and Map C shows redd locations in 2006.

Stream temperatures in spawning and rearing reaches

The running 7DADMax and MWMT were calculated at temperature logger stations in the Entiat and Mad rivers (see Figure 10). All monitored areas in the upper Entiat River exceeded 13 ° C MWMT in all years during 2000 – 2006 (Table 16), usually for more than 30 days (Appendix 4). The coldest water available to migratory bull trout in the Entiat River is at Entiat Falls, and in 2006, MWMT was near optimal (Table 16). In the Mad River, optimal temperatures were recorded most commonly upstream of Cougar Creek (Table 17), an area that was inaccessible to most spawning and rearing migratory bull trout from 1999 - 2005. In general, optimal MWMT was exceeded for only a few days in the areas between Cougar and Berg creeks during 1999 – 2006 (Appendix 5).

Table 16. Maximum weekly maximum temperatures (MWMT) at stream temperature monitoring stations in the upper Entiat River, 2001 - 2006.

Year	@ Stormy Cr (rkm 29) [1]	@ Forest bndry (rkm 41.8) [1]	@ Silver Cr (rkm 51.5) [1]	@ Entiat Falls (rkm 54) [2]
2000	17.4	15.1	13.3	-
2001	20.1	17.9	16.0	-
2002	17.7	15.6	13.9	-
2003	19.6	17.2	14.7	14.1
2004	20.2	18.5	16.4	15.7
2005	21.0	18.7	16.3	16.1
2006	18.2	15.9	14.8	13.5

Notes: 1- USFS data. 2- WDOE data

Table 17. Maximum weekly maximum temperatures (MWMT) at stream temperature monitoring stations in the Mad River, 1999 - 2005.

Year	upstream Windy Cr (rkm 14.2) [1]	@ Camp 9 gage station (rkm 16.9) [2]	upstream Young Cr (rkm 19.8) [1]	upstream Cougar Cr (rkm 24.0) [1]	upstream Berg Cr (rkm 28.5) [1]	upstream Jimmy Cr (rkm 31.9) [1]
1999	16.8	-	13.5	12.1	12	12.7
2000	19.2	-	14.9	-	14.2	15.3
2001	20.0	-	15.6	14.1	14.4	-
2002	15.9	-	14.2	13.1	13.2	14
2003	19.5	18.6	15.4	14.1	14.2	15.4
2004	19.1	19.5	16.5	14.5	15.3	17.1
2005	18.9	19.5	15.8	13.7	13.6	12.2
2006	18.7	17.7	-	14.2	14.5	15.7

Notes: 1- USFS data. 2- WDOE data

Post spawning downstream migrations in the upper Entiat River

BC fixed station (rkm 47.0)- Radio-tagged bull trout migrated downstream from the upper Entiat River spawning grounds and passed the BC station from September 27 – October 26, 2004, from September 13 – October 8, 2005, and from September 25 – October 8, 2006 (Table 18).

DB fixed station (rkm 46.7)- The DB station downstream of Box Canyon was monitored only during 2005. Tagged bull trout passed the station from September 17 – October 8, 2005 (Table 18).

SH fixed station (rkm 26.0)- During out-migration after spawning in 2004 and 2005, bull trout passed the SH station from September 23 – October 19 and September 25 – October 31, respectively (Table 18). Stream flow varied between 75 and 150 ft^3/s during 2004 and from 50 – 90 ft^3/s in 2005 (Figure 40).

MD fixed station (rkm 16.7) - Post-spawning upper Entiat River bull trout migrated downstream past the MD station at the mouth of the Mad River from October 3 – November 8, 2003, September 23 – October 19, 2004, September 25 – November 1, 2005, and September 20 – November 5, 2006 (Table 18). Tagged bull trout generally moved downstream during base flow discharge in most years (Figure 41).

Table 18. Dates that radio tagged upper Entiat River bull trout migrated downstream past fixed receiver stations after spawning in the Entiat River, 2003-2006.

	BC (rkm 47)	DB (rkm 46.7)	SH (rkm 26)	MD (rkm 16.7)	ER (rkm 5.1)
2003	not monitored	not monitored	not monitored	3-Oct to 8-Nov	6-Oct to 23-Nov
2004	27-Sep to 26-Oct	not monitored	23-Sep to 19-Oct	23-Sep to 19-Oct	25-Sep to 21-Nov
2005	13-Sep to 8-Oct	17-Sep to 8-Oct	25-Sep to 31-Oct	25-Sep to 1-Nov	27-Sep to 11-Dec
2006	25-Sept to 8-Oct	not monitored	not monitored	20-Sep to 5-Nov	28-Sep to 20-Oct[1]

Note- 1-Station not recording after 20-October.

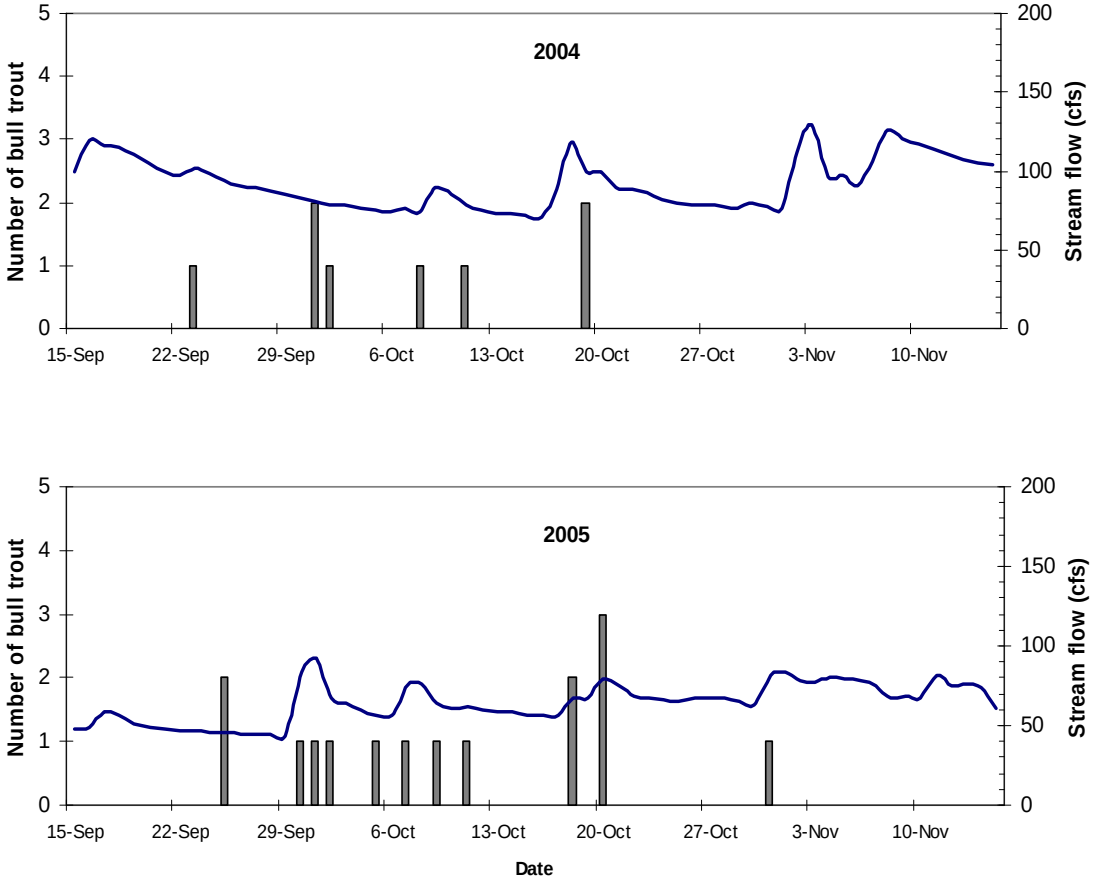

Figure 40. Entiat River discharge (USGS gage near Ardenvoir) and dates when radio-tagged bull trout migrated downstream past the SH fixed station (rkm 26), 2004 - 2005.

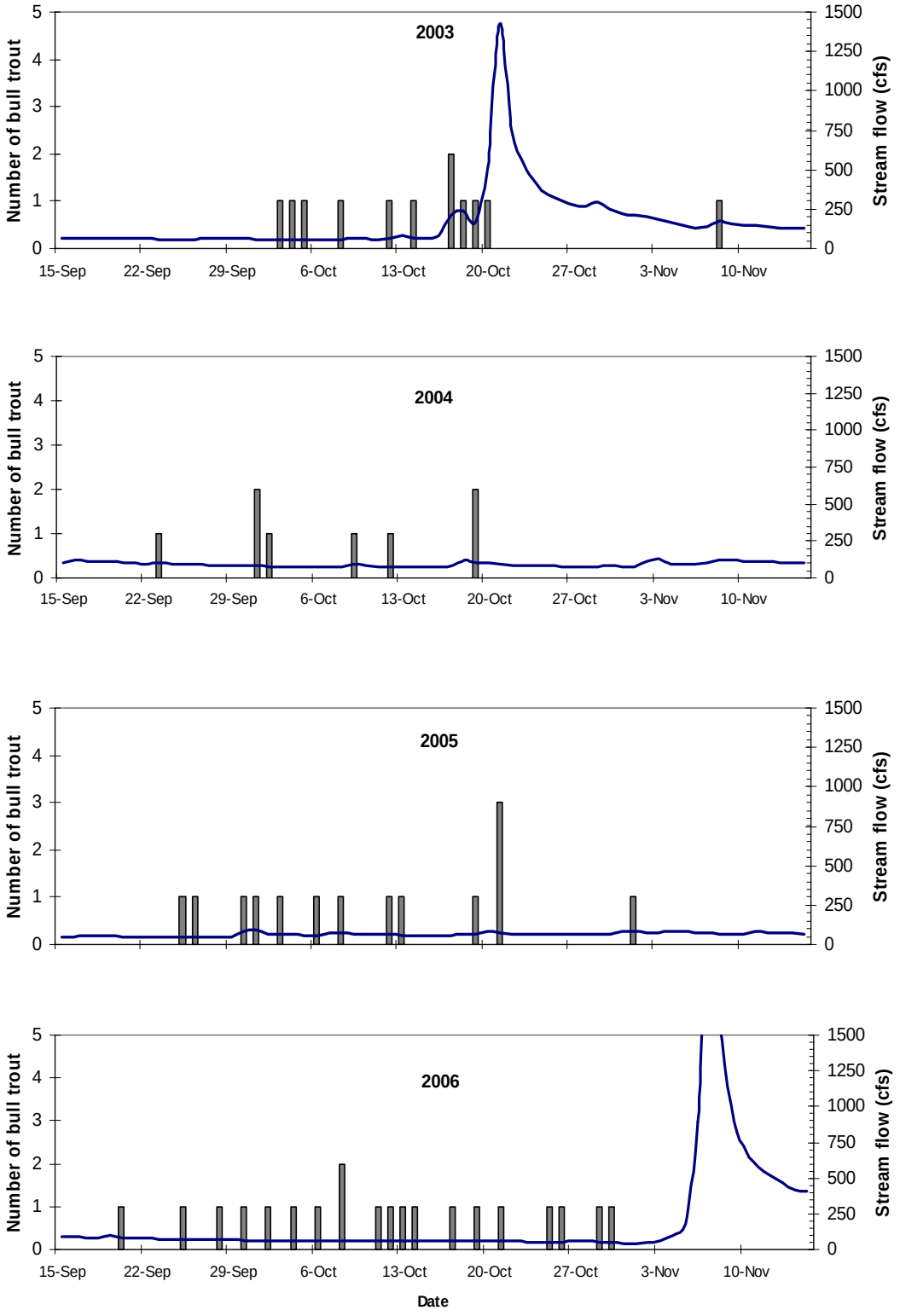

Figure 41. Entiat River discharge (USGS gage near Entiat) and dates that upper Entiat River radio-tagged bull trout migrated downstream past the MD fixed station (rkm 16.7), 2003 - 2006.

Post spawning downstream migrations in the Mad River

LB fixed station (Mad rkm 22.4)- Tagged bull trout migrated downstream past the LB station from September 4 – October 14, 2004 and from September 28 – September 30, 2005 (Table 19). Nine tagged bull trout migrated downstream in 2004 and two in 2005.

CN fixed station (Mad rkm 15.9)- Tagged bull trout migrated downstream past the CN fixed station from September 16 – October 18, 2004 and from September 6 to October 11, 2005 (Table 19).

MD fixed station (Entiat rkm 16.7)- During out-migration from the Mad River, tagged bull trout moved past the MD fixed station from September 27 – November 8, 2003, October 17 – November 3, 2004, and October 27 – November 5, 2006 (Table 19). Flows were near baseline when most bull trout exited the Mad River (Figure 42). The only 2005 tagged bull trout that exited the Mad River was code 40, which migrated past the MD station on May 16, 2006, after over-wintering upstream in the Mad. After entering the Entiat River, most Mad River tagged bull trout moved downstream. However, after code 74 exited the Mad River in 2004, it moved 1.5 km upstream in the Entiat River to the vicinity of Mud Creek, where it spent several days before migrating downstream and exiting the Entiat. It subsequently moved upstream in the Columbia River, and was located near the mouth of the Chelan River during boat surveys in December and February 2005 (see Figure 56).

Table 19. Dates that radio tagged Mad River bull trout migrated downstream past fixed receiver stations after spawning in the Entiat River system, 2003-2006.

Year	LB Station (rkm 22.4)	CN Station (rkm 15.9)	MD Station (rkm 16.7)	ER Station (rkm 5.1)
2003	not monitored	not monitored	27-Sep to 8-Nov	27-Sep to 18-Nov
2004	4-Sep to 14-Oct	16-Sep to 18-Oct	17-Oct to 3-Nov	3-Nov to 22-Nov
2005	28-Sep to 30-Sep	6-Sep to 11-Oct	16-May-06 [1]	16-May-06[1]
2006	not monitored	not monitored	27-Oct to 5-Nov	not recorded [2]

1- Code 40 over-wintered in the Mad River and was the only 2005 bull trout to exit the Mad River. 2- Station not recording after 20-October.

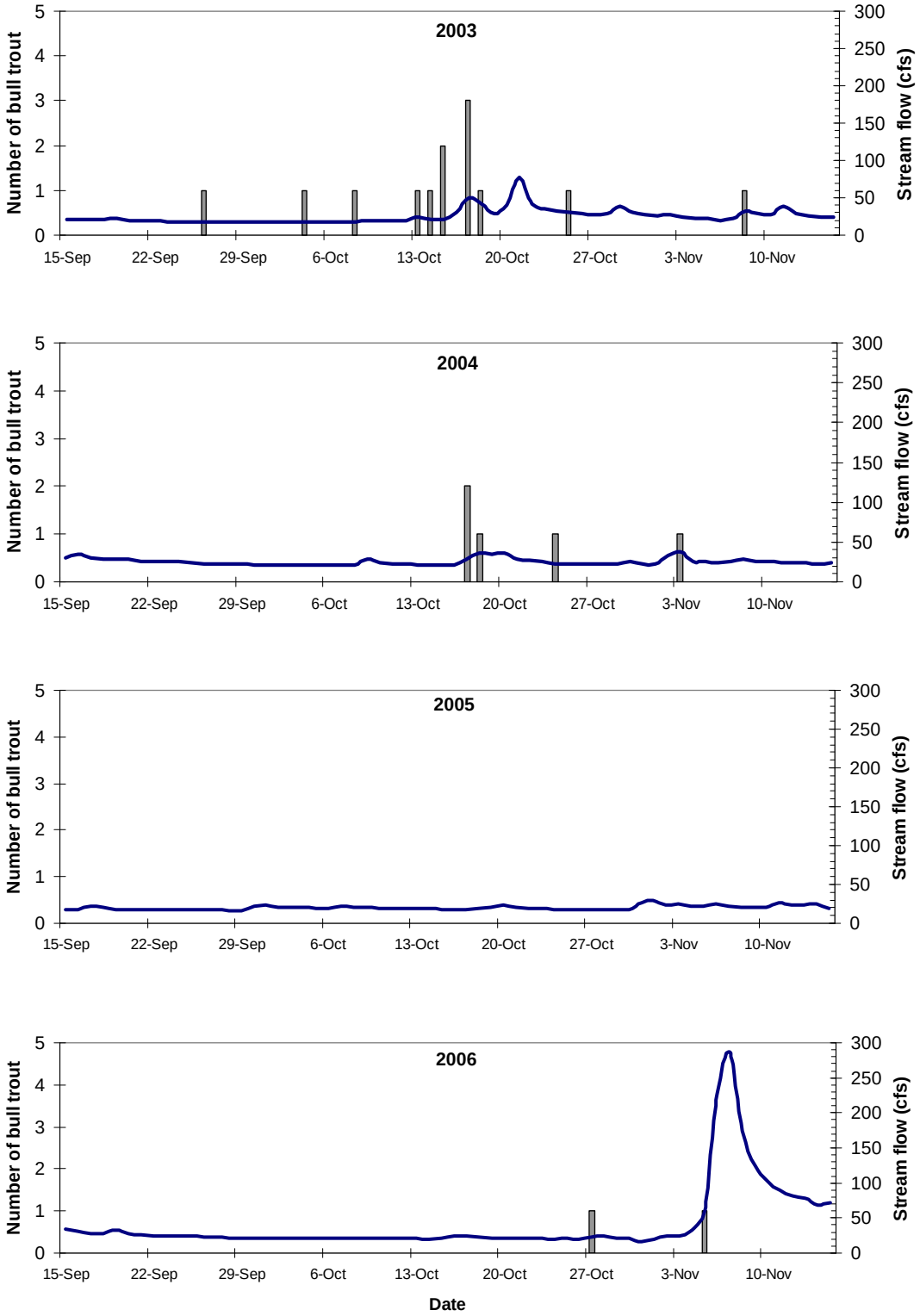

Figure 42. Mad River discharge (USGS gage Mad River at Ardenvoir) and dates when radio-tagged bull trout exited the Mad River and migrated downstream past the MD fixed station (rkm 16.7), 2003 - 2006.

Post spawning downstream migrations in the lower Entiat River

ER fixed station (rkm 5.1)- Radio-tagged bull trout migrated downstream and passed this station during September 27 – November 23, 2003, September 25 – November 22, 2004, September 27 – December 11, 2005, and August 7 – October 20, 2006 (Tables 18 – 19, note that in 2006, the station was not recording after October 20). During most years, stream discharge was < 250 ft^3/s during bull trout movements (Figure 43). In 2003, rainstorms increased the stream flow to 1500 ft^3/s and no bull trout moved downstream during this peak (Figure 43). In 2005, no tagged bull trout exited the Mad River or passed the fixed station in fall.

Movements downstream of ER station to mouth- During 2003 – 2005, based on mobile tracking, tagged bull trout spent variable amounts of time in the Entiat River downstream of the ER fixed station (rkm 5.1) before exiting the river. Some bull trout moved quickly and were not detected during mobile surveys after passing the station, while others spent considerable amounts of time before entering the Columbia River. In 2003, for tagged bull trout detected during mobile tracking, an average of 14.5 days (range 2.4 – 29.4) was spent in the lower river (Table 20), with most of the locations near the mouth as described for the congregating bull trout in the following paragraph. In 2004, an average of 16.2 days (range 0.8 -73.4) was spent by tagged bull trout located during mobile tracking downstream of the ER station (Table 20). In 2005, the average was 9.8 days (range 1.4 – 18.3) before entering the Columbia River (Table 20). Due to the interrupted operation of the ER station in 2006, this analysis was not conducted for 2006, but a similar pattern was evident during mobile tracking.

During the autumn of 2003, several tagged bull trout congregated in the lower Entiat River upstream of the mouth before exiting the river. On several tracking dates between October 15 – November 16, up to 6 bull trout at a time were recorded downstream of summer Chinook redds. The congregation behavior was not observed again during out-migrations from 2004 – 2006.

Table 20. Mean (SD), minimum, and maximum number of days that tagged bull trout were detected during mobile surveys in the lower Entiat River after passing the ER fixed station at rkm 5.1, 2003 - 2005.

Year	n bull trout	Mean (SD) days	Minimum days	Maximum days
2003	13	14.5 (9.6)	2.4	29.4
2004	9	16.2 (22.5)	0.8	73.4
2005	8	9.8 (6.7)	1.4	18.3

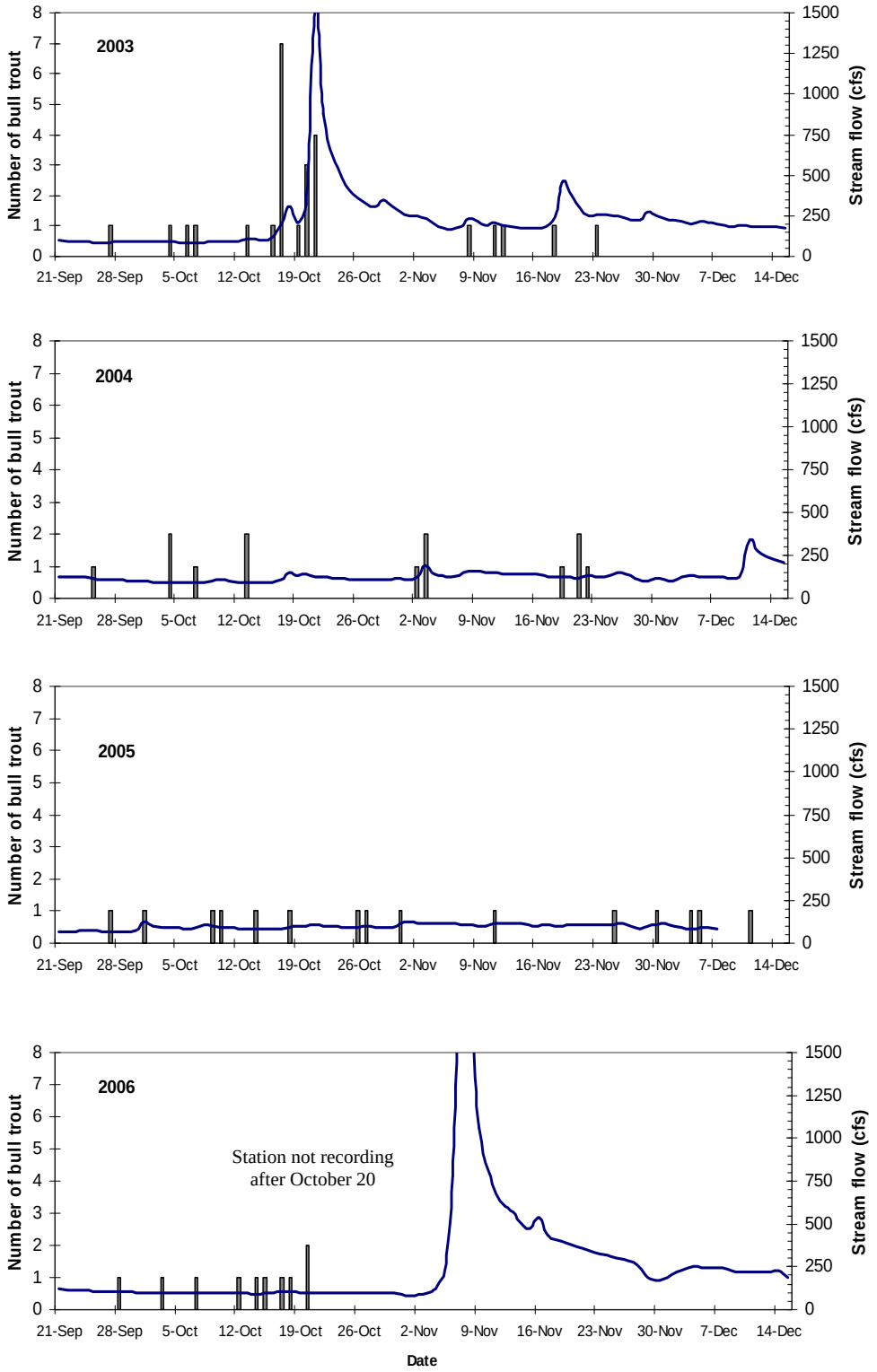

Figure 43. Entiat River discharge (USGS gage near Entiat at rkm 2.5) and dates when all radio-tagged bull trout migrated downstream past the ER fixed station (rkm 5.1), 2003 - 2006.

Downstream migration speed

During the entire downstream migration period in 2004, the speed of upper Entiat River bull trout ranged from 1.1 – 10.3 km/day (mean (SD) = 6.2 (3.1)), and the speed of Mad River bull trout ranged from 0.4 – 0.9 km/day (mean (SD) = 0.6 (0.2)). Upper Entiat River bull trout migrated significantly faster downstream than Mad River bull trout (1 tailed t-test, $p < 0.001$). In 2005, during the entire downstream migration period, the mean speed of upper Entiat River bull trout ranged from 0.5 – 8.5 km/day (mean (SD) = 2.7 (2.5)). No tagged bull trout migrated out of the Mad River in 2005.

The speed of post-spawn bull trout migrating between fixed stations varied according to river segment and individual fish. Similar to in-migration, the fastest mean speeds were recorded by upper Entiat River bull trout traveling downstream between the SH and MD stations (Table 21, Figure 44). The fastest an individual post-spawn bull trout was recorded was 93.2 km/day, moving between the MD and ER stations, but in 2005, prior to the spawning season, code 34 exited the Entiat traveling 125 km/day. In 2004, Mad River bull trout moved much slower downstream past all fixed stations than upper Entiat River bull trout (Table 22). In 2005, none of the Mad River tagged bull trout migrated downstream past fixed stations or exited the river.

Table 21. Downstream migration speed of upper Entiat River tagged bull trout moving between fixed stations in the Entiat River, 2004 - 2005.

year	km/day:	BC to SH	SH to MD	MD to ER
2004	mean (SD)	7.0 (3.1)	32.3 (29.1)	3.9 (2.4)
	range	2.3 – 10.9	2.4 – 79.5	0.4 – 6.5
2005	mean (SD)	5.1 (5.6)	38.9 (24.9)	8.9 (24.5)
	range	0.9 – 19.3	2.3 – 82.3	0.2 – 93.2

Table 22. Downstream migration speeds of Mad River tagged bull trout moving past fixed stations in the Mad and Entiat Rivers, 2004 - 2005.

year	km/day:	LB to CN	CN to MD	MD to ER
2004	mean (SD)	2.1 (2.2)	0.8 (0.4)	0.6 (0.2)
	range	0.2 – 4.7	0.5 – 1.3	0.3 – 0.7
2005 [1]	mean (SD)	--	--	--
	range			

Note: 1- No tagged bull trout migrated past fixed stations or exited the Mad River.

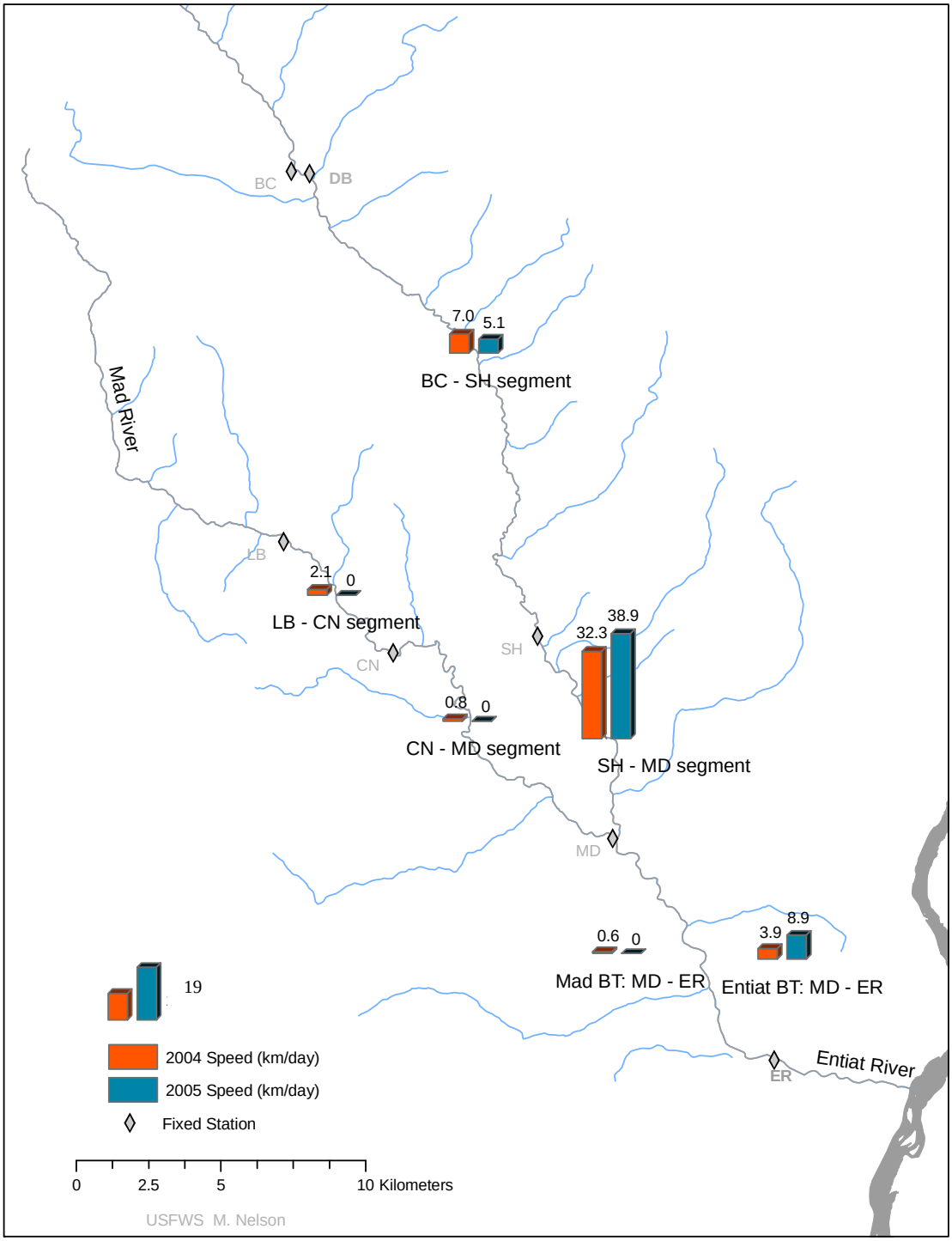

Figure 44. Mean downstream migration speed (km/day) of tagged bull trout in river segments during out-migration between fixed stations in the Mad River and Entiat River, 2004 - 2005.

Barriers and obstacles to out-migration

Log and debris jams- In the Mad River, several debris jams containing large logs, tree branches, twigs and bark, created dam-like barriers (Figures 45 – 46). In late fall of 2005, 30 log jams that completely spanned the channel were counted and mapped (Figure 47). Tagged bull trout stopped movement and were tracked into some of these jams during out-migration each year of the study. Bull trout were also observed holding in the upstream pools created by some jams and appeared to the observers as reluctant to move through the jam. There were no channel-spanning jams in the Entiat River.

In 2003, three tagged bull trout were located in log jams during the downstream migration. Code 125 (tagged by CPUD in 2002) was tracked into the large jam near Camp Nine (rkm 15.9) (Figure 31), where it was monitored until the signal died in late 2004. The tag of bull trout code 357 was recovered from a log jam upstream of Camp Nine (rkm 16.6), and code 65 was located (but not recovered) in a large jam near Switchback Ridge (rkm 11.7). In addition, code 61 was observed holding in a log jam pool near Memorial Flats (rkm 18), where the tag was recovered the following spring.

In 2004, 4 bull trout tagged at the Dolly Holes migrated downstream and were located in debris dams. Code 80 was determined to be within a large jam at Memorial Flats (rkm 18) (Figures 45 and 48) and code 127 was observed with 2 untagged bull trout in the pool created by the jam. Code BT 78 was tracked to a log jam near Camp Nine (the same jam where code 357 was recovered in 2003), and code 82 to a debris jam upstream of Hornet Creek (rkm 10.3) (Figure 46). None of these bull trout subsequently moved from the jams and the large amount of material prevented recovery of the tags, so no physical evidence of mortality was uncovered.

In 2005, physical evidence was discovered that directly linked log jams to entrapment and subsequent mortality of adult bull trout. On October 6, four radio-tagged bull trout (codes 2, 4, 18, 32) were all located in one area of several channel-spanning debris jams at Memorial Flats (rkm 18) (Figures 45 and 49). Bull trout code 18 was tracked in one of the debris jams, where 2 dead untagged bull trout, 1 live untagged bull trout, and the live code 18 were found trapped in the jam (Figure 49). The 2 dead bull trout were located in the dry top of the jam, trapped under a thicket of small branches, and it appeared they died when the water level dropped after rain the previous week. Examination of the dead fish revealed that both were female (FL 492 – 495 mm) and had successfully spawned; no fat deposits were observed around the pyloric cecae and the stomachs were empty. The live bull trout were located near the bottom of the jam in a pocket created by 2 small logs and surrounded by small branches and sticks (the “construction” of the jam was remarkably similar to a weir with the fish being caught in a trap box). They were in moving water, but obviously could not leave the log jam, so both were rescued and released downstream.

Figure 45. Photograph of series of log jams in the Mad River at Memorial Flats (rkm 18) in 2005.

Figure 46. Photograph of log and debris jam located at rkm 10.3 of the Mad River.

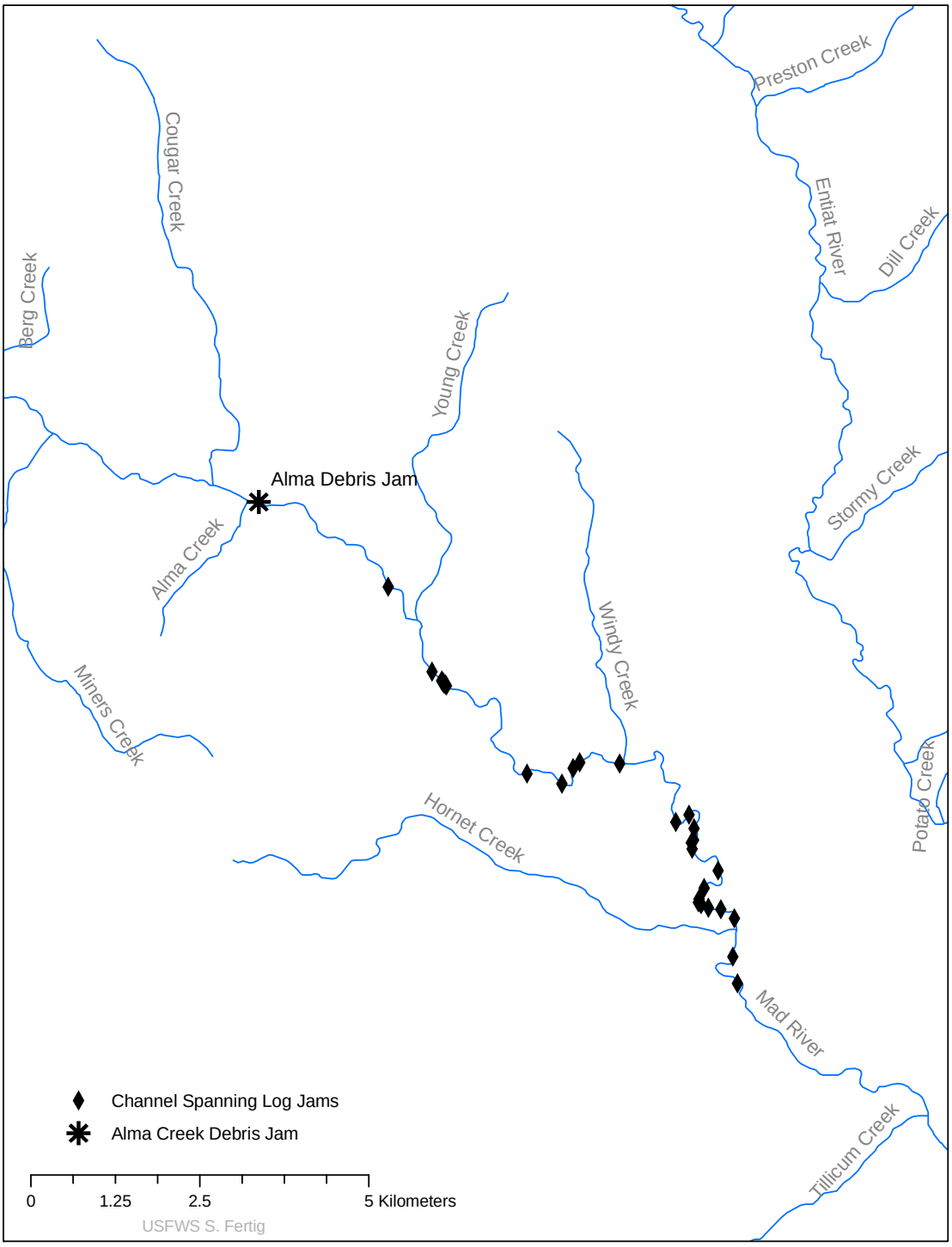

Figure 47. Map of channel-spanning log jams in the Mad River from Pine Flats Campground to the Alma Creek debris jam, 2005.

Figure 48. One of a series of six channel spanning log and debris jams located at Memorial Flats (rkm 18) in the Mad River, 2004.

Figure 49. Photograph of log jam at Memorial Flats (rkm 18) in the Mad River where 3 dead and 2 live bull trout were recovered in 2005.

The partially devoured carcass of male bull trout code 4 was located on the bank near the jam where the other dead bull trout were recovered. Bite marks and the partially devoured head and stomach indicate it was depredated or scavenged by a mammal, probably from that same jam. Bull trout code 32 was tracked to a large standing snag (apparently carried there by a predator or scavenger) but the tag could not be recovered. The tag of code 2 was recovered lying on the bottom of the stream, but it was not near a jam. Bull trout code 18 was recovered 3 weeks later, just downstream of its release area near another channel-spanning jam. This bull trout was depredated, as the tag was on the bank along with the entrails and testes of the fish.

In 2005, bull trout code 74 was located in the debris jam upstream of Camp Nine (rkm 16.6) and apparently died or shed the tag during the upstream migration.

Mortality and recovered tags

From 2003 to 2006, 33 tags of the 92 tagged bull trout in the Entiat Core Area were recovered or motionless, including 23 tags of 35 bull trout (66 %) in the Mad River and 10 of 57 bull trout (18 %) in the upper Entiat River. In the Mad River, 15 of the 23 tags (65 %) were in log jams (Figure 50). In contrast, none of the tags in the Entiat River were located in log jams (Figure 50).

Before 2005, no bull trout carcasses were recovered, making determination of the cause of mortality difficult or impossible. Several tags were recovered in-stream with no clues to the tagged fishes' fate, and tag expulsion could not be ruled out. In 2003, code 77 was recovered 30 m from the stream bed of the Mad River, and in 2005, code 32 was located in a snag, and both recovery locations indicate depredation or scavenging. In 2005 and 2006, 3 of 4 recovered carcasses of tagged bull trout, including those at Memorial Flats, were partially or mostly consumed, also indicating depredation or scavenging.

Three tags were recovered in the Rocky Reach reservoir of the Columbia River in 2003/2004 (Figure 51). The recovery locations of all three indicate mortality rather than expulsion as the cause of tag separation. Tag code 78 was recovered out of the Columbia River, in a marshy area of an old diversion ditch. No carcass or body parts were discovered, but the location suggests a predator or scavenger moved the fish from the Columbia River and brought it to the recovery spot in the ditch. The tag of code 73 was recovered in shallow water at a small island near the right bank of the river, while the tag of code 56 was recovered on the shore. No carcasses were recovered, but the shore positions indicate the dead fish washed up and were scavenged.

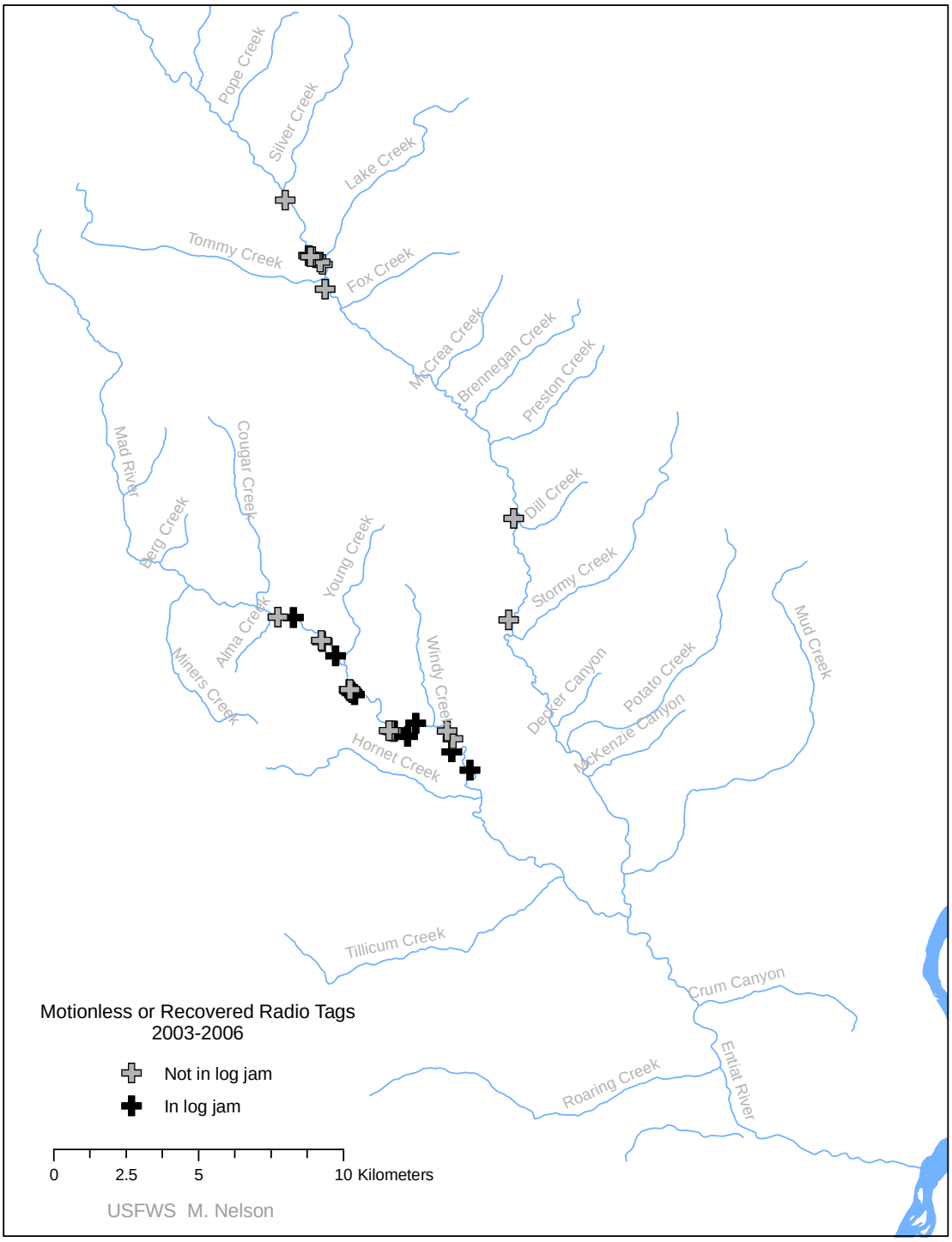

Figure 50. Locations of recovered or motionless radio tags in the Entiat Core Area, 2003 - 2006.

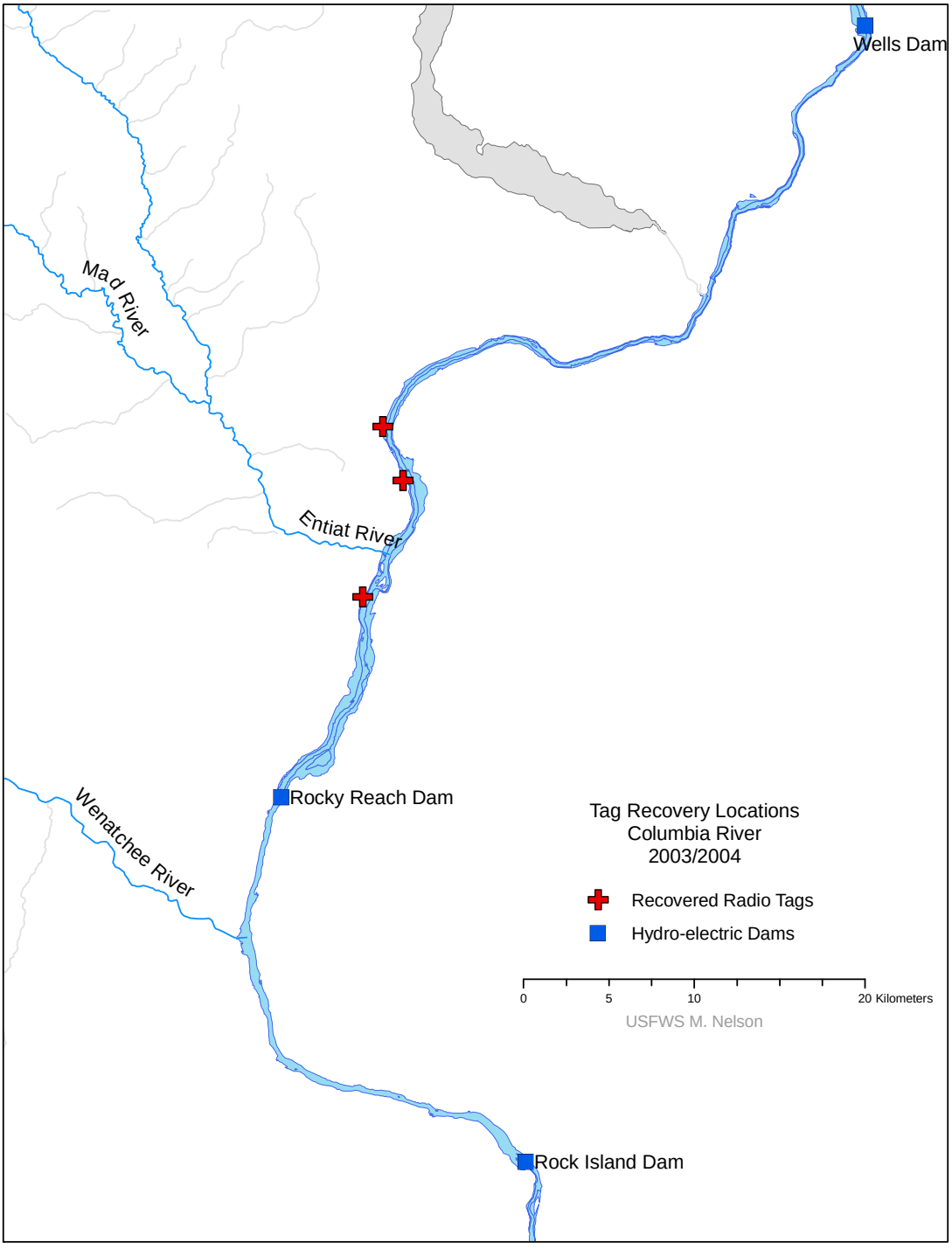

Figure 51. Map of tag recovery locations in the Columbia River, 2003 - 2004.

Movement periods

Diel period of movement during upstream migrations- As tagged bull trout migrated upstream in the Entiat Core Area during 2004 - 2006, the active movement period shifted. When bull trout entered the Entiat River in 2004 and migrated past the ER station, movements were recorded equally during the day or night, but as migration moved upstream, more movements were recorded during the night at fixed stations (Figure 52). Notably, movements shifted back towards the day at obstacles, such as Box Canyon and Fish Tail Falls, as well as the log jam at Camp Nine (Figure 53). Similar patterns were recorded during all years (Table 23).

Diel period of movement during downstream migrations- The majority of movements past fixed stations during downstream migrations occurred during the night (Table 23). In the Mad River, movements recorded during the day at the LB fixed station were probably related to spawning activity (Figure 53).

Table 23. Percentage of tagged bull trout moving in each diel period during upstream and downstream migrations past fixed stations, 2004-2006.

Migration	period	ER	MD	SH	DB	BC	CN	LB
Up	day	36	28	3	74	59	27	33
	night	47	64	70	0	10	33	67
	both	17	8	27	26	31	40	0
Down	day	0	4	4	19	0	0	36
	night	98	93	92	81	100	88	55
	both	2	4	4	0	0	13	9

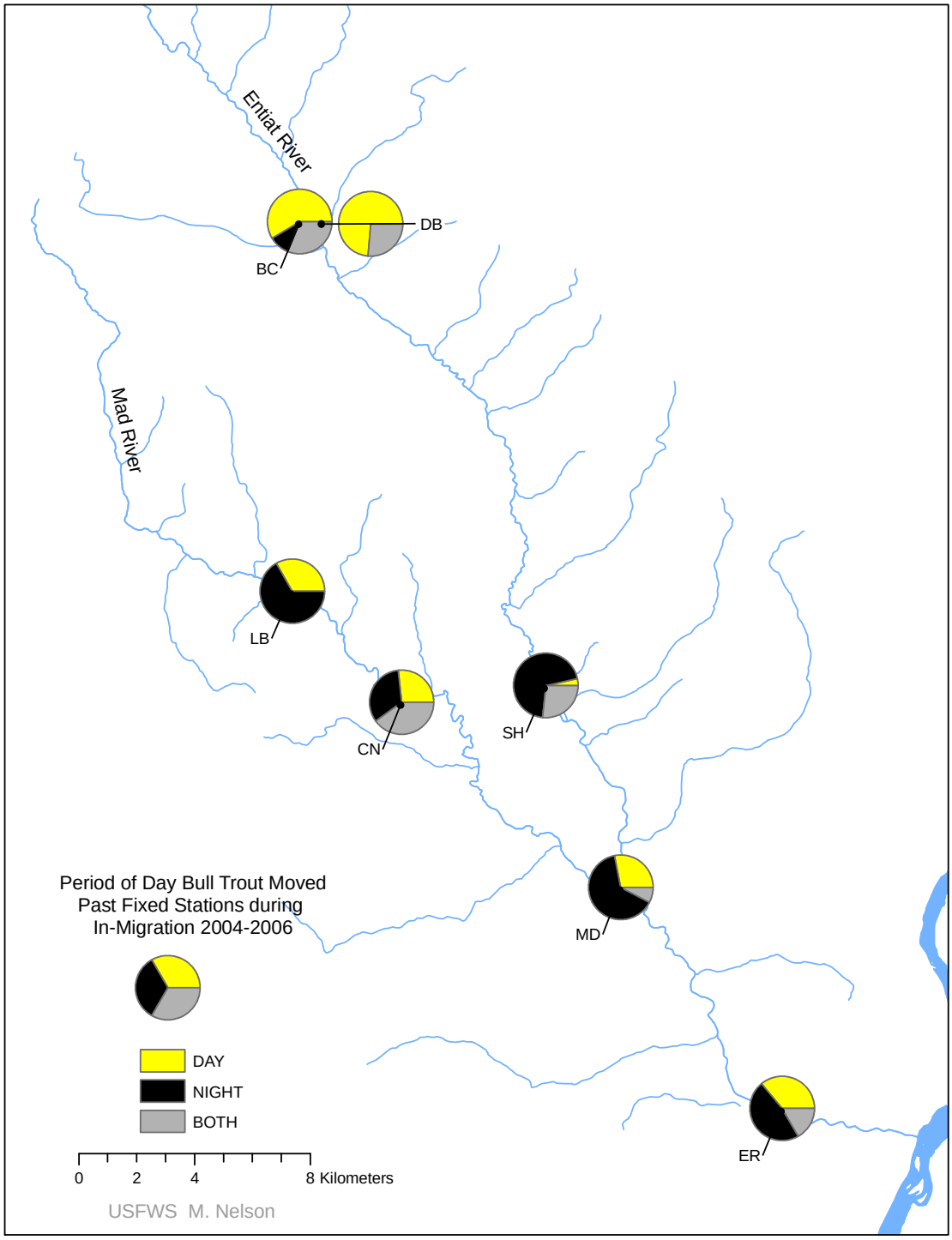

Figure 52. Period of day that tagged bull trout moved past fixed stations during in-migration in the Entiat Core Area, 2004 - 2006.

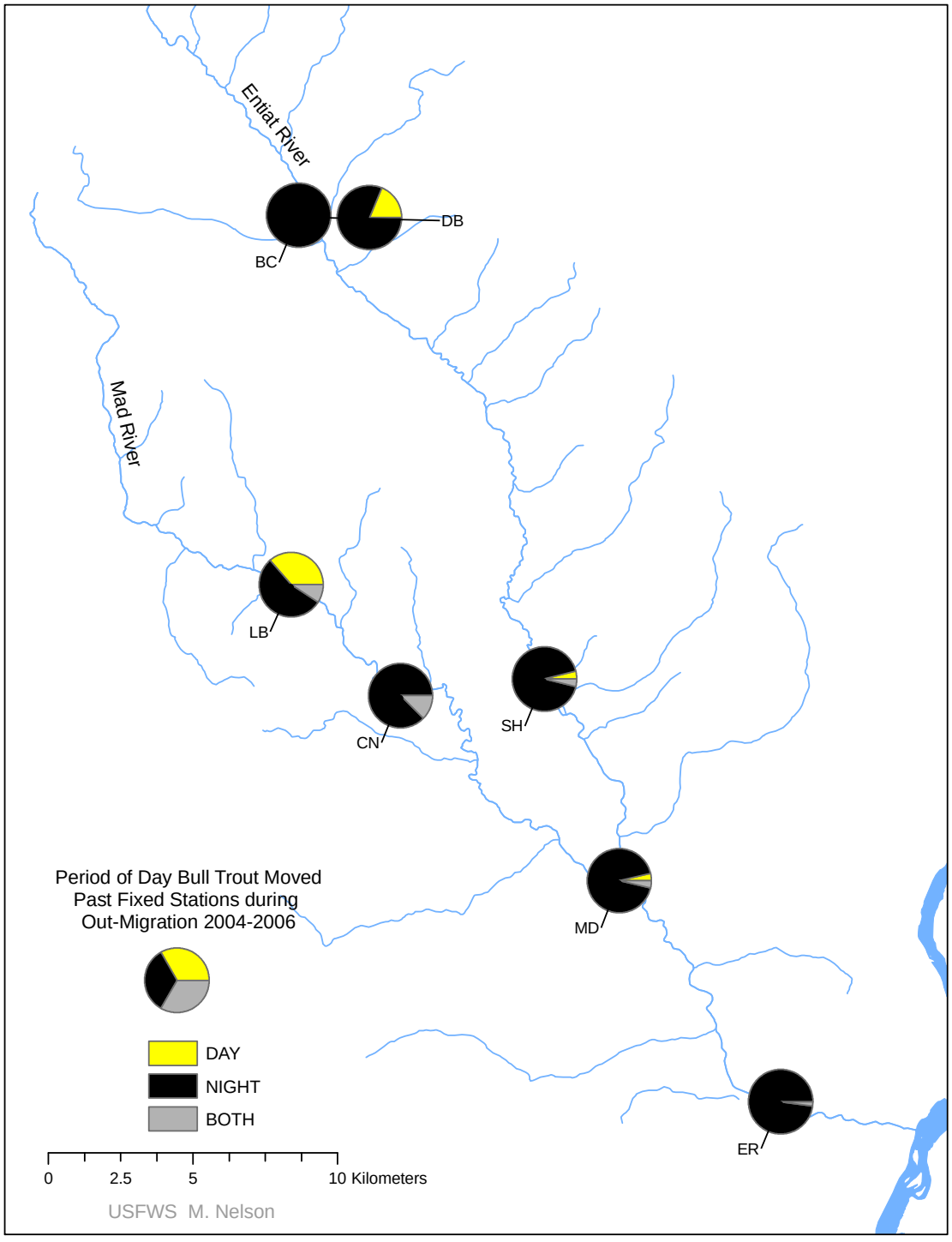

Figure 53. Period of day that tagged bull trout moved past fixed stations during out-migration in the Entiat Core Area, 2004 - 2006.

Time spent in Entiat system-

The number of days that tagged bull trout spent in river segments between fixed stations was variable during upstream migration to the spawning grounds (Tables 24 - 25). In the Mad River, tagged bull trout spent the longest migration time in the 15.9 km from the confluence with the Entiat River to Camp Nine (Table 24). Mad River bull trout were on the spawning grounds for 53.2 days in 2004 and 80.5 days in 2005 (Table 24). In the Entiat River tagged bull trout spent the longest upstream migration time in the 21 km between the SH and BC stations (Table 25). Entiat River bull trout were on the spawning grounds upstream of the BC station for 72.3 days in 2004 and 70.2 days in 2005 (Table 25).

Table 24. Number of days Mad River tagged bull trout spent in river segments between fixed stations during upstream migration in the Entiat River and Mad River, 2004 - 2005.

year	# days	ER-MD	MD-CN	CN-LB	Above LB [1]
2004	mean (SD):	12.3 (6.4)	28.4 (8.1)	19.2 (1.8)	53.2 (13.8)
	range:	6.0 – 20.9	17.7 – 40.2	17.9 – 21.2	36.5 – 67.7
2005	mean (SD):	7.0 (2.9)	32.7 (20.0)	9.0 (0.0)	80.5 (1.1)
	range:	2.2 – 10.7	11.5 – 59.4	9.0 – 9.0	79.7 – 81.3

Note: 1- Days spent on Mad spawning grounds.

Table 25. Number of days upper Entiat River tagged bull trout spent in river segments between fixed stations during upstream migration in the Entiat River, 2004 - 2005.

year	# days	ER-MD	MD-SH	SH-BC	Above BC [1]
2004	mean (SD):	9.4 (3.0)	3.7 (1.0)	40.5 (2.6)	72.3 (10.3)
	range:	4.7 – 13.2	2.1 – 4.7	36.8 – 43.9	57.3 – 87.1
2005	mean (SD):	5.6 (3.0)	2.3 (0.8)	36.7 (7.5)	70.2 (9.4)
	range:	2.8 – 14.2	1.2 – 4.8	20.9 – 47.8	53.4 – 85.2

Note: 1- Days spent on upper Entiat River spawning grounds.

During downstream migration, bull trout that left the Mad River in 2004 moved slowly through all segments and spent the most time moving through the CN – MD segment (Table 26). In 2005, none of the tagged bull trout exited the Mad River. In the upper Entiat River, tagged bull trout moved very quickly downstream and spent little time above the Mad River confluence (Table 27). In general, upper Entiat River bull trout spent their longest time in the MD to ER segment, averaging 7.3 days (range 1.8 – 32.2) in 2004 and 21.6 days (range 0.1 – 76) in 2005.

In 2004, the number of days that Mad River tagged bull trout spent in the Entiat Core Area upstream of the ER station was significantly greater than the time spent by upper Entiat River bull trout (168.9 vs. 130.3 days, 1-tailed Students t test, $df = 6$, $p < 0.001$).

Table 26. Number of days Mad River tagged bull trout spent in river segments between fixed stations during downstream migration in the Mad River and Entiat River, 2004 - 2005.

year	# days	LB-CN	CN-MD	MD-ER	Above ER
2004	mean (SD):	11.7 (14.7)	23.4 (10.0)	22.3 (8.9)	168.9 (4.7)
	range:	1.4 – 36.9	11.8 – 34.9	16.0 – 35.2	163.5 – 172.0
2005	mean (SD):	--	--	--	--
	range:				

Table 27. Number of days upper Entiat River tagged bull trout spent in river segments between fixed stations during downstream migration in the Entiat River, 2004 - 2005.

year	# days	BC-SH	SH-MD	MD-ER	Above ER
2004	mean (SD):	3.9 (2.7)	1.0 (1.2)	7.3 (10.1)	130.3 (11.4)
	range:	2.0 – 9.1	0.1 – 3.9	1.8 – 32.2	115.3 – 145.3
2005	mean (SD):	10.1 (8.3)	0.6 (1.0)	21.6 (24.0)	147.3 (25.2)
	range:	1.1 – 24.7	0.1 – 4.0	0.1 – 76.0	114.6 – 194.4

Migration order- For the migration periods in 2004-2006, the order or ranking position of when individual bull trout arrived at fixed stations was calculated (Tables 28 - 32). Overall, if migrations are viewed as a race between individual bull trout, there was some maintenance of race positions as well as considerable shifting as the migration proceeded. (Note that for 2004, bull trout tagged by USFWS in the upper rivers during that year are not included).

In 2004, the upstream migration of tagged bull trout moving into the upper Entiat River proceeded in an orderly fashion, with some minor changing of positions (Table 28). Code 103 did not pass the BC station or reach the spawning area, but was recorded during mobile surveys in Box Canyon, then moved downstream prior to the spawning season (Figure 37) where the tag was later recovered (Figure 50). In contrast, positions of tagged bull trout changed as upstream migration proceeded in the Mad River during 2004 (Table 29). Not all bull trout passed the LB station, but all except one were located in spawning areas in the fall (Figure 37). Downstream migrations generally proceeded by position, with the first to leave the spawning grounds the first to pass the ER station at rkm 5.1 (Tables 28 – 31).

Table 28. Rank of upper Entiat River tagged bull trout as they moved past fixed stations during upstream and downstream migrations in the Entiat River, 2004.

	Rank Upstream @				Rank Downstream @			
Code	ER	MD	SH	BC	BC	SH	MD	ER
53	5	5	4	7		1	1	1
54	4	4	5	4	2	3	3	2
68	2	1	1	3	1	2	2	3
69	1	2	2	1	3	4	4	4
71	6	7	6	5	4	5	5	5
79	3	3	3	2				
103	8	8	8					
106	7	6	7	6	5			

Table 29. Rank of Mad River tagged bull trout as they moved past fixed stations during upstream and downstream migrations in the Entiat River and Mad River, 2004.

	Rank Upstream @				Rank Downstream @			
BT Code	ER	MD	CN	LB	LB	CN	MD	ER
55	7	7	6	4	2	3		
59	2	3	1	1	1	1	2	1
63	6	2	3	3	3			
72	8	5	4				1	3
118	3	1	5			4	3	2
120	4	4	7					
121	5	8	8			2		
127	1	6	2	2	4			

In 2005, the first bull trout to enter the Entiat River were not necessarily the first on the spawning grounds. Bull trout code 35 was the 16th of 22 upper Entiat River tagged bull trout to enter the Entiat River and 15th at Box Canyon, but it was 1st to reach the spawning area (Table 30). Bull trout code 16 was the 2nd to enter, faded to 9th at Box Canyon and was 6th at the spawning area. There was a similar pattern during the out-migration. Bull trout code 25 was the first to leave the spawning grounds but was the last to enter the Columbia River, while code 21 was 2nd to leave the spawning area and 1st to enter the Columbia River. In the Mad River, there was also considerable shifting in positions as migration proceeded, and of the 2 tagged bull trout that made it past the LB station, one was 7th of 7 Mad River fish to enter the Entiat River, and the other was 5th of 7 to do so (Table 31). None of the tagged bull trout exited the Mad River during 2005.

Table 30. Rank of upper Entiat River tagged bull trout as they moved past fixed stations during upstream and downstream migrations in the Entiat River, 2005.

	Col. R	Rank Upstream @						Rank Downstream @			
Code	*RR*	ER	EF	MD	SH	DB	BC	BC	DB	SH	MD	ER
16	*1*	2	2	7	7	9	6	6	7	12	12	13
19	*2*	3	3	3	3	4	8	7	9	4	4	7
21	*3*	8	6	6	5	7	9	2	3	1	1	1
23	*4*	13	12	12	12	8			1	14	13	9
24	*5*	10	7	8	6	10	2	10	13	8	9	6
25	*6*	4	1	2	2	3		1	2	2	2	15
26	*7*	1	--	1	1	1	4	5	6	3	3	2
27	*8*	6	14	15	14	13	12	3	8	7	7	3
28	*9*	9	8	9	8	12	5	8	11	9	8	5
29	*12*	12	11	11	11	11	7	11	14	15	14	14
33	*13*	11	10	10	10	6	3					
34	*14*	18	17	18	17	17						
35	*15*	16	15	17	16	15	1	4	5	5	5	12
36	*16*	20	19	20	20	18			4			
37	*17*	19	18	19	18							
38	*18*	17	16	16	15	14	14	9	12	6	6	4
39	*19*	14	13	13	13	5						
43	*20*	21	20	21	21	19	11	12	15	11	10	10
45	*21*	22	21	22	22					13	11	11
53	*--*	15	9	14	19							
57	*10*	5	4	5	9	16	10					
81	*11*	7	5	4	4	2	13		10	10		8

Table 31. Rank of Mad River tagged bull trout as they moved past fixed station during upstream and downstream migrations in the Mad River and Entiat River, 2005.

	Col. R	Rank Upstream @					Rank Downstream @			
Code	*RR*	ER	EF	MD	CN	LB	LB	CN	MD	ER
2	*4*	4	4	5	5					
4	*5*	7	7	6	2	2	2			
17	*1*	2	2	2	6					
18	*2*	3	3	3	3					
32	*3*	5	5	4	1	1	1			
40	*6*	6	6	7	7					
74	*--*	1	1	1	4					

In 2006, only 3 fixed stations were operated, and rankings were recorded at ER, MD, and BC stations (Table 32). The migration proceeded in an orderly fashion, with some shifting of positions between the ER and MD stations in the lower river, and all the tagged bull trout were located during mobile surveys in Box Canyon. However, after arrival at Box Canyon, conditions prevented the majority of tagged bull trout from accessing the spawning grounds. Of the 6 tagged bull trout that passed the BC station upstream of Box Canyon, the order was not reflective of the overall migration pattern, and the 17th tagged bull trout to enter the Entiat River was the 3rd bull trout to reach the spawning grounds (Table 32).

Table 32. Rank of upper Entiat River tagged bull trout as they moved past fixed stations during upstream migration in the Entiat River, 2006.

	Col. R	Rank Upstream @		
Code	*RR*	ER	MD	BC
168	*4*	2	1	
166	*1*	1	3	2
173	*7*	4	2	4
23	*--*	6	5	1
172	*5*	5	4	
167	*2*	3	7	
29	*16*	9	6	
176	*9*	7	8	
170	*6*	8	9	
175	*8*	10	10	6
24	*17*	11	11	
38	*20*	--	17	5
178	*11*	17	14	3
25	*18*	12	12	
151	*3*	13	11	
181	*13*	14	16	
179	*12*	16	15	
42	*15*	15	18	
35	*10*	18	19	
19	*22*	20	21	
45	*19*	19	22	
189	*21*	21	20	
182	*14*	22	23	

Over-wintering locations

Columbia River- Each year most of the tagged bull trout migrated to the Columbia River. In the fall of 2003, eighteen USFWS-tagged bull trout migrated out of the Entiat River watershed and 15 were located by boat surveys over the winter (Figure 54). Based on the boat surveys and detections at Rocky Reach Dam, 45 % (8 of 18) over-wintered in Rocky Reach reservoir, 39 % (7 of 18) in Rock Island reservoir, 11 % (2 of 18) in Wanapum reservoir, and 5 % (1 of 18) the location was unknown. In 2004, thirteen USFWS-tagged bull trout migrated out of the Entiat Core Area and a similar pattern was observed (Figure 55). During boat surveys in the winter of 2004/2005, nine of the 13 were located, along with an additional 3 bull trout that had not returned to the Entiat River in 2004 (code 58 spent the entire year in Rock Island reservoir, code 70 spent the summer in Icicle Creek and the lower Wenatchee, and code 67's summer and fall location was unknown).

Five USFWS-tagged bull trout exhibited fidelity to their over-wintering locations, with 3 bull trout (codes 53, 67 and 72) returning to almost the exact location each winter (Figures 54 – 55). Code 70 returned to the same general area even though it visited a different core area in 2004 (Figure 58).

The distribution of USFWS-tagged bull trout in the Columbia River reservoirs differed between the Mad River and upper Entiat River populations (Table 33). Compared to tagged fish from the Mad River population, tagged upper Entiat River bull trout used the Rocky Reach and Wanapum reservoirs less than expected and the Rock Island reservoir more than expected (chi square test, df = 5, $p < 0.001$). No upper Entiat River bull trout were located in Wanapum Reservoir.

Table 33. Distributions of tagged bull trout from upper Entiat River and Mad River over-wintering in Columbia River reservoirs, 2003/2004 and 2004/2005.

		2003/2004		2004/2005	
Reservoir	Local Population	n	% of local	n	% of local
Rocky Reach	Upper Entiat	2	28.6	2	28.6
	Mad	4	50	3	60
Rock Island	Upper Entiat	5	71.4	5	71.4
	Mad	2	25	1	20
Wanapum	Upper Entiat	0	0	0	0
	Mad	2	25	1	20

During 2003/2004, the mean water depth at locations of tagged bull trout in the Columbia River was 6.9 m (range 1.5 – 14.6 m). During 2004/2005, the mean water depth at locations was 9.3 m (range 1.2 – 33.5 m).

Entiat River watershed- Each year, a few tagged bull trout did not migrate to the Columbia River but instead attempted to over-winter in the Entiat Core Area (Figure 56). From 2003 - 2006, 5 of the 10 bull trout that stayed in the watershed survived the winter, including 3 of 3 (100 %) in the upper Entiat River and 2 of 7 (29 %) in the Mad River. In 2003/2004, code 76 survived the winter in rapids near Lake Creek Campground (rkm 46.5) and was located on the upper Entiat River spawning grounds during the fall of 2004. Two tagged bull trout (codes 61 and 92) were observed in the Mad River near Camp Nine in late fall 2003, but the tags were recovered the following summer. In 2004/2005, 2 bull trout (codes 79 and 106) survived over winter in the upper Entiat River and were observed alive the following spring. The battery of code 79 died shortly after, but code 106 was tracked on the spawning grounds during the fall of 2005. Code 106 was then observed in late November 2005 in Box Canyon during the last tracking session before snows closed the road, and it apparently again over-wintered in the upper Entiat River during 2005/2006 (the battery died before the area was accessible again in spring). In 2004/2005, 3 tagged bull trout (codes 63, 121, 127) attempted to over winter in the Mad River, and were observed during late November and early December upstream of Camp Nine. Only one was observed alive the following spring (code 63 near rkm 8), and the other two tags were recovered near their last observed locations. Code 63 migrated to the Columbia River, but was not detected again, probably because it reached the battery life expectancy. During 2005/2006, 2 tagged bull trout (codes 17 and 40) stayed in the Mad River. Code 17 did not survive but code 40 did and exited the Mad River on May 15, 2006. It migrated to the Columbia River on May 16, then re-entered the Entiat River on July 3 and migrated back into the Mad River on July 9, 2006.

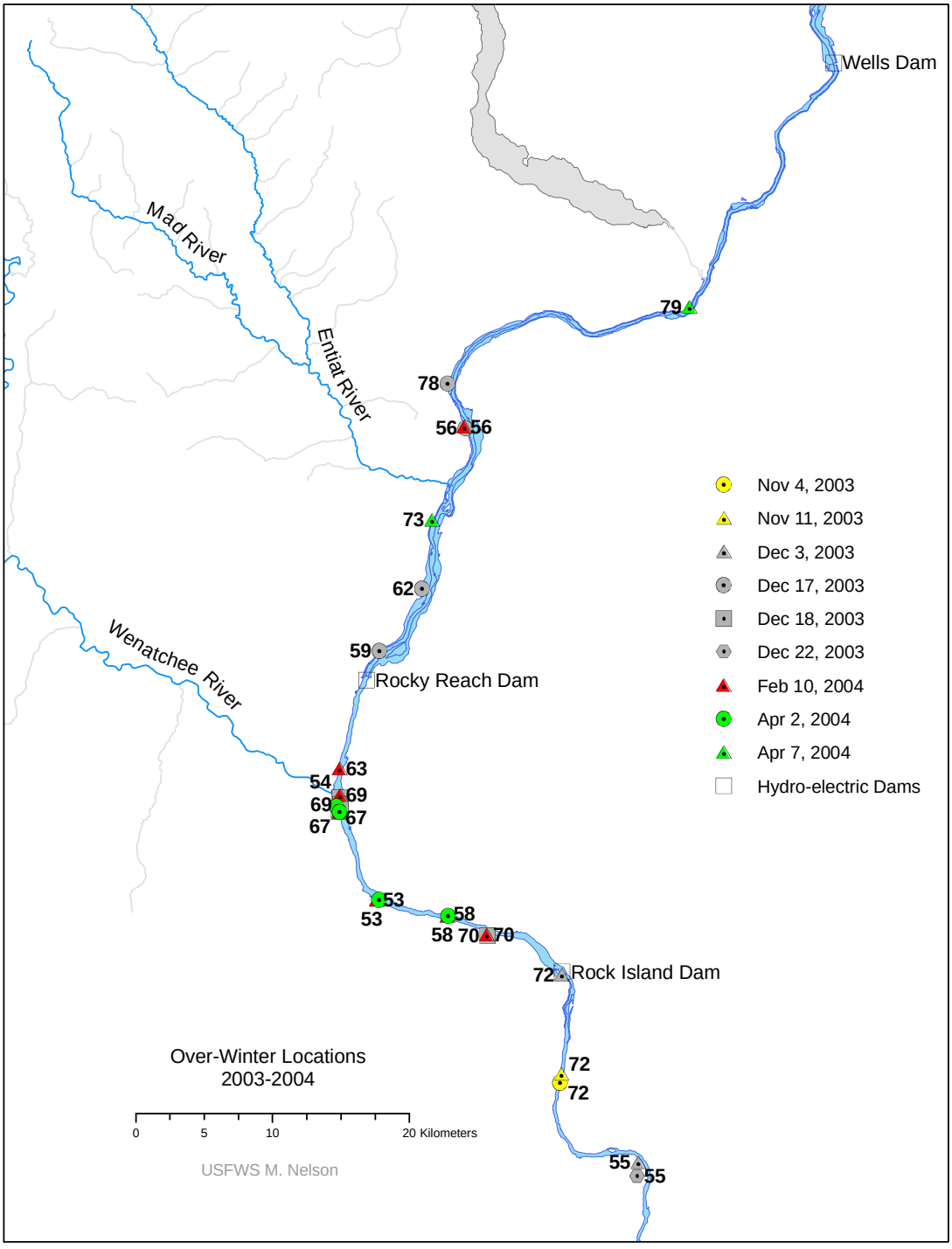

Figure 54. Over-winter locations of USFWS-tagged bull trout during boat surveys conducted on nine dates in the Columbia River during fall and winter, 2003/2004.

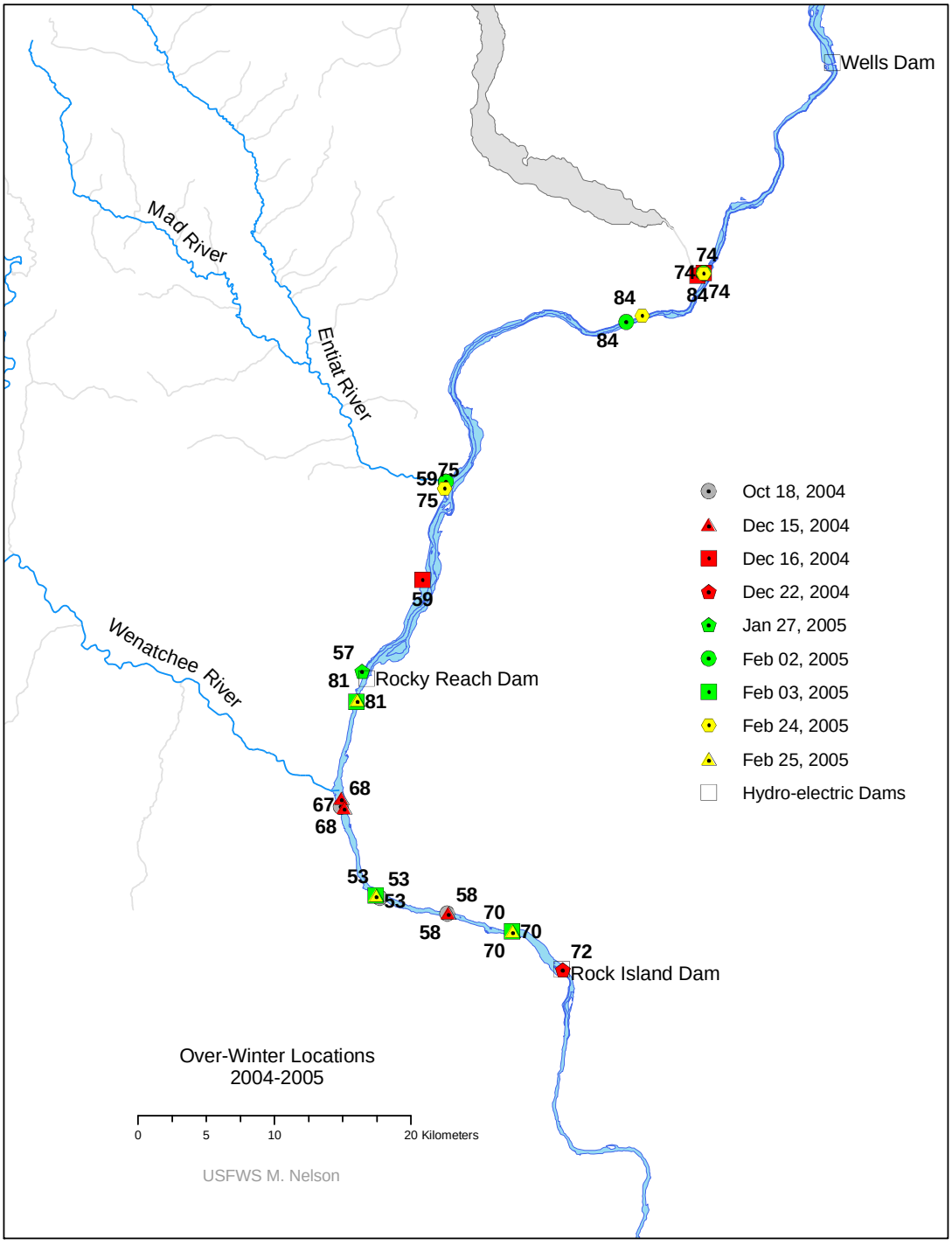

Figure 55. Over-winter locations of USFWS-tagged bull trout during boat surveys conducted on nine dates in the Columbia River during fall and winter, 2004/2005.

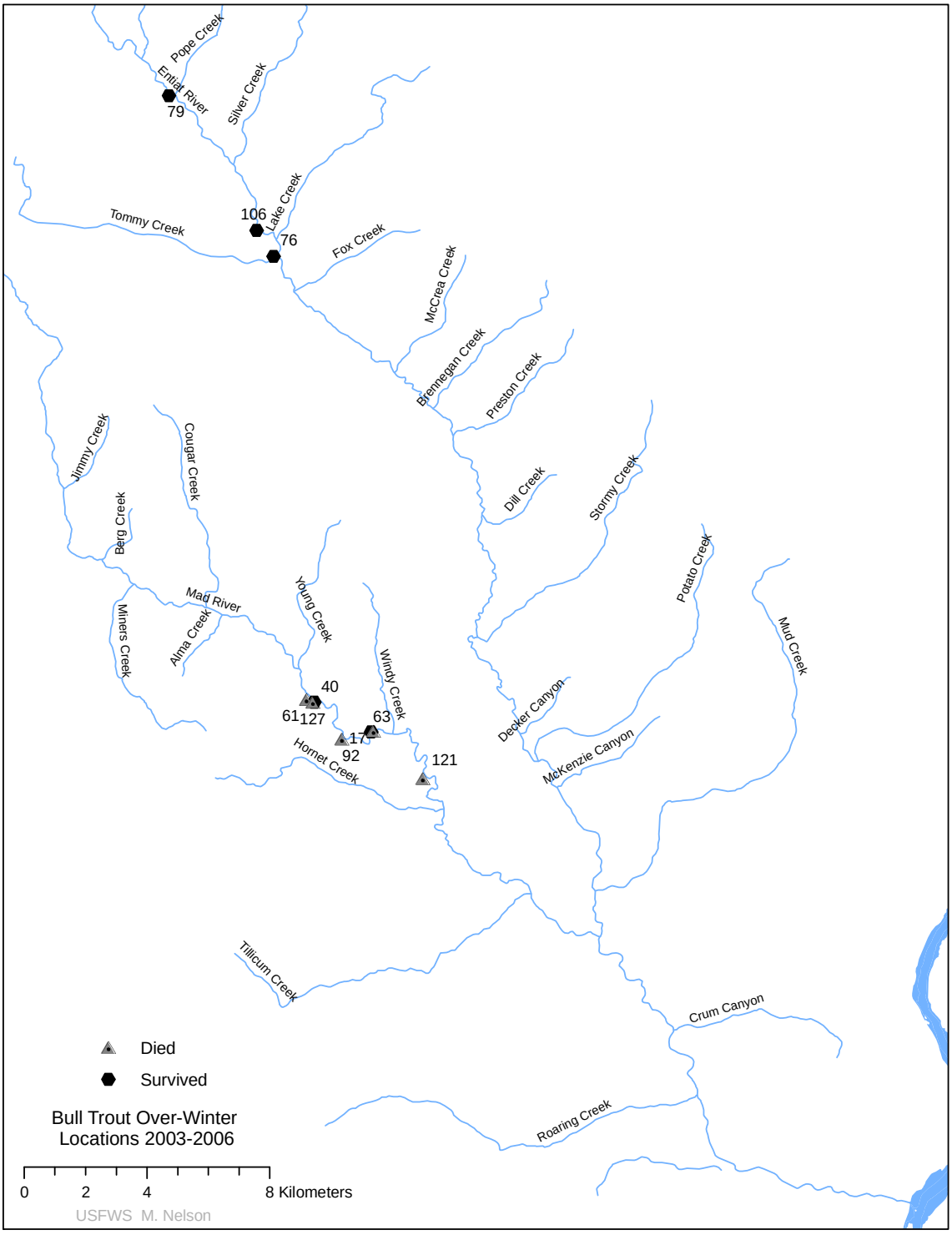

Figure 56. Locations of tagged bull trout that attempted to stay over-winter in the Entiat Core Area, 2003 - 2006.

Summer in Columbia River-
During the study, 3 tagged bull trout apparently stayed in the Columbia River over the summer (Figure 57). Code 58 spent over a year in the Rock Island reservoir before the radio signal disappeared in December of 2004. In late spring 2005, code 59 moved from the Rocky Reach reservoir to the Rock Island reservoir instead of migrating back to the Mad River. It was located in the same location until the signal disappeared in September, and the bull trout was not located again. In 2004, after migrating back from Icicle Creek and the Wenatchee River to its previous wintering location in Rock Island reservoir, code 70 spent the summer and fall of 2005 at that location until the signal disappeared in November. However, without a motion sensor in the tag, it could not conclusively be determined if these fish were alive, whether the tag was shed, or if the battery had died.

In 2004, code 67 migrated upstream through Rocky Reach Dam, but was not detected at any other fixed telemetry stations. In autumn, it was found again at its previous winter location, so apparently code 67 spent the summer in the Columbia River at an unknown location.

Migration distances
In-migration to spawning grounds- From Rock Island Dam, the minimum migration distance is 85.8 km to the Mad River spawning grounds and 103.5 km to the upper Entiat River spawning grounds. From Rocky Reach Dam, the minimum migration distances are 53.2 km to the Mad River and 70.8 km to the upper Entiat River.

In 2004, for USFWS-tagged bull trout that had been located over-wintering in the Columbia River, the mean in-migration distance to locations in the Mad River was 61.6 km (SD 25.5, n = 4, range 36.4 – 91.9 km), and the mean distance to locations in the upper Entiat River was 79.8 km (SD 2.0, n = 4, range 78.5 – 82.1 km). There was no significant difference in in-migration distance between Mad River and Entiat River bull trout (2 tailed Student's t test, $p = 0.19$). A similar pattern was observed in 2005.

Out-migration- In 2003/2004, for USFWS-tagged bull trout that migrated out of the Entiat Core Area and the over-winter location was known, the distance between the tagging location and the over-winter location was calculated. Mad River bull trout traveled a mean distance of 68.1 km (SD 25.2, n = 8, range 44 – 110.5 km) between tagging and over-wintering locations. Upper Entiat River bull trout traveled a mean distance of 75.7 km (SD 11.0, n = 7, range 57.1 – 89.5 km). There was no significant difference in migration distance between Mad River and Entiat River bull trout (2 tailed Student's t test, $p = 0.47$) during 2003/2004. Interestingly, after exiting the Entiat River, bull trout codes 73 and 53 moved upstream in the Columbia River and were located 31.6 and 43.5 km upstream of the Entiat River confluence before moving 35.1 and 77.3 km downstream to their eventual over-wintering locations.

In 2004/2005, for those USFWS-tagged bull trout that over-wintered in the Columbia River, the mean migration distance for Mad River fish was 68.1 km (SD 14.5, n = 4, range 47.8 – 82.1 km). The mean distance for upper Entiat River bull trout was 69.7 km (SD 12.4, n = 5, range 55.0 – 88.4 km).

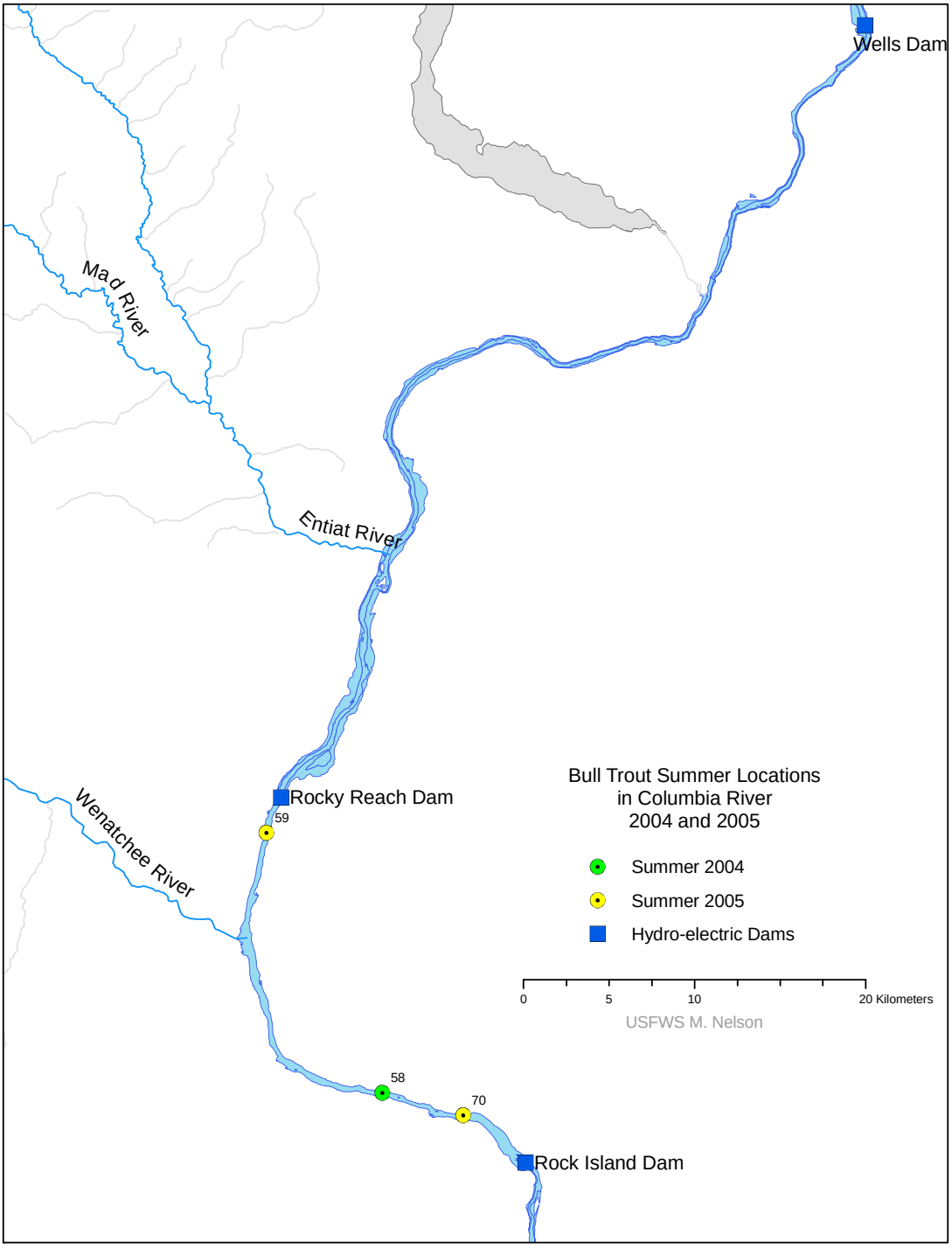

Figure 57. Map of tagged bull trout summer locations in the Columbia River, 2004 - 2005.

Longest recorded total movement- During the study, bull trout code 53 traveled a total known minimum distance of 558.7 kilometers between tagging in 2003 and its last record at the SH fixed station on June 26, 2005 (see *noteworthy movements* section for more information on bull trout code 53).

Movements to other Core Areas

Five tagged bull trout were detected moving between the Entiat Core Area and the Wenatchee Core Area. However, none of the movements were detected between spawning grounds in one core area to spawning grounds in the other.

Code 104 was tagged at Rocky Reach Dam in 2002 by Chelan PUD, and after release in the tailrace, it moved downstream and entered the Wenatchee River on July 1 (see BioAnalysts 2002, 2004). It resided in the lower Wenatchee River for most of the summer and fall, and its furthest upstream detection was near the confluence of Icicle Creek. In 2003, code 104 migrated into the Entiat River and was detected on the upper Entiat River spawning grounds upstream of Box Canyon August 21 – October 10. Most locations of code 104 were near the confluence of Pope Creek, an area where redds were noted each year during spawning ground surveys conducted 2004 – 2006.

Code 70 was tagged in Box Canyon in August 2003 (Figure 58). It was located downstream of Box Canyon on August 21, then in the Fish Tail Falls pool September 9 – 23, but was unable to pass the falls and was not recorded on the upper spawning grounds. Code 70 migrated downstream, entered the Columbia River and over-wintered upstream of Rock Island Dam. In spring, it migrated upstream and was detected during a mobile survey on June 16, 2004 in the Rocky Reach Dam tailrace. The amount of time it spent in the tailrace is unknown. Code 70 then moved downstream and entered the Wenatchee River, passed the fixed station at rkm 12.5 on June 28, 2004, and was located at rkm 41.1 near the confluence of Icicle Creek July 7 – 15. It then entered Icicle Creek, arrived at the spillway pool of Leavenworth National Fish Hatchery on August 4, and departed the spillway pool on August 5 or 6. It passed the station at rkm 12.5 on August 11, resided in the lower mile of the Wenatchee River from August 13 – October 15, and then over-wintered in the Columbia River upstream of Rock Island Dam.

In 2005, after over-wintering in the Columbia River upstream of the Wenatchee River confluence, code 81 migrated into the Wenatchee River and passed the fixed station at rkm 12.5 on May 19 (it was not detected at Rocky Reach Dam prior to entering the Wenatchee River). It was located in lower Peshastin Creek during a mobile survey on May 24 before it moved back downstream in the Wenatchee River and passed the fixed station at rkm 12.5 on May 25. It passed through Rocky Reach Dam on 5/26 – 27, migrated into the Entiat River on June 4, and moved to the upper Entiat River, where it was photographed digging and fanning a redd near Pope Creek.

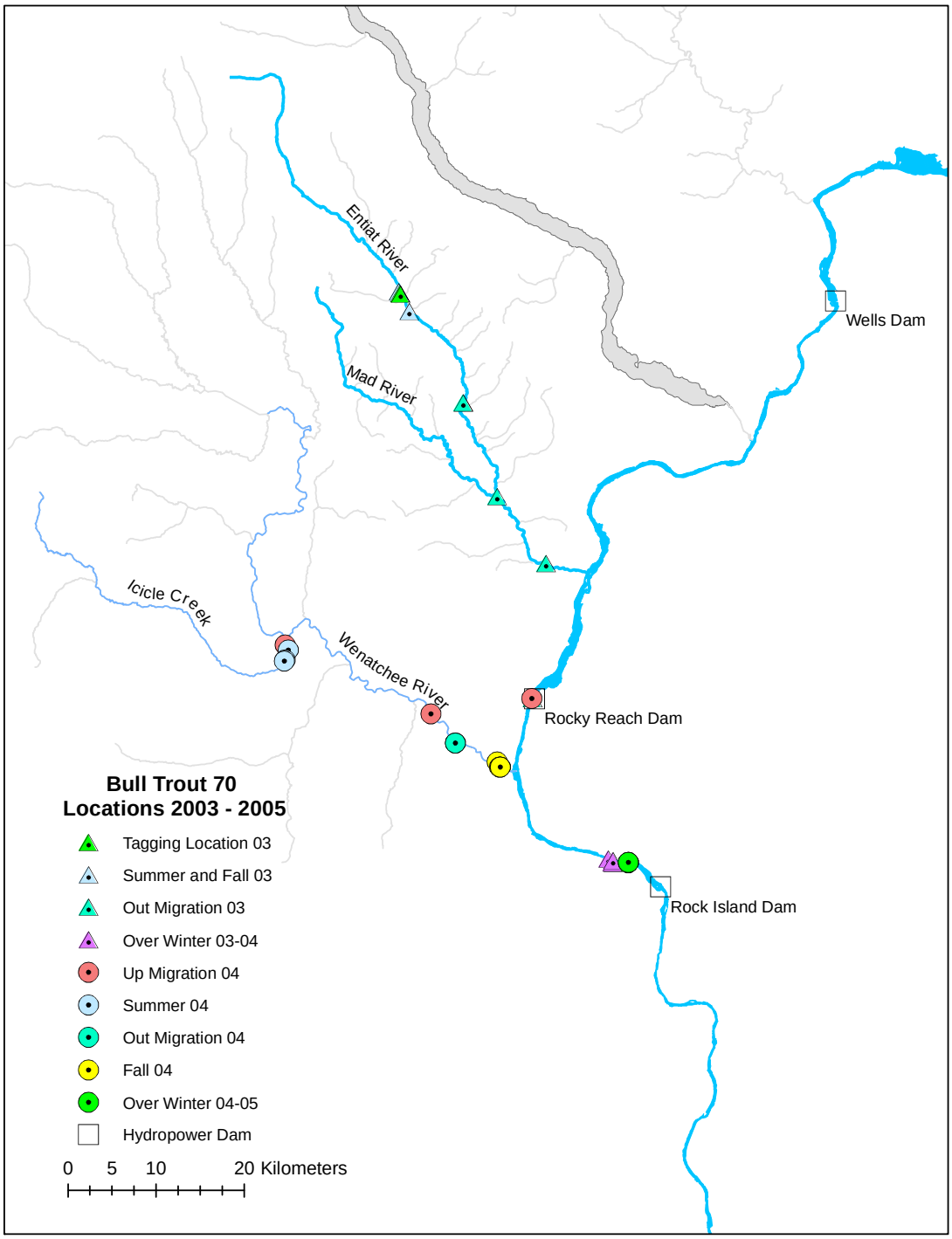

Figure 58. Map of locations of bull trout code 70 during movements in and between the Entiat and Wenatchee Core Areas and winter locations in the Columbia River, 2003 - 2005.

In 2006, bull trout codes 43 and 153 were detected for a short period in Icicle Creek. Code 43 was tagged at Rocky Reach Dam by Chelan PUD in 2005 and code 153 at Rock Island Dam in 2006. During 2005, Code 43 was located on the upper Entiat River spawning grounds August 5 – October 5. In 2006, Code 43 migrated up the Wenatchee River, passed the fixed station at rkm 12.5 on June 21 and was detected entering Icicle Creek on July 21. It was recorded at the spillway pool at Leavenworth National Fish Hatchery on July 22 at 01:56 and passed Structure 5 at 02:12. It moved back downstream past Structure 5 at 21:44 but did not enter the spillway pool. It exited Icicle Creek at 23:09 and moved downstream in the Wenatchee River. Code 153 entered the Wenatchee River and passed the fixed station at rkm 12.5 on June 18. It entered Icicle Creek on June 25 or 26, was detected at the spillway pool at Leavenworth NFH on June 26 from 02:25 – 03:39. It moved downstream, exited Icicle Creek on June 26 or 27, and was detected in the Wenatchee River at rkm 9.6 during a mobile survey on June 28. Code 153 migrated to the Entiat River, and passed the fixed station at rkm 5.1 on July 2, 2006. It was located during mobile surveys near rkm 12.5 until the tag was recovered by Chelan PUD on February 20, 2007.

Noteworthy movements and events

Noteworthy movements- During the study, a few tagged bull trout exhibited unusual behavior or movements. Most noteworthy were the alternating up and downstream movements exhibited by Code 53 after it entered the Entiat River in 2004 (Figure 59). Code 53 entered the Entiat River and passed the ER station on June 2. As it migrated upstream, it reversed direction several times, but was detected in Box Canyon on June 29. It almost immediately moved back downstream, reversing direction several times as it alternately moved downstream and back upstream past the lower fixed stations. On July 7, it was located at rkm 13 during a mobile survey before it moved back upstream and was detected moving past at the MD station later that night. By July 29, it was again detected in Box Canyon, and from July 31 – Aug 4, it was recorded on the BC station as it jumped Fish Tail Falls several times. During a mobile survey on August 10, it was detected in the pool at Entiat Falls, and then on August 15 it moved downstream past the BC station, through Box Canyon to rkm 33. From August 27 – September 4, it was back in Box Canyon; on September 3 it was recorded on the BC station as it unsuccessfully attempted to jump Fish Tail Falls. It once more moved downstream and was captured in the USFWS rotary screw trap at rkm 10.5. After release it moved back upstream, where it was detected in the Chinook salmon spawning reaches upstream of the SH fixed station until September 23, when it was detected moving back downstream past the SH station. By September 26, Code 53 exited the Entiat River system. As it moved up and downstream from June 2 to September 26, Code 53 traveled a minimum of 256 km within the Entiat River during 2004. Based on temperature data from the nearest temperature logger in the monitoring network, the highest daily maximum water temperature encountered by Code 53 was 20.2 C, near rkm 33 on August 16 (Figure 60).

After exiting the Entiat system, 5 bull trout moved upstream in the Columbia River, and over-wintered in the Rocky Reach reservoir at locations 5 – 30.5 km above the confluence (Figures 54 – 55). All other bull trout moved downstream of the confluence after exiting the Entiat River.

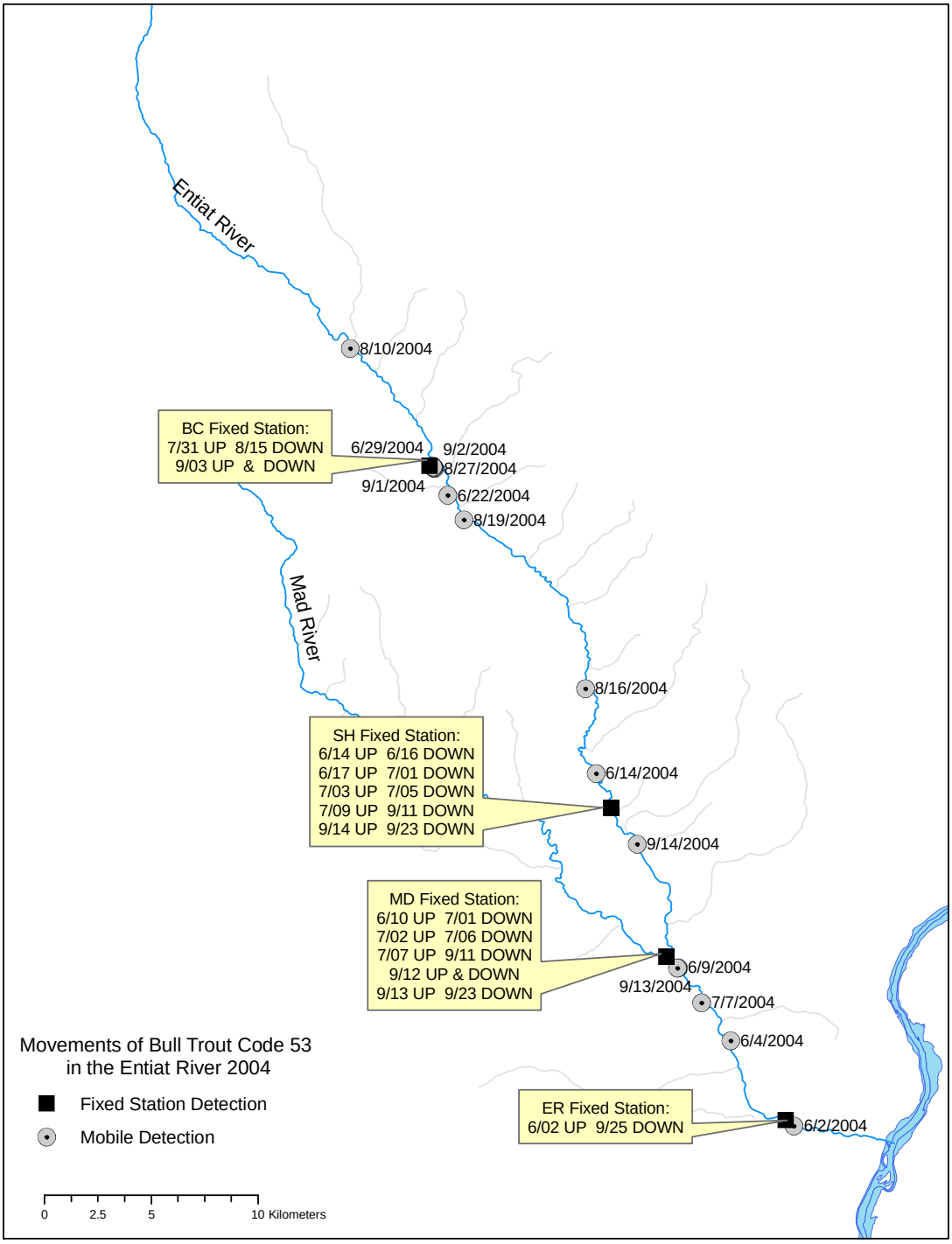

Figure 59. Map of the location and date of unusual movements of bull trout code 53 in the Entiat Core Area during 2004.

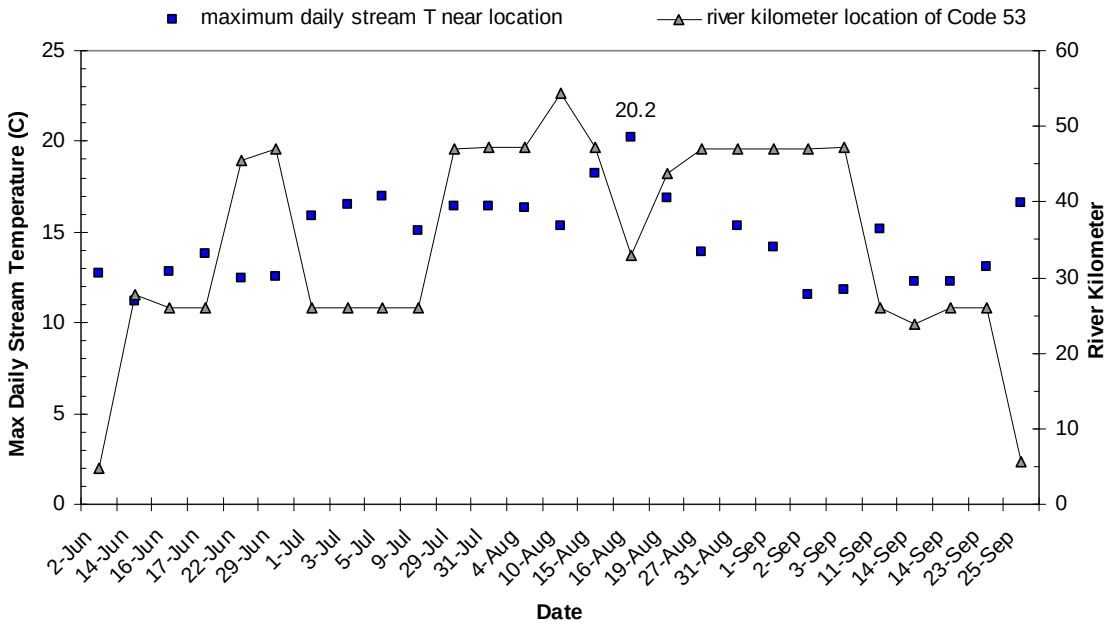

Figure 60. Chart of the mean daily stream temperature and the river kilometer of the location of bull trout code 53 during unusual movements in the Entiat Core Area in 2004.

In 2006, channel 1 codes 54, 66, and 68 were tagged at Wells Dam by DPUD and released 3.5 km upstream of the dam. These bull trout subsequently moved back downstream through the dam and traveled 51 km to the Entiat River. They migrated to Box Canyon, but did not pass to the upper spawning grounds. All 3 migrated out and over-wintered in the Columbia River. In 2007, Code 68 moved back to the upper Entiat River, but codes 54 and 66 migrated to the Twisp River in the Methow Core Area.

During out-migration in 2006, bull trout code 38 spent over 3 weeks at the Whitehall cross vane habitat improvement and stream restoration site at rkm 5.1. This bull trout arrived at the site after the in-stream work was completed, but stayed while heavy equipment was operated on the bank during construction at the diversion channel. The bull trout was recorded by the ER fixed station, and exact foot tracking revealed it was holding downstream of several summer Chinook salmon actively spawning on the newly exposed gravels at the site. Operation of the heavy equipment on the bank had no apparent effect on the tagged bull trout. On-site observers snorkeled to monitor the project and did not observe the bull trout or any risk to the bull trout in the immediate areas of work.

Response to landslide event- On August 17 – 18, 2004, landslides near Ice Lake in the upper Entiat River resulted in a large amount of sediment in the river (Figure 61). Turbidity was measured at the USFWS rotary screw trap (rkm 10.5) and increased from 0.67 to 9,547 NTUs before it slowly decreased (Figure 62). During this event, all tagged bull trout in the upper Entiat River stayed exactly where they were and did not seek out fresher water at tributaries or springs.

Figure 61. Photograph of confluence of the Entiat and Mad rivers during mud slide event on August 18, 2004, showing high sediment load of the Entiat River and clear water of the Mad River.

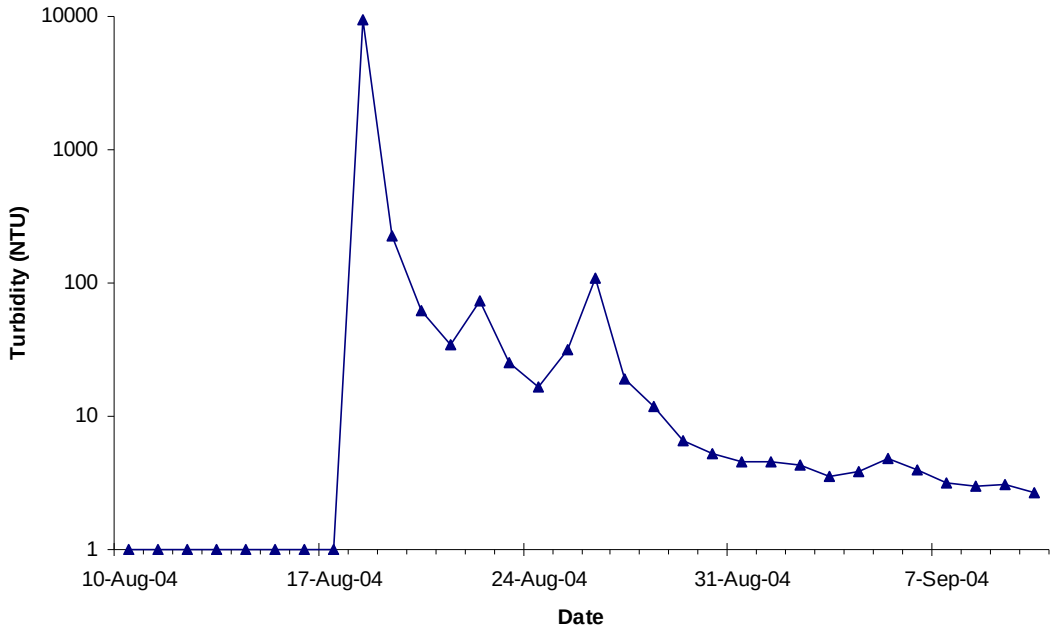

Figure 62. Turbidity values (logarithmic scale) in the Entiat River before, during, and after mud slide event in 2004.

Discussion

This telemetry study is the first intensive documentation of the movement patterns of adult fluvial bull trout in the Entiat Core Area of the Upper Columbia Recovery Unit. Several previously unknown factors were discovered to be important in the migration and spatial distribution of bull trout. Discussion of these factors is organized into the following sections on movement patterns, natural obstacles, stream temperatures, and recovery planning.

It is important to note the limitations of telemetry in understanding the migration biology of bull trout. Telemetry is useful in areas such as the description of movement patterns or correlation of migration with environmental factors, but it cannot yield a complete understanding of migration or provide solutions to anthropogenic problems such as migration barriers (Cooke et al. 2008). Thus, while the "when and where" of bull trout migration in the Entiat River is now known, determination of the "why" requires the integration of other disciplines, such as physiology, behavior, and experimental biology (Cooke et al. 2008). Such approaches were beyond the scope of the study; therefore, any discussion of "why" necessarily involves some speculation.

Movement patterns

The movements of adult fluvial bull trout in the Entiat Core Area confirm that the Mad River and upper Entiat River are separate local populations. Both local populations used the lower Entiat River as a migratory corridor, and tagged bull trout from the Mad River always migrated back to the Mad River while bull trout from the upper Entiat River always migrated back to the upper Entiat River. Tagged bull trout from one population were never observed on the spawning grounds of the other. These telemetry monitored movements demonstrate that fidelity to spawning area is the mechanism for the distinct genetic differences of the local populations observed in the analysis of tissue samples from the radio-tagged adults (DeHaan and Ardren 2005). Fidelity to spawning sites has also been observed during bull trout studies in the Morice River, British Columbia (Bahr and Shrimpton 2004). However, small numbers of both males and females have been documented switching tributaries during telemetry studies at Columbia River reservoirs in British Columbia (O'brien 2001, Bray 2003). Site-specific fidelity has been estimated from 46 – 90 % during telemetry studies in the North Fork Clearwater River, Idaho (Schiff et al. 2005), but these estimates were based on small sample sizes of presumed repeat-year spawning bull trout, and it was noted that actual spawning was not confirmed in all years.

It is not clear from metapopulation theory what degree or frequency of exchange between local populations is necessary for the continued persistence of normally isolated populations of bull trout (McCart 1997, Whitesel et al. 2004), and it may be that accurate measurement of dispersal rate is beyond the limited time frame of telemetry studies (Rieman and Dunham 2000), particularly studies focusing on adults. While this study did not observe adult tagged bull trout moving between the spawning grounds of different local populations, some movement data suggest it may be feasible for genetic exchange to occur between areas in the Upper Columbia Recovery Unit. Five tagged adult bull

trout were observed moving between the Entiat and Wenatchee core areas, and 4 of the 5 were in Icicle Creek and/or the spillway pool at Leavenworth National Fish Hatchery. Up to several dozen fluvial bull trout have been observed annually in the spillway pool since at least 1969 (Brown 1992, USFWS 2006), but it is unknown how many belong to the Icicle Creek local population. Access to spawning areas in upper Icicle Creek has been obstructed by structures at the hatchery and other artificial and natural obstacles, and it is unknown if or where those obstructed fluvial bull trout spawn. Our telemetry data suggests some may have spawned in the upper Entiat River, where at least 2 of the bull trout that used the spillway pool were tracked to vicinity of redds in the year before or after they were recorded in Icicle Creek. Alternatively, it may be that non-spawning bull trout from other local populations are staging for feeding or thermal refuge in Icicle Creek. For example, in Canada, significant numbers of tagged bull trout from separate populations migrated to the Bull River but did not spawn, and researchers speculated that foraging was the reason for the behavior (Westover and Heidt 2004). Genetic profiles of local populations in the Upper Columbia Recovery Unit are being developed, and comparison of the tissue samples from those fish may provide insights into movements between Entiat River, Icicle Creek and other local populations in the recovery unit.

Some of the movements of Columbia River tagged bull trout between core areas may have been influenced by tagging, handling, and release location (BioAnalysts 2004). It is therefore important that the complete history of a tagged fish be considered when interpreting individual movement patterns. For example, in 2006, three bull trout tagged at Wells Dam and released upstream of the dam subsequently moved downstream (LGL 2007), entered the Entiat River, and resided in Box Canyon. In 2007, two of those bull trout migrated upstream through Wells Dam (LGL 2007) and to the Twisp River spawning grounds in the Methow Core Area, while one bull trout entered the Entiat River and returned to Box Canyon. These are the only bull trout tagged at Wells Dam that entered the Entiat Core Area, and it appears that behavior may have been affected by tagging, transport, and release of the fish.

Staging of bull trout in the Columbia River at the confluence, prior to entering the Entiat River, has not yet been detected at the other tributaries in the Upper Columbia Recovery Unit (BioAnalysts 2004, LGL and DPUD 2006 and 2007, Stevenson et al. 2006 and 2007, Nelson et al. 2007), but has been observed elsewhere in the species' range. In the Flathead Lake and River system, Montana, bull trout migrated 80 – 250 km from the lake and then staged at the mouths of spawning tributaries for 2 -4 weeks prior to entrance and spawning (Fraley and Shepard 1989).

Stream discharge and water temperature influence the timing of migration into the Entiat Core Area. Tagged bull trout entered the Entiat River on the declining hydrograph, and it appeared high discharge may delay entrance dates and migration peak. Increasing daily stream temperature may also be a migration cue, as all movements into the Entiat River were recorded when the mean daily water temperature increased to > 8 °C. A similar pattern was noted during studies conducted from 2001 – 2003, when 95 % of all movements into the Entiat River occurred after mean daily water T increased to above 8 °C (BioAnalysts 2004). Stream temperature at migration may be an adaptation of local

populations- during migration at tributaries to Lake Revelstoke in the upper Columbia River, Canada, temperatures were 6.2 – 12 °C (Bray 2003), but in the Blackfoot River, Montana, daily mean temperature at the start of migration was 17.7 °C (Swanberg 1997). Photoperiod may also play a role in the timing of migration of bull trout, as been documented for other salmonid species (Ford et al. 1995).

In other areas, bull trout have been recorded as migrating mostly at night (Fraley and Shepard 1989, Swanberg 1997) or mostly during the day (Taylor 2000). In the Entiat Core Area, the period of movement is dependent on the time of year and the location. During in-migration, bull trout moved both day and night, but as migration proceeded upstream, movements were more common at night. However, at obstacles (log jams, rapids, and waterfalls) most movements were diurnal, which agrees with observations made elsewhere in the Wenatchee National Forest, most notably at Peek-a-Boo Falls- named for the behavior of fluvial bull trout there (Brown 1994). Upstream movements of fluvial bull trout in the Columbia River and in the ladders at Rock Island Dam and Rocky Reach Dam also occur mainly during daylight hours (BioAnalysts 2004, Stevenson et al. 2006 and 2007). During out-migration, the majority of movements in the Entiat Core Area were recorded at night.

Bull trout migrations in the Entiat Core Area are not necessarily an orderly and continuous movement. Both upstream and downstream migration speeds varied depending upon the stream reach, and individuals stopped moving for extended periods. Migration speed was significantly slower in the Mad River, and is probably related to the higher gradient, step pool geomorphology, and numerous natural obstacles. In addition, the size of individual bull trout can influence migration speed and distance (Schiff et al. 2005, Monnot et al. 2008), and some of the differences may be due to the significantly smaller bull trout in the Mad River. Overall, upstream migration speeds of bull trout in the Entiat Core Area were similar to other river systems, where speeds ranged from 0.2 – 1.2 km/day in tributaries to Lake Revelstoke on the Columbia River, British Columbia (Bray 2003) to 4.4 km/day in the Blackfoot River, Montana (Swanberg 1997). Although the overall downstream migration speeds were similar to the 1 – 4 km/day reported in British Columbia (Bray 2003), the speeds in some sections of the Entiat River were much faster. In particular, the reach between the confluence of the Mad River and the Stillwater Section at MacKenzie Diversion was traveled extremely fast during both up- and downstream migrations in all years. It may be that suitable bull trout habitat is limited in this reach, and stream restoration projects may have potential to improve habitat.

Post spawning bull trout altered their migratory behavior in response to local conditions and foraging opportunities. During the out-migration of 2003, bull trout congregated in the Entiat River upstream of the mouth, apparently taking advantage of ephemeral forage downstream of summer Chinook salmon redds. This behavior was observed only in 2003 when 189 summer Chinook salmon redds were counted in the lower 1.4 miles, including 99 redds immediately upstream of the congregated bull trout (Hamstreet and Carie 2004). It was not observed during out-migration in 2004 – 2006, when only 16 to 29 redds were counted in the entire reach (Hamstreet 2005, 2006, 2007). A similar opportunistic response was exhibited by bull trout code 38 in 2006, when it spent several days

downstream of summer Chinook salmon redds at the Whitehall restoration project at rkm 5.1. Prior to implementation of the restoration project, very few salmon redds were located there (Hamstreet 2007) and tagged bull trout quickly moved through the area. As restoration projects such as the Bridge to Bridge Restoration Project improve fish habitat, bull trout movement patterns and habitat use may change in response, and areas that currently appear unattractive to bull trout may be used.

Bull trout from all three core areas in the Upper Columbia Recovery Unit use the Columbia River reservoirs as over winter habitat (BioAnalysts 2004, LGL and DPUD 2006 and 2007, Stevenson et al. 2006 and 2007, Nelson et al. 2007), but migration distances of tagged bull trout from the Entiat Core Area were shorter than those from other core areas. In the Methow Core Area, tagged bull trout from the Columbia River migrated as far as 220 km between spawning tributaries and over-wintering sites in the Columbia River (Nelson et al. 2007), compared to a maximum distance of 110 km recorded for Entiat Core Area fish. No USFWS-tagged Entiat Core Area bull trout over-wintered downstream of Crescent Bar in the Columbia River (rkm 708). During the 2001 – 2004 PUD study, only 6% of all tagged bull trout were located further downstream, and half of those fish migrated into the Wenatchee Core Area (BioAnalysts 2004).

Tagged bull trout from the Entiat Core Area were distributed throughout the mid-Columbia River hydro-projects, with an equal number utilizing Rocky Reach reservoir and Rock Island reservoir. However, apparently more Mad River fluvial bull trout utilize the Rocky Reach pool than do upper Entiat River bull trout. This may be in part due to the smaller size, slower out-migration rate, and longer tributary residence of adult bull trout from the Mad River.

Although this study was not designed to determine the effects of Rock Island and Rocky Reach dams on bull trout movements and survival, several USFWS-tagged bull trout in the Columbia River were tracked and their movements were recorded at the telemetry systems at the dams. In 2004, USFWS-tagged bull trout averaged about 2 days to pass each dam during spring migration, compared to the 5.1 – 8.7 days observed during telemetry studies and monitoring programs by the Chelan County Public Utility District (BioAnalysts 2004, (Stevenson et al. 2006 and 2007). The difference could be due to the low sample size of USFWS tagged bull trout, yearly changes in Columbia River flow and conditions, or to post-tagging effects on the behavior and performance of the fish. Overall, the fish ladders appeared to provide adequate passage, and staging of bull trout at the mouth of the Entiat River and in Box Canyon provided a buffer to the delays at the dams.

It has been suggested that Columbia River dams block migration of bull trout to upriver natal streams or cause straying into other populations (WDFW 2004), but this is difficult to monitor and interpret. Unfortunately, there is no information on bull trout prior to the construction of the dams, so there is no baseline of “normal” movements for comparison. In addition, telemetry techniques have the potential to unintentionally alter behavior and influence movements. For example, in 2001 and 2002, several of the CPUD-tagged bull trout released in the tailrace of Rocky Reach moved downstream and entered the

Wenatchee River (BioAnalysts 2004). Because the bull trout were tagged at the top of the fish ladder, presumably they were migrating to upstream tributaries and it is reasonable to assume the experiment, rather than the dam, influenced the movement into the Wenatchee River. In addition, bull trout may not spawn every year (Fraley and Shepard 1989) and if these fish were not on a spawning migration, they may not have had the physiological drive to re-ascend the dam and instead moved to the nearest tributary. This is illustrated by the movements of USFWS-tagged bull trout codes 70 and 81. In 2004, code 70 was tracked to the tailrace of Rocky Reach Dam before moving downstream and ascending the Wenatchee River, where it ultimately resided in the lower river through the spawning season. In 2005, code 80 ascended the Wenatchee River without first approaching the dam, moved into Peshastin Creek before it descended the river, migrated through Rocky Reach Dam and spawned in the upper Entiat River. These movements may have been influenced by the reproductive state of the individual fish, as code 70 was in the upper Entiat River in 2003 during the spawning season, while code 81 exited the Entiat River in 2004 prior to spawning.

The recorded migration time in the Columbia River from Rocky Reach Dam to the Entiat River was influenced by staging at the mouth and the length of time bull trout spent in the lower Entiat River prior to passing the PUD fixed station at rkm 5.1. Thus the migration time to the Entiat River reported by Chelan PUD (BioAnalysts 2004, Stevenson et al. 2006 and 2007) is longer than the actual time bull trout took to arrive at the river. Bull trout migrations in the Entiat Core Area are not necessarily an orderly and continuous movement. Migration speed varied among individual fish and stream reach, and some bull trout stopped for extended periods before resuming migration. The fact that later bull trout passed earlier bull trout and sometimes arrived earlier on the spawning grounds supports the CPUD conclusion that the time spent passing Columbia River dams does not significantly delay or prevent bull trout from reaching the spawning areas in either the Mad or Entiat rivers (BioAnalysts 2004).

Several USFWS-tagged bull trout migrated downstream through Rocky Reach and Rock Island dams and no mortality of adult fluvial bull trout could be attributed to hydroelectric operations. Some tagged bull trout moved downstream through the dams in consecutive years with no apparent negative consequences. Similarly successful passage of bull trout tagged by Chelan PUD was observed during studies in 2001 – 2003 (BioAnalysts 2004), and during 2005 – 2006, a total of 34 downstream passage events without mortality were documented (Stevenson et al. 2006, 2007), including some of the bull trout from the Entiat Core Area reported on in this paper. Telemetry studies at other dams in the Northwest have also observed successful downstream passage of bull trout. In Idaho, tagged bull trout have survived entrainment through dams during high spring flows at Dworshak Dam on the North Fork Clearwater River (Schiff 2005) and Arrowrock Dam on the Boise River (Salow and Hostettler 2004). In the Clark Fork River, Montana, tagged bull trout moved downstream of Milltown Dam (Swanberg 1997b, Schmetterling 2003), and based on preliminary data from 2001 – 2004, more than 80 % of tagged bull trout survived downstream passage through the turbines at Cabinet Gorge Dam (Hintz and Lockard 2007). In British Columbia, Canada, tagged bull trout

successfully moved downstream through Duncan Dam in the upper Columbia River system (O'brien 2001).

The plasticity and flexibility of individual post-spawning dispersal patterns may be a behavioral adaptation that could reduce the risks to local populations. Not all bull trout returned to the Entiat Core Area each year- some visited other core areas or spent the summer in the Columbia River. Some fluvial bull trout successfully over wintered in the Entiat Core Area, including two that over-wintered on the upper Entiat River spawning grounds. Bull trout migrating to over-wintering sites in the Columbia River moved both up and downstream of the Entiat River confluence, and some exhibited fidelity to one location while others move around to several sites. Many bull trout stayed only in the Rocky Reach reservoir and never passed through any dams. Therefore, dam counts may not be an accurate measure of populations in the Columbia River and the Upper Columbia Recovery Unit.

Effects of natural obstacles and barriers in the migration corridors

During the study, several impacts of natural obstacles and barriers were documented in the fluvial bull trout migration corridors, including effects on upstream migration, spawning site accessibility, and downstream migration. There is little modern research on the effects of debris jams on upstream or downstream movements of migratory fish (Hendricks et al. 2003), but it is well known that large jams can sometimes block migrating fish and close off areas to spawning (Meehan 1974, Hall and Baker 1982). Most determinations of the degree of obstruction rely on the presence or absence of redds or large individuals upstream of the jam (Hendricks et al. 2003). Those types of observations in the Methow Core Area of the Upper Columbia Recovery Unit suggest that debris jams have acted as temporary barriers and obstacles to bull trout migrations in West Fork Methow River (USFS 2003, 2005a), Chewuch River (USFS 2005a), and Wolf Creek (USFS 2005b). Radio-telemetry observations of fluvial bull trout at the Wolf Creek debris jam indicated low stream flow is a factor in changing the jam from an obstacle to a barrier (Nelson et al. 2007).

Several factors directly contribute to the mortality of adult bull trout in log jams, including death from entrapment, stranding as water level drops, and predation. In Idaho, predation on bull trout "climbing" over log jams was judged as a likely source of mortality (Schill 1994). This behavior apparently increased the vulnerability of migrating bull trout to predation, and explained why most recovered tags were located well downstream of spawning areas, as the numerous log jams made it unlikely post-spawning carcasses merely drifted downstream (Schill 1994). This is similar to the situation in the Mad River, where the jams that most motionless tags were located were a minimum of 2 km downstream of the spawning area. The recovery of radio tags, carcasses, and live bull trout (tagged and untagged) confirmed that debris jams act as direct agents of mortality during both in- and out-migration in the Mad River. The indirect effects of debris jams include delay or prevention of out-migration. Several post-spawn tagged bull trout were observed holding in pools created by jams, and none of those fish survived the winter, as the tags were recovered at those locations the following spring.

From a population perspective, the greatest potential impact of log jams and obstacles occurs when in-migrating bull trout are prevented from reaching the preferred spawning grounds. In the upper Entiat River in 2006, the majority of adult bull trout could not pass through Box Canyon and were unable to spawn in the optimal reaches, and the redd count was much lower than expected. In the Mad River, from 1999 through 2005, no migratory bull trout were able to reach the best spawning grounds, and were forced to utilize only the lower third of the spawning habitat. Although the number of redds counted downstream of the Alma Creek barrier remained fairly constant until 2006, only one third of the rearing habitat was available to juveniles, presumably increasing densities of young bull trout. When densities of juvenile bull trout are high, interactions between the age cohorts reduce survival rates of age 1 and 2 bull trout (Paul et al. 2000). Coupled with the increased mortality of adults, those density-dependent cohort interactions can result in a cyclic pattern in the population (Paul et al. 2000). This may explain the low redd count in 2006, and illustrates that the effects of barriers may not become apparent in the population until years after the blockage began.

Large, channel spanning log jams are common in the Mad River, but are mostly absent from the Entiat River, mainly due to the geo-morphological differences and disturbance history of each area. Among other things, formation of log jams is dependent on flow conditions (O' Connor et al. 2003), stream width and log length (Gurnell et al. 2002), log orientation (Abbe and Montgomery 2003), and availability and/or sources of wood (Reeves et al. 2003). Once the log framework is in place, stream flows incorporate smaller woody debris into the structure (Jackson and Sturm 2002). Sediments and gravels then accumulate upstream of the jam, resulting in a step-pool formation (Buffington et al. 2002), with variable step height (Curran and Wohl 2003). The narrow channel of the Mad makes it more likely that a fallen tree or log will span the channel and anchor on one or both banks, either by root wad or wedged on boulders. The Entiat River is wide, stream flows orient logs parallel to the current, and most log jams are located in bends or at points of islands, so it is unlikely channel spanning jams will form, except at pinch points like Box Canyon.

Much of the historic large woody debris (LWD) was probably removed from the Entiat River prior to 1925 by the logging practices of splash dams and log drives (Andonaegui 1999). Splash damming and log drives apparently did not occur in the Mad River. In 1948, the lower Entiat River was channelized during flood rehabilitation (Andonaegui 1999), likely reducing further the amount of woody debris. In 1971, following fires and flooding, the Army Core of Engineers removed woody debris from 16 kilometers of river on both Federal and private lands (USDA 1979). In 1974, a natural log jam was removed on the Mad River, and debris was cleaned out of the Entiat River in a 1.2 kilometer stretch below Silver Creek and a 0.8 kilometer stretch downstream of Fox Creek (USDA 1979).

It appears that small pieces of woody debris, such as tree branches and bark, are the agents that interact with logs to make a barrier for migrating bull trout. Small branches in the jam can act like pickets in a weir (see Figure 46), and along with bark and other small debris, wedge against logs to make an effective barrier (see Figures 48 – 49). Intense

wildfires, such as the Tyee Fire of 1994, may increase the input of small woody debris by killing mature trees, and over time, the branches and bark slough off the trunk and enter the stream. The formation of debris dams containing this smaller material may not be evident until 10 years after a wildfire (Minshall et al. 1989). Much of the small material in the Mad River is dried or fire hardened, and may persist in the stream longer than expected. There are few long term studies on impacts of wildfire on in-channel large woody debris (Berg et al. 2002) or on the rates of input, retention and decomposition of small debris, but the effects of wildfire on woody debris recruitment can last for decades (Swanson and Lienkaemper 1978, Greswell 1999).

The longevity of in-stream large woody debris has been studied mainly in coastal streams, with little emphasis on inland waters, and decomposition and age of LWD is highly variable (Scherer 2004). In a coastal stream, time since recruitment ranged from 1 – 1400 years, with a mean of 84 years and a median of 19 years (Hyatt and Naiman 2001). Longevity of LWD is directly related to bole diameter- in Alaska, small LWD (10 – 30 cm) was less than 110 years old since recruitment and larger LWD (>60 cm) was up to 226 years old (Murphy and Koski 1989). Therefore, it is likely that the Mad River log jams have been in place for a long time. In 1972, during a USFS survey of the Mad River, several channel-spanning log jams were recorded (Holtby 1972), including the large log jams at Camp Nine and Alma Creek. Some of the jams were described as barriers to fish passage during the survey (Holtby 1972). Although the Alma Creek jam became passable to migrating bull trout during 2006, the framework of large logs remained in place, and the obstacle could become impassable again and re-block access to most of the spawning and rearing habitat. The log and debris jam at Camp Nine (rkm 15.9) could develop into a barrier to upstream migration and potentially block access to all bull trout spawning and juvenile rearing habitat, and force adult bull trout to endure warmer than optimal water temperatures.

It is important to note that it is not LWD per se, but rather a few log/debris jams at key locations that impact bull trout in the Entiat Core Area. Over the long term, the benefits of fire- or other-cause related debris recruitment probably outweigh the negative impacts (Reeves et al. 1995). It is well known that LWD has many benefits for stream ecosystems, including complexity of habitat (Bryant 1983, House and Boehne 1986), fish cover (Kiem et al. 2002), channel morphology (Hildebrand et al. 1997, Jackson and Sturm 2002), sediment transport and storage (Bilby and Ward 1989, May and Gresswell 2003, Montgomery et al. 2003), extent of alluvial channel beds (Montgomery, Massong, and Hawley 2003), accumulation of spawning gravels (MacPhail and Baxter 1996, Swanberg 1997), pool area and frequency (Beechie and Sibley 1997), increased carrying capacity and quality habitat for juvenile salmonids (Dolloff 1986, Cederholm et al. 1997), habitat for macroinvertebrates and macrobenthos (Elliot 1986), and juvenile fish movements (Harvey et al. 1999, Roni and Quinn 2001).

The smaller size of adult bull trout in the Mad River may be related to the high mortality of post-spawning adults in the Mad River, and most of the bull trout spawning there may be young adults reproducing for the first or only time. In contrast, prior to 2006, there were no major barriers in the Entiat River. More adults were able to freely migrate back

and forth between the Columbia River and the upper Entiat River spawning grounds, growing larger and spawning several times. Because log jams and obstacles affect the spawning, rearing and survival of bull trout, they may have also influenced some of the genetic differences observed between local populations (Rieman and Clayton 1997). Our study validates Brown's (1992) observation that spawning bull trout in the Mad River are smaller than in the upper Entiat River and probably other populations in the Upper Columbia Recovery Unit as well.

Congregation of adult bull trout at obstacles and barriers increase their vulnerability to poaching and illegal take. Anecdotal reports from local citizens and observations of snagged fishing tackle indicate poaching of bull trout occurs in the Entiat Core Area. In August 2004, when adult fluvial bull trout were visibly congregated in Box Canyon, two men with fishing rods were observed in this closed fishing area. Although they denied fishing for bull trout, their abandoned tackle was later discovered, including a closed fishing sign they had removed from the parking area. It was apparent from their comments that they were also aware of other areas that bull trout congregate downstream of obstacles. Although intentional poaching is probably relatively uncommon in the Entiat River, the actual number of poachers is difficult to determine. However, just a few people targeting these vulnerable bull trout could have a large impact on the spawning population (Long 1997).

Stream temperatures

Stream temperatures are strongly associated with the distribution of bull trout, and the probability of occurrence of small bull trout is relatively low (< 0.50) at temperatures above 16 °C (Dunham et al. 2003). Maximum weekly maximum temperatures (MWMT) of 13 °C during June, July, and August are considered necessary to be fully protective of juvenile bull trout rearing (Essig et al. 2003), and 13.2 °C is the optimal temperature for growth (Selong et al. 2001). In the Entiat Core Area, optimal temperatures are routinely exceeded, and in some years, for weeks at a time (Archibald and Johnson 2003, see also Appendices 4 - 5). In the upper Entiat River, MWMT ranged from 13.5 – 16.4 °C in the spawning and rearing reaches upstream of Box Canyon (rkms 47 – 54) during 2003 – 2006. Downstream of Box Canyon at rkm 41.8, MWMT ranged from 15.1 – 18.7 during 2000 – 2005, indicating that in most years, it is probable that very little rearing of juveniles occurs downstream of the optimal spawning reach. The coldest waters in the watershed normally accessible to bull trout occur in the Mad River spawning and rearing reach between Cougar and Berg Creeks (rkms 24 – 28.5), where MWMT ranged from 12 – 15.3 °C during 1999 – 2005 (Table 20). However, migratory access to this area was blocked by the Alma Creek debris jam from 1999 – 2005, so most of the spawning and rearing in those years occurred between Cougar Creek and Young Creek, where MWMT was 13.5 – 16.5 °C. Three kilometers downstream at the Camp Nine gage station, MWMT ranged from 18.6 – 19.5 °C during 2003 – 2005, indicating that the temperature limit to juvenile rearing is likely just downstream of Young Creek.

Most of the warming observed in the Mad River temperature profile occurs between Cougar Creek and Camp Nine (Archibald and Johnson 2003, see also Appendix 5), an area where much of the riparian overstory vegetation was killed during the 1994 Tyee

Fire. Wildfire can significantly increase stream temperatures (Amaranthus et al. 1989, Heck 2007) and summer maximum water temperatures can remain elevated for a least a decade (Dunham et al. 2007). Increased water temperatures after wildfire are correlated with the amount of surviving shade and summer stream flow (Amaranthus et al. 1989). Although loss of riparian shade may account for some of the magnitude of temperature increases in the vicinity of Camp Nine, the warming trend was also observed when the canopy was intact, and is most likely related to the geology and exposed bedrock of the area (Archibald and Johnson 2003).

Limited observations of movements and water temperature data for two tagged bull trout indicated that adults were able to tolerate maximum daily temperatures of 20 °C in the Entiat Core Area. In the Mad River, bull trout code 72 was located downstream of the Camp Nine log jam when water temperatures reached 20 °C in 2004. After deploying an automated temperature logger within 15 m of the bull trout's location, spot checks with a handheld thermometer at several locations in the 100 m stretch near the fish, including its exact location, did not detect any measurable temperature differences between points. Thus it appeared there were no local thermal refugia for the fish to use. However, the daily temperature change was as high as 7.5 °C at the site, suggesting the thermal refugium may be temporal rather than spatial. Laboratory and field studies of cutthroat trout have illustrated the importance of the diel temperature cycle and cool nighttime temperatures for tolerance of sub-optimal temperatures (Johnstone and Rahel 2003, Schrank et al. 2003).

In 2004, over a two month period, bull trout code 53 made repeated up- and downstream movements in the Entiat River and encountered maximum daily stream temperatures > 20 °C at rkm 33. It is possible this fish was using localized thermal refugia (Torgersen et al. 1999) and that the movements were behavioral thermoregulation (Baird and Krueger 2003). The daily temperature change was 2.9 °C at rkm 33, so a slight temporal refugium may have occurred as well. Thermal infrared (TIR) remote sensing indicated that stream temperatures are relatively constant between river kilometers 30 – 40 (temperature ranged from 18.9 to 20.1°C on August 11, 2001) , and tributaries, as well as groundwater, may contribute cooler water that mitigate temperatures in this reach (Watershed Sciences 2002). The Entiat River begins to warm again downstream of rkm 30, but it is unknown if this presents a seasonal thermal barrier to further downstream movement. There are indications there is not a lethal thermal barrier in the lower river, as a few tagged bull trout moved through the lower Entiat in late July and August when they exited the Entiat Core Area prior to spawning, and most returned the following spring.

Water temperatures in the Entiat River exhibited a downstream warming trend during the TIR survey (Watershed Sciences 2002). The Entiat River's natural meteorological conditions are the driving factor in elevated stream temperatures (Hendrick and Monahan 2003), and cooler water temperatures in the spawning reaches probably have natural limitations. Stream network temperature model (SNTEMP) simulations predicted that increasing shade and/or decreasing channel width were most feasible for reducing water temperatures in the lower 16 kilometers of the Entiat River, and a 50% increase in canopy cover and a 50% decrease in channel width would likely have the most achievable and

significant effect (Hendrick and Monahan 2003). An increase in shade in the upper river may also moderate high temperatures (Hendrick and Monahan 2003).

Recovery planning

Bull trout recovery planning is an ongoing and adaptive process, and plans for most recovery units are still in draft format (USFWS 2002 and 2004). The results of this telemetry study provide information that should help guide and refine recovery planning in the Upper Columbia Recovery Unit.

Bull trout recovery criteria are based on distribution among populations, total abundance, trends, and connectivity of core areas in the recovery unit (USFWS 2002 and 2004). In the Entiat Core Area, 148 redds in the upper Entiat River and 75 redds in the Mad River, maintained over at least 2 generations, were estimated as the minimum contribution to the total abundance in the unit necessary to achieve recovery in the Upper Columbia Recovery Unit (USFWS 2002 and 2004). During at least one year of this study, both the Mad River and upper Entiat River populations reached the minimum of 50 redds needed each year to minimize the risks of inbreeding in the populations (Rieman and Allendorf 2001). Without the effects of barriers at Alma Creek and Box Canyon, it appears that over 50 redds could have been attained in both local populations in several years.

Based on telemetry, temperature data, and spawning ground surveys, it appears the preferred spawning habitat in the upper Entiat River is between Box Canyon and Entiat Falls, a distance of about 7 km. Although this is longer than the 1.6 km presumed to be present by Washington Department of Fish and Wildlife (WDFW 2004), it is much shorter than the 24 km of spawning and rearing habitat used to calculate the estimated recovery abundance in the draft recovery plan (USFWS 2002 and 2004). Some spawning occurs within Box Canyon and perhaps downstream to Fox Creek, but suitable gravels are few and patchy in this reach. Stream temperatures downstream of Fox Creek are a limiting factor, and in most years it appear likely that little if any juvenile rearing would occur there. Thus, it may be misleading to assume that all of a presumed spawning reach is suitable habitat (see Baxter and Hauer 2000), and that simple expansion of numbers will result in a realistic estimate of potential population size and recovery. Most redds were clustered in the alluvial fans at the confluences of Pope Creek and Silver Creek, or in the tail-out of the gage hole pool downstream of Entiat Falls, and the clustering indicates suitable gravels and spawning habitat in the index reach are not evenly distributed. Therefore, it is important to accurately map redd locations with GPS units to determine if the same limited areas are used or if redd locations change or expand over time.

The actual number of adult bull trout per redd is unknown in the Upper Columbia Recovery Unit, but has been estimated from 2 to 3.2 fish per redd in other areas (Brown 1994). In the Mad River, a large tagged male was observed with digging females on two separate redds, with the second observation occurring 8 days later in the same area. A total of six other redds were constructed in the immediate vicinity, and no other males were observed competing for the females during either observation. This suggests that

one male may have spawned with several females, or that females may have constructed more than one nest, and that there may be less than 2 bull trout per redd in the Mad River.

Natural factors in the Entiat Core Area appear to have much greater impacts on local populations than previously realized and a greater awareness of natural variations in bull trout populations is needed in order to set realistic criteria of recovered abundances. For example, the range of numbers estimated for the Mad River in the initial draft recovery plan included a redd density based on the reach downstream of the Alma Creek debris barrier (USFWS 2002). However, that redd density was high only because bull trout could not pass to the preferred spawning habitat. When passage through the debris jam became possible, most redds were constructed upstream (Archibald and Johnson 2006), and redd densities both downstream and upstream of the debris jam were at much lower 'natural' levels.

Barriers, obstacles and major disturbances highlight the trade-offs of migratory versus resident life histories. Migrants gain increased size and reproductive potential, but can experience higher mortality (Jonsson and Jonsson 1993) or may not be able to return to realize that advantage. If migrants can return and spawn, they may not survive the out-migration or spawn more than once. However, the migratory form is very important in re-colonization after major disturbance events such as wildlfire (Rieman and Clayton 1997). In contrast, while a resident has reduced reproductive potential, it is always 'home' to spawn for several seasons and may not be affected by obstacles or temporary barriers. In turn, however, residents are susceptible to local extirpation due to major disturbances (Rieman and Clayton 1997). It is uncertain if the resident life history is present in the Entiat Core Area. Brown (1992) considered upper Entiat River bull trout to be fluvial, but thought Mad River bull trout may persist as both fluvial and resident stocks. All bull trout redds measured during spawning ground surveys of both populations have been considered fluvial in origin (Archibald and Johnson 2005, Nelson and Nelle 2007), but at least one resident-sized male was observed attempting to spawn with a tagged fluvial female in the Mad River. Snorkel surveys conducted in the Mad River upstream of Alma Creek while the debris jam was a migration barrier detected small bull trout but were inconclusive as to life history (Archibald and Johnson 2005b). No bull trout of either life history form have been detected upstream of Entiat Falls in the upper Entiat River (Brown 1992, USFWS 1996, Proebstel et al. 1998, Archibald and Johnson 2005c).

If the current trends in world warming and climate change continue as predicted, models indicate migratory bull trout will decline and disappear, and only resident bull trout at higher elevations will persist in the recovery unit (Rieman et al. 2007). The coldest water and highest elevations in the Entiat Core Area are upstream of Entiat Falls (Watershed Sciences 2002), and it may be prudent to consider some form of assisted passage of bull trout above the falls. There are ethical and biological issues to consider before providing any passage, including the effects of bull trout on salmonid populations above Entiat Falls. However, it is uncertain if the rainbow trout and westslope cutthroat trout present upstream of Entiat Falls are native. Rainbow, cutthroat and brook trout have been intensively planted since at least 1933 (CCCD 2004), and phenotypic and genetic analyses have not conclusively identified any native stocks upstream of Entiat Falls

(Proebstel et al. 1998, Howell and Spruell 2003). Perhaps more importantly for bull trout, introduced brook trout are present upstream (Archibald and Johnson 2005c), and removal or control of these fish would be needed to prevent potential competition and hybridization with bull trout. Even without passage assistance at the falls, control of brook trout is recommended, as these fish are a source for downstream movement and establishment of brook trout populations in the bull trout zone.

Because the Entiat Core Area contains only two local populations of bull trout, the probability of local extinction is much higher than in other areas of the Upper Columbia Recovery Unit. Factors that increase the risk include stream temperatures that limit spawning and rearing habitat and debris jams that act as migration barriers. Management and restoration actions have the most potential to reduce stream temperatures in the lower river, which may benefit subadult habitat and migration, but will have only limited effects on spawning and rearing. Actions that would have immediate and beneficial effects on migration, spawning, and rearing in both local populations would be removal or reduction of the Alma Creek debris jam and removal of the log and debris in the slot in Box Canyon. This would not require a wholesale removal of LWD, but rather a "surgical" action, targeted at those known problem areas. At the very least, the Box Canyon situation should be monitored, and if the number of redds remains low in the next two years, action may be required. The log jam at Camp Nine should also be monitored, for if it became a migration barrier, access to all spawning and rearing habitat in the Mad River would be blocked.

Recovery actions requiring monitoring should consider the length of studies needed to gather meaningful information on movement and population patterns. If this telemetry study had ended after two years, it would have missed most of the impacts of debris jams on adult migration and spawning, and we later may have erroneously interpreted that factors outside the core area were the cause of the decline in the number of redds observed during spawning ground surveys. While there are many other issues affecting bull trout in the watershed (USFWS 2002 and 2004), including fall floods causing scour as well as sedimentation of redds (Archibald and Johnson 2006), it appears access to spawning and rearing habitats and stream temperatures are the limiting factors to the growth of local populations in the Entiat Core Area.

Recommendations

The following actions regarding bull trout in the Entiat Core Area are recommended for consideration and implementation:

1. Monitor fluvial bull trout passage at Box Canyon in the upper Entiat River, and at the log debris jams at Camp Nine and Alma Creek in the Mad River, and if necessary, develop an action plan for providing passage.
2. Continue spawning ground surveys in both the Mad River and upper Entiat River.
3. Record the exact locations of all bull trout redds with GPS units for long-term monitoring and GIS mapping to precisely document utilization of spawning habitat.
4. Continue intensive snorkeling or electro-fishing surveys upstream of Entiat Falls to determine if resident bull trout are present.
5. Consider natural factors and incorporate their effects on populations into recovery planning and goals.
6. Review the estimated recovery numbers for upper Entiat River bull trout in the Draft Recovery Plan for the Upper Columbia Recovery Unit and adjust to reasonably reflect the available spawning and rearing habitat.
7. Increase patrols of USFWS and WDFW law enforcement officers to deter poaching of bull trout at Pine Flats, Box Canyon and the upper Entiat River.
8. Establish outreach and education of anglers to reduce angling in the closed fishing areas.
9. Explore options for brook trout removal and control.
10. Design, fund and implement scientific studies of juvenile and subadult bull trout habitat use and migration in the Entiat Core Area.

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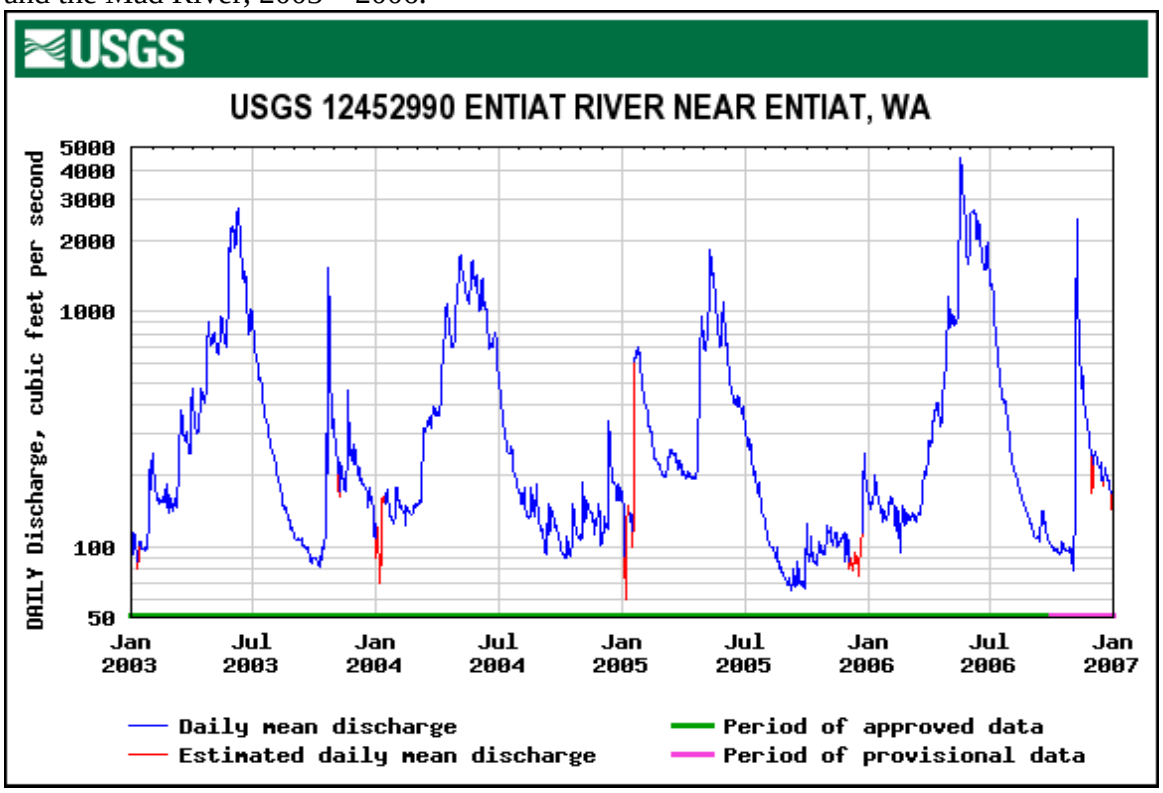
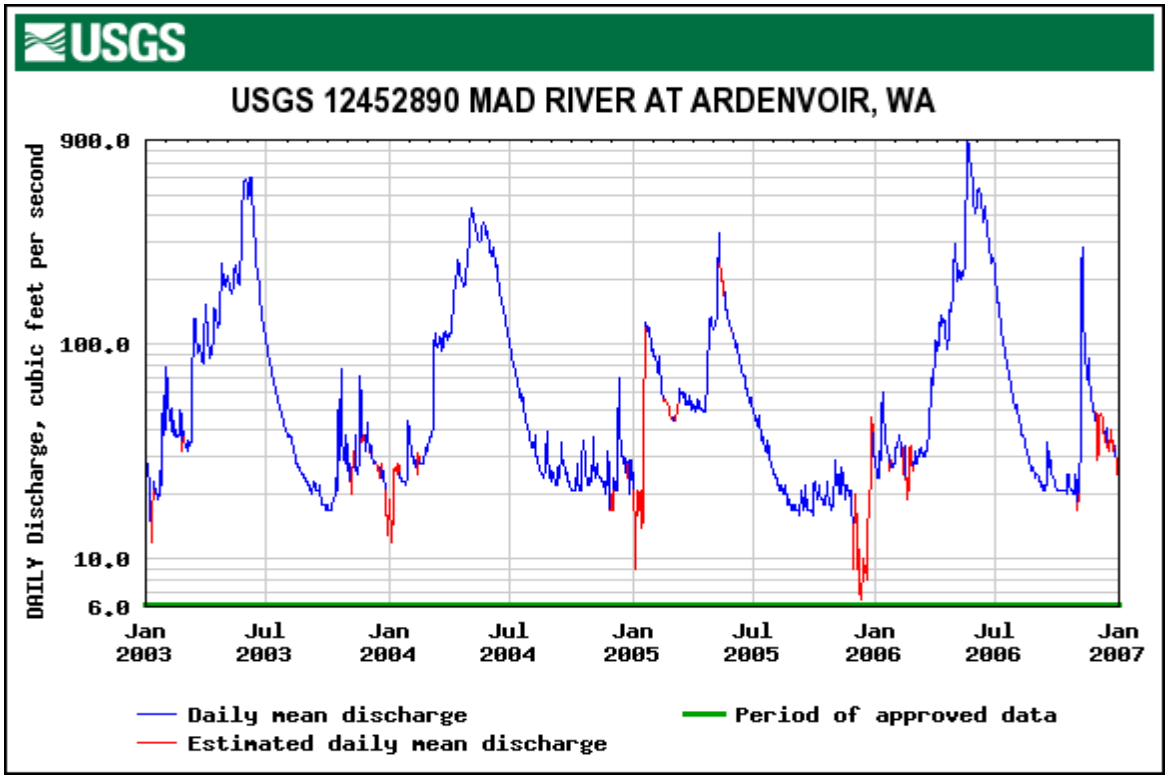
Appendices

Appendix 1: USGS hydrographs of daily stream discharge (ft^3/sec) in the Entiat River and the Mad River, 2003 – 2006.





Appendix 2. Tag code, tag size, tagging date, river, tagging location, river kilometer, mass, and length of adult fluvial bull trout tagged by USFWS in the Entiat Core Area, 2003 – 2004.

Tag code	Tag size (g)	Date	River	Location	rkm	Mass (g)	FL (mm)	TL (mm)
55	16	8/01/03	Mad	Dolly Holes	22.8	1225	485	509
56	16	8/01/03	Mad	Dolly Holes	22.8	1750	555	580
357	16	8/01/03	Mad	Dolly Holes	22.8	1250	496	520
58	16	7/30/03	Mad	Dolly Holes	22.8	1475	521	545
59	16	7/30/03	Mad	Dolly Holes	22.8	1250	500	522
60	16	7/30/03	Mad	Dolly Holes	22.8	1000	453	472
61	16	7/29/03	Mad	Dolly Holes	22.8	1025	464	482
62	16	7/30/03	Mad	Dolly Holes	22.8	1850	565	587
63	16	7/31/03	Mad	Dolly Holes	22.8	2000	570	592
64	16	7/31/06	Mad	Dolly Holes	22.8	1375	501	520
65	16	7/31/03	Mad	Dolly Holes	22.8	1475	524	549
366	16	7/31/03	Mad	Dolly Holes	22.8	1450	515	538
72	10	7/29/03	Mad	Dolly Holes	22.8	775	415	430
73	10	7/29/03	Mad	Dolly Holes	22.8	750	408	423
77	10	7/30/03	Mad	Dolly Holes	22.8	900	442	461
74	10	8/05/04	Mad	Dolly Holes	22.8	1000	465	483
80	10	8/05/04	Mad	Dolly Holes	22.8	1825	552	574
82	10	8/05/04	Mad	Dolly Holes	22.8	1750	540	563
83	10	8/05/04	Mad	Dolly Holes	22.8	1200	478	495
84	10	8/05/04	Mad	Dolly Holes	22.8	1250	493	512
78	10	8/05/04	Mad	Dolly Holes	22.8	1600	546	565
53	16	8/15/03	Entiat	Entiat Falls	54.5	2450	617	640
54	16	8/11/03	Entiat	Box Cyn	47	2750	638	668
67	16	8/11/03	Entiat	Box Cyn	47	1900	575	600
68	16	8/11/03	Entiat	Box Cyn	47	1575	540	565
69	16	8/11/03	Entiat	Box Cyn	47	2125	578	606
70	16	8/11/03	Entiat	Box Cyn	47	1425	522	548
71	16	8/11/03	Entiat	Box Cyn	47	1975	577	603
76	10	8/11/03	Entiat	Box Cyn	47	550	375	390
378	10	8/15/03	Entiat	Box Cyn	47	2325	610	635
79	10	8/15/03	Entiat	Box Cyn	47	1225	504	530
75	10	7/30/04	Entiat	Box Cyn	47	1470	512	533
81	10	8/02/04	Entiat	Box Cyn	47	1300	473	490
57	16	7/30/04	Entiat	Box Cyn	47	3100	656	682
66	16	7/30/04	Entiat	Box Cyn	47	1875	550	575

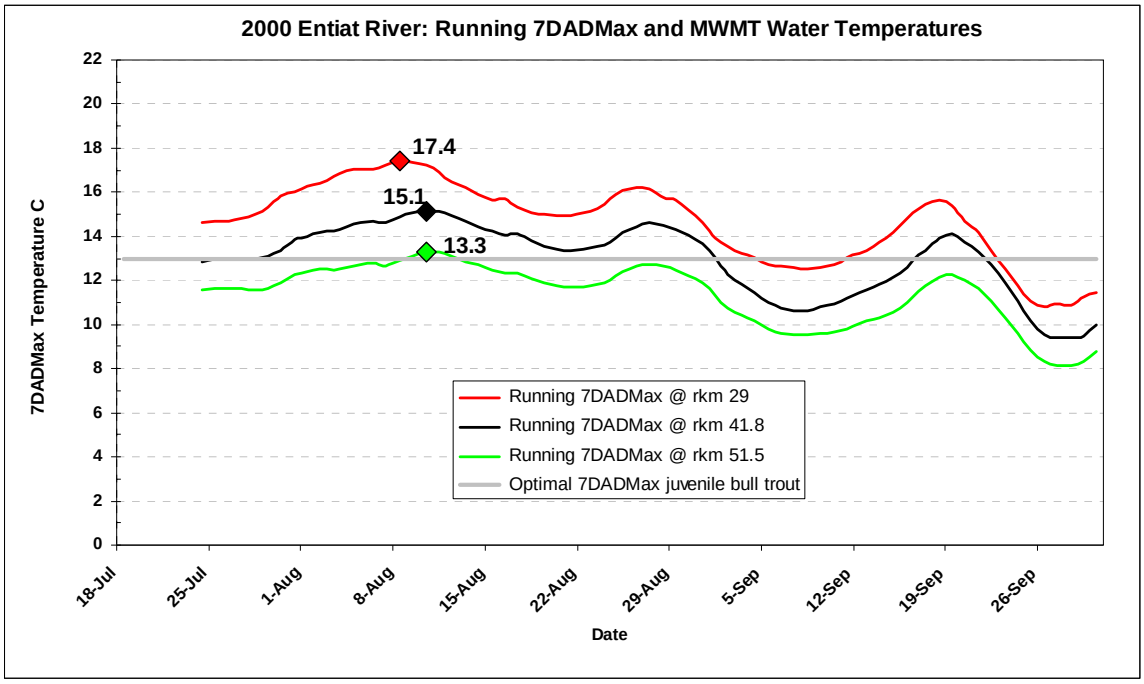
Appendix 3. Tag code, date, tagging location, river migrated to, mass, and length of adult fluvial bull trout radio-tagged by PUDs in the Columbia River that migrated to the Entait Core Area, 2002 – 2006.

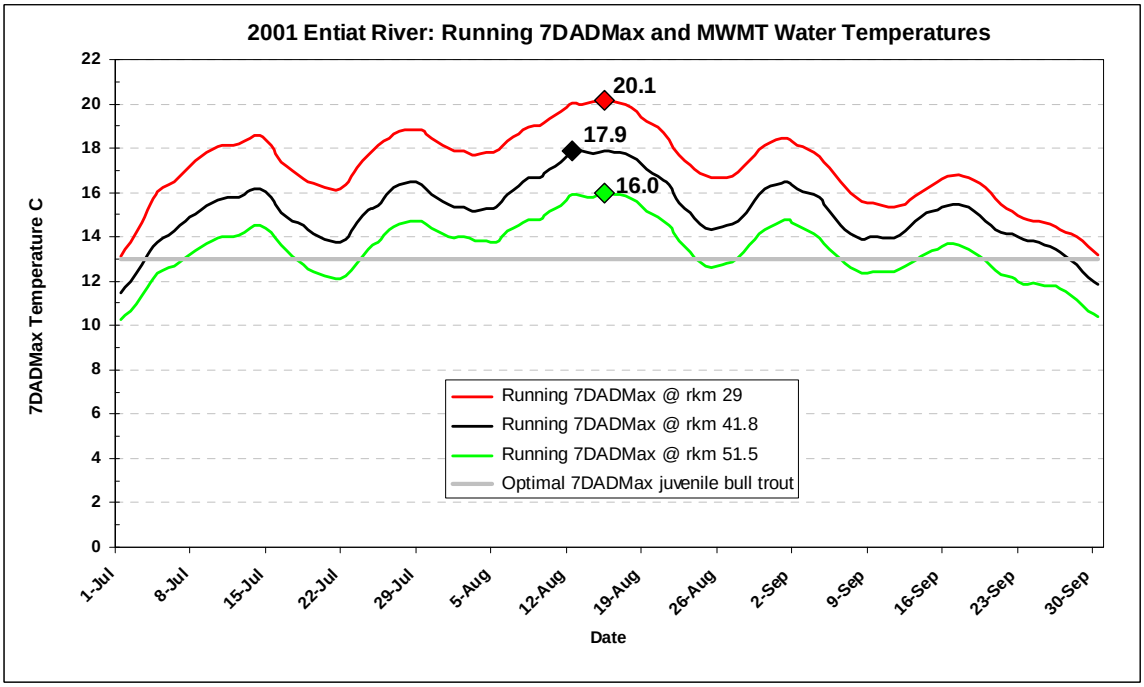
Channel	Tag code	Date	River	Location	Migrated to:	Mass (g)	FL (mm)
14	92	5/23/02	Columbia	RR	Mad	1950	505
14	103	6/06/02	Columbia	RR	Entiat	3300	614
14	104	5/30/02	Columbia	RR	Entiat	2000	560
14	106	6/06/02	Columbia	RR	Entiat	2500	585
14	114	6/10/02	Columbia	RR	Mad	1700	540
14	118	6/11/02	Columbia	RR	Mad	950	460
14	120	6/27/02	Columbia	RR	Mad	650	404
14	121	6/07/02	Columbia	RR	Mad	1350	481
14	125	6/26/02	Columbia	RR	Mad	1000	460
14	127	6/27/02	Columbia	RR	Mad	650	415
14	2	5/26/05	Columbia	RI	Mad	990	430
14	4	6/02/05	Columbia	RI	Mad	1224	460
14	16	5/19/05	Columbia	RR	Entiat	1834	550
14	17	5/20/05	Columbia	RR	Entiat	2343	590
14	18	5/24/05	Columbia	RR	Mad	1419	480
14	19	5/24/05	Columbia	RR	Entiat	2602	590
14	21	5/24/05	Columbia	RR	Entiat	3029	620
14	23	5/25/05	Columbia	RR	Entiat	2400	575
14	24	5/26/05	Columbia	RR	Entiat	2228	560
14	25	5/26/05	Columbia	RR	Entiat	2471	590
14	26	5/26/05	Columbia	RR	Entiat	3144	640
14	27	5/26/05	Columbia	RR	Entiat	4199	700
14	28	5/27/05	Columbia	RR	Entiat	3284	645
14	29	5/30/05	Columbia	RR	Entiat	1853	535
14	32	6/01/05	Columbia	RR	Mad	1127	475
14	33	6/03/05	Columbia	RR	Entiat	2227	585
14	34	6/06/05	Columbia	RR	Entiat	1222	465
14	35	6/07/05	Columbia	RR	Entiat	1399	495
14	36	6/07/05	Columbia	RR	Entiat	1458	490
14	37	6/07/05	Columbia	RR	Entiat	1316	465
14	38	6/07/05	Columbia	RR	Entiat	1384	495
14	39	6/08/05	Columbia	RR	Entiat	1123	455
14	40	6/16/05	Columbia	RR	Mad	1892	540
14	43	6/20/05	Columbia	RR	Entiat	1425	495
14	45	6/29/05	Columbia	RR	Entiat	1980	545
14	151	5/18/06	Columbia	RI	Entiat	2300	570
14	152	6/06/06	Columbia	RI	Entiat	3671	650
14	153	6/13/06	Columbia	RI	***unk***[1]	1972	555
14	166	5/17/06	Columbia	RR	Entiat	3392	645
14	167	5/17/06	Columbia	RR	Entiat	4163	720
14	168	5/25/06	Columbia	RR	Entiat	4167	700
14	169	5/25/06	Columbia	RR	Entiat	2736	590
14	170	5/25/06	Columbia	RR	Entiat	2796	600
14	172	5/25/06	Columbia	RR	Entiat	3640	660

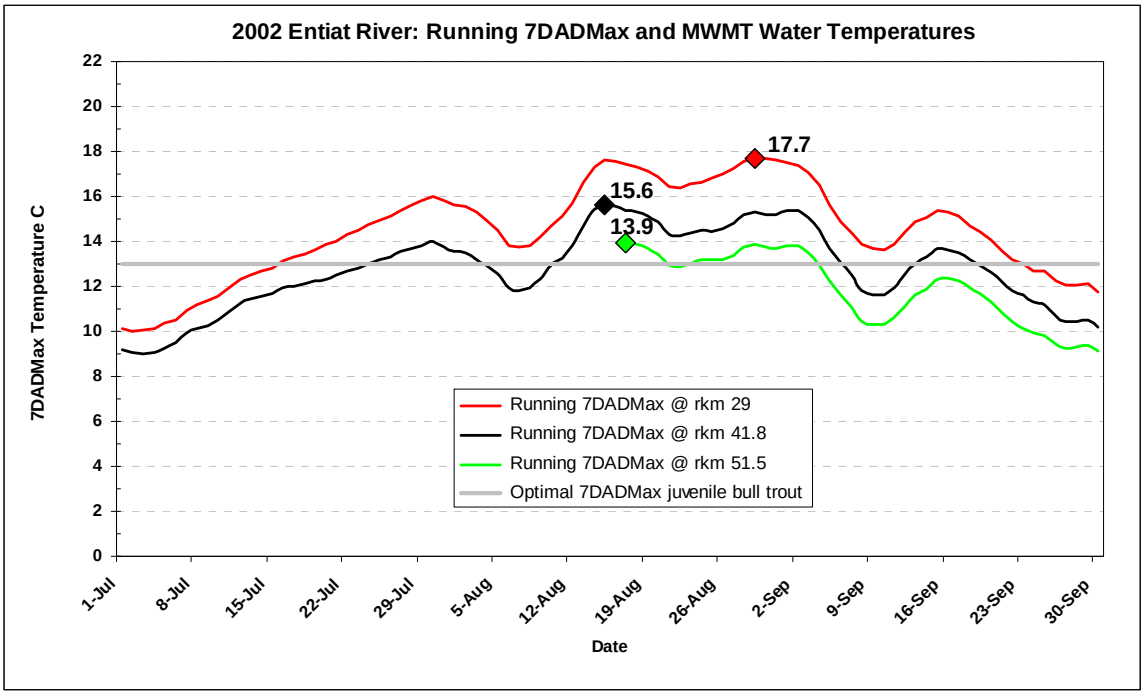
Channel	Tag code	Date	River	Location	Migrated to:	Mass (g)	FL (mm)
14	173	5/26/06	Columbia	RR	Entiat	3763	675
14	175	5/26/06	Columbia	RR	Entiat	2632	590
14	176	5/29/06	Columbia	RR	Entiat	3495	660
14	178	5/30/06	Columbia	RR	Entiat	1675	525
14	179	5/30/06	Columbia	RR	Entiat	2482	600
14	181	6/01/06	Columbia	RR	Entiat	1864	535
14	182	6/02/06	Columbia	RR	Entiat	3191	620
14	183	6/02/06	Columbia	RR	Entiat	1796	540
14	185	6/12/06	Columbia	RR	Mad	1525	510
14	187	6/16/06	Columbia	RR	Mad	1929	550
14	189	6/25/06	Columbia	RR	Entiat	3668	695
1	54	5/24/06	Columbia	Wells	Entiat	5160	650
1	66	5/24/06	Columbia	Wells	Entiat	3210	580
1	68	5/18/06	Columbia	Wells	Entiat	1890	540

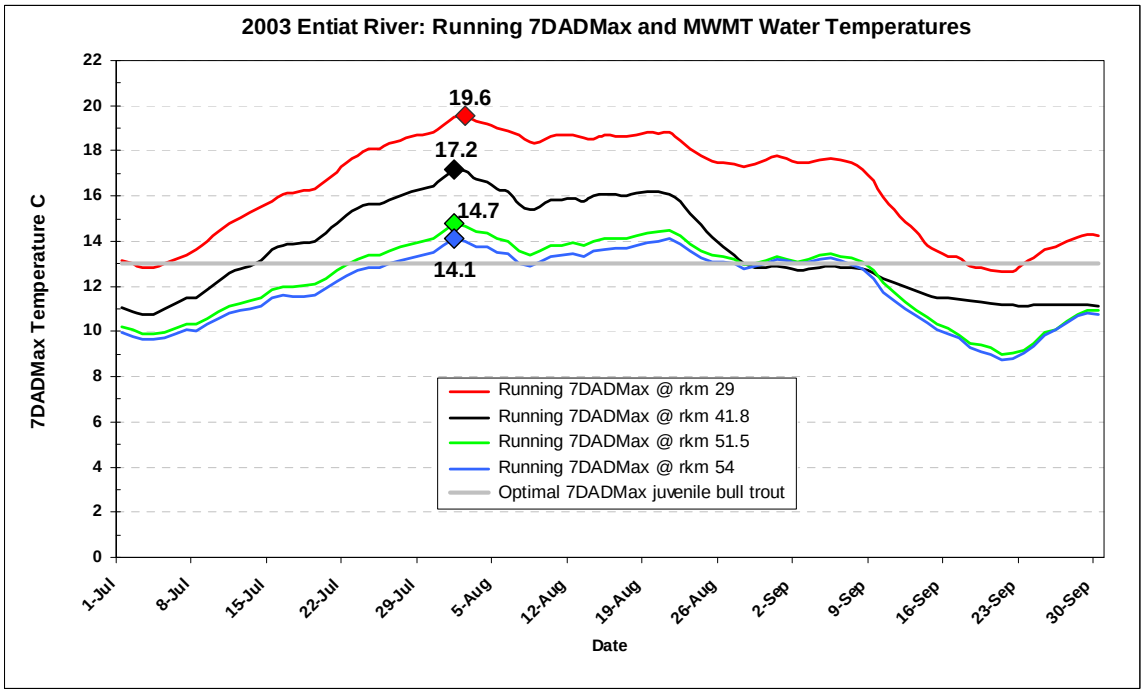
Note: 1- local population for code 153 is unknown: after tagging in 2006, it moved first to Icicle Creek in the Wenatchee Core Area before migrating into lower Entiat where the tag was recovered at rkm 12. Data from BioAnalysts (2004), Stevenson et al. 2006, Stevenson et al. 2007).

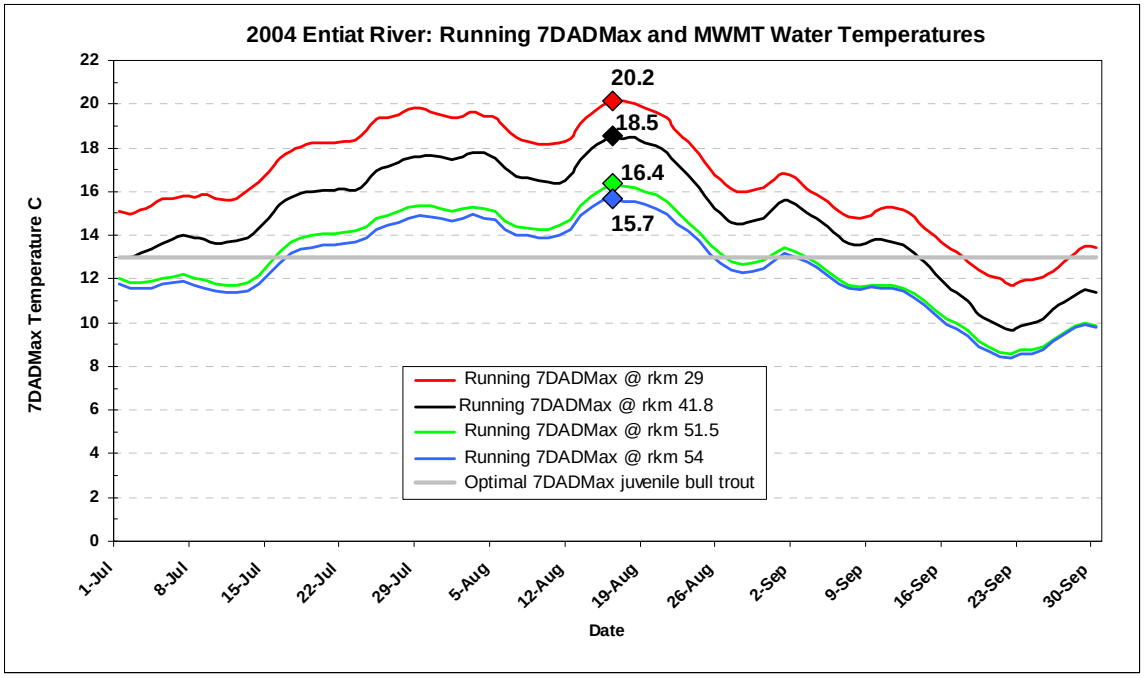
Appendix 4. Charts of running 7DADMax and MWMT Water Temperatures in the upper Entiat River, 2000 – 2006. Temperature data from USFS and WDOE.






2002 Entiat River: Running 7DADMax and MWMT Water Temperatures
7DADMax Temperature C
Date
17.7
15.6
13.9
Running 7DADMax @ rkm 29
Running 7DADMax @ rkm 41.8
Running 7DADMax @ rkm 51.5
Optimal 7DADMax juvenile bull trout


2003 Entiat River: Running 7DADMax and MWMT Water Temperatures
7DADMax Temperature C
Date
19.6
17.2
14.7
14.1
Running 7DADMax @ rkm 29
Running 7DADMax @ rkm 41.8
Running 7DADMax @ rkm 51.5
Running 7DADMax @ rkm 54
Optimal 7DADMax juvenile bull trout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20.2
18.5
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Running 7DADMax @ rkm 29
Running 7DADMax @ rkm 41.8
Running 7DADMax @ rkm 51.5
Running 7DADMax @ rkm 54
Optimal 7DADMax juvenile bull trout
7DADMax Temperature C
Date
1-Jul
8-Jul
15-Jul
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29-Jul
5-Aug
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19-Aug
26-Aug
2-Sep
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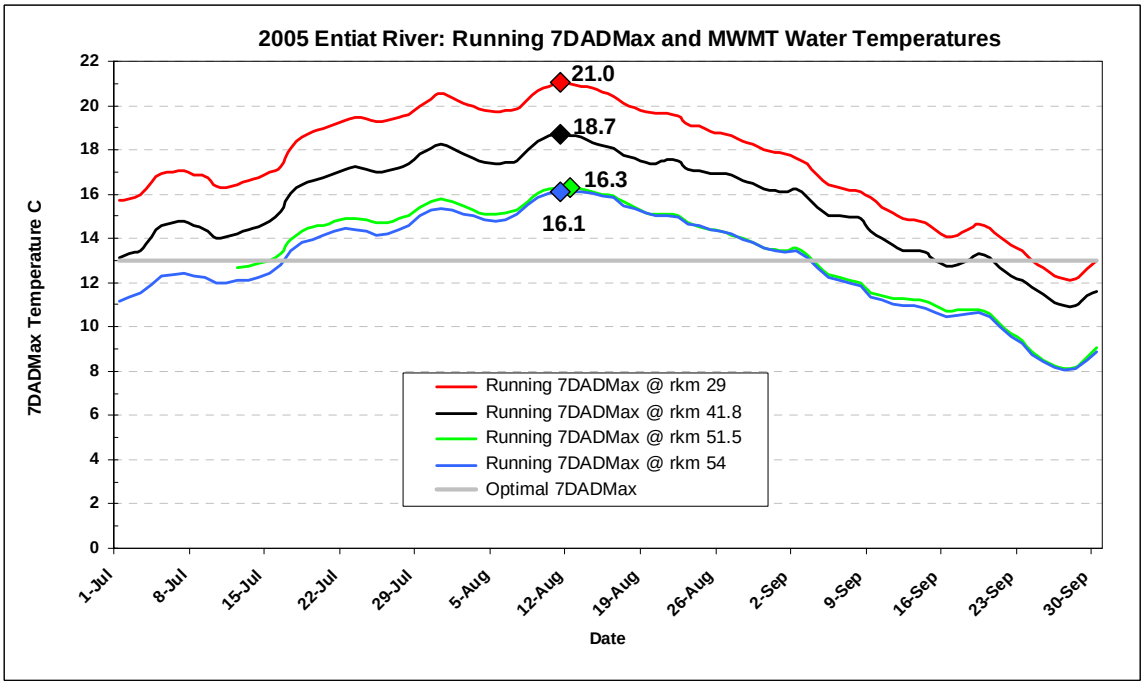
23-Sep
30-Sep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21.0
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Running 7DADMax @ rkm 29
Running 7DADMax @ rkm 41.8
Running 7DADMax @ rkm 51.5
Running 7DADMax @ rkm 54
Optimal 7DADMax
7DADMax Temperature C
Date
1-Jul
8-Jul
15-Jul
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26-Aug
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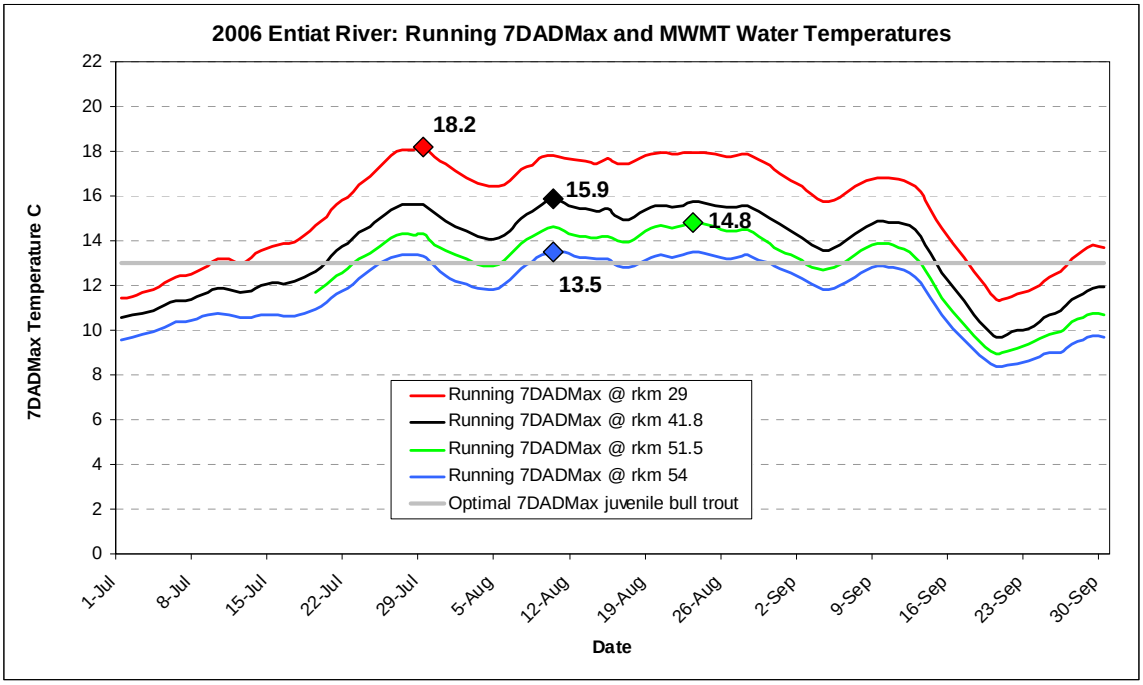
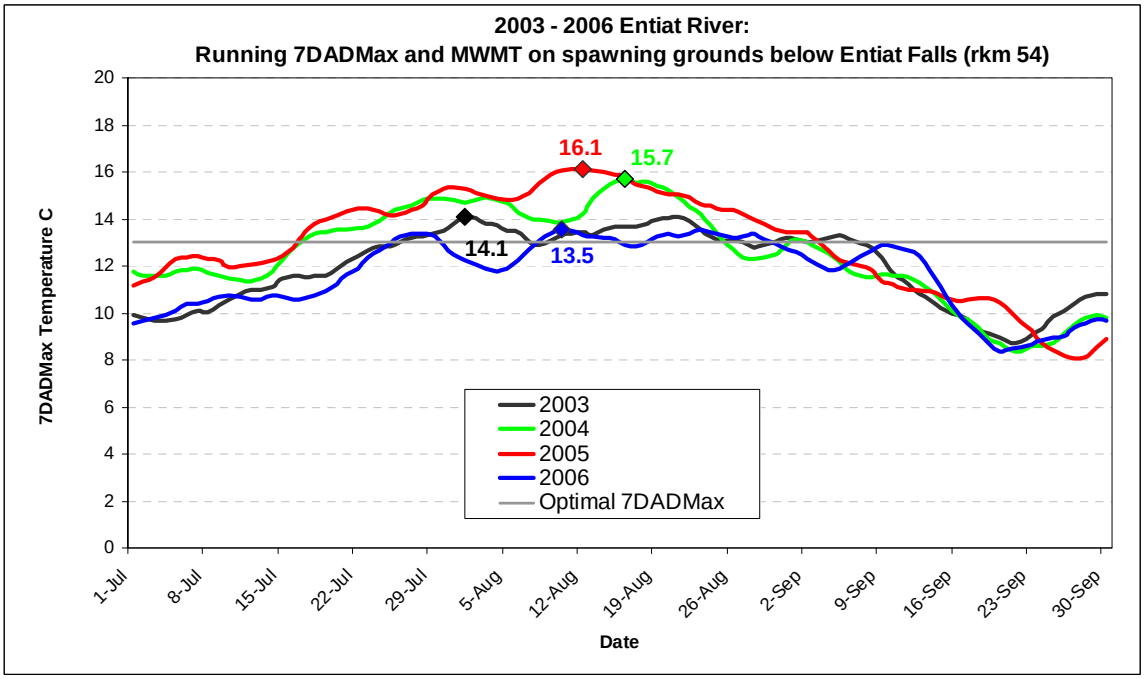
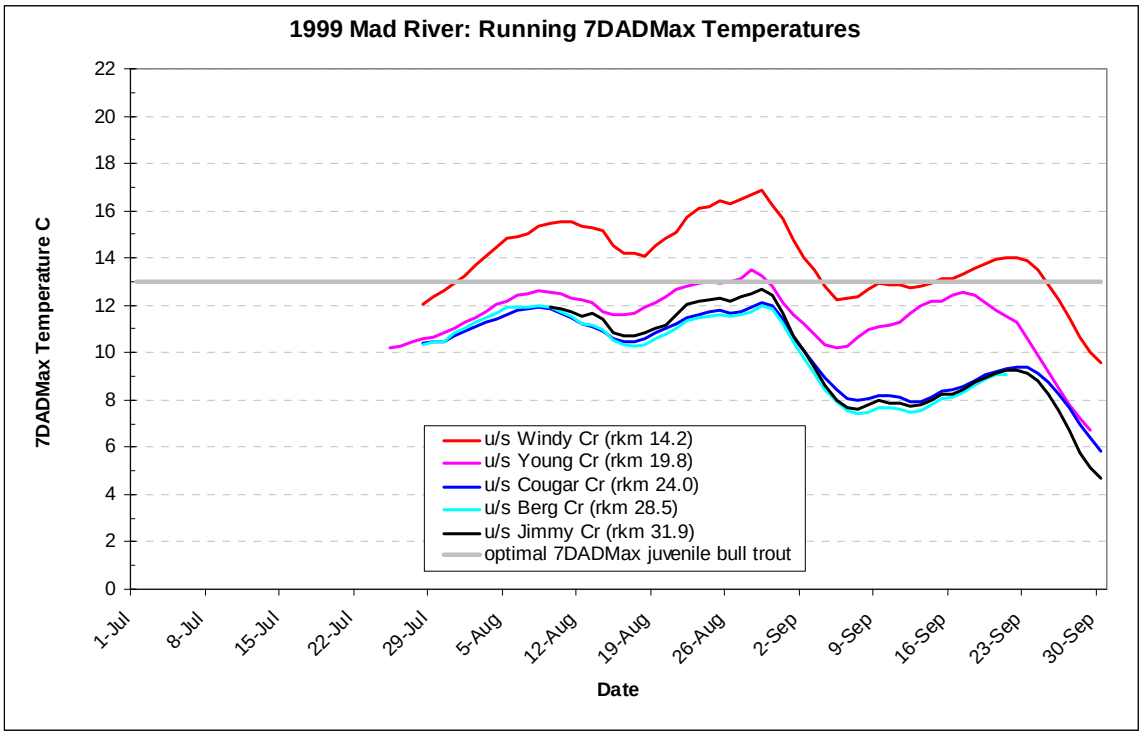
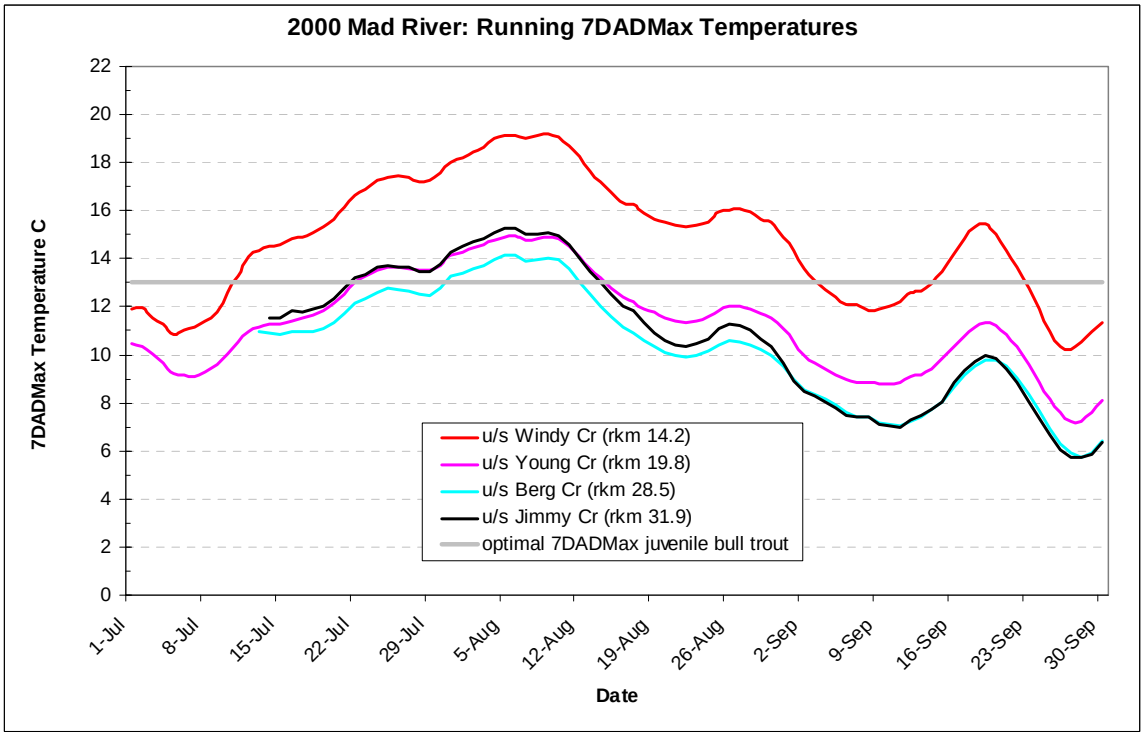
9-Sep
16-Sep
23-Sep
30-Sep

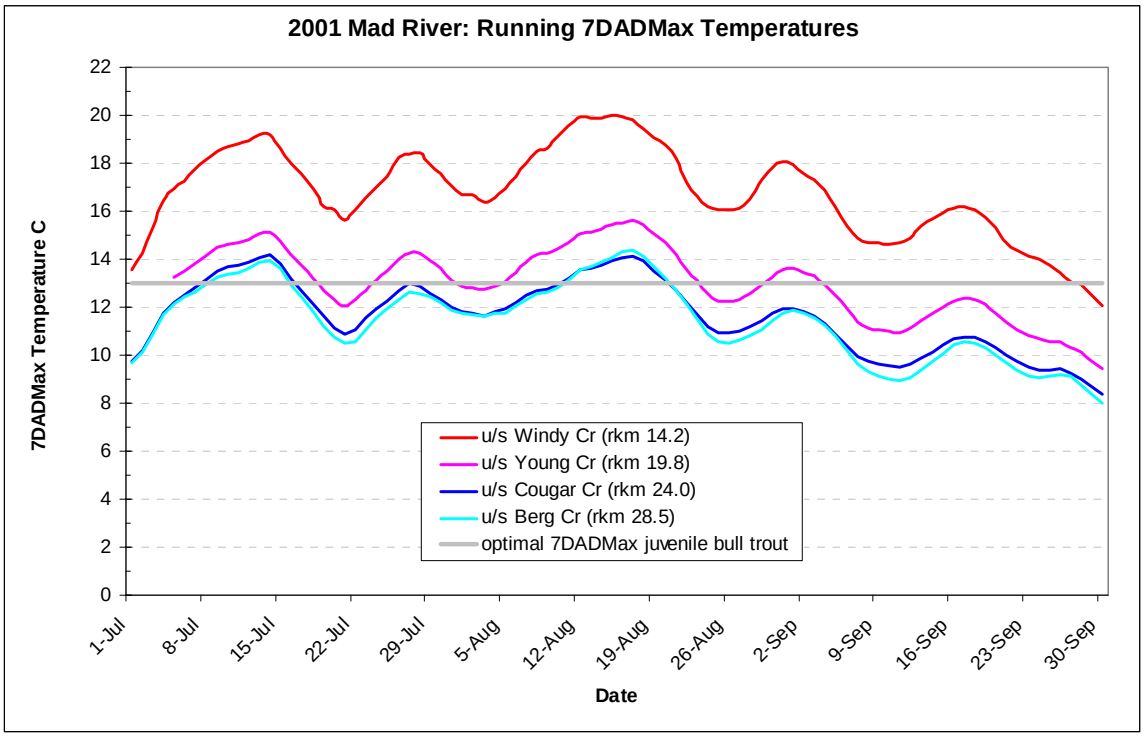

2006 Entiat River: Running 7DADMax and MWMT Water Temperatures
7DADMax Temperature C
Date
18.2
15.9
14.8
13.5
Running 7DADMax @ rkm 29
Running 7DADMax @ rkm 41.8
Running 7DADMax @ rkm 51.5
Running 7DADMax @ rkm 54
Optimal 7DADMax juvenile bull trout
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep

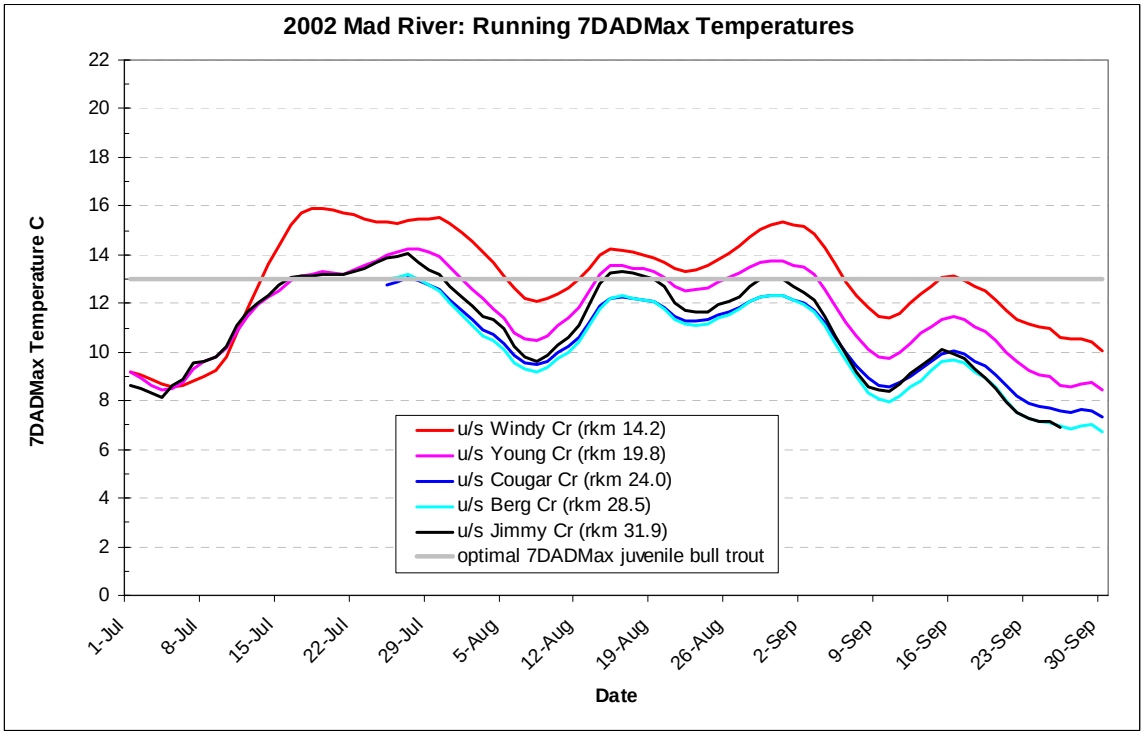

2003 - 2006 Entiat River:
Running 7DADMax and MWMT on spawning grounds below Entiat Falls (rkm 54)
7DADMax Temperature C
Date
16.1
15.7
14.1
13.5
2003
2004
2005
2006
Optimal 7DADMax
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep

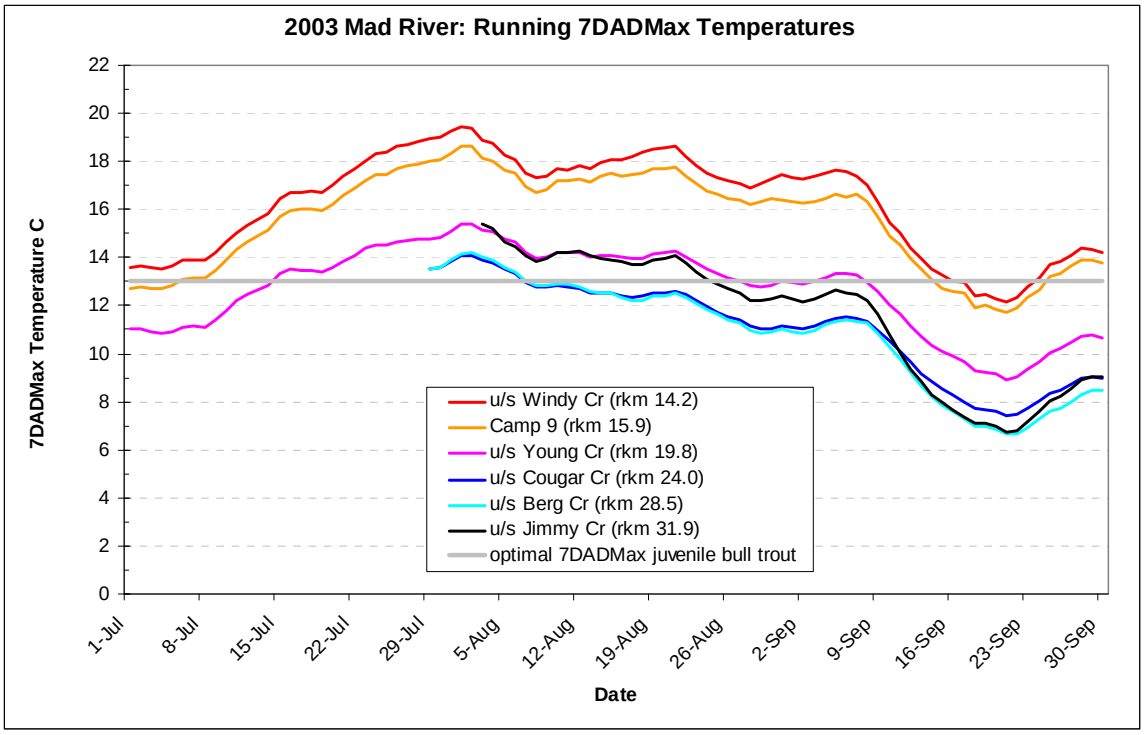
Appendix 5. Charts of running 7DADMax Water Temperatures in the Mad River, 1999 – 2006. Temperature data from USFS and WDOE.

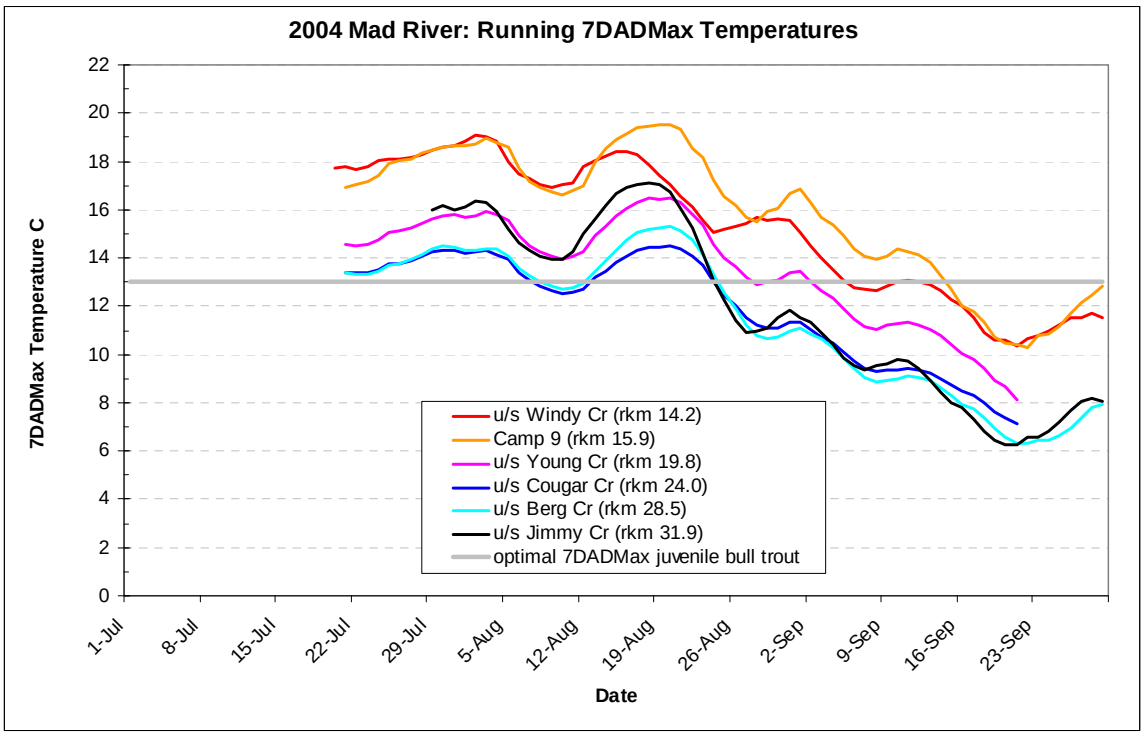


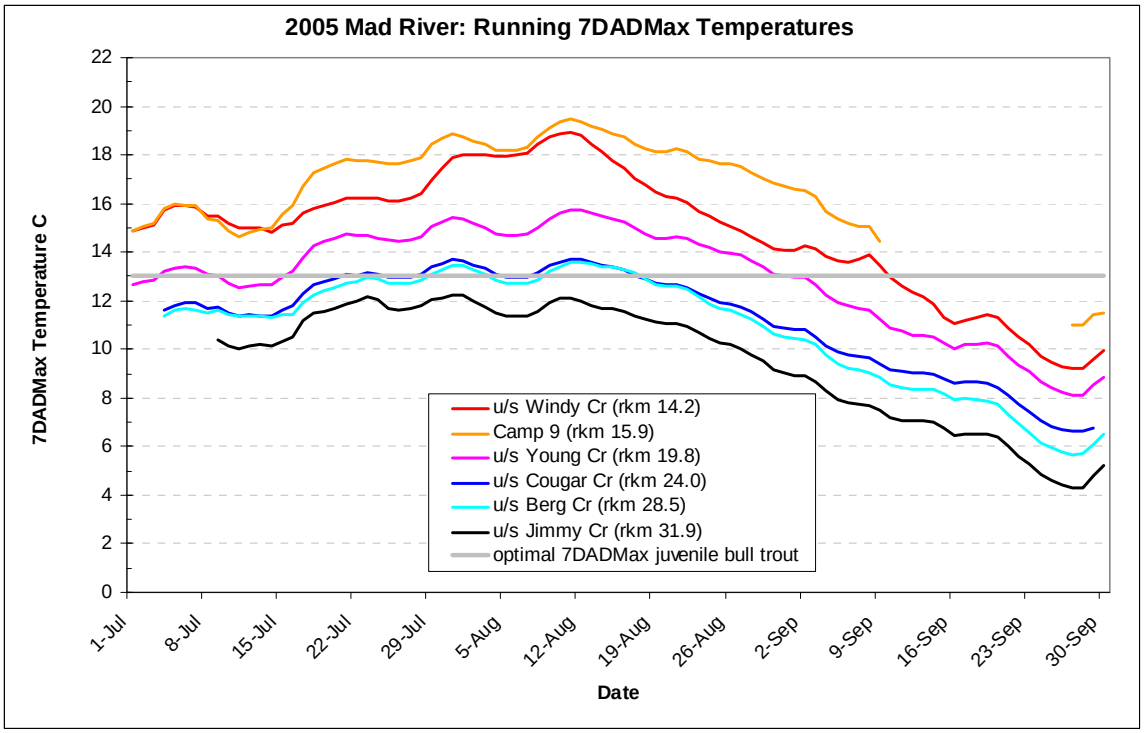


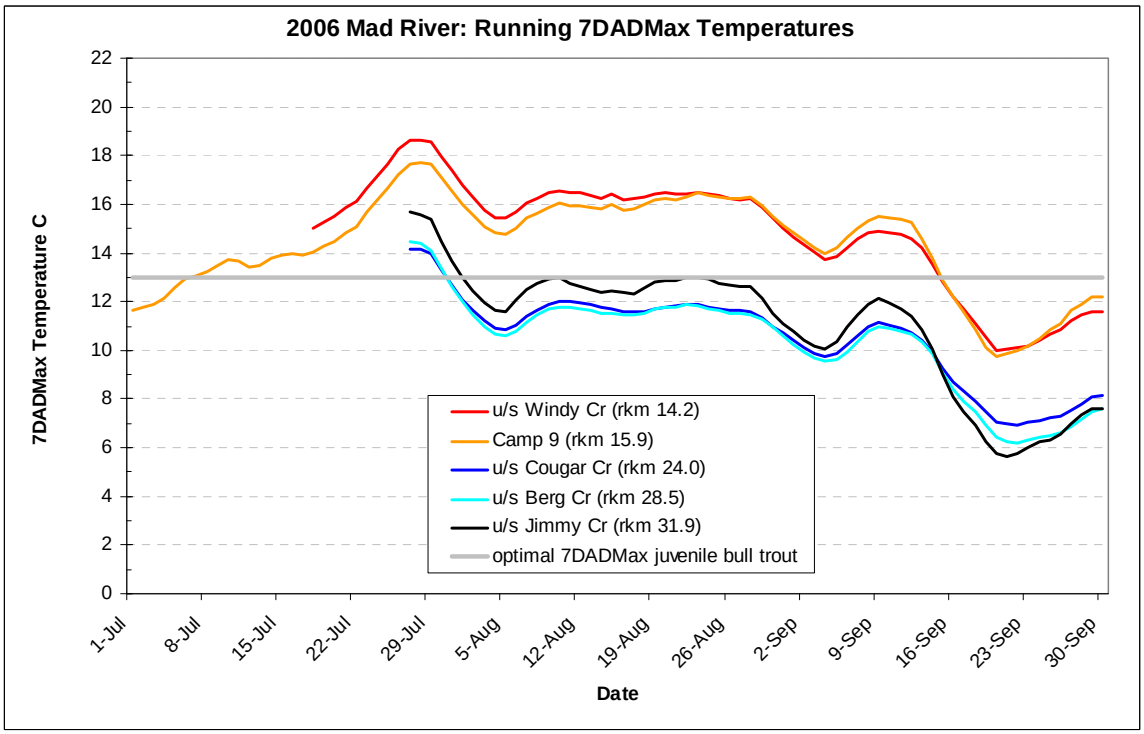

2001 Mad River: Running 7DADMax Temperatures
7DADMax Temperature C
22
20
18
16
14
12
10
8
6
4
2
0
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep
Date
u/s Windy Cr (rkm 14.2)
u/s Young Cr (rkm 19.8)
u/s Cougar Cr (rkm 24.0)
u/s Berg Cr (rkm 28.5)
optimal 7DADMax juvenile bull trout


2002 Mad River: Running 7DADMax Temperatures
7DADMax Temperature C
22
20
18
16
14
12
10
8
6
4
2
0
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep
Date
u/s Windy Cr (rkm 14.2)
u/s Young Cr (rkm 19.8)
u/s Cougar Cr (rkm 24.0)
u/s Berg Cr (rkm 28.5)
u/s Jimmy Cr (rkm 31.9)
optimal 7DADMax juvenile bull trout


2003 Mad River: Running 7DADMax Temperatures
7DADMax Temperature C
22
20
18
16
14
12
10
8
6
4
2
0
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep
Date
u/s Windy Cr (rkm 14.2)
Camp 9 (rkm 15.9)
u/s Young Cr (rkm 19.8)
u/s Cougar Cr (rkm 24.0)
u/s Berg Cr (rkm 28.5)
u/s Jimmy Cr (rkm 31.9)
optimal 7DADMax juvenile bull trout


2004 Mad River: Running 7DADMax Temperatures
7DADMax Temperature C
22
20
18
16
14
12
10
8
6
4
2
0
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
Date
u/s Windy Cr (rkm 14.2)
Camp 9 (rkm 15.9)
u/s Young Cr (rkm 19.8)
u/s Cougar Cr (rkm 24.0)
u/s Berg Cr (rkm 28.5)
u/s Jimmy Cr (rkm 31.9)
optimal 7DADMax juvenile bull trout


2005 Mad River: Running 7DADMax Temperatures
7DADMax Temperature C
Date
u/s Windy Cr (rkm 14.2)
Camp 9 (rkm 15.9)
u/s Young Cr (rkm 19.8)
u/s Cougar Cr (rkm 24.0)
u/s Berg Cr (rkm 28.5)
u/s Jimmy Cr (rkm 31.9)
optimal 7DADMax juvenile bull trout
0
2
4
6
8
10
12
14
16
18
20
22
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep


2006 Mad River: Running 7DADMax Temperatures
7DADMax Temperature C
Date
u/s Windy Cr (rkm 14.2)
Camp 9 (rkm 15.9)
u/s Cougar Cr (rkm 24.0)
u/s Berg Cr (rkm 28.5)
u/s Jimmy Cr (rkm 31.9)
optimal 7DADMax juvenile bull trout
0
2
4
6
8
10
12
14
16
18
20
22
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep

U. S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
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Leavenworth, WA

December 2008