

U.S. Fish and Wildlife Service

Spawning Migrations of Adult Fluvial Bull Trout in the Entiat River 2007 - 2013



Mark C. Nelson

**U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
7501 Icicle Road
Leavenworth, WA 98826**

*On the cover: An adult fluvial bull trout *Salvelinus confluentus* jumping at the cleared passage slot in Box Canyon of the Entiat River on August 21, 2012. The large log that impeded and blocked passage during 2006 to 2011 was washed downstream during high flows in spring 2012 and the smaller log in this photo later moved downstream as well. USFWS photograph by Robes Parrish.*

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2007 - 2013

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Authored by

Mark C. Nelson

U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
7501 Icicle Road
Leavenworth, WA 98826

Final Report
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Final Report

*U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
7501 Icicle Rd.
Leavenworth WA 98826*

Abstract- Detailed information on the spawning migrations and long-term seasonal movement patterns of adult fluvial bull trout *Salvelinus confluentus* is necessary for management actions including recovery planning, biological consultations, fisheries management, hydroelectric operations, and stream restoration. A radio-telemetry study of adult bull trout in the Entiat River was initiated by the U.S. Fish and Wildlife Service (USFWS) in 2003. The objectives were to define migration timing, movement barriers, spawning locations, factors affecting populations, and monitor seasonal movements. The first part of the study was conducted from 2003 through 2006 and was previously reported. During 2007 to 2012, a total of 29 radio-tagged adult bull trout were monitored in the Entiat River, including 26 bull trout tagged in the Columbia River by Chelan County Public Utility District (PUD) at Rocky Reach and Rock Island dams during 2005 to 2007, one bull trout tagged by Douglas County PUD at Wells Dam during 2006, and one bull trout tagged by USFWS in Icicle Creek during 2009. Overall, the movement patterns were similar to those reported in 2003 to 2006. Adult fluvial bull trout staged in the Columbia River at the mouth of the Entiat River prior to entering the tributary, with those arriving earliest most likely to stage the longest. Tagged bull trout entered the river between May 23 and July 7 on the descending limb of the hydrograph as flows declined to less than 1500 ft³/s and mean daily water temperatures ranged from 7.1 to 13.1°C. Eighty-five percent of the tagged bull trout migrated to the upper Entiat River. Similar to conditions in 2006, most tagged bull trout were blocked by a log impediment in Box Canyon and could not reach the optimal spawning area of the upper Entiat River as the number of redds continued to decline during 2007 to 2011. In 2012, the log impediment was washed downstream and the number of redds upstream of Box Canyon increased in 2012 and 2013. Only fifteen percent of the tagged bull trout migrated into the Mad River and the number of redds observed on that spawning ground also continued to decline. In 2010, resident bull trout redds were observed in the Mad River for the first time, but no migratory fish or redds were counted. During 2007 – 2010, post-spawn migrations occurred from September through December, and tagged adult bull trout averaged between 140.8 - 152.8 days in the Entiat River watershed before overwintering in the Columbia River. Maximum weekly maximum temperatures in the upper Entiat River at rkm 41.6 were significantly warmer during the period of 2000 – 2009 compared to the period of 1967 – 1977. Increasing stream temperatures, the presence of brook trout, and obstructions that reduce access to the spawning reaches with the resultant decline in redds are major threats to the survival of the two bull trout populations in the Entiat Core Area.

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Table of Contents

List of Tables	v
List of Figures.....	vi
Introduction.....	1
Study Area	3
Methods.....	6
Tagging	6
Tags.....	6
Radio-telemetry.....	6
Equipment	6
Fixed stations	6
Mobile surveys.....	7
Spawning ground surveys.....	7
Stream discharge data	7
Temperature data	11
Results.....	13
Radio-tagging.....	13
Number of radio-tagged bull trout tracked from 2007 to 2010	14
Trends in bull trout counts at Rocky Reach Dam.....	15
Pre-spawn upstream migrations	15
Staging near the Entiat River confluence and detection at EM fixed station (rkm 0.4)	15
Entiat River water temperatures near mouth	18
ER fixed station (rkm 5.1)	19
MD fixed station (rkm 16.7).....	20
DB fixed station (rkm 46.7).....	21
BC fixed station (rkm 47.0).....	24
Obstacles in Box Canyon.....	24
Log jam	24
Spawning.....	27
Redd counts in the Entiat River	27
Redd counts in the Mad River	27
Post-spawn downstream migrations	32

BC fixed station (rkm 47.0)	32
Days spent in Box Canyon.....	32
DB fixed station (rkm 46.7)	34
MD fixed station (rkm 16.7).....	35
ER fixed station (rkm 5.1)	36
MD fixed station (rkm 16.7).....	36
EM fixed station (rkm 0.4).....	37
Number of days in Entiat River	37
Water temperatures	40
Entiat River MWMT.....	40
Mad River MWMT	40
Historic water temperatures at rkm 41.6 (Forest Boundary)	41
Winter locations in the Columbia River	41
Recovered tags	43
Discussion	45
Acknowledgments.....	47
Literature Cited	48
Appendix 1: Juvenile bull trout and brook trout in the upper Entiat River	52

List of Tables

Table 1. Station names, river locations, and years of operation of fixed receiver telemetry stations in the Entiat Core Area.	7
Table 2. Code, tagging date, tagging location, population, length, weight, and condition factor (K) of adult fluvial bull trout tagged by Chelan County PUD in 2007 that entered the Entiat Core Area, 2007 to 2010.	13
Table 3. Total number of radio-tagged bull trout tracked in the Entiat Core Area each year during 2007 to 2010.	14
Table 4. Dates that radio-tagged adult fluvial bull trout were first detected at and then moved upstream past the EM fixed receiver telemetry station located at rkm 0.4 of the Entiat River, 2007 to 2010.	16
Table 5. Dates that radio-tagged adult fluvial bull trout migrated upstream past the ER fixed receiver telemetry station located at rkm 5.1 of the Entiat River, 2007 to 2009.	19
Table 6. Dates that radio-tagged adult fluvial bull trout migrated upstream past the MD fixed receiver telemetry station located at the confluence of the Mad River and Entiat River (rkm 16.7), 2007 to 2010.	21
Table 7. Dates that radio-tagged adult fluvial bull trout migrated upstream past the DB fixed receiver telemetry station located downstream of Box Canyon in the upper Entiat River (rkm 46.7), 2007 to 2009.	22
Table 8. Dates that radio-tagged adult fluvial bull trout migrated upstream past the BC fixed receiver telemetry station located upstream of Box Canyon and Fish Tail Falls in the upper Entiat River (rkm 47.0), 2007 to 2010.	24
Table 9. Percentage of radio-tagged adult fluvial bull trout that passed Box Canyon and were present on the upper Entiat River spawning grounds, 2007 to 2010.	24
Table 10. Number of bull trout redds counted during spawning ground surveys in the index reaches of the upper Entiat River, 2007 to 2013.	27
Table 11. Number of bull trout redds counted during spawning ground surveys in the index reaches of the Mad River, 2007 to 2013.	27
Table 12. Dates that radio-tagged adult fluvial bull trout migrated downstream past the BC fixed receiver telemetry station located at rkm 47.0 of the Entiat River, 2007 to 2010.	32
Table 13. Dates that radio-tagged adult fluvial bull trout migrated downstream past the DB fixed receiver telemetry station located downstream of Box Canyon at rkm 46.7 of the Entiat River, 2007 to 2009.	34
Table 14. Dates that radio-tagged adult fluvial bull trout migrated downstream past the MD fixed receiver telemetry station located at the confluence of the Mad River and Entiat River (rkm 16.7), 2007 to 2010.	35
Table 15. Dates that radio-tagged adult fluvial bull trout migrated downstream past the ER fixed receiver telemetry station located at rkm 5.1 of the Entiat River, 2007 to 2008.	36

Table 16. Dates that radio-tagged adult fluvial bull trout migrated downstream past the EM fixed receiver telemetry station located at rkm 0.4 of the Entiat River, 2007 to 2010.	37
Table 17. Number of days that radio-tagged adult fluvial bull trout spent in the Entiat River watershed, 2007 to 2010.	38
Table 18. Maximum weekly maximum temperature (°C) recorded at USFS temperature monitoring stations in the Entiat River, 2007 to 2010.	40
Table 19. Maximum weekly maximum temperature (°C) recorded at USFS temperature monitoring locations in the Mad River, 2007 to 2009.	40
Table 20. Results of ANOVA comparing MWMT recorded in 1967 – 1977 to MWMT recorded in 2000 – 2009 at rkm 41.8 in the upper Entiat River.....	41
Table 21. Sampling locations, total length (mm), and genetic tissue sample number of juvenile bull trout collected near rkm 50 of the Entiat River on September 4, 2008.	53
Table 22. Total length (mm), weight (g), sex, genetic tissue sample number, scale card number, and otolith number of brook trout collected near rkm 50 of the Entiat River on September 4, 2008.....	54

List of Figures

Figure 1. Map of the Wenatchee, Entiat, and Methow Core Areas of the draft Mid-Columbia Bull Trout Recovery Unit.	2
Figure 2. Map of the Entiat River watershed.	4
Figure 3. Locations of fixed receiver telemetry stations in the Entiat Core Area during 2007 to 2010.....	8
Figure 4. Locations of all fixed receiver telemetry stations in the draft Mid-Columbia Recovery Unit during 2007 to 2010.....	9
Figure 5. Map of bull trout spawning ground survey index reaches in the Mad River and upper Entiat River.	10
Figure 6. Locations of temperature and discharge monitoring stations in the Entiat Core Area..	12
Figure 7. Length vs. weight of adult fluvial bull trout radio-tagged by Chelan County PUD in 2007.....	13
Figure 8. Number of radio-tagged bull trout that entered the Mad River and the Entiat River, 2001 to 2010.	14
Figure 9. Number of bull trout counted at Rocky Reach Dam on the Columbia River, 1998 to 2013.....	15
Figure 10. Scatter plot of date of first mobile detection of radio-tagged bull trout at mouth of Entiat River and number of days spent near mouth area before moving upstream during 2007..	15

Figure 11. Entiat River discharge (USGS gage at rkm 2.5) and dates that radio-tagged adult fluvial bull trout arrived at and left the EM telemetry station (rkm 0.4) during upstream migrations, 2007 to 2010.	17
Figure 12. Mean daily temperatures of the Entiat River (USFS temperature logger at rkm 2.5) and dates that radio-tagged adult fluvial bull trout arrived at and left the EM fixed telemetry station (rkm 0.4) during upstream migrations, 2008 to 2010.	18
Figure 13. Entiat River discharge (USGS gage at rkm 2.5) and dates that radio-tagged adult fluvial bull trout migrated upstream past the ER fixed station (rkm 5.1) during 2007 to 2009. ..	20
Figure 14. Entiat River discharge ((WDOE gage at rkm 54.1) and dates when radio-tagged adult bull trout migrated upstream past the DB fixed receiver telemetry station (rkm 46.7) and the BC fixed receiver telemetry station (rkm 47.0), 2007 to 2009.	23
Figure 15. Photograph of log jammed in passage between the upper two pools in Box Canyon taken on August 17, 2010 (view is looking downstream into second pool or “Slot Pool”).	25
Figure 16. Photograph (taken in 2008) showing orientation of log that was lodged in the passage between Slot Pool (lower pool) and the Fish Tail Falls Pool in Box Canyon from 2006 to 2012.	26
Figure 17. Photograph (taken in 1939) showing orientation of logs lodged in passage between the Slot Pool (lower pool) and the Fish Tail Falls Pool in Box Canyon (Photo courtesy Oregon State University Archives).	26
Figure 18. Locations of fluvial bull trout redds in the upper Entiat River during 2007 to 2010. ..	28
Figure 19. Locations of fluvial bull trout redds in the upper Entiat River during 2011 to 2013. ..	29
Figure 20. Locations of radio-tagged bull trout during the spawning season in the upper Entiat River and Mad River, 2007.	30
Figure 21. Number of bull trout redds observed during spawning ground surveys in the upper Entiat River, 2004 to 2013 (surveys not conducted in Box Canyon during 2004 to 2007).	31
Figure 22. Number of bull trout redds observed during spawning ground surveys in the Mad River, 1989 to 2012.	31
Figure 23. Number of days radio-tagged adult fluvial bull trout spent in Box Canyon of the upper Entiat River during 2007 (asterisk * indicates bull trout that passed upstream to spawning grounds).	32
Figure 24. Number of days radio-tagged adult fluvial bull trout spent in Box Canyon of the upper Entiat River during 2008.	33
Figure 25. Number of days radio-tagged adult fluvial bull trout spent in Box Canyon of the upper Entiat River during 2009 (asterisk * indicates bull trout that passed upstream to spawning grounds).	33
Figure 26. Timelines of radio-tagged adult fluvial bull trout presence in the Entiat River watershed during 2007 (dark blue represents detection at the EM station at rkm 0.4, light blue represents time spent upstream of the station, and gray indicates bull trout did not exit).	39

Figure 27. Timelines of radio-tagged adult fluvial bull trout presence in the Entiat River watershed during 2008 (dark blue represents detection at the EM station at rkm 0.4 and light blue represents time spent upstream of the station). 39

Figure 28. Timelines of radio-tagged adult fluvial bull trout presence in the Entiat River watershed during 2009 (dark blue represents detection at the EM station at rkm 0.4 and light blue represents time spent upstream of the station). 40

Figure 29. Maximum weekly maximum temperatures (MWMT) recorded at rkm 41.8 of the Entiat River during each year from 1967 to 1977 (diamonds) and from 2000 to 2009 (squares). 41

Figure 30. Map of the Columbia River winter locations of Entiat Core Area radio-tagged adult fluvial bull trout, 2007 to 2009. 42

Figure 31. Locations of recovered or inactive transmitters of adult fluvial bull trout in the Entiat River watershed, 2007 - 2010. 44

Figure 32. Size classes of bull trout captured with hand nets and tissue sampled at rkm 50 of the Entiat River, September 4, 2008. 54

Figure 33. Size classes and sex of brook trout collected at rkm 50 of the Entiat River, September 4, 2008. 55

Figure 34. Percentage of brook trout stomachs containing each food item, September 4, 2008.. 55

Figure 35. Two juvenile bull trout with a larger brook trout in the upper Entiat River on August 20, 2008. 56

Figure 36. A pair of brook trout in spawning colors in lower Silver Creek on October 29, 2009. 56

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, originally designated the draft Upper Columbia River Recovery Unit (USFWS 2002 and 2004; Nelson and Nelle 2008), is now called the draft Mid-Columbia Recovery Unit (USDI 2010) 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 exist in the Entiat River watershed: the Mad River population and the upper Entiat River population (USFWS 2002 and 2004, Nelson and Nelle 2008).

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). Initial information on the timing of bull trout pre- and post-spawn migrations in the Entiat River was gathered during 2001 to 2004 by the Mid-Columbia (Chelan, Douglas and Grant counties) Public Utility Districts (PUD) while conducting telemetry studies required for relicensing of their Columbia River dams (BioAnalysts 2004). In 2003, a radio-telemetry study of adult fluvial bull trout in the Entiat River was implemented by the USFWS Mid-Columbia River Fishery Resource Office and detailed information on migration patterns was gathered from bull trout tagged in the Entiat Core Area and from bull trout tagged in the Columbia River by Chelan County PUD (CCPUD) that entered the Entiat River watershed (Nelson and Nelle 2008). In 2005, as part of their bull trout monitoring program, CCPUD began another multiyear radio-telemetry study and tagged bull trout at Rocky Reach and Rock Island Dams (Stevenson et al. 2006, 2007, 2008, 2009). Although the USFWS study was scheduled to conclude in 2005, after informal discussions with CCPUD fish biologists, it was voluntarily agreed that USFWS should continue to monitor the bull trout tagged by CCPUD after they entered the Entiat River. This maximized the amount of information collected from the tagged individual bull trout and provided a more complete picture of bull trout migratory patterns in the Entiat and Columbia rivers.

The objectives of this radio telemetry study are to further define migration timing, movement barriers, spawning locations, factors affecting populations, and seasonal movements of adult fluvial bull trout in the Entiat River Core Area. The results from 2003 through 2006 are reported in Nelson and Nelle (2008). This paper presents and discusses the results of the study from 2007 through 2013.

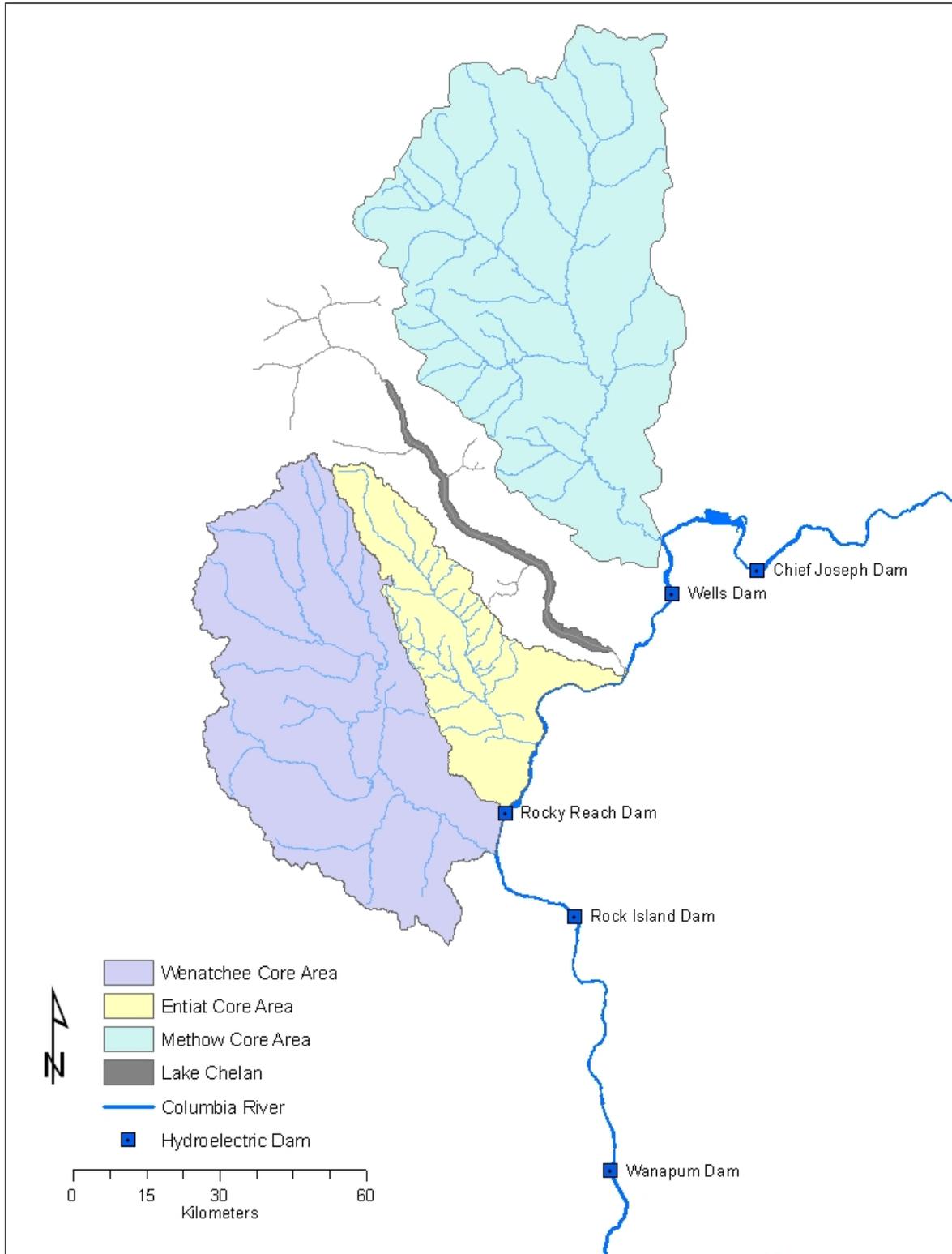


Figure 1. Map of the Wenatchee, Entiat, and Methow Core Areas of the draft Mid-Columbia Bull Trout Recovery Unit.

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 km², 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 ft³/s, mean low discharge is 266 ft³/s and flood discharge is 10,800 ft³/s (Mullan et al. 1992). In the Mad River, mean annual discharge is 69 ft³/s and mean minimum discharge is 17 ft³/s (Mullan et al. 1992).

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 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).

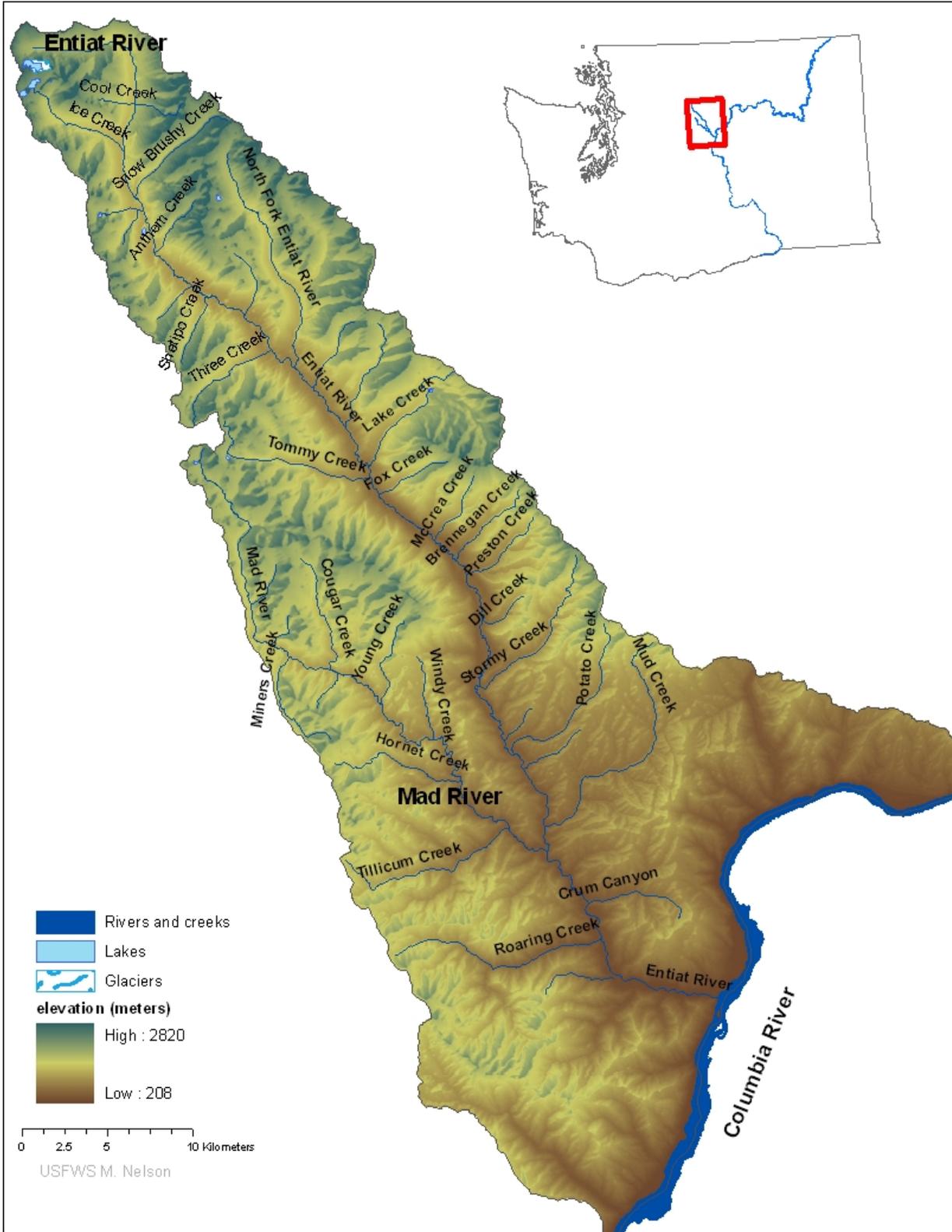


Figure 2. Map of the Entiat River watershed.

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 ponderosa*, Douglas fir *Pseudotsuga 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*, redbelt shiner *Richardsonius balteatus*, three spine stickleback *Gasterosteus aculeatus*, northern pikeminnow *Ptychocheilus oregonensis*, various sculpin *Cottus* spp., various sucker *Catostomus* spp., longnose dace *Rhinichthys cataractae*, and chiselmouth *Acrocheilus alutaceus*.

Methods

Tagging

The majority of bull trout that were tracked in the Entiat River from 2007 to 2010 were captured and tagged at mid-Columbia River hydro-projects by Chelan County PUD. For details of the capture and tagging procedures, see BioAnalysts (2004) and Stevenson et al. (2006).

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

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.

Fixed stations- Fixed receiver telemetry stations were set up at 5 locations in the Entiat River watershed during 2007 to 2010 (Table 1, Figure 3). Each station was designated by a two-letter site code referencing its location or other information (Table 1). Hence, **EM** refers to the station at the mouth of the Entiat River, **ER** refers to the station upstream of the mouth of the Entiat River (operated by Chelan PUD), **MD** to the confluence of the Mad River, **DB** to downstream of Box Canyon, **BC** to upstream of Box Canyon. Stations operated on the Mad River in earlier years were removed after the 2006 field season. Prior to 2007, the ER station at rkm 5.1 was used to record the first detection dates of tagged bull trout entering the Entiat River. In 2007, the EM station at rkm 0.4 was added in order to gather more precise information on staging and entry dates.

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 4). For

descriptions and locations of these systems, see BioAnalysts (2004), Stevenson et al. (2006), LGL and DCPUD (2006), Nelson et al. (2007), and Nelson et al. (2011).

Table 1. Station names, river locations, and years of operation of fixed receiver telemetry stations in the Entiat Core Area.

Receiver Station	River	River km	Years	Notes
EM	Entiat	0.4	2007-2012 ^A	Near mouth of Entiat River
ER	Entiat	5.1	2007-2009 ^B	At Whitehall property, CPUD site
MD	Entiat	16.7	2007-2010	At confluence of Mad River
DB	Entiat	46.7	2007-2009	Downstream of Box Canyon
BC	Entiat	47.0	2007-2010	Upstream of Box Cyn and Fishtail Falls
WR	Wenatchee	12.5	2007-2010	At Wenatchee R. Co. Park, CPUD site
RR	Columbia	762.3	2007-2009 ^B	At Rocky Reach Dam, CPUD site
RI	Columbia	729.7	2007-2009 ^B	At Rock Island Dam, CPUD site
WL	Columbia	830.1	2007-2008	At Wells Dam, DPUD site

Notes: A- EM station not in operation from 12/1/2007 to 5/7/2008. B- Chelan County PUD stations were removed on 6/19/2009.

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.

Spawning ground surveys

Bull trout spawning surveys were conducted by USFWS and USFS in several index reaches in the Entiat Core Area (Figure 5). The USFS has conducted surveys in the Mad River in three 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 2006). In 2004, during this telemetry study, USFWS added two index reaches in the upper Entiat River (rkm 47.3 – 54.1). Each index reach was surveyed three 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 2006, Nelson and Nelle 2007).

Stream discharge data

Stream discharge data were obtained from gage stations operated by United States Geological Survey and Washington Department of Ecology (USGS 2010, WDOE 2010). These included USGS stations 12452990 (Entiat River near Entiat) and WDOE station 46A160 (Entiat River below Entiat Falls- ceased operation in 2010). Stream discharge data is presented in ft³/s.

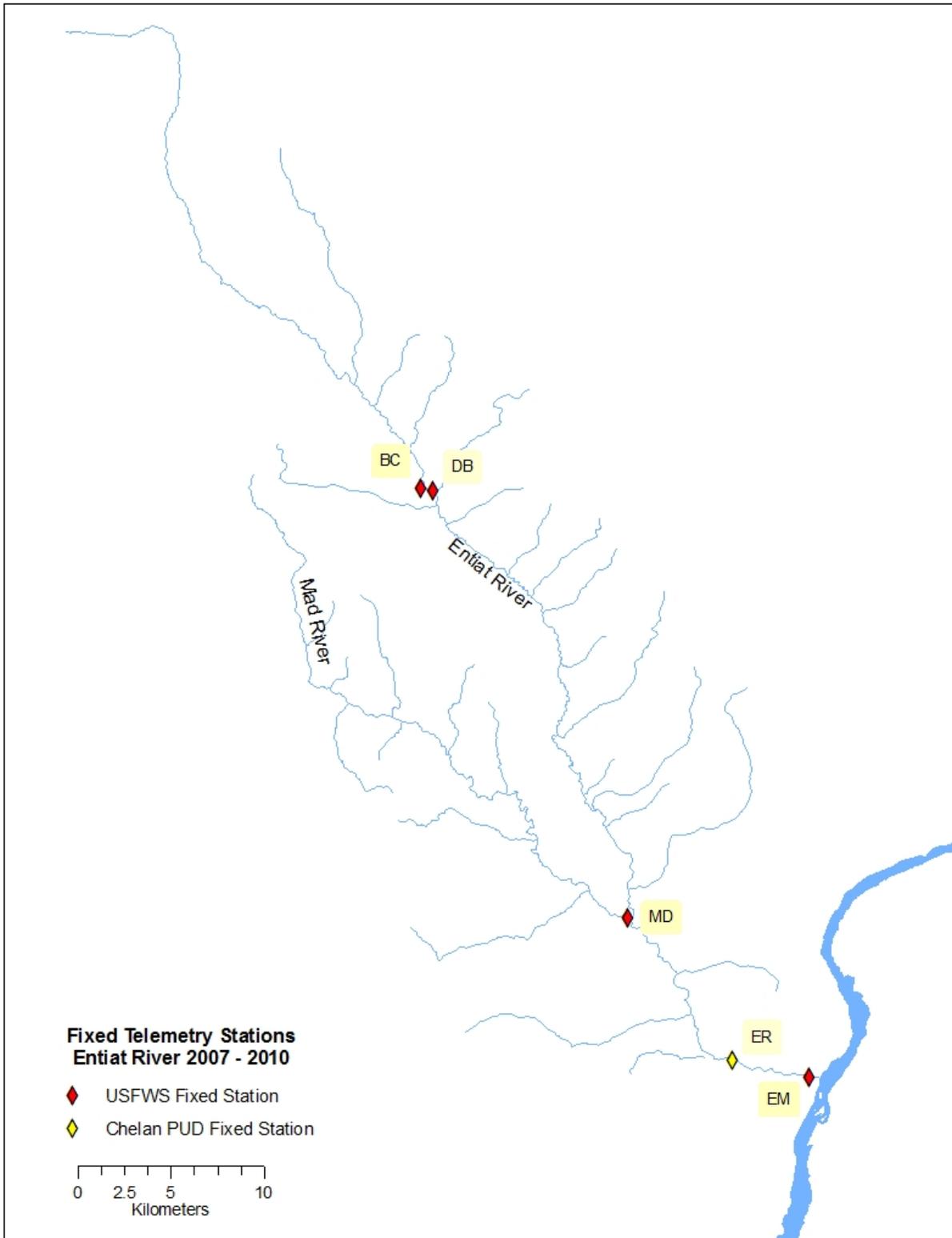


Figure 3. Locations of fixed receiver telemetry stations in the Entiat Core Area during 2007 to 2010.

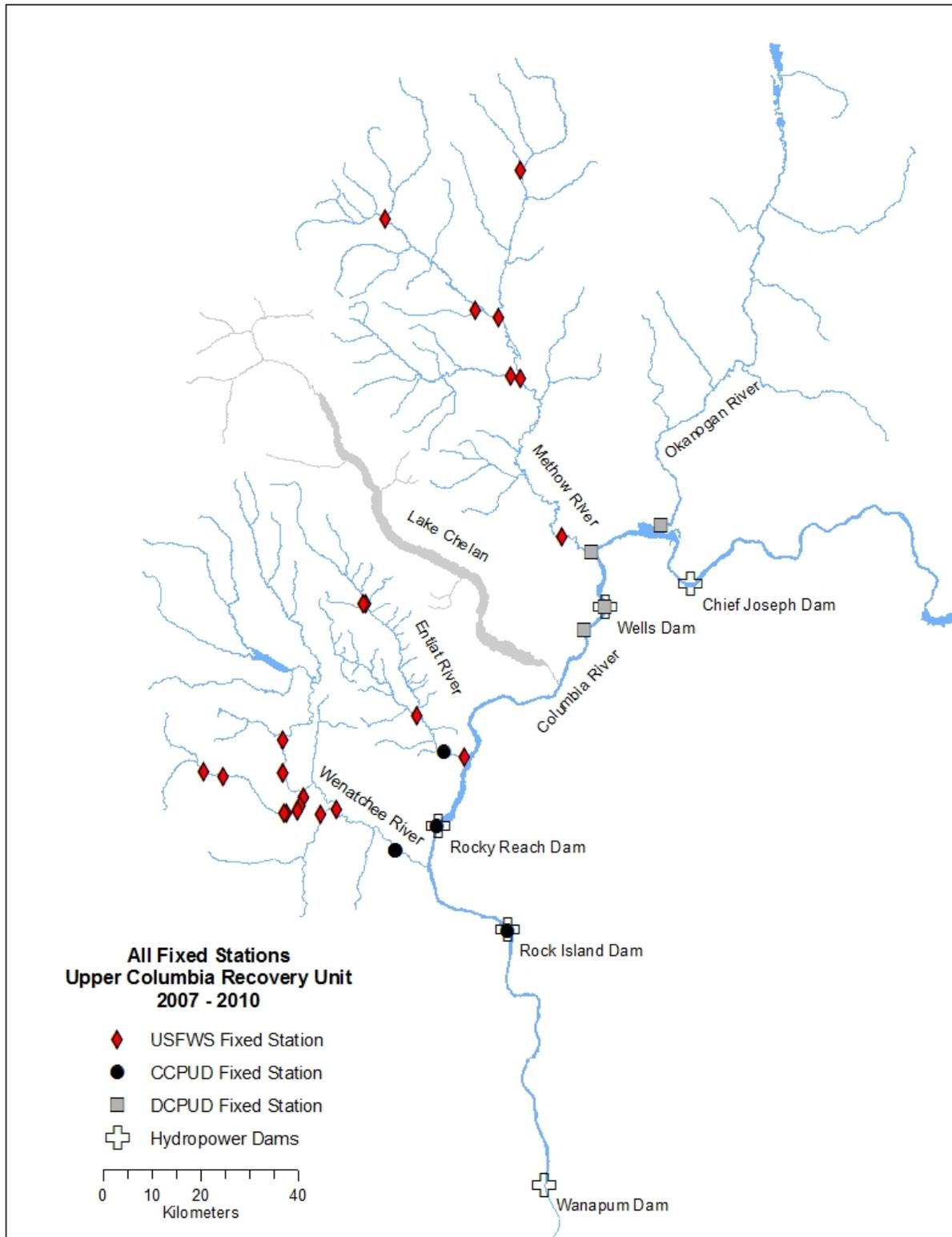


Figure 4. Locations of all fixed receiver telemetry stations in the draft Mid-Columbia Recovery Unit during 2007 to 2010.

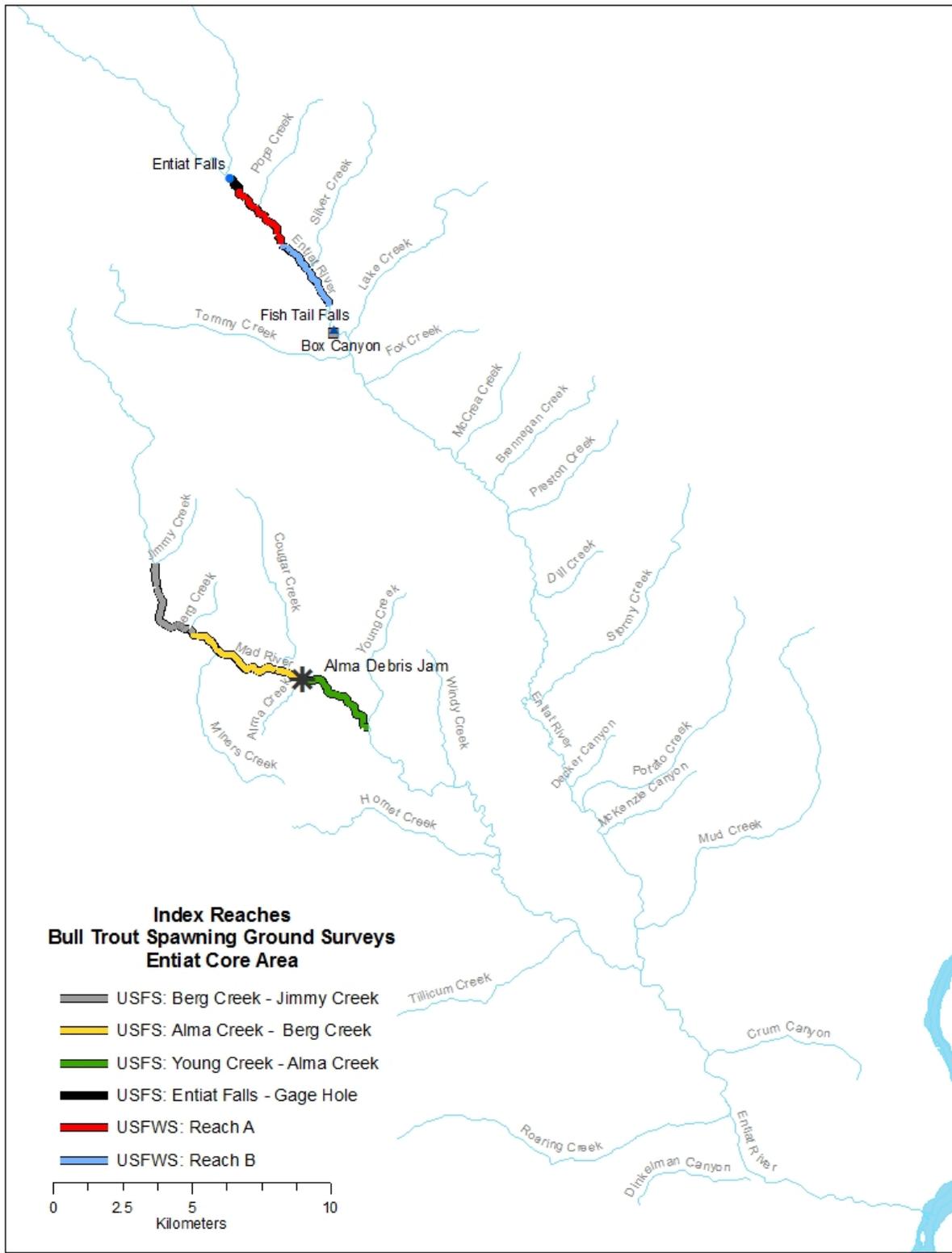


Figure 5. Map of bull trout spawning ground survey index reaches in the Mad River and upper Entiat River.

Temperature data

Stream temperatures were monitored at several locations in the Entiat River watershed (Figure 6). 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 et al. 2010) and temperature data were recorded by WDOE at gaging stations in their stream monitoring network (WDOE 2010). The daily mean, minimum, maximum, 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).

Historic water temperature data (1967 to 1977) for the Entiat River at river kilometer 41.6 (USFS Forest Boundary) were obtained from Copenhagen (1978). The historic temperature data were collected with a recording thermograph and reported to the nearest whole degree on the Fahrenheit scale. Because the recent water temperature data monitored at this same location were collected with electronic loggers that recorded to the nearest .01 degree F, the recent data were rounded to the nearest whole degree F. This standardized the data and allowed unbiased comparisons between the historic and recent data sets. All datasets were then converted to the Celsius scale. MWMT were calculated and used in an ANOVA single factor analysis (Microsoft Excel Data Analysis Tool 2003). To determine if the recording accuracy of the different temperature monitoring methods was responsible for the observed differences between the historic and recent temperatures, separate analyses were run using both the rounded and unrounded recent temperature datasets. The significance level was set at $p < 0.05$.

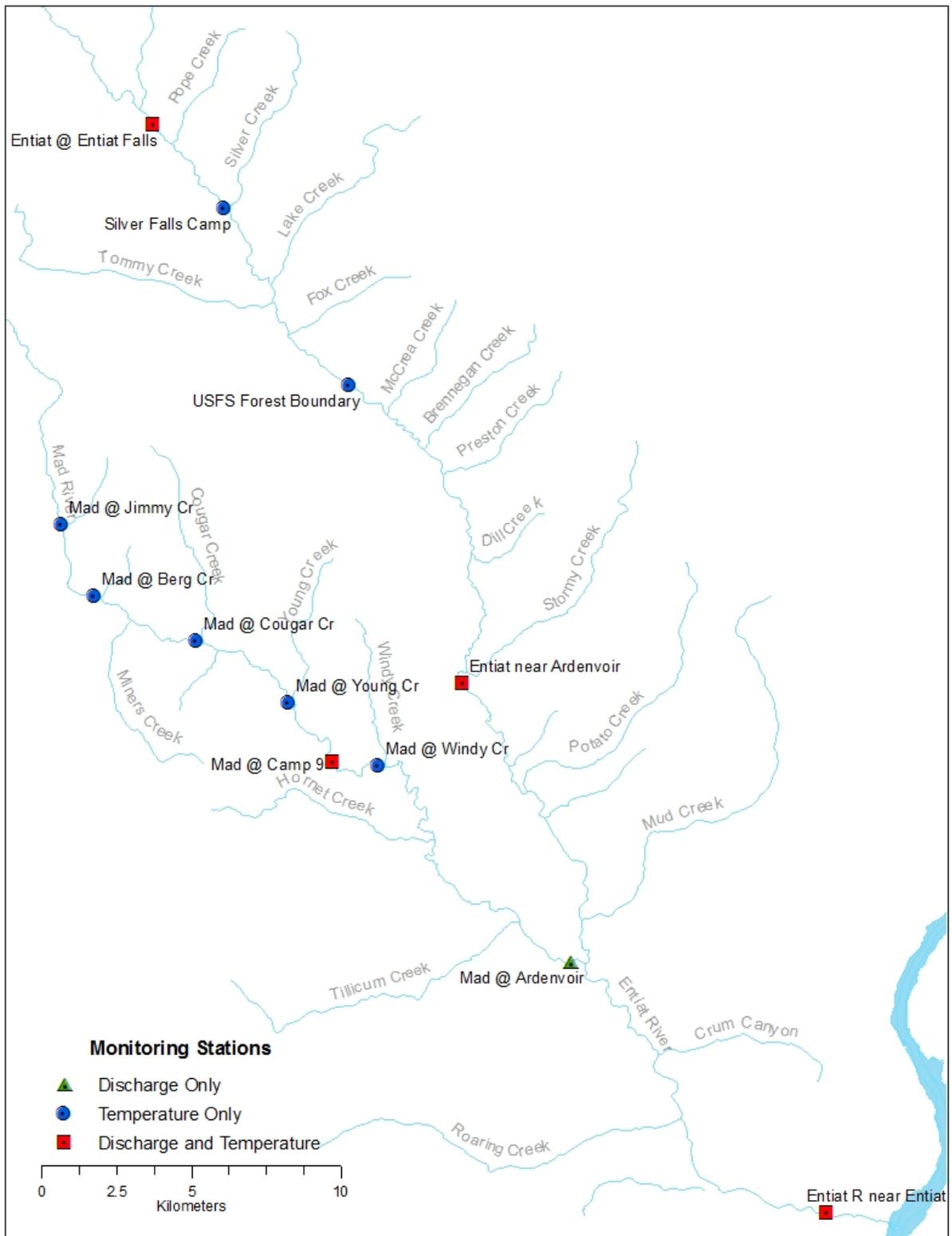


Figure 6. Locations of temperature and discharge monitoring stations in the Entiat Core Area.

Results

Radio-tagging

A total of 13 adult fluvial bull trout radio-tagged by Chelan County PUD in 2007 at Rocky Reach Dam on the Columbia River migrated to the Entiat Core Area. Lengths of the bull trout ranged from 430 to 710 mm, weights from 1128 to 4422 g, and condition factor ($K = (W/L^3) \times 100,000$) ranged from 1.04 to 1.49 (Table 2). Three of the tagged bull trout (codes 118, 120, 121) appeared to weigh less for than their length than the other fish (Figure 7).

Table 2. Code, tagging date, tagging location, population, length, weight, and condition factor (K) of adult fluvial bull trout tagged by Chelan County PUD in 2007 that entered the Entiat Core Area, 2007 to 2010.

Code	Date Tagged	Location	Population	Length (mm)	Weight (g)	K
112	5/17/2007	RR Dam	Upper Entiat	640	3897	1.49
113	5/18/2007	RR Dam	Mad	550	2114	1.27
114	5/21/2007	RR Dam	Upper Entiat	690	4006	1.22
117	5/29/2007	RR Dam	Upper Entiat	710	4422	1.24
118	6/1/2007	RR Dam	Upper Entiat	615	2619	1.13
119	6/4/2007	RR Dam	Mad	615	3005	1.29
120	6/4/2007	RR Dam	Upper Entiat	610	2580	1.14
121	6/12/2007	RR Dam	Mad	615	2423	1.04
122	6/12/2007	RR Dam	Upper Entiat	500	1642	1.31
123	6/12/2007	RR Dam	Upper Entiat	430	1128	1.42
124	6/13/2007	RR Dam	Upper Entiat	585	2680	1.34
125	6/19/2007	RR Dam	Upper Entiat	550	2165	1.30
126	6/19/2007	RR Dam	Upper Entiat	600	2979	1.38

Data from Stevenson et al. (2008)

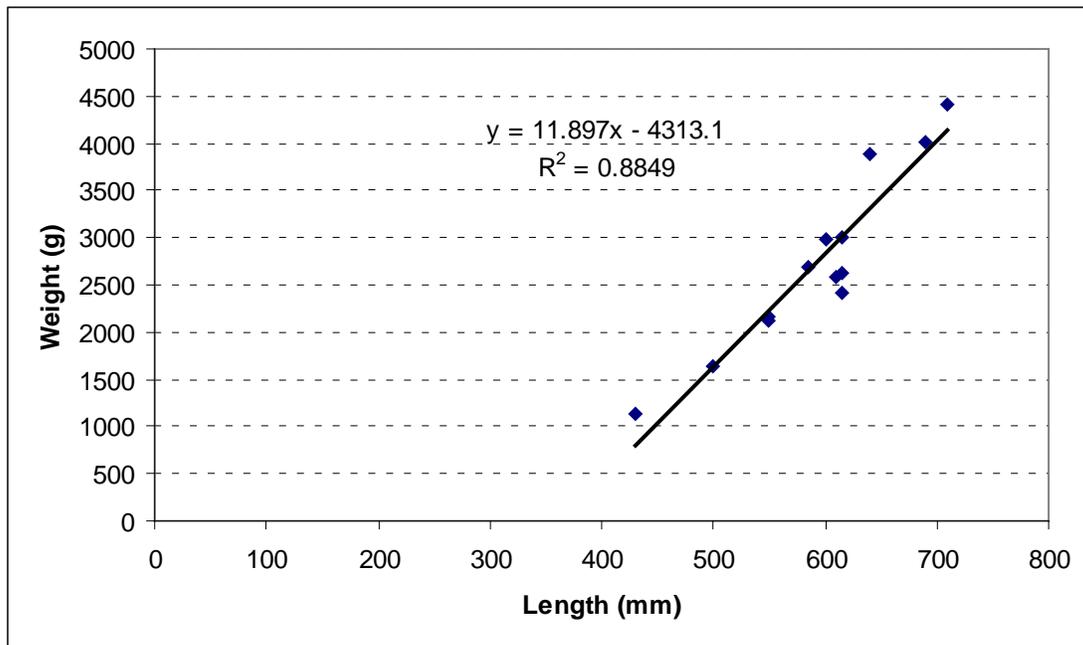


Figure 7. Length vs. weight of adult fluvial bull trout radio-tagged by Chelan County PUD in 2007.

Number of radio-tagged bull trout tracked from 2007 to 2010

Bull trout tagged by Chelan County PUD in 2005, 2006, and 2007 migrated into the Entiat Core Area during the years 2007 to 2010. The number of tagged bull trout tracked each year declined as the study progressed, with 28 tracked in 2007, 10 in 2008, 7 in 2009, 5 in 2010, and 1 during 2011 and 2012 (Table 3). Although most of the bull trout were tagged by CCPUD at Rocky Reach Dam on the Columbia River (see Stevenson et al. 2006, 2007, 2008), one bull trout (code 68) tagged at Wells Dam in 2006 (see Nelson and Nelle 2008) and one bull trout (code 96) tagged in Icicle Creek in 2009 (see Nelson et al. 2011) also migrated into the Entiat River. The majority of tagged bull trout migrated to the upper Entiat River, continuing the recent trend of fewer bull trout migrating into the Mad River (Figure 8).

Table 3. Total number of radio-tagged bull trout tracked in the Entiat Core Area each year during 2007 to 2010.

Year	Total tracked	n Tagged in 2005	n Tagged in 2006	n Tagged in 2007
2007	28	5	10	13
2008	10	0	3	7
2009	7	0	0	7
2010	5 ^A	0	0	4
2011	1 ^A	0	0	0
2012	1 ^A	0	0	0

Note: A- Includes code 96, tagged in Icicle Creek by USFWS during 2009 (Nelson et al. 2011).

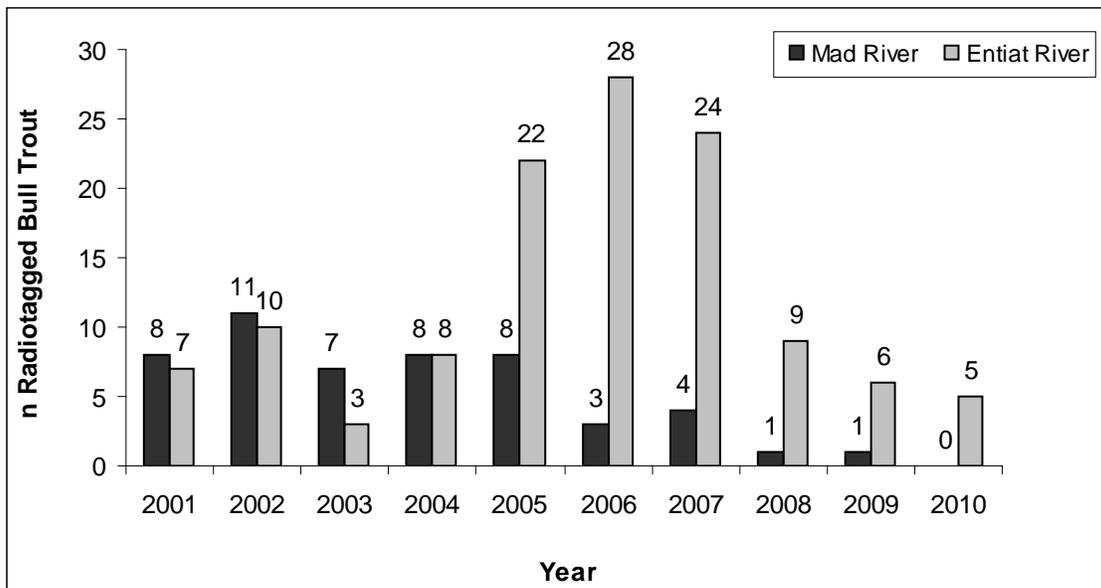


Figure 8. Number of radio-tagged bull trout that entered the Mad River and the Entiat River, 2001 to 2010.

Trends in bull trout counts at Rocky Reach Dam

During 2007 a total of 77 bull trout were counted in the fish ladder at Rocky Reach Dam on the Columbia River (rkm 762), the lowest number since counts began in 1998 (Figure 9). By 2012, the annual count increased to 219 bull trout (DART 2013).

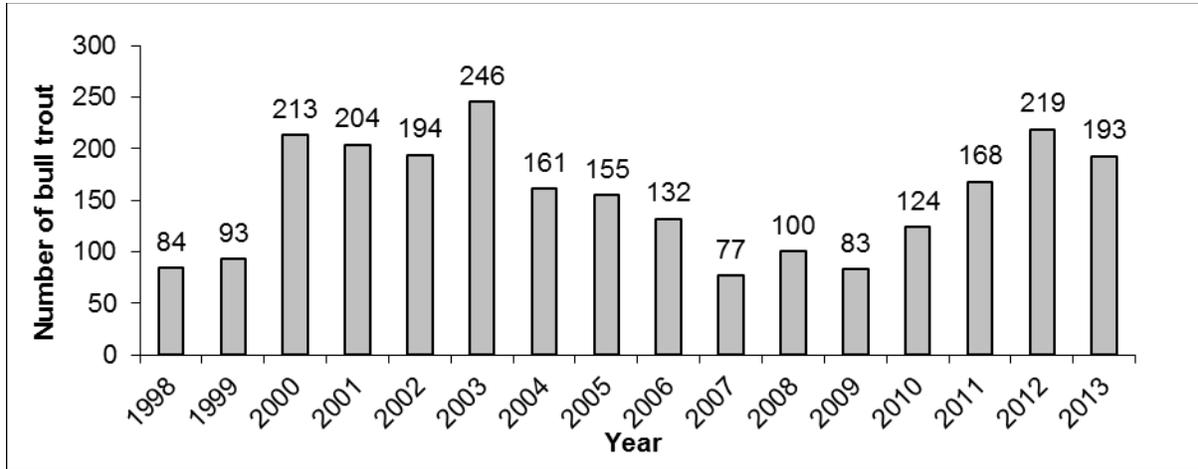


Figure 9. Number of bull trout counted at Rocky Reach Dam on the Columbia River, 1998 to 2013.

Pre-spawn upstream migrations

Staging near the Entiat River confluence and detection at EM fixed station (rkm 0.4)-

During mobile surveys bull trout were detected in the Columbia River near the mouth of the Entiat River. In 2007, 12 tagged bull trout were detected there 0.5 to 8.4 days before their first detection at the EM station. A total of 27 bull trout migrated into the Entiat River in 2007 and were detected at the EM station for 0.1 to 14.8 days before proceeding upstream. The total time that tagged bull trout were detected at the mouth area ranged from 0.1 to 17.5 days and bull trout that arrived during the first half of the migration period were more likely to stage for longer periods of time (Figure 10).

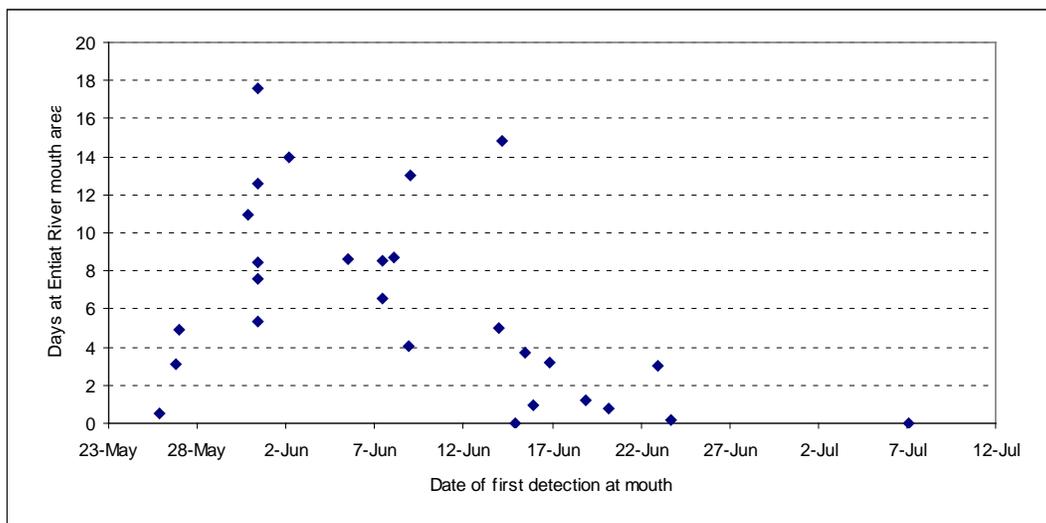


Figure 10. Scatter plot of date of first mobile detection of radio-tagged bull trout at mouth of Entiat River and number of days spent near mouth area before moving upstream during 2007.

The dates that tagged bull trout entered the Entiat River and were first detected at the EM station ranged from May 25 to July 7, 2007, May 23 to June 21, 2008, June 2 to June 20, 2009, and May 26 to June 13, 2010 (Table 4). In 2007, tagged bull trout were more likely to remain near the EM station for longer periods of time than in the following years (Table 4). Yearly peak discharges were variable during 2007 to 2010, but the majority of tagged bull trout entered the Entiat River after peak discharge when flows had declined to less than 1500 ft³/s each year (Figure 11). During 2007, in contrast to the other years, several bull trout entered the Entiat River and passed the EM station before peak discharge (Figure 11).

Table 4. Dates that radio-tagged adult fluvial bull trout were first detected at and then moved upstream past the EM fixed receiver telemetry station located at rkm 0.4 of the Entiat River, 2007 to 2010.

Code	Population	2007	2008	2009	2010
166	Entiat	not detected	27-May		
167	Entiat	25-May to 26-May	12-Jun		
173	Entiat	26-May to 29-May			
68	Entiat	27-May to 31-May			
181	Entiat	30-May to 10-Jun			
29	Entiat	2-Jun to 16-Jun			
40	Entiat	4-Jun to 12-Jun			
117	Entiat	4-Jun to 7-Jun	23-May to 4-Jun	2-Jun	26-May
113	Mad	5-Jun	23-Jun to 30-Jun	7-Jun	
120	Entiat	7-Jun to 14-Jun	18-Jun	5-Jun	13-Jun
178	Entiat	7-Jun to 13-Jun			
187	Mad	7-Jun to 17-Jun			
38	Entiat	8-Jun to 12-Jun			
114	Entiat	8-Jun	7-Jun	20-Jun	
118	Entiat	8-Jun to 16-Jun	27-May to 8-Jun	6-Jun	28-May
174	Entiat	8-Jun to 21-Jun			
124	Entiat	13-Jun to 18-Jun			
23	Entiat	14-Jun to 28-Jun			
175	Entiat	14-Jun			
45	Entiat	not detected			
119	Mad	15-Jun			
122	Entiat	15-Jun to 19-Jun	8-Jun	not detected	
151	Entiat	15-Jun to 16-Jun	4-Jun to 5-Jun	not detected	
121	Mad	16-Jun to 20-Jun			
123	Entiat	18-Jun to 20-Jun	21-Jun	20-Jun	13-Jun
126	Entiat	20-Jun			
125	Entiat	22-Jun to 25-Jun			
112	Entiat	7-Jul			
96	Entiat	--	--	--	13-Jun

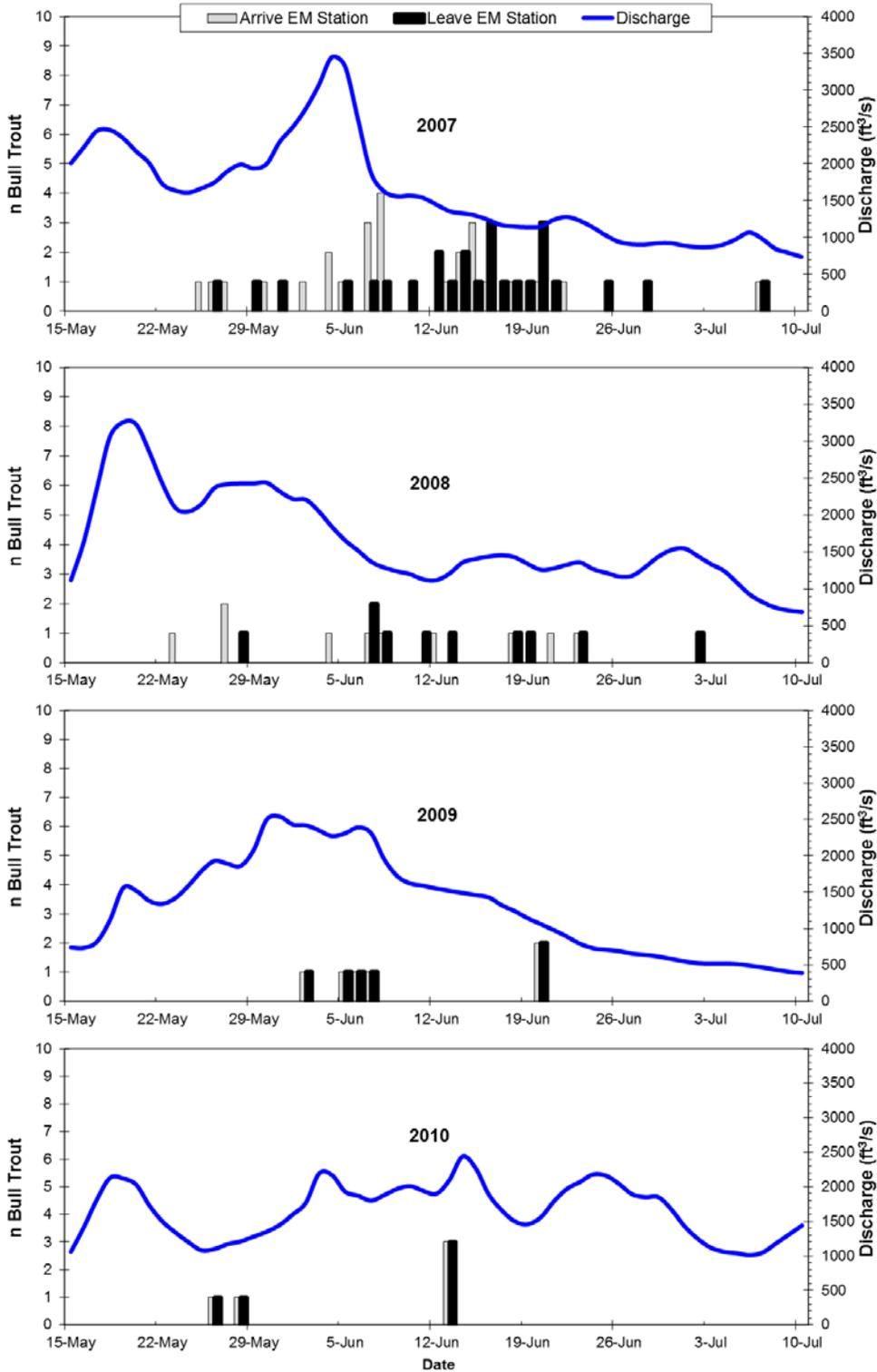


Figure 11. Entiat River discharge (USGS gage at rkm 2.5) and dates that radio-tagged adult fluvial bull trout arrived at and left the EM telemetry station (rkm 0.4) during upstream migrations, 2007 to 2010.

Entiat River water temperatures near mouth- During migrations of tagged bull trout into the Entiat River and past the EM station, mean daily water temperatures ranged from 7.1 to 13.1 °C in 2008, from 8.8 to 11.3 °C in 2009, and from 7.7 to 9.3 °C in 2010 (Figure 12).

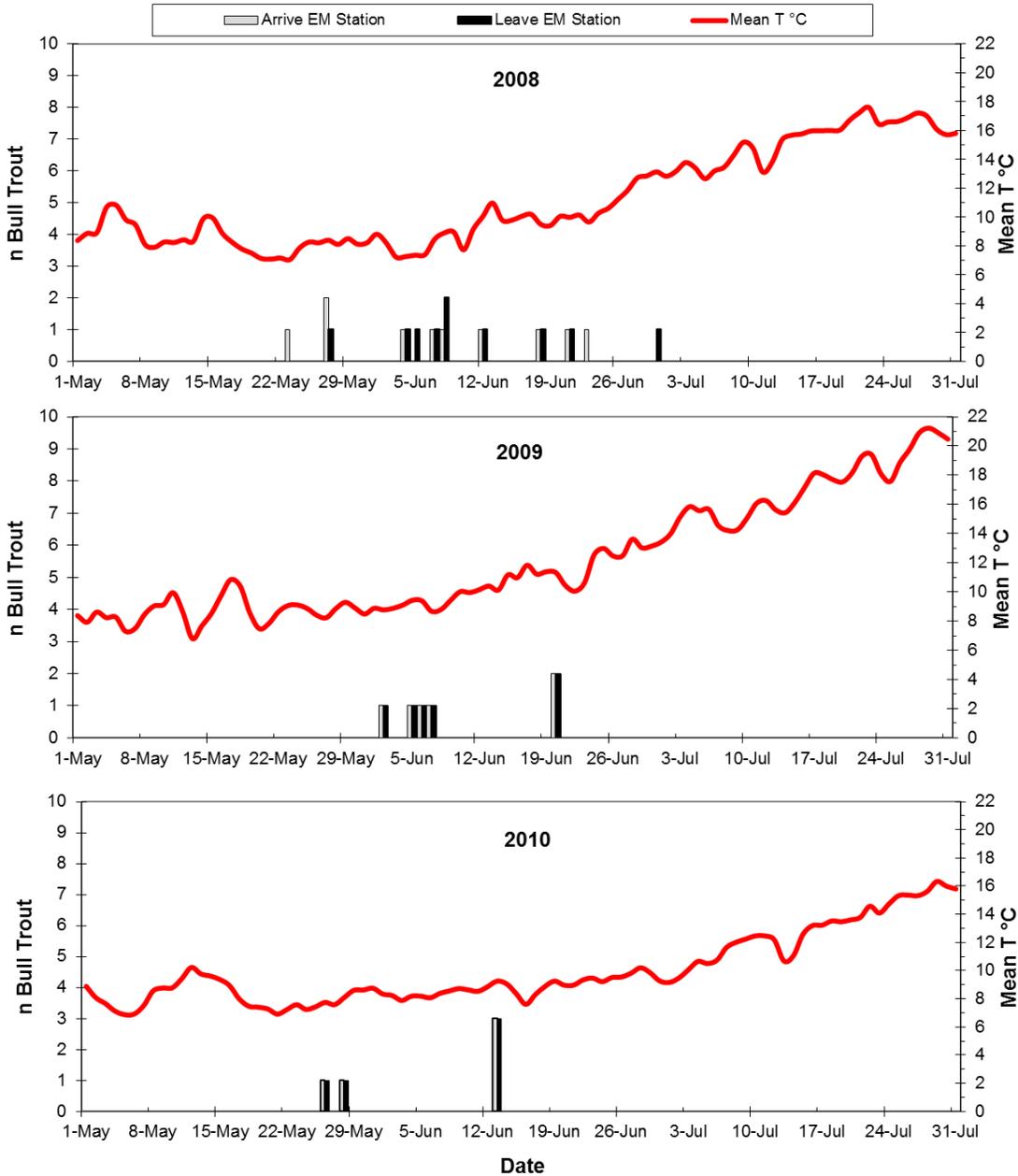


Figure 12. Mean daily temperatures of the Entiat River (USFS temperature logger at rkm 2.5) and dates that radio-tagged adult fluvial bull trout arrived at and left the EM fixed telemetry station (rkm 0.4) during upstream migrations, 2008 to 2010.

ER fixed station (rkm 5.1)- Tagged bull trout were detected moving upstream past the ER station from May 22 to July 7, 2007, from May 28 to June 23, 2008, and from June 8 to June 13, 2009 (Table 5). The number of days between first detection at the EM station (rkm 0.4) and first detection at the ER station (rkm 5.1) ranged from an average of 8 days (range 0 – 21 days) in 2007, 6 days (range 1 – 15 days) in 2008, and 5 days (range 3 – 7 days) in 2009. Bull trout passed the station after discharge declined to less than 1500 ft³/s (Figure 13). During 2007, two bull trout passed the ER station before peak discharge but in the other years all bull trout arrived after the peak (Figure 13).

Table 5. Dates that radio-tagged adult fluvial bull trout migrated upstream past the ER fixed receiver telemetry station located at rkm 5.1 of the Entiat River, 2007 to 2009.

Code	Population	2007	2008	2009 ^A
166	Upper Entiat	22-May	28-May	
167	Upper Entiat	28-May	13-Jun	
173	Upper Entiat	30-May		
29	Upper Entiat	8-Jun		
117	Upper Entiat	10-Jun	7-Jun	8-Jun
113	Mad	11-Jun	2-Jul	10-Jun
114	Upper Entiat	11-Jun	8-Jun	after 19-Jun ^A
181	Upper Entiat	12-Jun		
38	Upper Entiat	14-Jun		
40	Upper Entiat	14-Jun		
178	Upper Entiat	15-Jun		
120	Upper Entiat	16-Jun	19-Jun	8-Jun
119	Mad	17-Jun		
175	Upper Entiat	17-Jun		
151	Upper Entiat	18-Jun	7-Jun	8-Jun
118	Upper Entiat	19-Jun	11-Jun	13-Jun
121	Mad	21-Jun		
122	Upper Entiat	21-Jun	18-Jun	
124	Upper Entiat	21-Jun		
45	Upper Entiat	26-Jun		
174	Upper Entiat	26-Jun		
126	Upper Entiat	27-Jun		
187	Mad	28-Jun		
125	Upper Entiat	29-Jun		
23	Upper Entiat	1-Jul		
123	Upper Entiat	1-Jul	23-Jun	after 19-Jun ^A
112	Upper Entiat	7-Jul		
68	Upper Entiat			

Note: A- Telemetry station was removed by CCPUD on June 19, 2009.

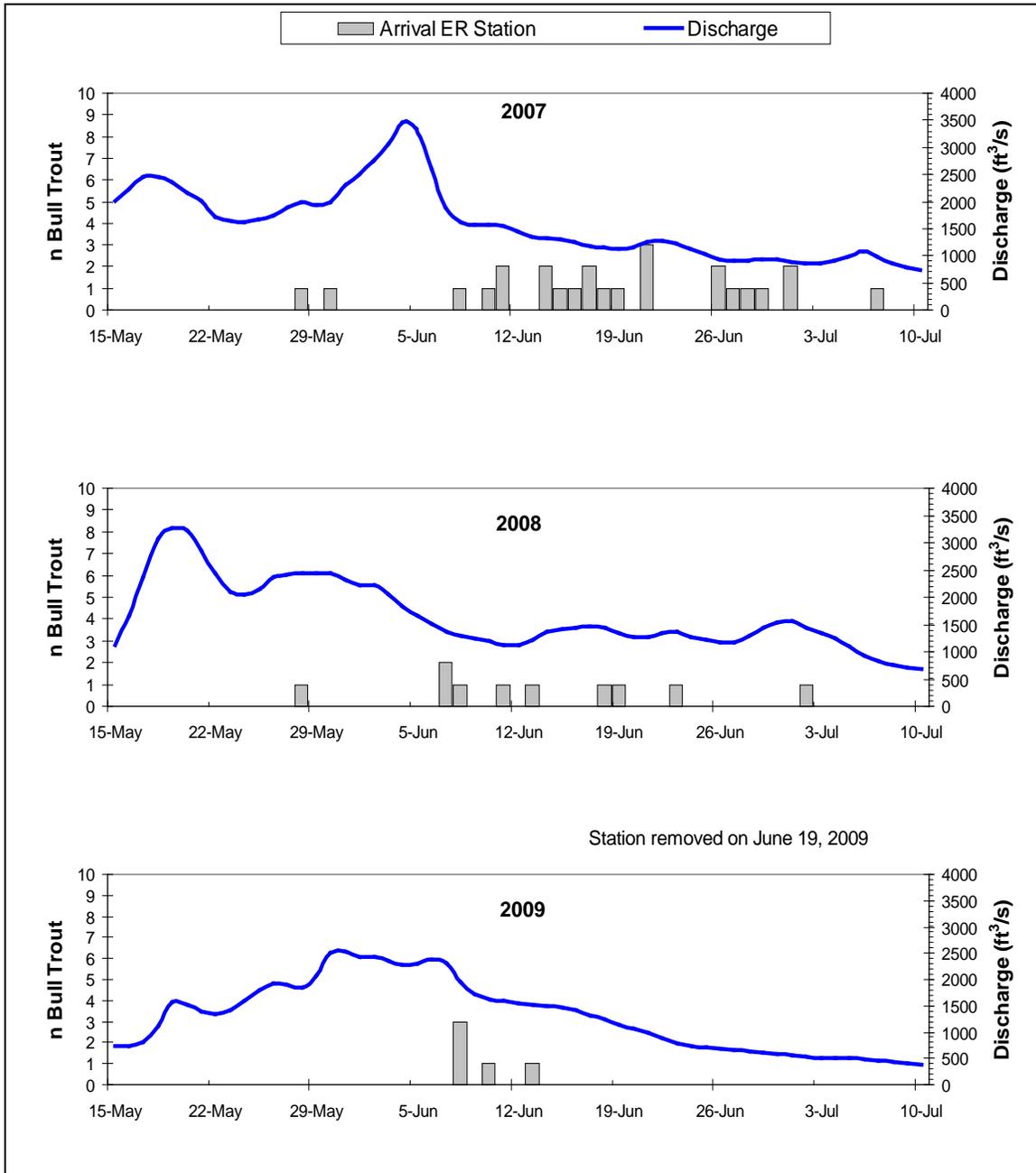


Figure 13. Entiat River discharge (USGS gage at rkm 2.5) and dates that radio-tagged adult fluvial bull trout migrated upstream past the ER fixed station (rkm 5.1) during 2007 to 2009.

MD fixed station (rkm 16.7)- Tagged bull trout were detected migrating upstream past the MD station at the confluence of the Mad River from May 29 to July 16, 2007, June 10 to July 10, 2008, June 12 to June 27, 2009, and June 19 to July 17, 2010 (Table 6). In all years, the majority of tagged bull trout migrated to the upper Entiat River. Of the four bull trout that migrated into the Mad River in 2007, only one returned in 2008 and 2009 (Table 6).

Table 6. Dates that radio-tagged adult fluvial bull trout migrated upstream past the MD fixed receiver telemetry station located at the confluence of the Mad River and Entiat River (rkm 16.7), 2007 to 2010.

Code	Population	2007	2008	2009	2010
166	Upper Entiat	29-May	10-Jun		
173	Upper Entiat	9-Jun			
167	Upper Entiat	11-Jun	20-Jun		
68	Upper Entiat	12-Jun			
113	Mad	16-Jun	9-Jul	16-Jun	
114	Upper Entiat	16-Jun	12-Jun	25-Jun	
181	Upper Entiat	17-Jun			
117	Upper Entiat	18-Jun	13-Jun	16-Jun	19-Jun
120	Upper Entiat	20-Jun	25-Jun	12-Jun	
178	Upper Entiat	20-Jun			
119	Mad	22-Jun			
151	Upper Entiat	22-Jun	13-Jun	A	
175	Upper Entiat	24-Jun			
118	Upper Entiat	28-Jun	22-Jun	20-Jun	4-Jul
121	Mad	29-Jun			
122	Upper Entiat	29-Jun	10-Jul		
126	Upper Entiat	8-Jul			
112	Upper Entiat	9-Jul			
123	Upper Entiat	9-Jul	28-Jun	27-Jun	17-Jul
124	Upper Entiat	10-Jul			
125	Upper Entiat	10-Jul			
174	Upper Entiat	11-Jul			
187	Mad	16-Jul			
23	Upper Entiat	Not detected			
29	Upper Entiat	Not detected			
38	Upper Entiat	not detected			
40	Upper Entiat	Battery died			
45	Upper Entiat	Not detected			
96	Upper Entiat				8-Jul

Note: A- In 2009 code 151 began to transmit as 255 (unknown code) during the upstream migration and was not identified after it was detected at the ER station.

DB fixed station (rkm 46.7)- Tagged bull trout were detected at the DB station downstream of Box Canyon from June 16 to July 26, 2007; June 26 to July 13, 2008; and June 24 to July 13, 2009 (Table 7). During all years Entiat River discharge had declined to less than 1000 ft³/s when tagged bull trout arrived at the DB station (Figure 14).

The DB station was not operated after 2009.

Table 7. Dates that radio-tagged adult fluvial bull trout migrated upstream past the DB fixed receiver telemetry station located downstream of Box Canyon in the upper Entiat River (rkm 46.7), 2007 to 2009.

Code	Population	2007	2008	2009
166	Upper Entiat	16-Jun	6-Jul	
68	Upper Entiat	21-Jun		
29	Upper Entiat	23-Jun		
181	Upper Entiat	26-Jun		
120	Upper Entiat	1-Jul	6-Jul	24-Jun
178	Upper Entiat	1-Jul		
23	Upper Entiat	2-Jul		
112	Upper Entiat	2-Jul		
151	Upper Entiat	2-Jul	26-Jun	
167	Upper Entiat	2-Jul	9-Jul	
38	Upper Entiat	3-Jul		
117	Upper Entiat	3-Jul	8-Jul	4-Jul
122	Upper Entiat	3-Jul	Not detected	13-Jul
114	Upper Entiat	5-Jul	7-Jul	8-Jul
175	Upper Entiat	8-Jul		
118	Upper Entiat	9-Jul	9-Jul	4-Jul
173	Upper Entiat	22-Jul		
123	Upper Entiat	23-Jul	13-Jul	12-Jul
126	Upper Entiat	23-Jul		
125	Upper Entiat	26-Jul		
124	Upper Entiat	Not detected		
45	Upper Entiat	Stayed downstream		
174	Upper Entiat	Stayed downstream		

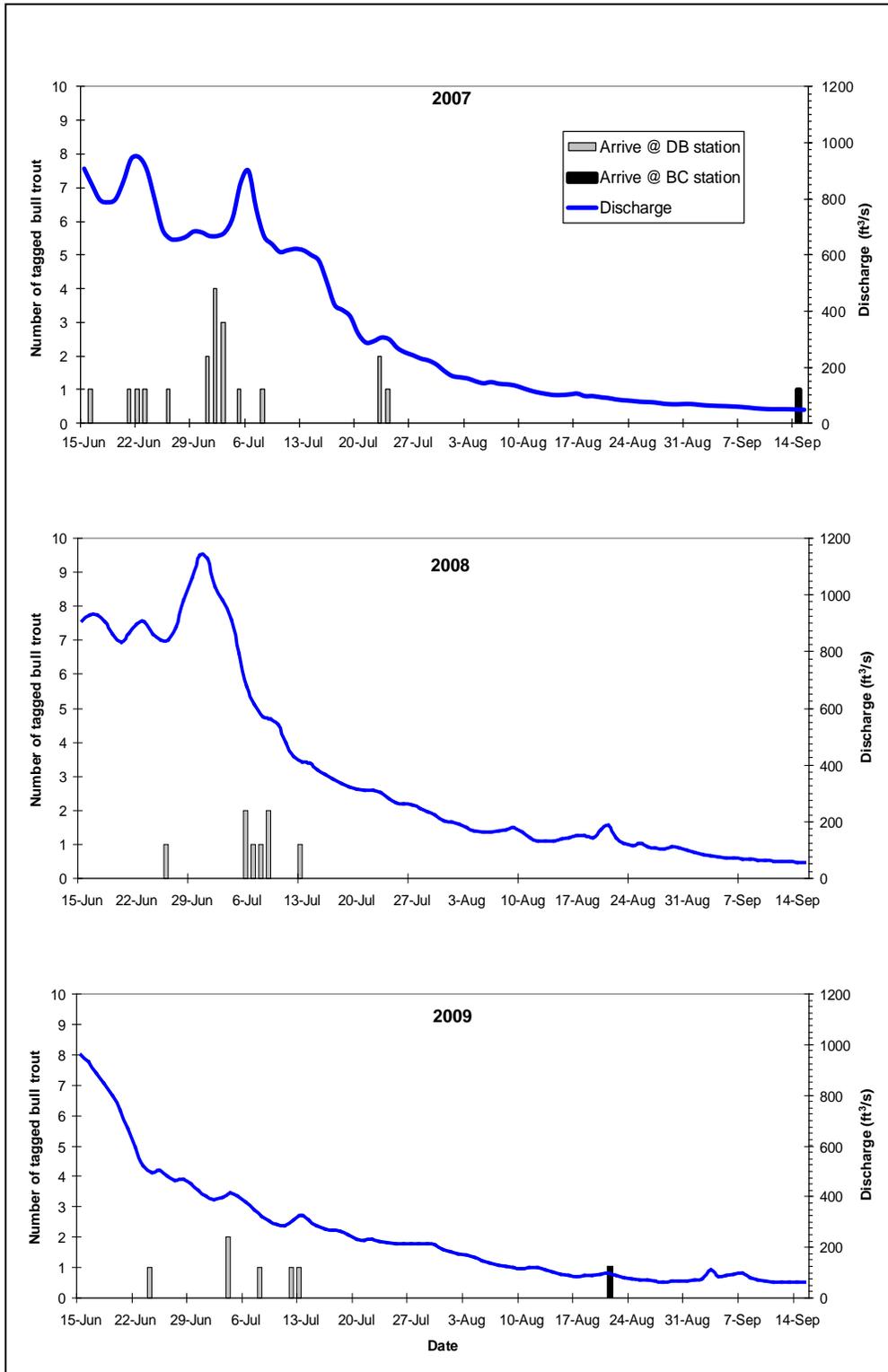


Figure 14. Entiat River discharge ((WDOE gage at rkm 54.1) and dates when radio-tagged adult bull trout migrated upstream past the DB fixed receiver telemetry station (rkm 46.7) and the BC fixed receiver telemetry station (rkm 47.0), 2007 to 2009.

BC fixed station (rkm 47.0)- During 2007 to 2010, very few tagged bull trout were able to pass Box Canyon and migrate to the upper Entiat River optimal spawning grounds. No tagged bull trout passed during the migration in 2008, and only one tagged bull trout made it through Box Canyon in each of the other years (Table 8). The percentage of tagged bull trout that reached the upper spawning grounds each year ranged from 0 to 25% (Table 9). The tagged bull trout that were able to pass Box Canyon did so when Entiat River discharge declined to less than 200 ft³/s (Figure 14). The Entiat Falls gage station was not operational in 2010, so the discharge was unknown when code 96 passed to the spawning grounds. In 2007, bull trout code 126 spent 53 days in Box Canyon before passing the BC station while in 2009, bull trout code 122 spent 39 days.

Table 8. Dates that radio-tagged adult fluvial bull trout migrated upstream past the BC fixed receiver telemetry station located upstream of Box Canyon and Fish Tail Falls in the upper Entiat River (rkm 47.0), 2007 to 2010.

Code	Population	2007	2008	2009	2010	2011	2012
126	Upper Entiat	14-Sep					
122	Upper Entiat			21-Aug			
96	Upper Entiat				28-Aug		

Table 9. Percentage of radio-tagged adult fluvial bull trout that passed Box Canyon and were present on the upper Entiat River spawning grounds, 2007 to 2010.

Year	n tagged BT in Box Canyon	n tagged BT on spawning grounds	% passed
2007	20	1	5%
2008	9	0	0%
2009	6	1	17%
2010	4	1	25%

Obstacles in Box Canyon

Log jam- In 2006, adult bull trout were obstructed from moving upstream by a log and debris jam in the passage channel between the upper two pools in Box Canyon (see Nelson and Nelle 2008). This log continued to affect upstream passage (Figure 15) from 2007 through 2011. This type of obstruction apparently has been occurring periodically since at least 1939 (Figures 16 and 17) but it is uncertain how long passage can be impeded. In spring of 2012 the log apparently was washed downstream during high flows and more bull trout were finally able to move upstream (see cover photo).



Figure 15. Photograph of log jammed in passage between the upper two pools in Box Canyon taken on August 17, 2010 (view is looking downstream into second pool or “Slot Pool”).



Figure 16. Photograph taken in 2008 showing orientation of log (arrow) that was lodged in the passage between Slot Pool (lower pool) and the Fish Tail Falls Pool in Box Canyon during 2006 to 2012.



Figure 17. Photograph taken in 1939 showing orientation of logs (arrow) lodged in passage between the Slot Pool (lower pool) and the Fish Tail Falls Pool in Box Canyon (Photo courtesy Oregon State University).

Spawning

Redd counts in the Entiat River- During 2007 to 2013, the number of bull trout redds observed in the upper Entiat River ranged from 7 to 26 (Table 10). In 2008, bull trout were observed spawning in Box Canyon downstream of the Slot Pool passage impediment, and surveys were expanded to include the river between Fish Tail Falls and Lake Creek. During surveys in 2008, 13 bull trout redds, accounting for 62% of the total observed in the upper Entiat River, were located within Box Canyon; however, in later years fewer redds were located there (Table 10). In 2012, the log impediment washed downstream and the number of redds upstream of Box Canyon increased in 2012 and 2013 (Table 10). Reach A consistently had the highest number of redds, with most occurring in the vicinity of Pope Creek (Figures 18 and 19). During the spawning season in 2007, only one tagged bull trout was located on the spawning grounds, while twelve were in Box Canyon, and six moved downstream to the lower Entiat River prior to the start of spawning (Figure 20).

The number of redds in the upper Entiat River has declined since the high count of 50 was observed in 2005 (Figure 21). This decline is related to the log jam in Box Canyon that prevented the majority of bull trout from accessing the upper spawning area during 2006 through 2011.

Table 10. Number of bull trout redds counted during spawning ground surveys in the index reaches of the upper Entiat River, 2007 to 2013.

Reach	Rkms	2007	2008	2009	2010	2011	2012 ^a	2013 ^b
USFS Index	54.1-54.5	4	2	4	2	0	4	2
A	51.2-54.1	7	4	9	4	2	3	7
B	47.3-51.2	1	2	2	0	0	4	9
Box to Fox	45.4-47.0	--	13	2	1	7	2	6
Totals	47.0-54.5	12	21	17	7	9	13	24

Notes: a- incomplete survey due to wildfires; b- incomplete survey due to government furlough.

Redd counts in the Mad River- The number of bull trout redds counted in the Mad River declined during 2007 to 2012 (Table 11), continuing the trend observed since 2003 (Figure 22). Most redds were located upstream of the Alma Creek log jam that had formed a barrier to further upstream movement prior to 2006. During 2007, three of the four tagged bull trout were located on the spawning grounds, including two upstream of the former log jam barrier (Figure 20).

In 2010, only six redds were detected during the USFS surveys. Observations of small bull trout (200 – 250 mm) on four redds as well as the small size of redds indicated that all were constructed by resident fish. Four redds were located downstream of the Alma Creek log jam site. In 2011, a total of 10 redds were observed and most were large and migratory-sized.

Table 11. Number of bull trout redds counted during spawning ground surveys in the index reaches of the Mad River, 2007 to 2013.

Reach	Rkms	2007	2008	2009	2010	2011	2012 ^a	2013 ^b
Young Cr-Alma Cr	18.0-21.7	2	2	1	4	0	2	?
Alma Cr-Berg Cr	21.7-26.4	16	5	3	2	10	1	2
Berg Cr-Jimmy Cr.	26.4-30.1	11	2	3	0	0	0	?
Totals	18.0-30.1	29	9	7	6	10	3	2

Notes: a- incomplete survey due to wildfires; b- incomplete survey due to government furlough.

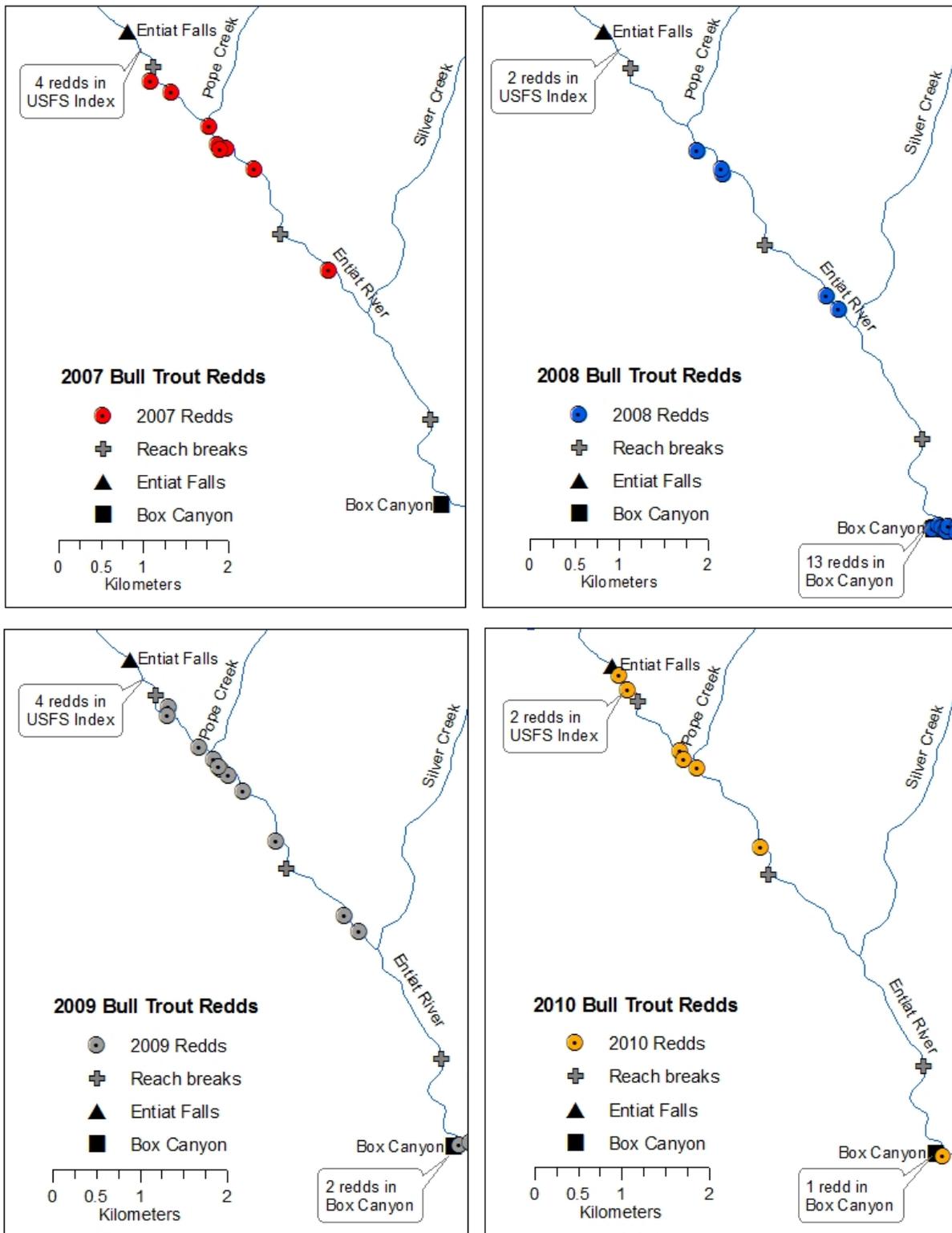


Figure 18. Locations of fluvial bull trout redds in the upper Entiat River during 2007 to 2010.

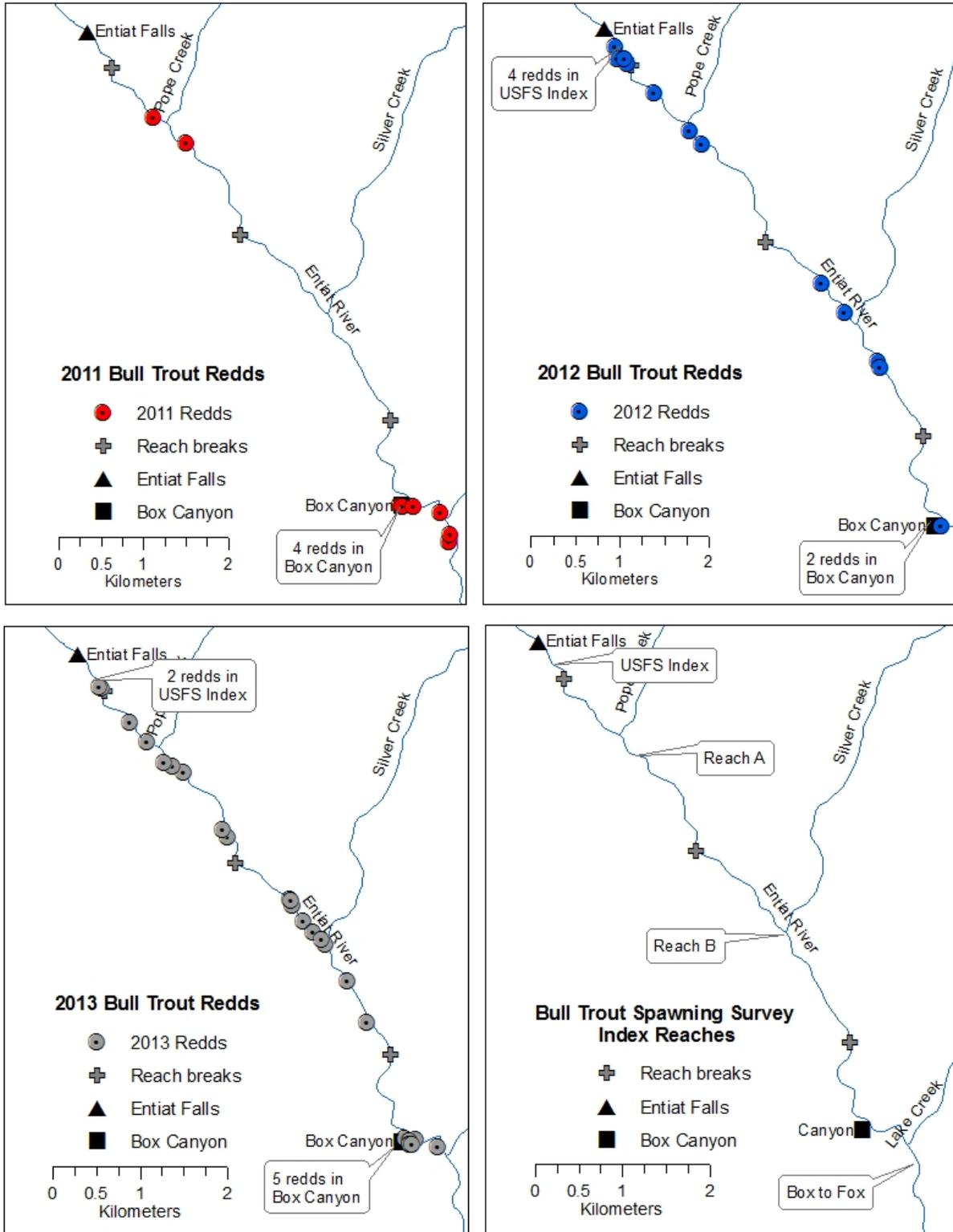


Figure 19. Locations of fluvial bull trout redds in the upper Entiat River during 2011 to 2013.

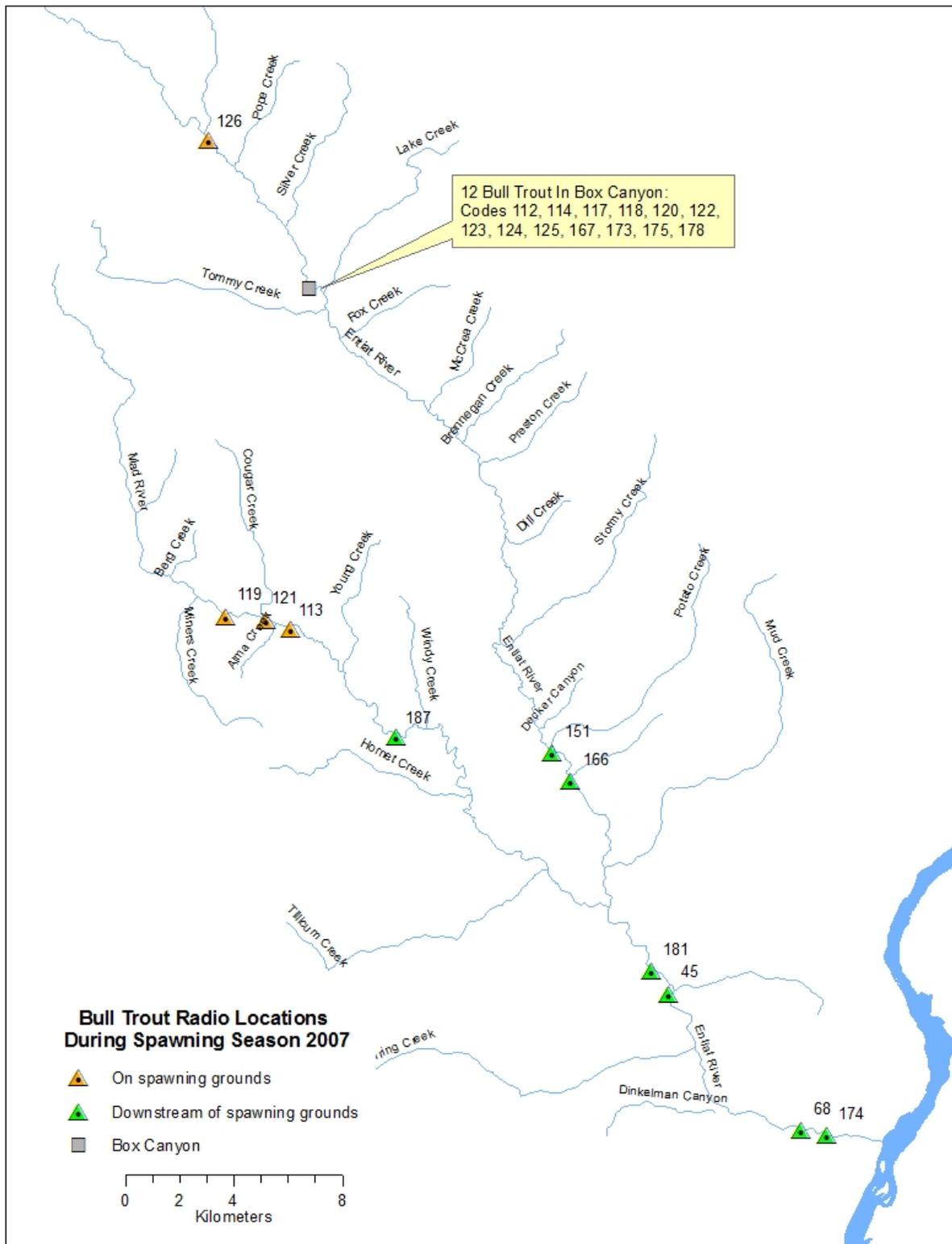


Figure 20. Locations of radio-tagged bull trout during the spawning season in the upper Entiat River and Mad River, 2007.

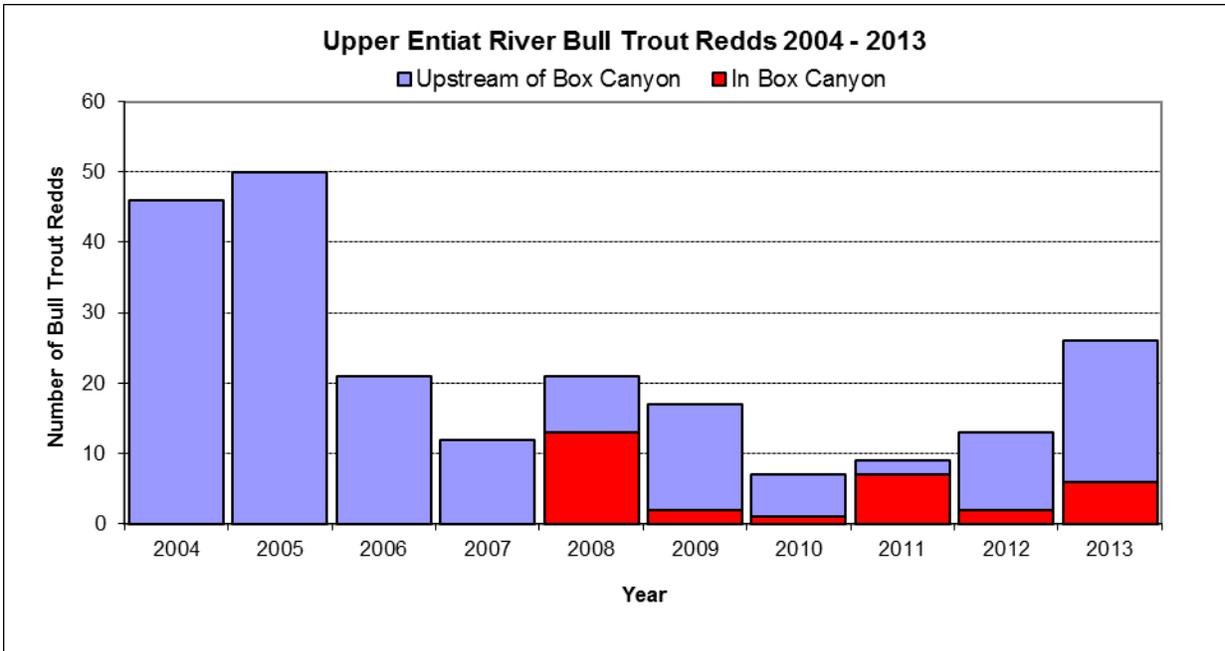


Figure 21. Number of bull trout redds observed during spawning ground surveys in the upper Entiat River, 2004 to 2013 (surveys not conducted in Box Canyon during 2004 to 2007).

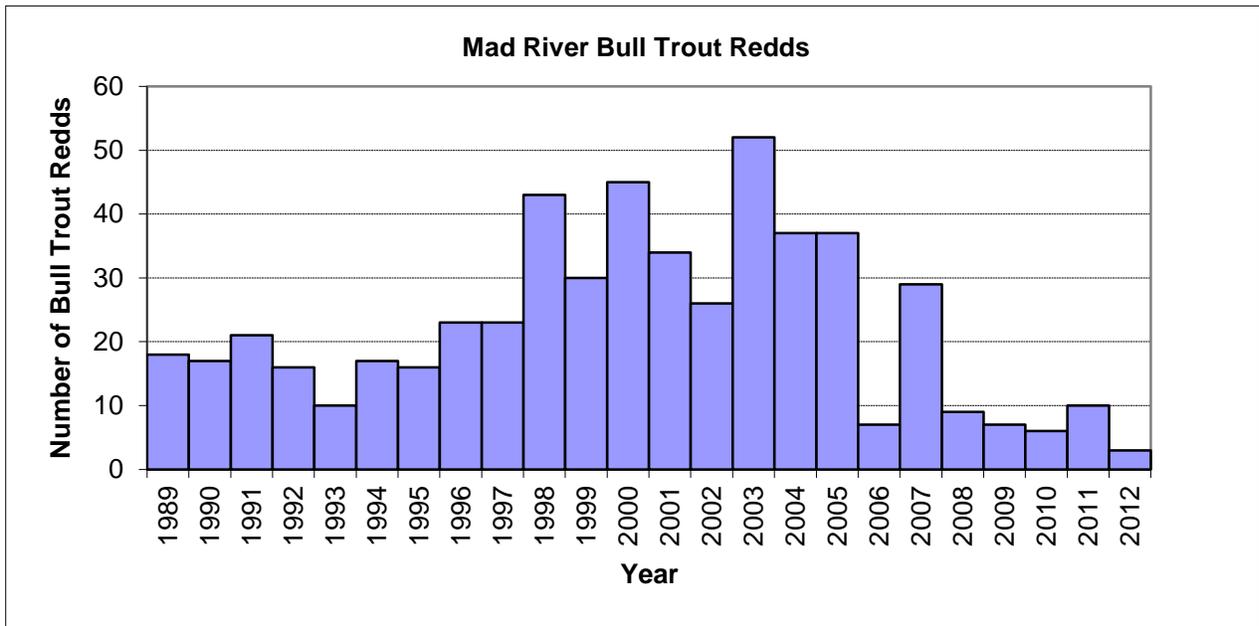


Figure 22. Number of bull trout redds observed during spawning ground surveys in the Mad River, 1989 to 2012.

Post-spawn downstream migrations

BC fixed station (rkm 47.0)- Radio-tagged bull trout left the spawning grounds, moved downstream and passed the BC station in mid-October (Table 12).

Table 12. Dates that radio-tagged adult fluvial bull trout migrated downstream past the BC fixed receiver telemetry station located at rkm 47.0 of the Entiat River, 2007 to 2010.

Code	Population	2007	2008	2009	2010
126	Upper Entiat	11-Oct			
122	Upper Entiat			17-Oct	
96	Upper Entiat				9-Oct

Days spent in Box Canyon- For the tagged bull trout that were unable to access the upper spawning grounds, the amount of time spent in Box Canyon prior to moving downstream ranged from 19 to 100 days during 2007 (Figure 23), from 55 to 114 days during 2008 (Figure 24), and from 67 to 109 days during 2009 (Figure 25). Some radio-tagged bull trout moved downstream before September, including 4 in 2007 and 2 in 2008 (Figures 23 and 24). On average, about 20% of the radio-tagged bull trout moved downstream before the start of the spawning season. Codes 125 and 114 did not move downstream and their tags were later recovered in Box Canyon.

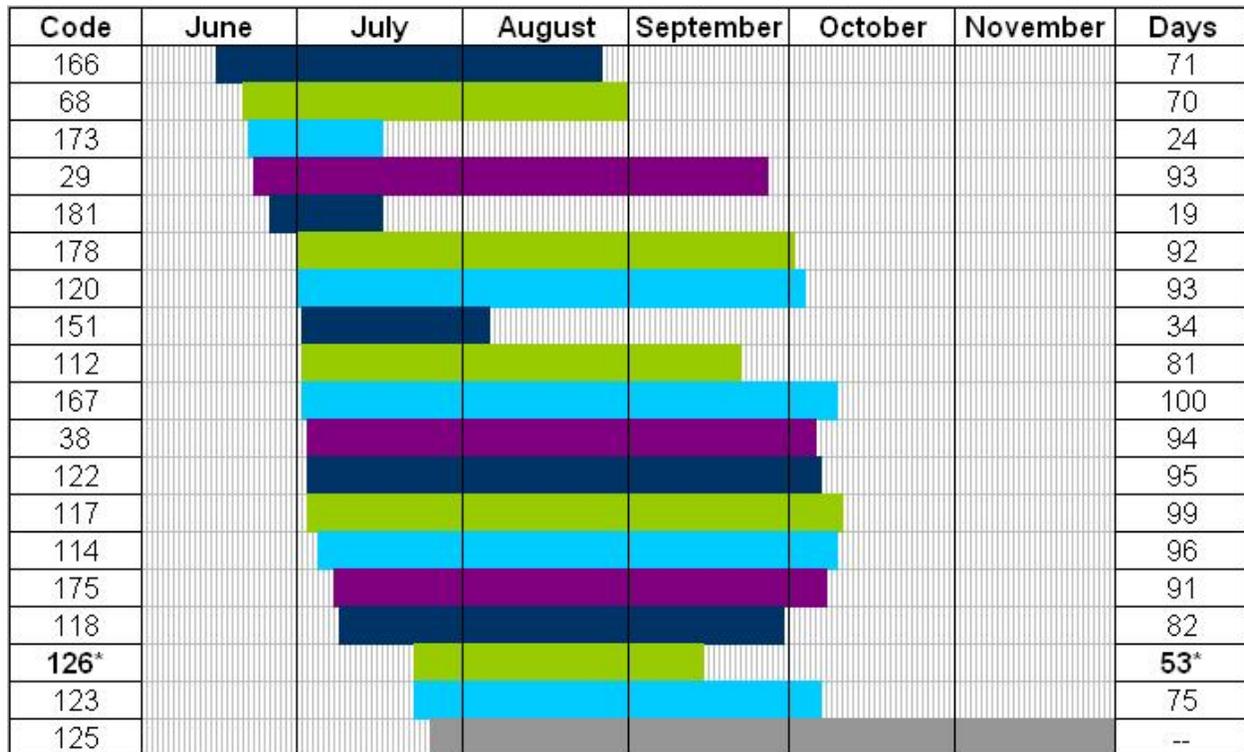


Figure 23. Number of days radio-tagged adult fluvial bull trout spent in Box Canyon of the upper Entiat River during 2007 (asterisk * indicates bull trout that passed upstream to spawning grounds).

Code	June	July	August	September	October	Days
114						114
117						86
118						69
120						56
122						unk
123						68
151						55
166						87
167						90

Figure 24. Number of days radio-tagged adult fluvial bull trout spent in Box Canyon of the upper Entiat River during 2008.

Code	June	July	August	September	October	Days
120						92
117						105
118						88
114						--
123						67
122*						39*

Figure 25. Number of days radio-tagged adult fluvial bull trout spent in Box Canyon of the upper Entiat River during 2009 (asterisk * indicates bull trout that passed upstream to spawning grounds).

DB fixed station (rkm 46.7)- Radio-tagged bull trout migrated downstream past this station downstream of Box Canyon from August 26 to November 13, 2007, August 21 to October 29, 2008, and September 17 to October 17, 2009 (Table 13).

Table 13. Dates that radio-tagged adult fluvial bull trout migrated downstream past the DB fixed receiver telemetry station located downstream of Box Canyon at rkm 46.7 of the Entiat River, 2007 to 2009.

Code	Population	2007	2008	2009
29	Upper Entiat	24-Sep		
38	Upper Entiat	Battery died		
23	Upper Entiat	Battery died		
45	Upper Entiat	Stayed downstream		
68	Upper Entiat	31-Aug		
112	Upper Entiat	21-Sep		
114	Upper Entiat	9-Oct	29-Oct	Did not pass
117	Upper Entiat	10-Oct	2-Oct	17-Oct
118	Upper Entiat	29-Sep	Not detected	30-Sep
120	Upper Entiat	2-Oct	31-Aug	24-Sep
122	Upper Entiat	6-Oct	3-Oct	17-Oct
123	Upper Entiat	6-Oct	20-Sep	17-Sep
124	Upper Entiat	Did not pass		
125	Upper Entiat	Did not pass		
126	Upper Entiat	9-Oct		
151	Upper Entiat	5-Aug	21-Aug	
166	Upper Entiat	26-Aug	1-Oct	
167	Upper Entiat	9-Oct	7-Oct	
173	Upper Entiat	Battery died?		
175	Upper Entiat	7-Oct		
178	Upper Entiat	1-Oct		
181	Upper Entiat	3-Jul		

MD fixed station (rkm 16.7).- The dates that radio-tagged bull trout migrated downstream past the MD station at the confluence of the Mad River were August 29 to October 25, 2007, August 17 to December 16, 2008, September 25 to October 25, 2009, and October 10 to October 29, 2010 (Table 14). In 2007, two bull trout did not exit the Mad River

Table 14. Dates that radio-tagged adult fluvial bull trout migrated downstream past the MD fixed receiver telemetry station located at the confluence of the Mad River and Entiat River (rkm 16.7), 2007 to 2010.

Code	Population	2007	2008	2009	2010
29	Upper Entiat	Not detected			
45	Upper Entiat	2-Sep			
68	Upper Entiat	4-Sep			
96	Upper Entiat				10-Oct
112	Upper Entiat	27-Sep			
113	Mad	3-Oct	17-Aug	17-Oct	
114	Upper Entiat	3-Oct	31-Oct		
117	Upper Entiat	13-Oct	6-Oct	19-Oct	
118	Upper Entiat	28-Oct	5-Nov	9-Oct	
119	Mad	4-Nov			
120	Upper Entiat	8-Oct	1-Sep	26-Sep	
121	Mad	Did not exit Mad			
122	Upper Entiat	Not detected	Not detected	Not detected	
123	Upper Entiat	14-Oct	16-Dec	25-Oct	29-Oct
124	Upper Entiat	Did not pass			
125	Upper Entiat	Did not pass			
126	Upper Entiat	13-Oct			
151	Upper Entiat	13-Oct	7-Sep		
166	Upper Entiat	25-Oct	4-Oct		
167	Upper Entiat	12-Oct	8-Oct		
174	Upper Entiat	29-Aug			
175	Upper Entiat	13-Oct			
178	Upper Entiat	Did not pass			
181	Upper Entiat	4-Oct			
187	Mad	Did not exit Mad			

ER fixed station (rkm 5.1)- The dates that radio-tagged bull trout were detected migrating downstream past the ER station ranged from September 29 to November 24, 2007 and August 18, 2008 to January 7, 2009 (Table 15). In 2007, three bull trout were not detected as they migrated downstream from the upper Entiat River.

Table 15. Dates that radio-tagged adult fluvial bull trout migrated downstream past the ER fixed receiver telemetry station located at rkm 5.1 of the Entiat River, 2007 to 2008.

Code	Population	2007	2008	2009 ^A
29	Upper Entiat	Not detected		
45	Upper Entiat	9-Nov		
68	Upper Entiat	Not detected		
112	Upper Entiat	29-Sep		
113	Mad	18-Oct	18-Aug	
114	Upper Entiat	4-Oct	3-Nov	
117	Upper Entiat	29-Oct	8-Nov	
118	Upper Entiat	14-Nov	8-Nov	
119	Mad	9-Nov		
120	Upper Entiat	30-Oct	29-Oct	
121	Mad	Did not exit Mad		
122	Upper Entiat	23-Nov		
123	Upper Entiat	18-Oct	7-Jan-09	
126	Upper Entiat	23-Oct		
151	Upper Entiat	24-Nov	5-Nov	
166	Upper Entiat	9-Nov	3-Nov	
167	Upper Entiat	12-Oct		
174	Upper Entiat	Not detected		
175	Upper Entiat	18-Oct		
178	Upper Entiat	Did not pass		
181	Upper Entiat	22-Nov		
187	Mad	Did not exit Mad		

Note: A- Telemetry station was removed by Chelan County PUD on June 19, 2009.

EM fixed station (rkm 0.4)- The dates that radio-tagged bull trout migrated downstream past this telemetry station near the mouth of the Entiat River ranged from August 30 to after November 30, 2007, August 18, 2008 to January 18, 2009, October 29 to December 29, 2009, and November 4 to 13, 2010 (Table 16).

Table 16. Dates that radio-tagged adult fluvial bull trout migrated downstream past the EM fixed receiver telemetry station located at rkm 0.4 of the Entiat River, 2007 to 2010.

Code	Population	2007	2008	2009	2010
29	Upper Entiat	3-Nov			
38	Upper Entiat	6-Nov			
45	Upper Entiat	21-Nov			
68	Upper Entiat	5-Sep			
96	Upper Entiat				4-Nov
112	Upper Entiat	29-Sep			
113	Mad	21-Oct	18-Aug	31-Oct	
114	Upper Entiat	4-Oct	?		
117	Upper Entiat	1-Nov	?	31-Oct	
118	Upper Entiat	15-Nov	8-Nov	11-Nov	
119	Mad	21-Nov			
120	Upper Entiat	23-Nov	?	27-Oct	
121	Mad	Did not exit Mad			
122	Upper Entiat	29-Nov	20-Dec	29-Dec	
123	Upper Entiat	?	18-Jan-09	17-Nov	13-Nov
126	Upper Entiat	1-Nov			
151	Upper Entiat	27-Nov	?		
166	Upper Entiat		8-Nov		
167	Upper Entiat	6-Nov	12-Oct		
174	Upper Entiat	30-Aug			
175	Upper Entiat	21-Oct			
181	Upper Entiat	After 30-Nov ^A			
187	Mad	Did not exit Mad			

Note: A- Station not in operation after November 30 during 2007.

Number of days in Entiat River

During 2007 – 2010, the amount of time that individual radio-tagged bull trout spent in the Entiat River ranged from 35.9 to 211.7 days (Table 17). The majority of bull trout entered the river in June and exited in November (Figures 26 – 28). On average, bull trout spent 140.8 days in 2007, 152.8 days in 2008, 150.6 days in 2009, and 148.8 days in 2010 in the Entiat River watershed.

Table 17. Number of days that radio-tagged adult fluvial bull trout spent in the Entiat River watershed, 2007 to 2010.

Code		2007	2008	2009	2010
23	Entiat	35.9			
29	Entiat	160.5			
38	Entiat	150.1			
45	Entiat	151.2			
68	Entiat	104.2			
96	Entiat				144.7
112	Entiat	86.7			
113	Mad	155.1	56.1	145.8	
114	Entiat	117.4			
117	Entiat	149.1		150.5	
118	Entiat	162.6	167.3	163.4	
119	Mad	158.1			
120	Entiat	169.2		143.9	
122	Entiat	166.8	194.7		
123	Entiat	121.3	211.7	149.4	152.9
126	Entiat	134.1			
151	Entiat	164.9			
166	Entiat		164.9		
167	Entiat	164.2	122.2		
174	Entiat	146.3			
175	Entiat	129.6			
181	Entiat	175.2			

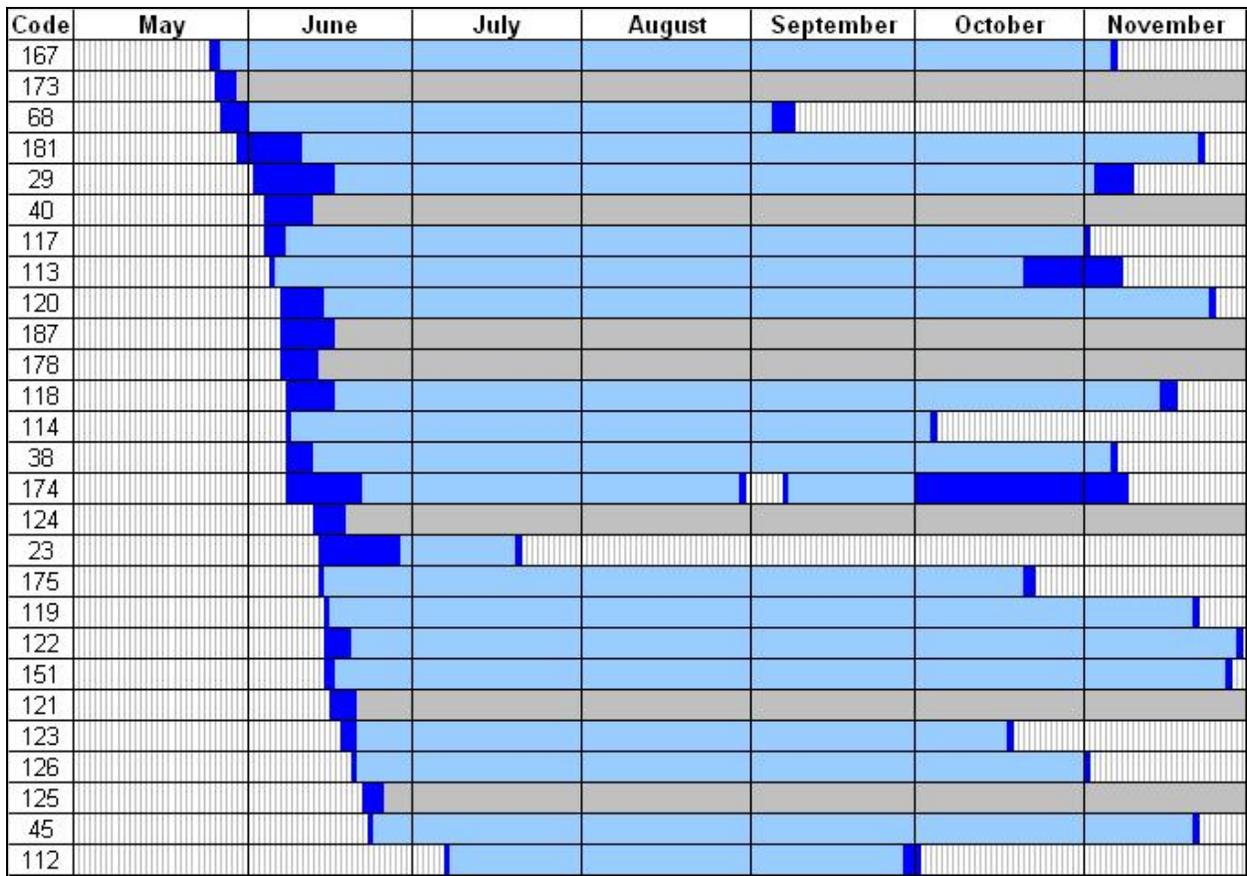


Figure 26. Timelines of radio-tagged adult fluvial bull trout presence in the Entiat River watershed during 2007 (dark blue represents detection at the EM station at rkm 0.4, light blue represents time spent upstream of the station, and gray indicates bull trout did not exit).



Figure 27. Timelines of radio-tagged adult fluvial bull trout presence in the Entiat River watershed during 2008 (dark blue represents detection at the EM station at rkm 0.4 and light blue represents time spent upstream of the station).



Figure 28. Timelines of radio-tagged adult fluvial bull trout presence in the Entiat River watershed during 2009 (dark blue represents detection at the EM station at rkm 0.4 and light blue represents time spent upstream of the station).

Water temperatures

Entiat River MWMT- Maximum weekly maximum temperatures were cooler at upstream locations in the Entiat River, with the coldest temperatures upstream of the migratory barrier of Entiat Falls (Table 18). Within the upper spawning reach, MWMTs ranged from 14.0 to 15.8 °C during 2007 to 2009. At all locations, MWMTs were cooler in 2007 than in 2008 and 2009. The maximum was recorded in August each year, including on August 7 during 2007, on August 19 during 2008, on August 3 during 2009, and on August 19 during 2010.

Table 18. Maximum weekly maximum temperature (°C) recorded at USFS temperature monitoring stations in the Entiat River, 2007 to 2010.

Location	2007	2008	2009	2010
Keystone Br. (rkm 2.3)	20.6	22.5	23.4	19.6
Entiat NFH (rkm 11.3)	19.9	23.4		
u/s Stormy Cr. (rkm 29)	18.0	19.3		
Forest Boundary (rkm 41.8)	15.8	17.4	17.7	
u/s Silver Cr. (rkm 51.5)	14.0	15.3		
d/s Entiat Falls (rkm 54)	14.3	15.3	15.8	
u/s North Fork (rkm 55.5)	12.9	14.4		
Cottonwood Camp (rkm 61.1)	12.0	12.9		

Mad River MWMT- Maximum weekly maximum temperatures in the Mad River were warmest at the outlet of Mad Lake and coolest in the spawning reaches upstream of Cougar Creek during 2007 – 2009 (Table 19). Within the spawning reaches, MWMTs ranged from 13.4 to 16.2 °C. The maximums were recorded on July 29 during 2007, on August 19 during 2008 and on August 3 during 2009.

Table 19. Maximum weekly maximum temperature (°C) recorded at USFS temperature monitoring locations in the Mad River, 2007 to 2009.

Location	2007	2008	2009
Mouth (rkm 0)	18.6	19.2	20.3
u/s Hornet Cr. (rkm 8)	18.7	18.7	19.9
u/s Windy Cr. (rkm 14.2)	18.3	17.9	19.2
u/s Young Cr. (rkm 19.8)	14.9	15.1	16.2
u/s Cougar Cr. (rkm 24)	13.4	13.6	15.1
u/s Berg Cr. (rkm 28.5)	--	13.7	15.3
u/s Jimmy Cr. (rkm 31.9)	14.4	14.5	16.2
Mad Lake outlet (rkm 39.6)	22.4	21.4	--

Historic water temperatures at rkm 41.6 (Forest Boundary)- Stream temperatures in the Entiat River at rkm 41.6 have warmed since the 1960s (Figure 29). During 1967 to 1977, MWMT recorded by Copenhagen (1978) at the Forest Boundary ranged from 12.3 to 16.4 °C (mean 14.1 °C). During 2000 to 2009, MWMT recorded by USFS at the same site ranged from 15.1 to 18.7 °C (mean 17.0 °C). The increase in MWMT by an average of 2.9 °C is statistically significant (Table 20).

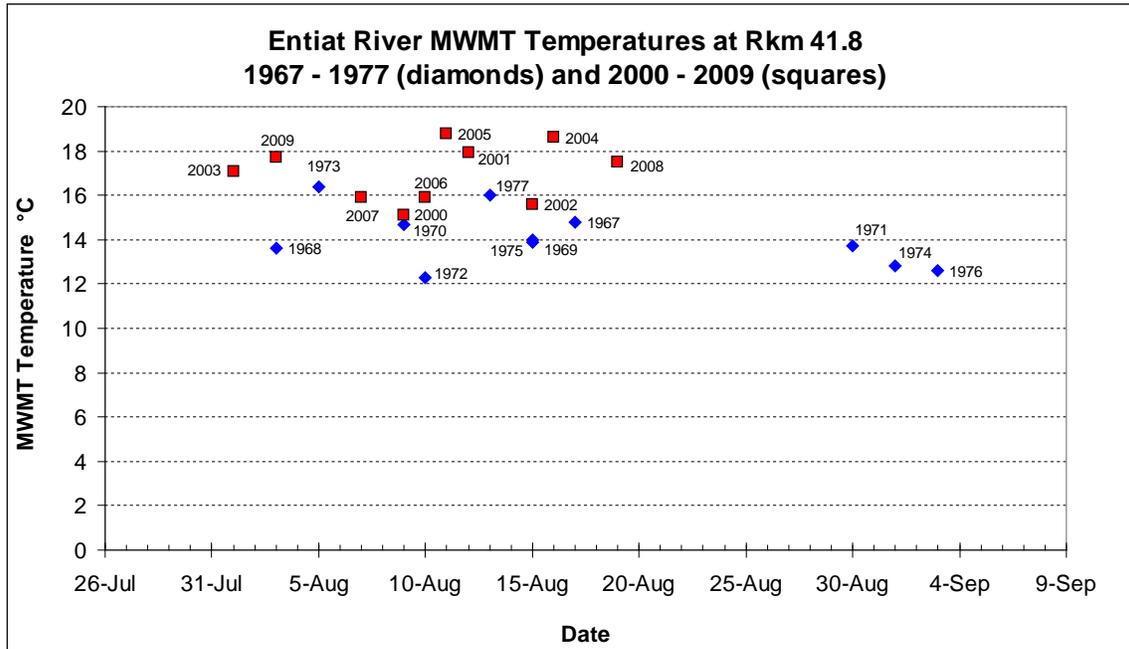


Figure 29. Maximum weekly maximum temperatures (MWMT) recorded at rkm 41.8 of the Entiat River during each year from 1967 to 1977 (diamonds) and from 2000 to 2009 (squares).

Table 20. Results of ANOVA comparing MWMT recorded in 1967 – 1977 to MWMT recorded in 2000 – 2009 at rkm 41.8 in the upper Entiat River.

ANOVA: Single Factor (MWMT)						
<u>Groups</u>	<u>Count</u>	<u>Sum</u>	<u>Average</u>	<u>Variance</u>		
1967 - 1977	11	154.8	14.07	1.74		
2000 - 2009	10	170.1	17.01	1.71		
<u>Source of Variation</u>	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>P-value</u>	<u>F crit</u>
Between Groups	45.19	1	45.19	26.2	0.00006	4.38
Within Groups	32.73	19	1.72			
Total	77.92	20				

Winter locations in the Columbia River

Radio-tagged bull trout migrated to the Columbia River and were located both up- and downstream of the Entiat River during 2007-2009 (Figure 30). Three of the mid-Columbia River reservoirs were used, but no tagged bull trout moved upstream past Wells Dam. During the three winters the Columbia River was tracked, 13 bull trout were located in the Rock Island reservoir, 10 were located in the Rocky Reach reservoir, and 2 were located in the Wanapum reservoir.

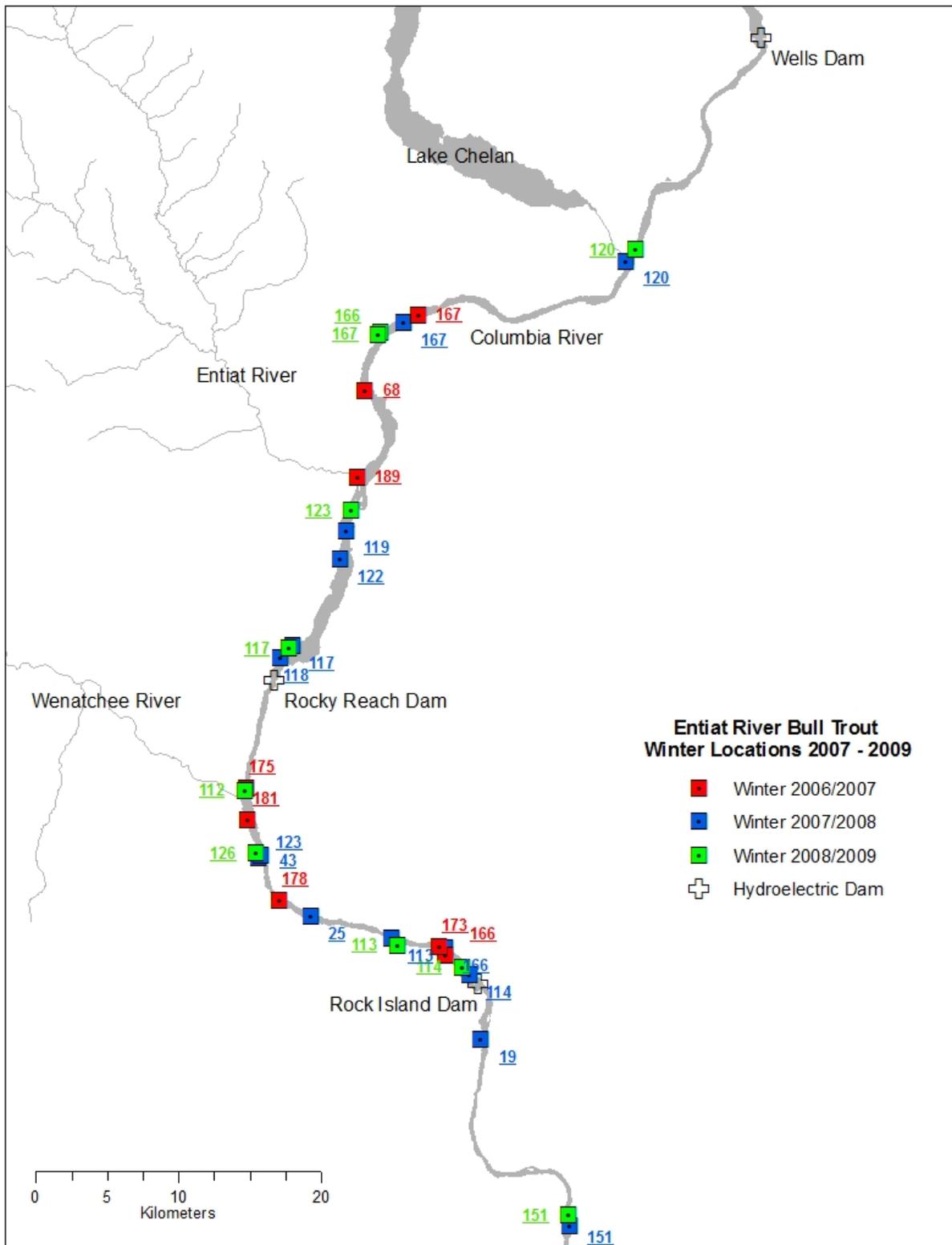


Figure 30. Map of the Columbia River winter locations of Entiat Core Area radio-tagged adult fluvial bull trout, 2007 to 2009.

The furthest upstream winter location of a tagged Entiat River bull trout in the Columbia River was near the Chelan River (rkm 812) and the farthest downstream winter location was near Crescent Bar (rkm 706). Several bull trout returned to the same winter location in subsequent years (Figure 30).

Recovered tags

A total of nine transmitters were recovered or inactive (Figure 31). Five of the transmitters (codes 168, 169, 179, 183, 185) were either motionless or had not left the Entiat River watershed by the end of 2006. Four transmitters were recovered or became inactive during 2007 to 2010: three in the upper Entiat River (codes 114, 125, 178) and one in the Mad River (code 187).

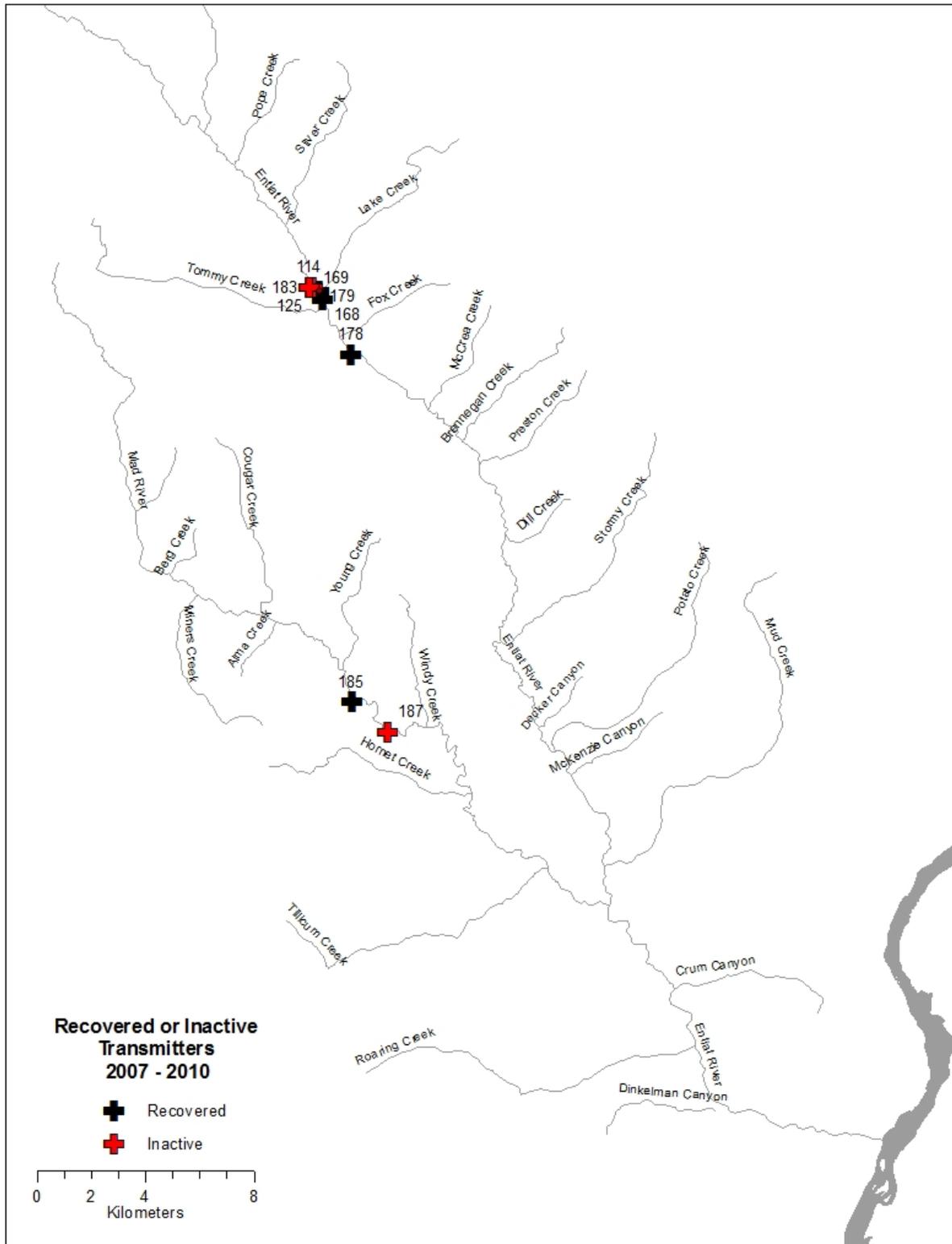


Figure 31. Locations of recovered or inactive transmitters of adult fluvial bull trout in the Entiat River watershed, 2007 - 2010.

Discussion

The bull trout populations in the Entiat and Mad rivers arguably face the highest risks of extirpation of all populations in the upper Mid-Columbia Recovery Unit. These are the only two local populations in the Entiat Core Area but we did not document movements from one to the other so apparently genetic exchange occurs only infrequently between them. We determined that several changes in the watershed magnify the risks, including wildfire-related log jams that impeded access to preferred spawning areas and resulted in a severe decline in the number of redds, recently elevated water temperatures in the upper Entiat River, and the presence of brook trout in the upper Entiat River spawning reach (see Appendix 1).

Factors that may mitigate the risks of decline have also been documented, including spawning downstream of the log obstacle in Box Canyon of the upper Entiat River and the presence of the resident life history form of bull trout in the Mad River. Overall, our telemetry studies have shown that the migratory corridors within the upper Mid-Columbia River Basin are largely intact and movements of bull trout from other core areas could supplement or increase the effective sizes of the two populations in the Entiat Core Area (Nelson et al. 2007; Nelson and Nelle 2008; Nelson et al. 2011; Nelson and Johnsen 2012). For example, an analysis of the genetics of local bull trout populations (DeHaan and Neibauer 2012) confirmed gene flow between core areas: bull trout code 81, tagged in the upper Entiat River in 2004 and documented spawning there in 2005 (Nelson and Nelle 2007, Nelson and Nelle 2008) was genetically assigned to the Twisp River population. The extent of gene flow between core areas is not known, but observations of two tagged bull trout near the upper Entiat River spawning area during one year and on the Twisp River spawning grounds the next suggests that genetic exchange may occur at least occasionally (Nelson and Johnsen 2012).

During 2007 to 2010, the overall movement patterns of tagged bull trout in the Entiat Core Area were similar to those observed from 2003 to 2007 (Nelson and Nelle 2008). The mid-Columbia River provided overwintering habitat and a migratory corridor during both spring and fall movements. The Columbia River hydroelectric dams operated by Chelan PUD did not prevent tagged bull trout from migrating to the Entiat River (Stevenson et al. 2008, Stevenson et al. 2009) and staging at the mouth appeared to buffer the delay presented by the dams (Nelson and Nelle 2008). No manmade impediments to movements were observed within the core area. The major obstacles to movements are log/debris jams from past wildfires in the Mad River and log jams at pinch points in the Mad River near Alma Creek as well as in the upper Entiat River at Box Canyon.

In 2010, for the first time since surveys began in 1989, no fluvial bull trout or migratory-sized redds were noted during the Mad River spawning ground survey. However, resident bull trout redds were observed for the first time (Willard 2010). To our knowledge, a shift from migratory to resident spawning has not been previously documented in other populations. It is not known whether log debris jams formed movement barriers downstream of the spawning reaches or if recruitment of migratory adults failed that year. It is recommended that the lower river be examined during late July and August to determine if barriers have formed downstream, particularly in the Windy Creek and Camp Nine areas as stream temperatures in this reach are unsuitable for spawning and rearing. Any fluvial bull trout that are blocked by a jam could be

netted and moved immediately upstream if possible. Log jams are dynamic structures that change over time and a jam that may be an impediment one year can blow out and be entirely passable the next, as we noted for the Camp Nine jam during a survey in 2011. However, if a large jam located downstream of the spawning reach is blocking migration and appears it will persist long term, then action to dismantle the jam or provide a passage route should be implemented. A review of forest management, fire management, and fire suppression strategies in the Mad River watershed needs to be conducted to determine if those activities affected the amount and/or placement of LWD and debris jams in the river.

The log obstacle in Box Canyon appears to be a recurring phenomenon, as indicated by the presence of logs in the photograph taken in 1939. In the past this obstruction may not have been as serious a problem for migratory bull trout as it is today. Water temperatures have significantly warmed during the last 50 years, reducing the area suitable for spawning and rearing in the upper Entiat River. Thus, areas below Box Canyon where blocked fluvial bull trout once may have spawned are now marginal or no longer suitable. It is recommended that the slot in Box Canyon be monitored and any logs be moved to allow adult bull trout to pass upstream to the optimal spawning grounds as soon as possible.

Non-native brook trout *Salvelinus fontinalis* are considered a threat to bull trout populations due to resource competition and hybridization (USFWS 2002). Brook trout are present on the bull trout spawning grounds upstream of Box Canyon and are competing with juvenile bull trout for food and space (see Appendix 1). Stocked in the upper Entiat River almost 100 years ago these fish are now abundant but they have not yet displaced bull trout. Field and laboratory studies of competition between the two species revealed differences in foraging tactics that favor one or the other depending on biotic and abiotic factors (Warnock 2012). Bull trout are able to out-compete brook trout when fish density is low, the water is cold, and habitat complexity is high. In addition, bull trout from migratory populations compete more successfully against brook trout than do bull trout from resident populations (Warnock 2012). However, brook trout are more successful at warmer sites with undercut banks (Warnock 2012). Habitat restoration projects that increase habitat complexity, provide cool water, and reduce or eliminate undercut banks would provide a greater competitive edge to bull trout and help reduce the threat that brook trout pose to the population. As recommended above, moving log obstacles in Box Canyon would also ensure that the competitive edge of the migratory life history prevails as well as providing higher density of juvenile bull trout in the spawning and rearing reach.

Although the upper Entiat bull trout population appears resilient to the invasion of brook trout, they are widespread in the upper Entiat River including Myrtle Lake (Archibald and Johnson 2005) and some type of control should be implemented to reduce their density and thus favor bull trout during competitive interactions. Techniques used to eliminate or suppress brook trout in alpine lakes and small streams include gill netting (Knapp and Matthews 1998, Parker et al. 2001), rotenone application (Walters and Vincent 1973), antimycin application (Gresswell 1991), electrofishing (Peterson et al. 2008) and the introduction of predatory fish (Kozfkay and Koenig 2006). During studies in Idaho, tiger muskellunge *Esox lucius x masquinongy* have shown some potential to reduce or eliminate brook trout populations in high mountain lakes (Koenig 2009). Tiger trout *Salvelinus fontinalis x Salmo trutta* are another possibility. Both of these hybrid species are functionally sterile and could be stocked into Myrtle Lake presumably

without the threat of creating self-sustaining populations. Use of predatory fish does carry some risk however, particularly if they were to move downstream below Entiat Falls and prey on juvenile bull trout. A technique specifically targeting brook trout that may also have potential is hoop nets seeded with a pair of sexually mature brook trout (Lamansky et al. 2009). These baited nets could be used below Entiat Falls to avoid captures of bull trout. The cost effectiveness and ecological impact of any removal technique would need to be considered before implementation.

Historical management actions in the Entiat Core Area resulted in long term impacts on bull trout and may make the populations more sensitive to modern activities in the upper Mid-Columbia Recovery Unit. Fluvial bull trout in the core area face elevated risks and their survival may require higher levels of assistance than normal. The draft bull trout recovery plan recommended the development of genetic management plans (USFWS 2002) including the establishment of protocols for genetic reserves (MBTSG 1995). Nelson and Nelle (2008) previously suggested it may be prudent to provide some form of assisted passage at the natural barrier of Entiat Falls and allow fluvial bull trout access to the coldest water and highest elevations in the upper Entiat River. This could increase the population size and counteract some of the negative effects of climate change on bull trout populations (Reiman et al. 2007). As noted, however, ecological interactions and hybridization with brook trout in the upper Entiat River and Myrtle Lake present a serious drawback to that proposal. Alternatively, because only cutthroat trout were planted in Larch and Ice Lakes in the upper watershed, stocking these lakes with an experimental population of bull trout from the upper Entiat population would minimize negative interactions with brook trout and could provide a hedge against habitat loss due to climate change. We suggest that the feasibility of establishing a genetic reserve of bull trout in these and other alpine lakes be investigated.

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Appendix 1: Juvenile bull trout and brook trout in the upper Entiat River

The bull trout spawning and rearing area of the upper Entiat River near Silver Falls Campground (rkm 50) was snorkeled in order to capture juvenile bull trout and collect tissue samples for genetic analysis. The area was chosen because surveyors reported possible bull x brook trout hybrids at the location during Integrated Status and Effectiveness Monitoring Program (ISEMP) surveys. We snorkeled and used fine mesh hand nets to capture bull trout and brook trout. Captured bull trout were brought to shore, placed in a metal tray with river water, measured to the nearest 5 mm, and a small tissue sample was taken from the upper lobe of the caudal fin before release back into the river. Brook trout were brought to shore and sacrificed for analysis.

On September 4, 2008, five locations near Silver Falls Campground were sampled. Locations Gen 1 through Gen 4 were point samples and location Gen 5 was a 200 m transect. A total of 42 juvenile bull trout were captured, tissue sampled, measured (± 5 mm), and released (Table 21). Size of bull trout ranged from 105 mm to 170 mm (Figure 32).

A total of 19 brook trout were captured and tissue sampled, and 17 were then sacrificed for analysis of stomach contents, otoliths, scales, gender and condition (Table 22). Brook trout ranged from 60 mm to 225 mm (Figure 33) and weights ranged from 2 g to 101 g. The mean condition factor (K) was 1.01 (range 0.64 – 1.18), indicating most of the brook trout were in good condition. Forty seven percent of the sacrificed brook trout were male, 29% were female, and 24% were unknown. All prey items were insects, with ants present in 82% of stomachs (Figure 34). Terrestrial insects were a large part of the diet.

No hybrids were visually identified during sampling or snorkeling. During snorkeling, brook trout were estimated to be only slightly less abundant than juvenile bull trout in the reaches we sampled. Rainbow trout were most aggressive, dominated both charrs, and were located in the best foraging sites. The larger brook trout were dominant to juvenile bull trout in the deeper pools and at the better foraging sites while juvenile bull trout were observed more frequently in shallower water nearer the stream margins.

Brook trout are much more abundant and widespread in the upper Entiat River bull trout zone than previously thought. The ISEMP snorkeling data should be analyzed to estimate densities of bull trout and brook trout in the upper Entiat River. We did not visually identify any hybrids and genetic analysis confirmed none were present in our sample (DeHaan and Neibauer 2012). Brook trout are larger than juvenile bull trout (Figures 32, 33 and 35) and are competing with them for both food and space. It is not known how many brook trout are reproducing in the bull trout spawning reach, how many of these are individuals dispersing from upstream of Entiat Falls, or how many are spawning concurrently with bull trout. Several brook trout in spawning colors and paired over gravels were observed in lower Silver Creek on October 29, 2009 (Figure 36). Because fluvial bull trout had already finished spawning in the main-stem Entiat by this date and most of the suitably small spawning gravels for brook trout are located in the lower reaches of small tributaries like Silver Creek, investigations should be implemented to determine whether brook trout spawning overlaps with bull trout or if it is spatially and temporally segregated in the upper Entiat River. This information is necessary for the implementation of a comprehensive brook trout management plan.

Table 21. Sampling locations, total length (mm), and genetic tissue sample number of juvenile bull trout collected near rkm 50 of the Entiat River on September 4, 2008.

Species	Sampling Location	Date	Total Length (mm)	Genetic Sample #
bull trout	Gen 1	9/4/2008	120	681-019
bull trout	Gen 1	9/4/2008	148	681-020
bull trout	Gen 1	9/4/2008	160	681-022
bull trout	Gen 1	9/4/2008	130	681-023
bull trout	Gen 1	9/4/2008	110	681-024
bull trout	Gen 1	9/4/2008	120	681-025
bull trout	Gen 1	9/4/2008	165	681-026
bull trout	Gen 1	9/4/2008	110	681-027
bull trout	Gen 1	9/4/2008	125	681-028
bull trout	Gen 2	9/4/2008	127	681-029
bull trout	Gen 2	9/4/2008	115	681-030
bull trout	Gen 2	9/4/2008	145	681-031
bull trout	Gen 2	9/4/2008	115	681-032
bull trout	Gen 2	9/4/2008	155	681-033
bull trout	Gen 3	9/4/2008	105	681-034
bull trout	Gen 3	9/4/2008	130	681-035
bull trout	Gen 3	9/4/2008	160	681-037
bull trout	Gen 3	9/4/2008	160	681-038
bull trout	Gen 3	9/4/2008	120	681-039
bull trout	Gen 3	9/4/2008	145	681-040
bull trout	Gen 3	9/4/2008	110	681-041
bull trout	Gen 3	9/4/2008	150	681-042
bull trout	Gen 3	9/4/2008	115	681-043
bull trout	Gen 4	9/4/2008	160	681-044
bull trout	Gen 4	9/4/2008	130	681-045
bull trout	Gen 4	9/4/2008	155	681-046
bull trout	Gen 4	9/4/2008	160	681-047
bull trout	Gen 4	9/4/2008	120	681-048
bull trout	Gen 4	9/4/2008	160	681-049
bull trout	Gen 4	9/4/2008	155	681-050
bull trout	Gen 4	9/4/2008	150	681-051
bull trout	Gen 4	9/4/2008	115	681-052
bull trout	Gen 5	9/4/2008	165	681-053
bull trout	Gen 5	9/4/2008	125	681-054
bull trout	Gen 5	9/4/2008	140	681-055
bull trout	Gen 5	9/4/2008	165	681-056
bull trout	Gen 5	9/4/2008	135	681-057
bull trout	Gen 5	9/4/2008	145	681-058
bull trout	Gen 5	9/4/2008	170	681-060
bull trout	Gen 5	9/4/2008	135	681-061
bull trout	Gen 5	9/4/2008	130	681-062
bull trout	Gen 5	9/4/2008	160	681-063

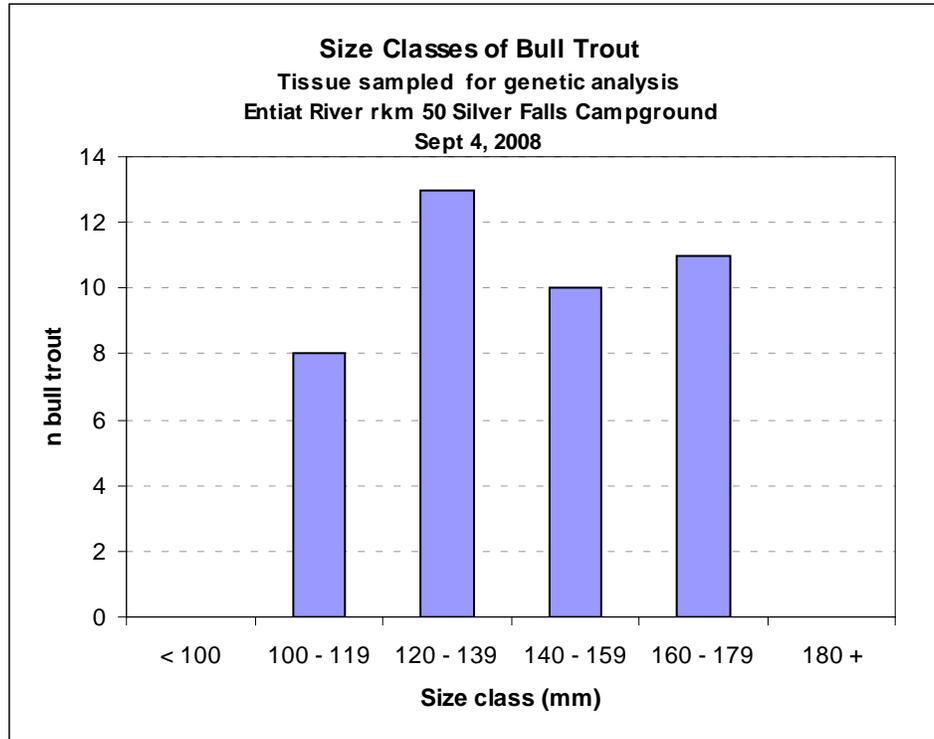


Figure 32. Size classes of bull trout captured with hand nets and tissue sampled at rkm 50 of the Entiat River, September 4, 2008.

Table 22. Total length (mm), weight (g), sex, genetic tissue sample number, scale card number, and otolith number of brook trout collected near rkm 50 of the Entiat River on September 4, 2008.

Species	Date	Total Length (mm)	Weight (g)	Sex	Genetic #	Scale Card #	Otolith #
brook trout	9/4/2008	177	63	F	681-064	1	681-064
brook trout	9/4/2008	210	92	F	681-065	2	681-065
brook trout	9/4/2008	208	96	M	681-066	3	681-066
brook trout	9/4/2008	214	101	M	681-067	4	681-067
brook trout	9/4/2008	118	19	M	681-068	5	681-068
brook trout	9/4/2008	130	24	M	681-069	6	681-069
brook trout	9/4/2008	175	62	F	681-070	7	681-070
brook trout	9/4/2008	75	4	U	681-071	8	681-071
brook trout	9/4/2008	186	65	M	681-072	9	681-072
brook trout	9/4/2008	130	22	U	681-059	10	681-059
brook trout	9/4/2008	205	80	F	681-073	11	681-073
brook trout	9/4/2008	195	75	F	681-074	12	681-074
brook trout	9/4/2008	115	18	M	681-075	13	681-075
brook trout	9/4/2008	117	13	M	681-076	14	681-076
brook trout	9/4/2008	116	10	U	681-077	15	681-077
brook trout	9/4/2008	60	2	U	681-078	16	681-078
brook trout	9/4/2008	190	68	M	681-079	17	681-079

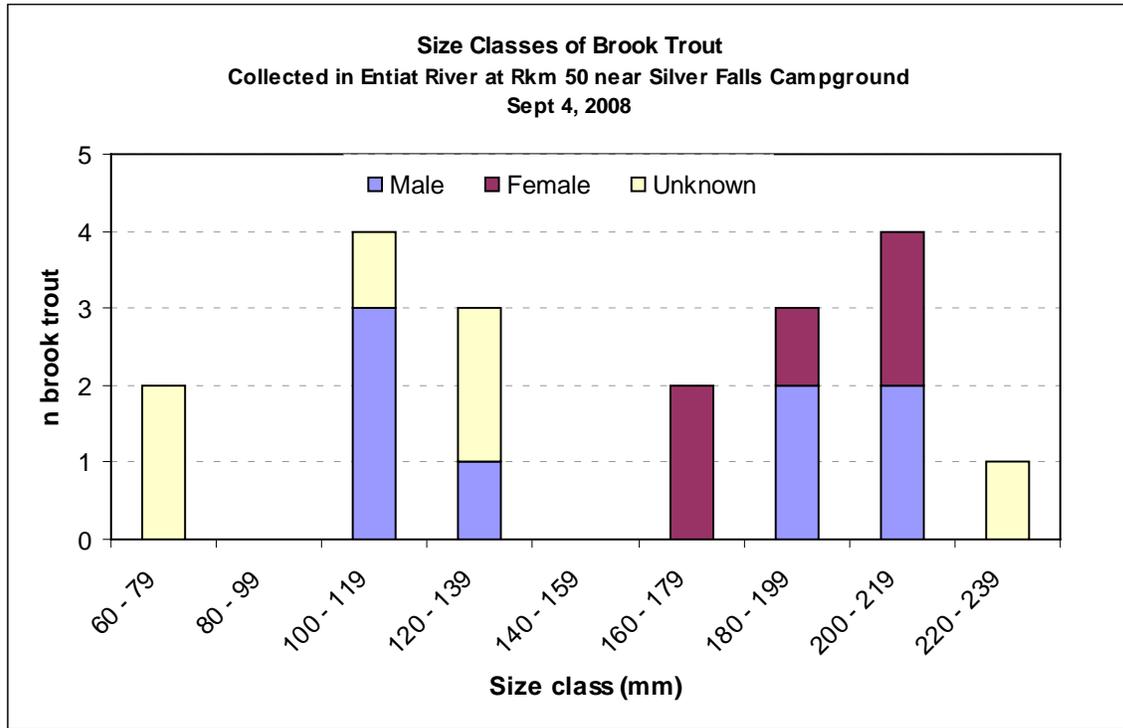


Figure 33. Size classes and sex of brook trout collected at rkm 50 of the Entiat River, September 4, 2008.

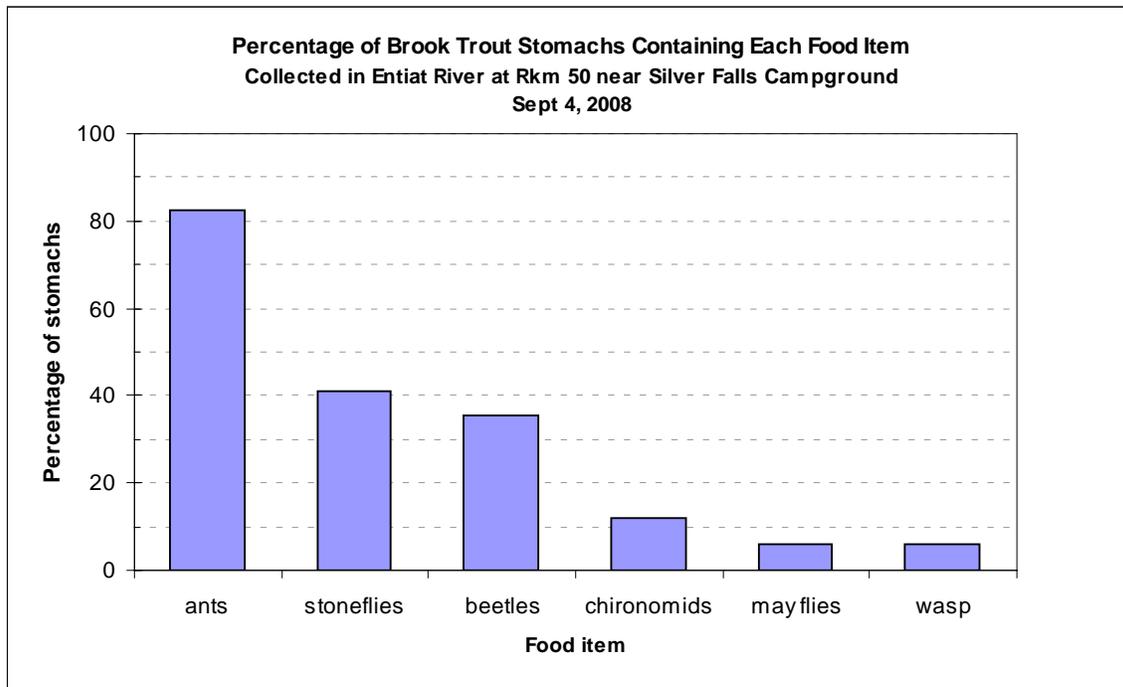


Figure 34. Percentage of brook trout stomachs containing each food item, September 4, 2008.



Figure 35. Two juvenile bull trout with a larger brook trout in the upper Entiat River on August 20, 2008.



Figure 36. A pair of brook trout in spawning colors in lower Silver Creek on October 29, 2009.

**U. S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
7501 Icicle Road
Leavenworth, WA**



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