Migratory Patterns, Structure, Abundance, and Status of Bull Trout Populations from Subbasins in the Columbia Plateau and Blue Mountain Provinces

2004 Annual Report

Prepared by:

Steven J. Starcevich
Steve Jacobs
Oregon Department of Fish and Wildlife
Salem, Oregon
and
Philip J. Howell
USDA Forest Service
Pacific Northwest Research Station
La Grande, OR

Prepared for:

U.S. Department of Energy
Bonneville Power Administration
Environment, Fish and Wildlife
P.O. Box 3621
Portland, OR 97208-3621
Project Number 199405400
Contract Number 4101

May 2005

CONTENTS

TABLES

FIGURES

I. Migration Patterns and Temperature Selection of Adult Bull Trout in the Lostine River

Introduction

For restoration and protection of bull trout habitats, conservation strategies depend on determining the distribution of bull trout. However, that distribution may vary seasonally depending on the age and life history type of the fish. Most juvenile bull trout distributions in Oregon have been determined during summer, and consequently, little is known about the distributions and movements of bull trout of any life stage during other seasons. Most bull trout life history information comes from adfluvial populations (Pratt 1992), whereas most of the populations in this province and the rest of Oregon likely consist of fluvial and resident forms. We have previously described migratory forms of bull trout in the Grande Ronde River subbasin primarily from the Wenaha River (Hemmingsen et al. 2001c; Baxter 2002). However, evidence of migratory fish is minimal or lacking for many bull trout populations in Oregon and the Columbia Basin. For example, little quantitative information is available regarding the life history and seasonal distributions and habitats of migrant adult bull trout in the Wallowa and Lostine rivers. The persistence of migratory forms is dependent on protection and restoration of all habitats used, including migratory corridors.

Temperature has been identified as an important potential habitat limiting factor for bull trout (Selong et al. 2001; USFWS 2002; Poole et al. 2001). However, available data on temperature requirements for bull trout is generally limited to spawning, egg incubation, and juvenile rearing/resident adult habitats (EPA 2003). Information on temperature relationships of fluvial bull trout and downstream migratory habitats is lacking. These migratory habitats are more subject to development and elevated temperatures. As a result of this data limitation, recently adopted water temperature guidance of the U. S. Environmental Protection Agency (EPA 2003) and criteria of Oregon Department of Environmental Quality (DEQ) (OAR 340-041-0028 and 340-041-0151) for bull trout are focused on spawning and rearing habitat. Migratory habitat is covered by criteria for “core” salmonid rearing habitat. To fully protect water quality for bull trout, application of numeric temperature criteria is also dependent on accurately identifying spawning, rearing, and migratory habitats and the timing when those habitats are used.

This portion of the project was designed to address the following questions:

1. What is the seasonal distribution of fluvial bull trout from the Lostine River?

2. What water temperatures are used by fluvial adults?

3. What relationships are there between fish movements and water temperatures?

4. How do the ambient temperatures compare to the water temperature of areas selected by fluvial bull trout?

5. Do the fish use thermal refugia (i.e., cooler habitats than adjacent areas)?

6. How do temperatures used by bull trout and ambient temperatures compare with state water quality criteria?

Study Area

The bull trout in this study spawn and rear in the Lostine River, which drains the Wallowa Mountains in northeastern Oregon (Figure. 1). The Lostine River flows into the Wallowa River at river kilometer (RK) 41, and the Wallowa River enters the Grande Ronde River at RK 132. This population was selected because of uncertainty about their migratory distribution and potential temperature limitations in their migratory habitat. Flows are diverted for irrigation from the Lostine and Wallowa Rivers downstream of town of Lostine (RK 19) during late spring through early fall, when fluvial bull trout could be migrating through those reaches. A weir and upstream trap near the mouth of the Lostine River (RK1) is operated primarily to capture adult spring chinook salmon (*Oncorhynchus tshawytscha*), but migratory bull trout are also intercepted.

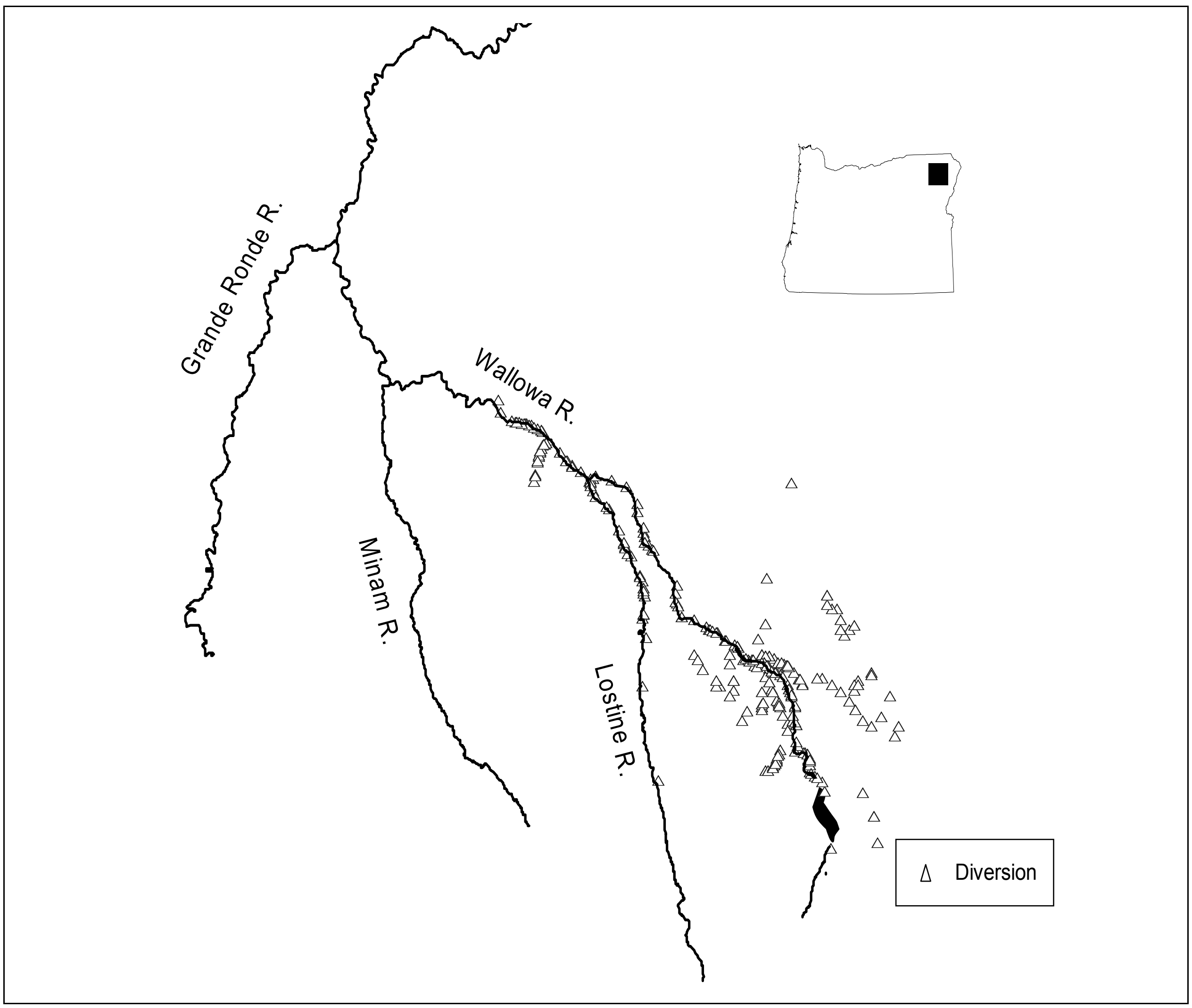


Figure 1. Study area including irrigation diversions.

Methods

In 2001 we captured and tagged 21 bull trout (4 at the Lostine trap, June 11-27 and the remainder by angling in the Lostine River (RK 17-39), July 16-19); 15 were radio- and temperature-tagged, 6 had only radio tags. In 2004 we captured and radio- and temperature-tagged 24 bull trout at the Lostine trap during mid-May through mid-July. A radio tag (Advanced Telemetry Systems, Inc. in 2001 and Lotek, Inc. in 2004) was surgically implanted in the abdominal cavity of the fish. Following anesthesia using tricaine methosulfonate (MS 222, 60 mg/l), an incision long enough to accommodate the cross-section of the radio tag was made anterior and dorsal to the pelvic fin. A 152 mm, 16 gauge hypodermic needle inside a plastic sheathe was used to internally puncture the abdominal cavity posterior and dorsal to the vent and pelvic girdle and feed the tag antenna to the exterior of the fish. The radio tag was then pulled inside through the incision. The incision was sutured, and it and the exit hole for the antenna were sealed with Nexaband surgical glue. The archival temperature tag (LTD 1100, Lotek, Inc.) was attached through musculature below the dorsal fin using primarily nickel (Peterson disk) pins. Each pin was inserted through a round plastic (approximately 1 cm diameter, 1 mm thick) backing plate on the side of the fish opposite of the temperature tag. The end of the pin was then bent and twisted to form a T-shaped knot to secure the tag. The combined radio and temperature tag weight was limited to no more than 3 percent of the fish's body weight (Winter 1996). The mean length (FL) of the fish tagged was 457 mm (range=360-600 mm) in 2001 and 478 mm (range=363-575 mm) in 2004.

Most of the archival tags used had a fixed memory (32K or 64K)-variable recording interval with an initial maximum of 256 samples per hour. The sampling interval then doubled each time the memory filled. Twelve of the archival tags used in 2004 had fixed hourly recording intervals.

Stowaway or Tidbit thermographs (Onset Computer, Inc.) programmed to hourly recording intervals were placed in well mixed zones at five locations in the Lostine River, seven locations in the Wallowa River, and three locations in the Grande Ronde River to measure ambient water temperatures in the suspected range of the fishes' distribution.

Locations of the fish tagged in 2001 were primarily tracked using a receiver in vehicle or on foot, except in the Wallowa River below the confluence of the Minam River (RK 16) and in the Grande Ronde River, where they were aerially tracked from a plane. The fish were generally tracked once per week from July through November 2001 and about once per month from December 2001 through April 2002, when the bull trout remained in their overwintering areas and moved little. Weekly tracking then resumed until the three remaining fish with temperature tags were recaptured in September prior to spawning. Fish tagged in 2004 were also tracked weekly in a vehicle or on foot through the time four fish were recaptured late August 2004.

Seven fish were recaptured by angling, dipnetting them in pools blocked off with seines, or herding them into small-mesh gillnets. The temperature tags were then removed and downloaded from fish recaptured in 2002. In 2004 the temperature tags were downloaded while still attached to the fish recaptured so additional data could continue to be collected. All recaptured fish were then released.

Results and Discussion

Fish tagged in 2001 showed four main distribution patterns based on overwintering locations (Figure 2):

1. The Grande Ronde River from the mouth of the Wallowa River to approximately 15 km upstream near the mouth of Lookingglass Creek,

2. The Wallowa River from 3.5 km downstream from the mouth of the Minam River (RK 16) to Rock Cr (RK 31),

3. Near the mouth of the Lostine (RK 41),

4. The Lostine River from the Lostine Ranch to Green Bridge (RK 60-62) not far from where they were tagged the previous July.

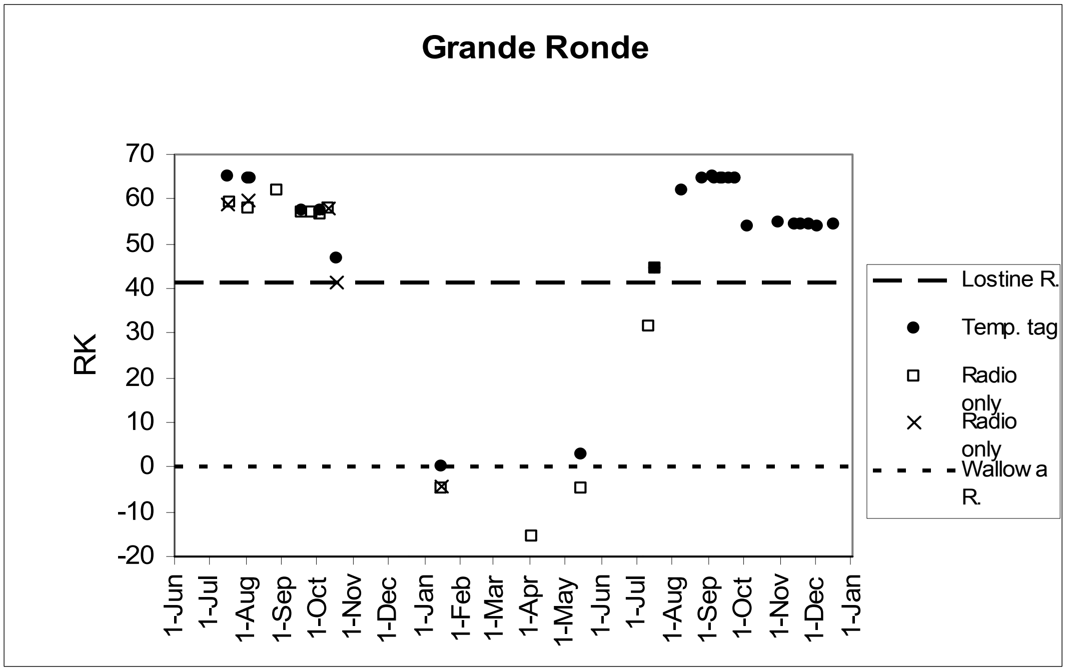
The three temperature tags recovered in 2002 are representative of the three downstream migratory winter distribution patterns.

In 2002, the fish in the Grande Ronde were the first fish to begin moving upstream from their winter locations in May. The 7DADM (running 7-day average of the daily maximum) temperature experienced by the fish increased from 10.6 C when it was in the Grande Ronde River at the mouth of the Wallowa River to 11.7 C two weeks later 3 km upstream in the Wallowa R. (Table 1). That fish continued to move upstream during the next three months encountering peak temperatures in the lower Lostine River in July. The archival-tagged fish overwintering in the Wallowa R. remained in their winter locations through June despite increasing temperatures; they similarly recorded peak temperatures in July after moving up the lower Lostine River. The 7DADM temperatures of the fish in August were 1.5-3.6 C cooler than in July after the fish moved further upstream.

Table 1. Monthly 7DADM temperatures (^{o}C) and locations (RK) of archival-tagged bull trout during May-August, 2002. (RK 0=mouth of Wallowa R., RK 42=mouth of Lostine R., RK >42=Lostine R.)

Temp. Tag	April			May			June			July			August		
	Temp.	Date	RK	Temp.	Date	RK	Temp.	Date	RK	Temp.	Date	RK	Temp.	Date	RK
1	11.7	4/30	23	13.2	5/16	23	13.8	6/27	23	16.3	7/17	49	14.2	8/15	53
2	11.6	4/30	42	13.4	5/16	42	14.1	6/27	42	16.7	7/17	47	15.2	9/3	61
3	10.6	4/30	0	11.7	5/16	3	13.3	6/29	43	17.5	7/15	44	13.9	8/15	63

In 2001 the archival-tagged fish experienced peak temperatures in August of 16-18 C in areas near where they may have eventually spawned (Figure 3). In 2004 temperatures of archival-tagged fish peaked at about 16C. Peak temperatures of fish in habitat classified by DEQ as migratory corridor ranged from 15.6-17.5 C compared to the state criteria of 16 C. Peak temperatures of tagged fish in the reach classified by DEQ as rearing habitat were approximately 4-6 C warmer than the criteria of 12 C.



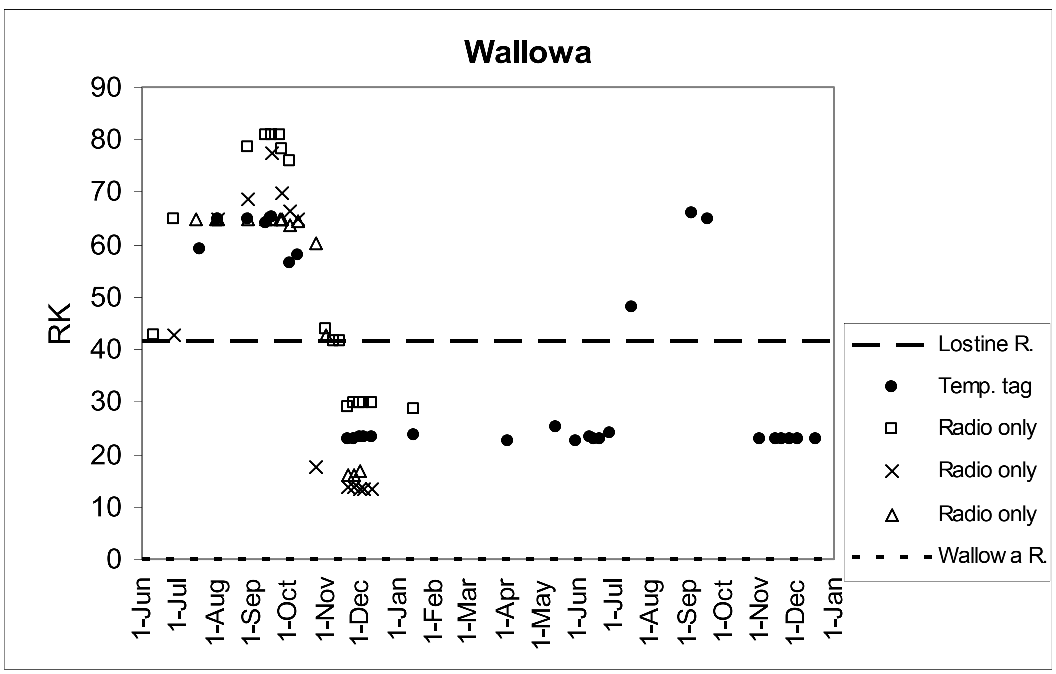
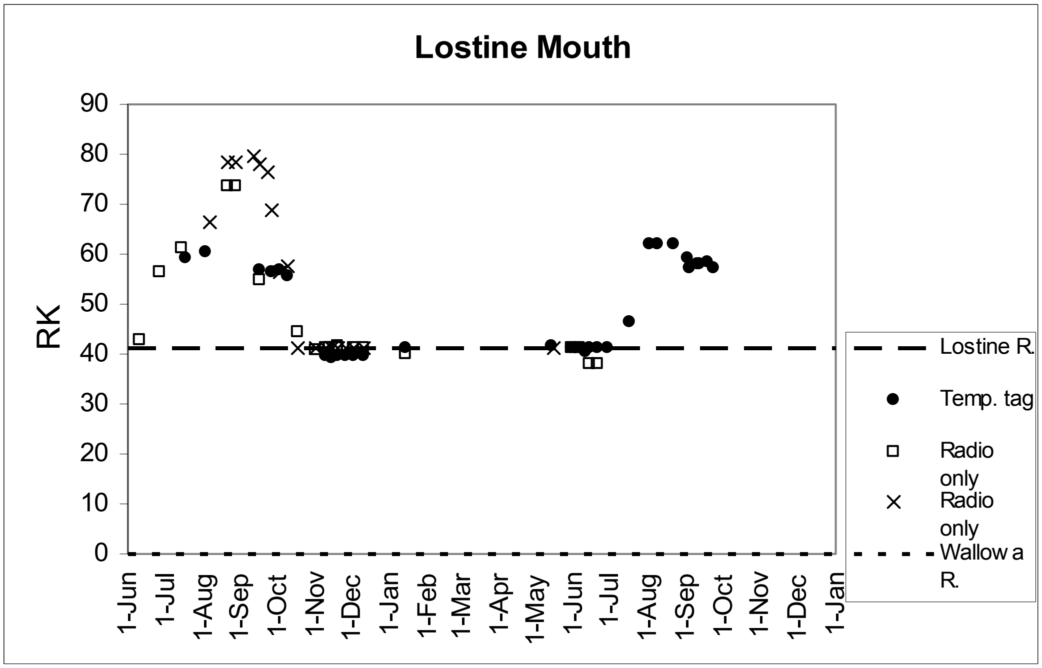


Figure 2. Locations (river km (RK)) of recovered archival temperature-tagged bull trout (Temp. tag) and other radio-tagged bull trout (Radio only) grouped by winter distribution. The mouth of the Wallowa River is RK 0. The mouth of the Lostine River is RK 41. Negative location values are in the Grande Ronde River upstream of the mouth of the Wallowa River.



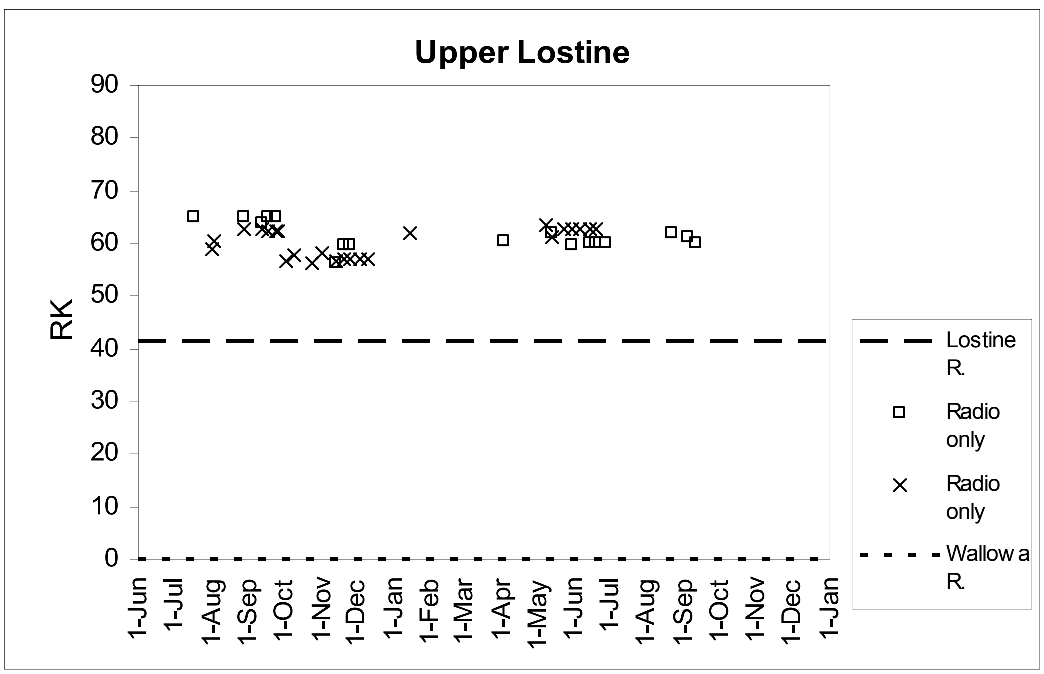


Figure 2 (continued). Locations (river km (RK)) of recovered archival temperature-tagged bull trout (Temp. tag) and other radio-tagged bull trout (Radio only) grouped by winter distribution. The mouth of the Wallowa River is RK 0.

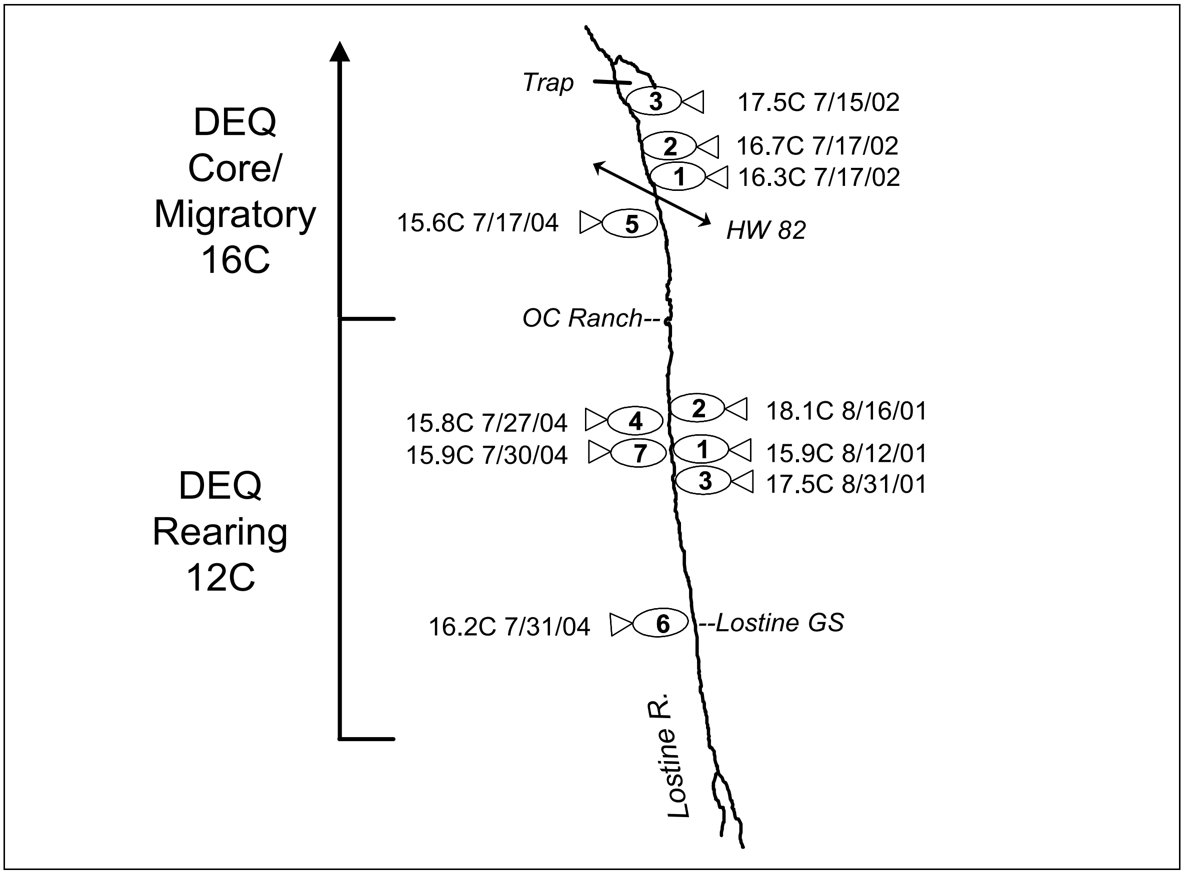
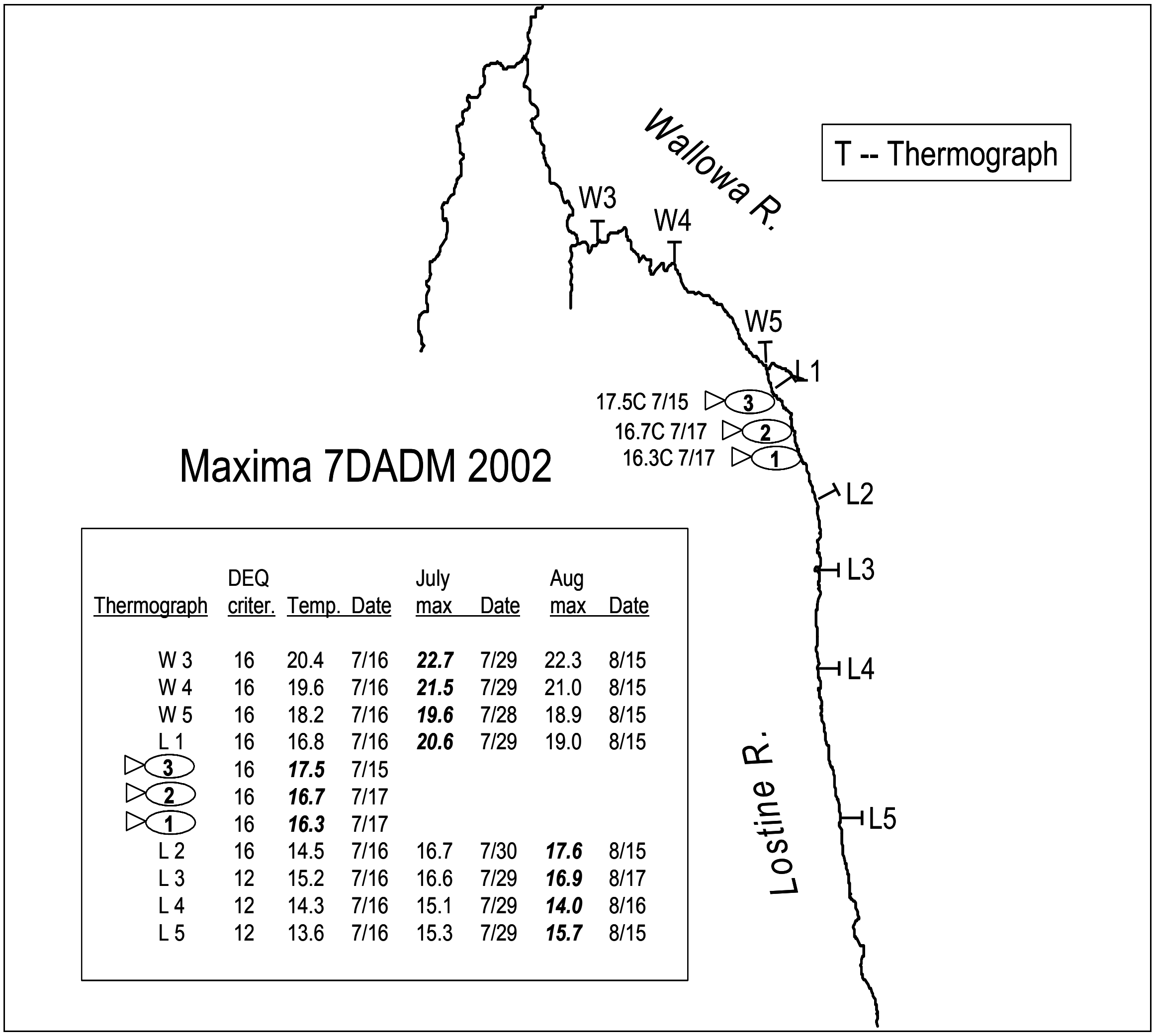


Figure 3. Maximum 7DADM temperatures of archival-tagged fish, 2001-2004, and corresponding DEQ temperature criteria**.**

Radio-tagged fish were widely distributed in the Wallowa and Lostine rivers during July (RK 24, 6/28-RK 76, 7/31). In mid-July 2002 when the archival-tagged fish recorded their highest temperatures of 16-18 C, water temperatures downstream were as warm or warmer; however, water 2-3 C cooler was available several km upstream (Figure 4). In 2002 ambient 7DADM water temperatures in the Wallowa and lower Lostine peaked in late July at 20-23C compared to the temperature criteria of 16 C. Water temperatures peaked in the river above the town of Lostine in mid-August at 14-18 C, 2-5 C higher than the criteria.



Thermograph	DEQ criter.	Temp.	Date	July max	Date	Aug max	Date
W 3	16	20.4	7/16	***22.7***	7/29	22.3	8/15
W 4	16	19.6	7/16	***21.5***	7/29	21.0	8/15
W 5	16	18.2	7/16	***19.6***	7/28	18.9	8/15
L 1	16	16.8	7/16	***20.6***	7/29	19.0	8/15
3	16	***17.5***	7/15				
2	16	***16.7***	7/17				
1	16	***16.3***	7/17				
L 2	16	14.5	7/16	16.7	7/30	***17.6***	8/15
L 3	12	15.2	7/16	16.6	7/29	***16.9***	8/17
L 4	12	14.3	7/16	15.1	7/29	***14.0***	8/16
L 5	12	13.6	7/16	15.3	7/29	***15.7***	8/15

Figure 4. Maximum 7DADM water temperatures recorded by thermographs and archival-tagged bull trout within the distribution of radio-tagged fish during 6/28-7/31 in the Wallowa and Lostine rivers, 2002. Summer maxima temperatures are in italics.

Temperatures of bull trout with the archival tags were highly correlated with the water temperatures of the adjacent thermograph (R^2= 0.95) (Figure 5). Furthermore, the regression equation showed a one-to-one correspondence between the two temperature measurements. This indicates the tagged fish did not use cooler refugia. In fact, temperatures of the fish tended to be slightly warmer than ambient temperatures, even at the upper temperatures recorded.

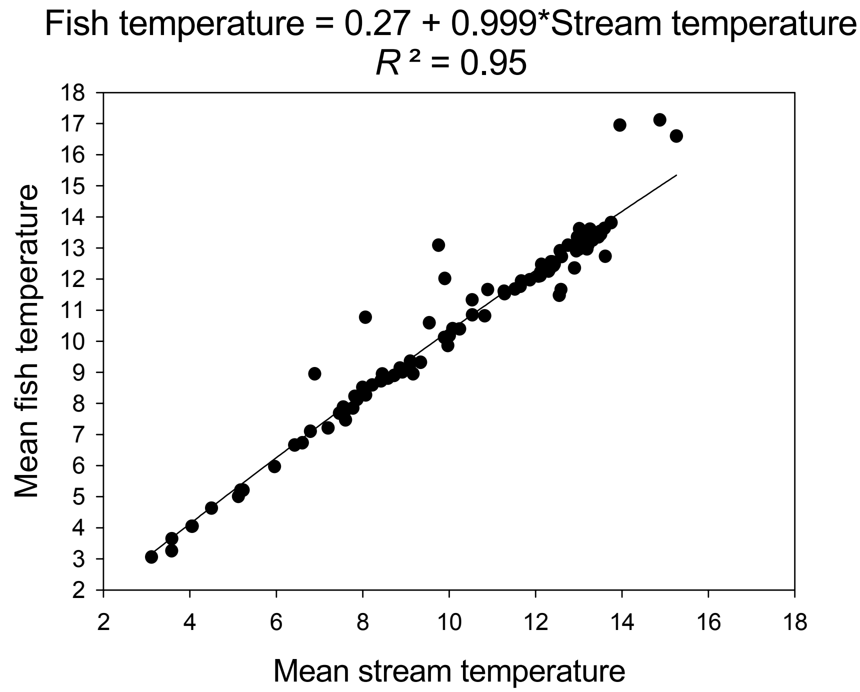


Figure 5. Regression of temperature of archival-tagged bull trout from the Lostine River on ambient stream temperature**.**

Based on the timing of their uppermost locations and subsequent downstream migrations, archival-tagged fish appeared to spawn at 7DADM temperatures of about 14-16C, 5-7C higher than the spawning temperature criteria (Figure 6). Ambient 7DADM water temperature during September 2004 were also elevated, 1-5C higher than the temperature criteria.

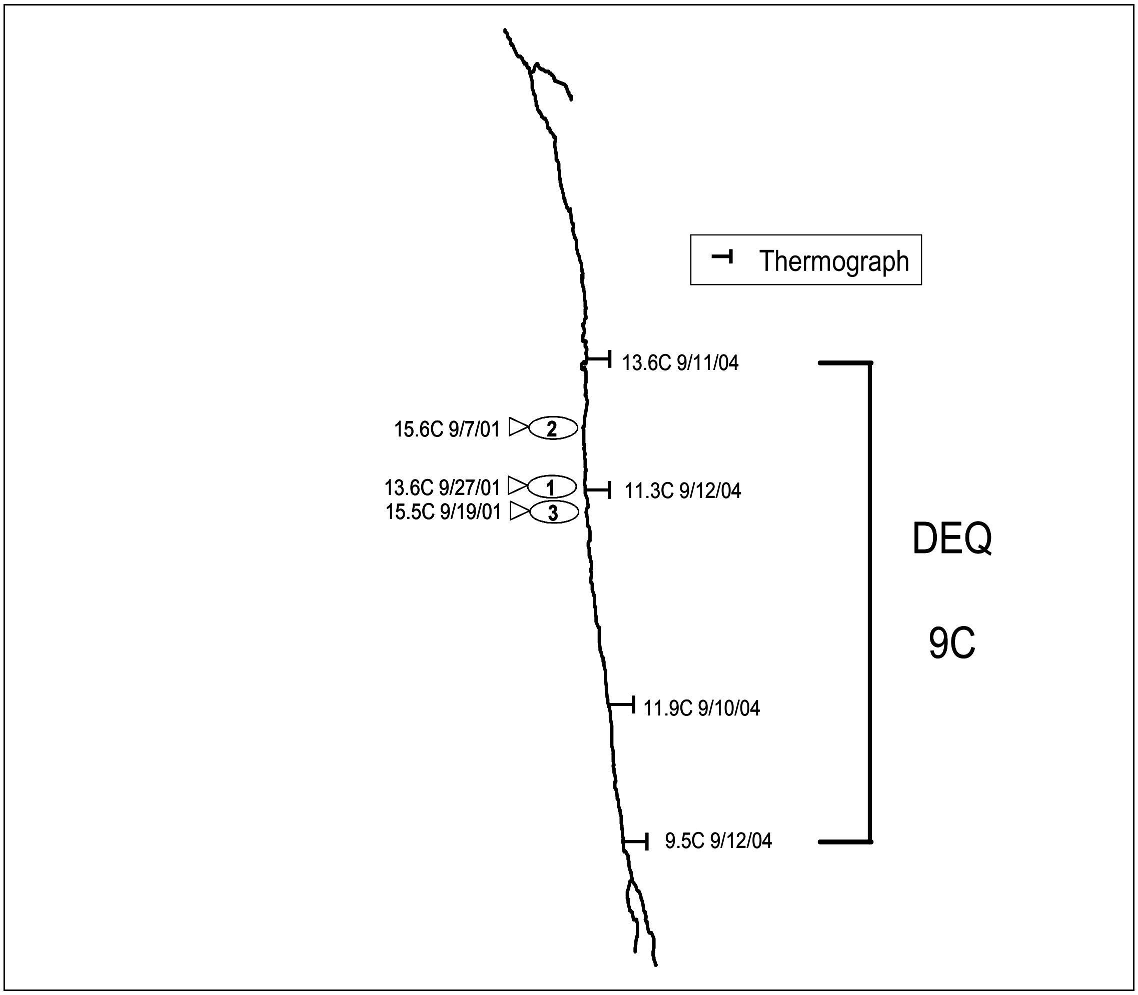


Figure 6. 7DADM temperatures of archival-tagged bull trout at suspected time of spawning in 2001, 7DADM September water temperatures and DEQ temperature criteria in designated spawning habitat in the Lostine River.

II. Comparing Methods of Estimating the Abundance of Adult Bull Trout

Introduction

Quantitative estimates of bull trout abundance are required to determine the status of populations, monitor changes in population size, and evaluate the effectiveness of conservation strategies. Little data are available on bull trout abundance and population trends (Rieman and McIntyre 1993). Obtaining such information has been identified as a critical research need (Rieman and McIntyre 1993; Buchanan et al. 1997). Redd counts typically have been used to monitor bull trout abundance and evaluate population trends (Rieman and Myers 1997). Counting redds is an attractive technique because it is relatively easy, inexpensive, and un-intrusive compared to other methods of monitoring, and is thought to provide an indirect measure of adult abundance (i.e., of breeding population size).

Despite their frequent use, redd counts may not be sufficient or appropriate to quantify bull trout abundance. Detecting changes in population size may not be possible using the most extensive sets of redd count data available (7-17 years) (Maxell 1999) and is unlikely for populations for which more limited data sets exist (Rieman and Myers 1997). Errors in redd identification not considered in these earlier analyses may further limit the utility of redd counts. Recent studies have shown substantial sampling error associated with counts of bull trout redds (Bonneau and LaBar 1997; Dunham et al. 2001; Hemmingsen et al. 2001b). In addition, we have found that redd counts may not relate well to the abundance of resident adult bull trout (Hemmingsen et al. 2001c), which build relatively small and inconspicuous redds compared to those of fluvial and adfluvial adults.

Standard, appropriate, and powerful methods to assess bull trout abundance across all ranges of habitats have not been established (see Bonar et al. 1997). Although data are beginning to accumulate on the validity of bull trout redd counts (Bonneau and LaBar 1997; Dunham et al. 2001; Hemmingsen et al. 2001b,c), more information is needed to fully evaluate this monitoring technique. The objective of this study is to compare redd counts to other measures of adult bull trout abundance in the Mill Creek drainage (Walla Walla River subbasin), which supports fluvial and resident fish. As in 2002-3, our approach in 2004 was to estimate the abundance of mature fluvial and resident females and subsequently count redds in the drainage in order to assess the relationship between the redd count and the number of mature females.

Methods

This study was conducted at and upstream from a dam and intake structure in Mill Creek that supplies water to the city of Walla Walla (Figure 7). A ladder on the dam allows passage for upstream migrants. We operated a trap, designed as described in Hemmingsen et al. (2001b), at the head of the dam's ladder from 25 May to 1 October 2004. The trap was usually checked daily, but sometimes as infrequently as every third day during periods when few fish had been trapped previously. As in previous years, bull trout trapped at the ladder were anesthetized, measured, weighed, interrogated for a PIT tag, and, if no PIT tag was present, injected with one. Since redd counts in Low Cr. were relatively low in 2003, we did not estimate adult abundance in that stream as we did in 2003 to minimize impacts on the resident population there. Each fish was also inspected for maturity using ultrasound, and mature females were identified. All bull trout were marked by removing the adipose fin unless that fin had been removed during trapping in 2002. The upper lobe of the caudal fin was hole-punched to distinguish fish marked in 2003 during snorkel counts.

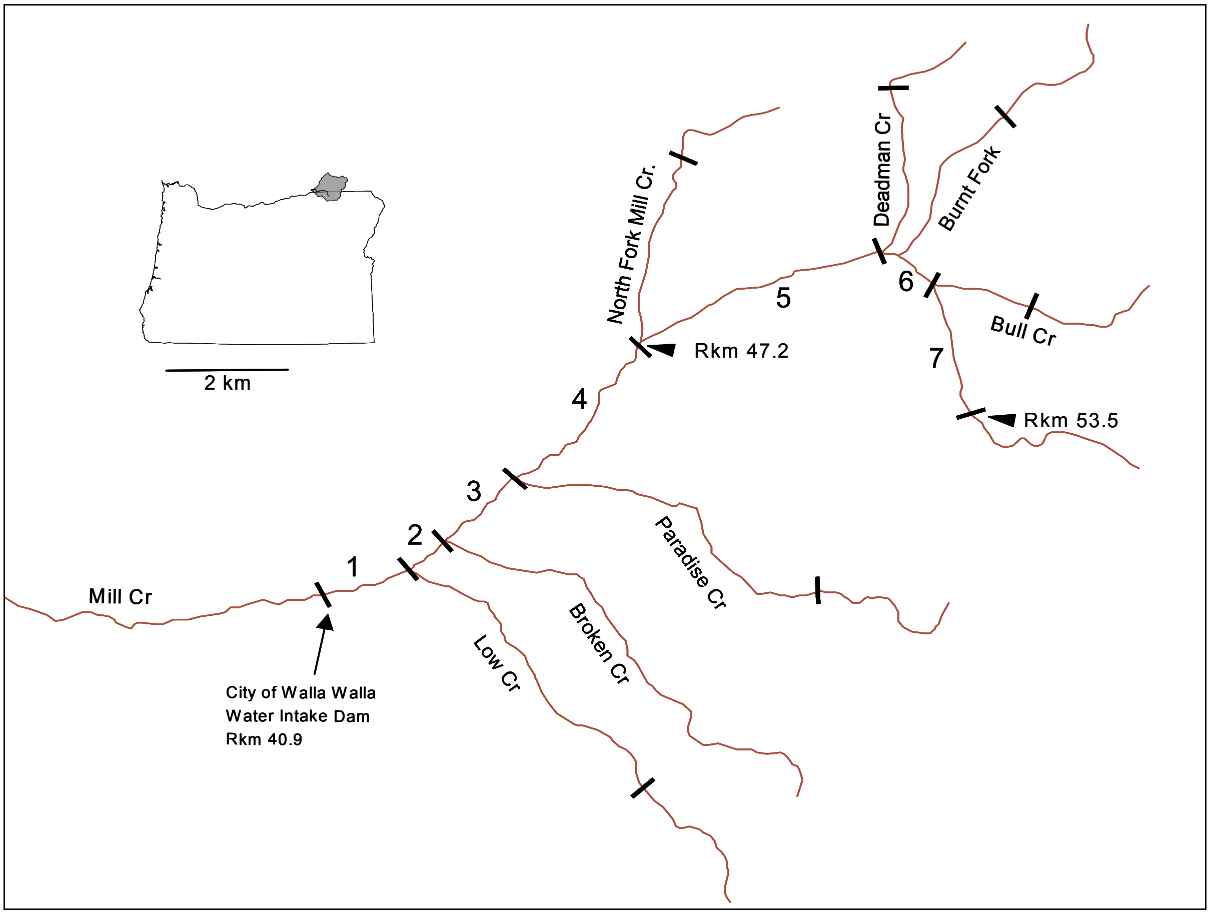


Figure 7. Map of the Mill Creek study area showing landmarks and units in which redds were counted during spawning ground surveys.

Fluvial adult bull trout previously radio-tagged in the Mill Creek drainage overwintered downstream from the dam (Hemmingsen et al. 2001a,b,c,d; 2002), and most used the ladder when returning upstream in late spring or summer. Some fish, however, may overwinter upstream from the dam or jump it upon their return. During our snorkel counts above the dam 2002 we observed unmarked bull trout >300 mm, which would have been marked had they been trapped at the ladder. To fully enumerate the number of fish that overwintered below the dam and eliminate the possibility of fish avoiding the trap by jumping the dam, we installed a net across the stream near the base of the dam. The net was made of 3.8 cm square, nylon mesh and was positioned vertically like a tennis net. Two parallel cables supported the net's top and bottom ends approximately 3 m and 0.75 m, respectively, above the water's surface. We hung sections of rubber matting (approximately 1.5 m long x 0.75 m high) from the bottom cable across the full width of the stream to close the gap between the bottom of the net and the stream, yet allow large debris to pass without damaging the net. Each section of matting had grommets in its upper corners and was attached to the bottom cable with carabineers. Once erected, the net and matting formed an aerial barrier between the dam's shallow, concrete-bottomed spill basin and the deep pool immediately downstream.

To account for any fluvial females that might have overwintered upstream from the dam, we snorkeled the study area from 8/30-9/1 2004. A single diver snorkeled all the pools and a portion of the other habitats capable of holding fluvial adult-sized fish. The diver recorded the number of marked (adipose fin-clip + caudal fin punch) and unmarked (no marks or adipose fin-clip only) bull trout $\geq$ 300 mm FL that were observed. Bull trout $\geq$ 300 mm FL were considered fluvial adults for two reasons: 1) few fluvial fish <300 mm FL have been trapped at the ladder since 1997 and no mature females <300 mm have been trapped (Hemmingsen et al. 2001a,b,c; 2002; Sankovich et al. 2003; Sankovich et al. 2004), and 2) we have not observed bull trout $\geq$ 300 mm FL in other streams in northeast Oregon supporting only resident bull trout. We estimated the number of unmarked bull trout $\geq$ 300 mm FL by incorporating the number of marked and unmarked bull trout observed snorkeling and the number marked bull trout released upstream of the trap at the time of snorkeling into Bailey's (1951) mark-recapture estimator:

$$\hat{N} = \frac{(C+1)M}{R+1}$$

where *N* is the population size, *M* is the number of bull trout marked, *C* is the number marked and unmarked bull trout observed snorkeling, and *R* is the number of marked bull trout observed snorkeling. The Bailey estimate accounts for the possibility a marked bull trout may be resighted multiple times in the snorkel count. Since the percentage of marked fish the snorkel count exceeded 10% of the total snorkel count, confidence intervals were based on a binomial distribution (Seber 1982).

The number of unmarked fish (N_U), therefore, equals he population estimate (N) minus the number of fish marked at the trap (M), and the number of unmarked mature females equals N_U times the fraction of mature females $\geq$ 300 mm observed at the trap, assuming females were as prevalent among the unmarked fish as they were among the fish inspected at the trap. The overall estimate for mature fluvial females in the study area, then, was calculated as the sum of the unmarked females above the trap plus the females counted at the trap. The confidence interval assumes all of the error is from the estimate of unmarked females.

Redd counts in the study area were conducted three times between mid-September and early November throughout all spawning areas. During each survey, we flagged newly observed redds, identified them with a unique number, measured their length (from the beginning of the pit to end of the pillow) and width (at the widest part of the mound), and noted all fish observed.

To estimate potential observer error in our redd surveys, we established three approximately 1-km test reaches in section 5, which typically has the highest redd counts of the survey reaches used by larger, fluvial fish, and three 1-km reaches in Low Cr. , which has generally smaller redds created by smaller, resident-sized fish. Redds were identified and flagged during the first survey on 21-22 September. During the next three week period, when the peak of spawning occurs, redds were identified and flagged at weekly intervals by an experienced surveyor not responsible for routine surveys of those reaches. At the end of the three-week period, the normal interval between routine surveys, flags were removed from all redds identified after the first survey. Each of the surveyors responsible for the routine surveys of fluvial redds (all survey sections except Low Cr.) independently counted unflagged redds in each of the test reaches in section 5, and the surveyor responsible for routine surveys in Low Cr. independently counted redds in the 3 test reaches in Low Cr. In addition, each member of the ODFW EMAP survey crew that conducted redd surveys in the Umatilla-Walla Walla subbasin independently counted redds in all six test reaches. On the following day, 4 experienced surveyors together resurveyed and flagged all new redds in all of the test reaches. Thus, we had 2 potential sources of "true" redd counts in each of the test reaches to compare with individual counts: the cumulative count of the 3 weekly surveys and the consensus, group count.

Results and Discussion

We captured 150 bull trout in the upstream trap, 70 of which were identified as mature females (Table 2). Ten of the bull trout were < 300 mm FL, including two < 200 mm. There were four mature females less than 300 mm, but all were $\geq$ 289 mm. Five fish recycled through the trap a second time.

Table 2. Number, sex, and maturity status of bull trout captured in an upstream migrant trap in Mill Creek in 2003. Mature females were classified using ultrasound. Counts of other species are also included.

Species	Mature females	Mature males and immature males and females	Total
bull trout	70	80	150
rainbow trout			20
mountain whitefish			11
chinook salmon (adult) [a]			5

a. *Hatchery fish released in Mill Cr. downstream from the trap.*

Ninety-four marked bull trout were released at the trap before the study area was snorkeled. The diver located 38 marked fish and 17 unmarked bull trout $\geq$ 300 mm. Thus, we estimated there were a total of 41 unmarked fluvial adults, of which 20 (95% CL = 17-25) were assumed to be mature females based on the female fraction (0.489) at the trap at the time of the snorkel survey. Combining these females with the 70 released at the trap yielded an estimate of 90 (95% CL = 87-95) mature fluvial females in the study area.

A total of 97 fluvial redds were counted during regular census surveys in Mill Cr. and tributaries (Table 3), not including Low Cr., which is suspected to be a purely resident population since only small redds and small mature and spawning bull trout have been observed (Sankovich et al. 2004); 61 redds were recorded in Low Cr. during census surveys.

Table 3. Redd counts from regular surveys in Mill Creek in 2004. The locations of survey sections are shown in Figure 7.

Survey section	No. of redds
1	0
2	0
3	1
4	18
5	45
6	17
7	10
Paradise Cr.	0
N.F. Mill Cr.	6
Deadman Cr.	0
Bull Cr	0
Total	97
Low Cr.	61

The greatest deviation from the estimated true redd counts in test reaches where we evaluated observer error was in Low Cr. (Table 4), where the total surveyor count was 55% of the total true count. Differences for individual surveyors from combined true counts for the three reaches in Mill Cr. reaches ranged from 6% to 33% with no consistent bias. This is consistent with our previous estimates of observer error in redds counts, which suggest larger error and a negative bias in counting redds of resident populations (Hemmingsen et al. 2001b). If the census counts of individual surveyors are adjusted based on the proportional difference between their total test count and the true count in the test reaches, there is coincidentally no difference in the total redd count of fluvial redds in Mill Cr.; however, there is a substantial increase in the Low Cr. count (Table 5). While using the combined total count for the three test reaches may be representative census counts in terms of averaging bias and precision in a typical survey reach (e.g., over- and underestimates cancel each other), the absolute error is a better indicator of the overall magnitude of the error in terms of both missing redds and counting "non-redds." (*see* Dunham 2001).

Table 4. Differences between surveyor redd count and "true" redd counts in test reaches of Mill Cr. and Low Cr. Absolute error is the sum of the absolute value of differences in the three test reaches. Results are shown for the five surveyors responsible for surveys in the Mill Cr. Basin.

Surveyor	Stream	Reach	Redd count	"True" count	Difference
1	Mill	1	6	8	-2
	Mill	2	7	4	3
	Mill	3	4	6	-2
		Total	17	18	-1
		Absolute error			7
2	Mill	1	5	8	-3
	Mill	2	3	4	-1
	Mill	3	4	6	-2
		Total	12	18	-6
		Absolute error			6
3	Mill	1	10	8	2
	Mill	2	8	4	4
	Mill	3	4	6	-2
		Total	22	18	4
		Absolute error			8
4	Mill	1	8	8	0
	Mill	2	7	4	3
	Mill	3	5	6	-1
		Total	20	18	2
		Absolute error			4
5	Low	1	3	9	-6
	Low	2	18	29	-11
	Low	3	21	39	-18
		Total	42	77	-35
		Absolute error			35

Table 5. Redd counts in Mill and Low Creeks adjusted for surveyor error in test reaches.

Stream	Surveyor	Census	Adjustment	Adjusted count
Mill Cr.	2	22	+33%	29
	3	14	-22%	11
	4	39	-11%	35
	Test[a]	22	0%	22
	Total	97		97
Low Cr.	5	61	+45%	88

a. *"True" count for the second survey visit of section 5, where the test reaches were located and for which there was no regular survey.*

In Mill Cr. there were 1.08 redds/mature female in 2004 compared to 1.18 redds/mature female in 2003. With the exception of 2001, we have observed a highly significant relationship ($p<0.001$) between the estimated number of mature fluvial females and the total number of redds counted in Mill Creek during 1998-2004 (Figure 8). To estimate the number of mature females in years prior to using ultrasound (1998-2001) we applied the average proportion of mature females observed during 2002-2004 (48.8%) to the total trap catch. During these three most recent years the ratio of mature females in the adult run has been generally consistent (range: 46.7%-50.0%). Compared to results observed in other years, the ratio of redds to mature female was abnormally high in 2001. At present we can find no reason to exclude this data point because of errors in estimates or data collection.

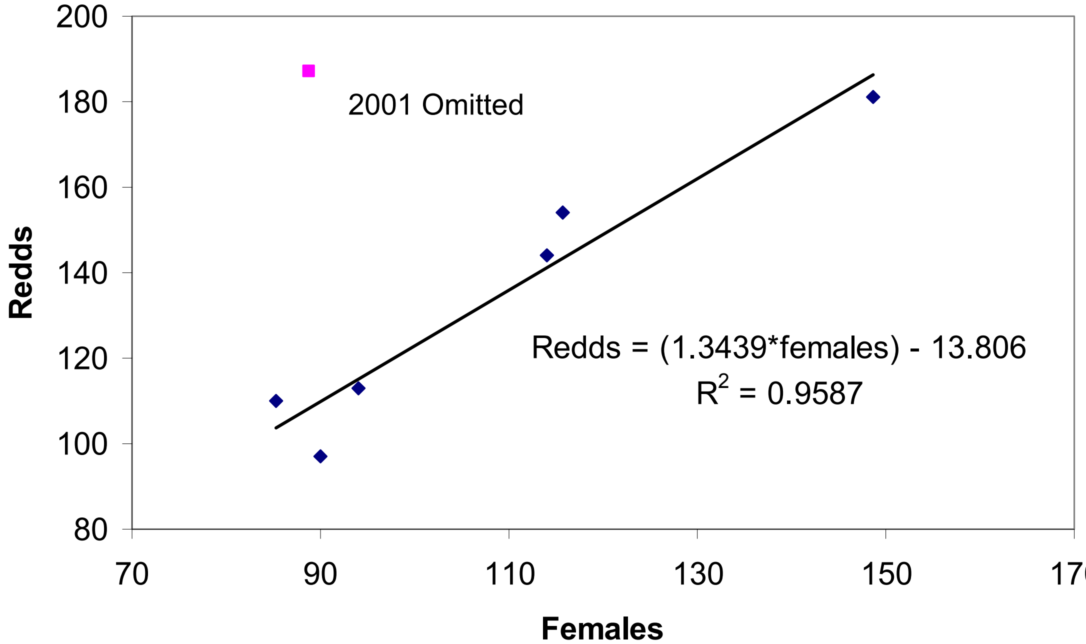


Figure 8. Relationship between the estimate number of mature female fluvial bull trout in upstream of the trap site and the total number of redds counted in Mill Creek 1998-2004**.** Relationship excludes redds counted in Low Creek which are believed to be made by resident females.

III. Monitoring the Abundance of Adult Bull Trout in the Walla Walla, Umatilla, John Day, and Deschutes River Subbasins using the Environmental Monitoring and Assessment Program (EMAP) Protocol

Introduction

The ability to accurately assess bull trout population status, trend, and distribution is central to conservation efforts for the species. A coordinated approach to conducting such assessments is needed to support restoration efforts. Currently, most monitoring activities are not part of an overall framework for coordinating effort and synthesizing and interpreting results. The Environmental Protection Agency (EPA) has developed the Environmental Monitoring and Assessment Program (EMAP) to evaluate the status of natural resources at regional and national scales. The goal of EMAP is to provide a scientific basis for monitoring programs that measure current and changing resource status.

EMAP employs a probabilistic sampling design that allows resource assessment over large areas based on data from representative sample locations. The design involves a spatially balanced random sampling strategy that distributes sample locations evenly throughout the area of assessment. Trends in status are best assessed by visiting randomly selected sampling sites on annual and multi-year cycles. The EMAP sampling design allows evaluation of status, trend, and distribution at multiple scales with statistical rigor.

From 2002 to 2004, we used the EMAP protocol to monitor the abundance of adult bull trout in the Oregon portion of the Columbia Plateau Province; specifically, the Deschutes, John Day, Umatilla, and Walla Walla River subbasins. (The Walla Walla River subbasin includes the Touchet River and its tributaries in Washington.) We used redd counts to assess adult abundance. Counting redds is the easiest and often the least costly way to estimate adult abundance. Although there can be substantial error associated with the enumeration of redds (Bonneau and LaBar 1997; Dunham et al. 2001; Hemmingsen et al. 2001b), research has shown that redd counts are strongly correlated with estimates of adult escapement (Dunham et al. 2001).

Methods

The sampling frame in the John Day and Walla Walla-Umatilla subbasins consisted of all wadable stream reaches that contain current and potential bull trout spawning habitat. In 2004, the sample frame in the Deschutes subbasin did not include current and potential bull trout spawning habitat within the Warm Springs Indian Reservation because tribal officials did not want to participate in this study. The identification of these reaches was based on ODFW maps of current distribution (derived from the EPA's 1:100k river reach data set) and input from ODFW district biologists and other fishery managers via Streamnet's (http://www.streamnet.org) 1:24K mapping effort. We included only wadable stream reaches because redds can be difficult to count effectively in unwadable areas. The sampling frame was the pool of possible locations from which sample sites were selected and represents our scope of inference.

Site selection was conducted by the EPA Research Lab in Corvallis, Oregon. The site selection process is based on a spatial grid design with hexagonal areas centered at grid points (Stevens and Olsen 1999). Points along all streams in the sampling frame were plotted sequentially by computer and then randomly selected. The randomly selected points were then re-plotted on maps for survey site location.

The number of sample sites within subbasins was based on the minimum number of sites necessary to quantify status and detect trends over time. Our target measure of precision for the estimated number of redds was ± 45% at the subbasin scale and ± 25% at the provincial (all subbasins combined) scale. Bull trout spawning in the Walla Walla and Umatilla subbasins is less widely distributed than the other subbasins so they were combined and the two subbasins were treated as an aggregate when selecting sites. The site selection process produced 50 spatially balanced sites in each of the Deschutes, John Day, and combined Walla Walla–Umatilla subbasins. We thought 50 sites would be the maximum number a crew of two surveyors could effectively survey multiple times throughout the spawning period. We determined that a minimum of 30 sites should be surveyed per subbasin. Fifty additional sites were selected in each subbasin for use as replacements in the event some sites were unsuitable (e.g., located in a dry stream channel) or on private property we could not get permission to access.

Each sample point served as the mid-point of a 1.6 km spawning survey section. Midpoints were plotted on quad maps using mapping software (Terrain Navigator) and coordinates for individual site endpoints were produced using the distance tool. During August, field crews located the start and end points of each survey section using Universal Transverse Mercator (UTM) coordinates, maps, and a GPS receiver. The suitability of each site was judged by the presence of potential spawning habitat and the absence of barriers to bull trout migration, unless bull trout were known to exist upstream from a barrier. Survey end-points were flagged with surveyor's tape, and plastic identification signs were fixed to a nearby tree on the stream bank.

From early September through early November, all sites in each subbasin were surveyed three to five times. Five two-person survey crews conducted the surveys. We assigned single crews to the Deschutes, Middle Fork and upper John Day River, and North Fork John Day River subbasins and two crews in the Walla Walla–Umatilla River subbasin. Crews were trained in the identification of bull trout redds, and spawning surveys were conducted according to ODFW protocols (Bellerud 1997). During the surveys, each newly observed redd was recorded and flagged. In streams where the presence of sympatric fall-spawning species made bull trout redd identification difficult, redds were attributed to bull trout only if bull trout were observed on them.

Bull trout population status was assessed based on cumulative redd counts. These counts were analyzed using analytical algorithms developed by the EMAP (Stevens 2002). To assess the accuracy of the EMAP estimates, we also surveyed the entire sampling frame (full census) in the Walla Walla-Umatilla River subbasin. The census surveys were conducted multiple times throughout the spawning period, as for the EMAP surveys. The total redd count within the sampling frame was compared to the estimated number of redds obtained using the EMAP protocol.

Results and Discussion

Using the EMAP sampling strategy, we estimated there were 235 (±84) bull trout redds in the John Day subbasin, 511 (± 95) in the Walla Walla-Umatilla subbasin, and 709 (± 84) in the Deschutes subbasin, and 1,455 (± 127) in the Columbia Plateau province in 2004

(Table 6). Precision of estimates was ± 36%, ± 19%, and ± 12% in the John Day, Walla Walla-Umatilla, and Deschutes subbasins, respectively, and ± 9% for the Columbia Plateau province, well within our target of ± 45% for the individual subbasins and ± 25% for the province. We met our goal of completing 50 sites in each subbasin except in the John Day, where one site was dropped because the stream channel remained dry throughout the season.

Table 6. Bull trout redds counted in survey sections (n) and estimated to be within three subbasins in 2004.

Subbasin	n	Estimated no. of redds	C.I. (%) [a]
John Day	49	235	36
Walla Walla-Umatilla	50	511	19
Deschutes	50	709	12
Province	149	1,455	9

a. *± 95% confidence interval.*

As during the past two seasons (Sankovich et al. 2002 and Sankovich et al. 2003) the EMAP estimate for the John Day subbasin, was more imprecise than estimates the other subbasins. This difference was due partly to surveying only 27% of the relatively large sampling frame in John Day subbasin, compared to sample rates 60% of the Walla Walla-Umatilla subbasin and 84% of the Deschutes subbasin. It was also due to the relatively low site occupancy rate (proportion of survey sections in which redds were identified) in the John Day subbasin. Redds were recorded in only 35% of the survey sections in the John Day subbasin, compared to 60% in the Walla Walla-Umatilla subbasin and 54% in the Deschutes subbasin. Under the EMAP protocol, it is expected that some sites will be unoccupied and that changes in fish distribution through time will be reflected by changes in site occupancy and the distribution of occupied sites. However, site occupancy rates we observed may have been artificially low. Especially in the John Day subbasin, current and potential spawning distributions were based largely on professional judgment rather than existing data; and, despite our modification of the sampling frame used in 2004, we still may have surveyed some stream reaches that do not support bull trout spawning and thus should be excluded from the sampling frame. In addition, in areas where fall-spawning species other than bull trout were present (primarily brook trout), we recorded only redds occupied by bull trout. As a result, we may have recorded no bull trout redds in survey sections that actually contained them.

The high precision of the Deschutes subbasin estimate was largely due to the high sampling rate and the use of the finite population correction in calculating estimates of variance. After the Warm Springs Indian Tribe denied ODFW permission to survey on their reservation, the Deschutes sampling frame was reduced by 42%. Surveying 50 sites in the Deschutes sampling frame, which was only 59% the size of the Walla Walla-Umatilla sampling frame, resulted in greater coverage and relatively more site overlap.

The EMAP estimate of the number of redds in the Walla Walla-Umatilla subbasin in 2004 was significantly lower than the census redd count. The EMAP estimate of 517 redds was 22% lower than the census count of 660 redds (Table 7). This increased inaccuracy is a surprising result compared to the previous two years in which the census count and EMAP estimate differed by less than 2% (Figure 9). The EMAP surveys comprised 60% of the stream kilometers encompassed in the 2004 census (Table 7), which was slightly higher percentage than in the previous two years.

Table 7. Comparison of two strategies used to count bull trout redds in the Walla Walla-Umatilla subbasin in 2004.

	Census	EMAP
Number of redds	660	511
Stream km surveyed	113.5	67.7

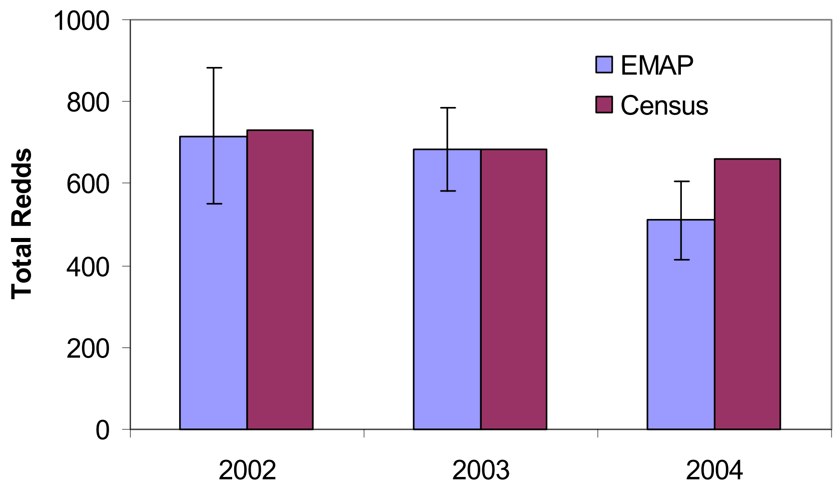


Figure 9. Comparison of the number of bull trout redds estimated through the EMAP methodology and censused in the Umatilla-Walla Walla subbasin, 2002-04. Vertical lines at the top of the EMAP bars of the graph represent 95% confidence intervals.

We also compared our EMAP estimate in the Deschutes subbasin to a census conducted by the ODFW District office in Bend that included surveyors from the EMAP crew, Forest Service, and volunteers. There were some differences between the district census surveys and the EMAP protocol: the sampling frame for the District census is 5% smaller than the EMAP sampling frame, the census is only done twice during the season, and in some cases, different survey crews were used for each survey visit. Despite these differences, we believe that the results of the census are sufficiently accurate to judge the accuracy of the EMAP methodology in estimating the total number of redds in the Deschutes subbasin. Comparing the EMAP estimate to the district census in the Deschutes subbasin, we found a significant difference and greater inaccuracy than in the Walla Walla-Umatilla subbasin in 2004 (Table 8). In the Deschutes subbasin, the 2004 EMAP estimate was 32% lower than the district census.

Table 8. Comparison of two strategies used to count bull trout redds in the Deschutes subbasin in 2004.

	Census	EMAP
Number of redds	1,045	709 ±84[a]
Stream km surveyed	66.6	55.9

a. *± 95% confidence interval.*

The inaccuracy of the EMAP estimate in the Deschutes subbasin suggests the relatively inaccurate estimate in 2004 in the Walla Walla-Umatilla subbasin may not be anomalous. In fact, a closer look at the EMAP site selection protocol and the distribution of redd densities within a subbasin suggests an important source of potential error in the EMAP estimate. EMAP sites are selected in a spatially balanced manner so that sites are evenly distributed throughout the sampling frame; however, bull trout redds are not evenly distributed (see Figures 10-12). Spatial patchiness in bull trout spawning distribution and variation in redd density has been noted in other studies (Baxter et al. 1999). In the portion of the Umatilla-Walla Walla sampling frame made up by the North and South Forks of the Walla Walla River is approximately 47 km long. In 2003 and 2004, more than 80% of the redds were counted in one 12.5 km reach in the South Fork Walla Walla River, which accounted for only 26% of this portion of the sampling frame. In 2004, no EMAP sites occurred in a section within this reach that constituted only 3% of this part of the sampling frame but accounted for 22% of the redd count. Thus it appears that when redds have a patchy spatial distribution EMAP may underestimate redd abundance if areas of high redd density are not contained among the sample sites.

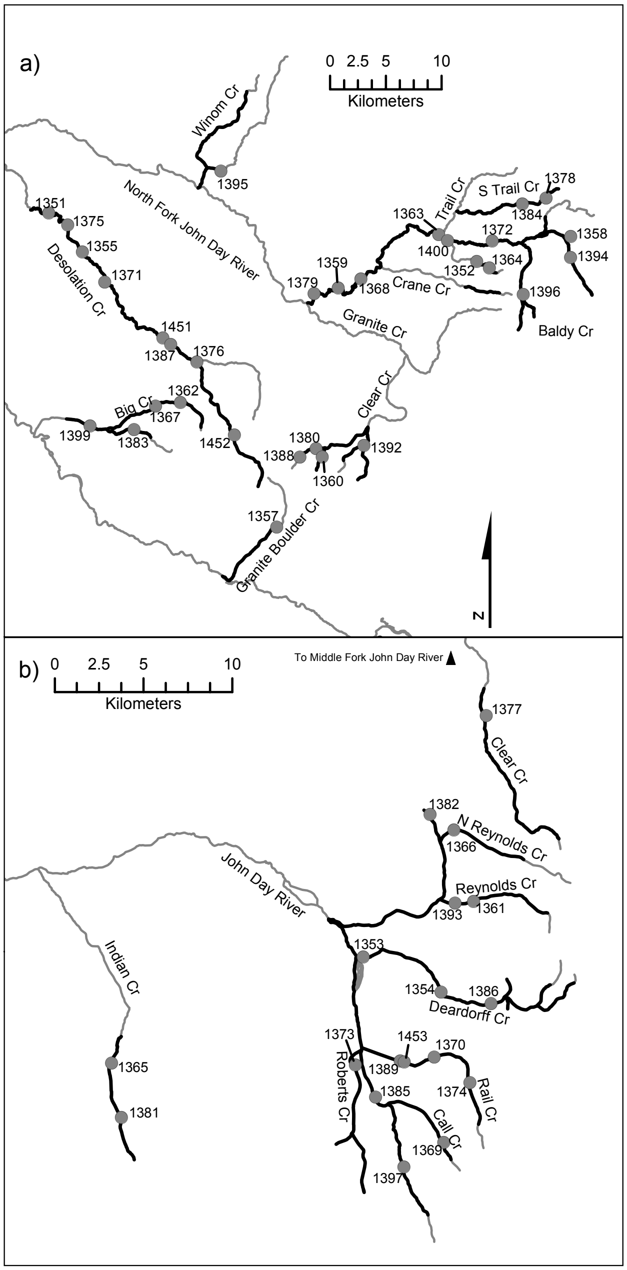
In the Deschutes subbasin, the patchiness of bull trout spawning distribution and variation in redd density is even more apparent (Table 9) and may help explain why the EMAP estimate was significantly lower than the District census. In 2004, Roaring Creek only constituted 4% of the Deschutes sampling frame but accounted for 14% of the total redd count. The Metolius River and Jefferson Creek represented 42% of the sampling frame but combined they accounted only for the same number of redds as Roaring Creek. No EMAP sites occurred on Roaring Creek but 18 sites (36% of the total) occurred on the Metolius River and Jefferson Creek.

Table 9. Individual streams in the Deschutes subbasin and their corresponding percentage of the Deschutes sample frame and redd count in 2004.

	Percent of Total	
Stream	Sample Frame	Redds
Jack Creek	7	29
Roaring Creek	4	14
Heising Springs	<1	5
Metolius River	16	2
Jefferson Creek	26	12

This was the final year of a three-year pilot study to evaluate the EMAP protocol as a method to monitor bull population trends in the Columbia Plateau province in Oregon. Our results suggest that a spatially balanced random sampling strategy that distributes sample locations evenly throughout the area of assessment may produce biased estimates if redd distribution is highly fragmented. To correct this potential source of error, we suggest a random sampling strategy that stratifies the sample frame by differences in bull trout spawning distribution and redd density in areas where prior knowledge of redd distribution exists.

Within the province, the John Day subbasin is unique because of its large size (constituting more than 60% of the provincial sampling frame), relatively low redd density. Its bull trout spawning distribution has never been censused. In 2005, we intend to improve our knowledge of the bull trout spawning distribution and redd density in the John Day subbasin by conducting a subbasin census of the bull trout sampling frame. Our goal is to acquire GPS coordinates for each redd counted, map them using GIS, and, with the assistance of the US Environmental Protection Agency statisticians, evaluate various sampling strategies. This information will improve our evaluation of the EMAP protocol and our ability to develop an effective sampling strategy for monitoring bull trout populations in the Columbia Plateau province.



Site	Stream Name	Redds/Km
1351	Desolation Creek	0
1352	Onion Creek	1
1353	Deardorff Creek	0
1354	Deardorff Creek	3
1355	Desolation Creek	0
1357	Granite Boulder Creek	6
1358	Cunningham Creek	0
1359	North Fork John Day River	0
1360	West Fork Clear Trib	2
1361	Reynolds Creek	0
1362	Big Creek	0
1363	North Fork John Day River	0
1364	Onion Creek	0
1365	Indian Creek	1
1366	North Reynolds Creek	0
1367	Big Creek	0
1368	North Fork John Day River	0
1369	Call Creek	1
1370	Rail Creek	1
1371	Desolation Creek	0
1372	North Fork John Day River	0
1373	Roberts Creek	0
1374	Rail Creek	1
1375	Desolation Creek	0
1376	Desolation Creek	0
1377	Clear Creek	1
1378	South Trail Creek	0
1379	North Fork John Day River	0
1380	West Fork Clear Creek	0
1381	Indian Creek	6
1382	Mossy Gulch	1
1383	Deadwood Creek	0
1384	South Trail Creek	0
1385	John Day River	1
1386	Deardorff Creek	3
1387	Desolation Creek	0
1388	West Fork Clear Creek	0
1389	Rail Creek	0
1392	Dry Creek	3
1393	Reynolds Creek	0
1394	North Fork John Day River	5
1395	Big Creek	0
1396	Baldy Creek	2
1397	John Day River	4
1398	Clear Creek	Dry
1399	Big Creek	0
1400	North Fork John Day River	0
1451	Desolation Creek	0
1452	South Fork Desolation Creek	0
1453	Rail Creek	0

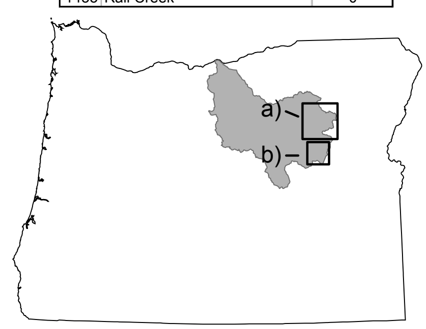
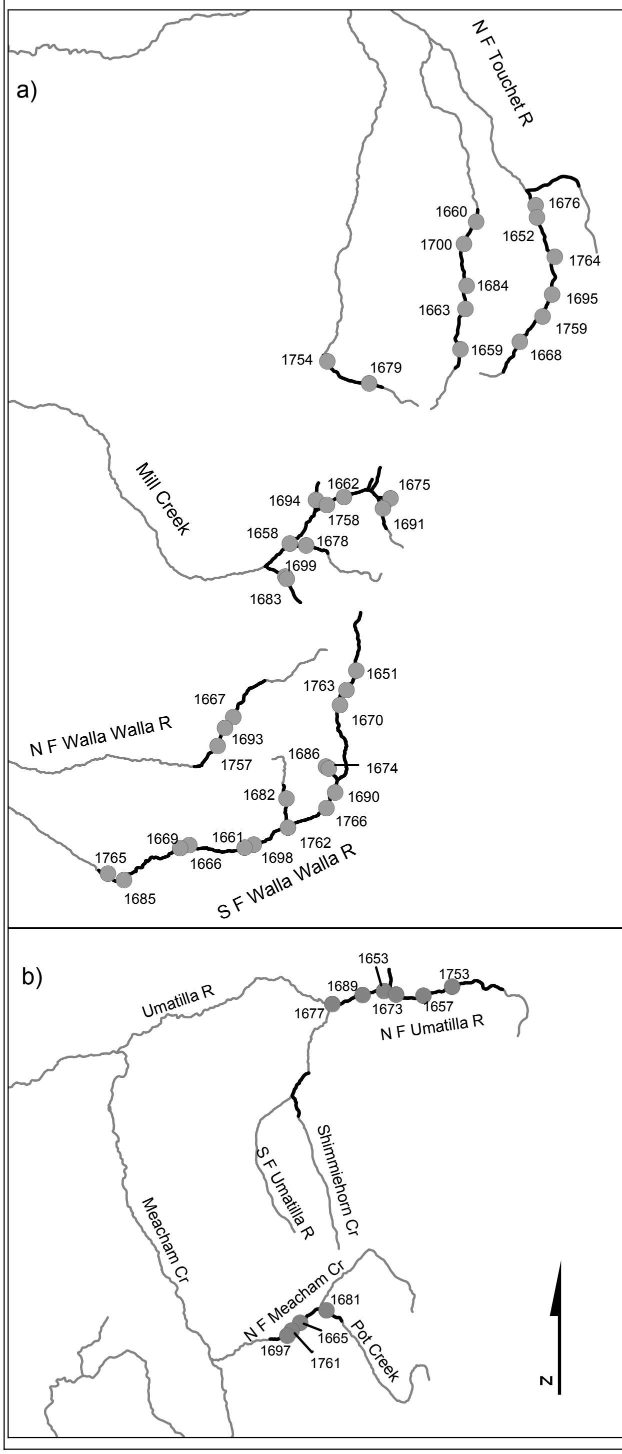


Figure 10. Location and number of bull trout redds per km for 2004 sample sites in a) North and Middle Forks and b) Mainstem John Day River subbasins, OR.



Site	Stream Name	Redds/Km
1651	South Fork Walla Walla River	3
1652	North Fork Touchet River	0
1653	North Fork Umatilla River	1
1657	North Fork Umatilla River	4
1658	Mill Creek	4
1659	Wolf Creek	2
1660	Wolf Creek	0
1661	South Fork Walla Walla River	6
1662	Mill Creek	8
1663	Wolf Creek	8
1665	North Fork Meacham Creek	0
1666	South Fork Walla Walla River	1
1667	North Fork Walla Walla River	0
1668	North Fork Touchet River	6
1669	South Fork Walla Walla River	0
1670	South Fork Walla Walla River	3
1673	North Fork Umatilla River	2
1674	Reser Creek	9
1675	Bull Creek	0
1676	North Fork Touchet River	0
1677	North Fork Umatilla River	1
1678	Paradise Creek	0
1679	Burnt Fork	0
1681	Pot Creek	0
1682	Skiphorton Creek	1
1683	Low Creek	4
1684	Wolf Creek	18
1685	South Fork Walla Walla River	0
1686	Reser Creek	6
1689	North Fork Umatilla River	3
1690	South Fork Walla Walla River	23
1691	Mill Creek	9
1693	North Fork Walla Walla River	0
1694	North Fork Mill Creek	4
1695	North Fork Touchet River	0
1697	North Fork Meacham Creek	0
1698	South Fork Walla Walla River	6
1699	Low Creek	6
1700	Wolf Creek	3
1753	North Fork Umatilla River	16
1754	Burnt Fork	0
1757	North Fork Walla Walla River	0
1758	Mill Creek	13
1759	North Fork Touchet River	0
1761	North Fork Meacham Creek	0
1762	South Fork Walla Walla River	26
1763	South Fork Walla Walla River	5
1764	North Fork Touchet River	0
1765	South Fork Walla Walla River	0
1766	South Fork Walla Walla River	24

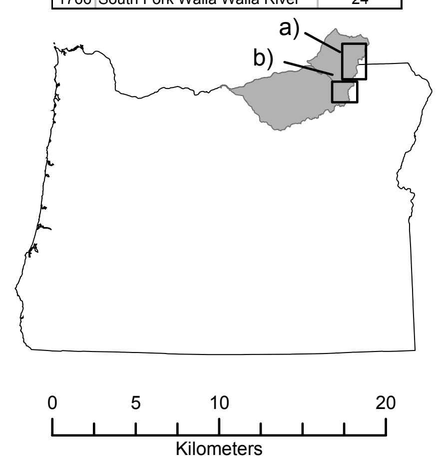
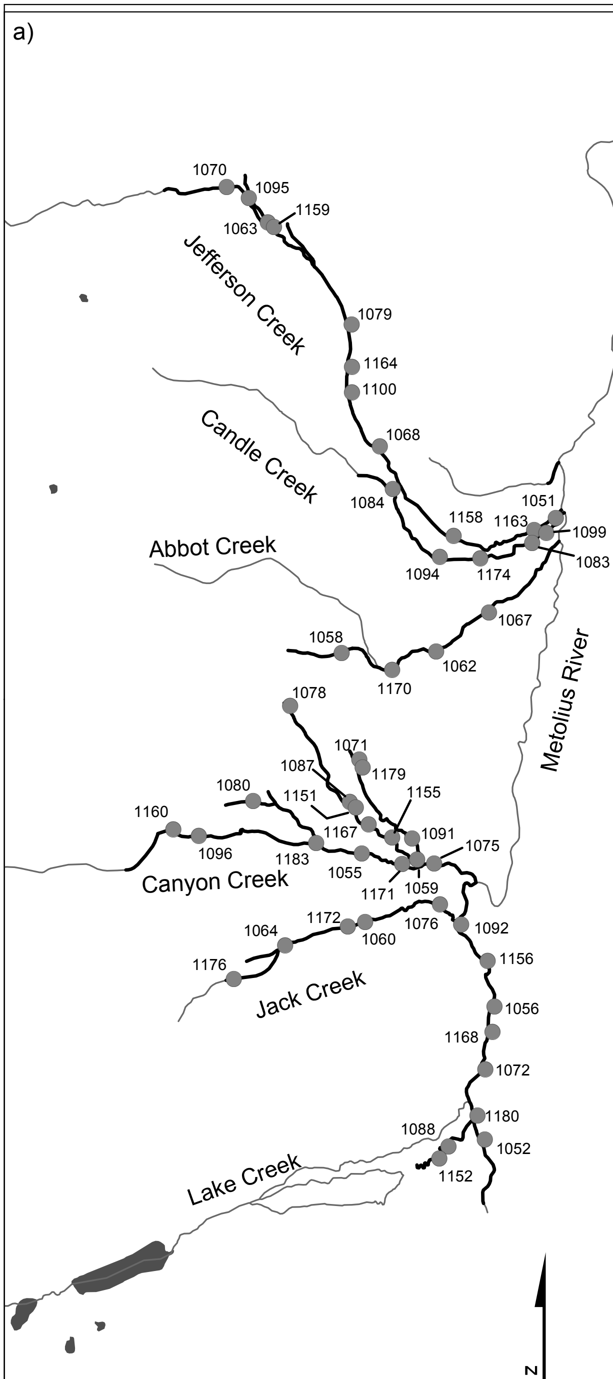


Figure 11 Location and number of redds per km of 2004 bull trout EMAP sample sites in a) Walla Walla River and b) Umatilla River subbasins, OR.



Site	Stream Name	Redds/Km
1051	Jefferson Creek	26
1052	Metolius River	0
1055	Canyon Creek	50
1056	Metolius River	0
1058	Abbot Creek Trib	0
1059	Brush Creek	2
1060	Jack Creek	13
1062	Abbot Creek	1
1063	Jefferson Creek	0
1064	Jack Creek	70
1067	Abbot Creek	1
1068	Jefferson Creek	6
1070	Jefferson Creek	0
1071	Canyon Creek Trib	0
1072	Metolius River	1
1075	Canyon Creek	31
1076	Jack Creek	6
1078	Brush Creek	0
1079	Jefferson Creek	0
1080	Roaring Creek Trib	0
1083	Candle Creek	33
1084	Candle Creek	18
1087	Brush Creek	0
1088	Middle Fk South Fk Lake Creek	0
1091	Canyon Creek Trib	0
1092	Metolius River	16
1094	Candle Creek	18
1095	Jefferson Creek	0
1096	Canyon Creek	0
1099	Candle Creek	32
1100	Jefferson Creek	2
1151	Brush Creek	0
1152	Middle Fk South Fk Lake Creek	0
1155	Brush Creek	0
1156	Metolius River	1
1158	Jefferson Creek	15
1159	Jefferson Creek	0
1160	Canyon Creek	0
1163	Jefferson Creek	34
1164	Jefferson Creek	1
1167	Brush Creek	0
1168	Metolius River	1
1170	Abbot Creek	0
1171	Canyon Creek	41
1172	Jack Creek	11
1174	Candle Creek	36
1176	Jack Creek	43
1179	Canyon Creek Trib	0
1180	Metolius River	0
1183	Canyon Creek	24

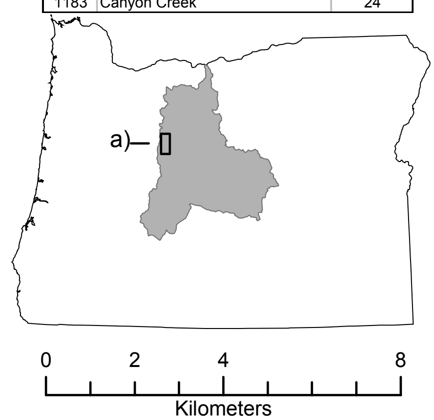


Figure 12. Location and number of bull trout redds per km for sample sites in the Deschutes subbasin, OR**.**

Acknowledgements

We are grateful to the following individuals for their assistance in the field: Ari Martinez, Randy Roe, Matt Weeber, Luke Freeman, Matt Hutchinson, Jonathan Hyde, Robert Weiss, Mae Noble, Devin Best, Dana McCoskey, David Kwasniewski, and Alex Higgins of ODFW; Larry Boe and Dave Crabtree of the USFS and Marshall Barrows, Tad Kisaka, and Darren Gallion of USFWS. We thank Tim Whitesel of USFWS for recruiting and organizing volunteers; Glen Mendel of WDFW for his cooperation and providing data on the Touchet River, Washington; Ralph Hartman and Craig Smith-Dixon of the North Fork John Day Ranger District for permission to locate a crew at the Fremont Powerhouse housing; Michael Leake of Union Pacific Railroad for permission to survey in NF Meacham Creek; Dan Bishop of Prairie Wood Products for cooperation and permission to access private land; and many other landowners for permission to access their private land. Finally, we wish to extend our sincere gratitude to Paul Sankovich of the USFWS. Paul's dedication and expertise was vital in completing many of the tasks reported here.

References

Bailey, N.T.J. 1951. On estimating the size of mobile populations from capture-recapture data. Biometrika 38:293-306.

Baxter, C.V. 2002. Fish movement and assemblage dynamics in a Pacific Northwest riverscape. Ph.D., Oregon State University, Corvallis, OR.

Bonar, S.A., M. Divens, and B. Bolding. 1997. Methods for sampling the distribution and abundance of bull trout and Dolly Varden. Washington Department of Fish and Wildlife, Olympia, WA.

Bonneau, J., and LaBar. 1997. Interobserver and temporal bull trout redd count variability in tributaries to of Lake Pend Oreille, Idaho: Completion Report. Department of Fisheries and Wildlife, University of Idaho, Moscow.

Buchanan, D.V., M. Hanson, and B. Hooton. 1997. Bull trout status report for Oregon. Oregon Department of Fish and Wildlife. Portland, OR.

Dunham, J., B. Rieman, and K. Davis. 2001. Sources and magnitude of sampling error in redd counts for bull trout *Salvelinus confluentus*. North American Journal of Fisheries Management 21: 343-352.

Fraley, J. J., and B. B. Shepard. 1989. Life history, ecology, and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake river system, Montana. Northwest Science 63 (4): 133-143.

Hankin, D.G. 1986. Sampling designs for estimating the total number of fish in small streams. Research Paper PNW-360. USDA Forest Service, Pacific Northwest Research Station. Portland, OR.

Hemmingsen, A.R., S.L. Gunckel, P.M. Sankovich, and P.J. Howell. 2001a. Bull trout life history, genetics, habitat needs, and limiting factors in central and northeast Oregon. 2000 Annual Report. Project 199405400, Bonneville Power Administration. Portland, OR.

Hemmingsen, A.R., B.L. Bellerud, and S.L. Gunckel. 2001b. Bull trout life history, genetics, habitat needs, and limiting factors in central and northeast Oregon. 1998 Annual Report. Project 199405400, Bonneville Power Administration. Portland, OR.

Hemmingsen, A.R., S.L. Gunckel, J.S. Shappart, B.L. Bellerud, D.V. Buchanan, and P.J. Howell. 2001d. Bull trout life history, genetics, habitat needs, and limiting factors in central and northeast Oregon. 1997 Annual Report. Project 199405400, Bonneville Power Administration. Portland, OR.

Hemmingsen, A.R., S.L. Gunckel, P.M. Sankovich, and P.J. Howell. 2002. Bull trout life history, genetics, habitat needs, and limiting factors in central and northeast Oregon. 2001 Annual Report. Project 199405400, Bonneville Power Administration. Portland, OR.

Maxell, B. A. 1999. A prospective power analysis on the monitoring of bull trout stocks using redd counts. North American Journal of Fisheries Management 19:860-866.

Poole, G. and 11 coauthors. 2001. Technical synthesis: scientific issues relating to temperature criteria for salmon, trout, and char native to the Pacific Northwest, a summary report submitted to the policy workgroup of the EPA Region 10 Water Temperature Criteria Guidance Project. EPA-910-D-01-007, May 2001.

Pratt, K.L. 1992. A review of bull trout life history. Pages 5-9 in P.J. Howell and D.V. Buchanan, editors. Proceedings of the Gearhart Mountain Bull Trout Workshop. Oregon Chapter of the American Fisheries Society, Corvallis.

Rieman, B.E., and J.B. Dunham. 2000. Metapopulations and salmonids: a synthesis of life history patterns and empirical observations. Ecology of Freshwater Fish 9:51-64.

Rieman, B.E., and J.D. McIntyre. 1993. Demographic and habitat requirements for conservation of bull trout. General Technical Report INT-302, Intermountain Research Station, Ogden, UT.

Rieman, B.E., and D.L. Myers. 1997. Use of redd counts to detect trends in bull trout (Salvelinus confluentus) populations. Conservation Biology 11(4): 1015-1018.

Sankovich, P.M., S.L. Gunckel, A.R. Hemmingsen, I.A. Tattam, and P.J. Howell. 2003. Migratory patterns, structure, abundance, and status of bull trout populations from subbasins in the Columbia Plateau. 2002 Annual Report. Project 199405400. Bonneville Power Administration, Portland, OR.

Sankovich, P.M., S. J. Starcevich, A.R. Hemmingsen, S.L. Gunckel, A.R. Hemmingsen, and P.J. Howell. 2004. Migratory patterns, structure, abundance, and status of bull trout populations from subbasins in the Columbia Plateau. 2003 Annual Report. Project 199405400. Bonneville Power Administration, Portland, OR.

Seber, G. A. F. 1982. Estimation of animal abundance and related parameters. Oxford Univ. Press, New York, 654 p.

Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. 2001. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Transactions of the American Fisheries Society 130:1026-1037.

Stevens, D.L., Jr. 2002. Sampling design and statistical analysis methods for integrated biological and physical monitoring of Oregon streams. OPSW-ODFW-2002-07, Oregon Department of Fish and Wildlife, Portland, Oregon.

Stevens, D.L., Jr., and A.R. Olsen. 1999. Spatially restricted surveys over time for aquatic resources. Journal of Agriculture, Biological, and Environmental Statistics 4: 415-428.

U.S. Environmental Protection Agency (EPA). 2003. EPA region 10 guidance for Pacific Northwest state and tribal temperature water quality standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.

U.S. Fish and Wildlife Service. 2002. Draft recovery plan for the klamath river and Columbia River distinct population segments of bull trout (*Salvelinus confluentus*). U.S. Fish and Wildlife Service, Portland, Oregon.

U.S. Fish and Wildlife Service. 2002. Chapter 11, Umatilla-Walla Walla Recovery Unit, Oregon and Washinton. 153 p. *In*: U.S. Fish and Wildlife Service. Bull Trout (*Salvelinus confluentus*) Draft Recovery Plan. Portland, Oregon.