BURNS PAIUTE TRIBE

Natural Resources Department

Fisheries Division

Evaluate the Life History of Native Salmonids
in the Malheur Subbasin

FY 2008 Annual Report

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Evaluate the Life History of Native Salmonids in the Malheur Subbasin

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**Synopsis of 2000 - 2008 Stream
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in the Upper Malheur**

Logan Valley Wildlife Mitigation Property, 2008

Chad Abel
Fisheries Program Manager
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SYNOPSIS OF 2000 - 2008 STREAM TEMPERATURE MONITORING With Implications for Bull Trout Recovery in the Upper Malheur

Logan Valley Wildlife Mitigation Property 2008

Chad Abel, Fisheries Program Manager
Burns Paiute Tribe Natural Resources Dept

INTRODUCTION

The Burns Paiute Tribe Natural Resources Dept (BPT) has been monitoring stream temperatures in the Upper Malheur River since acquiring the Logan Valley Wildlife Mitigation Property in April 2000. In addition to the reporting of 2008 stream temperature data, the daily Maximum Weekly Maximum Temperature (MWMT) value from 2000 – 2008 was averaged through the 120 day time period of 7 June – 4 October in order to establish trend data at the five temperature monitoring sites initiated in 2000. Data reveals that monitoring sites on Big and Lake Creeks consistently surpass the Department of Environmental Quality (DEQ) Stream Temperature Standard of 12° C for bull trout (*Salvelinus confluentus*) during the summer period. Lake Creek sites surpass the Incipient Lethal Temperature (ILT) of bull trout (21.9° C) by 6 July on average, whereas Big Creek sites do not reach such critical temperature maximums. Lake Creek also warms earlier than Big Creek, and this phenomenon may explain why no radio tagged fluvial bull trout were found to have migrated into the Lake Creek drainage during past tracking efforts.

METHODS

Study Area

The Logan Valley Wildlife Mitigation Property is located south of the Strawberry Wilderness in Grant County, OR. The project consists of 1760 deeded acres in which Lake Creek, Big Creek and McCoy Creek combine to form the Upper Malheur River. BPT has maintained five temperature sites on the Upper Malheur since acquiring the property in April 2000 (Namitz 2000, Schwabe 2001, Schwabe 2002, Schwabe 2003, Schwabe 2004, Schwabe and Fenton 2005, Fenton 2006, Schwabe 2007). Of these five sites, two sites are stationed on Lake Creek, two sites are stationed on Big Creek and one site is stationed at their confluence (Table 1). In 2007 two additional sites, with a focus on the Lake Creek drainage, were selected for temperature monitoring (Schwabe 2007) (Table 1). Another site was again added to Lake Creek in 2008 (Table 1). Site locations are mapped on Figure 1.

Table 1: Temperature Sites Monitored by BPT

Site	Location	Year Initiated
1	Lake Creek below McCoy Creek “upper Lake”	2000
2	Lake Creek below Crooked Creek “lower Lake”	2000
3	Malheur River below Big and Lake Creek “Malheur”	2000
4	Big Creek 1 Mile below 16 Road “lower Big”	2000
5	Big Creek below 16 Road “upper Big”	2000
6	Lake Creek below 16 Road	2007
7	McCoy Creek above Lake Creek	2007
8	Lake Creek at Cabin Bridge	2008

Figure 1: Water temperature monitoring site locations.

Field Techniques

In 2008, Tidbit v2 Temperature Loggers (hobos) manufactured by Onset Computer Corporation were deployed on 17 June and retrieved by 11 October. Hobos were subjected to accuracy checks prior to deployment using methods recommended by the Oregon Water Quality Monitoring Technical Guidebook (2001). Standards dictate that hobo readings can not vary from actual by more than $\pm 0.5^{\circ}\text{C}$.

Eight pound anchors were used to secure hobos at or near stream substrate. Two hobos were anchored at each site in case one hobo failed. Timing of deployment has varied slightly from year to year, usually as a result of seasonal weather conditions. 17 June was a late start comparative to other years.

Data Analysis

Temperature data is expressed by the rolling daily maximum temperature averaged over a seven day period that is referred to as MWMT. This unit of measurement is also known as Seven Day Average Daily Maximum or 7DADM, and is synonymous with MWAT calculations utilized in previous reports by BPT.

The daily MWMT value from 2000 – 2008 was averaged through the 120 day time period of 7 June – 4 October for the five temperature monitoring sites initiated in 2000. The 120 day period was chosen because it represents the time of highest summer temperatures and encompasses the period annually when hobos were most often deployed. A trend line of the daily mean over the 120 day period ± 1 SD is plotted in Figures 1B – 5B (Appendix B). Each figure represents one of the five sites. For the three new sites with less data history, MWMT data is similarly plotted but without being averaged (Appendix B, Figures 6B – 8B).

The timeframe 15 July – 15 August was outlined as the critical period for high stream temperatures by Perkins (1999) and has been used in previous BPT reports as an index for interpreting stream temperature data. Mean of the Daily Average Temperature (DAT) and mean MWMT at the eight monitoring sites were calculated for the Critical Stream Temperature Period (Table 2). Temporal occurrence of highest stream temperatures was identified to see if dates fell within the 32 day critical period (Table 2).

The DEQ Stream Temperature Standard of 12° C MWMT for bull trout migration and juvenile rearing is heavily incorporated in the analysis of this report (OAR 2004). Also incorporated is the 16° C MWMT standard for salmonids in core rearing areas (i.e. an area of moderate to high density use generally in a basin's middle to upper reaches) (OAR 2004). Sixteen centigrade has been cited as an important benchmark in relation to the thermal tolerance of bull trout as well. Lab research found that feed consumption of bull trout declined significantly at temperatures greater than 16° C (Selong et al. 2001). The same lab study identified 21.9° C as the ILT for bull trout. Thus 21.9° C is used in this report to identify absolute times of zero bull trout habitat utilization.

Migrating bull trout telemetry data collected by BPT in 2000 and 2001 underscores the importance of satisfactory stream temperatures prior to 15 July (Appendix A). Table 3 illustrates how DEQ temperature standards are breached earlier in the Primary Migration Period on Lake Creek. Table 4 illustrates the average number of days and percent of total days in the summer period from 2000 – 2008 that MWMT eclipsed cited temperature benchmarks.

RESULTS

Logan Valley streams surpass temperature maximums through the selected 120 day summer period based on DEQ temperature standards for bull trout migration and juvenile rearing habitat (12° C) as well as standards for salmonid core rearing habitat (16° C) (OAR 2004). On average, the two Lake Creek sites initiated in 2000 first surpassed 16° C on 7 June compared to the 19 June for lower Big Creek (site 4) and 4 July at upper Big Creek (site 5) (Table 3). Lake Creek sites passed above 21.9° C, by 6 July on average whereas the Malheur site (site 3) and the two Big Creek sites never eclipsed the threshold (Table 3). Of the sites associated with the Lake Creek drainage, three sites (sites 1, 2 and 8) were above the 12° C MWMT bull

trout standard every day (100%) of the summer period (Table 4). The two other sites in the Lake Creek drainage were over the bull trout temperature standard for 107 days (89%, site 6) and 109 days (91%, site 7) (Table 4). ILT was breached only at Lake Creek sites. 21.9° C was breached for 45 of 120 days (38%) at site 1, 46 of 120 days (38%) at site 2, 12 of 120 days (10%) at site 6, 57 of 120 days (48%) at site 7 and 1 of 104 days (1%) at site 8 (Table 4).

Mean MWMT through the Critical Stream Temperature Period ranged from 15.46 – 24.24° C across the eight sites (Table 2). Only site 5 (upper Big Creek) remained at a mean MWMT under 16° C (Table 2). The other seven sites averaged above 16° C MWMT during the 32 day period. The mean MWMT was over 20° C for five sites, and three of those sites averaged above the ILT (Table 2). The date of highest stream temp correlated generally well but not perfectly with the identified Critical Stream Temperature Period (Table 2). Mean of the daily average temp (DAT) for the eight sites during the same period ranged from 11.33 – 17. (Table 2). Though the mean DAT is considerably lower than the mean MWMT within each site, it should be emphasized that DEQ standards are based on MWMT and not on DAT.

Daily maximum, minimum, average and MWMT temperature data for 2008 can be found in Appendix C.

Table 2: Profile of Mean DAT and MWMT during 2008 Critical Stream Temperature Period (15 July – 15 August) and Timing of 2008 Highest Recorded Temperatures

Site	Mean DAT (° C)	Mean MWMT (° C)	Highest Temp (° C)	Highest Temp Date
1	16.71	23.61	28.26	7/21
2	17.58	21.90	23.64	8/14 – 8/16
3	14.11	18.82	20.84	6/28
4	13.03	17.80	19.53	7/3, 8/15, 8/16
5	11.33	15.46	17.11	8/16
6	14.94	20.07	25.57	8/1
7	16.95	24.24	26.65	7/25
8	16.58	20.38	22.98	9/18

Table 3: Average Date of First Recorded MWMT over Cited Benchmarks ±1 SD for the 120 Day Period Beginning 7 June (2000 – 2008)

	Site 1 "upper Lake"	Site 2 "lower Lake"	Site 3 "Malheur"	Site 4 "lower Big"	Site 5 "upper Big"
>12° C	<i>no readings < 16 ° C</i>	<i>no readings < 16 ° C</i>	7 June	7 June	14 June
>16° C	7 June ± 4.7 days	7 June ± 3.1 days	16 June ± 3.4 days	19 June ± 5.7 days	4 July ± 5.6 days
>21.9° C	6 July	6 July	<i>no readings >21.9 ° C</i>	<i>no readings >21.9 ° C</i>	<i>no readings >21.9 ° C</i>

Table 4: Average Number of Days and Percent of Total Days in the Summer Period that MWMT Eclipsed Cited Temperature Benchmarks (2000-2008 ¹)

Site	# Days >12 ° C	# Days > 16 ° C	# Days > 21.9 ° C
1	120 (100%)	102 (85%)	45 (38%)
2	120 (100%)	104 (87%)	46 (38%)
3	120 (100%)	83 (69%)	0 (0%)
4	110 (92%)	76 (63%)	0 (0%)
5	96 (80%)	46 (38%)	0 (0%)
6	107 (89%)	70 (58%)	12 (10%)
7	109 (91%)	102 (85%)	57 (48%)
8 ²	104 (100%)	92 (88%)	1 (1%)

¹ Data from site 6 and 7 is from 2007 and 2008 only. Data from site 8 is from 2008 only.

² Site 8 MWMT was acquired for only 104 days in 2008.

DISCUSSION

In 2000 Burns Paiute Tribe entered into a cooperative effort with the USDA Forest Service and the Oregon Department of Fish and Wildlife to document stream temperature trends in the Upper Malheur (Namitz 2000). The primary purpose of the monitoring effort was to utilize stream temperature data as an indicator of habitat suitability for the federally threatened bull trout (Namitz 2000). Bull trout are stenothermal, requiring a narrow range of cold temperature conditions to rear and reproduce (Buchanan and Gregory 1997). In western North America, the bull trout is believed to be among the most thermally sensitive species in coldwater habitats (Buchanan and Gregory 1997; Haas 2001; Selong et al. 2001; Dunham et al. 2003), and maximum temperature has consistently been suggested as likely the most critical variable determining health and presence of bull trout (Haas 2001).

Since BPT began stream temperature monitoring in Logan Valley, water temperatures have consistently surpassed the DEQ Bull Trout Temperature Standard of 12° C MWMT for a majority of the summer period at all monitoring sites (Namitz 2000, Schwabe 2001, Schwabe 2002, Schwabe 2003, Schwabe 2004, Schwabe and Fenton 2005, Fenton 2006, Schwabe 2007). Figures 1B – 5B (Appendix B) plot a trend line of the mean daily MWMT value from 2000 - 2008 $\pm$ 1 SD against DEQ Temperature Standards and the ILT for the selected 120 day summer period. 2008 MWMT data is similarly plotted in Figures 1B – 5B (Appendix B). Figures 1B – 5B yield two observations. Those are: 1. Stream temperatures were slightly lower in 2008 but overall have remained in a relatively static range since 2000. 2. Lake Creek sites 1 and 2 (Figures 1B and 2B) warm earlier in the season, reach much higher maximum temperatures, and sustain critical temperatures for longer durations than in Big Creek sites 4 and 5.

From 2000 – 2008, Lake Creek sites 1 and 2 were already above 16° C, the temperature cited by Selong et al. (2001) with significant decreases in food consumption by bull trout in lab tests, on the very first day of the 120 day summer period beginning 7 June (Table 3). On average the bull trout ILT of 21.9° C was eclipsed by 6 July at Lake Creek sites 1 and 2 (Table 3) and remained above 21.9° C for 45 and 46 days respectively (Table 4). It is fair to assume there was zero habitat use by bull trout in Lake Creek when temperatures passed above ILT. By comparison, 16° C was not surpassed on the Upper Malheur (site 3), lower Big Creek (site

4) or upper Big Creek (site 5) until 16 June, 19 June, and 4 July respectively (Table 3). None of the latter three sites' averages ever eclipsed the ILT during the summer period (Table 4).

While ILT is an important benchmark for zero habitat utilization, the temporal variation between Big Creek and Lake Creek of when stream temperatures begin to reach critical maximums may trump mid-summer temperature extremes. Data collected from radio tagged bull trout in 2000 and 2001 suggests that, at least for fluvial bull trout populations, migration through the property occurs before the Critical Stream Temperature Period associated with annual temperature maximums (Appendix A *see also* Schwabe 2000 and Fenton and Schwabe 2001). In 2000, all radio tagged bull trout except one individual were above the Upper Malheur weir by 29 June (Map 1) and had successfully migrated upstream of the property by 6 July (Map 2). Similar movement patterns occurred in 2001 when all live individuals were above the weir by 29 June (Map 4), and all spawning participants were upstream of the property by 13 July ¹ (Map 5).

It bears noting that not all bull trout that passed above the weir were radio tagged. However, a majority of migrants from both years were above the weir by the beginning of July. In 2000 41 of the 51 bull trout (80%) passed the weir by 3 July (Schwabe 2000). 60 of 67 (90%) passed by the same date in 2001 (Fenton and Schwabe 2001). The earlier installation of the weir in 2001 (17 May versus 1 June in 2000) accounted for the higher number of bull trout passed. Seventeen bull trout had passed the weir before 1 June in 2001 (Fenton and Schwabe 2001), hinting that migration of the fluvial population begins early in the season when stream temperatures are still relatively cool. A graduate study of bull trout migrants on the North Fork Boise River in 2000 first began operation of their screw trap on 31 May (Salow 2001) at a similar upstream reach to the weir operated in Logan Valley. Most bull trout in the graduate study were caught in the first three weeks of June. Because of the surge of captures right after the screw trap was opened, the author postulated that some bull trout in that reach had already passed upstream before trapping started (Salow 2001).

Exploring ways to maintain adequate stream temperatures for a longer duration of the spring could prove beneficial to migratory success of the breeding population, especially in regards to Lake Creek. Stream temperatures in Lake Creek during the Primary Migration Period reach critical thresholds sooner than in Big Creek (Table 3) and could be creating a thermal barrier that prevents upstream movements of fluvial bull trout migrants. A thermal barrier early in the Primary Migration Period would explain why no radio tagged bull trout used the Lake Creek corridor to access upstream spawning grounds in either 2000 or 2001. In 2001 bull trout 151224 attempted migration up Lake Creek (Map 3) but had retreated by the 29 June to join Big Creek migrants (Map 4). The 2000 - 2008 mean MWMT approaches 20° C at lower Lake Creek when 151224 had attempted the Lake Creek migration (Figure 2B).

Current redd counts in the upper reaches of Lake Creek are low, and redd count data is muddled by indecipherable brook trout redds. In 2008 at least three positively identified bull trout redds were counted at Lake Creek spawning grounds upstream (Perkins 2008). It is

¹ The two fish that remained on the property after 13 July, namely 151755 and 151134, did not migrate past the 16 road through the entirety of the spawning period. Stream temperature at the upper Big Creek site never surpassed 16° C MWMT in 2001, thus adequate temperatures were thought to have been maintained for the two remaining individuals.

likely from stream temperature data and past tracking efforts that the Lake Creek breeding population is comprised solely of a small resident, non-migratory population. The current status of the entire Upper Malheur bull trout metapopulation is considered to be at a high risk of extinction (Buchanan et al. 1997). If the small Lake Creek subpopulation truly is isolated and incapable of genetic drift from thermal barriers, then the status of Lake Creek bull trout is indeed precarious.

Stream temperatures recorded on Big Creek are not up to par with DEQ standards either, but temperatures may be just adequate enough for a small migratory population to endure. Even if bull trout migration is largely completed before 15 July, the migratory population is still being subjected to stream temperatures in excess of 16° C on the average year (Figures 4B and 5B), causing untold physical stress to the fluvial population.

The 2008 CREP plantings that occurred in all the property's riparian areas are a source of hope for future stream temperature challenges. Propagation of a woody riparian element will create shade, promote increased beaver activity, and restore natural stream function. Beaver dams in particular are known to promote ground water recharge by raising water levels, which in turn cools stream temperatures.

RECOMMENDATIONS FOR FUTURE MANAGEMENT

Timing of irrigation on the property should be reevaluated. Currently the property draws from Lake Creek irrigation canals until 1 July, when the most amount of water is available in-stream. A later start to irrigation until after the Primary Migration Period could prove beneficial to the maintenance of more adequate stream temperatures. Research conducted on the property by Boyd and Zamora (2005) contradicts this assumption though. They found that irrigation from Lake Creek diversions had a moderating effect on maximum daily in-stream temperatures by controlling the influence of air temperature on water temperature (Boyd and Zamora 2005). Some evidence exists of this occurrence from BPT stream temperature monitoring. Upper Lake Creek and lower Lake Creek (site 1 and site 2) on average crossed temperature benchmarks the same day (Table 3). For example, site 1 and site 2 both crossed the 16° C benchmark on 7 June and the 21.9° C benchmark on 6 July (Table 3). Big Creek sites 4 and 5, on the other hand, had dissimilar dates of warming (Table 3). Upper Big Creek (site 5) did not surpass 16° C until 4 July on average whereas lower Big Creek (site 4) was warmed to 16° C by 19 June (Table 3). At the very least, irrigation diversions on Lake Creek may mitigate warming effects on stream flows through the property. These findings should be considered before changing management strategies.

Cooperation with the upstream landowner on Lake Creek is another potential avenue to improved water quality. An agreement to delay the timing of upstream dewatering would be of long term benefit to fluvial bull trout returning to Lake Creek by presenting a longer window of adequate stream temperature conditions.

For the 2009 field season, plans are to add two more hobos on the Lake Creek drainage in the hope of identifying the main source of warm flows onto the property. Monitoring site 9 will be stationed on McCoy Creek below the 16 Road. Monitoring site 10 will be stationed on the Lake Creek ditch also near the 16 Road, but downstream of current beaver activity at that location. The deployment of hobos earlier in the season is another management objective; the

current outlook is circa 1 May. Earlier deployment will allow for data to be gathered before temperatures spike, thus timing of stream warming can be documented and can be related to both management activities on the property as well as upstream of the property.

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APPENDIX A

BULL TROUT MOVEMENT IN THE UPPER MALHEUR, 2000

BULL TROUT MOVEMENT IN THE UPPER MALHEUR, 2001

APPENDIX B STREAM TEMPERATURE TRENDS

FIGURE 1B: LAKE CREEK BELOW McCOY CREEK (site 1)

*Retrieval of hobos was unsuccessful in 2007 for site 1.

FIGURE 2B: LAKE CREEK BELOW CROOKED CREEK (site 2)

*Retrieval of hobos was unsuccessful in 2001 and 2007 for site 2.

FIGURE 3B: MALHEUR BELOW BIG AND LAKE CREEKS (site 3)

FIGURE 4B: BIG CREEK ONE MILE BELOW 16 ROAD (site 4)

*Retrieval of hobos was unsuccessful in 2003 and 2004 for site 4.

FIGURE 5B: BIG CREEK BELOW 16 ROAD (site 5)

*Retrieval of hobos was unsuccessful in 2002 and 2004 for site 5.

FIGURE 6B: LAKE CREEK BELOW 16 ROAD (site 6)

FIGURE 7B: McCOY CREEK ABOVE LAKE CREEK (site 7)

FIGURE 8B: LAKE CREEK AT BRIDGE (site 8)

APPENDIX C

SITE 1: LAKE CREEK BELOW McCOY CREEK “upper Lake”

DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT
6/17/08	19.2	6.67	12.47		8/1/08	24.54	11	17.20	24.58	9/15/08	16.63	6.04	11.16	15.90
6/18/08	18.39	6.2	11.81		8/2/08	23.51	11.93	17.17	24.38	9/16/08	16.15	6.2	11.02	15.99
6/19/08	17.58	5.88	11.52		8/3/08	24.72	10.54	16.94	24.31	9/17/08	15.36	6.36	10.79	15.92
6/20/08	19.36	6.82	12.72		8/4/08	25.42	10.07	17.15	24.36	9/18/08	15.36	6.98	11.23	15.95
6/21/08	14.1	7.91	11.04		8/5/08	24.54	11	17.52	24.80	9/19/08	12.71	7.44	10.48	15.50
6/22/08	18.07	7.13	12.18		8/6/08	21.66	12.55	16.94	24.03	9/20/08	11.16	8.68	10.27	14.81
6/23/08	18.55	6.67	12.41	17.89	8/7/08	23.51	13.79	18.11	23.99	9/21/08	11.46	7.29	8.98	14.12
6/24/08	19.04	7.75	13.05	17.87	8/8/08	24.37	13.17	18.27	23.96	9/22/08	11.46	6.04	8.35	13.38
6/25/08	18.71	7.44	13.02	17.92	8/9/08	21.83	10.69	16.26	23.72	9/23/08	10.85	1.81	6.32	12.62
6/26/08	18.88	8.98	13.59	18.10	8/10/08	22.16	10.23	15.89	23.36	9/24/08	12.24	4.01	7.93	12.18
6/27/08	20.83	8.52	14.37	18.31	8/11/08	23.33	9.29	15.66	23.06	9/25/08	13.33	5.73	9.13	11.89
6/28/08	21.99	9.76	15.49	19.44	8/12/08	20.18	9.76	15.13	22.43	9/26/08	11.93	3.23	7.61	11.78
6/29/08	21.16	10.23	15.32	19.88	8/13/08	21.99	11	16.11	22.48	9/27/08	12.71	4.01	8.07	12.00
6/30/08	19.69	11.46	15.28	20.04	8/14/08	22.83	11	16.62	22.38	9/28/08	12.55	3.23	7.76	12.15
7/1/08	17.42	11.16	13.73	19.81	8/15/08	23.33	11.46	17.07	22.24	9/29/08	13.17	3.86	8.39	12.40
7/2/08	21.49	9.76	15.46	20.21	8/16/08	23.33	11.77	17.21	22.45	9/30/08	14.88	6.36	10.48	12.97
7/3/08	22.16	11.31	16.52	20.68	8/17/08	22.66	11.77	16.92	22.52	10/1/08	14.88	6.98	10.93	13.35
7/4/08	20.18	12.71	16.07	20.58	8/18/08	19.2	11.62	14.78	21.93	10/2/08	13.17	8.37	10.47	13.33
7/5/08	21.49	11.93	16.38	20.51	8/19/08	16.78	11	13.93	21.45	10/3/08	10.69	7.59	9.23	13.15
7/6/08	22.66	12.24	16.87	20.73	8/20/08	17.27	12.08	14.07	20.77	10/4/08	9.76	6.98	8.79	12.73
7/7/08	21.49	9.92	15.44	20.98	8/21/08	18.07	11	14.04	20.09	10/5/08	8.83	4.95	6.88	12.20
7/8/08	22.83	10.07	16.06	21.76	8/22/08	18.07	6.98	12.29	19.34	10/6/08	11.16	5.73	8.09	11.91
7/9/08	22.99	10.38	16.47	21.97	8/23/08	19.53	7.29	13.14	18.80	10/7/08	11.77	5.26	7.99	11.47
7/10/08	22.33	11.16	16.25	22.00	8/24/08	20.34	9.29	14.74	18.47	10/8/08	8.83	2.12	5.28	10.60
7/11/08	21.66	9.45	15.16	22.21	8/25/08	15.99	10.54	13.45	18.01	10/9/08	3.54	0.04	1.88	9.23
7/12/08	21.99	8.83	15.15	22.28	8/26/08	17.27	6.82	11.76	18.08	10/10/08	3.07	0.69	1.73	8.14
7/13/08	22.66	9.61	15.79	22.28	8/27/08	17.91	7.13	12.05	18.17	10/11/08	3.54	-0.11	1.16	7.25
7/14/08	21.66	10.69	16.26	22.30	8/28/08	19.04	7.75	13.14	18.31					
7/15/08	22.49	12.86	17.49	22.25	8/29/08	20.18	8.68	14.21	18.61					
7/16/08	21.83	12.71	16.98	22.09	8/30/08	19.53	9.92	14.40	18.61					
7/17/08	21.83	11.31	16.15	22.02	8/31/08	15.04	7.59	10.87	17.85					
7/18/08	21.66	10.38	15.55	22.02	9/1/08	15.2	5.73	9.88	17.74					
7/19/08	22.16	8.83	15.17	22.04	9/2/08	14.1	4.48	9.22	17.29					
7/20/08	22.99	10.38	16.32	22.09	9/3/08	15.67	4.48	9.80	16.97					
7/21/08	28.26	12.39	16.87	23.03	9/4/08	15.83	5.42	10.42	16.51					
7/22/08	22.16	14.26	17.38	22.98	9/5/08	16.15	5.73	10.85	15.93					
7/23/08	25.24	11.31	17.23	23.47	9/6/08	17.74	7.13	12.17	15.68					
7/24/08	26.11	8.83	16.40	24.08	9/7/08	17.58	7.44	12.24	16.04					
7/25/08	26.29	9.92	17.06	24.74	9/8/08	16.78	6.2	11.45	16.26					
7/26/08	24.89	11.31	17.32	25.13	9/9/08	15.52	6.98	11.21	16.47					
7/27/08	25.24	10.54	16.88	25.46	9/10/08	15.83	6.82	11.02	16.49					
7/28/08	25.07	10.85	17.12	25.00	9/11/08	15.2	4.64	9.81	16.40					
7/29/08	21.49	11.16	15.85	24.90	9/12/08	15.83	5.26	10.32	16.35					
7/30/08	26.99	10.23	16.70	25.15	9/13/08	15.99	5.73	10.66	16.10					
7/31/08	23.85	9.29	16.20	24.83	9/14/08	16.31	5.57	10.79	15.92					

All temperatures are listed in degrees centigrade.

SITE 2: LAKE CREEK BELOW CROOKED CREEK "lower Lake"

DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT
6/17/08	19.81	7.86	13.57		8/1/08	21.95	13.28	17.66	21.71	9/15/08	16.63	6.04	11.16	16.63
6/18/08	18.83	7.39	12.87		8/2/08	21.78	14.37	17.93	21.59	9/16/08	16.15	6.2	11.02	16.39
6/19/08	18.34	7.08	12.43		8/3/08	22.28	12.82	17.48	21.66	9/17/08	15.36	6.36	10.79	16.05
6/20/08	19.97	7.86	13.68		8/4/08	22.45	12.66	17.70	21.69	9/18/08	15.36	6.98	11.23	15.88
6/21/08	14.84	8.94	12.20		8/5/08	23.12	13.59	18.34	22.09	9/19/08	12.71	7.44	10.48	15.24
6/22/08	19.16	8.17	13.18		8/6/08	20.62	14.84	17.63	21.93	9/20/08	11.16	8.68	10.27	14.56
6/23/08	19.48	7.86	13.36	18.63	8/7/08	22.62	15.47	18.88	22.12	9/21/08	11.46	7.29	8.98	14.12
6/24/08	19.97	8.94	14.18	18.66	8/8/08	22.96	15.16	18.86	22.26	9/22/08	11.46	6.04	8.35	13.38
6/25/08	19.48	8.48	13.97	18.75	8/9/08	20.13	12.97	16.90	22.03	9/23/08	10.85	1.81	6.32	12.62
6/26/08	19.32	10.18	14.60	18.89	8/10/08	20.79	12.35	16.44	21.81	9/24/08	12.24	4.01	7.93	12.18
6/27/08	21.62	9.72	15.47	19.12	8/11/08	21.45	11.42	16.39	21.67	9/25/08	13.33	5.73	9.13	11.89
6/28/08	22.79	11.11	16.76	20.26	8/12/08	20.46	11.88	16.51	21.29	9/26/08	11.93	3.23	7.61	11.78
6/29/08	21.28	11.42	16.57	20.56	8/13/08	22.45	12.51	17.31	21.55	9/27/08	12.71	4.01	8.07	12.00
6/30/08	20.29	12.82	16.49	20.68	8/14/08	23.64	12.66	17.91	21.70	9/28/08	12.55	3.23	7.76	12.15
7/1/08	17.54	12.04	14.64	20.33	8/15/08	23.64	13.13	18.30	21.79	9/29/08	13.17	3.86	8.39	12.40
7/2/08	22.28	10.81	16.46	20.73	8/16/08	23.64	13.59	18.63	22.30	9/30/08	14.88	6.36	10.48	12.97
7/3/08	22.96	12.66	17.77	21.25	8/17/08	22.96	13.44	18.23	22.61	10/1/08	14.88	6.98	10.93	13.35
7/4/08	20.79	14.06	17.27	21.13	8/18/08	20.46	13.13	16.03	22.46	10/2/08	13.17	8.37	10.47	13.33
7/5/08	22.12	13.28	17.62	21.04	8/19/08	18.02	12.04	15.01	22.12	10/3/08	10.69	7.59	9.23	13.15
7/6/08	22.79	13.9	18.19	21.25	8/20/08	17.38	13.13	14.84	21.39	10/4/08	9.76	6.98	8.79	12.73
7/7/08	21.28	11.42	16.66	21.39	8/21/08	18.51	12.35	14.86	20.66	10/5/08	8.83	4.95	6.88	12.20
7/8/08	22.79	11.57	17.27	22.14	8/22/08	17.54	8.32	13.22	19.79	10/6/08	11.16	5.73	8.09	11.91
7/9/08	22.79	12.19	17.73	22.22	8/23/08	19.16	8.63	14.02	19.15	10/7/08	11.77	5.26	7.99	11.47
7/10/08	22.12	12.82	17.44	22.10	8/24/08	20.29	10.81	15.73	18.77	10/8/08	8.83	2.12	5.28	10.60
7/11/08	21.45	11.11	16.31	22.19	8/25/08	17.38	12.04	14.67	18.33	10/9/08	3.54	0.04	1.88	9.23
7/12/08	21.78	10.81	16.40	22.14	8/26/08	17.06	8.02	12.56	18.19	10/10/08	3.07	0.69	1.73	8.14
7/13/08	22.45	11.42	17.05	22.09	8/27/08	17.7	8.48	12.94	18.23	10/11/08	3.54	-0.11	1.16	7.25
7/14/08	21.95	12.35	17.47	22.19	8/28/08	19.16	9.25	14.18	18.33					
7/15/08	22.96	14.52	18.78	22.21	8/29/08	20.29	10.18	15.29	18.72					
7/16/08	22.28	14.37	18.25	22.14	8/30/08	19.97	11.42	15.44	18.84					
7/17/08	21.45	12.97	17.29	22.05	8/31/08	15.31	8.48	11.61	18.12					
7/18/08	21.45	11.88	16.71	22.05	9/1/08	14.99	6.46	10.45	17.78					
7/19/08	21.78	10.81	16.44	22.05	9/2/08	13.9	5.68	10.03	17.33					
7/20/08	22.62	12.19	17.56	22.07	9/3/08	15.47	5.68	10.54	17.01					
7/21/08	20.29	14.21	17.07	21.83	9/4/08	15.79	6.62	11.23	16.53					
7/22/08	21.28	15.63	17.98	21.59	9/5/08	16.11	6.93	11.66	15.93					
7/23/08	22.79	13.59	17.95	21.67	9/6/08	18.02	8.32	13.04	15.66					
7/24/08	22.45	11.57	17.23	21.81	9/7/08	18.02	8.63	13.27	16.04					
7/25/08	22.96	12.82	18.02	22.02	9/8/08	17.06	7.71	12.40	16.34					
7/26/08	22.62	13.9	18.30	22.14	9/9/08	15.94	8.17	12.07	16.63					
7/27/08	21.78	13.28	17.64	22.02	9/10/08	16.58	7.86	11.97	16.79					
7/28/08	22.28	13.59	18.04	22.31	9/11/08	15.47	5.84	10.74	16.74					
7/29/08	20.29	13.74	17.06	22.17	9/12/08	15.94	6.31	11.12	16.72					
7/30/08	21.78	12.51	17.17	22.02	9/13/08	16.26	6.77	11.47	16.47					
7/31/08	21.28	11.88	16.80	21.86	9/14/08	16.42	6.77	11.62	16.24					

All temperatures are listed in degrees centigrade.

SITE 3: MALHEUR RIVER BELOW BIG AND LAKE CREEKS "Malheur"

DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT
6/17/08	17.29	7.33	12.02		8/1/08	18.74	9.49	14.08	18.44	9/15/08	15.23	5.94	10.34	14.54
6/18/08	16.5	6.87	11.51		8/2/08	18.74	10.27	14.29	18.40	9/16/08	14.76	5.94	10.27	14.63
6/19/08	16.18	6.72	11.22		8/3/08	19.07	9.19	13.92	18.44	9/17/08	14.29	5.94	9.97	14.58
6/20/08	17.61	7.33	12.39		8/4/08	19.23	8.88	13.92	18.51	9/18/08	14.6	6.56	10.47	14.69
6/21/08	13.67	8.42	11.38		8/5/08	20.03	9.65	14.63	18.97	9/19/08	11.51	6.87	9.57	14.27
6/22/08	17.13	7.8	12.08		8/6/08	17.46	10.73	13.90	18.84	9/20/08	10.12	7.96	9.32	13.63
6/23/08	17.46	7.49	12.27	16.55	8/7/08	18.91	11.35	14.88	18.88	9/21/08	11.2	6.72	8.53	13.10
6/24/08	18.09	8.26	12.95	16.66	8/8/08	18.58	11.2	14.75	18.86	9/22/08	11.04	5.32	7.81	12.50
6/25/08	17.46	7.96	12.79	16.80	8/9/08	17.29	9.19	13.44	18.65	9/23/08	10.58	2.34	6.40	11.91
6/26/08	17.93	9.34	13.48	17.05	8/10/08	17.93	8.88	13.25	18.49	9/24/08	11.82	4.23	7.72	11.55
6/27/08	19.87	8.88	14.14	17.37	8/11/08	18.74	8.11	13.23	18.42	9/25/08	12.75	5.63	8.76	11.29
6/28/08	20.84	10.12	15.25	18.40	8/12/08	18.58	8.88	13.63	18.21	9/26/08	11.51	3.44	7.48	11.29
6/29/08	19.71	10.43	15.18	18.77	8/13/08	19.55	9.81	14.46	18.51	9/27/08	12.13	4.23	7.90	11.58
6/30/08	18.74	11.66	15.06	18.95	8/14/08	20.19	9.81	14.84	18.69	9/28/08	12.13	3.6	7.68	11.71
7/1/08	16.5	10.89	13.49	18.72	8/15/08	20.52	10.12	15.19	18.97	9/29/08	12.59	4.07	8.16	11.93
7/2/08	20.19	9.81	14.79	19.11	8/16/08	20.52	10.43	15.30	19.43	9/30/08	14.13	6.1	9.85	12.44
7/3/08	20.68	11.04	15.77	19.50	8/17/08	20.03	10.27	15.06	19.73	10/1/08	13.98	6.56	10.21	12.75
7/4/08	18.42	12.13	15.08	19.30	8/18/08	17.13	10.27	13.53	19.50	10/2/08	11.82	7.64	9.54	12.61
7/5/08	20.19	11.35	15.31	19.20	8/19/08	15.71	10.27	12.90	19.09	10/3/08	9.96	6.87	8.49	12.39
7/6/08	20.52	11.51	15.66	19.32	8/20/08	15.39	10.58	12.54	18.50	10/4/08	9.81	6.87	8.37	12.06
7/7/08	19.39	9.49	14.32	19.41	8/21/08	17.13	9.96	12.87	18.06	10/5/08	8.42	4.86	6.63	11.53
7/8/08	20.36	9.49	14.76	19.96	8/22/08	15.71	6.72	11.22	17.37	10/6/08	10.89	5.79	7.93	11.29
7/9/08	20.52	9.81	15.00	20.01	8/23/08	17.29	6.72	11.82	16.91	10/7/08	10.89	5.32	7.56	10.82
7/10/08	19.87	10.12	14.81	19.90	8/24/08	18.26	8.42	13.23	16.66	10/8/08	8.73	2.82	5.58	10.07
7/11/08	18.91	8.88	13.74	19.97	8/25/08	14.92	9.49	12.28	16.34	10/9/08	4.07	0.76	2.64	8.97
7/12/08	19.39	8.26	13.67	19.85	8/26/08	15.39	6.41	10.69	16.30	10/10/08	3.76	1.39	2.35	8.08
7/13/08	20.03	8.73	14.23	19.78	8/27/08	16.18	6.56	11.05	16.41	10/11/08	4.7	-0.04	1.77	7.35
7/14/08	18.91	9.65	14.45	19.71	8/28/08	17.13	7.18	11.91	16.41					
7/15/08	19.87	11.35	15.52	19.64	8/29/08	17.93	7.96	12.82	16.73					
7/16/08	19.23	11.04	15.08	19.46	8/30/08	17.61	8.88	12.94	16.77					
7/17/08	18.74	9.96	14.29	19.30	8/31/08	13.52	6.87	9.98	16.10					
7/18/08	19.07	9.34	14.04	19.32	9/1/08	13.67	5.48	9.15	15.92					
7/19/08	19.23	8.26	13.67	19.30	9/2/08	12.28	4.54	8.45	15.47					
7/20/08	19.87	9.34	14.57	19.27	9/3/08	14.13	4.54	9.11	15.18					
7/21/08	17.13	11.04	13.87	19.02	9/4/08	14.44	5.32	9.72	14.80					
7/22/08	17.61	11.51	14.01	18.70	9/5/08	14.6	5.63	9.99	14.32					
7/23/08	19.39	9.81	14.21	18.72	9/6/08	16.18	6.72	11.15	14.12					
7/24/08	19.07	8.11	13.43	18.77	9/7/08	16.02	7.03	11.27	14.47					
7/25/08	19.71	8.73	14.04	18.86	9/8/08	15.07	5.94	10.47	14.67					
7/26/08	19.07	9.81	14.36	18.84	9/9/08	14.13	6.56	10.31	14.94					
7/27/08	18.74	9.34	13.95	18.67	9/10/08	14.6	6.25	10.14	15.01					
7/28/08	18.74	9.49	14.04	18.90	9/11/08	13.83	4.7	9.18	14.92					
7/29/08	16.82	9.65	13.23	18.79	9/12/08	14.44	5.17	9.60	14.90					
7/30/08	18.42	8.88	13.54	18.65	9/13/08	14.6	5.48	9.91	14.67					
7/31/08	18.58	8.26	13.27	18.58	9/14/08	14.92	5.48	10.03	14.51					

All temperatures are listed in degrees centigrade.

SITE 4: BIG CREEK ONE MILE BELOW 16 ROAD “lower Big”

DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT
6/17/08	15.53	6.53	10.61		8/1/08	17.75	8.54	13.05	17.48	9/15/08	14.58	5.44	9.72	13.91
6/18/08	14.89	6.22	10.20		8/2/08	17.43	9.16	13.19	17.39	9/16/08	14.27	5.59	9.68	14.03
6/19/08	14.73	6.06	10.04		8/3/08	18.07	8.23	12.87	17.41	9/17/08	13.65	5.59	9.44	13.98
6/20/08	16	6.69	11.14		8/4/08	18.07	7.93	12.82	17.45	9/18/08	13.96	6.22	9.90	14.09
6/21/08	12.72	7.77	10.32		8/5/08	18.88	8.54	13.53	17.89	9/19/08	11.02	6.53	9.02	13.67
6/22/08	15.84	7.31	11.05		8/6/08	16.16	9.77	12.81	17.71	9/20/08	9.62	7.62	8.79	13.05
6/23/08	16.32	6.84	11.23	15.15	8/7/08	17.59	10.24	13.65	17.71	9/21/08	10.56	6.38	8.08	12.52
6/24/08	16.64	7.31	11.66	15.31	8/8/08	17.43	10.09	13.53	17.66	9/22/08	10.71	4.97	7.31	11.97
6/25/08	16.16	7.16	11.52	15.49	8/9/08	16.32	8.23	12.46	17.50	9/23/08	10.4	2.31	6.12	11.42
6/26/08	16.79	8.23	12.24	15.78	8/10/08	16.96	7.93	12.27	17.34	9/24/08	11.48	4.04	7.43	11.11
6/27/08	18.56	7.93	12.74	16.15	8/11/08	17.75	7.31	12.25	17.30	9/25/08	12.41	5.28	8.34	10.89
6/28/08	19.37	9	13.70	17.10	8/12/08	17.43	7.77	12.56	17.09	9/26/08	11.18	3.26	7.14	10.91
6/29/08	18.23	9.16	13.71	17.44	8/13/08	18.56	8.84	13.43	17.43	9/27/08	11.95	4.04	7.62	11.24
6/30/08	17.43	10.4	13.58	17.60	8/14/08	19.21	8.84	13.78	17.67	9/28/08	11.79	3.42	7.40	11.42
7/1/08	15.84	9.93	12.38	17.48	8/15/08	19.53	9.16	14.09	17.97	9/29/08	12.26	3.88	7.85	11.64
7/2/08	19.04	8.84	13.58	17.89	8/16/08	19.53	9.31	14.19	18.42	9/30/08	13.65	5.75	9.45	12.10
7/3/08	19.53	9.77	14.32	18.29	8/17/08	19.04	9.31	14.01	18.72	10/1/08	13.34	6.22	9.71	12.37
7/4/08	17.11	10.71	13.62	18.08	8/18/08	16	9.31	12.62	18.47	10/2/08	11.33	7.31	9.03	12.21
7/5/08	18.72	9.93	13.76	17.99	8/19/08	14.89	9.31	11.95	18.11	10/3/08	9.62	6.38	8.01	11.99
7/6/08	19.21	10.09	14.15	18.13	8/20/08	14.58	9.77	11.69	17.54	10/4/08	8.84	6.38	7.79	11.55
7/7/08	18.23	8.23	13.01	18.24	8/21/08	16.32	9	12.09	17.13	10/5/08	8.23	4.51	6.33	11.04
7/8/08	19.37	8.39	13.47	18.74	8/22/08	14.89	5.91	10.42	16.46	10/6/08	10.56	5.59	7.62	10.80
7/9/08	19.37	8.54	13.64	18.79	8/23/08	16.48	5.91	11.02	16.03	10/7/08	10.71	5.13	7.29	10.38
7/10/08	18.88	9	13.56	18.70	8/24/08	17.27	7.62	12.33	15.78	10/8/08	8.54	2.62	5.33	9.69
7/11/08	18.07	7.93	12.63	18.84	8/25/08	13.96	8.54	11.34	15.48	10/9/08	4.19	0.72	2.69	8.67
7/12/08	18.39	7.16	12.48	18.79	8/26/08	14.58	5.91	9.97	15.44	10/10/08	4.04	1.67	2.55	7.87
7/13/08	19.04	7.77	13.06	18.76	8/27/08	15.53	5.91	10.34	15.58	10/11/08	4.97	-0.08	1.94	7.32
7/14/08	18.07	8.54	13.29	18.74	8/28/08	16.16	6.38	11.08	15.55					
7/15/08	18.88	10.09	14.21	18.67	8/29/08	17.11	7.16	11.92	15.87					
7/16/08	18.23	9.93	13.83	18.51	8/30/08	16.64	8.08	12.01	15.89					
7/17/08	17.91	9	13.12	18.37	8/31/08	13.03	6.22	9.35	15.29					
7/18/08	18.07	8.39	12.94	18.37	9/1/08	13.34	4.97	8.63	15.20					
7/19/08	18.23	7.31	12.55	18.35	9/2/08	11.64	4.04	7.85	14.78					
7/20/08	18.88	8.39	13.42	18.32	9/3/08	13.49	4.04	8.59	14.49					
7/21/08	16.16	9.93	12.78	18.05	9/4/08	13.96	4.82	9.13	14.17					
7/22/08	16.79	10.71	13.04	17.75	9/5/08	14.11	5.13	9.39	13.74					
7/23/08	18.39	8.84	13.18	17.78	9/6/08	15.37	6.22	10.44	13.56					
7/24/08	18.07	7.16	12.40	17.80	9/7/08	15.21	6.38	10.51	13.87					
7/25/08	18.72	7.77	13.01	17.89	9/8/08	14.27	5.44	9.73	14.01					
7/26/08	18.07	8.84	13.33	17.87	9/9/08	13.49	5.91	9.66	14.27					
7/27/08	17.91	8.39	12.98	17.73	9/10/08	13.96	5.75	9.48	14.34					
7/28/08	17.75	8.39	12.96	17.96	9/11/08	13.18	4.35	8.58	14.23					
7/29/08	15.84	8.69	12.19	17.82	9/12/08	13.96	4.66	9.03	14.21					
7/30/08	17.43	8.08	12.53	17.68	9/13/08	13.96	5.13	9.30	14.00					
7/31/08	17.59	7.31	12.21	17.62	9/14/08	14.27	5.13	9.43	13.87					

All temperatures are listed in degrees centigrade.

SITE 5: BIG CREEK BELOW 16 ROAD "upper Big"

DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT
6/17/08	13.65	6.06	9.39		8/1/08	15.37	7.77	11.35	15.17	9/15/08	13.03	5.28	8.73	12.37
6/18/08	13.03	5.75	8.97		8/2/08	15.85	8.39	11.47	15.20	9/16/08	12.88	5.28	8.77	12.52
6/19/08	13.03	5.59	9.03		8/3/08	15.69	7.46	11.09	15.20	9/17/08	12.26	5.28	8.62	12.52
6/20/08	14.11	6.22	9.97		8/4/08	15.69	7.15	11.13	15.26	9/18/08	12.57	5.91	8.95	12.63
6/21/08	11.18	7.31	9.21		8/5/08	16.32	7.93	11.77	15.64	9/19/08	10.09	6.22	8.40	12.28
6/22/08	13.49	6.68	9.71		8/6/08	13.8	8.85	11.14	15.44	9/20/08	8.85	6.99	8.14	11.77
6/23/08	14.11	6.37	9.95	13.23	8/7/08	15.06	9.31	11.84	15.40	9/21/08	9.46	5.91	7.26	11.31
6/24/08	14.42	6.68	10.19	13.34	8/8/08	15.22	9.16	11.81	15.38	9/22/08	9.31	4.82	6.51	10.77
6/25/08	14.42	6.68	10.39	13.54	8/9/08	14.58	7.77	10.97	15.19	9/23/08	9.31	2.46	5.63	10.26
6/26/08	14.89	7.62	10.88	13.80	8/10/08	14.89	7.15	10.64	15.08	9/24/08	10.4	4.03	6.86	10.00
6/27/08	16.17	7.46	11.28	14.10	8/11/08	15.37	6.84	10.63	15.03	9/25/08	11.18	5.13	7.56	9.80
6/28/08	16.79	8.39	12.09	14.90	8/12/08	15.22	7.31	10.95	14.88	9/26/08	9.93	3.41	6.50	9.78
6/29/08	16.32	8.54	12.20	15.30	8/13/08	16.17	8.23	11.67	15.22	9/27/08	10.71	4.19	7.01	10.04
6/30/08	15.37	9.46	12.08	15.48	8/14/08	16.64	8.23	11.96	15.44	9/28/08	10.71	3.56	6.84	10.22
7/1/08	13.96	9.16	11.11	15.42	8/15/08	16.79	8.39	12.16	15.67	9/29/08	11.18	4.03	7.28	10.49
7/2/08	16.48	8.23	12.04	15.71	8/16/08	17.11	8.54	12.29	16.03	9/30/08	12.26	5.59	8.58	10.91
7/3/08	16.79	9	12.62	15.98	8/17/08	16.79	8.54	12.17	16.30	10/1/08	12.26	6.06	8.84	11.18
7/4/08	15.37	9.77	12.00	15.87	8/18/08	14.42	8.39	11.01	16.16	10/2/08	10.09	6.84	8.22	11.02
7/5/08	16.01	9.16	12.04	15.76	8/19/08	13.03	8.39	10.52	15.85	10/3/08	9	6.06	7.47	10.89
7/6/08	16.64	9.16	12.28	15.80	8/20/08	13.03	8.85	10.41	15.40	10/4/08	7.93	5.59	7.09	10.49
7/7/08	16.01	7.62	11.43	15.89	8/21/08	14.11	8.54	10.62	15.04	10/5/08	7.62	4.66	6.03	10.05
7/8/08	16.79	7.62	11.74	16.30	8/22/08	13.34	5.44	9.10	14.55	10/6/08	9.62	5.44	7.00	9.83
7/9/08	16.79	7.77	11.87	16.34	8/23/08	14.58	5.59	9.70	14.19	10/7/08	9.46	5.13	6.75	9.43
7/10/08	16.64	8.23	11.90	16.32	8/24/08	15.37	7.15	10.84	13.98	10/8/08	7.46	2.93	4.81	8.74
7/11/08	15.53	7.15	10.85	16.34	8/25/08	11.95	7.77	9.82	13.63	10/9/08	4.34	1.19	2.85	7.92
7/12/08	16.01	6.53	10.83	16.34	8/26/08	12.72	5.44	8.69	13.59	10/10/08	3.56	1.99	2.60	7.14
7/13/08	16.48	7.15	11.35	16.32	8/27/08	13.8	5.44	9.11	13.70	10/11/08	4.34	0.55	1.99	6.63
7/14/08	15.69	7.93	11.69	16.28	8/28/08	14.11	5.91	9.57	13.70					
7/15/08	16.64	9.16	12.37	16.25	8/29/08	14.89	6.68	10.37	13.92					
7/16/08	16.17	9	12.07	16.17	8/30/08	14.42	7.31	10.38	13.89					
7/17/08	15.06	8.08	11.41	15.94	8/31/08	11.64	5.28	7.99	13.36					
7/18/08	15.85	7.77	11.27	15.99	9/1/08	11.64	4.82	7.53	13.32					
7/19/08	15.85	6.68	10.89	15.96	9/2/08	10.56	3.88	7.02	13.01					
7/20/08	16.48	7.62	11.68	15.96	9/3/08	12.1	4.03	7.62	12.77					
7/21/08	13.65	9	11.11	15.67	9/4/08	12.26	4.66	8.04	12.50					
7/22/08	14.27	9.62	11.39	15.33	9/5/08	12.26	4.82	8.22	12.13					
7/23/08	16.01	8.23	11.50	15.31	9/6/08	13.34	5.75	9.15	11.97					
7/24/08	15.53	6.53	10.68	15.38	9/7/08	13.34	5.91	9.17	12.21					
7/25/08	16.32	7.15	11.34	15.44	9/8/08	12.57	4.97	8.55	12.35					
7/26/08	15.69	8.08	11.53	15.42	9/9/08	11.79	5.59	8.57	12.52					
7/27/08	15.69	7.62	11.34	15.31	9/10/08	12.26	5.59	8.33	12.55					
7/28/08	15.22	7.62	11.16	15.53	9/11/08	11.79	4.03	7.55	12.48					
7/29/08	13.65	7.93	10.63	15.44	9/12/08	12.57	4.5	8.13	12.52					
7/30/08	15.22	7.31	10.79	15.33	9/13/08	12.41	4.97	8.31	12.39					
7/31/08	15.37	6.68	10.69	15.31	9/14/08	12.72	4.97	8.46	12.30					

All temperatures are listed in degrees centigrade.

SITE 6: LAKE CREEK BELOW 16 ROAD

DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT
6/17/08	14.56	5.57	9.60		8/1/08	25.57	10.84	17.24	23.12	9/15/08	12.85	11.3	12.34	13.03
6/18/08	13.93	5.26	9.13		8/2/08	24.35	11.61	17.26	23.26	9/16/08	13.01	11.3	12.35	12.96
6/19/08	13.32	5.1	9.08		8/3/08	20.16	10.37	15.80	22.84	9/17/08	13.01	10.22	11.88	12.92
6/20/08	14.72	5.88	10.11		8/4/08	16.29	10.68	14.04	21.88	9/18/08	13.01	9.44	11.34	12.94
6/21/08	10.84	6.81	9.00		8/5/08	15.98	11.46	14.38	21.26	9/19/08	12.54	10.06	11.24	12.90
6/22/08	13.93	6.34	9.80		8/6/08	15.98	12.69	14.59	20.26	9/20/08	11.92	11.46	11.76	12.76
6/23/08	14.56	6.03	10.09	13.69	8/7/08	16.46	13.93	15.51	19.26	9/21/08	11.61	10.37	10.97	12.56
6/24/08	15.03	6.81	10.57	13.76	8/8/08	16.77	13.62	15.35	18.00	9/22/08	11.46	9.59	10.79	12.37
6/25/08	15.34	6.5	10.79	13.96	8/9/08	15.34	11.46	13.89	16.71	9/23/08	10.68	7.58	8.54	12.03
6/26/08	15.19	7.89	11.30	14.23	8/10/08	15.66	10.68	13.73	16.07	9/24/08	11.15	8.36	9.51	11.77
6/27/08	16.77	7.58	11.89	14.52	8/11/08	15.19	9.91	13.14	15.91	9/25/08	11.15	9.13	10.17	11.50
6/28/08	17.41	8.82	12.88	15.46	8/12/08	15.34	10.53	13.51	15.82	9/26/08	10.99	9.91	10.48	11.28
6/29/08	16.77	9.28	13.02	15.87	8/13/08	16.46	11.77	14.47	15.89	9/27/08	11.46	10.37	10.89	11.21
6/30/08	16.14	10.37	13.08	16.09	8/14/08	16.62	11.77	14.59	15.91	9/28/08	12.07	10.22	11.09	11.28
7/1/08	14.87	10.06	12.07	16.07	8/15/08	16.93	12.07	14.94	15.93	9/29/08	12.07	8.51	9.67	11.37
7/2/08	17.57	9.13	13.24	16.39	8/16/08	17.26	12.23	15.18	16.21	9/30/08	12.54	9.59	10.86	11.63
7/3/08	17.73	10.37	14.12	16.75	8/17/08	17.09	12.23	15.14	16.41	10/1/08	12.85	10.68	11.66	11.88
7/4/08	16.93	11.3	13.81	16.77	8/18/08	15.82	12.38	14.28	16.50	10/2/08	12.23	11.46	11.80	12.03
7/5/08	17.57	10.53	13.92	16.80	8/19/08	14.72	11.61	13.34	16.41	10/3/08	11.77	11.15	11.41	12.14
7/6/08	18.38	10.84	14.23	17.03	8/20/08	15.03	12.69	13.83	16.21	10/4/08	11.3	10.84	11.06	12.12
7/7/08	17.73	9.13	13.29	17.25	8/21/08	15.51	11.77	13.87	16.05	10/5/08	10.99	10.22	10.41	11.96
7/8/08	18.7	9.13	13.76	17.80	8/22/08	13.78	8.36	11.63	15.60	10/6/08	10.99	10.37	10.66	11.81
7/9/08	19.03	9.44	14.10	18.01	8/23/08	13.93	8.67	11.91	15.13	10/7/08	10.99	10.37	10.68	11.59
7/10/08	18.38	10.06	13.99	18.10	8/24/08	14.87	10.53	13.22	14.81	10/8/08	10.84	9.75	10.11	11.30
7/11/08	17.09	8.67	12.82	18.13	8/25/08	14.4	11.77	13.49	14.61	10/9/08	10.22	9.28	9.61	11.01
7/12/08	17.57	8.05	12.78	18.13	8/26/08	13.62	8.2	11.35	14.45	10/10/08	9.44	9.13	9.28	10.68
7/13/08	18.38	8.82	13.52	18.13	8/27/08	13.62	8.67	11.60	14.25	10/11/08	9.28	8.97	9.17	10.39
7/14/08	18.06	9.75	14.14	18.17	8/28/08	13.93	9.13	12.18	14.02					
7/15/08	19.03	11.61	15.19	18.22	8/29/08	14.56	10.22	12.95	14.13					
7/16/08	18.7	11.3	14.82	18.17	8/30/08	15.03	11.46	13.78	14.29					
7/17/08	20.98	10.22	14.94	18.54	8/31/08	14.72	9.59	12.12	14.27					
7/18/08	21.64	9.59	15.02	19.19	9/1/08	12.54	7.74	10.33	14.00					
7/19/08	22.31	8.51	14.84	19.87	9/2/08	12.07	7.27	9.88	13.78					
7/20/08	23.15	10.06	16.05	20.55	9/3/08	12.23	7.12	9.93	13.58					
7/21/08	20.16	11.77	15.59	20.85	9/4/08	12.54	8.2	10.80	13.38					
7/22/08	20.98	13.32	16.19	21.13	9/5/08	12.69	8.97	11.22	13.12					
7/23/08	23.49	10.84	16.24	21.82	9/6/08	17.26	9.59	13.00	13.44					
7/24/08	23.49	8.51	15.41	22.17	9/7/08	14.24	8.36	11.47	13.37					
7/25/08	24.01	9.59	16.16	22.51	9/8/08	13.62	8.05	10.78	13.52					
7/26/08	23.32	10.84	16.51	22.66	9/9/08	13.47	9.59	11.62	13.72					
7/27/08	23.15	10.22	16.11	22.66	9/10/08	13.32	11.3	12.40	13.88					
7/28/08	22.98	10.37	16.24	23.06	9/11/08	12.85	10.99	12.05	13.92					
7/29/08	20.32	10.68	15.38	22.97	9/12/08	12.85	10.99	12.13	13.94					
7/30/08	22.98	9.91	15.77	22.89	9/13/08	12.85	11.15	12.22	13.31					
7/31/08	23.49	8.97	15.73	22.89	9/14/08	13.01	11.3	12.33	13.14					

All temperatures are listed in degrees centigrade.

SITE 7: McCOY CREEK ABOVE LAKE CREEK

DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT
6/17/08	21.68	7.16	13.79		8/1/08	25.08	10.72	17.24	24.57	9/15/08	17.45	6.23	11.62	16.52
6/18/08	20.69	6.38	13.00		8/2/08	23.87	11.49	17.15	24.30	9/16/08	16.97	6.38	11.56	16.68
6/19/08	20.2	6.23	12.88		8/3/08	24.91	10.26	16.85	24.23	9/17/08	15.86	6.38	11.22	16.61
6/20/08	21.68	7.01	13.97		8/4/08	25.94	9.63	17.10	24.32	9/18/08	16.02	7.16	11.66	16.63
6/21/08	15.38	8.09	12.01		8/5/08	25.26	10.57	17.48	24.88	9/19/08	13.04	7.78	10.78	16.14
6/22/08	20.52	7.31	13.43		8/6/08	22.18	12.27	16.94	24.52	9/20/08	11.65	9.01	10.56	15.42
6/23/08	20.85	6.85	13.50	20.14	8/7/08	23.53	13.51	18.19	24.40	9/21/08	11.49	7.47	9.11	14.64
6/24/08	21.34	7.78	14.17	20.09	8/8/08	25.08	13.04	18.27	24.40	9/22/08	11.81	6.07	8.43	13.83
6/25/08	21.18	7.62	14.13	20.16	8/9/08	22.68	10.26	16.23	24.23	9/23/08	11.03	1.83	6.47	12.99
6/26/08	20.52	9.17	14.53	20.21	8/10/08	22.85	9.63	15.80	23.93	9/24/08	12.42	4.04	8.11	12.49
6/27/08	23.36	8.71	15.55	20.45	8/11/08	24.39	8.86	15.87	23.71	9/25/08	13.51	5.76	9.26	12.14
6/28/08	24.39	10.1	16.71	21.74	8/12/08	21.02	10.1	15.59	23.10	9/26/08	12.27	3.57	7.72	12.03
6/29/08	22.34	10.41	16.34	22.00	8/13/08	22.34	11.34	16.62	23.13	9/27/08	12.73	4.19	8.23	12.18
6/30/08	21.18	11.81	16.16	22.04	8/14/08	23.19	11.49	17.19	23.08	9/28/08	12.58	3.42	7.91	12.34
7/1/08	19.23	11.34	14.51	21.74	8/15/08	23.87	11.81	17.68	22.91	9/29/08	13.04	4.04	8.57	12.51
7/2/08	24.04	10.1	16.74	22.15	8/16/08	23.87	12.27	17.85	23.08	9/30/08	14.76	6.54	10.66	13.04
7/3/08	23.87	11.81	17.80	22.63	8/17/08	23.02	12.11	17.48	23.10	10/1/08	14.91	7.16	11.20	13.40
7/4/08	22.18	13.04	17.33	22.46	8/18/08	19.72	12.11	15.34	22.43	10/2/08	13.04	8.71	10.71	13.33
7/5/08	23.7	12.42	17.65	22.36	8/19/08	17.61	11.19	14.32	21.95	10/3/08	10.88	7.78	9.46	13.13
7/6/08	24.22	12.89	18.01	22.63	8/20/08	17.77	12.42	14.53	21.29	10/4/08	10.26	7.16	8.94	12.78
7/7/08	23.19	9.94	16.32	22.92	8/21/08	18.58	11.19	14.39	20.63	10/5/08	9.01	4.98	6.98	12.27
7/8/08	24.91	10.1	17.07	23.73	8/22/08	18.74	7.01	12.75	19.90	10/6/08	11.34	5.76	8.29	12.03
7/9/08	24.91	10.57	17.45	23.85	8/23/08	20.04	7.47	13.64	19.35	10/7/08	11.96	5.45	8.26	11.63
7/10/08	23.87	11.34	17.07	23.85	8/24/08	21.02	9.63	15.28	19.07	10/8/08	8.86	1.99	5.37	10.76
7/11/08	23.7	9.17	15.98	24.07	8/25/08	16.33	10.72	13.80	18.58	10/9/08	3.42	0.07	1.85	9.39
7/12/08	24.22	8.71	16.10	24.15	8/26/08	17.61	6.69	11.99	18.58	10/10/08	3.1	0.56	1.62	8.28
7/13/08	24.91	9.63	16.80	24.24	8/27/08	18.42	7.31	12.54	18.68	10/11/08	3.42	-0.08	1.08	7.30
7/14/08	23.53	10.57	17.19	24.29	8/28/08	19.72	7.93	13.58	18.84					
7/15/08	24.56	13.04	18.46	24.24	8/29/08	20.85	9.01	14.76	19.14					
7/16/08	23.7	12.73	17.86	24.07	8/30/08	20.04	10.26	14.87	19.14					
7/17/08	23.36	11.03	16.93	24.00	8/31/08	15.38	7.62	11.19	18.34					
7/18/08	23.02	10.41	16.28	23.90	9/1/08	15.54	5.61	10.18	18.22					
7/19/08	23.53	9.01	15.90	23.80	9/2/08	14.44	4.51	9.61	17.77					
7/20/08	24.39	10.72	17.22	23.73	9/3/08	16.18	4.51	10.19	17.45					
7/21/08	21.02	12.73	16.56	23.37	9/4/08	16.18	5.61	10.78	16.94					
7/22/08	22.85	14.13	17.47	23.12	9/5/08	16.49	5.92	11.20	16.32					
7/23/08	25.6	11.03	17.32	23.40	9/6/08	18.26	7.47	12.61	16.07					
7/24/08	26.12	8.39	16.47	23.79	9/7/08	18.09	7.62	12.74	16.45					
7/25/08	26.65	9.48	17.21	24.31	9/8/08	17.13	6.38	11.77	16.68					
7/26/08	25.77	11.03	17.58	24.63	9/9/08	15.86	7.16	11.57	16.88					
7/27/08	25.43	10.26	17.05	24.78	9/10/08	16.33	7.01	11.37	16.91					
7/28/08	25.26	10.41	17.25	25.38	9/11/08	15.86	4.82	10.22	16.86					
7/29/08	21.34	10.88	16.06	25.17	9/12/08	16.49	5.45	10.76	16.86					
7/30/08	24.73	9.79	16.52	25.04	9/13/08	16.66	5.92	11.09	16.63					
7/31/08	24.39	9.01	16.12	24.80	9/14/08	16.97	5.76	11.27	16.47					

All temperatures are listed in degrees centigrade.

SITE 8: LAKE CREEK AT BRIDGE

DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT	DATE	MAX	MIN	AVG	MWMT
6/17/08	16.93	6.34	11.28		8/1/08	20.81	12.7	16.53	20.44	9/15/08	21.64	-2.07	8.32	18.95
6/18/08	16.14	5.88	10.71		8/2/08	20.32	13.47	16.77	20.30	9/16/08	22.48	-2.39	8.25	20.30
6/19/08	15.51	5.72	10.42		8/3/08	20.98	12.39	16.47	20.30	9/17/08	22.82	-1.74	9.18	21.23
6/20/08	16.93	6.5	11.57		8/4/08	21.14	12.08	16.47	20.35	9/18/08	22.98	-0.28	9.33	21.96
6/21/08	12.54	7.59	10.29		8/5/08	20.98	12.86	16.90	20.67	9/19/08	19.03	0.52	10.16	21.59
6/22/08	16.14	6.81	11.10		8/6/08	19.35	14.09	16.63	20.56	9/20/08	13.01	6.34	9.44	20.61
6/23/08	16.62	6.66	11.43	15.83	8/7/08	20.48	14.87	17.59	20.58	9/21/08	12.54	2.91	7.55	19.21
6/24/08	17.09	7.43	12.02	15.85	8/8/08	20.65	14.87	17.76	20.56	9/22/08	12.23	2.28	7.54	17.87
6/25/08	17.09	7.12	11.99	15.99	8/9/08	18.7	13.32	16.23	20.33	9/23/08	12.08	4.01	7.44	16.38
6/26/08	17.09	8.52	12.61	16.21	8/10/08	19.03	12.39	15.75	20.05	9/24/08	14.09	4.47	8.35	15.14
6/27/08	18.54	8.36	13.19	16.44	8/11/08	19.19	11.77	15.48	19.77	9/25/08	14.4	6.5	9.46	13.91
6/28/08	19.35	9.59	14.21	17.42	8/12/08	19.68	12.23	16.00	19.58	9/26/08	17.26	0.36	7.18	13.66
6/29/08	18.7	9.9	14.24	17.78	8/13/08	21.14	12.86	16.77	19.84	9/27/08	17.09	-0.6	7.07	14.24
6/30/08	17.89	11.15	14.29	17.96	8/14/08	21.98	13.17	17.44	20.05	9/28/08	19.68	-1.9	6.79	15.26
7/1/08	16.14	10.84	12.96	17.83	8/15/08	22.65	13.47	17.92	20.34	9/29/08	20.98	-1.41	8.01	16.51
7/2/08	19.52	9.59	14.25	18.18	8/16/08	22.65	13.63	17.97	20.90	9/30/08	21.98	2.91	11.33	17.93
7/3/08	19.52	10.99	15.24	18.52	8/17/08	22.14	13.47	17.59	21.35	10/1/08	21.31	3.07	11.05	18.96
7/4/08	18.22	12.08	14.99	18.48	8/18/08	19.84	13.32	15.66	21.44	10/2/08	13.63	7.12	10.32	18.85
7/5/08	19.52	11.46	15.13	18.50	8/19/08	17.57	12.39	14.87	21.14	10/3/08	11.3	5.72	8.93	18.00
7/6/08	20.16	11.77	15.56	18.71	8/20/08	17.57	13.63	15.06	20.63	10/4/08	10.37	8.06	9.40	17.04
7/7/08	19.35	9.74	14.36	18.92	8/21/08	18.54	12.7	14.94	20.14	10/5/08	9.9	5.88	7.77	15.64
7/8/08	20.16	9.74	14.83	19.49	8/22/08	18.06	9.13	13.41	19.48	10/6/08	12.08	6.5	8.74	14.37
7/9/08	20.48	10.22	15.22	19.63	8/23/08	19.03	8.97	13.79	18.96	10/7/08	12.54	5.88	8.47	13.02
7/10/08	20	10.84	15.22	19.70	8/24/08	20	10.53	15.12	18.66	10/8/08	10.84	2.75	6.06	11.52
7/11/08	18.7	9.28	13.98	19.77	8/25/08	16.77	11.77	14.15	18.22	10/9/08	5.26	1.17	2.89	10.33
7/12/08	19.19	8.67	13.83	19.72	8/26/08	16.77	8.67	12.58	18.11	10/10/08	4.01	1.96	2.81	9.29
7/13/08	19.84	9.43	14.52	19.67	8/27/08	16.93	8.67	12.58	18.01	10/11/08	5.41	0.52	2.34	8.58
7/14/08	19.52	10.53	15.09	19.70	8/28/08	18.38	9.59	13.74	17.99					
7/15/08	20.32	12.54	16.29	19.72	8/29/08	19.52	10.06	14.87	18.20					
7/16/08	19.84	12.39	15.89	19.63	8/30/08	18.87	11.92	15.09	18.18					
7/17/08	19.19	11.15	15.24	19.51	8/31/08	15.34	9.9	11.92	17.51					
7/18/08	20.48	12.7	16.28	19.77	9/1/08	14.56	7.12	10.62	17.20					
7/19/08	21.14	11.61	16.14	20.05	9/2/08	14.4	6.5	10.27	16.86					
7/20/08	22.14	12.7	17.14	20.38	9/3/08	14.71	7.12	10.67	16.54					
7/21/08	20	14.4	17.05	20.44	9/4/08	15.19	7.59	11.07	16.08					
7/22/08	20.16	15.34	17.30	20.42	9/5/08	15.82	7.74	11.32	15.56					
7/23/08	21.64	13.47	17.12	20.68	9/6/08	17.57	8.67	12.75	15.37					
7/24/08	21.31	11.46	16.24	20.98	9/7/08	16.62	9.13	12.58	15.55					
7/25/08	21.81	12.08	16.71	21.17	9/8/08	18.06	7.28	12.11	16.05					
7/26/08	21.31	13.32	17.11	21.20	9/9/08	13.01	6.81	10.01	15.85					
7/27/08	20.98	12.7	16.73	21.03	9/10/08	16.29	3.69	9.10	16.08					
7/28/08	20.81	12.86	16.83	21.15	9/11/08	17.89	-1.57	7.32	16.47					
7/29/08	18.7	13.17	16.06	20.94	9/12/08	21.64	-2.39	8.31	17.30					
7/30/08	20.16	12.39	16.06	20.73	9/13/08	19.84	-2.07	7.31	17.62					
7/31/08	20.32	11.46	15.78	20.58	9/14/08	22.31	-2.89	7.94	18.43					

All temperatures are listed in degrees centigrade.

Bull Trout Spawning Survey Report, 2008

Ray Perkins
Oregon Department of Fish and Wildlife
Malheur Fish District
Ontario, OR

Bull Trout Spawning Survey Report, 2008
Malheur Fish District
Ray Perkins
January , 2009

INTRODUCTION

Bull trout (*Salvelinus confluentus*) were known to exist in the North Fork and upper Malheur River watersheds prior to 1992. Because of increased interest in the status of bull trout, ODFW began bull trout spawning surveys in the North Fork Malheur River watershed in 1992 to track trends in spawning bull trout abundance. The North Fork watershed was selected for initial surveys because no brook trout (*Salvelinus fontinalis*) were present in the system. Brook trout are present in the upper Malheur River system, and spawn timing overlaps with that of bull trout.

Survey timing and location have varied slightly over the years. Initial stream reaches were selected using data from stream habitat surveys and population estimates completed in 1991-2 for tributaries of the upper North Fork. From 1992 through 1996, the stream reaches surveyed varied. Many ending points were moved upstream and entire stream reaches were added or dropped as we gained more information on spawning locations. During the early years, survey timing remained similar, with surveys occurring in mid-September and mid-October. In 1997, stream reaches were surveyed in late August for the first time. From 1997 to 2002, crews surveyed stream reaches three times: late August, mid-September, and late September. In 2003, timing changed again. Volunteers surveyed one stream section (upper Little Crane Creek) in late August. The rest of the sections of streams were surveyed in mid September and mid October. From 2004 through 2007, three stream sections were surveyed in late August, and all stream reaches were surveyed in mid September and mid October. Conducting surveys from August through mid October allowed us to separate bull trout and brook trout spawning in the upper Malheur River watershed. Comparing data from the North Fork and mainstem Malheur River indicates that bull trout spawn earlier than brook trout. To the best of our knowledge, the core bull trout spawning areas in the North Fork Malheur River basin are being surveyed.

Spawning surveys began in the Upper Malheur River watershed in 1998. As with the North Fork watershed, stream reaches were selected from the stream habitat surveys and population estimates. These early surveys were completed in 1994 in Meadow Fork, Snowshoe, Big, and Lake creeks. Since initiating spawning surveys, we have added, dropped, and adjusted stream reaches to take advantage of new information and changes in personnel. Stream reaches in lower Summit and Bosonberg creeks were added for a couple of years and then dropped because no spawning activity was observed. A stream section on Upper Summit Creek was added and surveyed for eight years, but dropped in 2007 due to a lack of personnel and new survey information indicating bull trout were not present. The survey sections on Big Creek have been continually adjusted. From 2004 to 2007, Meadow Fork was surveyed three times, first in late August, then again in mid September and mid October. The sections on other streams were surveyed in mid-September and again in mid-October. All streams sections in the upper Malheur River with known bull trout populations are currently being surveyed. Stream sections may be extended or dropped in the future to incorporate new information. This report summarizes data collected through 2008.

METHODS

We have reduced the number of objectives for this project to the four listed below. All four objectives apply to both watersheds.

Objectives

1. Determine where bull trout spawn.
2. Determine when bull trout spawn.
3. Determine the number of spawning bull trout.
4. Estimate the amount of time redds are visible to the surveyors.

Spawning surveys were completed on streams in the North Fork Malheur and Upper Malheur watersheds known or suspected to support bull trout spawning. One or more people surveyed each stream reach in an upstream direction with at least one experienced surveyor per team. If there were multiple surveyors, they usually walked on opposite sides of the stream. Since 2003, crews have counted redds, determined redd size, noted redd visibility, and recorded numbers and estimated total length (inches) of bull trout observed. All redds, except for those first observed on the final survey, were flagged to avoid double counting on subsequent surveys. All flags were pulled on the last survey.

Each crew used a GPS unit to record starting and ending locations of each stream section as well as the location of each redd. GPS readings were transferred to data sheets manually during surveys. Each GPS unit was set to record coordinates in decimal degrees and use NAD 1983 as the datum. All GPS coordinates were entered into GIS and mapped. Attempts were made to correct for GPS unit or recording errors when points were mapped. In the Upper Malheur Watershed, distinguishing between bull trout and brook trout redds is impossible without identifying the fish creating each redd. Very few fish were identified and associated with redds. Therefore, redds enumerated and mapped in the upper Malheur watershed are an aggregate of both species with estimates for the number of bull and brook trout redds based on spawn timing.

Since 1992, stream sections have been surveyed multiple times to better identify spawn timing. From 1993 to 1996, we surveyed stream sections during mid-September and mid-October. From 1997 to 2002, stream segments were surveyed three times; the last week of August, mid-September, and the last week of September. Starting in 2003, we were forced to reduce the number of times stream sections were surveyed to match reductions in personnel from all participating agencies. In 2003, we surveyed all stream sections in both watersheds twice, once in mid-September and again in mid-October. In addition, volunteers walked Little Crane Creek on September 1. In 2004 and 2005, we surveyed Little Crane, lower Sheep, upper Swamp, and Meadow Fork stream sections three times; in late August, mid-September and in mid-October. All other stream sections were surveyed twice, in mid-September and again in mid-October. In 2006, all stream sections were surveyed three times at times similar to 1997-2002 surveys. The Burns Paiute Tribal staff walked a majority of the stream sections primarily due to further reductions in department staff time. In 2007, we reverted back to the 2004-2005 survey methodology.

In 2008, we modified the timing and survey sections to accommodate the latest reductions in available personnel and incorporate information on redd locations and redd visibility through time. We conducted an analysis of the available location data from 1999-2007 surveys and visibility data from 2003 to 2007. Location data was used to determine which stream segments could be dropped with the least impact to the precision of the counts. Visibility data was used to determine the amount of time possible between surveys without affecting the precision of the counts. In 2008, streams sections were surveyed during the second week of September and again during the last week of September. Major changes to some stream sections occurred. These changes included dropping: the lower 4.2 miles of Little Crane Creek, the upper 0.5 miles of Sheep Creek, the lower 1.5 miles of Swamp Creek, and the lower 1.0 miles of the North Fork Malheur River. In the upper Malheur River watershed the lower 0.25 miles of Meadow Fork or Big Creek was dropped, and about 1.0 miles of Big Creek between Meadow Fork and Snowshoe creeks was added.

In 2003, we began efforts to determine the amount of time redds are visible to surveyors. This information was intended to determine the appropriate amount of time between surveys and possibly help determine when surveys will take place. For each redd, we determined size and visibility. Redd size was grouped into small ($<0.5\text{m}$), medium ($0.5\text{-}1.5\text{m}$), and large ($\geq 1.5\text{m}$). Redd visibility was categorized into three groups: class 1 (clearly defined, no algae growth), class 2 (some erosion and algae growth), class 3 (difficult or impossible to detect).

We continued to track redd visibility by estimating the amount time in days redds remained visible to surveyors. The first day a redd was observed was designated as day one. Upon the second and third surveys, redd visibility was again recorded, and the number of days from first observation determined. Redd visibility at each point in time was recorded along with the number of days from first observation. This information was compiled based on the day of observation. We compiled the data by year of observation and then combined all data together. For comparison purposes, a regression line was applied to each year's data and through all data combined. In this process, the y-intercept was fixed to 1.00. This assumes that on the first day all redds were visible. By fixing the y-intercept at 1.00 (100% visible on day one) the only variation in the visibility occurs in the slope of the regression line. However, fixing the y-intercept also causes the coefficient of correlation to drop or to be less than it would without fixing the y-intercept.

RESULTS

North Fork Malheur River Watershed

North Fork Malheur River

We surveyed the upper North Fork Malheur River two times. The survey began at the mouth of Horseshoe Creek and ended 1.6 miles upstream. We observed a total of seven redds. We observed four redds on September 9 and three redds on September 30 (Table 1).

Table 1. Bull trout redds observed in the mainstem of the North Fork Malheur River.

YEAR	REDDS	MILES	REDDS/MILE
1992 ^a	1	5.9	0.2
1993	1	15.5	0.1
1994	0	7.3	0.0
1995	0	6.0	0.0
1996	6	3.9	1.5
1997	10	2.3	4.4
1998	3	3.8	0.8
1999	9	3.5	2.6
2000	16	3.5	4.3
2001	5	3.0	1.7
2002	8	2.3	3.5
2003	0	3.8	0.0
2004	3	2.5	1.2
2005	3	2.5	1.2
2006	7	2.6	2.7
2007	5	1.5	3.3
2008	7	1.6	4.4

^a- Does not include 14 questionable redds observed by volunteers included in earlier reports.

Horseshoe Creek

We surveyed Horseshoe Creek two times. The survey began at the confluence with North Fork Malheur River and ended about 1.2 miles upstream. We observed a total of six redds. We observed six redds on September 9, and no redds on September 30 (Table 2).

Table 2. Bull trout redds observed in Horseshoe Creek, tributary to North Fork Malheur River.

YEAR	REDDS	MILES	REDDS/MILE
1998	4	0.4	10.0
1999	4	0.8	5.0
2000	7	0.8	6.3
2001	6	0.6	10.3
2002	3	1.2	2.5
2003	1	0.8	1.3
2004	1	0.8	1.3
2005	4	1.2	3.3
2006	15	1.1	11.8
2007	3	1.1	2.7
2008	6	1.2	5.0

Deadhorse Creek

Deadhorse Creek was not surveyed this year.

Flat Creek

Flat Creek was not surveyed this year

Spring Creek

Spring Creek was not surveyed this year.

Swamp Creek

We surveyed the upper and lower sections of Swamp Creek twice. The lower section began at about river mile 1.5 and continued upstream about 1.25 miles. The upper section began at the end of the lower section (RM 2.75) and continued upstream an additional 1.25 miles. We observed 20 redds. We observed 17 redds on September 9, and 3 redds on September 30 (Table 3).

Table 3. Bull trout redds observed in Swamp Creek, tributary to North Fork Malheur River.

YEAR	REDDS	MILES	REDDS/MILE
1992	0	1.2	0.0
1993	3	2.2	1.4
1994	9	3.9	2.3
1995	0	3.9	0.0
1996	8	3.8	2.1
1997	21	4.1	5.1
1998	24	4.2	5.7
1999	35	4.1	8.5
2000	40	4.1	9.8
2001	22	4.2	5.3
2002	19	2.0	9.5
2003	13	4.2	3.1
2004	19	4.3	4.5
2005	20	4.2	4.8
2006	32	4.2	7.6
2007	36	4.3	8.4
2008	20	2.6	7.3

Sheep Creek

We surveyed the lower and upper sections of Sheep Creek twice. The lower section began at the confluence with the North Fork and continued upstream about 2.0 miles. This year, the upper section began where the lower section ended and continued upstream an additional 1.2 miles. We observed 16 redds. We observed 13 redds on September 9, and 3 redds on September 30 (Table 4).

Table 4. Bull trout redds observed in Sheep Creek, tributary to North Fork Malheur River.

YEAR	REDDS	MILES	REDDS/MILE
1992	0	1.1	0.0
1993	0	2.2	0.0
1994	0	2.2	0.0
1995	2	2.9	0.7
1996	13	3.4	3.8
1997	8	2.9	2.8
1998	17	3.5	4.9
1999	22	3.0	7.3
2000	25	4.0	6.3
2001	15	3.5	4.3
2002	17	3.5	4.9
2003	12	3.9	3.1
2004	14	2.9	4.8
2005	15	3.9	3.8
2006	17	2.9	5.9
2007	34	3.9	8.2
2008	16	3.2	5.0

Cow Creek

Cow Creek was not surveyed this year.

Little Cow Creek

Little Cow Creek was not surveyed this year.

Elk Creek

We surveyed Elk Creek two times. The survey began at the Culvert under Forest Road 16 and extended about 0.6 miles upstream to the confluence of North Fork and South Fork Elk creeks. The survey continued up the South Fork 0.6 miles and up the North Fork 1.2 miles. We observed 12 redds. We observed nine redds on September 9, and three redds on September 30 (Table 5).

Table 5. Bull trout redds observed in Elk Creek and its two tributaries, the North and South forks.

YEAR	REDDS	MILES	REDDS/MILE
1992	1	1.0	1.0
1993	1	2.3	0.4
1994	0	2.0	0.0
1995	1	4.0	0.3
1996	3	4.1	0.7
1997	9	4.1	2.2
1998	6	3.5	1.7
1999	12	3.0	4.0
2000	5	3.0	1.7
2001	3	3.2	0.9
2002	7	2.8	2.5
2003	7	3.2	2.2
2004	5	2.5	2.0
2005	10	3.5	2.9
2006	12	3.7	3.2
2007	9	3.0	3.0
2008	12	2.4	5.0

Crane Creek

Crane Creek was not surveyed this year.

Little Crane Creek

We surveyed Little Crane Creek twice. The survey started at the lower fence enclosing Little Crane Creek Campground and continued upstream about 1.8 miles to Forest Service Road 1665-0498. We observed a total of 14 redds. We observed 11 redds on September 10, and three redds on October 1 (Table 6).

Table 6. Bull trout redds observed in Little Crane Creek, tributary to North Fork Malheur.

YEAR	REDDS	MILES	REDDS/MILE
1992			
1993	3	5.6	0.5
1994	4	7.5	0.5
1995	6	6.0	1.0
1996	8	6.0	1.3
1997	16	4.2	3.8
1998	20	6.0	3.3
1999	33	6.1	5.4
2000	60	6.1	9.8
2001	74	6.2	12.0
2002	45	2.8	16.1
2003	30	6.1	4.9
2004	22	3.2	6.9
2005	15	6.1	2.5
2006	14	2.6	5.4
2007	25	2.0	12.5
2008	14	1.8	7.8

Upper Malheur River Watershed

Summit Creek

We did not survey Summit Creek this year. Inventory data collected since 1999 indicated that bull trout currently do not reside in upper Summit Creek.

Snowshoe Creek

We surveyed Snowshoe Creek twice. This survey began at the confluence with Big Creek and ended about 1.0 miles upstream near the wilderness boundary sign. The first 0.3 mile was not surveyed due to a thick stand of alder and brush that made stream access and stream visibility almost impossible. We observed a total of six redds. We observed two redds on September 10, and four redds on October 1. (Table 7).

Table 7. Redds observed in Snowshoe Creek, tributary to Big Creek, from mid September to mid October.

YEAR	REDDS	MILES	REDDS/MILE
1998	10	1.7	5.9
1999	25	1.7	14.7
2000	3	1.7	1.8
2001	16	1.7	9.4
2002	0	1.4	0.0
2003	6	1.1	5.5
2004	9	0.6	15.0
2005	3	0.8	3.8
2006	8	0.9	8.9
2007	32	0.9	35.6
2008	6	0.7	8.6

Big Creek

We surveyed Big Creek twice. The survey began at the confluence of Meadow Fork and Big creeks and continued upstream for 1.6 miles. We observed a total of four redds. We observed no redds on September 10, and four redds on October 1 (Table 8).

Table 8. Redds observed in Big Creek,
tributary to Upper Malheur River,
from mid September to mid
October.

YEAR	REDDS	MILES	REDDS/MILE
1998	0	2.3	0.0
1999	8	4.6	1.7
2000	22	4.6	4.8
2001	31	5.2	5.9
2002			
2003			
2004	5	0.8	6.3
2005	2	0.6	3.3
2006	3	0.7	4.3
2007	1	0.5	2.0
2008	4	1.6	2.5

Meadow Fork Big Creek

We surveyed Meadow Fork twice. The survey section began at the USFS bridge at river mile 0.2 and continued upstream about 3.0 miles to a waterfall. We observed a total of 17 redds. We observed 11 redds on September 10, and six redds on October 1 (Table 9).

Table 9. Redds observed in Meadow Fork Big Creek,
tributary to Big Creek, from mid September to mid
October.

YEAR	REDDS	MILES	REDDS/MILE
1998	39	3.3	11.8
1999	25	3.3	7.6
2000	51	3.3	14.8
2001	92	3.2	28.9
2002	16	3.2	5.0
2003	0	3.2	0.0
2004	2	3.2	0.6
2005	7	3.2	2.2
2006	16	3.2	5.0
2007	10	3.2	3.1
2008	17	3.0	5.7

Lake Creek

We surveyed Lake Creek twice. The survey began at Forest Road 1648 and ended 4.2 miles upstream at a waterfall. We observed 65 redds. We observed three redds on September 10, and 62 redds on October 1 (Table 10).

Table 10. Redds observed in Lake Creek, tributary to Upper Malheur River, from mid September to mid October.

YEAR	REDDS	MILES	REDDS/MILE
1998	34	2.1	16.2
1999	21	4.3	4.9
2000	22	4.3	5.1
2001	44	4.2	10.5
2002			
2003	21	4.2	5.0
2004	55	4.2	13.1
2005	51	4.2	12.1
2006	25	4.3	5.8
2007	74	4.2	17.6
2008	65	4.2	15.5

Bosonberg Creek

Bosonberg Creek was not surveyed this year.

Redd Size and Redd Visibility

Redd Size

The number of redds observed in all size classes in both watersheds dropped compared to 2007 levels. Sixteen percent (12/75) of the observed redds in the North Fork watershed (Figure 1) and two percent (2/92) of the observed redds in the upper Malheur River watershed (Figure 2) were classified as large ($\geq 1.5\text{m}$ in length). These redds are assumed to have been constructed by large migratory adults (Hemmingson et al. 1997). Thirty-nine percent (29/75) of the observed redds in the North Fork watershed (Figure 1) and seventeen percent (16/92) of the observed redds in the upper Malheur River watershed (Figure 2) were classified as small ($\leq 0.5\text{m}$ in length). These redds are assumed to have been constructed by small resident individuals (Hemmingson, et al. 1997). Many of the small redds and some of the medium redds in the upper Malheur River watershed were probably constructed by brook trout.

Figure 1. Estimated size of observed redds in the North Fork Malheur River watershed recorded during spawning surveys, 2003 through 2008.

Figure 2. Estimated size of observed redds in the Upper Malheur River watershed recorded during spawning surveys, 2003 through 2008.

Redd Visibility

Redd visibility in the North Fork has not varied much since 2003. The slope of the line or the rate of change in visibility per day averaged -0.016 (-1.6% per day) with a coefficient of variation of 14.1 percent (Figure 3). Redd visibility in the North Fork Watershed in 2008 was 51.7 percent after 20 days (Table 11), which was low compared to basin averages (Table 11). However, visibility was not re-evaluated for five redds on the second pass. If all five redds were visible, visibility would increase to 60 percent after 20 days, which is a little closer to the average (Table 11).

Table 11. The number of days a given percentage of bull trout redds remains visible in the North Fork Malheur River watershed.

Percent Visible	Mean Number of Days
75%	16
67%	21
50%	31

Redd visibility in the Upper Malheur has been more variable than redd visibility in the North Fork since 2003. The slope of the line or the rate of change in visibility per day averaged -0.021 (-2.1%) per day with a coefficient of variation of 30.0 percent (Figure 5). Redd visibility in the Upper Malheur Watershed in 2008 was 50 percent after 20 days. Redd visibility was low compared to basin averages in Table 12. However, visibility was not re-evaluated for seven redds on the second pass. Assuming all seven redds were rated as visible, visibility would increase to 94 percent after 20 days, which is well above average (Table 12).

Table 12. The number of days a given percentage of bull trout redds remains visible in the Upper Malheur River watershed.

Percent Visible	Mean Number of Days
75%	12
67%	16
50%	24

DISCUSSION

Survey data can be compared effectively from 1996 to the present. Survey techniques and timing varied from 1992 to 1995 on the North Fork Malheur. During those years project personnel were struggling with uncertainties related to spawn timing and location. Consequently, there was variation in timing of surveys and areas surveyed. In addition, livestock were abundant in some spawning areas during those years, making identification of redds difficult. Since 1996, survey areas and timing have been standardized. Expertise of surveyors has also increased and most are familiar with all survey sections. A change in livestock management has reduced stream disturbance and made redds more easily identifiable.

We observed 75 redds in the North Fork Malheur watershed in 2008 compared to 112 redds in 2007, a decline of 33 percent (Appendix C-1, 2). Redd counts in Little Crane, Swamp, and Sheep creeks declined, while counts in Elk, upper North Fork, and Horseshoe creeks increased, just the opposite of observations in 2007. Little Crane Creek, Swamp Creek, and Sheep Creek continue to be prime spawning areas for bull trout in this watershed, containing 67 percent of all redds counted. Redds continued to be concentrated in areas with strong groundwater influence. In Little Crane, Swamp, and Sheep creeks, most redds were concentrated in areas with strong ground water influence.

Based on spawn timing comparisons between the North Fork and upper Malheur rivers, redds observed prior to mid September in the upper Malheur River are most likely bull trout redds. In 2008, the number of presumed bull trout redds declined 53 percent from 2007 counts. Most of the decline occurred in Lake Creek. This year 16 redds were counted in the upper Malheur watershed prior to mid-September, with 11 redds observed in Meadow Fork, two in Snowshoe Creek, and three in Lake Creek. The redd count continues to indicate that the adult spawning population in the Upper Malheur River watershed is very low.

The intent of redd visibility evaluation is to determine the amount of time redds are visible to surveyors. This information was intended to determine the appropriate amount of time between surveys and possibly help determine when surveys will take place. Current visibility information from the North Fork Malheur indicates that on average, a majority of redds (75%) are still visible after two weeks (17 days), 67percent are still visible after 3 weeks (22 days), and 50 percent are still visible after four weeks (33 days). Given this data, conducting only two spawning surveys per year will result in a slight decline in observed redds. However, after several years of data collection, we should be able to calibrate for that loss by expanding the redd counts to compare to those years when three full surveys were conducted.

Snowpack (and projected flow levels) for water year 2008 was higher than levels observed in 2007. As a result, redd counts in 2009 in the North Fork are expected to increase a little from 2008 levels.

Law enforcement effort continues to be directed into the North Fork watershed, especially in the Little Crane Creek area. This may help prevent potential problems with illegal bull trout harvest in Little Crane Creek.

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APPENDIX

Total redds observed and redds per mile in the Upper Malheur River and North Fork Malheur Watersheds from Aug-Oct. 1992-2008, Baker and Grant Counties, Oregon.

Appendix Figure A-1. The number bull trout redds observed in the North Fork Malheur River watershed from 1992-2008.

Appendix Figure A-2. The number bull trout redds per mile of stream observed in the North Fork Malheur River watershed from 1992-2008.

Appendix Figure A-3. The number of redds observed in the upper Malheur River watershed, 1998-2008. The redd bars represent the number redds counted prior to September 15. The light green bars represent the total number of redds counted.

Appendix Figure A-4. The number of redds per mile in the upper Malheur River watershed, 1998-2008. Red bars represent the number redds per mile prior to September 15. Light Green bars represent the total number of redds per mile.

**2008 Efforts to Trap and Haul Entrained
Bull Trout *Salvelinus confluentus* over
Agency Valley Dam on the North Fork
Malheur River, Oregon**

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2008 Efforts to Trap and Haul Entrained Bull Trout *Salvelinus confluentus* over Agency Valley Dam on the North Fork Malheur River, Oregon

**Daniel Brown and Lawrence Schwabe
Burns Paiute Tribe Natural Resources Department**

Abstract

Bull trout *Salvelinus confluentus* collection in the tailrace of Agency Valley Dam on the North Fork Malheur River was implemented with the use of angling gear. Any bull trout captured were to be transported upstream 3 miles where the North Fork Malheur River flows into the head of Beulah Reservoir. A total angling effort of 90 hours was expended that yielded no bull trout. Other species angled in the tailrace include: Rainbow trout *Oncorhynchus mykiss*, northern pike minnow *Ptychocheilus oregonensis*, and large scale sucker *Catostomus macrocheilus*.

Introduction

Bull trout are listed as a threatened species as a result of historical and current land use activities, the construction of dams and fish eradication projects by poisoning (Bowers et al. 1993). One element of the negative effects on bull trout is entrainment. Bureau of Reclamation, Oregon Department of Fish and Wildlife, and the Burns Paiute Tribe Natural Resources Department (BPT) have determined that bull trout entrainment occurs over the Agency Valley Dam spillway (Schwabe et al. 2001, 2007). Changes made in the 2000 irrigation season resulted in the release of water through the flow valves rather than over the spillway in an effort to reduce the number of entrained bull trout. Starting in 2001 and continuing until 2005, BPT did not angle any bull trout below the spillway. Water levels were high in 2006 and resulted in water being released over the spillway. BPT continued the effort to monitor bull trout below the reservoir and collected 7 bull trout in the pool below the spillway in 2006 (Schwabe et al. 2007). Bull trout that are entrained below Agency Valley Dam are lost to the breeding population, and it is assumed entrained bull trout eventually perish due to poor habitat conditions below the reservoir. Therefore an effort must be made to return any entrained bull trout to the reservoir.

The objective of this project is to reduce bull trout loss due to entrainment in the tailrace of Agency Valley Dam.

Methods

BPT angled below the reservoir in the spillway for sixteen hours each week from May 12 to June 13, 2008. Methods of angling included fly fishing, artificial lures and bait. Tribal employees conformed to all state regulations on fishing. Data collection included total hours angled and total number and estimated size of each fish species caught per day. All other anglers within ¼ mile below the dam were also interviewed by staff for the information stated above.

Species of fish were recorded and returned to the spillway pool. Any bull trout captured were to be measured in millimeters (Fork Length). All other species lengths were

estimated. Upon capture, bull trout were transported in a five gallon bucket equipped with an aerator to the north end of Beulah Reservoir and released.

Results

Angling began on May 12, 2008 and continued for 16 hours a week until June 13, 2008. A total of 90 angling hours were recorded. This includes 84 hours of effort logged by BPT and an additional 6 hours logged by other anglers not affiliated with the Tribe.

No bull trout were collected below the spillway in 2008. Fish species collected during the 2008 angling efforts include: Rainbow trout *Oncorhynchus mykiss*, northern pike minnow *Ptychocheilus oregonensis*, and large scale sucker *Catostomus macrocheilus* (Table 1). Lengths of fish were estimated and ranged from 25-40cm for large scale sucker, 15-45cm for northern pike minnow, and 20-45cm for redband trout (Table 1). A summary of the daily fish angling effort is provided in Table 2.

Table 1 Number and size of species angled in the tailrace of Agency Valley Dam in 2008.

Species	15cm+	20cm+	25cm+	30cm+	35cm+	40cm+
large scale sucker <i>C. macrocheilus</i>			5	10	3	
northern pike minnow <i>P. oregonensis</i>	42	15	8	2	1	1
redband trout <i>O. mykiss</i>		5	60	56	11	8

Discussion

Dam operations at Beulah Reservoir appear to have successfully reduced bull trout entrainment. The Tribe's 2008 effort yielded no bull trout in the tailrace of Beulah Reservoir. US Geological Survey (USGS) expended many hours of effort to collect fish in the reservoir in the spring of 2008. From March 26 to April 28, 2008, USGS collected 17 bull trout ranging from 262 mm to 376 mm fork length (Rose pers. comm. 2008). Their success of collecting bull trout in the reservoir suggests the bull trout population was vulnerable to entrainment but water release practices have resulted in a reduced entrainment risk. Fish that were angled were not marked so recapture rates cannot be determined.

In 1999, spill operations was the predominant method of water release and anglers collected a total of 20 bull trout in the tailrace equating to 1 bull trout collected for every 20 angling hours (Table 3) (Schwabe et al. 2001). Since 2000, water releases have been primarily through the tubes at the base of Agency Valley Dam rather than over the spillway. Despite operational changes, BPT collected five bull trout from the tailrace in 2000 (Table 3) (Schwabe et al. 2001). Bull trout collected in 2000 may have overwintered in the tailrace from the previous season. Bull trout presence in the tailrace of Beulah Reservoir was also documented in 2006 (Table 3) (Schwabe et al. 2007). The water practices in 2006 were modified to spill water over the spillway due to a high water year which led to bull trout entrainment (Schwabe et al. 2007).

Table 2 Summary of daily fish angling effort below Agency Valley Dam in 2008.

Date	Species	# Fish Captured	Hours Angled
5-12	Rainbow Trout	26	12
5-15	Rainbow Trout	22	11 (included is 3 hours effort from sport anglers)
	Northern Pike Minnow	3	
5-19	Rainbow Trout	28	8
	Northern Pike Minnow	3	
5-22	Rainbow Trout	16	8
	Large Scale Sucker	1	
5-28	Rainbow Trout	18	8
	Northern Pike Minnow	3	
	Large Scale Sucker	1	
5-29	Rainbow Trout	11	8
	Northern Pike Minnow	3	
	Large Scale Sucker	2	
6-2	Rainbow Trout	8	8
	Northern Pike Minnow	40	
	Large Scale Sucker	4	
6-6	Rainbow Trout	3	11 (included is 3 hours effort from sport anglers)
	Northern Pike Minnow	5	
	Large Scale Sucker	8	
6-9	Rainbow Trout	3	8
	Northern Pike Minnow	5	
	Large Scale Sucker	1	
6-13	Rainbow Trout	5	8
	Northern Pike Minnow	7	
	Large Scale Sucker	1	
Total	Rainbow Trout	140	90
	No. Pike Minnow	69	
	Large Scale Sucker	18	

Acknowledgements

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Table 3 Bull trout and rainbow trout catch below Agency Valley Dam from 1999 to 2008.

	# Fish Caught Spring		# Fish Caught Fall	
	Bull	Rainbow	Bull	Rainbow
1999	20	150	NA*	NA*
2000	5	107	0	4
2001	0	13	0	34
2002	0	73	0	36
2003	0	7	NA*	NA*
2004	0	49	NA*	NA*
2005	0	6	NA*	NA*
2006	7	106	NA*	NA*
2008	0	140	NA*	NA*
	Catch Rate (#/hour) Spring		Catch Rate (#/hour) Fall	
	Bull	Rainbow	Bull	Rainbow
1999	0.05	0.34	NA*	NA*
2000	0.01	0.21	0.00	0.02
2001	0.00	0.08	0.00	0.59
2002	0.00	0.44	0.00	0.43
2003	0.00	0.35	NA*	NA*
2004	0.00	0.48	NA*	NA*
2005	0.00	0.08	NA*	NA*
2006	0.04	0.67	NA*	NA*
2008	0.00	1.56	NA*	NA*

* No creel in fall

**Distribution and Abundance of Redband
Trout *Oncorhynchus mykiss* in the
Malheur River Basin, 2008**

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Burns Paiute Tribe Natural Resources Department
Burns, OR

DISTRIBUTION AND ABUNDANCE OF REDBAND TROUT *ONCORHYNCHUS MYKISS* IN THE MALHEUR RIVER BASIN

2008 Report of Continued Field Research

Chad Abel, Fisheries Program Manager
Burns Paiute Tribe Natural Resources Dept

INTRODUCTION

The Malheur River Basin supports resident populations of native redband trout *Oncorhynchus mykiss*. Though resident populations existed in the basin prior to large-scale human activity, all of the basin's redband were forced to adopt a resident life history after dam construction projects in the twentieth century severed connectivity to marine environments. In addition to native populations of redband trout, recreational fisheries were historically supported by stocking of hatchery rainbow trout fingerlings (Hanson et al. 1990). Stocking occurred primarily in reaches of the mainstem and North Fork Malheur River.

Prior to 2007, surveys had been conducted to assess relative abundance and distribution of native trout in the Malheur Basin (Pribyl and Hosford 1985, Fenton et al. 2005), but no systematic, basin-wide survey of redband distribution and abundance had transpired before Oregon Department of Fish and Wildlife (ODFW) and Burns Paiute Tribe (BPT) undertook this study. Data collected from electrofishing in 2007 provided a population estimate of 156,200 redband in the basin $\pm$ SE of 23,273 (Relative CI 29%) (Bangs et al. 2008).

BPT is repeating the study design over a five year cyclic schedule on public and tribal sites visited in 2007. The exclusion of sites located on private holdings reduces the total number of sites to be revisited to 108. This translates into a workload of 21-23 sites per year. Figure 1 maps survey sites visited in 2008 with associated fish densities recorded at each site.

STUDY AREA

A detailed description of the Malheur River Basin including geographic location, river kilometers, elevation, climate, ownership and native fishes can be found in the 2007 report produced by ODFW (Bangs et al. 2008). Roughly one-third of the basin is in private ownership and is being excluded from further sampling. The remaining 108 sites are on state, federal or tribal lands.

METHODS

Methods in the field were derived from the *Redband Trout, Warner Sucker and Goose Lake Fishes Distribution and Abundance Survey Protocols* (Scheerer et al. 2007). Bangs et al. (2008) also summarizes sampling methods in good detail. The mark-recapture methods to estimate abundance is the only aspect of the 2007 effort to be excluded from the current sampling protocol. Electrofishing methods and the gathering of basic habitat data remain unaltered.

Figure 1 Redband densities associated with 2008 monitoring sites.

RESULTS

Redband trout were observed at 9 of the 22 sites completed. Seven of the 22 sites visited were dry, 1 site was deemed inaccessible, and 5 sites with water had no redband present (Appendix A). Density estimates were calculated for each site that contained redband trout with lengths greater than 60 mm. Of the 9 sites containing redband trout in the 2008 project year, all 9 sites yielded trout >60mm. Densities ranged from 0.005 fish/m² to 0.730 fish/m² (Appendix A). Number of redband at the 8 sites ranged from 2 individuals at MalRiv-03 to 209 individuals at MalRiv-46 (Appendix A). Mean redband density at the 9 sites was 0.181 fish/m² with a mean number of 43 redband per site.

Total biomass of redband at the 9 sites was calculated using the following length-weight regression in Excel:

$$\text{Weight (g)} = 10^{(2.9916 * \text{Log}_{10}(\text{Length (mm)}) - 4.9055)}$$

Redband biomass ranged from 114.2 grams to 5010.3 grams at the 9 sites with redband (Appendix A). In reference to surface area at the sample sites, redband biomass ranged from 0.258 grams/m² to 17.496 grams/m² (Appendix A).

Fork lengths were measured on all redband trout captured. Redband trout ranged in length from 40 to 225 mm with a peak length frequency between 90 and 125 mm (Figure 2). The 2007 report surmised that the peak in length frequency that year between 80 and 120 mm likely represented a mixture of age-1 and age-2 fish (Bangs et al. 2008). Only 3% of the sample consisted of fish large enough for legal harvest (200mm).

DISCUSSION

New redband population estimates in the Malheur River Basin were not figured from the 2008 data collected. With only 9 confirmed redband sites of 22 sites visited in 2008, there is not enough data available to substantially change the population estimate of 156,200 redband in the basin $\pm$ SE of 23,273 from 2007. BPT plans are to refigure the population estimate after the 5 year cyclic site schedule is concluded in 2012. BPT will continue to report its annual findings from fieldwork throughout that timeframe.

ACKNOWLEDGEMENTS

BPT appreciates Bonneville Power Administration's continued financial support of this research project.

A special thanks to Stephanie Gunckel (ODFW) for providing the length - weight regression used to estimate fish biomass (and then patiently explaining to me how to use it).

Figure 2 Length frequency histogram (5mm intervals) of redband trout captured by electrofishing in the Malheur River Basin, 2008 (N=384).

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APPENDIX A

SUMMARY TABLE OF SURVEY SITES 2008 REDBAND STUDY

SITE ID	STREAM	STATUS	LENGTH	MEAN WIDTH	AREA	# REDBAND	DENSITY	RB BIOMASS	BIOMASS (AREA)	TOTAL FISH	OTHER SPECIES
			meters	meters	meters ²	N	fish/m ²	grams	grams/m ²	N	
MalRiv-03	Big	Completed	112	4.0	442.4	2	0.005	114.2	0.258	83	BT, COT, LND
MalRiv-06	Bear	Completed	100	3.0	296.0	79	0.267	2415.0	8.159	108	COT, SPD
MalRiv-07	Magpie	Completed	33	1.4	47.1	0	0.000	0.0	0.000	0	--
MalRiv-10	Crane	Completed	71	2.8	199.8	33	0.165	522.7	2.616	50	COT
MalRiv-11	Buttermilk	Dry	--	--	--	--	--	--	--	--	--
MalRiv-13	Calamity	Dry	--	--	--	--	--	--	--	--	--
MalRiv-14	Lt Crane	Completed	100	2.9	285.0	41	0.144	1214.0	4.260	42	BUT
MalRiv-19	Lake	Completed	100	3.5	353.0	0	0.000	0.0	0.000	25	BT, BUT, COT
MalRiv-23	Summit	Completed	82	2.5	207.1	4	0.019	201.5	0.973	--	--
MalRiv-24	Cottonwood	Dry	--	--	--	--	--	--	--	--	--
MalRiv-26	No Fork Malheur	Completed	96	4.7	455.0	6	0.013	220.5	0.485	31	BUT, COT
MalRiv-27	We Fork Wolf	Completed	100	2.3	234.0	4	0.017	80.7	0.345	4	--
MalRiv-29	Pine	No Access	--	--	--	--	--	--	--	--	--
MalRiv-31	Hog	Completed	100	0.2	20.0	0	0.000	0.0	0.000	0	--
MalRiv-33	Camp	Dry	--	--	--	--	--	--	--	--	--
MalRiv-34	Griffin	Dry	--	--	--	--	--	--	--	--	--
MalRiv-35	Big	Completed	35	1.2	42.0	0	0.000	0.0	0.000	0	--
MalRiv-39	Lt Logan	Dry	--	--	--	--	--	--	--	--	--
MalRiv-41	Crane	Not Comp	--	--	--	--	--	--	--	--	--
MalRiv-42	Rock	Completed	61	1.8	106.8	0	0.000	0.0	0.000	0	--
MalRiv-43	Md Fork Wolf	Completed	31	0.7	22.3	6	0.269	176.1	7.892	7	COT
MalRiv-45	Lt Pine	Dry	--	--	--	--	--	--	--	--	--
MalRiv-46	Camp	Completed	109	2.6	286.4	209	0.730	5010.3	17.496	216	COT

Code	Species
BT	Brook Trout
BUT	Bull Trout
COT	Sculpin
LND	Longnose Dace
SPD	Speckled Dace

Spatial Patterns of Hybridization between Bull Trout, *Salvelinus confluentus*, and Brook Trout, *Salvelinus fontinalis* in an Oregon Stream Network

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Spatial patterns of hybridization between bull trout, *Salvelinus confluentus*, and brook trout, *Salvelinus fontinalis* in an Oregon stream network

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Abstract Hybridization with introduced species represents a serious threat to the persistence of many native fish populations. Brook trout (*Salvelinus fontinalis*) have been introduced extensively throughout the native range of bull trout (*S. confluentus*) and hybridization has been documented in several systems where they co-exist and is seen as a significant threat to the persistence of bull trout populations. We identified a group of diagnostic microsatellite loci to differentiate bull trout and brook trout and then used these loci to examine the spatial distribution of hybrids in the Malheur River basin, Oregon USA. In random samples of approximately 100 fish from each of three creeks we identified 181 brook trout, 112 bull trout and 14 hybrids. Although bull trout, brook trout and hybrids were found in all three creeks, they were not evenly distributed; brook

trout were primarily found in the lower sections of the creeks, bull trout further upstream, and hybrids in the areas of the greatest overlap. One creek with a population of brook trout in a headwater lake provided an exception to this pattern; brook trout were found distributed throughout the creek downstream of the lake. Several post-F1 hybrids were identified suggesting that hybrids are reproducing in the Malheur River Basin. Mitochondrial DNA analysis indicated that both female bull trout and brook trout are involved in hybridization events. Analysis of population structure suggested that brook trout have established multiple spawning populations within the Malheur system. Data presented in this study suggest that relative abundance of brook trout and habitat quality are important factors to consider when evaluating the threat of hybridization to bull trout populations.

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Introduction

Hybridization with nonnative species poses a serious risk of extinction for many native species (Rhymer and Simberloff 1996). Among fish species, hybridization between native and nonnative species has been documented within several families (Scribner et al. 2001). Hybridization among fishes raises several concerns, especially in instances where one (or both) of the species involved is a species of conservation concern. For example, the formation of hybrid swarms between westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) and introduced rainbow trout (*O. mykiss*) and Yellowstone cutthroat trout (*O. c. bouvieri*) has been responsible for the loss of several westslope cutthroat trout

populations (Leary et al. 1995). The threat of hybridization between native and nonnative salmon and trout is of particular concern; many species have been widely introduced outside of their native range and are now in contact with historically isolated but closely related native species (Allendorf et al. 2001).

Bull trout (*Salvelinus confluentus*) and brook trout (*Salvelinus fontinalis*) are two species of salmonids that evolved allopatrically and frequently hybridize when they occur sympatrically. Previous analyses of mitochondrial DNA have demonstrated 4–7% sequence divergence between these two species (Grewe et al. 1990; Taylor et al. 1999). Bull trout are native to northwestern North America, historically ranging from northern California to the Yukon Territory and from the Pacific Coast as far inland as the headwaters of the Saskatchewan River (Cavender 1978; Hass and McPhail 1991). Bull trout have experienced substantial declines in abundance throughout their native range and they are currently listed as threatened in the United States under the US Endangered Species Act (US Fish and Wildlife Service 1999). Brook trout are native to eastern North America, historically ranging from Eastern Manitoba, Ontario, Minnesota and Iowa to the Atlantic Coast (MacCrimmon and Campbell 1969). Since the late 1800s brook trout have been introduced extensively outside their native range. As a result of these introductions brook trout have established naturalized populations throughout the native range of bull trout (MacCrimmon and Campbell 1969). In systems where the two species co-occur, bull trout typically occupy headwater habitats while brook trout typically occupy habitats further downstream with some overlap taking place (Paul and Post 2001; Rieman et al. 2006). When brook trout are introduced into headwater lakes, they are often found more widely dispersed throughout a stream (Adams et al. 2001).

Hybridization between bull trout and brook trout has been documented in several watersheds where the two species co-occur (Leary et al. 1993, 1995; Kitano et al. 1994; Kanda et al. 2002) and is seen as a major threat to the persistence of bull trout populations (Rieman et al. 1997). The degree of hybridization between the two species varies among watersheds (Leary et al. 1995; Kanda et al. 2002). Genetic studies utilizing allozyme markers indicated the majority of bull × brook hybrids appeared to be first generation (F1) and suggested that bull × brook hybrids were mostly sterile (Leary et al. 1993, 1995). More recent evidence from nuclear DNA markers has revealed increased numbers of post-F1 hybrids (F2 and backcrossed fish) although F1 hybrids still appear to be the dominant class (Kanda et al. 2002).

Previous studies of hybridization between bull trout and brook trout focused primarily on genetic species identification of individuals identified in the field as hybrids and

did not address the extent of hybridization in specific streams or the spatial distribution of bull trout, brook trout and hybrids in those streams. Recent studies of hybridization between other native and introduced salmonids have demonstrated that oftentimes the pattern of hybridization within a stream network is not random and that the extent of hybridization within a stream can be influenced by a number of biotic and abiotic factors (Weigel et al. 2003; Bettles et al. 2005; Rubidge and Taylor 2005; Boyer et al. 2008; Gunnell et al. 2008). Given these results, a more thorough examination of the spatial patterns of hybridization between bull trout and brook trout is warranted. Information on spatial patterns of hybridization will be important for identifying systems that may be more vulnerable to invasion by brook trout as well as guiding management actions (e.g. placement of barriers, selective removal of brook trout, habitat restoration) for protection or restoration of habitats and local populations of bull trout.

We studied patterns of hybridization between native bull trout and nonnative brook trout in the Malheur River basin in Eastern Oregon, USA. Recent bull trout population surveys in the upper Malheur River documented a number of individuals with intermediate phenotypic characteristics suggesting that hybridization is occurring in this river system. Given the concerns associated with bull trout hybridization, we wished to investigate the degree of hybridization in this system. There were two main objectives of this study. First, we wanted to identify a suite of nuclear microsatellite DNA markers that could be used to distinguish bull trout and brook trout and identify hybrids between the two species. Genetic confirmation of species identification will be useful for verifying the phenotypic characteristics that were used to perform species identification at the time of capture. Secondly, we wanted to use these markers to examine the spatial patterns of hybridization in three tributaries within the Malheur River Basin. Specifically, we were interested in determining the relative abundance of bull trout, brook trout and hybrids and whether the two species constitute separate populations or if there is random mating among the two species. Results of this work will be important for identifying areas where hybridization is most prevalent and establishing management and conservation strategies to benefit bull trout.

Methods

Study location

The Malheur River is a tributary to the Snake River in Eastern Oregon (Fig. 1). There are two populations of bull trout in the Malheur River; one in the headwaters of the North Fork Malheur River and one in the headwaters of the

Fig. 1 Study location; the Malheur River Basin, Oregon USA. **A** Shows the location of the Malheur River in Oregon. **B** Shows the location of the upper Malheur River where samples for this study were collected. **C** shows the location of the upper Malheur tributaries that were sampled for this project

upper Malheur River. Both of these populations are located above impassable dams and therefore isolated from one another. Brook trout are thought to have been introduced into the Malheur River system in the 1930s (Schwabe et al. 2004). Presently, naturalized populations of brook trout exist above a waterfall that prevents all upstream movement in Lake Creek, a tributary to the upper Malheur River, and in High Lake, the headwaters for Lake Creek (Fig. 1). These two areas are thought to provide a periodic source of brook trout recruitment for downstream habitat within the upper Malheur River. Recently, fish with intermediate phenotypic characteristics to those of bull and brook trout have been observed in tributaries of the upper Malheur River suggesting that hybridization between native bull trout and introduced brook trout may be occurring (Markle 1992; Schwabe et al. 2004).

Previous population assessments in the upper Malheur River Basin have documented local populations of bull trout in Big Creek, Meadow Fork (a tributary of Big Creek), and Lake Creek (Fig. 1) with both resident and migratory individuals observed (Bowers et al. 1993; Schwabe et al. 2004). Historically bull trout were also observed in Snowshoe Creek but the species was extirpated from this tributary following a wildfire in 1989 and now only brook trout are observed. Radio telemetry has shown

that migratory adult bull trout collected downstream of spawning areas in the upper Malheur River primarily utilize the Big Creek system for spawning (Big Creek and Meadow Fork; Schwabe et al. 2001; Fenton et al. 2006). It is suspected that bull trout in Lake Creek are primarily resident fish that are isolated due to current land use practices. Bowers et al. (1993) identified the lower reaches of Lake Creek as a potential thermal barrier to fish passage and irrigation water withdrawals also affect summer rearing bull trout in Lake Creek and disrupt migratory connectivity (Fenton et al. 2006). Recent population surveys found that bull trout outnumbered brook trout 15:1 in Meadow Fork, and a small number of hybrids were believed to be present. In Lake Creek however, brook trout are the dominant species outnumbering bull trout 8:1. Hybrids are believed to be much more prevalent in Lake Creek (Schwabe et al. 2004).

Sample collection

In order to identify a suite of markers that would distinguish bull trout and brook trout, we collected a total of 100 'learning samples': 33 fish that were identified in the field as bull trout, 33 fish that were identified in the field as brook trout and 34 fish that were identified in the field as

putative hybrids. These fish were all collected from Lake Creek. Samples were collected via electrofishing during July 2003 and field biologists identified species using basic phenotypic observations:

Bull trout—bright spotting on a dark back with clear or uniform colored dorsal fin

Brook trout—light green or creamy wavy lines on back with banding present on dorsal fin

Putative hybrid—white spotting present on dorsal fin that extends up $\geq 50\%$ of the total height of the dorsal fin *or* bright spotting on a dark back with banding present on dorsal fin

We also collected bull trout and brook trout from areas where the two species were allopatric. Thirty bull trout were collected from the upper North Fork Malheur River (Fig. 1) and 30 brook trout were collected from South Pine Creek, in northeastern Iowa, USA.

To examine the spatial patterns of hybridization in the Malheur River Basin we collected approximately 100 fish from each of three creeks: Lake Creek ($n = 108$), Big Creek ($n = 95$) and Meadow Fork ($n = 111$) (Fig. 1). Each creek was divided into an equal number of sites that represented the lower, middle and upper reaches. Sampling start locations were determined by public ownership of land. From the start location, 50 m sites were measured and sampled. One-hundred percent of the wetted channel was sampled upstream of the start location. In this case, sampling efforts did not target specific numbers of pure bull trout, pure brook trout or putative hybrids, but rather represented a random collection of the *Salvelinus* sp. present in each reach of the creeks sampled. A minimum of 30 fish was collected from each reach. In Big Creek, the lower reach was 600 m longer than the middle and upper reaches in order to obtain the minimum requirement of 30 fish per reach. Individuals were collected via electrofishing during July and August 2003 and 2004. Fin clips were taken from all fish collected and preserved in 100% non-denatured ethanol.

Laboratory analyses

We first extracted DNA from the 100 learning samples from Lake Creek, the 30 bull trout from the North Fork Malheur and the 30 brook trout from Pine Creek using a Chelex 100 (Sigma Chemical Co.) resin solution as described by Miller and Kapuscinski (1996). We screened a total of 46 microsatellite markers developed in bull trout, brook trout, rainbow trout (*O. mykiss*) and Dolly Varden (*S. malma*) to identify loci that appeared to distinguish bull trout and brook trout and identify hybrids (Online Appendix). PCR reactions were carried out in 15 μ l volumes containing 1X PCR buffer (10 mM Tris-HCl, 50 mM KCl, 1% Triton

X-100), 0.2 mM dNTPs, 0.5 μ M forward and reverse primer, 1.5 or 2.0 mM MgCl₂, and 0.2 U of *Taq* DNA polymerase (Promega Co.). PCR conditions were as follows: an initial DNA denaturation at 94°C for 3 min, followed by 38 cycles of 94°C for 30 s, 30 s at the primer specific annealing temperature, and extension at 72°C for 30 s, and a final annealing and extension at 72°C for 7 min.

Following PCR amplification, reactions were pooled and automated electrophoresis was carried out on an ABI 3130xl Genetic Analyzer (Applied Biosystems Inc., Foster City California) using the GeneScan-500LIZ size standard (Applied Biosystems, Inc.). Electropherograms were analyzed and genotypes were determined for each individual at each locus using the program GENEMAPPER v4.0 (Applied Biosystems, Inc.). We examined the quality of amplification, the distribution of alleles and the allele frequencies for all 46 loci and selected a group of loci that consistently amplified in both species and showed no overlap in allele size between species (i.e. diagnostic markers).

We then extracted DNA from the individuals collected in each of the three creeks to analyze the spatial patterns of hybridization. DNA was extracted from all samples using the Chelex method described above. All samples were then genotyped following the procedures described above using a sub-set of 11 loci we identified to distinguish the two species (see Appendix 1 for PCR conditions). The use of multiple microsatellite loci allowed us to classify hybrid individuals as either F1 hybrids, later generation hybrids (e.g. F2) or as backcrossed individuals with either of the two parental species.

In addition to microsatellite DNA markers, we also amplified a region of the mitochondrial cytochrome B gene for all fish identified as hybrids to determine the direction of hybridization. PCR reactions for mtDNA analysis were conducted in 15 μ l volumes and contained 1X PCR buffer (10 mM Tris-HCl, 50 mM KCl, 1% Triton X-100), 0.5 mM dNTPs, 0.5 μ M of forward primer 765F (Brown and Thorgaard 2002), 0.5 μ M of reverse primer 766R (Brown and Thorgaard 2002), 2.5 mM MgCl₂, and 0.2 U of *Taq* DNA polymerase (Promega Co.). PCR conditions were as follows: 38 cycles of 95°C for 45 s, 54°C for 40 s and 70°C for 2 min 30 s, followed by a final extension at 72°C for 3 min. PCR products were then digested overnight with the restriction enzyme *Rsa* I (New England Biolabs) according to the manufactures' instructions. Fragments were separated on 2% agarose gels stained with ethidium bromide and visualized using UV light. Fragment banding patterns produced by each sample were then compared to samples of known bull trout and brook trout from allopatric populations to confirm the diagnostic nature of this marker and to determine the mtDNA lineage for each hybrid fish. Bull trout produced bands of 550, 400,

250 and 50 base pairs and brook trout produced bands of 500, 400, 200, and 150 base pairs (Schriever et al. 2004).

To determine our genotyping error rate, 10% of the samples analyzed plus all individuals genetically identified as hybrids were re-analyzed (i.e. DNA was re-extracted and samples were re-genotyped). A total of 95 samples were re-analyzed for error analysis.

Statistical analyses

We used a simple hybrid index (Campton and Utter 1985; Rubidge and Taylor 2004) to classify individuals as pure bull trout, pure brook trout or bull trout $\times$ brook trout hybrids. For each individual the number of brook trout alleles present was summed and divided by the total number of alleles. Individuals possessing all bull trout alleles (hybrid index score of 0.0) were considered pure bull trout and individuals possessing all brook trout alleles (hybrid index score of 1.0) were considered pure brook trout. Individuals with some combination of both bull trout and brook trout alleles were classified as hybrids. Individuals that were heterozygous for a bull trout and a brook trout allele at each locus were considered to be first generation (F1) hybrids (hybrid index score 0.5). Individuals that possessed both bull trout and brook trout alleles and had at least one locus that was homozygous for each parental genotype were considered later generation hybrids (Fn). Individuals that possessed both bull trout and brook trout alleles and had loci that were homozygous for only one of the parental species were considered backcrosses with the parental species (BC_Brook or BC_Bull). These methods were used to classify all of the learning samples as well as the random collections from the three creeks.

For the random collections from each creek, we conducted a chi-squared contingency table analysis to determine if bull trout, brook trout and hybrids were evenly distributed among the three sections of each creek. Because very few individuals of a certain class were observed in some sections of the three tributaries (e.g. 1 hybrid observed in upper Meadow Fork), we performed a Fisher exact test to determine if there were significant differences in species distribution among the three sections of each creek (Zar 1999). We used tests for gametic disequilibrium to determine if the sample of fish from each creek represented multiple spawning populations or if a single *Salvelinus* mating population was present in each creek. Forbes and Allendorf (1991) suggest hybridized populations containing two distinct spawning populations (e.g. bull trout and brook trout) should show evidence of gametic disequilibrium at a high number of loci whereas hybridized populations containing a single mating population (i.e. hybrid swarm) should not show evidence of gametic disequilibrium. Tests for gametic disequilibrium were

conducted using the program GENEPOP v4.0 (Raymond and Rousset 1995) and significance values were adjusted for multiple comparisons using a Bonferroni adjustment (Rice 1989).

Although a self sustaining population of brook trout exists in High Lake and Lake Creek, it was unclear if the other two creeks contained additional brook trout spawning populations or if brook trout collected in Big Creek and Meadow Fork were individuals that originated in Lake Creek. We used the Bayesian clustering method of STRUCTURE v2.2 (Pritchard et al. 2000) to investigate the population structure of brook trout in the upper Malheur system. We applied the admixture model that assumes gene flow among populations and allows for correlations of allele frequencies across clusters. This admixture model assigns a proportion of each individual's genome to each of the clusters pursuing solutions that maximize Hardy-Weinberg equilibrium (HWE) and linkage equilibrium within clusters. Using data from all individuals collected during the random sampling efforts that were genetically identified as pure brook trout, 20 replicated unsupervised STRUCTURE runs were performed for each K from 1 to 7. All runs had a burn-in of 30,000 iterations followed by 100,000 iterations. We used the method of Evanno et al. (2005) to infer the correct value of K for the dataset. Evanno et al. (2005) suggested that the method of Pritchard et al. (2000) often leads to an over estimate of K and recommended using the second order rate of change between K and $K + 1$ clusters, Delta K , as a more effective identifier of the correct K for the dataset.

The symmetric similarity coefficient (SSC) was used to determine the similarity of outcomes among the 20 replicate STRUCTURE runs for each K . Using the LargeK-Greedy algorithm of CLUMPP (Jakobsson and Rosenberg 2007) with 1,000 random input sequences we determined the number of distinct modes among the 20 runs at each K by grouping pairs of runs that had a SSC >0.9. Graphical displays of STRUCTURE results were generated based on each individual's mean membership in each cluster over the replicate runs.

Following the STRUCTURE analysis, brook trout were grouped into one of three putative clusters (the most likely outcome of the STRUCTURE analysis; see below) based on the cluster they had the greatest level of ancestry from (i.e. maximal q value). Putative clusters were tested for conformance to HWE expectations using an exact test implemented in the program GENEPOP and significance values were adjusted for multiple comparisons using a sequential Bonferroni adjustment (Rice 1989). We estimated measures of genetic variation including mean number of alleles per locus and expected and observed heterozygosity within each putative brook trout population using the program FSTAT v2.9.3.2 (Goudet 2001). To account for differences in

samples size among brook trout populations, we also used FSTAT to estimate allelic richness based on a minimum sample size of 49 individuals. We conducted Wilcoxon's signed rank tests (Zar 1999) to test for significant differences in allelic richness and expected and observed heterozygosity among the putative clusters. FSTAT was also used to estimate the overall level of genetic variation among clusters and the associated 95% confidence level based on 1,000 bootstrap replicates as well as the level of genetic variation among pairs of clusters (F_{ST} ; Weir and Cockerham 1984).

The microsatellite markers used in this study were chosen for their ability to distinguish bull trout and brook trout and most of the loci chosen showed little variability within bull trout (Appendix 1). Because of this we did not perform a STRUCTURE analysis to determine the number of bull trout populations present in the upper Malheur River.

Results

Error analysis

A total of 95 samples were re-analyzed for the error analysis. When we excluded missing genotypes due to failed PCR, we found 67 alleles that did not match between the original genotype and the error analysis genotype resulting in an overall error rate of 3.3%. Approximately 33% of these errors were due to allele dropout and 67% were due to genotyping errors. The majority of the genotyping errors occurred in two individuals. These two fish were removed from subsequent analyses. Re-genotyping confirmed the genotypes and classifications of all hybrid individuals.

Selection of loci and analysis of learning samples

Of the 46 microsatellite loci screened, we selected a subset of 11 loci that were easily amplified and scored and exhibited diagnostic differences between bull trout and brook trout (i.e. no overlap in the distribution of alleles). Diagnostic differences were consistent across allopatric and sympatric sampling areas. Our set of loci included: *Omm1128*, *Sco102*, *Sco104*, *Sco202*, *Sco204*, *Sco215*, *Sco216*, *Sco217*, *Sco218*, *Sfo18* and *SfoC88* (see Appendix 1 for PCR conditions and measures of diversity). Six of the learning samples failed to amplify at more than five loci and were excluded from further analysis. Using these loci we identified 26 pure bull trout and 35 pure brook trout in the group of learning samples. The remaining 33 individuals had a combination of bull trout and brook trout alleles, indicating that hybridization was indeed taking place in Lake Creek. Several of the learning samples had hybrid

index scores consistent with backcrossed individuals and later generation hybrids (Fig. 2) and examination of the genotypes of these individuals confirmed the presence of Fn hybrids (hybrid index score 0.71), BC_Brook (hybrid index scores 0.68–0.90) and BC_Bull (hybrid index scores 0.22–0.40).

Of the 33 fish that we identified as hybrids in the group of learning samples, 24 were identified as F1 hybrids, five of which had brook trout mtDNA genotypes and 19 of which had bull trout mtDNA genotypes. Two of the learning samples were identified as a backcross with a bull trout and both of these fish had bull trout mtDNA genotypes. Six of the learning samples were identified as a backcross with a brook trout and all six had brook trout mtDNA genotypes. One of the learning samples was identified as a later generation hybrid and this individual had brook trout mtDNA. Analysis of the allopatric bull trout and brook trout samples confirmed that the mtDNA marker was diagnostic between the two species.

Overall we found that the field identification based on the phenotypic characteristics described above corresponded to the genetic identification 89% of the time. All of the brook trout in the group of learning samples were correctly identified as brook trout in the field. Of the 31 fish we analyzed that were identified in the field as bull trout, 25 were genetically identified as bull trout and 6 of them were genetically identified as hybrids. Four of these six hybrids were identified as F1s and the remaining two were identified as BC_Bull. Of the 31 fish we analyzed that were identified in the field as hybrids, 27 of them were genetically identified as hybrids (F1 and post-F1), four were genetically identified as brook trout and one was genetically identified as a bull trout. In summary, 100% of the brook trout were correctly identified in the field, 80% of the bull trout were correctly identified in the field and 87% of the hybrids were correctly identified in the field.

Spatial distribution of species

Two samples from each creek failed to amplify and were excluded from further analysis. When we examined the species distribution in each of the three creeks, genetic analyses showed that brook trout, bull trout and hybrids were present in all three of the creeks surveyed. In Lake Creek the majority of the fish sampled (89 out of 106) were genetically identified as brook trout and their distribution was nearly equal among the 3 sections of the creek. Bull trout and hybrids were only found only in middle and upper Lake Creek Lake, however (Table 1; Fig. 3). The greatest number of hybrids ($n = 10$) was observed in Lake Creek. The majority of the fish sampled in Big Creek were genetically identified as brook trout (74 of 93). Unlike Lake Creek, the majority of the brook trout in Big Creek

Fig. 2 Hybrid index scores for 94 learning samples collected in Lake Creek. A score of 0.0 indicates that an individual is a pure bull trout and a score of 1.0 indicates an individual is a pure brook trout. The distribution of scores suggests that hybridization does occur and does proceed beyond the F1 generation

were found in the lower and middle sections. There were 18 bull trout in Big Creek, 16 of which were found in the upper section. One fish from upper Big Creek was genetically identified as a hybrid (Table 1; Fig. 3). The majority of the fish sampled in Meadow Fork were genetically identified as bull trout (100 of 109) and were distributed nearly equally among the three sections of the creek (Table 1; Fig. 3). Six fish in Meadow Fork were genetically identified as brook trout and three fish were genetically identified as hybrids (Table 1; Fig. 3).

Of the 14 fish identified as hybrids in our random sample of the three creeks, five were classified as F1 (one from Meadow Fork, four from Lake Creek), six were classified as Fn (two from Meadow Fork, four from Lake Creek) and three were classified as BC_Brook (one from Big Creek, two from Lake Creek; Fig. 3). All of the F1 hybrids had bull trout mtDNA, three of the Fn hybrids had bull trout

mtDNA and three had brook trout mtDNA and all of the BC_Brook hybrids had brook trout mtDNA.

Chi-squared contingency table analysis revealed a non-uniform distribution of species classes (bull, brook, hybrid) among the three sections (lower, middle, upper) of all three creeks surveyed (Table 1). In each of the three creeks we observed the following number of locus pairs (out of 55) that showed evidence of gametic disequilibrium: Big Creek 52 pairs of loci, Meadow Fork 53 pairs of loci, and Lake Creek 22 of pairs of loci ($P < 0.001$).

Five clusters (i.e., $K = 5$) had the highest mean probability in the brook trout STRUCTURE analysis ($\text{LnP(D)} = -5,253.94$). However, estimates of ΔK indicated that a K of 3 ($\Delta K = 8.82$) was the appropriate value for the number of brook trout clusters with a second most likely K of 4 ($\Delta K = 4.60$). We plotted proportional membership for individuals assuming a K of 3 (Fig. 4). Results for the 20

Table 1 Chi-squared contingency table analysis of the spatial distribution of bull trout, brook trout and hybrids for each of the three Malheur River tributaries

	Lake Creek*			Big Creek***			Meadow Fork*		
	Bull	Brook	Hybrid	Bull	Brook	Hybrid	Bull	Brook	Hybrid
Lower	0 (2.11)	32 (26.87)	0 (3.02)	1 (6.19)	31 (25.46)	0 (0.34)	25 (28.70)	4 (1.44)	2 (0.86)
Middle	3 (2.58)	32 (32.75)	4 (3.68)	1 (6.19)	31 (25.46)	0 (0.34)	35 (33.33)	1 (1.67)	0 (1.00)
Upper	4 (2.31)	25 (29.39)	6 (3.30)	16 (5.61)	12 (23.08)	1 (0.31)	40 (37.96)	1 (1.90)	1 (1.14)

In each cell the first value represents the observed number of each type and the value in parentheses represents the expected values. Significance levels were evaluated using a Fisher's exact test

* $P < 0.05$; *** $P < 0.0001$

Fig. 3 Spatial distribution of bull trout, brook trout and hybrids in the Malheur River system. *Horizontal lines* through the streams show the approximate boundaries of the different sampling strata (*lower, middle, upper*). The number of fish sampled in each strata can be found in Table 1

replicate STRUCTURE runs with $K = 3$ showed a high degree of consistency ($SSC = 0.968$). Brook trout with membership to cluster 1 were found almost exclusively in Lake Creek. Individuals with membership to cluster 2 were found in all sampling locations. Fish with membership to cluster 3 were found primarily in Big Creek/Meadow Fork and to a lesser extent in the lower section of Lake Creek (Fig. 4).

When brook trout were grouped into three putative clusters, all three clusters conformed to HWE expectations at all loci. Estimates of variation within the three clusters were similar (Table 2) and we observed no significant differences in any of these measures among the three clusters (Wilcoxon's signed rank tests $P > 0.05$). The overall level of genetic variation among brook trout clusters (i.e. F_{ST}) was 0.055 (95% CI 0.029–0.083). We observed the greatest amount of genetic divergence among clusters 1 and 3 ($F_{ST} = 0.064$; $P < 0.05$) and the least amount of divergence among clusters 2 and 3 ($F_{ST} = 0.046$; $P < 0.05$). The level of divergence among clusters 1 and 2 was 0.055 ($P < 0.05$).

Discussion

Genetic markers have been used to document hybridization between bull trout and brook trout in multiple river systems where the two species co-occur (Leary et al. 1993, 1995; Spruell et al. 2001; Kanda et al. 2002). While some earlier studies were limited by the number and types of markers used (e.g. allozymes, Leary et al. 1993; PINES, Spruell et al. 2001), the use of multiple microsatellite loci in this study allowed us not only to identify individuals with hybrid ancestry, but also to classify individuals as F1, backcross and later generation hybrids, and determine the extent of hybridization in the upper Malheur River. Our analyses demonstrated that hybridization does proceed beyond the F1 generation in the upper Malheur River. Furthermore mtDNA analyses of F1 and Fn hybrids suggest that hybridization events involve both male and female bull trout. Although the two species co-occur in each of the three streams we surveyed, in our random sample from the three streams we documented relatively few hybrids overall (14 hybrids out of 307 fish analyzed) and the species appear to remain genetically distinct.

Fig. 4 Output from the program STRUCTURE assuming three ($K = 3$) populations of brook trout in the upper Malheur River system. Each vertical bar on the graph corresponds to an individual and the different shaded regions represent the proportional membership in each of the three clusters. Individuals are grouped by sampling

locations and sampling locations are arranged with increasing distance from High Lake (at the headwaters of Lake Creek), the original source of brook trout introduction. Because only five brook trout were observed in Meadow Fork, they were combined into a single group on the graph

Table 2 Estimates of genetic variation (based on 11 microsatellite loci) within the three upper Malheur brook trout clusters identified by the program STRUCTURE

Cluster	<i>n</i>	<i>A</i>	<i>A_R</i>	<i>H_{exp}</i>	<i>H_{obs}</i>
1	62	6.909	6.662	0.605	0.612
2	56	7.273	7.194	0.664	0.663
3	50	6.909	6.884	0.656	0.648
Mean		7.030	6.913	0.642	0.641

n Number of individuals; *A* Mean number of alleles per locus; *A_R* Allelic richness based on a minimum sample size of 49 individuals; *H_{exp}* Heterozygosity expected; *H_{obs}* Heterozygosity observed

Identification and classification of hybrids

Our analyses showed that there was a high correlation between phenotypic (field) and genetic methods of species identification. Among the learning samples from Lake Creek, we found that the genetic identification corresponded to the field identification 89% of the time. This suggests that the criteria established for identifying the different species in the Malheur River Basin are fairly accurate. It is important to consider, however, that this study only tested these identification criteria in the Malheur River Basin and the same criteria may not be as effective when dealing with bull trout and brook trout in other geographic locations. For example, Baumsteiger et al. (2005) found that the percentage of cutthroat trout, steelhead trout and hybrids correctly classified in the field varied substantially among three watersheds where these two species were sympatric.

Hybridization among members of the genus *Salvelinus* is not uncommon (Hammar et al. 1991; Wilson and Hebert

1993; Baxter et al. 1997). While the majority of hybrids documented among *Salvelinus* have been F1s, post-F1 hybrids have been produced for aquaculture (Anderson and Collins 1995) and observed in the wild (Baxter et al. 1997). Previous studies of bull trout $\times$ brook trout hybridization documented primarily F1 hybrids between these two species (Leary et al. 1993, 1995). Although post-F1 hybrids have been documented (Kanda et al. 2002), it has been suggested that the majority of the bull trout $\times$ brook trout hybrids are sterile (Leary et al. 1995). Between the learning samples and the random samples from each of the three creeks, we identified 47 fish with hybrid ancestry, 18 of which were identified as post-F1. These data indicate that a number of hybrids in the Malheur River system are capable of successful reproduction.

Oftentimes hybrids express phenotypic characteristics that are intermediate to those of the parental species; however, this is not always the case, especially for post-F1 hybrids (Rhymer and Simberloff 1996; Allendorf et al. 2001). Previous studies that examined hybridization between bull trout and brook trout focused on the genetic identification of fish phenotypically identified as hybrids and documented primarily F1 hybrids (Leary et al. 1993, 1995). The fact that our collection efforts targeted not only individuals with intermediate phenotypes but also phenotypic bull trout and brook trout is one possible explanation for the increased number of post F1 hybrids we observed. A number of post-F1 hybrids in this study were mistakenly identified in the field as one of the parental species. Collection efforts that specifically targeted fish with intermediate phenotypes may have missed post-F1 hybrids that phenotypically resembled one of the parental species. Based on our data, it seems that to truly understand the

extent and degree of hybridization in a population, it is best not to limit collections only to individuals that phenotypically appear to be hybrids.

The increased number of post-F1 hybrids we observed in this study may also be related to the sheer abundance of brook trout in the upper Malheur system, specifically in Lake Creek. Recent population surveys found that brook trout outnumber bull trout in Lake Creek by a ratio of 8:1 (Schwabe et al. 2004), presumably due to periodic downstream recruitment from a population of brook trout in a headwater lake. Given the abundance of brook trout and the paucity of bull trout in Lake Creek, spawning opportunities for bull trout would likely favor hybrid matings and backcrosses. It is worth noting that Lake Creek was the only location where we observed individuals classified as BC_Bull and the learning samples also contained a number of BC_Brook. In a study of hybridization in five streams in Montana, Kanda et al. (2002) also observed greater numbers of post-F1 hybrids in a stream where brook trout significantly outnumbered bull trout.

Spatial distribution of species

In our random sample of 307 fish from the three creeks, we found that bull trout, brook trout and hybrids were present in all three creeks; however we observed only 14 hybrid individuals total, the majority of which came from Lake Creek. Although brook trout have been present in the Malheur River system for over 70 years, these data suggest that although the two species co-occur in all three creeks, some isolating mechanism(s) exists that allow the two species to maintain their genetic integrity and distinctiveness. The greatest overlap between the two species was in upper Big Creek where we observed 16 bull trout and 12 brook trout yet only one hybrid. The substantial number of loci that were out of gametic equilibrium in each creek provides further evidence that separate spawning populations exist in these three creeks; i.e. we observed no evidence of a hybrid swarm. These results were similar to those of Leary et al. (1995) and Kanda et al. (2002) who also found that overall the two species appear to maintain their genetic distinctiveness when they co-occur.

Spatial segregation of species in different habitats may facilitate a degree of reproductive isolation between non-native brook trout and native bull trout. In a study of sympatric populations of Dolly Varden and bull trout, Hagen and Taylor (2001) suggested constrained gene flow between these two species was the result of differential habitat use. Studies of spatial segregation between bull trout and brook trout have found when the two species occur sympatrically, brook trout generally occupy the lower regions of the stream and bull trout generally occupy the upper regions (Paul and Post 2001; Rieman et al. 2006).

Contingency table analysis showed that the species were not equally distributed in any of the three creeks we surveyed. In Big Creek the dominant species shifted from brook trout in the lower reaches of the stream to bull trout in the upper reaches. In Meadow Fork the majority of the brook trout are also found in the lower reaches of the stream (Table 1; Fig. 3). Bull trout populations are highly sensitive to temperature (Selong et al. 2001; Dunham et al. 2003) as well as habitat modifications (Rieman et al. 1997; Baxter et al. 1999) and laboratory studies have found that brook trout can have a competitive advantage at warmer temperatures (McMahon et al. 2007; Rodtka and Volpe 2007). The upper reaches of all three streams are located at higher elevations within a designated wilderness area and water temperatures and habitat remains relatively pristine, presumably areas that are more favorable for bull trout. Recent surveys of the physical stream conditions in the upper Malheur River basin classified the upper sections of Big Creek and Lake Creek and all of Meadow Fork as nearly 100% of historic conditions. Habitat in the lower reaches of Big Creek was classified as 77% of historic conditions and habitat in lower Lake Creek was classified as 65% of historic conditions (Malheur Watershed Council and Burns Paiute Tribe 2004). Habitat degradation in the lower reaches of the streams we surveyed is another likely cause for the species distribution pattern we observed.

The distribution of species in Lake Creek was somewhat different however; although bull trout were found only in the middle and upper sections (in relatively small numbers), large numbers of brook trout were also found in the upper section of the creek (Table 1; Fig. 3). The difference we observed in the species distribution in Lake Creek is likely due to a self sustaining population of brook trout that exists in the headwaters of the creek (i.e. High Lake; Fig. 1). Adams et al. (2001) found that when brook trout are introduced into a stream via a headwater lake and disperse downstream they tend to be more widely distributed throughout the watershed. Additionally, habitat in the lower reaches of Lake Creek has been modified for irrigation and agricultural purposes (Fenton et al. 2006) and it has been suggested that increased water temperature in the lower section of Lake Creek acts as a thermal barrier for migratory bull trout (Bowers et al. 1993). The combination of these factors may be excluding migratory bull trout from historic spawning grounds in Lake Creek (Schwabe et al. 2004) and preventing bull trout spawning necessary to maintain the population in Lake Creek.

Although High Lake at the headwaters of Lake Creek was the original source of brook trout in the upper Malheur, our results indicate the presence of multiple brook trout populations/clusters within the system. Individuals from one cluster were found primarily in upper and middle Lake

Creek (cluster 1), individuals from a second cluster were found in lower Lake Creek and Big Creek (cluster 2) and individuals in a third cluster were found primarily in Big Creek and Meadow Fork (cluster 3; Fig. 4). Levels of genetic variation among clusters suggested that the least amount of gene flow occurs among clusters 1 and 3 and greater levels of gene flow occur among adjacent clusters. Although we are unaware of physical barriers that would prevent migration of brook trout among upper Malheur River tributaries, thermal barriers and degraded habitat in the lower reaches of Lake Creek that presumably limit bull trout migration may limit brook trout migrations among Lake Creek and Big Creek/Meadow Fork as well. Analysis of brook trout from the original source population in High Lake will be important to fully understand the pattern of brook trout invasion and population structure in the upper Malheur River. Our results illustrate that brook trout in Big Creek and Meadow Fork are not necessarily migrants from upper Lake Creek. Conservation efforts aimed at controlling brook trout in the system should take into account that multiple spawning populations are present and not focus solely on High Lake and upper Lake Creek.

Direction of hybridization

In cases where hybridization is observed between naturally sympatric salmonids, it is often unidirectional (Redenbach and Taylor 2003; Baumsteiger et al. 2005; Kozfkay et al. 2007). Previously Kitano et al. (1994) observed smaller, resident brook trout males “sneaking” fertilizations with larger, migratory bull trout females. Mitochondrial DNA data suggest that this behavioral mechanism is not solely responsible for hybridization in the Malheur River. We observed F1 and F_n hybrids with both bull trout and brook trout mtDNA genotypes illustrating that hybridization proceeds in both directions in the Malheur system. These results were similar to other studies involving hybridization between native and introduced salmonids, including bull trout and brook trout (Kanda et al. 2002; Rubidge and Taylor 2004; Gunnell et al. 2008). Kanda et al. (2002) reported that hybridization between bull trout and brook trout was unidirectional (male brook trout with female bull trout) in three populations, but they observed reciprocal hybridization between bull trout and brook trout in another population that had a higher proportion of brook trout. When two species evolve separately and behavioral isolating mechanisms are weak, demographic factors seem to influence the direction of hybridization (Forbes and Allendorf 1991; Gunnell et al. 2008). The results of our study and others (Kanda et al. 2002) suggest that this is the case for bull trout and brook trout hybridization events, particularly in streams such as Lake Creek where brook trout significantly outnumber bull trout.

Conservation implications

Bull trout are currently listed as a threatened species under the United States endangered species act and hybridization with brook trout is viewed as a major threat to their persistence (US Fish and Wildlife Service 1999). Extinction of local bull trout populations presumably due to hybridization has been documented in systems where large numbers of brook trout were present (Leary et al. 1993; Kanda et al. 2002). In our survey of Lake Creek, brook trout outnumbered bull trout in our random sample by a ratio greater than 10:1 (89 brook trout vs. 7 bull trout). These numbers were consistent with previous population surveys in Lake Creek that found brook trout outnumbered bull trout by a ratio of 8:1 (Schwabe et al. 2004). We also observed greater numbers of hybrids in Lake Creek ($n = 10$) than the other two streams we surveyed. Given that brook trout may display a competitive advantage in some cases when the two species are sympatric (Gunkel et al. 2002; McMahon et al. 2007), interspecific competition has likely contributed to the low abundance of bull trout as well. The likely threats posed by brook trout in Lake Creek suggest that active measures (e.g. construction of barriers to exclude brook trout, selective removal of brook trout; Buktenica 1997) may be needed to ensure long-term persistence of bull trout in this tributary.

In addition to species abundance, there are other important factors that may influence hybridization between bull trout and brook trout. Although brook trout were the predominant species in Big Creek as well, we found only one hybridized individual in Big Creek and three hybrids in Meadow Fork. As mentioned above, habitat in the lower section of Lake Creek has been highly modified and temperatures in sections of Lake Creek are thought to be unsuitable for bull trout. Although habitat in lower Big Creek has also been somewhat degraded, upper Big Creek and Meadow Fork likely provide a refuge for bull trout where habitat remains relatively pristine and, unlike upper Lake Creek, few brook trout are present. The persistence of migratory bull trout has also been recognized as an important factor for the persistence of bull trout populations (Northcote 1997; Rieman and Dunham 2000; Nelson et al. 2002). Although migratory bull trout spawn in Big Creek and Meadow Fork, they are absent from Lake Creek presumably due to seasonal thermal barriers downstream of spawning habitat. In conclusion, the variable pattern of hybridization we observed in the Malheur River can be attributed both to differences in the relative abundance of brook trout and bull trout as well as environmental conditions that may favor one species at the expense of the other. A clear understanding of these different influences can help to guide restoration actions to benefit native bull trout. In the Malheur River, controlling brook trout alone

Table 3 PCR conditions and estimates of diversity for the 11 diagnostic microsatellite loci selected for this study

Locus name	Multiplex set ^a	Flourescent label	T_A	$MgCl_2$ concentration (mM)	Reference/ accession number	<i>S. confluentus</i>				<i>S. fontinalis</i>									
						Upper North Fork Malheur River		Upper Malheur River		Lake Creek		South Pine Creek		Upper Malheur River		Lake Creek			
						Size range	NA	Size range	NA	H_{exp}	H_{obs}	HWE	Size range	NA	Size range	H_{exp}	H_{obs}	HWE	
<i>Omm1128</i>	MS1	VIC	50	1.5	Rexroad et al. (2001)	277–331	5	277–327	4	0.651	0.720	0.269	215–235	3	208–268	10	0.768	0.833	0.536
<i>Sco102</i>	MS1	VIC	55	1.5	AY973576 ^b	167–171	2	163–171	3	0.038	0.038	–	129–133	2	129–133	2	0.282	0.333	0.560
<i>Sco204</i>	MS1	NED	60	1.5	DeHaan and Ardren (2005)	185–193	3	189–193	2	0.000	0.000	–	123–139	4	107–185	14	0.873	0.889	0.446
<i>Sco215</i>	MS1	PET	55	1.5	DeHaan and Ardren (2005)	289–293	2	289–293	2	0.498	0.615	0.257	335–345	3	329–349	9	0.493	0.556	0.855
<i>Sfo18</i>	MS1	PET	52	1.5	Angers et al. (1995)	149	1	149	1	0.000	0.000	–	173–181	5	173–187	7	0.720	0.667	0.129
<i>Sco202</i>	MS2	6FAM	50	1.5	DeHaan and Ardren (2005)	127–135	2	127–135	2	0.509	0.654	0.236	104–108	2	104–108	2	0.504	0.528	1.000
<i>SfoC88</i>	MS2	6FAM	58	1.5	AY168192 ^c	167	1	167	1	0.000	0.000	–	183–193	4	181–199	7	0.744	0.750	0.406
<i>Sco104</i>	MS2	VIC	55	1.5	AY973578 ^b	350–480	8	411–472	7	0.688	0.731	1.000	269–287	4	265–350	15	0.714	0.667	0.388
<i>Sco217</i>	MS2	NED	60	1.5	DeHaan and Ardren (2005)	214–341	7	214–341	8	0.812	0.808	0.220	184	1	168–204	4	0.230	0.250	1.000
<i>Sco216</i>	MS2	PET	55	1.5	DeHaan and Ardren (2005)	241–260	4	241–264	4	0.571	0.692	0.492	135–173	4	131–177	10	0.730	0.750	0.913
<i>Sco218</i>	MS3	PET	55	1.5	DeHaan and Ardren (2005)	222–226	2	222–226	2	0.000	0.000	–	158–174	4	140–218	14	0.873	0.886	0.455

The size range and number of alleles observed at each locus for each species is given separately for allopatric and sympatric populations. Estimates of heterozygosity and conformance to Hardy–Weinberg expectations are based on 26 bull trout and 35 brook trout collected from Lake Creek in 2003

^a The loci in each multiplex set were amplified separately and combined for electrophoresis following PCR

^b Ken Warheit and Sewall Young, Washington Department of Fish and Wildlife, personal communication

^c Tim King, US Geological Survey, personal communication

T_A Locus specific annealing temperature; NA number of alleles observed; H_{exp} heterozygosity expected; H_{obs} heterozygosity observed; HWE P -value for Hardy–Weinberg exact test

may not be sufficient to benefit bull trout. An emphasis on restoring environmental conditions that favor bull trout may be equally important over the long-term.

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Appendix 1

See Table 3.

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