Crooked River Redband Trout Study

Jason Vaughan[1], Shadia Duery[1], Todd W. Kassler[2], and Ian Courter[1]

[1]Cramer Fish Sciences 600 NW Fariss Road Gresham, OR

[2]WDFW Molecular Genetics Laboratory 600 Capitol Way N Olympia, WA

For

Ochoco Irrigation District

October 2013

Suggested Literature Citation:

Vaughan, J., S. Duery, T. Kassler, and I. Courter*. 2013. Crooked River Redband Trout Study. Cramer Fish Sciences. Gresham, Oregon. Report Prepared for Ochoco Irrigation District, Prineville, Oregon.

*Corresponding author: courter@fishsciences.net, 503-491-9577

Acknowledgements: We would like to thank Brett Hodgson, ODFW for his assistance planning our study, as well as Tim Porter, ODFW for helping with the electrofishing surveys and sending us valuable information from ODFW’s database. We also appreciate the generosity of those that shared their reports and research findings.

TABLE OF CONTENTS

List of Figures iv

Project Background 1

Introduction 1

Redband Trout Distribution in the Crooked River Basin 2

Life-History of Redband Trout in the Crooked River Basin 6

Methods 7

  Habitat Survey 8

  Electrofishing 8

  Genetic Analysis 9

Results 13

  Habitat Survey 13

  Electrofishing 15

  Genetic Analysis 18

Discussion 22

References 24

Appendix 28

List of Figures

Figure 1. Redband trout density below Bowman Dam. (Estimates are for trout >8” and calculated using unpublished ODFW data from mark-recapture sampling in the 3.6 km reach below Bowman Dam, population abundance estimates calculated using the Lincoln-Petersen method). 5

Figure 2. Map of the Crooked River basin and study reach below Prineville Reservoir (Bowman Dam) detailing the location of the eight 100-meter survey sites. 11

Figure 3. Substrate composition in each mesohabitat (P = pool, RI = riffle, GL = glide) unit surveyed in the 1.6 km reach below Bowman Dam in May and October 2012. Unit 1 begins approximately 100 meters downstream of Bowman dam... 14

Figure 4. Water temperature and dissolved oxygen measurements within each of the 100 meter electrofishing survey sites in May. All measurements were taken within a half an hour to ensure temporal fluctuations did not alter values. (Site 8 is closest to the dam)..................................... 15

Figure 5. Length distribution of redband trout captured while backpack electrofishing during the spring and fall of 2012 below Bowman Dam, compared to the 12-year average length distribution calculated from ODFW boat electrofishing surveys below Bowman Dam. 17

Figure 6. Predicted age composition of redband trout captured during annual ODFW boat electrofishing surveys, 1996-2011, and backpack electrofishing surveys, May and October 2012, downstream of Bowman Dam. 18

Figure 7. Factorial correspondence analysis conducted with GENETIX showing the distribution of steelhead from upper and lower Crooked River, Round Butte Hatchery and a collection of samples with unknown origin. 20

Figure 8. Length-frequency distribution of redband trout genetically assigned to the upper Crooked River and Round Butte Hatchery. 21

Project Background

The Crooked River Habitat Conservation Plan, currently being developed by Ochoco Irrigation District (OID) along with other local, State and Federal stakeholders, identified the need for a redband trout (*Oncorhynchus mykiss gairdneri*) population assessment downstream of the Arthur R. Bowman Dam (Bowman Dam), and existing, relevant and available information regarding redband trout in the river reach directly below Bowman Dam was thought to be insufficient to analyze potential effects of proposed hydroelectric development. Additional data and information synthesis is necessary to establish baseline population information for the 1.6 km reach below Bowman Dam. This will be used to compare current operations with potential hydropower operation, should a hydroelectric project be constructed at Bowman Dam. Consultation with state and federal fishery agencies and other interested parties indicated the preferred methods of evaluating potential effects of a hydroelectric project on redband trout include literature review, assembly of existing, unpublished data, and electrofishing surveys.

Primary project objectives include the following:

1. Characterize the population biology and distribution of redband trout in the upper Crooked River basin, including the Chimney Rock reach below Bowman Dam and in the tributaries to Prineville Reservoir.
2. Analyze potential effects of construction and initial operation of a hydroelectric project on production, survival, and growth of redband trout in the one-mile reach below Bowman Dam.

Introduction

Redband trout are a phenotypically distinct form of rainbow trout endemic to arid and semi-arid climates east of the Cascade Mountain Range, including central and eastern Washington, Oregon, and Northern California. They exhibit a wide tolerance for both cool and warm temperatures (>28°C) (Li et al. 2007), necessary for persistence in volcanic, high desert regions, which distinguishes redband from their coastal rainbow counterparts. As with all O. mykiss ecotypes, redband trout express a variety of life-history tactics, including resident and migratory types.

The historical range of redband trout included freshwaters west of the Rocky Mountains, extending from northern California to northern British Columbia, Canada (Stuart et al. 2007), and they remain the most widely distributed salmonid in the interior Columbia River basin (Thurow et al. 2007). Although redband trout were broadly distributed in the past, recent declines and local extirpations have reduced their range. Despite this general decline, robust populations still exist in many places, including central and eastern Oregon.

O. mykiss is one of the most-studied fishes in Oregon streams, primarily because of regional interest in protecting and enhancing the anadromous form, known as steelhead; however, considerably less is known about resident O. mykiss populations in central and eastern Oregon (Currens 1997). Redband trout inhabit five distinct ecoregions in Oregon and are typically found in arid, montane forests, desert shrub and grasslands (Dambacher and Jones 2007). Concern about redband trout persistence led to a surge in research in the late 1980s. While considerable advances in redband trout biology have been made, factors driving population abundance on a localized scale are still poorly understood.

Redband Trout Distribution in the Crooked River Basin

The Crooked River, located in eastern Oregon, is the largest tributary to the Deschutes River. Redband trout are well adapted to this area and are present throughout 75% of their historic range, but their abundance is predicted to be depressed, and few areas remain that can support large numbers of these fish (Stuart et al. 2007). Most streams in the southeastern Crooked River basin do not sustain significant numbers of redband trout, likely due to anthropogenic impacts, principally those that led to increases in water temperature. Stuart et al. (2007) reported that the majority of the habitats above Bowman Dam, which demarcates the divide between the upper and lower watershed, are too warm to support redband trout.

Water quality conditions in the upper Crooked River subbasin are characterized as “moderate to severe” by Oregon Dept. of Environmental Quality because of the high temperatures and low flow (ODEQ 1998). Habitat surveys conducted by the U.S. Forest Service in the upper basin found a general lack of riparian vegetation leading to a reduction in habitat complexity and water quality (USFS 1998). Low summer flows cause much of the upper Crooked River, North Fork, South Fork, Beaver Creek, and other tributaries to warm to levels that exceed acceptable summer rearing temperatures for trout (DCG 2004). Whitman (2002) noted that due to habitat conditions in the upper Crooked River, redband trout populations are fragmented between Bowman Dam and the headwaters, and fish surveys conducted during the 1990s did not find established trout populations in this reach (ODFW 1996, USFS 1998).

The South Fork Crooked River has particularly poor instream habitat and water quality. ODEQ (1998) and Whitman (2002) report that redband are incapable of maintaining a naturally reproducing population here and only hatchery-released rainbow trout are found in the South Fork. The North Fork Crooked River contains the most widespread and interconnected trout population in the upper watershed (DCG 2004), and Beaver Creek hosts a self-sustaining population of redband trout as well, particularly at higher elevations (ODFW 1996, Whitman 2002, DCG 2004). The most suitable unseeded habitat in the upper basin is thought to be located within the Ochoco National Forest near the headwaters of Camp Creek, Beaver Creek, and the North Fork Crooked River where the habitat is more intact and summer temperature and flows are not as critical (Whitman 2002). However, ODFW (1996) observed that habitat in the South Fork Crooked River was unlikely to support native redband trout since it was treated with rotenone in 1981 and restocked trout have not survived well.

In the lower Crooked River there are still robust populations of redband trout found in the main stem immediately below Bowman Dam and upstream of Lake Billy Chinook. Additional populations can also be found in headwater areas of McKay and Ochoco Creeks, two major tributaries to the Crooked River that enter near the town of Prineville, Oregon. In general, fish species assemblage in the lower portion of the Crooked River, downstream of Prineville, can be characterized by a downstream – upstream gradient dominated by salmonids in the downstream reaches and cyprinids further upstream. Water quality parameters change dramatically in a downstream direction on the lower Crooked River, and patterns of fish distribution in the lower river suggest water temperature and possibly turbidity are primary physical drivers of redband trout density (Torgersen et al. 2007).

The common factor among areas that support large numbers of redband trout in lower Crooked River main stem appears to be the stable input of cool water. High trout densities observed below Bowman Dam are attributed to steady, cool water releases from Prineville Reservoir, and the abundance of trout upstream of Lake Billy Chinook is sustained by numerous natural springs that supplement flow and temperature in the lower river.

The redband trout population immediately below Bowman Dam, the largest population in the basin, has persisted and continues to support a vibrant tailrace fishery. Density predictions from mark-recapture studies in the 3.6 km reach below the dam yielded estimates ranging from ~3,000 trout/km in 1994, 1995 and 2012 to as low as 300 trout/km in 2006 (ODFW unpublished data, Stuart et al. 2007) (Figure 1). The population showed conservative growth from the observed low point in 2006 through 2009 and then decreased over the next three years to a low of ~750 trout/km in 2011. This low point was followed by the highest density value ever recorded since surveys began in 1989. In June 2012, ODFW conducted their annual boat electrofishing survey and estimated density of redband trout >200 mm to be 3,258. It is important to note that all of ODFW's population density estimates are calculated for trout >200 mm, which roughly corresponds to a 2-yr old fish. Little is known about potential drivers of these large fluctuations, but the Oregon Department of Fish and Wildlife (ODFW) continue to monitor redband trout abundance below Bowman Dam annually.

Historical accounts document dramatically different habitat conditions in the Crooked River basin compared with conditions found today (Buckley 1992). Stuart et al. (2007) provided a thorough description of habitat alterations that may have led to changes in redband distribution throughout the basin. By their account, low gradient areas along the mainstem Crooked River were the first to be colonized in the late 1800s. These areas were used extensively for sheep and cattle grazing and now comprise the most degraded redband habitat. In the 1950s, the first surveys of fish distributions were performed and it was found that large expanses of the Crooked River basin had already experienced severe degradation, dewatering and fish passage impediments. Continued habitat changes in the second half of the twentieth century led to an increase in other species, such as pikeminnow and suckers, which may compete directly with native trout for resources.

In an effort to remove these problem species, large-scale rotenone treatments were conducted from the late 1950s – mid 1980s. The extensive use of chemical treatments and introduction of hatchery rainbow trout to supplement the depressed recreational fishery, led to further reductions of native redband trout in the area. This continued until the mid-1980s when the Oregon Fish and Wildlife Commission adopted the Wild Fish Management Policy, which shifted agency focus to preserving wild native fish rather than relying on hatchery fish to sustain the fishery (Stuart et al. 2007).

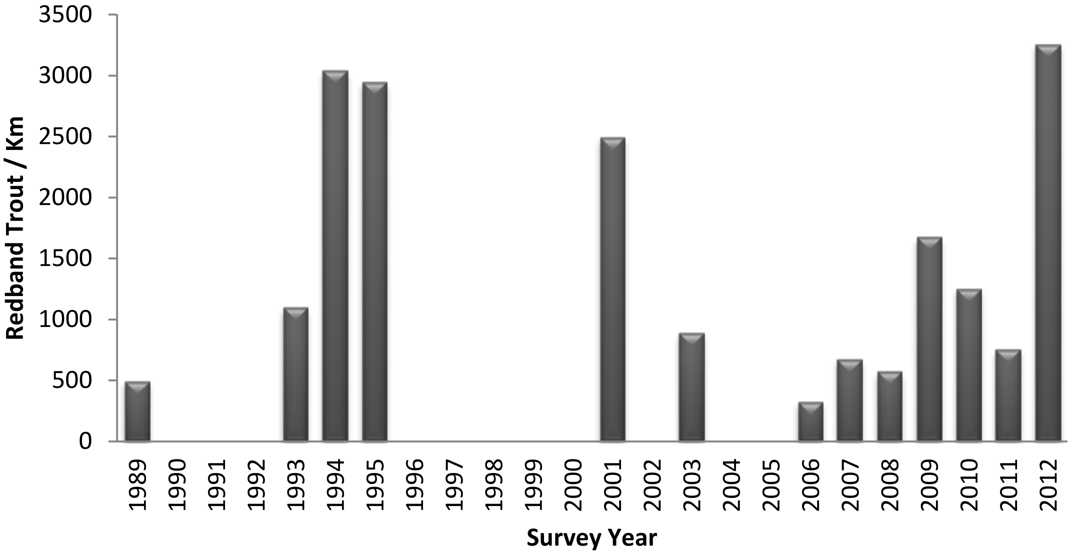


Figure 1**.** Redband trout density below Bowman Dam. (Estimates are for trout >8” and calculated using unpublished ODFW data from mark-recapture sampling in the 3.6 km reach below Bowman Dam, population abundance estimates calculated using the Lincoln-Petersen method).

Life-History of Redband Trout in the Crooked River Basin

Redband trout exhibit broad phenotypic diversity including varying age-at-maturity, frequency and timing of spawning, seasonal timing and patterns of migration, longevity, and habitat selection (Thurow et al 2007). There are two primary life-history strategies, anadromous and non-anadromous, which include adfluvial and fluvial types. Some evidence suggests that a small portion of Crooked River fish have adopted an adfluvial life-history strategy that allows them to take advantage of abundant food resources in lakes after migrating from spawning streams (Stuart et al 2007). Native anadromous redband trout have not returned to the Crooked River since construction of the Pelton Round Butte hydropower complex between 1957 and 1964. Downstream access to the ocean was discontinued in 1967; however, ocean access has recently been restored through construction of the Selective Water Withdrawal and Fish Collection Facility at Round Butte Dam, designed to increase fish attraction flows in the reservoir and improve downstream fish passage. In an effort to enhance reestablishment of anadromous O. mykiss in the upper Deschutes River basin, the ODFW has been planting hatchery steelhead fry in the Crooked River and upper Deschutes River since 2007. Genetic sampling of emigrating juvenile O. mykiss (Hill and Quesada 2011) indicates phenotypic expression of the full suite of historically present resident and migratory life-history types. However, tracking studies showed the vast majority of redband trout in the Crooked River basin are non-migratory fish (Nesbit 2010). In September of 2012, the first returning hatchery origin adult steelhead were passed over the Opal Springs Dam and into the Crooked River, demonstrating the ability of anadromous fish to emigrate and successfully return to the basin.

Trout in the mainstem Crooked River below Bowman Dam spawn from mid-April to late June, and juveniles begin emerging between late-May and early June (Stuart et al 2007). Age-at-maturity data is not available for Crooked River redband trout, but redband trout downstream in the Deschutes River typically spawn for the first time at age 3-4 at about 300-330 mm in length, with females producing an average of 1,300-1,500 eggs (Schroeder and Smith 1989). O. mykiss are interoparous, which means spawning may occur multiple times during a fish’s lifespan. In any given spring, as many as half of the mature redband trout in the Deschutes Basin may be spawning for at least their second time (Schroeder and Smith 1989).

Size and age of redband trout in the Crooked River are similar to rates observed in other eastern Oregon streams (Stuart et al. 2007). Borgerson (1994) back-calculated length at age based on annulus formation in scales from redband trout below Bowman Dam and found that fish averaged 119, 206, 237, and 300 mm for ages 1-4, respectively. Two and three year old trout from collections five years prior were slightly larger on average, potentially due to better growing conditions when fish density was lower (Figure 1). Redband trout as old as six years have been documented by ODFW in the Crooked River (Stuart et al. 2007).

Methods

Cramer Fish Sciences (CFS) collaborated with OID, PGE and ODFW to develop a research plan to evaluate the distribution and abundance of redband trout in the 1.6 km reach immediately below Bowman Dam on the Crooked River. We determined that backpack electrofishing combined with ODFW's boat electrofishing surveys would provide the baseline information necessary to complete this evaluation. Electrofishing is a proven, effective technique for non-lethal capture of redband trout in the Crooked River, which has a conductivity of ~ 250 μS/m and reasonably good water clarity in the spring and fall.

Our goal was to accurately describe abundance and distribution of all redband trout age/size classes present in the area below the dam. Previous boat electrofishing surveys conducted by ODFW targeted the larger size classes that were present in deeper portions of the river while the addition of backpack electrofishing along the margins of the river would provide density information on those fish that are typically not captured during boat surveys. The collection of in-river trout density data combined with previously published data contribute to our analysis, and provide the baseline needed to evaluate impacts from development of a hydroelectric project.

Habitat Survey

Prior to electrofishing, we conducted a complete habitat survey of the 1.6 km reach below Bowman Dam. The results of the survey, in combination with backpack electrofishing data, were useful for estimating redband trout abundance throughout the study reach. Eight 100-meter sections of stream were electrofished (Figure 2). Therefore, it was important to describe habitat conditions in the remaining portions of the reach so that density estimates could be properly expanded to un-surveyed areas.

The habitat survey methods followed protocols used by the ODFW (Moore et al. 2002), and were modified to suit the specific needs of this study. Mesohabitat units by type (i.e. pool, riffle, glide) were classified and average depth and active channel width were measured. Substrate (i.e. fines, gravel, cobble, boulder) composition was estimated for each habitat unit. Electrofishing observations in adjacent, similar habitat types were applied to un-sampled habitat areas to calculate an estimate of fish per kilometer for the entire study area.

Electrofishing

Single-pass backpack electrofishing in small streams is known to provide a reliable index of fish abundance (Kruse et al. 1998 and Bateman et al. 2005). Therefore we believe this methodology provided a reasonable estimate of relative abundance of juvenile redband trout in the study reach below Bowman Dam. Surveys were conducted along the edge habitat which were primarily occupied by YOY and age–1 fish in late May and October 2012 (245 and 90 cfs stream flow below Bowman Dam) using a Smith/Root Model 12B backpack electrofisher with programmable output waveform. There was a high likelihood that threatened Middle Columbia River steelhead were present in the project area because of fry out-plantings that occurred earlier in the spring; thus, we used the National Marine Fisheries Service guidelines and ODFW recommendations to establish our electrofishing protocol and equipment settings. Settings used while electrofishing ranged, but they were typically: pulse width = 5 ms, pulse rate = 30 – 50 Hz and voltage = 300 – 500.

Eight 100-meter electrofishing sampling sites were selected at random starting at the lower end of the study reach and working upstream towards the dam. A buffer of 50 to 100 m was left between each electrofishing site such that sites were roughly equidistant from each other and spread over the entire reach. Prior to electrofishing, field staff marked the upper and lower ends of each site and measured water quality data including temperature, pH, dissolved oxygen, and conductivity.

Electrofishing surveys were completed using a three-member crew; one person operated the electrofishing backpack and the others captured stunned fish with a dip net and transferred fish to shoreline holding areas. The crew thoroughly swept the entire length of each sample site along both shorelines focusing on lower velocity, edge habitat where small juvenile trout are expected to congregate and extending out into the channel as far as water depth and velocity permitted (maximum 5 m from shore). Approximately one hour was spent per site, 30 minutes per shore. The amount of time actively electrofishing accounted for an average of 1,700 seconds for each site. Captured fish were individually identified to species, measured, weighed, and notes were recorded about condition before fish were released back into the river.

Genetic Analysis

Hawkins et al. (2011) analyzed *O. mykiss* from the Crooked River, Oregon to evaluate the genetic population structure of natural-origin and hatchery-origin individuals. They found that redband trout in the upper and lower reaches of the Crooked River were genetically distinct from each other, and that natural- and hatchery-origin individuals were genetically differentiated. In the study reported here, we used data from Hawkins et al. (2011) for the baseline to identify the population origin of an additional 150 fish sampled from the upper Crooked River.

A small tissue sample was taken from the caudal fin of 80 of the redband trout at random throughout the eight sites eight electrofishing sites (40 in May and 40 in October). In addition, ODFW collected 70 more tissue samples during their boat electrofishing surveys in June. The combination of samples collected during both backpack and boat electrofishing was expected to provide a representative sample of the trout present below the dam.

Tissue samples were sent to the Washington Department of Fisheries and Wildlife genetics laboratory in Olympia, Washington for analysis to determine the composition of hatchery steelhead and resident redband trout observed during our surveys. Caudal fin clips collected by Cramer Fish Sciences were sent to the Washington Department of Fish and Wildlife Molecular Genetics Laboratory in Olympia, WA for analysis. Genomic DNA was extracted from all samples by digesting each piece of fin tissue using silica membrane based kits obtained from Qiagen (Valencia, CA, USA) following the manufacturers recommendations. Thirteen microsatellite loci combined into six multiplexes were screened for this study (Table 1). These samples are a subset of the standardized SPAN microsatellite markers (Stephenson et al. 2009). PCR reactions were conducted with a thermal profile as follows: an initial denaturation step of 2 min at 94° C, 40 cycles of denaturation at 94° C for 15 s, 30 s at the appropriate temperature for each multiplex, and 1 min at 72° C, plus a final extension at 72° C for 10 min and final holding step at 10° C. Genotypes were visualized using an ABI-3730 DNA Analyzer (Applied Biosystems, Foster City, CA, USA) with internal size standards (GS500LIZ 3730) and GENEMAPPER 5.0 software.

We used ONCOR (Kalinowski et al. 2008) to assign to each individual to their population of origin. ONCOR uses conditional maximum likelihood to estimate mixture proportions (Millar 1987) and genotype probabilities are calculated using a partial Bayesian procedure method of Rannala and Mountain (1997). This method uses the expectation-maximization (EM) algorithm to calculate the population-source probabilities (posterior probabilities) for each sample. The upper Crooked River, lower Crooked River, and Round Butte Hatchery data from Hawkins et al. (2011) were used to define the genetic baselines. Data were provided to us by Denise Hawkins, USFWS Abernathy Fish Technology Center, Longview, WA.

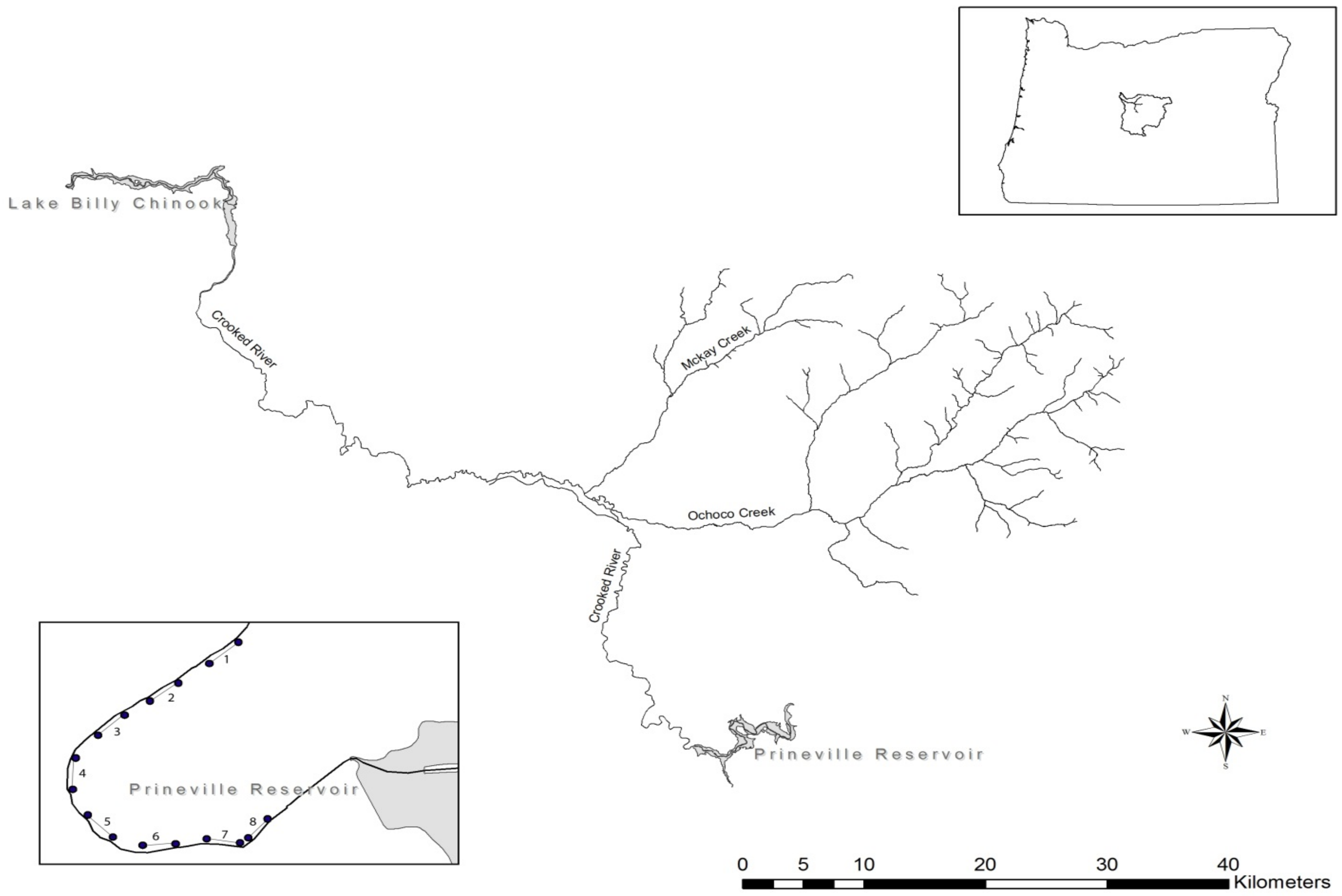


Figure 2**.** Map of the Crooked River basin and study reach below Prineville Reservoir (Bowman Dam) detailing the location of the eight 100-meter survey sites.

Table 1. The standardized suite of SPAN microsatellite loci for analyses of steelhead. The two loci that were not analyzed by USFWS in the baseline collections are highlighted in grey

PCR Conditions			
Poolplex	Locus	Dye Label	References
Omy-L	*One-102*	blue	Olsen et al. 2000
	Oke-4	green	Buchholz et al. 2001
	Ots-100	yellow	Nelson and Beacham 1999
Omy-M	*Oki-23*	blue	Smith et al. 1998
	Omy-7	green	K. Gharbi, pers. comm.
	Ssa-408	red	Cairney et al. 2000
Omy-N	*Ots-4*	blue	Banks et al. 1999
	Omy-1011	yellow	Spies et al. 2005
Omy-O	*Omy-1001*	blue	Spies et al. 2005
	Ots-3M	yellow	Banks et al. 1999
Omy-P	*Ssa-407*	blue	Cairney et al. 2000
	Ogo-4	green	Olsen et al. 1998
	One-14	red	Scribner et al. 1996
Omy-Q	*Ssa-289*	green	McConnell et al. 1995
	Oki-10	none	Smith et al. 1998

Results

Habitat Survey

Stream segments were categorized into three different types of habitat: pools, glides, and riffles. In May, the 1.6 km study reach was comprised of 16 different habitat units of which 49% were pools, 23% glides, and 28% riffles. During the October sampling effort there were 23 habitat units within the same study reach. The proportion of habitat types changed as well and was now dominated by glide habitat, 76%, with the remaining area made up of 16% pools and only 9% riffles. The increase in habitat units identified during the survey in the fall and the corresponding shift in dominant habitat type is expected due to the large decrease in flow observed during the second sampling effort. The flow in October was only 35% of the flow we observed during our May surveys (90 cfs vs. 245 cfs), which reduced water velocity through the study reach and altered the length of area classified as riffle habitat. The lower flows decreased the average wetted channel width from 31 m to 28 m and decreased the average depth in glides, 0.8 m vs. 0.4 m, but did not affect maximum pool depth which held steady at 1.3 m during both seasons. Substrate composition was a mix of boulder, cobble, gravel and fines and detailed composition for each mesohabitat unit in the survey reach is shown in (Figure 3). No large woody debris were observed anywhere within the study reach so the majority of cover was provided by large boulders and some macroalgae.

Temperature and dissolved oxygen differed significantly throughout the study reach. The lowest values measured were both in the sample reach (8), immediately below the outlet of the dam. At this site, the water temperature was 7° C and dissolved oxygen was 11.52 mg/L in May and 11.5° C and 9.9 mg/L in October. Downstream at site 1, the temperatures increased, ~1-2° C and dissolved oxygen increased significantly, ~3 mg/L during both spring and fall sampling seasons (Figure 4).

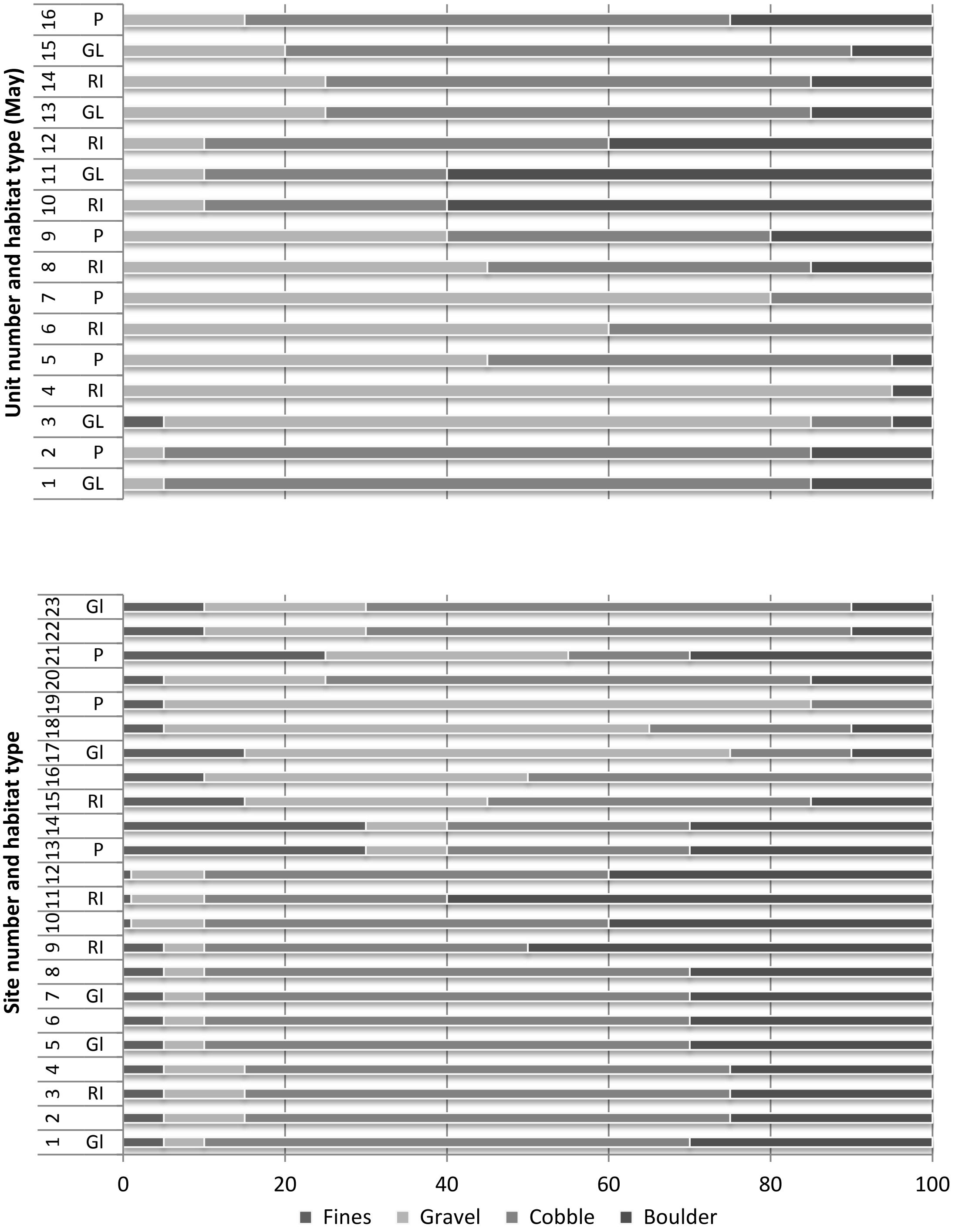


Figure 3**.** Substrate composition in each mesohabitat (P = pool, RI = riffle, GL = glide) unit surveyed in the 1.6 km reach below Bowman Dam in May and October 2012. Unit 1 begins approximately 100 meters downstream of Bowman dam.

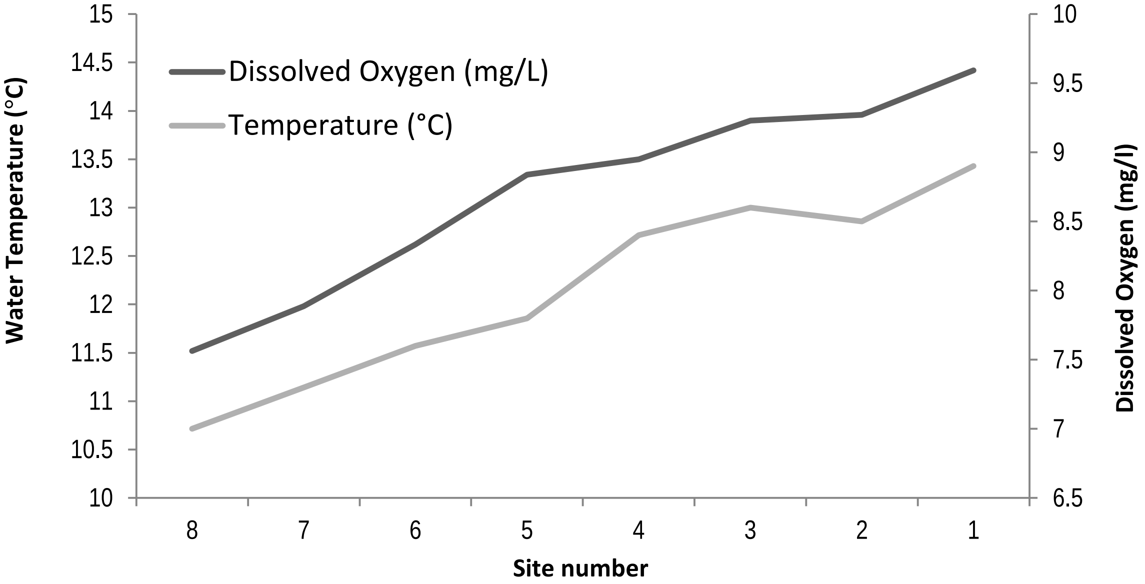


Figure 4**.** Water temperature and dissolved oxygen measurements within each of the 100 meter electrofishing survey sites in May. All measurements were taken within a half an hour to ensure temporal fluctuations did not alter values. (Site 8 is closest to the dam)

Electrofishing

There did not appear to be a trend in catch rates associated with the increasing temperature or dissolved oxygen levels observed in the study reach. The primary determinant of density was habitat type. Catch rates were highest in sites that were either riffles or a mixture of riffles and glides (Table 2). Fish appeared to be attracted to these areas with stronger flows, particularly when larger substrate was available for cover. The slower moving, deeper pools tended to hold less fish, though we were unable to sample the middle portion of the pools effectively using backpack electrofishing. In May we caught 767 fish, of which ~ 72% (551) were redband trout, 27% sculpin and 1% mountain whitefish comprised the remainder of the catch. The catch composition in October was similar, 456 total fish, 87% (396) of those were redband trout while the remaining catch was 12% sculpin and 1% mountain whitefish. Readers should note that we were targeting redband trout, so abundance of whitefish and sculpin are not comparable with trout. Redband trout captured during backpack electrofishing surveys in May and October 2012 had a mean length of 109 and 97.5 mm, respectively, and ranged between 26 – 405 mm. Fiftynine percent of our catch was in the 40 – 100 mm size class, which suggests that most were young-of-the-year (YOY) (Figure 5). The majority of the remaining catches were classified as 1-year old trout which overlaps with the smallest size fish sampled during boats electrofishing surveys (Figure 6). The density of redband trout that we observed while backpack electrofishing was 345 trout/km in May and 248 trout/km during the October surveys. The decreased density was observed during a period of increased temperatures, lower flow and less wetted stream width.

Table 2**.** Number of redband trout caught in each survey site and a description of the habitat type(s) represented within each site. (Site 8 is closest to the dam)

	May		**October**	
Site	**Habitat Type**	**Redband trout**	**Habitat Type**	**Redband trout**
8	Glide	68	Glide	18
7	Glide/Pool	63	Pool	43
6	Pool	36	Pool	8
5	Riffle/ Pool	99	Riffle/Glide	56
4	Pool	66	Pool	41
3	Riffle	158	Glide/Riffle	105
2	Glide/Riffle/Glide	48	Riffle/Glide	58
1	Glide/Pool	13	Glide	67

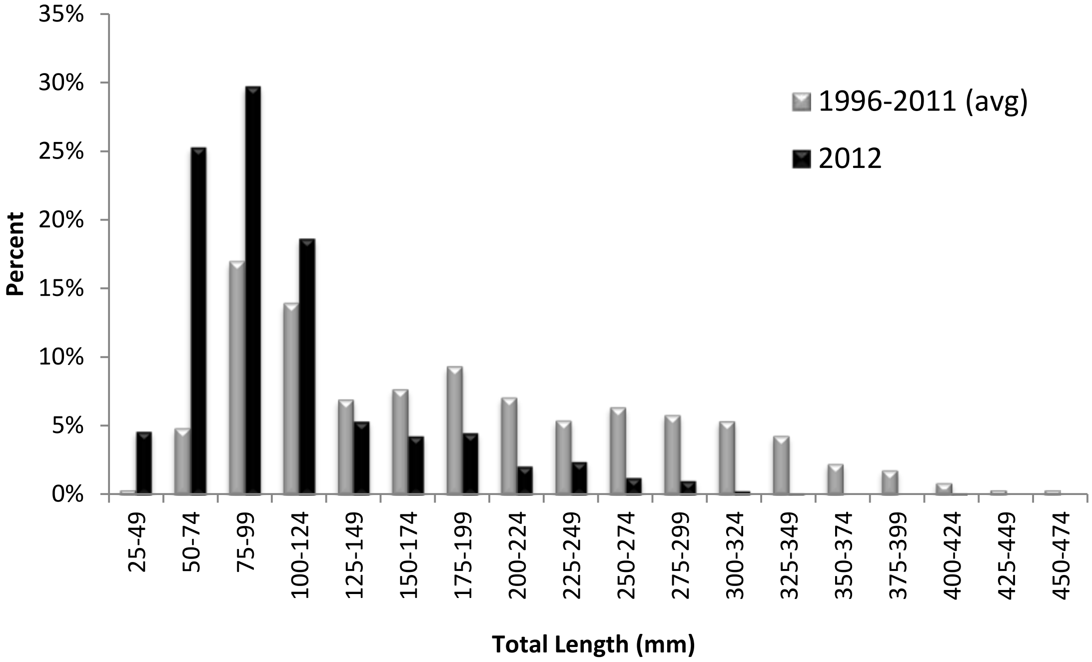


Figure 5**.** Length distribution of redband trout captured while backpack electrofishing during the spring and fall of 2012 below Bowman Dam, compared to the 12-year average length distribution calculated from ODFW boat electrofishing surveys below Bowman Dam.

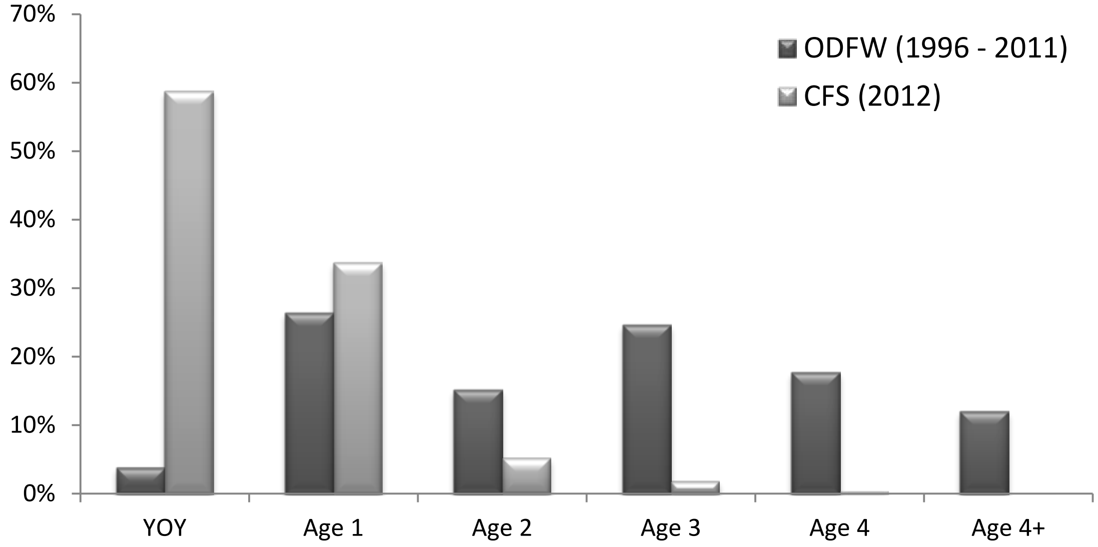


Figure 6. Predicted age composition of redband trout captured during annual ODFW boat electrofishing surveys, 1996-2011, and backpack electrofishing surveys, May and October 2012, downstream of Bowman Dam[1].

Genetic Analysis

Of the 150 samples collected in this study, 148 assigned to baseline populations at probabilities greater than 80%: 143 assigned to upper Crooked River and five to Round Butte Hatchery. Two of the 150 samples were assigned to a population at <80% probability and, therefore, were not included in our results summaries.

Baseline data from USFWS were evaluated to confirm the samples were in Hardy Weinberg equilibrium. These individuals were also plotted using a factorial correspondence analysis to

---

[1] Catch data represents first drift only while boat electrofishing, [YOY = 40 – 100 mm, Age 1 = 101 – 180 mm, Age 2 = 181 – 215, Age 3 = 216 – 275 mm, Age 4 = 276 – 325 mm, Age 4+ > 325 mm (Stuart et al. 2007)]

show the separation of individuals between the three baseline collections (Figure 7). Hawkins et al. (2011) evaluated the baseline populations and concluded they were genetically differentiated; therefore, we did not conduct any additional analysis of the USFWS data.

Assignment to population of origin for each individual is shown in the Appendix for all samples analyzed. Some individuals had a high probability of assignment to both upper Crooked and Round Butte Hatchery source populations; therefore, the probability of assignment for each population is shown. The upper Crooked River population accounted for 96.7% of the assignments and 3.3% of the assignments were to Round Butte Hatchery (Figure 8). Two of the unknown Crooked River samples amplified, but the probability of assignment was below 80% and results from the samples were not considered.

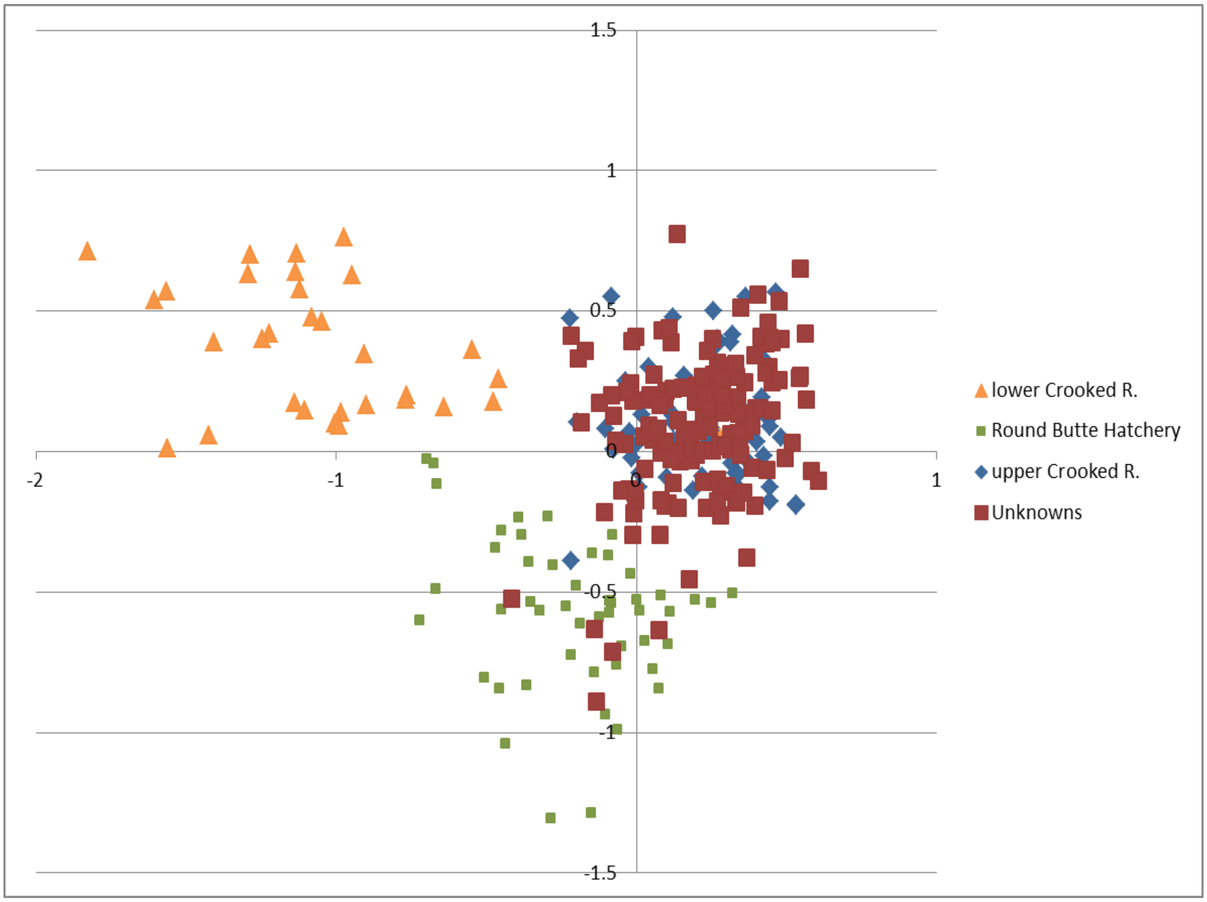
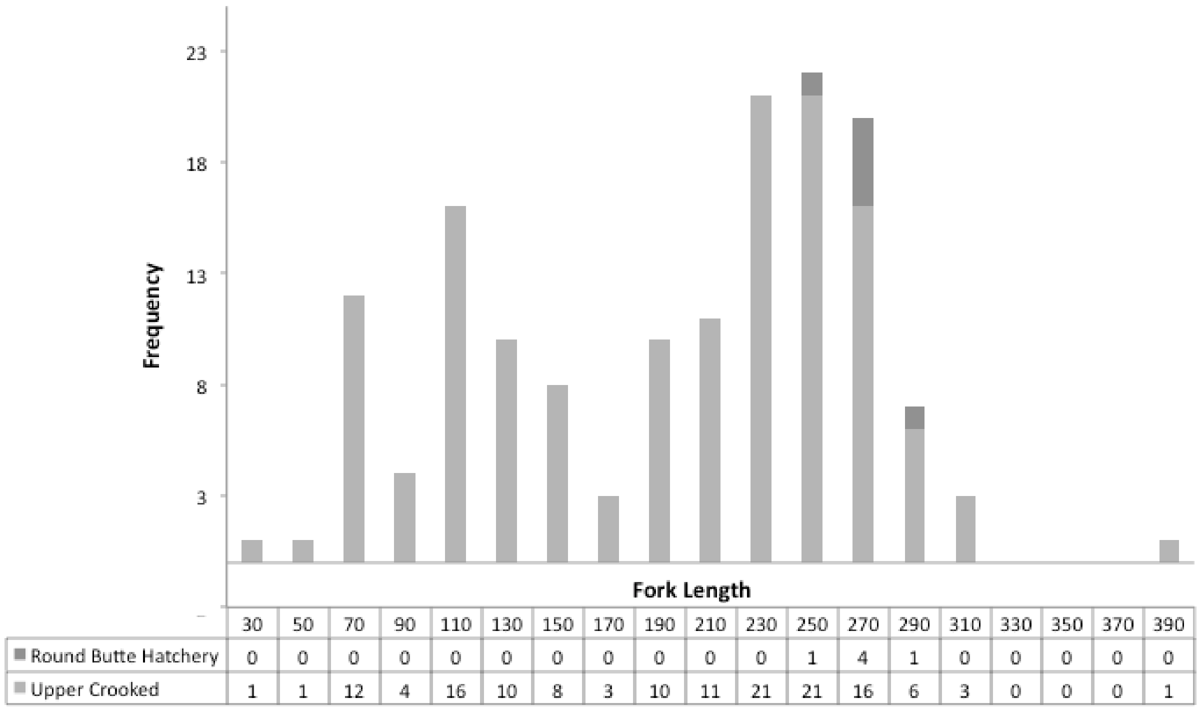


Figure 7. Factorial correspondence analysis conducted with GENETIX showing the distribution of steelhead from upper and lower Crooked River, Round Butte Hatchery and a collection of samples with unknown origin.



	30	50	70	90	110	130	150	170	190	210	230	250	270	290	310	330	350	370	390
■ Round Butte Hatchery	0	0	0	0	0	0	0	0	0	0	0	1	4	1	0	0	0	0	0
■ Upper Crooked	1	1	12	4	16	10	8	3	10	11	21	21	16	6	3	0	0	0	1

Figure 8. Length-frequency distribution of redband trout genetically assigned to the upper Crooked River and Round Butte Hatchery.

Discussion

ODFW’s 2012 boat electrofishing density estimate of 3,258 trout/km below Bowman Dam is the highest value calculated since sampling began in 1989 (Figure 1). This follows an estimate in 2011 of 759 trout/km, the fifth lowest value in more than 20 years of monitoring. It is difficult to determine the causes of these large interannual fluctuations (which range from 300 – 3,000 trout), but we suspect they are partially due to the uncertainty in abundance estimates, as well as changes in fish density downstream of Bowman Dam. An important consideration when evaluating the potential mechanism behind large differences in observed trout densities is the seasonal movement of fish in response to warming temperatures in the spring and early summer, which can have a major impact on the number of trout present during surveys.

The inability of boat electrofishing to adequately sample juvenile redband trout is clear (Figure 5; Figure 6). Boat electrofishing targets larger size classes and does not provide data on the smallest fish that are typically found in the stream margins, habitat that is unreachable using a boat mounted electrofishing unit. Thus, the long-term monitoring dataset lacks information about recruitment and YOY survival. Based on length-at-age data presented by Stuart et al. (2007), 59% of the fish captured in 2012 while backpack electrofishing would be classified as YOY, <100 mm. ODFW did release hatchery steelhead fry below Bowman Dam in April 2012, but genetic analysis indicates that the large number of YOY captured in our sample were native upper Crooked River redband trout. It is interesting to note that during our May surveys catch was dominated by fish classified as large YOY, or small 1-yr olds from the 2011 brood year. However, in October the mean length of redband trout was less than 100 mm and appears to have been made up of fish from the 2012 brood year. Since the dominant brood year represented in the catch switched between sampling events it allowed us to gather valuable recruitment data for both year classes. Combining backpack electrofishing data from 2012 with ODFW boat electrofishing data proved useful for reconciling the bias that would result if only one of the sampling techniques was relied upon, and provided data for all size classes present in the study reach below Bowman Dam (Figure 5).

The redband trout density estimate derived from boat electrofishing surveys in 2012 is difficult to explain without sufficient juvenile monitoring data from previous years; however, the large increase, > 4 times the density estimate for 2011, is especially interesting given the fact that ODFW recently started an aggressive hatchery steelhead stocking program in this region. A possible explanation for the large increase in adult abundance in 2012 is that some of the juvenile hatchery steelhead, planted in an effort to reintroduce anadromous O. mykiss, are not outmigrating as expected. This type of life-history plasticity is commonly observed in O. mykiss populations (Pavlov et al. 2001; Pascual et al. 2001; Thrower and Joyce 2004). However, results of genetic analyses did not support this hypothesis.

Data collected while backpack electrofishing allowed us to effectively enumerate juvenile trout present within the area surveyed. We recommend more data collection on YOY and 1-year old fish as a means of anticipating fluctuations in adult redband trout abundance. While boat electrofishing does an adequate job of enumerating the breeding population of redband trout greater than 200 mm (~2 years old), it does not provide data pertinent to tracking annual recruitment. Altering the current monitoring plan to include backpack electrofishing and analyzing the data collected from both sampling methodologies would provide greater insight into potential drivers causing the apparent large fluctuations in redband trout abundance. It would also increase our capacity to monitor impacts from hatchery stocking. A more robust sampling program would eventually allow estimation of annual recruitment and YOY survival, useful for quantifying the effects of environmental variability and anthropogenic factors influencing redband trout populations below Bowman Dam.

References

Banks, M.A., M.S. Blouin, B.A. Baldwin, V.K. Rashbrook, H.A. Fitzgerald, S.M.

Bateman, D.S. R.E. Gresswell, C.E. Torgersen. 2005. Evaluating Single-Pass Catch as a Tool for Identifying Spatial Pattern in Fish Distribution. Series: Journal of Freshwater Ecology, Vol.(20)2, Page(s): 335-345

Blankenship, and D. Hedgecock. 1999. Isolation and inheritance of novel microsatellites in chinook salmon. Journal of Heredity 90: 281-288.

Borgerson, L.A. 1994. Unpublished memorandum to ODFW Ochoco District Office, Oregon Department of Fish and Wildlife, Prineville.

Buchholz, W.G., S.J. Miller, and W.J. Spearman. 2001. Isolation and characterization of chum salmon microsatellite loci and use across species. Animal Genetics 32(3):162-165.

Buckley, G.L. 1992. Desertification of the Camp Creek drainage in central Oregon, 1826–1905.Master’s thesis.University ofOregon, Eugene.

Cairney, M., J.B. Taggart, and B. Hoyheim. 2000. Characterization of microsatellite and minisatellite loci in Atlantic salmon (Salmo salar L.) and cross-species amplification in other salmonids. Molecular Ecology 9:2175–2178.

Currens, K.P. 1997. Evolution and risk in conservation of Pacific salmon. Doctoral dissertation. Oregon State University, Corvallis.

Dambacher, J.M. and K.K. Jones. 2007. Benchmarks and Patterns of Abundance of Redband Trout in Oregon Streams: a Compilation of Studies. Pages 47–55*in* R.K. Schroeder and J.D. Hall, editors. Redband trout: resilience and challenge in a changing landscape. Oregon Chapter, American Fisheries Society, Corvallis.

Deschutes Coordinating Group (DCG). 2004. Deschutes Subbasin Plan. Northwest Power and Conservation Council.

Hauser, L., T.R. Seamons, M. Dauer, K.A. Naish, and T.P. Quinn. 2006. An empircal verification of population assignment methods by marking and parentage data: hatchery and wild steelhead (Oncorhynchus mykiss) in Forks Creek, Washington, USA. Molecular Ecology 15(11): 3157-3173.

Hawkins, D., B. Adams, and B. Kammerer. 2011. Genetic determination of stock of origin of Oncorhynchus mykiss collected in the Crooked River. Progress Report.

Hill, M. and C. Quesada. 2012. Juvenile Migration Test and Verification Study Annual Report. Portland General Electric Company and Confederated Tribes of the Warm Springs Reservation of Oregon. Madras, OR. Portland General Electric Company. Portland, Oregon.

Kalinowki, S.T., K.R. Manlove, and M.L. Taper. 2008. ONCOR. A computer program for genetic stock identification. http://www.montana.edu/kalinowski/Software/ONCOR.htm

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 1998. Single-Pass Electrofishing Predicts Trout Abundance in Mountain Streams with Sparse Habitat. Series: North American Journal of Fisheries Management, Vol. 18, Page(s): 940-946.

Li, H.W., J.M. Dambacher and D. Buchanan. 2007. Phenotypic Variation in Redband Trout. Pages 14–18*in* R.K. Schroeder and J.D. Hall, editors. Redband trout: resilience and challenge in a changing landscape. Oregon Chapter, American Fisheries Society, Corvallis.

McConnell, S., L. Hamilton, D. Morris, D. Cook, D. Paquet, P. Bentzen, and P. Wright. 1995. Isolation of salmonid microsatellite loci and their application to the population genetics of Canadian east coast stocks of Atlantic salmon. Aquaculture 137:19–30.

Millar, R.B. 1987. Maximum likelihood estimation of mixed stock fishery composition. Canadian Journal of Fisheries and Aquatic Sciences 44: 583–590.

Nelson, R.J. and T.D. Beacham. 1999. Isolation and cross species amplification of microsatellite loci useful for study of Pacific salmon. Animal Genetics 30:228-229.

Nesbit, Shivonne M. 2010. Population Characteristics and Movement Patterns of Redband Trout and Mountain Whitefish in the Crooked River, Oregon. Oregon State University.June.2010.

Olsen, J.B., S.L. Wilson, E.J. Kretschmer, K.C. Jones, and J.E. Seeb. 2000. Characterization of 14 tetranucleotide microsatellite loci derived from sockeye salmon. Molecular Ecology, 9:2185-2187.

Oregon Department of Environmental Quality. 1998. 303d Water Quality Limited Streams List.

Oregon Department of Fish and Wildlife. 1996. Crooked River Basin Fish Plan. Prineville, Oregon.

Pascual, M., Bentzen, P., Rossi, C.R., Mackey, G., Kinnison, M.T., and Walker, R. 2001. First documented case of anadromy in a population of introduced rainbow trout in Patagonia, Argentina. Trans. Am. Fish. Soc. 130:53-67.

Pavlov, D.S., Savvaitova, K.A., and Kuzishchin, K.V. 2001. Theoretical aspects of the problem of the distribution pattern and formation of life-history strategy of mikizha (*Parasalmo mykiss* (Walbaum), Salmonidae, Salmoniformes) on the Kamchatka Peninsula. Doklady Bio. Sci. 379:344–346. Translated from 2001 Doklady Akademii Nauk 379(1):139–141. Portland, Oregon.

Rannala, B. and J.L. Mountain. 1997. Detecting immigration by using multilocus genotypes. Proceedings of the National Academy of Sciences USA 94, 9197-9201.

Schroeder, R.K. and L.H. Smith, 1989. Life history of rainbow trout and effects of angling regulations Deschutes River, Oregon. Oregon Department of Fish and Wildlife, Information Report (Fish) 89-6, Portland, Oregon.

Scribner, K. T., J. Gust, and R. L. Fields. 1996. Isolation and characterization of novel salmon microsatellite loci: Cross –species amplification and population genetic applications. Canadian Journal of Fisheries and Aquatic Sciences 53:833.841.

Smith, C.T., B.F. Koop, and R.J. Nelson. 1998. Isolation and characterization of coho salmon (Oncorhynchus kisutch) microsatellites and their use in other salmonids. Molecular Ecology 7:1614-1617.

Spies, I.B., D.J. Brasier, P.T. O'Reilly et al. 2005. Development and characterization of novel tetra-, tri-, and dinucleotide microsatellite markers in rainbow trout (Oncorhynchus mykiss). Molecular Ecology 5:278-281.

Stephenson, J.J., M.R. Campbell, J.E. Hess, C. Kozfkay, A.P. Matala, M.V. McPhee, P. Moran, S.R. Narum, M.M. Paquin, O. Schlei, M.P. Small, D.M. Van Doornik, and J.K. Wenburg. 2009. A centralized model for creating shared, standardized, microsatellite data that simplifies interlaboratory collaboration. Conservation Genetics 10:1145–1149.

Stuart, A.M., D. Grover, T.K. Nelson, and S.L. Thiesfeld. 2007. Redband Trout Investigations in the Crooked River Basin. Pages 76–91 *in* R.K. Schroeder and J.D. Hall, editors. Redband trout: resilience and challenge in a changing landscape. Oregon Chapter, American Fisheries Society, Corvallis.

Taylor, E.B. and A.B. Costello. 2006. Microsatellite DNA analysis of coastal populations of bull trout (Salvelinus confluentus) in British Columbia: zoogeographic implications and its application to recreational fishery management. Canadian Journal of Fisheries and Aquatic Sciences 63(5):1157-1171.

Thrower, F.P., and Joyce, J.E. 2004. Effects of 70 years of freshwater residency on survival, growth, early maturation, and smolting in a stock of anadromous rainbow trout from southeast Alaska. Am. Fish. Soc. Sym. 44:485–496.

Thurow, R.F., B.E. Rieman, D.C. Lee, P.J. Howell, and R.D. Perkinson. 2007. Distribution and Status of Redband Trout in the Interior Columbia River Basin and Portions of the Klamath River and Great Basins. Pages 28–46 *in* R.K. Schroeder and J.D. Hall, editors. Redband trout: resilience and challenge in a changing landscape. Oregon Chapter, American Fisheries Society, Corvallis.

Torgersen, C.E.,D.P.Hockman-Wert, D.S. Bateman, D.W. Leer, and R.E.Gresswell.2007. Longitudinal Patterns of Fish Assemblages, Aquatic Habitat, and Water Temperature in the Lower Crooked River, Oregon: U.S. Geological Survey, OF 2007-1125, p. 37.

USDA Forest Service. 1998. Upper Crooked River Sub-basin Review, Ochoco National Forest. PNW:Prineville, Oregon.

Waples, R.S. and O. Gaggiotti. 2006. What is a population? An empirical evaluation of some genetic methods for identifying the number of gene pools and their degree of connectivity. Molecular Ecology 15(6):1419-1439(21)

Whitman, Tina. 2002. Crooked River Watershed Assessment. Crooked River Watershed Council, Prineville, Oregon.

Contact Information:

Ian Courter

Cramer Fish Sciences

600 NW Fariss Road

Gresham, OR 97030

503-491-9777 x109

courter@fishsciences.net

Appendix

Population of origin assignments for 150 juvenile and adult O. mykiss collected in the Crooked River, OR. Two individuals highlighted in grey were below 80% assignment probability.

Individual	Best Estimate	Probability	2nd Best Estimate	Probability
12FH0001	upper Crooked Cr.	1.0000		
12FH0002	upper Crooked Cr.	1.0000		
12FH0003	upper Crooked Cr.	1.0000		
12FH0004	upper Crooked Cr.	0.9992		
12FH0005	upper Crooked Cr.	1.0000		
12FH0006	upper Crooked Cr.	0.9999		
12FH0007	upper Crooked Cr.	1.0000		
12FH0008	upper Crooked Cr.	0.9998		
12FH0009	upper Crooked Cr.	1.0000		
12FH0010	upper Crooked Cr.	1.0000		
12FH0011	upper Crooked Cr.	1.0000		
12FH0012	upper Crooked Cr.	1.0000		
12FH0013	upper Crooked Cr.	1.0000		
12FH0014	upper Crooked Cr.	1.0000		
12FH0015	upper Crooked Cr.	1.0000		
12FH0016	upper Crooked Cr.	0.9977		
12FH0017	upper Crooked Cr.	1.0000		
12FH0018	upper Crooked Cr.	0.9974		
12FH0019	upper Crooked Cr.	1.0000		
12FH0020	upper Crooked Cr.	0.9891	Round Butte Hatchery	0.0109
12FH0021	upper Crooked Cr.	1.0000		
12FH0022	upper Crooked Cr.	1.0000		
12FH0023	upper Crooked Cr.	1.0000		
12FH0024	upper Crooked Cr.	1.0000		
12FH0025	upper Crooked Cr.	1.0000		
12FH0026	upper Crooked Cr.	1.0000		
12FH0027	upper Crooked Cr.	0.9896	Round Butte Hatchery	0.0104
12FH0028	upper Crooked Cr.	1.0000		
12FH0029	upper Crooked Cr.	0.9993		
12FH0030	upper Crooked Cr.	1.0000		
12FH0031	upper Crooked Cr.	1.0000		
12FH0032	upper Crooked Cr.	1.0000		
12FH0033	upper Crooked Cr.	1.0000		
12FH0034	upper Crooked Cr.	1.0000		
12FH0035	upper Crooked Cr.	1.0000		
12FH0036	upper Crooked Cr.	1.0000		
12FH0037	upper Crooked Cr.	1.0000		
12FH0038	upper Crooked Cr.	1.0000		
12FH0039	upper Crooked Cr.	1.0000		
12FH0040	upper Crooked Cr.	1.0000		
12FH0041	upper Crooked Cr.	0.7330	Round Butte Hatchery	0.2670

Individual	Best Estimate	Probability	2nd Best Estimate	Probability
12FH0042	upper Crooked Cr.	1.0000		
12FH0043	upper Crooked Cr.	1.0000		
12FH0044	upper Crooked Cr.	1.0000		
12FH0045	upper Crooked Cr.	1.0000		
12FH0046	upper Crooked Cr.	1.0000		
12FH0047	upper Crooked Cr.	1.0000		
12FH0048	upper Crooked Cr.	1.0000		
12FH0049	upper Crooked Cr.	1.0000		
12FH0050	upper Crooked Cr.	1.0000		
12FH0051	upper Crooked Cr.	0.9994		
12FH0052	upper Crooked Cr.	1.0000		
12FH0053	upper Crooked Cr.	1.0000		
12FH0054	upper Crooked Cr.	1.0000		
12FH0055	upper Crooked Cr.	1.0000		
12FH0056	upper Crooked Cr.	1.0000		
12FH0057	upper Crooked Cr.	1.0000		
12FH0058	upper Crooked Cr.	1.0000		
12FH0059	upper Crooked Cr.	1.0000		
12FH0060	upper Crooked Cr.	1.0000		
12FH0061	upper Crooked Cr.	1.0000		
12FH0062	upper Crooked Cr.	1.0000		
12FH0063	upper Crooked Cr.	1.0000		
12FH0064	upper Crooked Cr.	1.0000		
12FH0065	upper Crooked Cr.	1.0000		
12FH0066	upper Crooked Cr.	0.9998		
12FH0067	upper Crooked Cr.	1.0000		
12FH0068	upper Crooked Cr.	1.0000		
12FH0069	upper Crooked Cr.	1.0000		
12FH0070	upper Crooked Cr.	1.0000		
12FH0071	upper Crooked Cr.	1.0000		
12FH0072	upper Crooked Cr.	1.0000		
12FH0073	upper Crooked Cr.	1.0000		
12FH0074	upper Crooked Cr.	1.0000		
12FH0075	upper Crooked Cr.	0.9811	Round Butte Hatchery	0.0189
12FH0076	upper Crooked Cr.	0.9601	Round Butte Hatchery	0.0399
12FH0077	upper Crooked Cr.	1.0000		
12FH0078	upper Crooked Cr.	0.9999		
12FH0079	upper Crooked Cr.	1.0000		
12FH0080	upper Crooked Cr.	1.0000		
12FH0081	upper Crooked Cr.	0.9992		
12FH0082	upper Crooked Cr.	1.0000		
12FH0083	upper Crooked Cr.	1.0000		
12FH0084	upper Crooked Cr.	1.0000		
12FH0085	upper Crooked Cr.	1.0000		
12FH0086	Round Butte Hatchery	0.9953		

Individual	Best Estimate	Probability	2nd Best Estimate	Probability
12FH0087	upper Crooked Cr.	1.0000		
12FH0088	upper Crooked Cr.	1.0000		
12FH0089	upper Crooked Cr.	0.9999		
12FH0090	Round Butte Hatchery	0.9141	upper Crooked Cr.	0.0859
12FH0091	upper Crooked Cr.	1.0000		
12FH0092	upper Crooked Cr.	1.0000		
12FH0093	upper Crooked Cr.	1.0000		
12FH0094	upper Crooked Cr.	1.0000		
12FH0095	upper Crooked Cr.	1.0000		
12FH0096	upper Crooked Cr.	1.0000		
12FH0097	upper Crooked Cr.	1.0000		
12FH0098	upper Crooked Cr.	0.9999		
12FH0099	upper Crooked Cr.	1.0000		
12FH0100	Round Butte Hatchery	0.9921		
12FH0101	upper Crooked Cr.	1.0000		
12FH0102	Round Butte Hatchery	0.9994		
12FH0103	upper Crooked Cr.	0.9986		
12FH0104	upper Crooked Cr.	1.0000		
12FH0105	upper Crooked Cr.	1.0000		
12FH0106	upper Crooked Cr.	1.0000		
12FH0107	upper Crooked Cr.	1.0000		
12FH0108	upper Crooked Cr.	1.0000		
12FH0109	upper Crooked Cr.	1.0000		
12FH0110	upper Crooked Cr.	1.0000		
12FH0111	upper Crooked Cr.	1.0000		
12FH0112	upper Crooked Cr.	1.0000		
12FH0113	upper Crooked Cr.	0.9994		
12FH0114	upper Crooked Cr.	1.0000		
12FH0115	upper Crooked Cr.	1.0000		
12FH0116	upper Crooked Cr.	1.0000		
12FH0117	upper Crooked Cr.	1.0000		
12FH0118	upper Crooked Cr.	1.0000		
12FH0119	upper Crooked Cr.	0.9999		
12FH0120	upper Crooked Cr.	1.0000		
12FH0121	upper Crooked Cr.	1.0000		
12FH0122	upper Crooked Cr.	1.0000		
12FH0123	upper Crooked Cr.	1.0000		
12FH0124	upper Crooked Cr.	1.0000		
12FH0125	upper Crooked Cr.	1.0000		
12FH0126	upper Crooked Cr.	1.0000		
12FH0127	upper Crooked Cr.	1.0000		
12FH0128	upper Crooked Cr.	1.0000		
12FH0129	upper Crooked Cr.	1.0000		
12FH0130	upper Crooked Cr.	1.0000		
12FH0131	upper Crooked Cr.	1.0000		

Individual	Best Estimate	Probability	2nd Best Estimate	Probability
12FH0132	upper Crooked Cr.	1.0000		
12FH0133	upper Crooked Cr.	1.0000		
12FH0134	upper Crooked Cr.	1.0000		
12FH0135	upper Crooked Cr.	1.0000		
12FH0136	upper Crooked Cr.	1.0000		
12FH0137	Round Butte Hatchery	1.0000		
12FH0138	upper Crooked Cr.	1.0000		
12FH0139	upper Crooked Cr.	1.0000		
12FH0140	upper Crooked Cr.	1.0000		
12FH0141	upper Crooked Cr.	1.0000		
12FH0142	upper Crooked Cr.	1.0000		
12FH0143	Round Butte Hatchery	0.5110	upper Crooked Cr.	0.4890
12FH0144	upper Crooked Cr.	1.0000		
12FH0145	upper Crooked Cr.	0.9991		
12FH0146	upper Crooked Cr.	1.0000		
12FH0147	upper Crooked Cr.	1.0000		
12FH0148	upper Crooked Cr.	1.0000		
12FH0149	upper Crooked Cr.	1.0000		
12FH0150	upper Crooked Cr.	1.0000		