Beaver Creek Passage Improvement Study
Methow Subbasin

Twisp, Washington

Bureau of Reclamation

Bonneville Power Administration

May 2013

This report is an update to Appendix C1 in the Methow Intensively Monitored Watershed 2012 Annual Report and can be found at:
http://www.usbr.gov/pn/fcrps/rme/methowimw/MethowIMW032013.pdf

Introduction

Many streams in the Pacific Northwest have small dams to divert water for irrigation. These diversion structures may constitute complete or partial barriers to upstream migration of anadromous salmonids. Reduced access to historic spawning and rearing habitat has had an adverse impact on some salmonid populations. Beaver Creek, a tributary of the lower Methow River in north-central Washington that drains into the Methow River near Twisp, Washington, at rkm 57, has an area of 179 km^2 with numerous small tributaries. It was occupied historically by anadromous salmonids, particularly steelhead (*Oncorhynchus mykiss*) and perhaps Chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*). The listed bull trout (*Salvelinus confluents)* also occupied the stream. Some other resident salmonids such as resident rainbow trout (*O. mykiss*), cutthroat trout (*O. clarki*), and the introduced brook trout (*S. fontinalis*) are also present. This report focuses primarily on anadromous (*O. mykiss*).

Among anadromous salmonids *O. mykiss* have a complex life history. They are iteroparous (do not necessarily die after spawning and can spawn more than once); the juveniles have variable growth rates and life spans in freshwater rearing areas, dependant in part on water temperature and food availability, with outmigration ranging from one to four or more years; they spend a variable time rearing in the ocean before returning to freshwater spawning tributaries, resulting in various combinations of freshwater and ocean residency. *O. mykiss* also exhibit several life history polymorphisms, including resident and fluvial forms. Resident *O. mykiss* were abundant upstream from the diversion dams.

Water for irrigation has been diverted from Beaver Creek for over 100 years by barriers and diversions mostly impassable to migratory fish. This time span represents many generations of steelhead and other anadromous salmonids. The ESA-listed species are the target for habitat improvement. Improving access to suitable habitat and the quality of instream habitat are RPA action items in the 2008 NOAA Fisheries Biological Opinion on the Federal Columbia River Power System. Removing migration barriers or otherwise improving passage can provide access to previously blocked habitat, re-establish native fish populations, increase marine-derived nutrients to the aquatic and terrestrial ecosystem, improve spawning and rearing habitat and re-establish connectivity of disjunct fish populations (Martens and Connolly 2008). On the other hand, barrier removal or replacement could also allow introduction of non-native species, introduce disease by incoming fish, increase negative interactions among fish species, increase hybridization rates, and allow colonization by less successful stocks of fish. Besides diversion structures, some other activities in the watershed contributed to degraded salmonid habitat, such as sedimentation from roads, stream channelization, livestock grazing, timber harvest, large wildland fires, and landslides.

The Beaver Creek Passage Improvement Study was an interagency and landowner effort initially undertaken in 2002 to replace or modify four barriers to migration (push-up dams or small concrete dams to divert water for irrigation) and replace them with a series of rock vortex weirs (RVWs) that were expected to provide passage for adult and juvenile anadromous salmonids, particularly *O. mykiss*, while maintaining the ability to divert water for irrigation. Some other projects such as culvert removal and pump and headgate replacement were also implemented; some additional diversion replacement and water acquisition actions also occurred. A major objective of passage improvements on Beaver Creek was to reopen and reconnect historically utilized habitat for anadromous salmonids and assess recolonization of Beaver Creek by anadromous salmonids. Some passage based on seasonal stream flows might have been possible prior to replacement of barriers. Another objective was to evaluate upstream passage of smaller juvenile fish. Some novel aspects of the study included coupling new PIT-tag interrogation technology with genetic markers wherein PIT tags indicate movement of fish in the basin while genetics provides information about the reproductive contribution of individuals and the establishment of successful spawning. Table 1 lists the diversions, location in the stream, type of action taken, and the date of completion. Figure 1 shows the location of the diversions replaced in Beaver Creek.

Project at a Glance

Formal Project Name: Beaver Creek Passage Improvement Study	
Project Type: Re-opening Tributary Habitat for Use by Anadromous Salmonids	
Project Construction Sponsor: Okanogan Conservation District	
Project Design: Bureau of Reclamation	
Landowner(s): Private, Washington Department of Fish and Wildlife, and US Forest Service	
Partners: US Geological Survey, Washington Department of Fish and Wildlife, Columbia River Research Laboratory, University of Idaho Ecohydraulics Research Group (Boise, ID) Aquaculture Research Institute (Hagerman, ID and Bureau of Reclamation (Technical Assistance and Design)	**Reclamation Development Costs:** **$ 541,000**
Funding Source(s): BPA	**Implementation Cost: $ 544,000**

Table 1. List of irrigation diversions in Beaver Creek, location, type of action taken to correct passage problem, and date of completion.

Diversion	Distance from Mouth of Beaver Creek (km)	Type of Action	Date Diversion Completed
Fort-Thurlow	2.427	Replace existing diversion with RVW. Piped 2 years after RVW installed.	2004
Tice Diversion	2.484	Replaced diversion with pump and moved POD downstream to rkm 2.48.	2011
Lower Stokes	4.531	Replace existing diversion with RVW. Landowner piped diversion.	2003
Thurlow Transfer	6.342	Replace existing diversion with RVW. Not piped.	2003
Upper Stokes	7.063	Replace existing diversion with RVW. Some piping.	2003
Redshirt	8.065	Replace existing diversion structure with rock. Reconfigured head gate to provide water at low flow	2007
Batie	10.31	Partial or seasonal barrier, logs and plastic	2013/2014
Marracci	10.539	Replace existing diversion with RVW. Diversion piped by Reclamation at same time diversion was replaced. Water acquisition.	2005 2011
Fork in Upper Beaver Creek	14.974		

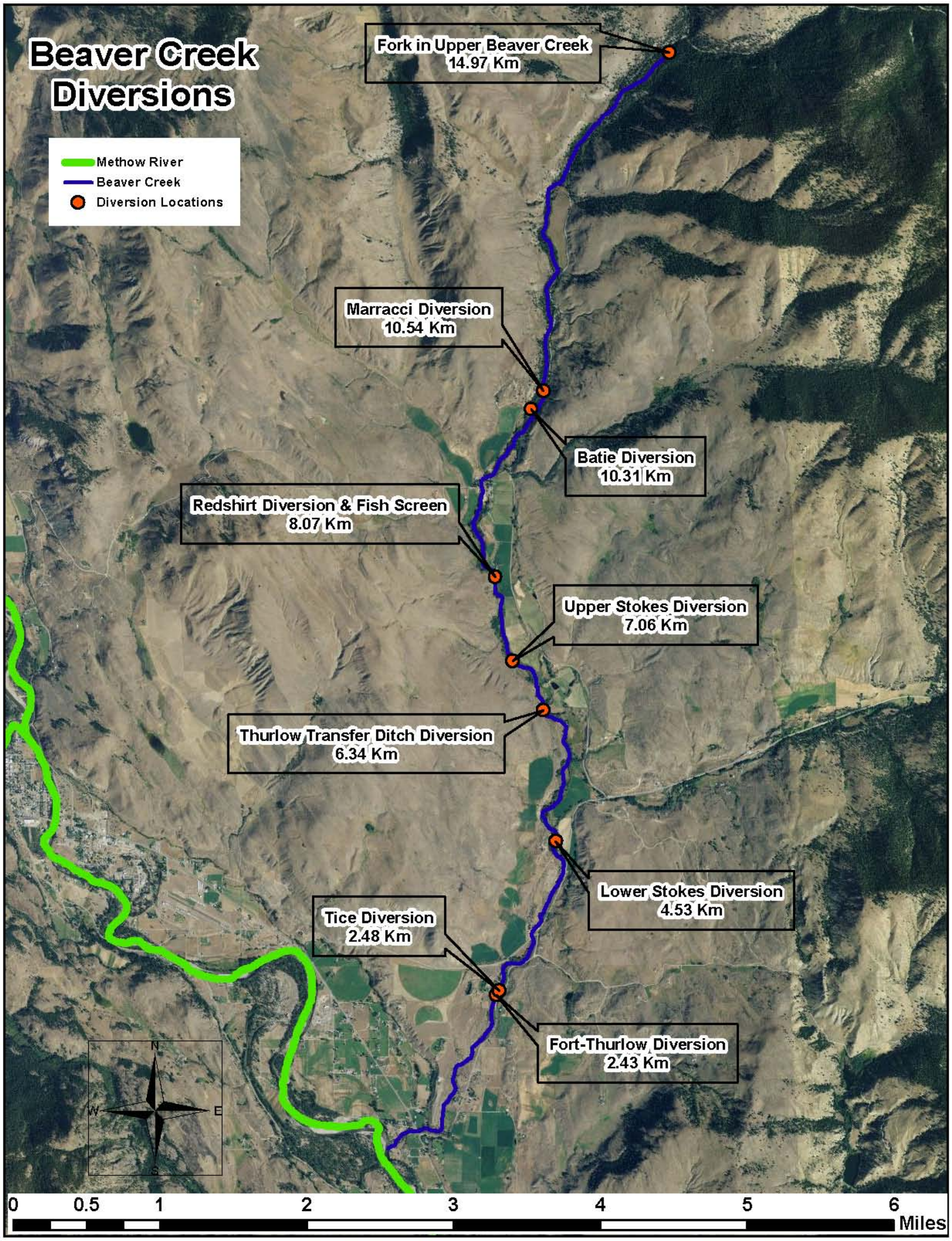

Figure 1. Location of diversion structures in Beaver Creek.

Rock Vortex Weirs (RVWs)

RVWs are a relatively new methodology for providing fish passage. Little information was available as to their effectiveness at passing fish species of the Pacific Northwest (Connolly et al. 2010). RVWs in Beaver Creek were designed to replace existing barriers to fish migration and constructed under supervision of the Bureau of Reclamation (Connolly et al. 2010). Large boulders were placed in a V-shaped configuration pointed upstream to provide hydraulic conditions that would aid upstream fish passage across a low rock weir (Photo 1). The "legs" angled downstream from 15° to 30° relative to the streambank. Boulders and rocks used in construction of RVWs were sized to remain in place and stable at a range of streamflows. RVWs are designed to create a scour pool just downstream of the weir, which may provide juvenile rearing or holding habitat and a jump pool. Two, three, or more such weirs were needed at each replaced irrigation diversion to reduce the gradient from the water surface elevation needed to divert water for irrigation and at the same time provide passage to all sizes and species of fish (Photo 2). A detailed account of hydraulic modeling of RVWs is presented by Ruttenberg et al. (2009).

1)

2)

Photo 1. Lower Stokes RVW under construction. Large boulders are placed in a V-shaped configuration pointing upstream to provide hydraulic conditions that aid upstream fish passage. Boulders and rocks were sized to remain in place and stable at various stream flows.

Photo 2. Completed Fort-Thurlow RVW. Each weir consists of a low head structure that provides relatively easy passage for upstream migrating fish.

In Beaver Creek, replacement of barriers with RVWs began in 2002 at the fourth upstream barrier and progressed downstream. Three existing diversion dams on lower Beaver Creek were replaced in 2003 (Lower Stokes, Thurlow Transfer, and Upper Stokes) and one in 2004 (Fort-Thurlow) (Table 1) (Martens and Connolly 2008). Several other passage barriers further upstream were replaced or the point of diversion was moved and replaced with a pump (Tice Diversion, for example) (Table 1).

Effectiveness Monitoring

Intensive effectiveness monitoring evaluates whether the management action achieved the desired effect or goal while examining mechanistic ecological relationships in a hypothesis testing experimental design. The before-after-control design was used for this monitoring project using two nearby tributaries (Libby and Gold creeks) as comparison streams.

Methods for Monitoring and Evaluation

Monitoring and evaluation of both the replaced diversions dams and the use of the RVWs by adult and juvenile anadromous salmonids was important to measure the success of this project for re-opening historic tributary habitat for salmonids and the potential to use this methodology and structures to replace barriers to migration in other tributaries. Effectiveness is being measured by changes in target biological populations upstream and downstream of the modified diversions, by

- monitoring upstream passage of juvenile fish and physical attributes of rosgen vortex weirs;
- colonization of newly re-opened habitat measuring changes in fish assemblage and distribution, population estimates, individual growth, and survival;
- assessing changes in population genetic measures of the colonizing population above and below the modified diversions;
- identification of the number and source of colonizing migratory salmon and steelhead, reproductive success of colonizing steelhead and tracking the complete life cycle of the anadromous steelhead returning to the stream as adults;
- measuring nitrogen 15 (15N) and carbon 13 (13C) isotope levels in fish, vegetation, and aquatic insects to detect change in ocean derived nutrients to the stream; and
- effectiveness of fish screens in diversion canals.

Various studies were designed to evaluate the effectiveness of the new RVWs to pass upstream migrating fish. Study-specific sites were established in lower Beaver Creek to address effectiveness monitoring questions. Some sampling and surveys were conducted in nearby Libby and Gold creeks, which served as comparisons for the barrier removal projects in Beaver Creek.

Fish assemblage and distribution

Electrofishing gear was used to collect fish throughout the three creeks. A fish weir located near rkm 1 in Beaver Creek was also used to collect upstream and downstream migrating fish. Fish collected were lightly anesthetized using MS-222 (tricaine methane sulfonate), identified, and measured to fork length in mm and weighed to the nearest 0.1 g. Captured juvenile fish were PIT tagged according to standard practices and guidelines.

Fish movement, population estimates, and growth

A study site was established at Lower Stokes Diversion RVW to assess upstream juvenile fish passage during 2004 – 2007 (Connolly et al. 2010). Adult and juvenile *O. mykiss* were trapped in a weir located about 1 km from the mouth of Beaver Creek and PIT-tagged. PIT-tagged fish and PIT tag interrogation systems were used to evaluate upstream passage of small salmonids through the Lower Stokes series of RVWs (Connolly et al. 2010). A multiplex PIT tag interrogation system with three antenna arrays was installed above the Lower Stokes diversion and could be used to determine direction of fish movement. Smaller, one-antenna PIT tag interrogation systems were installed in Beaver Creek 3 km downstream from Lower Stokes, 20 m downstream from Lower Stokes, 100 m upstream from Lower Stokes and about 5 km upstream from Lower Stokes, to monitor movement of fish in 2004 and 2005 (Ruttenberg et al. 2009). Downstream passage of juvenile fish through the RVWs was not specifically evaluated since streamflows were expected to assist any downstream migrating fish.

Three 500-m-long sites were selected in Beaver Creek to estimate fish populations. Initial assessments began with a habitat survey, based on habitat type (pools, glides, riffles, and side channels). Prior to sampling each site, the section was blocked with nets to retain fish. A backpack electrofishing unit was employed to capture fish.

Data from recaptured PIT-tagged juvenile fish were used to assess fish growth seasonally and annually.

Colonization

Annual counts of fish entering Beaver Creek and moving upstream were determined from PIT-tagged fish interrogated at PIT tag detectors or fish captured and tagged in the weir. PIT tag interrogation stations were installed at stream km 1, 4, and 12 to monitor instream movements of tagged salmonids.

Juvenile fish entrainment into irrigation canals

A fish screen was installed within the Lower Stokes irrigation canal. The effectiveness of the fish screens and bypasses were evaluated on three occasions during July and August 2005 by releasing 30 or more PIT-tagged juvenile rainbow trout/steelhead into the canal above the screen. Two PIT tag interrogations systems monitored movement of the fish released into the first 20 m of the canal.

Isotope Studies

Three sites at rkm 3, 12, and 15 in Beaver Creek and in two other nearby streams were selected for isotope analysis to determine the ratios of nitrogen 15 to nitrogen 14 and carbon 13 to carbon 12 (Connolly et al. 2010). The ratios of 15N to 14N and 13C to 12C can be used to provide an indication of the contribution of marine-derived nutrients to the system from returning adult anadromous salmonids. Adult salmon provide a subsidy of marine-derived nutrients to the ecosystem when they die and decompose after spawning. Nutrients are leached from the carcasses into the stream and contribute to primary production; juvenile fish and aquatic macroinvertebrates often feed directly on the carcasses, and mammalian predators can remove carcasses from the stream to the riparian areas where leached nutrients support growth of vegetation, as well as of terrestrial organisms. Samples of fish, vegetation, and aquatic insects from Beaver Creek were collected at the sites, preserved, and analyzed in the laboratory.

Genetic Structure of the Population

Genetic data can be used to monitor populations and identify interbreeding groups and source populations. In some cases hatchery-origin fish provide an over-abundant source population to colonize unoccupied habitat. Hatchery-origin fish have been documented to have lower relative reproductive success compared to naturally produced fish. Hatchery fish may not be a desirable source population for colonization of newly accessible habitat. Genetic parameters were used to determine if anadromous *O. mykiss* successfully established in Beaver Creek after replacement of passage barriers with RVWs. The objectives of the study were to identify the source and abundance of colonizers after barrier removal, identify if and where detectable changes occurred to population metrics, and identify if a population of anadromous *O. mykiss* was successfully established in Beaver Creek. Pair-wise comparisons between the before-after samples were used to detect changes due to the barrier replacements with RVWs. Details of the genetic analysis are provided in Weigel (2013).

Results, Interpretations, and Trends

Replacement of four impassable irrigation diversions in lower Beaver Creek with RVWs was completed in 2004. Some other diversions were modified later. Adult anadromous *O. mykiss* entered the newly accessible habitat in Beaver Creek in 2005, the first year that upstream passage was provided. In 2005, two juvenile Chinook salmon were collected above the two RVWs. An adult Chinook salmon was seen near rkm 10 in 2006.

Adult anadromous *O. mykiss* entered Beaver Creek the first spring after barrier removal (Weigel et al. in press) (Figure 2). Adult anadromous *O. mykiss* migrated into upper Beaver Creek in 2007 and 2008, 3 and 4 years after barrier reconstruction (Weigel et al. in press). Juvenile *O. mykiss* tagged in Beaver Creek returned as adults to the creek after two years, indicating the establishment of a full anadromous life cycle in the study area (Weigel et al. 2013).

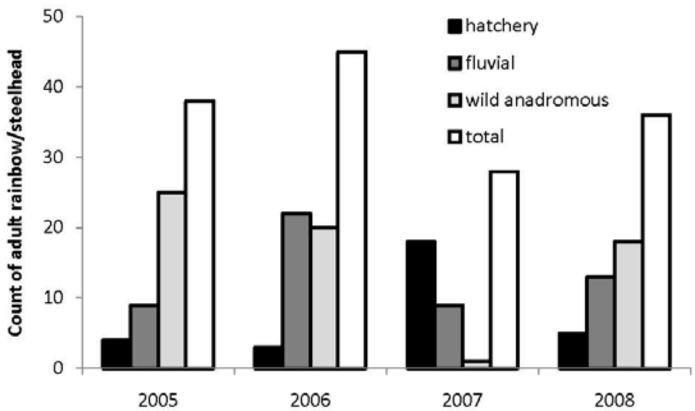

Figure 2. Adult *O. mykiss* counts into Beaver Creek 2005-2008 by life history and source (fluvial, wild anadromous, and hatchery) with the total adult count (total) by year. Figure reproduced from Weigel et al. (in press).

Fish Assemblage

At least 10 species of fish were collected throughout Beaver Creek in 2004-2005; the predominant species was juvenile rainbow trout/steelhead. About 3,300 were PIT tagged. Fewer brook trout, Chinook salmon, coho salmon, bull trout, and cutthroat trout were collected and tagged. Other fish species collected included smallmouth bass (*Micropterus dolomieu*), bridgelip sucker (*Catostomus columbianus*), longnose dace (*Rhinichthys cataractae*), shorthead sculpin (*Cottus confuses*) and mountain whitefish (*Prosopium williamsoni*). Except for the shorthead sculpin, most of these fish species were collected only in the lower 1 km of Beaver Creek. Figure 3 shows fish species and distribution in Beaver Creek.

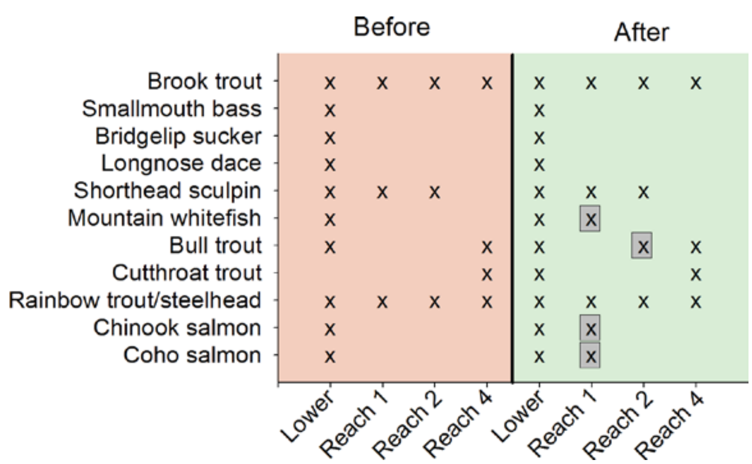

Figure 3. The presence of fish species in selected sections of Beaver Creek before and after the replacement of the downstream-most water diversion. Grey highlighted boxes represent newly represented species after the barrier was modified. Figure reproduced from Connolly et al. (2010).

Fish movement, population estimates, and growth

Tagged juvenile *O. mykiss* moved upstream past the RVWs mostly during the spring and summer months. Of the 3,699 juvenile *O. mykiss* tagged, 88 *O. mykiss*, 20 brook trout, and one coho salmon were recorded passing upstream (Martens and Connolly 2010). Some *O. mykiss* ascended the series of RVWs quickly, while others took up to 87 days to move upstream (Martens and Connolly 2010). Some delay in movement was noted at flows of < 0.32 m/s (Martens and Connolly 2010). Delay may indicate that the juvenile fish were utilizing the habitat below the weir for rearing and resting during upstream movement. The smallest documented fish moving upstream was a 77 mm *O. mykiss*.

Juvenile *O. mykiss* outmigrated from Beaver Creek during the spring or the fall. *O. mykiss* that reared in Beaver Creek prior to smolting returned at very low rates; however, *O. mykiss* parr that reared in habitats downstream from Beaver Creek were much more successful returning as adults. Parr reared in these downstream habitats for 200 to 600 days between that last detection in Beaver Creek and the first detection during smolt outmigration (Connolly and Weigel, unpublished data).

Several other species of native salmonids moved upstream through the Lower Stokes weir. These included Chinook salmon, coho salmon, and mountain whitefish (Martens and Connolly 2008). Non-native brook trout already present in Beaver Creek also moved upstream through the weir. Bull trout are expected to utilize the RVWs to move throughout the basin. Low numbers of bull trout have been documented in some headwater tributaries and at the fish trap near the mouth of Beaver Creek.

Fish recaptured over time showed a seasonal growth pattern, with most growth occurring in the spring-summer time period, with less growth occurring during winter.

Juvenile fish entrainment into irrigation canals

Tagged juvenile trout released into an irrigation diversion upstream from the fish screen for the most part moved upstream and out of the canal (75 percent); some fish were later recaptured in the canal (16 percent) and a few fish were not detected (5 percent). Some fish appeared to be rearing in the canal. The fish screens and bypass successfully prevented juveniles from being entrained into irrigation canals.

Colonization

Anadromous *O. mykiss* successfully began colonizing Beaver Creek the first year after barriers to migration were replaced with RVWs (Figure 2). Most of the fish were natural-origin; few fish were hatchery-produced, even though about 80 percent of the adult *O. mykiss* at Wells Dam are of hatchery-origin. Few hatchery-origin fish were documented entering the basin during the study, and did not contribute to production of juveniles; only one of the hatchery steelhead produced two parr offspring, but none of these offspring returned as adults (Weigel 2013). The number of colonizing adults fluctuated over the years 2005 to 2008, and followed the adult counts at Wells Dam conducted by WDFW. This may simply reflect overall fluctuations in the returning adult *O. mykiss* population to the upper Columbia River during this period. Adult *O. mykiss* migrated higher into the Beaver Creek basin past the PIT tag reader at stream km 12 in 2007 and 2008 (Weigel et al. in press). There were significant changes in genetic comparisons at lower monitoring sites comparing before and after treatments (Weigel et al. in press). The shift in genetics matches tag migration data supporting that adult fish were beginning to migrate into upper Beaver Creek about one generation after barrier removal. The process of colonization and full utilization of the re-opened habitat in Beaver Creek is likely to progress over several steelhead generations, as natural production becomes established and additional adults enter the basin. Chinook and coho salmon and mountain whitefish also moved upstream through the RVWs.

Genetic data were coupled with PIT tag movement data in Beaver Creek to understand the source and success of anadromous steelhead that were the primary target for stream improvement projects. This study used microsatellite data to track 1) success of individual adults in Beaver Creek after barrier replacement; 2) spatial extent of population genetic changes coinciding with the movements of adult *O. mykiss* into Beaver Creek; and 3) assess the effect of small irrigation diversion barriers on recent migration prior to barrier removal.

Hatchery salmon and steelhead have also been found to have reduced reproductive success in natural stream environments. The extensive hatchery programs in the upper Columbia Basin provide an abundant source of adult steelhead. Therefore, an understanding of the role and success of hatchery *O. mykiss* in this basin was critical to understanding the effectiveness of habitat improvement projects in the Methow and other local basins.

This study identified that adult *O. mykiss* entered Beaver Creek the first spawning season after barrier removal. These individuals successfully reproduced in Beaver Creek and established anadromous progeny that returned to Beaver Creek as adults. Fluvial *O. mykiss* (riverine migrants) crossed with anadromous *O. mykiss* and contributed directly to the establishment of the population by matching to progeny that return to Beaver Creek as adults; few hatchery fish were encountered at the Beaver Creek weir during the parentage study (2005 and 2006) and only one of these adults matched to parr, but none of these parr returned as adults.

The site upstream from the barrier removal projects showed significant change in population genetic parameters after 5 years. Tag movement data indicated that adults were continuing to migrate into habitats further upstream.

Isotope Studies

The ratio of 15N to 14N were highest for the lower Beaver Creek site, while the ratio of 13C to 12C were similar between sites within the watershed. The higher nitrogen ratio in lower Beaver Creek may indicate some anadromous fish use of lower Beaver Creek prior to replacement of the Fort-Thurlow and Lower Stokes diversions with RVWs, or it may be the result of upstream land-use practices. Nitrogen ratios were highest for age-1 and age-0 fish (Martens and Connolly 2008). Vegetation samples generally exhibited a similar pattern of nitrogen ratios in lower Beaver Creek as did the juvenile fish. Nitrogen ratios for several insect groups were generally higher in lower Beaver Creek, but less consistent than observed for juvenile fish. These initial isotope data suggest that anadromous salmonids did not use or could not access the middle and upper reaches of Beaver Creek (Connolly et al. 2010). However, adult anadromous *O. mykiss* were documented migrating into upper Beaver Creek in 2007 and 2008, two and three years after barrier replacement, indicating that colonization of the stream was in progress. The higher ratio of 15N to 14N in lower Beaver Creek may indicate some input of marine-derived nutrients into the system from returning adult salmonids. Additional data collection and analyses are required over a long term to determine if adult salmonids returning to Beaver Creek provide a substantial nutrient subsidy in the form of marine derived nutrients that can be detected in stable isotope ratios for nitrogen and carbon in aquatic and terrestrial biota. Since steelhead are iteroparous and do not necessarily die after spawning as do salmon and may move down river, begin feeding again and return to spawn again in their natal stream, their overall contribution to the nutrient dynamics of Beaver Creek may be difficult to detect in the short term.

Conditions Prior to Barrier Removal

Genetic data provide information about population and species interactions that cannot be derived from movement and other tag-based observations. Barriers (primarily waterfalls) have been found to be related to genetic differentiation in stream species (particularly resident salmonids like bull trout). However, small diversion dams (<=2.0m) are not necessarily complete barriers to migration like large waterfalls.

The genetic measurements in Beaver, Libby, and Gold creeks (F_{st}, heterozygosity, allelic richness) were similar to other documented populations of *O. mykiss*. A standard genetic differentiation measure (F_{st}) was used as an indicator of isolation. There was a slightly higher range of F_{st} in Beaver Creek (0-0.019) versus Libby and Gold creeks (0-0.09), two nearby comparable tributaries. The higher F_{st} values in Beaver Creek are similar to those detected upstream of barriers in other *O. mykiss*, indicating more isolation and genetic drift in this basin prior to barrier removal. Estimates of migration among sample sites in Beaver Creek indicates complete fragmentation for at least one generation prior to barrier removal (Weigel 2013). Therefore, these data indicate that the diversion dams were preventing migration in Beaver Creek.

Summary

Several barriers to upstream migration in Beaver Creek were replaced with a series of RVWs. Pre-treatment data from denetic samples indicate no successful migration among sampled sites throughout Beaver Creek. Adult anadromous *O. mykiss* began occupying Beaver Creek soon after barriers to migration were replaced. Movement of adults to upper Beaver Creek occurred within a few years of barrier replacement. Several other salmonid species migrated upstream to newly accessible habitat. Juvenile *O. mykiss* tagged in Beaver Creek were detected at several Columbia River dams, and some of these smolts returned to the stream years later as adults, indicating that anadromy has been re-established in Beaver Creek with the replacement of impassable diversion with RVWs.

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