Hangman Creek Fisheries Enhancement RM&E Progress Report, 2014-2016

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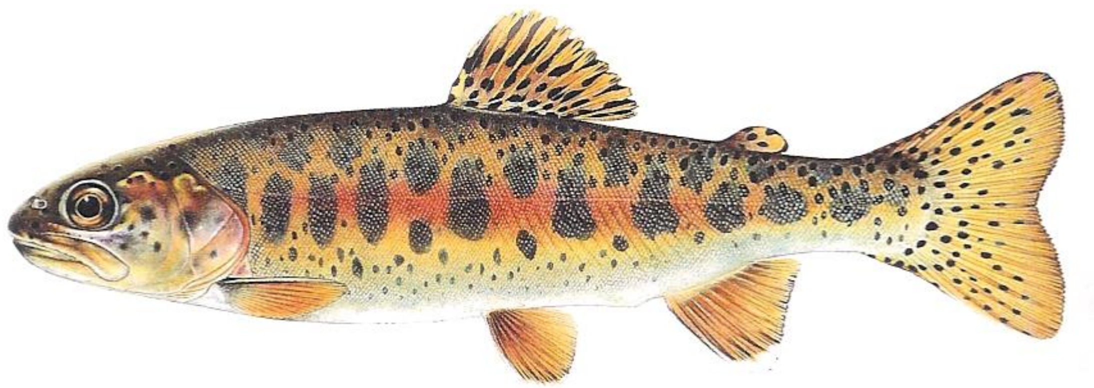

Redband trout (Oncorhynchus mykiss gairdneri)

5/1/2014 - 04/30/2017

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Abstract

The Hangman Creek Fisheries Project monitors and evaluates multiple characteristics of redband trout *Oncorhynchus mykiss gairdneri* and their associated habitats throughout the upper Hangman Creek watershed. Within this reporting period, redband trout were sampled in areas across the project area. The vast majority however were restricted to stream reaches where water temperatures are consistently cool and riparian habitat is largely intact. Data from annual index monitoring also suggests that trout densities across the watershed are impacted by region-wide influences. Although many subpopulations are isolated from one another, they have similar trends in annual densities. Indian Creek however appears to be somewhat buffered from these effects, likely due to a larger, more diverse and hospitable reach of habitat conditions. Impacted stream reaches such as those throughout the lower elevation floodplains where dryland agriculture dominates, have been found to provide rearing habitat in the winter and a migration corridor to and from spawning habitats for fluvial trout. Data suggests that mainstem habitat downstream of kilometer 25.5 and many of the lower tributary reaches are routinely subject to inhospitable summer temperatures. This has been especially apparent from 2013 through 2016, where we have recorded the hottest summer stream temperatures since the project's inception. This data reinforces our objective that restoration actions should provide diverse conditions which incorporate refuge-habitat throughout the year, and serve to reconnect isolated subpopulations in order to provide an avenue for recolonization and increased genetic integrity. Our restoration actions will also serve to increase resilience of the aquatic ecosystem in order to provide a palatable environment for fish and wildlife as the climate is rapidly changing.

Upon initiation of the Fish and Wildlife Program's restoration actions throughout a focus reach of mainstem Hangman Creek in 2014, we hope to illicit a positive response from fluvial fish whereas a higher proportion utilize this reach, return rates to spawning tributaries increase, and trout are observed to utilize adjacent tributaries at higher rates. It may however be too soon to record a measurable response to fish due to restoration actions. Physical parameters in this reach however do reflect an increase in habitat diversity and preferred habitat conditions such as a higher proportion of pools, backwater, and stream temperature refugia in an area where water temperatures consistently exceeded threshold values throughout summer rearing periods. Monitoring actions focused on the effectiveness of restoration on fluvial fish will continue throughout the upper Hangman watershed, especially as our restoration activities expand across the upper Hangman Creek basin.

1. Introduction

Since 2002, the Coeur d'Alene Tribe has been assessing and monitoring fisheries and habitat conditions throughout the upper Hangman watershed. Results from these surveys indicate distinct linkages between land management practices and the presence of salmonids, specifically redband trout *Oncorhynchus mykiss gairdneri*. As late as 1950, redband trout were thought to be distributed throughout the upper watershed in a largely continuous expanse of suitable habitat (Aripa 2003). Presently however, the majority of redband trout are confined to the forest dominated tributaries which provide decent water quality and habitat conditions. This has resulted in a largely fragmented resident population exhibiting various levels of genetic drift (Small et al 2005).

A fluvial life history strategy is still present within the upper Hangman watershed. These individuals are restricted to short reaches of mainstem rearing habitat where conditions are marginal, while utilizing adjacent reaches as migratory corridors. The Coeur d'Alene Tribe has recently pursued a better understanding of how this life history strategy influences population dynamics within the upper Hangman watershed. Specifically through dispersal and the effects on gene flow, and the resiliency they may offer in light of projected climate change scenarios. Concurrently, large scale habitat restoration is being conducted to improve mainstem and tributary habitat conditions, facilitating movement between disconnected subpopulations and to increase survival and growth across all life history stages of remnant populations of redband trout.

1.1. Study Area

Hangman Creek drains 430,000 acres of northern Idaho and eastern Washington. The study area consists of the portion of the Hangman Creek watershed that lies within the Coeur d'Alene Reservation and east into the headwaters outside of the reservation. The Washington-Idaho State border, which corresponds to the border of the Coeur d'Alene Indian Reservation, marks the western boundary of the project area. The total acreage is 157,586, with 147,993 of that within the reservation. Elevations range from 754 meters in the northwest corner of the Project Area where Hangman Creek flows west into Washington to 1,505 meters at the top of Moses Mountain on the southeastern end of the Hangman/Coeur d'Alene Basin watershed divide (Figure 1). The named tributaries within the basin include Mission, Tensed, Sheep, Smith, Mineral, Nehchen, Indian, the SF Hangman and its' tributaries Conrad, Martin, and the upper part of Hangman Creek east of the Reservation along with its' named tributaries Hill and Bunnel (Figure 2).

The lower elevation valleys are dominated by various dryland agricultural and ranching practices where habitat conditions frequently become inhospitable for salmonids, especially during summer base flow periods. Specific limiting habitat conditions include but are not limited to; low discharge, elevated stream temperature, low dissolved oxygen, substrate composition, and lack of complexity. These limiting conditions are thought to be the result of one large underlying problem; the loss of interaction between the stream and the adjacent floodplain.

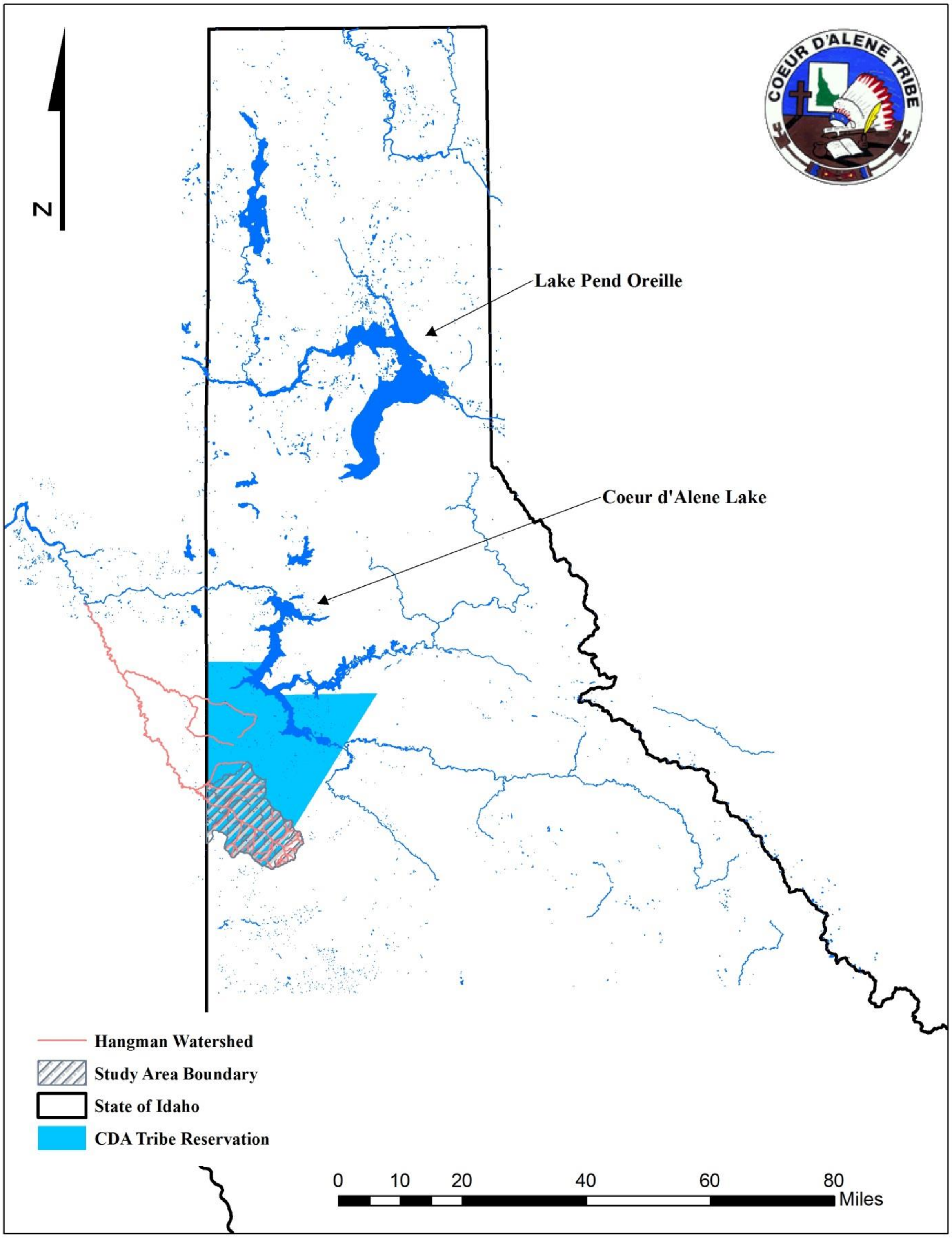


Figure 1. The Hangman Creek watershed study area, located in Idaho almost entirely within the Coeur d'Alene Reservation.

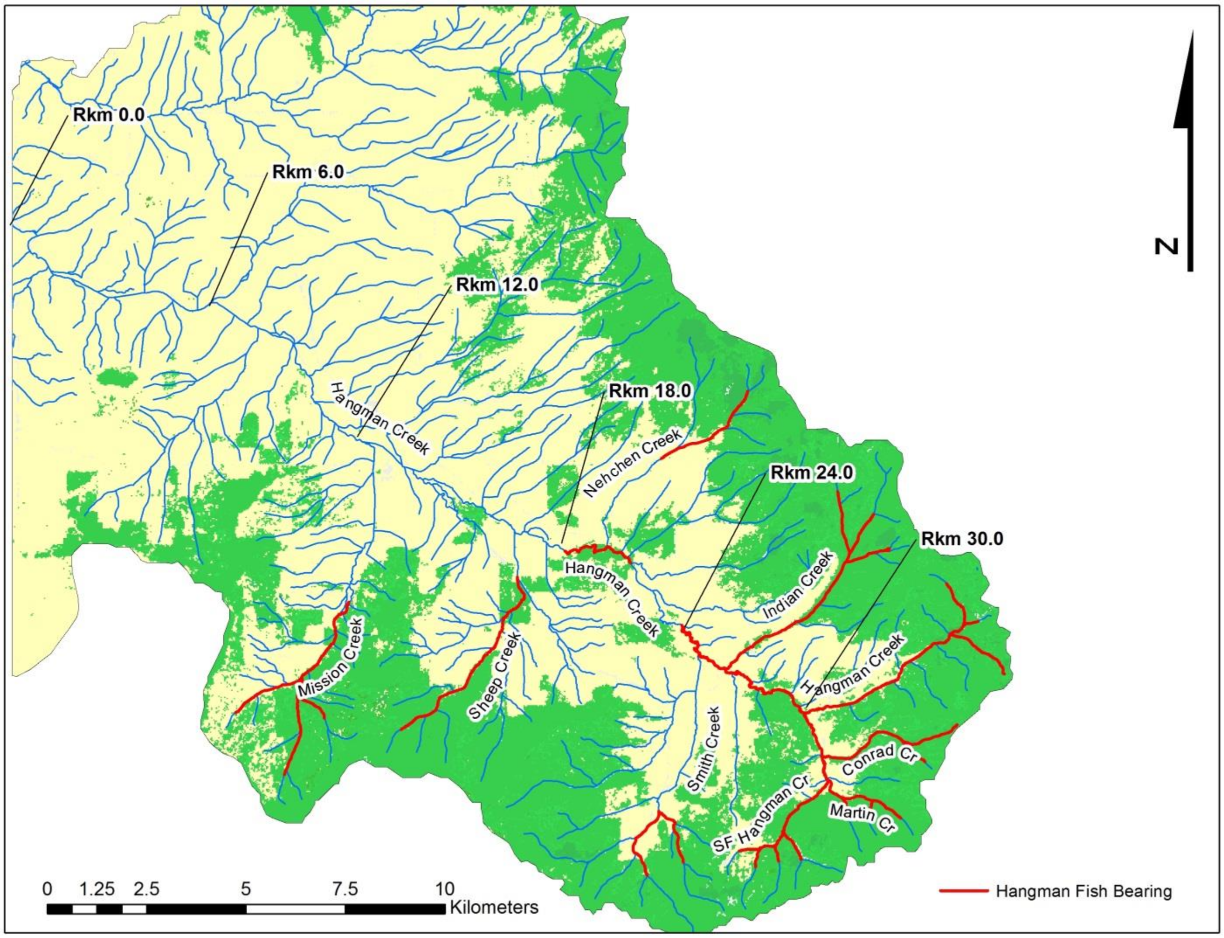


Figure 2. Hangman Creek watershed study area with updated stream kilometer reference points and current fish bearing stream reaches highlighted in red. Stream kilometer 0.0 is located at the Idaho-Washington state line.

The mainstem of upper Hangman Creek predominantly flows within large floodplain valleys which historically supported a dynamic riparian and wetland ecosystem dominated by beaver ponds and low gradient (< 0.5%) meandering streams (Washington State Dept. of Ecology 2005). The US Fish and Wildlife Service Historic Wetland Inventory (2017) estimates the upper Hangman watershed was composed of over 18,000 acres of wetland, many of which were within the floodplain(s) adjacent to valley streams. The Coeur d'Alene Tribe estimates just over 3,000 acres of 'functioning' wetland and/or floodplain are currently present in the same geographic region upstream of the state line of Idaho. Decades of channelization and stream straightening, compounded by land clearing and other land management actions have resulted in an unnaturally monotypic ecosystem with high rates of erosion, sedimentation, topsoil loss, and a hydrograph with extreme peaks and valleys.

1.2. Status and Trend Monitoring

Assessment of the fisheries populations included a broad spatial sampling in order to determine distribution over the entire Hangman watershed within Idaho boundaries, and later was prioritized in 2005 to exclude the northern part of the watershed that was almost entirely devoted to dry-land farming (Green and Kinkead 2008). Previous fish assessment surveys find redband trout to be distributed throughout the upper-most portion of the watershed with fairly stable trends in density. The sub-watersheds located downstream of Smith Creek however have shown trout densities to be more volatile. This is due to the isolation of these streams from the more connective habitat in the upper Hangman watershed and the dominant resident-type life history strategy of the trout which reside in each tributary. These populations are affected by regional as well as localized changes in habitat, whether they are anthropogenic or natural in origin. The Fisheries Program continues to monitor the fish bearing tributaries annually for trends in fish densities in each subwatershed, specifically to determine if habitat restoration actions carried out by our program have a positive effect on the populations within each subwatershed and the upper Hangman watershed as a whole.

Many populations of redband trout throughout the Columbia River basin exhibit multiple life history strategies; such as resident, fluvial, and adfluvial forms. The retention of these life history strategies is interpreted as an evolutionary strategy that promotes adaptive flexibility in stochastic environments (McPhee et al. 2007). Fluvial forms of redband trout in the Hangman watershed are therefore important to the continued presence of trout within each subwatershed as well as the potential recolonization of subwatersheds that have been identified in their historic range. Furthermore, interbreeding between subwatersheds can decrease the likelihood of genetic isolation and the associated problems that occur with it. Previous monitoring of marked fluvial redband trout has confirmed that dispersal rates between tributaries is very low. The Fisheries Program has recently upgraded our trapping and marking of fluvial redband trout to include the use of half-duplex PIT tags along with a series of passive interrogation sites to improve the monitoring of dispersal to adjacent tributaries and into mainstem rearing habitats. This monitoring is used to gather baseline data on how fluvial and resident individuals influence the trout population structure throughout the Hangman watershed. This data is also used to help guide future restoration and monitoring efforts, and how specific restoration actions influence dispersal and rearing habits of redband trout.

1.3. Effectiveness Monitoring

As the rate and magnitude of restoration actions increase in the Hangman Creek watershed, it is important to understand not only how our efforts change the physical habitat, but what influence restoration has on the fish communities they are expected to help. In 2013, restoration efforts were initiated on what started out as a 5.8 kilometer reach of Hangman Creek mainstem habitat. Today, this same reach of Hangman Creek is 6.8 kilometers long due to the reactivation of 3.3 kilometers of historic channel. Additionally, in-stream structures have been incorporated and extensive riparian vegetation has been planted throughout this focus reach of Hangman Creek (see Kinkead & Biladeau 2017: BPA Annual Report "Hangman Creek Fisheries Enhancement Summary, 5/1/2012 – 4/30/2017 for detailed restoration actions carried out in this stream reach). This portion of Hangman Creek is an important connection between a large area of continuous habitat and two fish bearing tributaries (Smith and Nehchen Creeks) which are relatively cut off from the rest of the population. It is our hope the restoration actions that have been initiated will provide more summer and winter rearing habitat and provide a larger extent of continuous and preferable fish habitat which will facilitate dispersal and gene flow between subpopulations.

2. Methods

2.1. Trout Status and Trend Monitoring

2.1.1. Trout Abundance Trends and Distribution Surveys

https://www.monitoringresources.org/Document/Protocol/Details/572

Thirty three sites were sampled annually in 2014 – 2016 via single-pass electrofishing throughout the upper Hangman watershed to monitor annual trends in trout density (Figure 3). The length of each sampled site was defined as a minimum of 200 feet. Trout larger than 65mm total length captured in Indian and Nehchen Creek were implanted with a 12 mm half-duplex PIT tag to monitor for dispersal. Each trout implanted with a PIT tag was marked through the removal of the adipose fin. All other aquatic vertebrates captured during electrofishing surveys were counted and recorded.

Status and trend monitoring methodology is not intended to compare densities from one tributary to another. This methodology is however intended to compare density trends over time within each tributary. Monitoring sites, with the exception of Indian Creek, are not distributed throughout each tributary in a manner that would represent the overall density. Many of the reaches in the project area are either not accessible or the stream habitat type does not permit trout to be recruited to our sampling gear.

In 2014 and 2015, mark-recapture sampling methods were used to estimate abundance of redband trout across three distinct reaches of Indian Creek that were delineated according to coarse-scale channel features. During 2014, eight sites were sampled and were each 61 meters in length. In 2015, nine sites were sampled that were each 100 meters in length. The first pass electrofishing was conducted using the protocol above. Fish were marked with PIT tags and an adipose fin clip and then returned to the sampled site which remained bounded by block seines to ensure no immigration or emigration occurred. Each site was sampled for recapture 24 hours later using the same protocol. Total abundance and variance for each of the three reaches in Indian Creek was then estimated using the methodology described by Hankin (1984), and then summed across all three reaches to generate a tributary-wide abundance estimate and 95% confidence interval. Detailed equations for generating estimates associated with tributary-wide abundances are located in Appendix **Error! Reference source not found.**.

2.1.2. Migrant Trout Trapping

https://www.monitoringresources.org/Document/Protocol/Details/536

Fixed weir migration traps were installed near the mouth of Nehchen Creek (km 0.4) and Indian Creek (km 2.4) to capture upstream migrating pre-spawn adults as well as emigrating post-spawn adults and juveniles (Figure 3). Traps were fished annually from early March through early June. Each trout over 65mm captured in the trap was counted, measured, and implanted with a 12 mm half-duplex PIT tag. Each trout was also marked with an adipose clip and a temporary hole-punch in the operculum for identification upon recapture in the same trapping season. This additional mark was also used to determine if a post spawn adult had shed its tag while spawning.

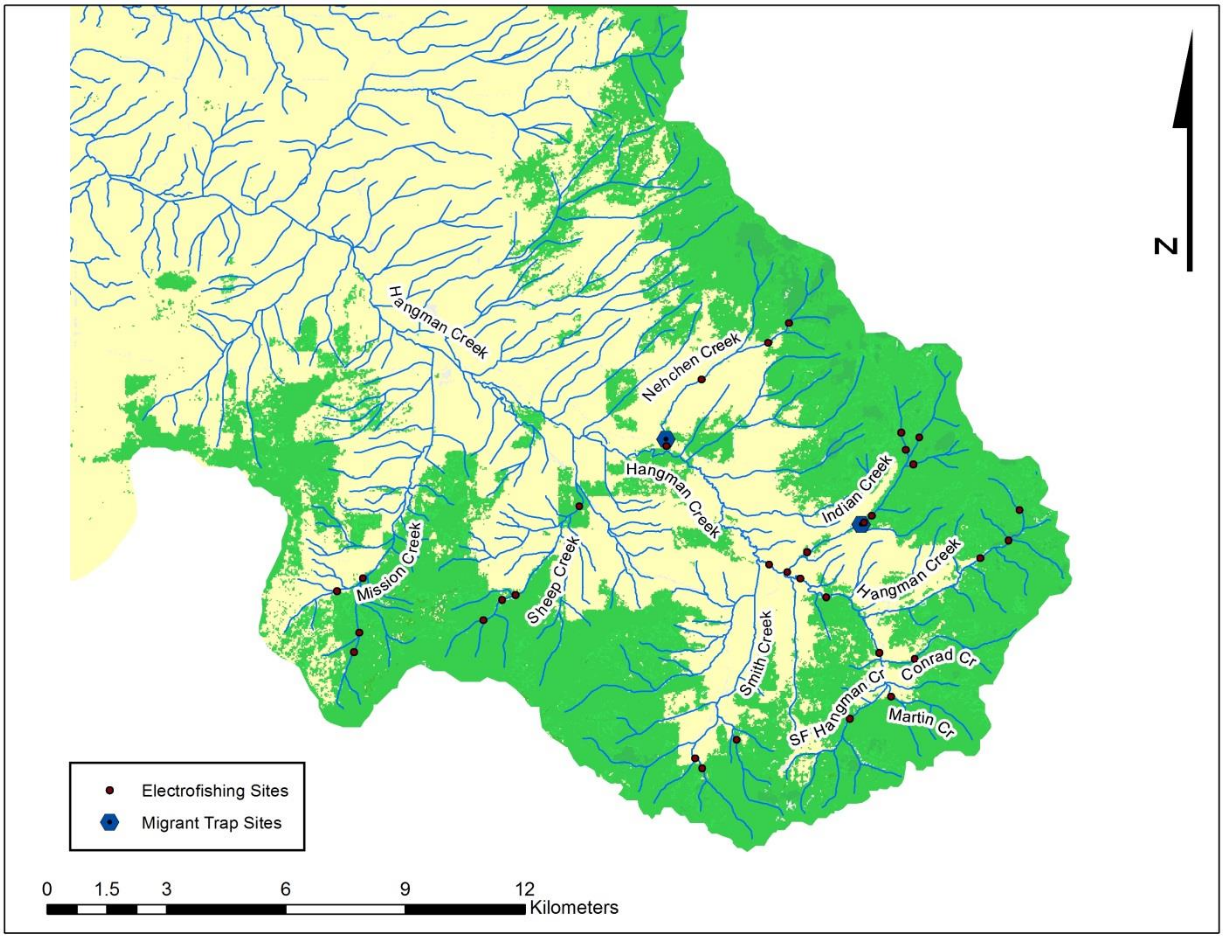


Figure 3. Location map of trout monitoring sites within the upper Hangman Creek watershed study area.

2.1.3. Fluvial Life-history of Trout

https://www.monitoringresources.org/Document/Protocol/Details/3279

Passive interrogation sites were installed in the upper Hangman Creek watershed to monitor movement of PIT tagged individuals. These interrogation sites were installed near the mouths of Sheep (rkm 1.3), Nehchen (rkm 0.1), Smith (rkm 0.7), and Indian Creek (rkm 0.8), and in the mainstem of Hangman Creek at two locations (rkm 19.8 and 25.6). Detections of tagged individuals were used to estimate the prevalence of the fluvial life-history within tributaries of upper Hangman Creek. The sites were also installed strategically to monitor movements of fluvial redband trout in the mainstem of Hangman Creek, specifically into and through a reach undergoing active restoration, and to monitor seasonal movements of all tagged redband trout into adjacent tributaries. Each site, with the exception of the one in lower Sheep Creek, used multiple antennas in order to acquire direction of movement (Figure 4).

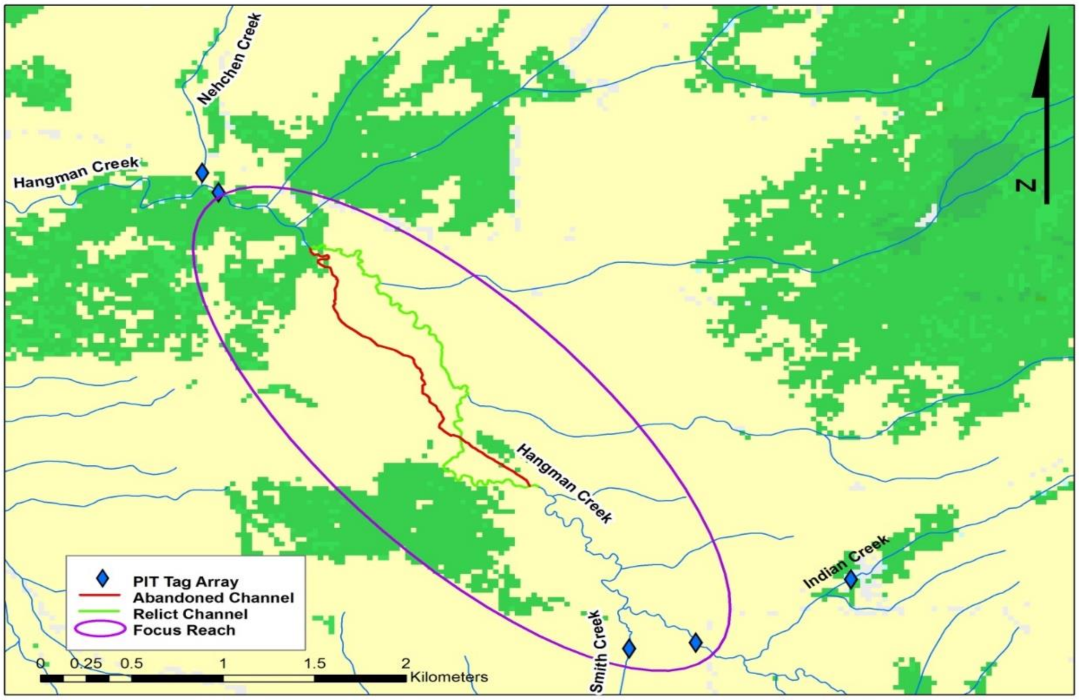


Figure 4. Hangman Creek reach undergoing active restoration beginning in 2014 and the associated fixed PIT tag interrogation sites bounding this reach.

2.2. Effectiveness Monitoring

2.2.1. Spatial and Temporal Temperature Trends

https://www.monitoringresources.org/Document/Protocol/Details/3280

HOBO temperature loggers (onset Computer Corp.) were installed at 34-37 locations in 2014-16, and distributed across the upper Hangman Creek watershed to develop a stream temperature profile. Seasonal trends in stream temperatures were compared before and during active restoration of Hangman Creek from stream kilometer 21.5 through 26.3 initiated in 2014. We compared the percent time temperatures exceeded threshold values in spring (14°C) and summer (20°C) from 2013 through 2016. Five temperature loggers were also deployed within a large backwater area created from restoration activities at stream kilometer 24.1 from 8/19/14 – 11/10/14. The loggers were suspended vertically within the water column at depths of 8’, 6’, 4’, 2’, and near the water surface in order to record the temperature profile.

2.2.2. Physical Habitat Changes Following Restoration Activities

https://www.monitoringresources.org/Document/Protocol/Details/3281

Three sites within a recently reactivated relict channel in the upper Hangman watershed were surveyed for physical habitat attributes such as canopy cover, substrate composition, large woody debris volume, and pool habitat. These sites were surveyed in two consecutive years, immediately after reactivation and 1 year post-reactivation, to monitor for changes in pool habitat following the establishment of multiple beaver dams (Figure 5).

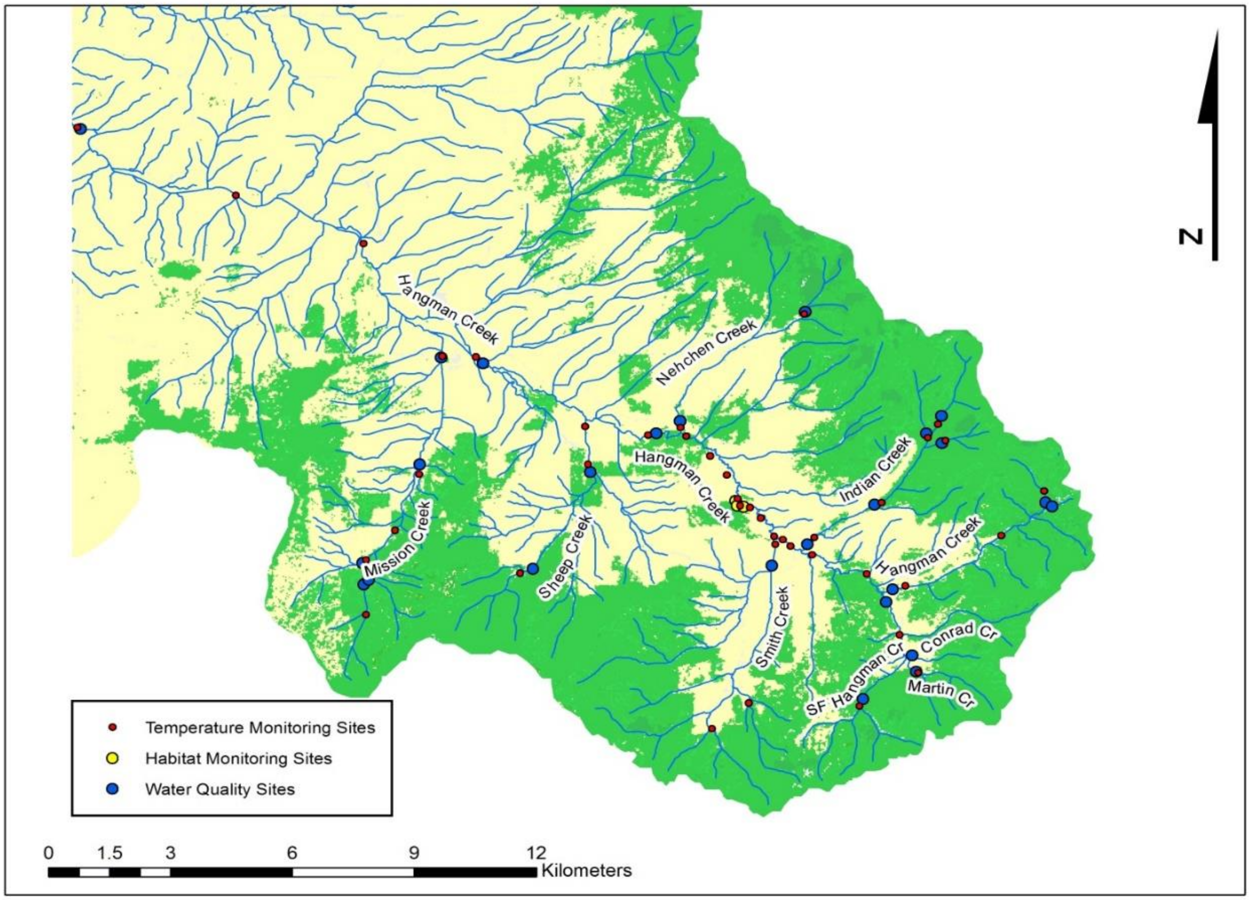


Figure 5. Location map of habitat and temperature monitoring sites within the upper Hangman Creek watershed study area.

3. Results

3.1. Trout Status and Trend Monitoring

3.1.1. Trout Abundance Trends and Distribution Surveys

Trout densities across the upper Hangman Creek watershed during the summer continue to be highly variable and dependent on habitat conditions. Densities range from 0 to 136 redband trout per 100 meters. Highest densities are continually observed near the headwaters of Hangman Creek, and the lowest densities near the mouths of tributaries and in mainstem habitats. Exceptions to these trends exist in the upper-most reaches of tributaries where, although forest cover is extensive and temperatures are cool, stream size and gradient are influencing relatively low densities (Table 1).

For the majority of the tributaries sampled, mean redband trout densities were found to increase from 2012 to 2014, but then decrease from 2014 to 2016 (Figure 6). Smith Creek was not sampled in 2012 and 2013, and Nehchen Creek was omitted from this analysis due to the lack of fish captured. Indian Creek was the only tributary which did not reflect this annual trend in trout densities, specifically, densities did not decrease significantly from 2014 to 2016.

Table 1. Trout densities sampled across the upper Hangman Creek watershed, 2014 - 2016.

Index Site	Stream km	2014 RBT Captured	2014 RBT density fish/100m	2015 RBT Captured	2015 RBT density fish/100m	2016 RBT Captured	2016 RBT density fish/100m
			Hangman mainstem				
Hangman 1	24.5	0	0.0	9	14.8	5	8.2
Hangman 2	27.3	9	14.8	3	4.9	2	3.3
Hangman 3	29.8	37	60.7	3	4.9	2	3.3
			Mission Creek				
Mission 2	6.8	15	24.6	12	19.7	12	19.7
Mission 3	8.3	23	37.7	0	0.0	0	0.0
Mission 4	9.1	11	18.0	9	14.8	7	11.5
W.F. Mission 1	0.6	37	60.7	8	13.1	9	14.8
			Nehchen Creek				
Nehchen 1	0.1	0	0.0	.	.	.	.
Nehchen 2	2.2	3	4.9	.	.	.	.
Nehchen	4.6	8	13.1	7	1.0	1	1.6
Nehchen 3	5.0	1	1.6	12	4.0	0	0.0
			Sheep Creek				
Sheep 1	1.9	1	1.6	.	.	0	0.0
Sheep 2	4.8	28	45.9	15	24.6	28	45.9
Sheep 4	5.2	30	49.2	10	16.4	11	18.0
Sheep 6	5.6	25	41.0	8	13.1	3	4.9
			Upper Hangman Creek				
Hangman 5	33.3	34	55.7	47	77.0	24	39.3
Hangman 6	34	49	80.3	83	136.1	54	88.5
Bunnel 1	1.0	0	0.0	2	3.3	5	8.2
Conrad 1	0.9	0	0.0	0	0.0	0	0.0
Martin 1	0.4	44	72.1	54	88.5	.	.
S.F. Hangman 1	1.1	8	13.1	7	11.5	.	.
S.F. Hangman 2	3.3	2	3.3	3	4.9	0	0.0
			Indian Creek				
Indian 1	0.1	2	3.3	7	7.0	5	5.0
Indian 2	0.8	12	19.7	39	39.0	39	39.0
Indian 5	2.6	22	36.1	52	52.0	50	50.0
Indian 6	2.9	32	52.5	36	36.0	26	26.0
Indian 9	5.1	14	23	9	9.0	10	10.0
N.F. Indian 1	0.2	6	9.8	12	12.0	17	17.0
N.F. Indian 2	0.7	9	14.8	11	11.0	22	22.0
E.F. Indian 1	0.2	0	0	9	9.0	5	5.0
			Smith Creek				
M.F. Smith 1	0.4	27	44.3	11	18.0	0	0.0
M.F. Smith 2	0.7	4	6.6	7	11.5	0	0.0
E.F. Smith 1	0.9	0	0.0	0	0.0	0	0.0

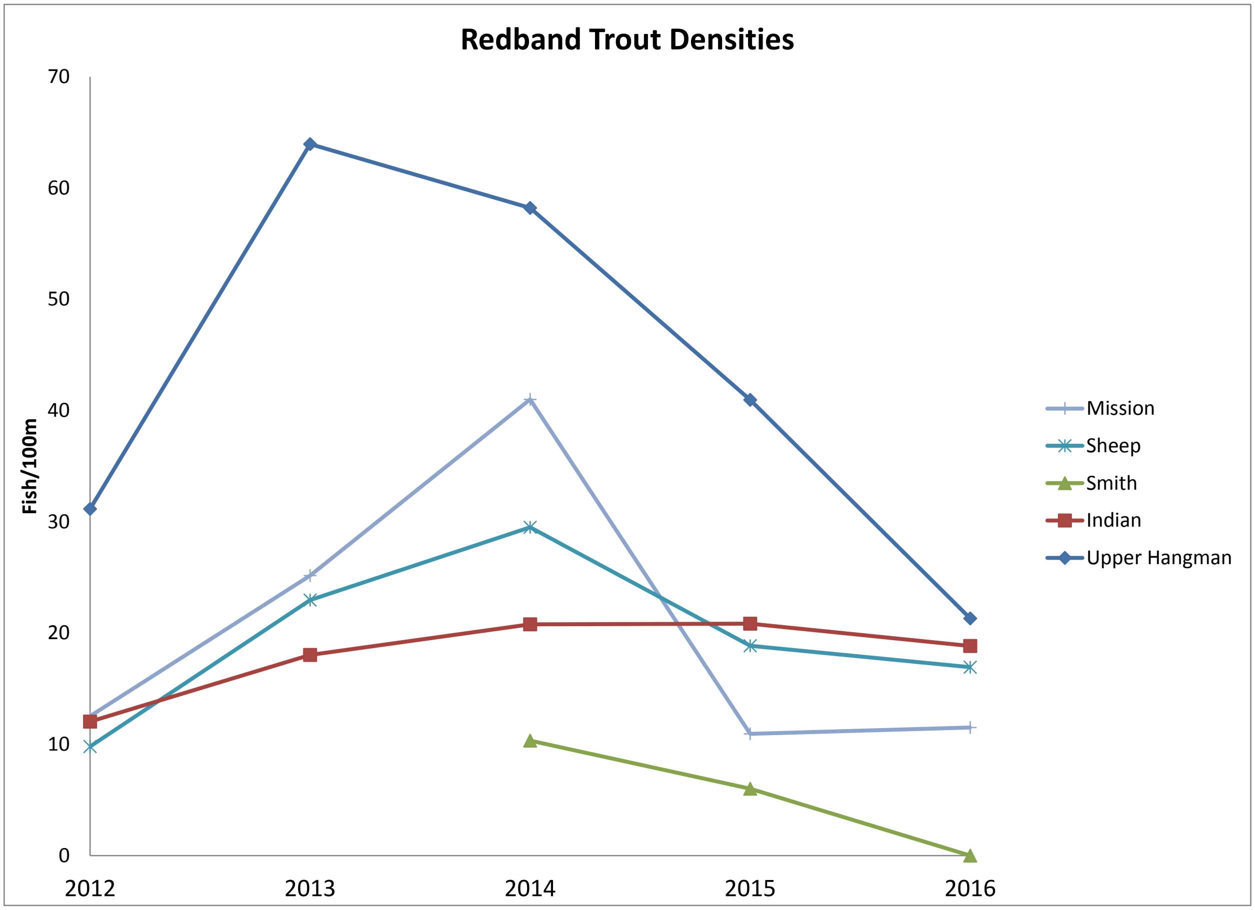


Figure 6. Mean trout densities within each tributary calculated from annual index monitoring sites.

3.1.2. Indian Creek Mark-Recapture Population Estimates

Tributary-wide estimates of redband trout in Indian Creek that were generated from mark-recapture sampling events were at least 90% larger than estimates obtained through multiple pass depletion sampling (Table 2). Mark-recapture sampling throughout Indian Creek in 2014 and 2015 yielded a tributary-wide population estimate of 2,672 (+/- 943) and 2,757 (+/- 1115) redband trout, respectively. In comparison, population estimates for redband trout in Indian Creek generated in 2009 and 2010 through multi-pass depletion sampling were 1,129 (+/- 489) and 1,405 (+/- 276), respectively. Additionally, the estimated probability of capturing a fish in the first pass was on average 20% lower using mark-recapture versus depletion methods. Calculations of error were greatest and most variable among years in the lowermost reach.

Table 2. Comparison of tributary-wide estimates of population and capture probability in Indian Creek using two different methods. Multiple-pass depletion in 2009 and 2010, and mark-recapture in 2014 and 2015.

Reach	Abundance Estimate	95% CI (+/-)	1st Pass Capture Probability
	2009		
Lower	238	338	96%
Mid	736	330	81%
Headwaters	155	128	100%
Total	**1129**	**489**	**86%**
	2010		
Lower	193	8	90%
Mid	901	192	77%
Headwaters	311	199	83%
Total	**1405**	**276**	**81%**
	2014		
Lower	411	478	49%
Mid	1633	537	62%
Headwaters	628	610	66%
Total	**2672**	**943**	**60%**
	2015		
Lower	705	1056	80%
Mid	1592	341	60%
Headwaters	459	117	69%
Total	**2757**	**1115**	**68%**

3.1.3. Migrant Trout Trapping

From 2014 to 2016, we trapped a total of 642 trout in Indian Creek and 274 trout in Nehchen Creek. Of these trapped fish, 208 were recaptured (previously marked) within the same year's trapping efforts. In Nehchen Creek, we trapped a total of 85, 129, and 60 unique fish in 2014, 2015, and 2016, respectively. In Indian Creek we trapped a total of 115, 261, and 266 unique fish in 2014, 2015, and 2016, respectively. Within Indian Creek, 65% of the captured fish ascending were considered adults (over 150mm) and 44% of captured fish descending were considered adults. Of those descending adults, 82% had been previously captured ascending through the trap. In Nehchen Creek, 57% of the captured fish ascending were considered adults and 75% of the captured fish descending were considered adults. Of those descending adults, 25% had been previously captured ascending through the trap. In Nehchen Creek, 38% and 57% of the small fish (<150 mm) captured descending had previously been captured ascending through the trap in 2015 and 2016, respectively (Table 3).

Of the recaptured fish descending through the traps, rates of tag-loss (percent shed tags) were relatively low. From 2014 through 2016, 3% and 7% of recaptured fish which were implanted with tags while ascending the traps were found to have shed their tags during the same spawning season in Nehchen Creek and Indian Creek, respectively. Of the fish found to have shed their tag, 85% were considered to be adults.

Table 3. Summary of migrant trap data for Indian and Nehchen Creek, 2014 - 2016.

	Indian			Nehchen		
	Ascending	Descending		Ascending	Descending	
Length (mm)	Number	Number	Number (%) that were recaps	Number	Number	Number (%) that were recaps
2014						
0-150	54	12	3 (25%)	6	12	0
150+	47	11	6 (55%)	9	61	3 (5%)
Totals	101	23	9 (39%)	15	73	3 (4%)
2015						
0-150	56	91	20 (22%)	28	24	9 (38%)
150+	120	57	43 (75%)	38	66	18 (27%)
Totals	176	148	63 (43%)	66	90	27 (30%)
2016						
0-150	56	79	13 (16%)	18	14	8 (57%)
150+	137	75	68 (91%)	23	30	17 (56%)
Totals	193	154	81 (53%)	41	44	25 (57%)

3.1.4. Fluvial Life-history of Trout

Distribution of the Fluvial life-History Variant Across the Upper Hangman Watershed

From 2013 through 2016, we tracked 282 PIT tagged redband trout from their tagging tributary and into Hangman Creek. These fish were captured and tagged in Indian and Nehchen creeks during spring trapping and in Indian Creek during summer electrofishing surveys. Virtually all (95%) of the fish tagged at the Nehchen trap were detected leaving that tributary to reside in the mainstem of Hangman Creek. Of the 683 fish captured and tagged at the Indian Creek trap, 51 (7%) were detected at a fixed array in the mainstem of Hangman Creek. Additionally, of the 682 fish tagged during summer electrofishing in Indian Creek, 47 (7%) were detected at a fixed array in the mainstem of Hangman Creek. All of the 47 fish were sampled in either the lower or middle reach of Indian Creek, with a higher incidence of fluvial behavior detected in the lowermost reach (**Error! Reference source not found.**). Redband trout tagged in Sheep, Smith, Nehchen, and the upper reach of Indian creeks during summer electrofishing surveys in 2014 – 2016 (n=779) were not detected leaving these tributaries or passing by fixed arrays in Hangman Creek.

Table 4. Summary of fluvial redband trout emigration from the tributary they were tagged in and into the Mainstem of Hangman Creek, 2013 - 2016.

	2013			2014			2015			2016	
	# Fish Marked	# (%) 1st Detected in Hangman Cr.		# Fish Marked	# (%) 1st Detected in Hangman Cr.		# Fish Marked	# (%) 1st Detected in Hangman Cr.		# Fish Marked	# (%) 1st Detected
Indian Cr. Electrofishing		Year 1	Year 1+		Year 1	Year 1+		Year 1	Year 1+		Year 1
Reach 1: 0 - 2km	11	1 (9%)	5 (45%)	18	1 (6%)	6 (33%)	61	3 (5%)	6 (10%)	37	0
Reach 2: 2 - 4 km	56	1 (2%)	7 (13%)	74	0	8 (11%)	172	0	9 (5%)	73	0
Reach 3: 4+ km	39	0	0	31	0	0	56	0	0	54	0
Indian Cr. Trap (Rkm 2.3)											
< 150mm	37	3 (8%)	3 (8%)	25	0	2 (8%)	118	6 (5%)	6 (5%)	110	1 (1%)
150mm+	86	7 (8%)	1 (1%)	50	3 (6%)	2 (4%)	129	7 (5%)	1 (1%)	128	9 (7%)
Nehchen Cr. Down Trap (Rkm 0.2)											
< 150mm	17	16 (94%)	.	14	14 (100%)	.	9	9 (100%)	.	7	6 (86%)
150mm+	40	36 (90%)	.	55	51 (93%)	.	36	36 (100%)	.	12	12 (100%)

Mainstem Movement and Rearing Habits of Fluvial Redband Trout

From 2013 through February 2017, tagged fish were detected a total of 312 times moving into or through a 6.9 km reach of mainstem Hangman Creek undergoing active restoration. Of those 312 fish detected moving into this reach, 172 (55%) were thought to have reared within this reach for the entire summer and/or winter. In all but the last year, descending fish were more likely to rear in this reach than ascending fish (Table 5). A total of 118 fluvial redband trout were detected descending from upstream into this reach throughout the year. Seventy-five (64%) of these fish remained in this reach for the entire summer and/or winter, while the other 36% either continued downstream below this reach, or returned upstream to reside within the year. A total of 194 fluvial redband trout were detected ascending from downstream into this reach throughout the year. Ninety-eight (51%) of these fish remained in this reach for the entire summer and/or winter, while the other 49% continued upstream of kilometer 26.7 or returned downstream below stream km 19.8.

Table 5. Summary of movements of fluvial redband trout within the reach of Hangman Creek undergoing active restoration, 2013 - 2016. Fish were either detected moving into the reach in the summer (prior to July 15) or winter (prior to December 15).

	Ascending Fish		**Descending Fish**	
Season Detected Entering Reach	# Fish	# (%) Holding in Focus Reach	# Fish	# (%) Holding in Focus Reach
		2013		
Summer	26	12 (46%)	12	9 (75%)
Winter	1	1 (100%)	6	4 (67%)
Subtotals	**27**	**13 (48%)**	**18**	**13 (72%)**
		2014		
Summer	67	26 (39%)	27	14 (52%)
Winter	3	3 (100%)	14	8 (57%)
Subtotals	**70**	**29 (41%)**	**41**	**22 (54%)**
		2015		
Summer	69	32 (46%)	23	14 (61%)
Winter	0	0	11	10 (91%)
Subtotals	**69**	**32 (46%)**	**34**	**24 (71%)**
		2016		
Summer	27	23 (85%)	20	12 (60%)
Winter	1	1 (100%)	5	4 (80%)
Subtotals	**28**	**24 (86%)**	**25**	**16 (64%)**

Seasonal Tributary Use by Fluvial Redband Trout

Thirty-seven of the 267 fish (16%) detected in the mainstem of Hangman Creek from 2014 - 2016 were either detected or recaptured the following spring spawning season returning to the tributary in which they were tagged, 8 of which originated from Indian Creek and 29 from Nehchen Creek. The return rate of fluvial fish tagged in 2015 was extremely low, with only 6 out of 152 (4%) detected the following spring. In comparison, the return rates for the 2013 and 2014 cohorts were 22 of 64 (34%) and 13 of 85 (15%), respectively.

Throughout different seasons, sixty-one of the 267 (21%) redband trout detected in the mainstem of Hangman Creek were detected entering a tributary different than the one in which they were tagged, 37 of which originated from Indian Creek and 24 from Nehchen Creek (Table 6). Fish tagged in Indian Creek primarily were found to ascend Smith Creek, whereas fish tagged in Nehchen Creek were most often found to ascend Sheep Creek. Ascensions during the spring were the most prevalent of all seasons, with ascensions during the winter occurring more frequently than those in the summer. Many of the spring ascensions were attributed to Indian-tagged fish that spent extended periods of time in Smith Creek.

Table 6. Seasonal tributary use of fluvial fish tagged in Indian and Nehchen Creek, 2013 - 2016. Mean number of days is not reported for Sheep Creek due to a lack of directional detection data.

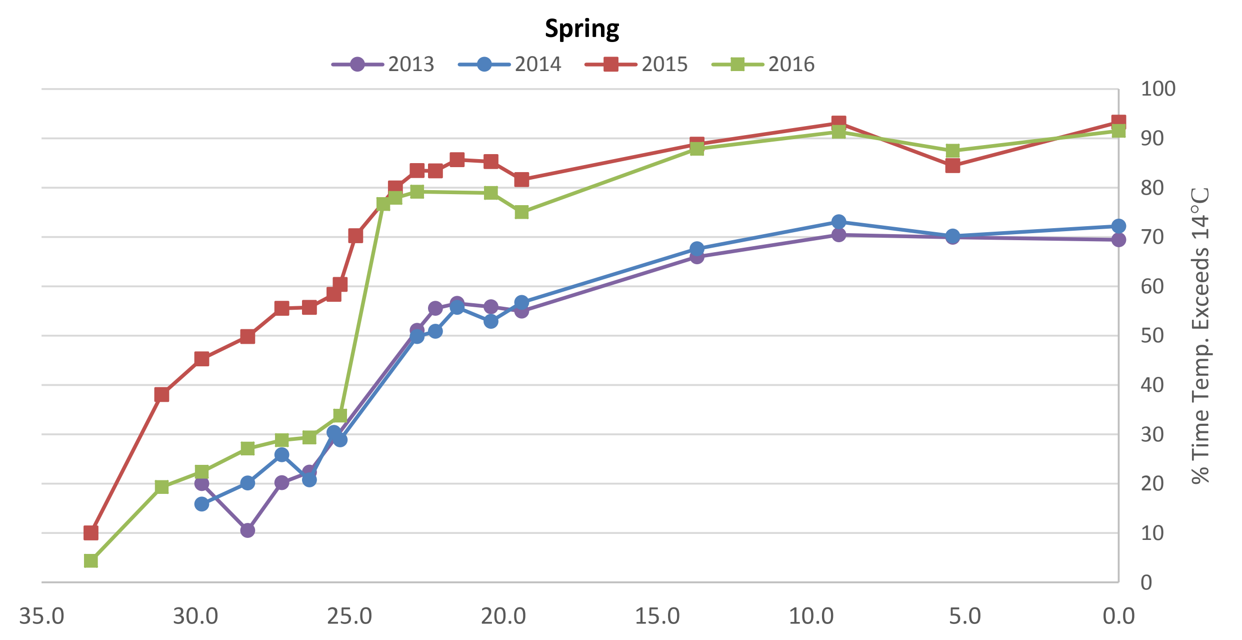
Stream Ascended (Hangman Creek Rkm)	Season Detected					
	Spring		Summer		Fall/Winter	
	# Fish	Mean # Days	# Fish	Mean # Days	# Fish	Mean # Days
	Fish Tagged in Indian Creek					
Sheep (12.2)	4	.	0	.	0	.
Nehchen (19.8)	2	29	0	.	1	9
Smith (25.7)	24	24[a]	1	10	9	14
	Fish Tagged in Nehchen Creek					
Sheep (12.2)	8	.	1	.	5	
Smith (25.7)	3	4[b]	0	.	2	37
Indian (27.7)	8	3	1	31	0	.

[a] Ten of these fish were detected in Smith Creek for 5 days or less
[b] Two of these fish were detected in Smith Creek for 1 day, the other for 9 days

3.2. Effectiveness Monitoring

3.2.1. Spatial and Temporal Temperature Trends

Over the years 2013 to 2016, water temperatures during the spring increased from the headwaters downstream through the mainstem of Hangman Creek, with substantial increases observed each year across the reach between stream kilometer 25.3 to 22.2 (Figure 7). Overall, spring water temperatures across the mainstem of Hangman Creek were greater in 2015 and 2016, years of warmer winters and earlier snowmelt, than in 2013 and 2014. Summer stream temperatures in the Hangman mainstem also exhibited a substantial increase across the 3.1 kilometer reach where spring temperatures were observed to rise, though the degree of increase differed among the four years (Figure 7). The largest increases were observed in 2013 and 2014, whereas the smallest increase was observed in 2016. In addition, though summer air temperatures were the warmest in 2015, the increase observed across this reach was not as great as that found in the two prior years. Over all years, summer stream temperatures were found to decrease through the Nehchen Bluff reach from stream km 22.0 through 19.4



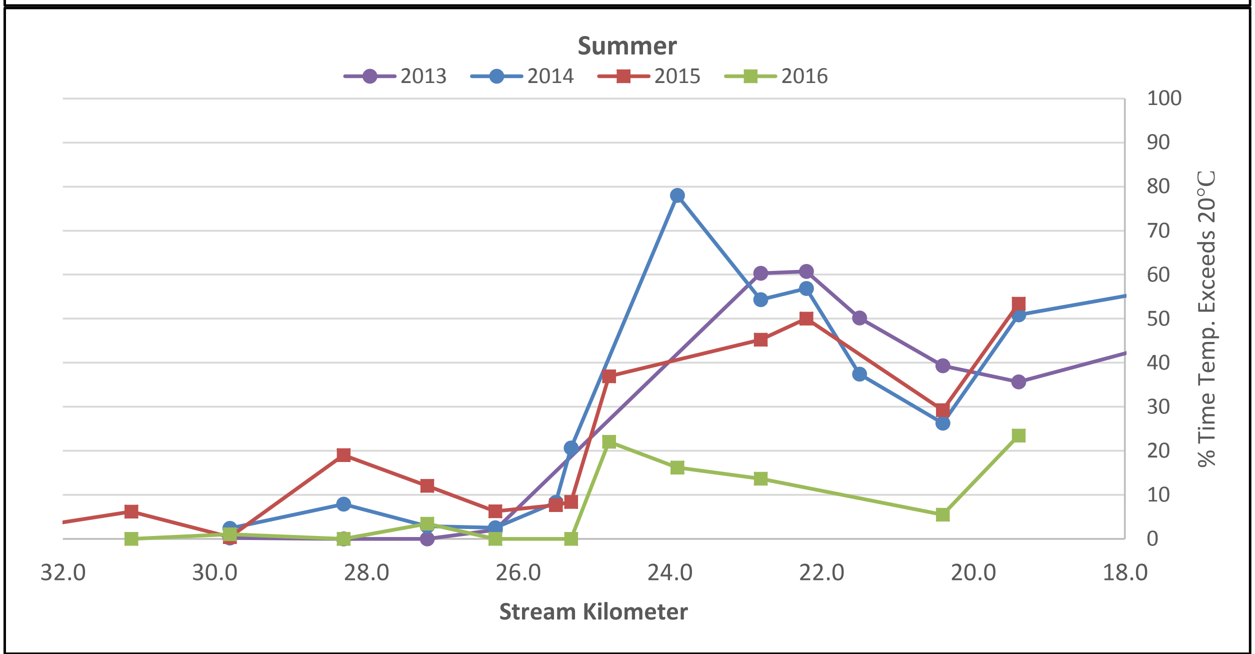


Figure 7. Stream temperature data through the mainstem of Hangman Creek from 2013 - 2016. The upper figure highlights the mainstem of Hangman Creek from the headwaters through the area of restoration and into the Nehchen Bluff reach from May 1 - June 30. The lower figure highlights the mainstem of Hangman Creek from July 1 – Aug. 31.

Variations in water temperature throughout the water column were recorded at stream kilometer 24.0 within a relatively deep backwater area, especially during periods with the hottest recorded air temperatures. Throughout the monitoring period, the largest differences in adjacent water temperature loggers were observed between the water surface and 2 feet of depth. On average, the difference was 0.9° Celsius. During time periods where ambient air temperatures exceeded 25°C, differences in the water temperature between the surface and 2 feet in depth was on average 1.5°C and ranged from 0.7° to 2.3°C (Figure 8).

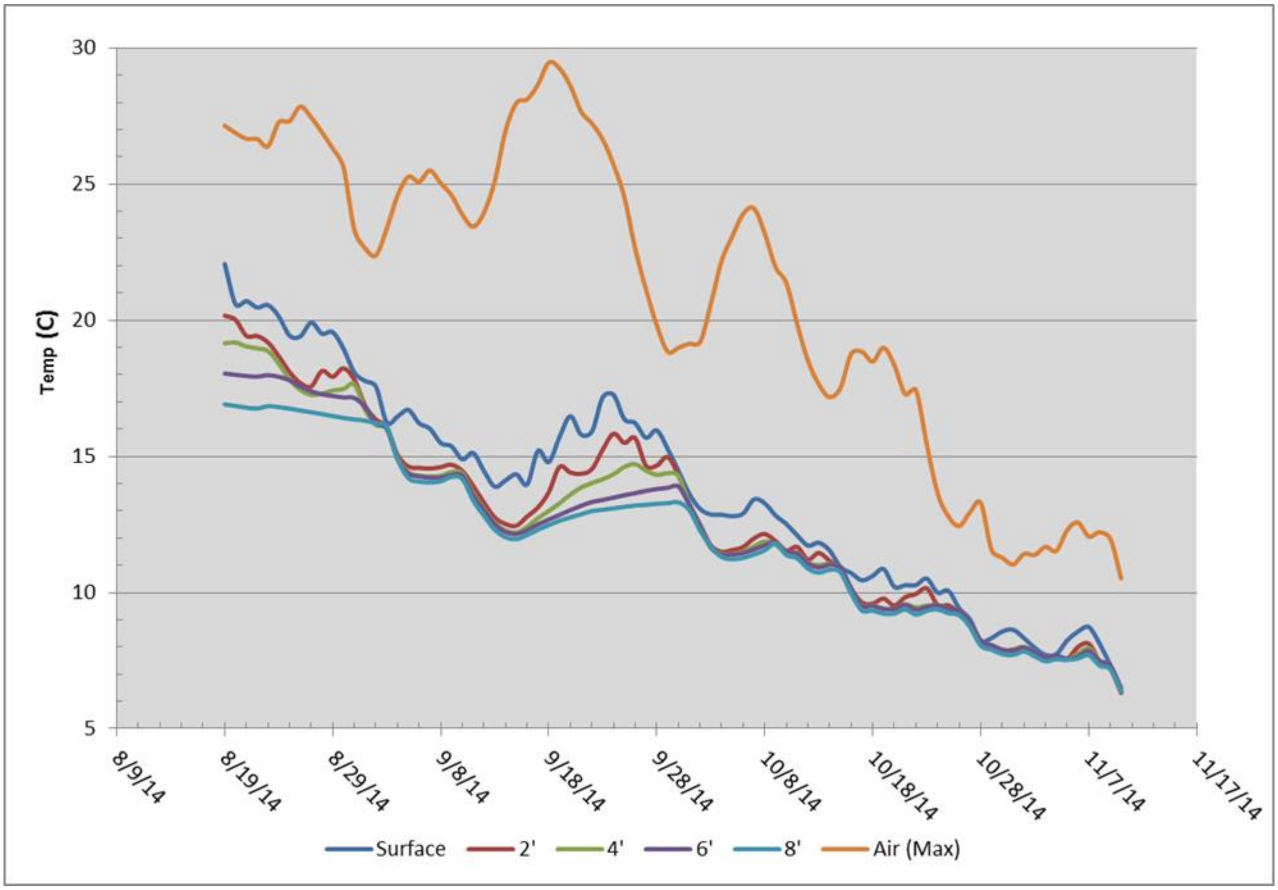


Figure 8. Water temperature trends throughout the water column at stream kilometer 24.1, 2014.

3.2.2. Physical Habitat Changes Following Restoration Activities

Following activation of a 1.5 kilometer reach of relict stream channel, 3 survey sites were established to summarize the physical stream habitat attributes. On average, total canopy cover was 73%, with 28% of that contributed by non-woody plants. Stream sediment across all sites was composed of 100% silt and/or organic matter. The average volume of large woody debris was estimated to be 1.33 m^3/100 meters (Table 7).

Pool habitat metrics were found to increase between survey years at two of the three survey sites located in the relict channel (Table 7). In 2014, the first year following reactivation, 68.1% of stream length on average was composed of pool habitat, and pool volume averaged 46.6 m^3/100 m of stream length at these sites. The following year, after the establishment of multiple beaver dams throughout this reach, length of pool habitat increased by 22% and averaged 83.4% across sites. In addition, pool volume was found to increase by 468% and averaged 264.7 m^3/100 m of stream length.

Table 7. Physical habitat parameters from 3 sites throughout the relict channel in Hangman Creek directly following reactivation and 1 year post-activation following the establishment of multiple beaver dams.

		Canopy Cover		Large Woody Debris		Pool Habitat Metrics					
Site	% Fine Sediment	% Total Cover	% Woody Plants	Count (#/100m)	Volume (m^3/100m)	# pools	pools / 100 m	% of Reach Length	Mean length/ pool (m)	Residual Volume (m^3)	Mean Volume/ pool
					2014						
Relict 1	100	51.6	60	9	1.19	5	3.5	65.9	18.8	42.2	8.4
Relict 2	100	82.1	71.5	8	1.54	2	2.0	65.3	32.2	44.8	22.4
Relict 3	100	84.9	83.5	2	1.24	3	2.0	73.2	35.9	95.0	31.7
					2015						
Relict 1	.	.	.	.	.	5	3.1	58.2	19.0	30.9	6.2
Relict 2	.	.	.	.	.	3	3.0	96.3	47.4	444.8	148.3
Relict 3	.	.	.	.	.	3	2.0	95.6	70.3	475.1	158.4

4. Discussion

4.1. Trout Status and Trend Monitoring

Summer rearing densities of redband trout continue to be much greater in headwaters of tributaries than in downstream reaches and connective mainstem habitat throughout the project area. The observed spatial distribution of fish is reflective of land-use practices that influence the suitability of habitat conditions. Streams are consistently less impacted in or near headwater reaches of tributary habitat, while anthropogenic influence is more prolific at lower elevations which comprise the majority of mainstem and lower tributary habitat. This has resulted in isolated subpopulations of redband trout across the upper Hangman watershed that are confined to headwater tributary reaches. There exists an obvious lack of connectivity between these subpopulations due to sub-optimal rearing conditions in not only the mainstem of Hangman Creek, but in the lower reaches of these fish-bearing tributaries.

The annual trends in trout densities throughout summer electrofishing sampling are similar throughout most of sampled tributaries. From 2012 through 2014, trout densities appear to be increasing across the entire project area. Conversely, from 2014 to 2016, we observed a decrease in trout densities across all tributaries. This suggests that large scale environmental influences such as annual temperature regimes and precipitation patterns are having a measurable effect on densities of redband trout. The increasing densities observed in through 2014 may be a direct result of the cooler summer temperatures coupled with higher base flows observed from 2010 to 2012. These conditions likely provided favorable spawning and early-life history rearing environments that were measurable in older life-stages a couple years later. The conditions from 2013 to 2016 however were much different, with unseasonably warm temperatures and drier summer conditions. This was especially true in 2015 where we observed earlier runoff, extremely low base flows, and the hottest local summer temperatures on record. This has no doubt impacted redband trout densities throughout the project area, resulting in a measurable decrease across nearly all tributary subpopulations.

Indian Creek however appeared to be somewhat buffered from the severe thermal and hydrologic conditions observed in recent years and supports a more resilient subpopulation of redband trout. This may be attributed to the overall quality and diversity of habitat within this tributary. Indian Creek consistently provides stable base flows with cooler stream temperatures, and as past habitat surveys have shown, provides complex in-stream habitat with fairly stable riparian cover throughout the entire tributary. Providing a larger area of contiguous suitable habitat for redband trout in the entire upper Hangman Creek watershed, such as what exists within Indian Creek, continues to be an important objective. This is especially apparent now and into the future as annual trends in weather patterns have become and are speculated to be warmer and more volatile.

Indian Creek is an important core refugia in the upper Hangman Creek basin, and accurately monitoring trends of trout populations in this tributary is vital. Prior sampling periods have utilized multi-pass, depletion methodology (2009-2010) to calculate overall abundance estimates in Indian Creek and to determine the probability of capture of any given fish in the first pass of electrofishing. Those estimates are based on a series of assumptions, one of which is that the capture probability is the same during all passes. However, previous research has found that capture probabilities substantially decline after the first pass (Firehammer et al. 2011), yielding abundance estimates that are negatively biased and first pass capture probabilities that are inflated. In our results, first pass capture probabilities obtained with the mark-recapture method that was implemented in 2014 and 2015 were much lower than those obtained using depletion sampling corroborating the biases that have been reported. These results all point to a high probability that the estimates obtained using depletion methodology were not accurate and under-estimated the number of redband trout in Indian Creek. Consequently, tributary wide estimates in the future will continue to be obtained using mark-recapture methodology. Further, the high levels of error calculated in some reaches, particularly in the lower reach, suggests that we may be able to improve the precision of our estimates by increasing the number of sample sites and/or further stratifying the stream.

Migrant trout trapping has been employed to sample and mark a high proportion of fluvial individuals. We may also be able to use this monitoring method to track trends in fluvial redband trout densities. We quite frequently capture a large proportion of the spawning adults in Indian and Nehchen Creek as they are ascending the trap, in addition to recapturing the same fish post-spawn as they are descending back down through the trap. There is however a marked difference in the rate of recaptured adult fish between the Nehchen and Indian Creek traps. In Nehchen Creek, we typically capture more descending than ascending adults (i.e., many of those descending were not captured ascending), though the recapture rate of marked, ascending adults is high, indicating that trap efficiency is not lacking. The large number of unmarked fish captured descending may be the result of a large proportion of spawning adults ascending through the trap site to stage in holding habitats before traps are deployed. If the trap were installed earlier, we may be able to intercept a larger proportion of ascending fish and generate a fairly precise estimate of spawner abundance in Nehchen Creek. In Indian Creek, however, due to the migrant trap location, generating a reliable index of fluvial abundance may be much more difficult. Because the trap is located over two kilometers from the mouth, it is likely that a large portion of the fluvial fish population are spawning downstream of the trap site, and although we would still intercept the individuals spawning upstream, that proportion may change from one year to the next depending on stream conditions such as temperature, snowpack, or the timing of spring runoff. Furthermore, the fact that a large proportion of ascending fish were not recaptured as they were descending may suggest that the trap intercepts a high proportion of resident fish that are only engaged in localized upriver spawning movements. Thus, estimates obtained from trapping data in Indian Creek may be an admixture of both resident and fluvial life-histories.

4.2. Spatial Distribution and Seasonal Movements of Fluvial Trout

Our monitoring program continues to collect data that describes the prevalence, spatial distribution, and seasonal movement patterns of the fluvial life-history of redband trout in the upper Hangman watershed. This life history characteristic is thought to be highly important for overall population resiliency and genetic integrity. Restoration actions we have most recently implemented have also been focused on recovery of this life history attribute, specifically to promote quality rearing habitat for fluvial redband trout while connecting isolated subpopulations throughout the upper Hangman watershed.

Fish that have been tagged during the trapping season and in summer stream surveys indicate that the fluvial life-history is present in Indian and Nehchen creeks but apparently absent in

Smith and Sheep creeks. Trap results suggest that the composition of fish in lower Nehchen Creek is comprised almost entirely of fluvial individuals. This is most likely due to the hydrology of Nehchen Creek. The lower 4.5 kilometers of Nehchen Creek completely dries out from mid-July through early November each year and therefore cannot support a robust population of resident trout. Summer electrofishing data from Nehchen Creek indicates that the only resident fish are confined to headwaters reaches.

In comparison, the fluvial life form is apparently less prevalent in Indian Creek than in Nehchen Creek. The lack of a detectable, strong fluvial signature may in part be due to the inability to capture many of the migratory fluvial fish that are spawning in reaches downstream of the trap location. Fish tagged during summer stream surveys attest to a higher incidence of fluvial behavior in reaches downstream than upstream of the trap. Habitat downstream of the trap may be sufficient to support current levels of fluvial spawning activity, whereas under greater numbers of fluvial spawners more fish may be inclined to migrate further upstream. Alternatively, due to the current location of the PIT tag detection arrays in Indian Creek (rkm 0.8) and in Hangman Creek, which is one kilometer downstream of the mouth of Indian Creek, there may be a large portion of the fluvial fish population that are not detected leaving Indian Creek to reside in the mainstem. Plans to coordinate with a private landowner are currently underway to install a new fixed detection site at the mouth of Indian Creek which would not only detect fish exiting the tributary, but to determine if they are moving upstream or downstream in the mainstem of Hangman Creek to rear.

Unlike Indian and Nehchen creeks, Smith and Sheep creeks were not found to support fluvial behavior. In these two tributaries, fish are restricted to upper forested reaches, and similar to what was found in upper reaches of Indian and Nehchen creeks, exhibit resident life-histories. Downstream reaches, which have been shown to support fluvial fish in Indian and Nehchen creeks, may not provide suitable spawning and early life-stage rearing habitat for the fluvial life-history in Sheep and Smith creeks. Both of these tributaries have extensive lengths of stream which flow through very low gradient and wide floodplain valleys. These reaches have been plagued by decades of channelization and riparian vegetation removal in order to encourage agriculture productivity. This has resulted in a complete lack of large wood recruitment, high stream temperatures, low levels of spawning substrate, and a volatile annual flow regime with frequent flushing events in the winter and spring, and critically low flows during the summer. Although Nehchen Creek is also lacking summer rearing habitat in the lower reaches due to critically low base flows, the high incidence of fluvial fish caught at the trap suggests this alone does not restrict a fluvial component in a stream. Focusing habitat restoration efforts within lower reaches of Smith and Sheep creeks could be an initial step toward re-establishing a fluvial component in these two systems.

Monitoring data indicated that a high proportion of tagged fish from Indian and Nehchen creeks are moving into the mainstem reach that is undergoing restoration, with many of these movements occurring during the summer. This is especially true for the fish descending into this reach from upstream, most of which are originating from Indian Creek which lies directly upstream of this mainstem habitat. There were also a significant number of fish ascending into this reach as well, most of which were tagged in Nehchen Creek. This is not surprising given that quality mainstem rearing habitat is in short supply downstream of Nehchen Creek and lower Nehchen Creek itself dewaters during the late summer and early fall. Clearly, this reach of

Hangman Creek which makes up the vast majority of mainstem habitat between Indian and Nehchen Creek is important for fluvial redband trout throughout the year. However, there is still a high proportion of fish which move into this reach and do not stay, likely seeking more preferable habitat, most of which is upstream where although space is more restricted, stream temperatures are cooler during the summer. There is certainly potential for an increase in utilization of this focus reach after conditions become more favorable.

The low return rate of fluvial fish to tributaries during the spawning seasons that was documented during this reporting period indicates that the suitability of the mainstem reach as summer rearing habitat may have been sub-optimal in some years. Fluvial fish tagged in 2015, which were detected at much lower rates in subsequent trapping years than the 2013 and 2014 cohorts, experienced an extremely hot and dry summer which likely led to high mortality rates. A significant warming trend has occurred in the upper Hangman watershed from 2013 to 2016 leading to earlier runoff, lower base flows, and drier summers, all of which contribute to unfavorable conditions throughout the summer rearing period. As restoration actions continue to improve the suitability of rearing habitat in this reach, which may become especially important under climate change scenarios, the percentage of fish that remain and survive in this reach should increase.

Data collected during the reporting period suggest that a significant proportion of marked fluvial fish are entering adjacent tributaries throughout the year. Proximity to an adjacent tributary appears to be the largest factor in determining what tributary is being utilized by any particular fish. Fish marked in Indian Creek appear in Smith Creek at a much higher rate than fish tagged in Nehchen Creek. Conversely, fish tagged in Nehchen Creek are more likely to be detected in Sheep Creek than fish that were tagged in Indian Creek. This suggests fish are entering these tributaries opportunistically, possibly to avoid undesirable conditions. For example, lower reaches of tributaries may serve as refuge habitat for fluvial fish during late fall/winter or spring periods when velocities and turbidity in mainstem habitats become too great during high discharge events. This may be an explanation as to why we observed a large proportion of juvenile fish captured and recaptured at the trap in Nehchen Creek during the late winter and spring. Fluvial fish may also be temporarily entering tributaries for increased foraging opportunities during times when invertebrates are more plentiful in these reaches than in mainstem habitats.

Alternatively, movements into adjacent tributaries may reflect spawning behavior. For example, a large number of the fish marked in Indian Creek were found ascending Smith Creek in the spring for extended periods of time. However, it is unclear as to where these tagged fish originated. These individuals, although marked in Indian Creek, may have actually originated in Smith Creek, were flushed out as juveniles and were seeking refuge in Indian Creek (the closest adjacent tributary) during the sampling period. Although we have marked nearly 50 individuals with PIT tags in the upper reaches of Smith Creek and none of these fish have been detected leaving this stream, there may be some remnant fluvial component still present.

On the other hand, the springtime movement of tagged Indian Creek fish into Smith Creek may be evidence of straying behavior. Straying is common across many populations of salmonids, and may not be that uncommon in fluvial redband trout in Hangman Creek. If these fish are actually straying from Indian Creek to Smith Creek or to and from other adjacent tributaries, this natural process should be encouraged given that it has been shown to reduce genetic drift and increase population resilience. Regardless of the reasons trout are moving, the lower reaches of these tributaries are clearly serving an important role in the annual life cycle of fluvial redband trout. Furthermore, restoration of these stream reaches is instrumental in expanding the distribution of the fluvial form across the entire project area.

4.3. Effectiveness of Mainstem Habitat Restoration

Though it is still too early to evaluate whether fluvial fish are positively responding to mainstem restoration efforts, preliminary data indicate that the suitability of these mainstem reaches as rearing habitat is improving. The reach undergoing restoration is providing physical improvements to the landscape by decreasing erosion, providing an area for sediment to settle out, improving riparian habitat, and providing a continuous connection between the stream and the shallow groundwater throughout the valley. This connection is vital for this watershed to provide a prolonged supply of cool water through base flow periods, which is currently lacking throughout the mainstem of Hangman Creek and the lower reaches of most tributaries. Significant backwater habitat has also been established within the restored reach, which is important for rearing juvenile trout, especially during periods of high runoff.

Restoration actions were also observed to increase the frequency and duration of overbank flooding. This has permitted the dispersal of flood energy across the floodplain which has promoted the rapid and sustained establishment of beaver dams, like that which was documented in the restored relict channel. Beaver influenced habitat is known to have many benefits to the surrounding ecosystem. Habitat surveys through the restored reach have shown how beaver dams increased the amount of pool habitat by orders of magnitude. These pools provide areas of refuge for rearing trout during summer months via cool water habitat and backwater habitat for refuge during periods of high runoff. Additionally beaver complexes provide sediment retention, higher water tables, increased summer flow, greater habitat complexity, and expanding wetlands (Pollock et al, 2014). Sustaining the beaver complex in the restored reach will require available materials for foraging and dam building. Fortunately, riparian canopy in the restored reach more closely resembles natural conditions compared with adjacent unrestored reaches, providing the necessary building and foraging materials that can sustain a small population of beaver over a longer time period. Further, riparian plantings by the Fish and Wildlife programs throughout the floodplain are focused on preferred forage that will help sustain and even expand beaver populations across the landscape.

The aforementioned habitat benefits provided by beaver are lacking across much of the Hangman watershed. Beaver were thought to be historically abundant throughout the local valleys. Recent surveys throughout the watershed have provided evidence of beaver presence, although most dams are not maintained long enough to significantly influence ecosystem functions. A lack of riparian vegetation, incised channels, and concentrated runoff power undermine the conditions necessary for more persistent beaver dams. Restoration actions, similar to those implemented in the four kilometer reach of Hangman Creek, should be prioritized in other areas to address these habitat limitations and promote the expansion of beaver and the habitat afforded by stable dam complexes across the upper Hangman Creek landscape.

Temperature data have also indicated rearing conditions have improved in mainstem reaches that received restoration treatments. Summer stream temperatures during the reporting period were found to increase downstream at a much lesser rate after restoration actions were completed, despite the extremely warm summer air temperatures that were documented in 2015 and 2016. Prior to restoration, this reach was severely incised and disconnected from the perched water table within the valley bottom, which resulted in mainstem temperatures that exceeded recommended summer threshold levels for a significant amount of time. Restoration has apparently altered this trend. This is especially apparent through the portion of the focus reach where relict channels have been reactivated. Much of this reach moves through mature riparian habitat and directly along the toe of a mountain slope where groundwater inputs are likely present. The establishment of large amounts of pool habitat in this reach, resulting from the construction and establishment of a beaver pond complex, has provided additional thermal refuge areas for redband trout during summer rearing periods. The expansion and persistence of beaver throughout this reach should promote increased groundwater exchange. Hyporheic exchange of stream water is an important process by which streams can continuously provide cool water throughout the hottest period of the year. Meandering streams at natural elevations such as the recently reactivated historic channels in the restored reach as well as persistent beaver activity help to maintain this connectivity to the shallow ground water throughout the year and sustain hyporheic exchange well into the summer.

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6. Appendices

6.1. Mark/Recapture Population Estimate Equations

Population estimates for each sample site were calculated using the Chapman modification of the Lincoln/Peterson mark-recapture formula:

$$\hat{N} = \frac{(K+1)(n+1)}{k+1} - 1$$

With a variance calculated as:

$$\sigma^2 = \frac{(K+1)(n+1)(n-k)}{(n+1)^2(n+2)}$$

And capture efficiency calculated as:

$$\frac{n}{\hat{N}}$$

where:

n = number of fish marked on the first pass

K = number of fish captured on the second pass

k = number of recaptured fish on the second pass

The site population estimates were then used to estimate the population of trout throughout the entire tributary of Indian Creek. Indian Creek was stratified into 3 reaches based on gradient and habitat type. Each reach had a minimum of 2 sample sites.

Population estimates for each stratum were calculated as:

$$\widehat{N_x} = \left(\frac{\sum \hat{N}}{\sum l_x}\right) L_x$$

where:

l_x = length of each sampled site within stratum (x)

L_x = total length of stratum (x)

And total variance within stratum (x) as:

$$\sigma_x^2 = \left\{ \left(\frac{L}{\sum l}\right)\left(\sum var(r)\right) + \left[\frac{\left(\left(\frac{L}{\sum l}\right)(t)\right)\left(\left(\left(\frac{L}{\sum l}\right)(t)\right) - t\right)\left(\sum varC(y)\right)}{(t)(t-1)}\right]\right\}$$

where:

$\left(\frac{L}{\sum l}\right)\left(\sum var(r)\right)$ = Measurement Variance

and:

$\left[\frac{\left(\left(\frac{L}{\sum l}\right)(t)\right)\left(\left(\left(\frac{L}{\sum l}\right)(t)\right) - t\right)\left(\sum varC(y)\right)}{(t)(t-1)}\right]$ = Sampling Variance

where:

σ_x^2 = Total variance in stratum (x)

$\sum$*var(r)* = Total variance among sites in stratum (x)

t = # of sites sampled within stratum (x)

$\sum$*varC(y)* = Calculation used to generate sampling variance among fish densities at sampled sites within stratum (x)

where:

varC(y) $= l^2(y_i - \hat{y})^2$

and:

y_i = Density estimate at site *i*

$\hat{y}$ = Mean density within stratum (x)

6.2. Continuous Temperature Data

Table 8. Temperature threshold exceedance values for sites across the project area in upper Hangman Creek, 2014 - 2016.

Location (River Km)	Spawning Limit % hrs exceeds 14 degrees C May 1 - June 30			Rearing Limit % hrs exceeds 20 degrees C July 1 - Aug 31		
	2014	*2015*	*2016*	*2014*	*2015*	*2016*
Hangman-Stateline (0)	72	93	92	69	43	22
Hangman-Liberty (5.4)	70	84	88	50	31	19
Hangman-Farm (9.1)	73	93	91	48	32	26
Hangman-HWY 95 (13.7)	68	89	88	68	37	8
Hangman-Buckless (19.4)	57	82	75	51	53	23
Hangman-Nehchen Bluff (20.4)	53	85	79	26	29	5
Hangman-Morefield (21.5)	56	86		37		
Hangman-Relief Channel (22.2)	51	83		57		
Hangman-Beasley (22.8)	50	84	79	54	45	14
Hangman-Mid-Relict (23.5)		80	78		0	0
Hangman-Relict Inlet (23.9)			77	78		16
Hangman-Shaw (24.8)		70	92		37	22
Hangman-Airport Bridge (25.3)	29	60	34	21	8	0
Hangman-Above Smith (25.5)	30	58		8	8	
Hangman-Vernon-Larson (26.3)	21	56	29	3	6	0
Hangman-Bear Tree (27.2)	26	56	29	3	12	0
Hangman-Cordell (28.3)	20	50	27	8	19	3
Hangman-Bennett (29.8)	16	45	22	2	0	0
Hangman-SF Road (31.1)		38	19		6	1
Hangman-Forest (33.4)		10	4		0	0
Bunnel-Bunnel (0.1)	0		1	0		0
Mission-DeSmet (0.1)		71			7	
Mission-KVR (3.5)	29		29	1		1
Mission-A632 (6.1)	0	6	3	0	0	0
Mission-WF (6.2)			15			2
Mission-MF (7.6)	0			0		
Sheep-Lower Sheep (0.1)	41	100	37	0	DRY	0
Sheep-BD1 (1.2)		70	57		2	0
Sheep-Upper Sheep (5)	0	8	1	0	0	0
Nehchen-Lower (0.6)	6	32	23	DRY	DRY	DRY
Nehchen-Upper (5)	0	7	1	0	0	0
Smith-Lower (0.7)			46			0
Smith-EF (5.1)			8			0
Smith-MF (5.7)			7			1
Indian-Wise (0.2)	7	46	23	3	6	0
Indian-Pow-wow (2.3)	0	18	7	0	0	0
Indian-EF (4.6)	0	4	0	0	0	0
Indian-NF (5)	0	18	0	0	0	0
Indian-MF (5.1)	0	5		0	0	
SF Hangman-Lower (1.3)	7	31	0	0	0	0
SF Hangman-Upper (3.5)	0	9	0	0	3	0
Martin (2.1)	0	16	0	0	0	0

6.3. Water Quality Data

Table 9. Water quality data collected at 23 locations in the Hangman Creek watershed, June 2014 - August 2016.

Hangman-Stateline			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/23/2014 12:35	5.37	6.5	7.69
8/9/2014 9:57	3.36	0.32	5.96
7/1/2015 15:30	8.51	0.3	2.78
8/24/2015 10:00	5.35	<0.3	2.57
8/24/2016 12:10	4.15	<0.3	2.89

Hangman-Buckless			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/23/2014 13:36	8.36	3.2	7.25
8/9/2014 10:25	7.29	0	2.87
7/8/2015 11:40	6.26	0.01	2.94
6/30/2015 15:10	4.95	0.3	5.23
8/26/2015 14:30	NA	0	NA
8/24/2016 12:36	NA	0	NA

Hangman @ South Fork Road			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/22/2014 14:36	5.84	4.93	7.63
8/9/2014 11:26	4.19	0.32	6.47
8/26/2015 15:30	3.76	0.18	5.37
8/24/2016 13:15	3.64	0.19	5.49

Hangman-Forest			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/22/2014 15:15	4.38	3.23	8.32
8/9/2014 11:56	3.32	0.45	7.15
6/30/2015 13:05	5.11	0.72	6.65
8/26/2015 15:50	4.34	0.22	6.05
8/24/2016 13:45	2.94	0.27	6.36

Table 9 continued.

Mission-Desmet			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 10:35	NA	0	NA
8/9/2014 8:56	NA	0	NA
7/8/2015 14:20	5.87	0	0.57
8/24/2015 10:32	NA	0	NA
8/26/2016 10:30	NA	0	NA

Mission-King Valley			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/21/2014 10:45	4.38	0.19	6.89
8/8/2014 13:35	31.7	0	5.65
7/8/2015 14:12	4.11	0	2.52
8/24/2015 10:40	NA	0	NA
8/26/2016 11:00	3.79	0.01	1.87

Mission-MF			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/21/2014 11:00	4.56	0.02	7.89
8/8/2014 11:15	4.19	0.01	6.41
7/8/2015 13:35	8.96	0.02	4.69
8/24/2015 11:05	7.84	0.01	4.68
8/26/2016 11:59	6.43	0.03	6.16

Mission-EF			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/21/2014 11:15	12.84	0.02	6.9
8/8/2014 13:00	NA	Dry	NA
7/8/2015 12:30	NA	Dry	NA
8/24/2015 11:25	NA	Dry	NA
8/26/2016 11:45	NA	Dry	NA

Mission-WF			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/21/2014 11:35	6.38	0.03	7.25
8/8/2014 12:45	11	0	6.43
7/8/2015 13:00	3.91	0.01	4.81
8/24/2015 11:57	NA	0	NA
8/26/2016 12:40	9.45	0.01	5.85

Table 9 continued.

Sheep-HWY 95			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/21/2014 10:15	8.5	0.3	5.9
8/8/2014 9:15	3.34	0.01	3.69
7/1/2015 14:30	2.3	0.11	7.29
8/24/2015 10:30	NA	0	NA
8/28/2016 11:00	NA	0	NA

Sheep-Upper			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/21/2014 11:55	2.59	0.11	8.06
8/8/2014 9:56	2.15	0.02	6.85
7/1/2015 14:00	3.14	0.16	3.68
8/24/2015 11:10	2.64	0.01	5.83
8/28/2016 11:11	2.45	0.15	6.32

Nehchen-Lower			
Date/Time	**Turbidity (NTU)**	**DS ft³/sec**	**D.O. mg/L**
6/21/2014 12:15	5.15	0.05	7.14
6/15/2015 15:30	NA	0	NA
8/24/2015 13:10	NA	Dry	NA
8/18/2016 14:00	NA	Dry	NA

Nehchen-Upper			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 12:30	2.26	0.87	8.16
8/8/2014 14:30	2.53	0.02	6.26
7/8/2015 12:30	3.41	0	5.17
8/24/2015 14:00	NA	0	NA
8/18/2016 14:29	2.25	0.01	4.26

Smith Creek			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 13:15	4.78	0.13	5.64
7/1/2015 15:30	NA	0	NA
8/26/2015 14:30	NA	0	NA
8/25/2016 15:40	NA	0	NA

Table 9 continued.

Indian Creek-Sanders			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 13:30	3.19	1.06	6.42
8/9/2014 15:01	2.93	0.39	7.84
7/2/2015 14:11	2.31	0.42	5.14
8/25/2015 12:10	3.44	0.22	5.01
8/31/2016 13:15	3.54	0.3	6.03

Indian Creek-Pow Wow			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 14:00	2.98	0.9	10.58
8/9/2014 14:13	2.08	0.39	8.57
7/2/2015 13:30	2.21	0.7	6.14
8/25/2015 12:50	2.79	0.33	5.95
8/25/2016 14:00	5.88	0.37	6.5

Indian Creek-Upper			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 14:30	3.56	0.39	9.15
8/9/2014 13:15	2.12	0.18	7.12
7/2/2015 11:00	1.27	0.11	6.58
8/25/2015 13:30	2.68	0.12	6.95
8/31/2016 9:32	2.68	0.12	6.95

Indian Creek-NF			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 15:00	4.14	0.2	8.45
8/9/2014 13:00	2.89	0.18	7.36
7/2/2015 12:32	3.06	0.42	6.76
8/25/2015 13:10	3.26	0.1	6.31
8/25/2016 14:45	3.48	0.14	9.02

Indian Creek-EF			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 14:45	3.81	0.18	7.15
8/9/2014 13:35	2.35	0.09	6.83
7/2/2015 12:00	1.38	0.07	6.69
8/25/2015 13:55	3.16	0.07	5.89
8/25/2016 15:15	1.24	0.79	9.45

Table 9 continued

SF Hangman-Lower			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/22/2014 10:30	5.15	1.23	5.9
6/30/2015 11:45	5.49	0.05	3.46
8/25/2015 14:30	NA	0	NA
8/27/2016 12:16	4.76	0.12	5.13

SF Hangman-Upper			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/22/2014 11:00	4.56	2.19	7.76
6/30/2015 11:30	7.95	0.03	4.95
8/25/2015 15:00	NA	Dry	NA
8/27/2016 13:00	NA	0	NA

Conrad Creek			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/22/2014 11:30	NA	0	NA
7/1/2015 15:30	NA	0	NA
8/25/2015 14:00	NA	Dry	NA
8/27/2016 13:45	NA	Dry	NA

Martin Creek			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/22/2014 11:45	2.95	0.216	7.32
8/9/2014 11:02	2.45	0.06	6.27
7/1/2015 15:30	2.2	0.09	7.48
8/25/2015 14:45	6.25	0.02	4.24
8/27/2016 14:30	1.89	0.04	5.24

Bunnel Creek			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 15:30	4.32	0.84	7.83
8/8/2014 15:30	3.14	0.15	7.19
6/30/2015 14:00	2.91	0.05	6.71
8/25/2015 15:11	3.97	0.01	6.1
8/24/2016 14:20	2.84	0.2	7.65

Parrot Creek			
Date/Time	**Turbidity (NTU)**	**DS Ft³/sec**	**D.O. mg/L**
6/21/2014 15:45	6.42	0.56	7.16
8/8/2014 15:15	4.51	0.07	6.95
6/30/2015 14:15	4.25	0.03	6.06
8/25/2015 15:12	NA	Dry	NA
8/24/2016 14:10	3.79	0.1	7.02

6.4. Photos

Picture 1. Migrant redband trout traps at Indian Creek (above) and Nehchen Creek (below).

Picture 2. Fixed half-duplex PIT tag interrogation site in the mainstem of Hangman Creek. Similar sites are located near the mouths of Indian, Smith, Nehchen, and Sheep creeks as well as a 2nd location in Hangman Creek.

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