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Centennial Valley Arctic Grayling Report 2010-2018

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Introduction

Upper Missouri River Arctic grayling (*Thymallus arcticus*; grayling) were patchily distributed throughout the upper Missouri River drainage prior to the mid-1850s. This population segment declined to about 4% of their perceived historic distribution by the 1990s, which led to formal consideration for listing under the Endangered Species Act. In 2014, Montana grayling were found not warranted for listing (USFWS 2014); however, a court decision in 2018 mandated reassessment of that finding by 2020 (Bill Schenk, pers. comm.). One of the last populations of indigenous grayling resides in the Centennial Valley (CV). Grayling were historically distributed among at least a dozen CV streams and three lakes at presumably high abundances; however, grayling began rapidly declining in the early 1950s and spawning was confined to Red Rock and Odell Creek by 1977 (Nelson 1954, Mogen 1996). Distribution and abundance of CV grayling reached a historic low in 1995 and have fluctuated since.

The species-wide conservation goal for Montana Arctic grayling is to "*Ensure the long-term, self-sustaining persistence of Arctic Grayling in the upper Missouri River Basin (*MAGWG, in press)*."* A stakeholder group was convened in 2011 to provide resource managers a forum to discuss approaches that would achieve the range-wide goal in the CV. The workgroup comprises individuals representing agencies that have either direct grayling or land management authority in the CV. Montana Fish, Wildlife & Parks (FWP) has management responsibility for grayling in the CV, the U.S. Fish and Wildlife Service (FWS), Bureau of Land Management (BLM), and Forest Service (FS) manage CV lands that are part of the federal estate, Montana Department of Natural Resources and Conservation (DNRC) manages state-owned lands, and The Nature Conservancy (TNC) owns land in the CV they manage to benefit grayling. This workgroup has no formal governance process and is voluntary and consensus-based. The workgroup developed the following objectives to attain the range-wide goal and guide CV grayling conservation:

1) Conserve existing Centennial Valley Arctic grayling genetic diversity.
2) Establish or maintain Arctic grayling spawning and/or refugia in at least two tributaries up and downstream of Upper Red Rock Lake and connectivity among tributaries.
3) Implement management alternatives to maintain at least 1000 spawning fish in the Upper Red Rock Lake Arctic grayling population.

This report describes actions FWP completed between 2010 and 2018 pursuant to Objectives 1 and 2. To achieve Objective 3 the workgroup developed and implemented the Centennial Valley Arctic Grayling Adaptive Management Plan (AMP; Warren and Jaeger 2017), whose activities are separately reported biannually (e.g., Warren et al. 2018, Warren et al. 2019).

Study Area

The CV is a high-elevation valley located in southwestern Montana. The valley is contained by the steep, timbered Centennial Mountains to the south and the sage-covered foothills of the Gravelly and Snowcrest mountains to the north. The CV encompasses all waters upstream of Lima Dam that form the Red Rock River (Figure 1). CV geology (Sonderegger 1981), hydrology (Deeds and White 1926, MTFWP 1989, MCA 2000), and fish assemblages (Nelson 1954, Randall 1978, Gillin 2001, Oswald et al. 2008) are well described elsewhere.

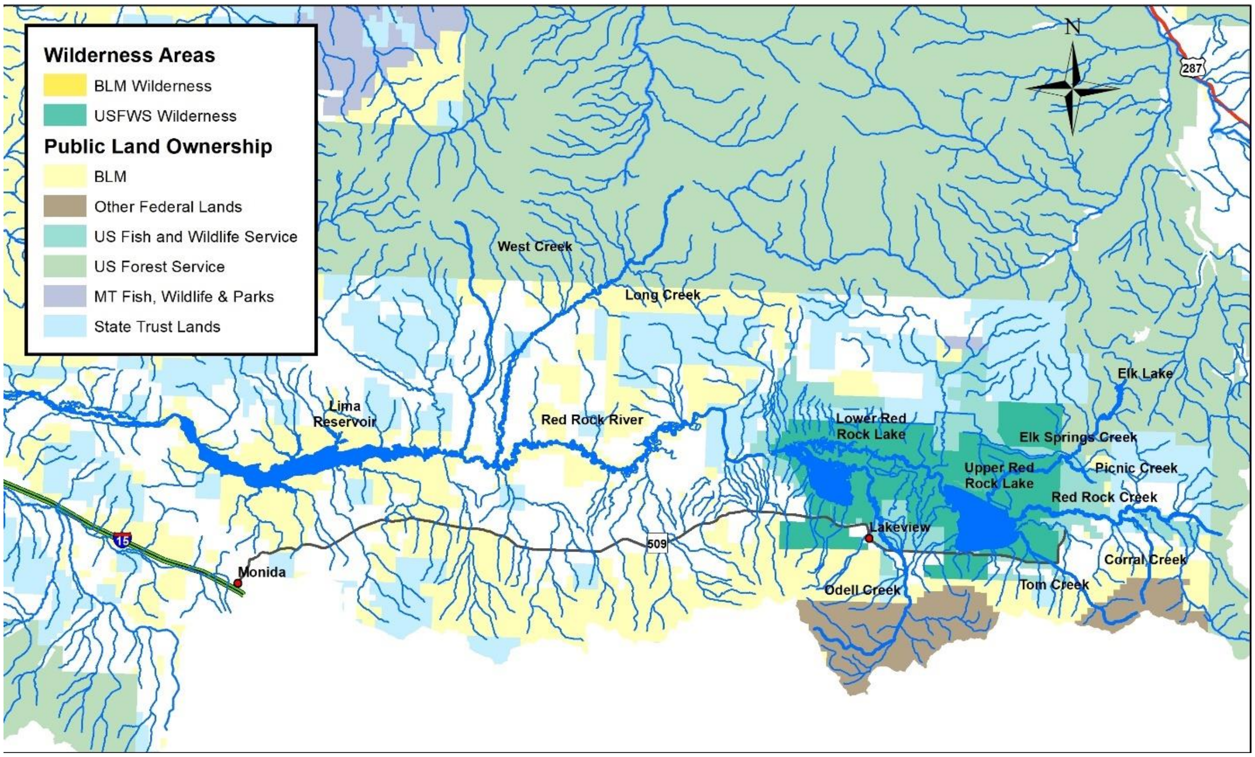

Figure 1. The Centennial Valley and upper Red Rock River watershed.

The CV has undergone drastic changes in the last 150 years. Initially used as summer range beginning in 1876, year-round livestock operations quickly became common. By 1892, 21 ranches existed within the present-day Red Rock National Wildlife Refuge (Refuge) boundary and settlement and grazing was associated with most waters throughout the CV (Vincent 1962, Unthank 1989, Centennial Valley Historical Society 2006). Extensive irrigation occurred from most tributary streams by the early 1900s and complete dewatering of streams for irrigation, especially during periods of drought, likely had a large influence on distribution, abundance, and life history strategies of grayling through time (Deeds and White 1926, Vincent 1962, Randall 1978). Decline of spawning habitat quantity and suitability resulted from land use changes associated with livestock and water management. Sedimentation of spawning reaches resulting from grazing had been repeatedly documented and was reported as the primary threat to grayling persistence for much of the 1900s (Vincent 1962, Myers 1977, Mogen 1996). Manipulation, consolidation of flow among channels, and impoundment to facilitate irrigation and improve waterfowl habitat caused erosion, sedimentation, and fragmentation of spawning tributaries (Gillin 2001, Centennial Valley Historical Society 2006). Fragmentation and degradation of spawning tributaries by beaver dams have also been suggested to preclude grayling spawning in CV tributaries to varying degrees (Nelson 1954, Unthank 1989). Early settlers introduced non-native fishes, followed by decades of agency introductions, largely for recreational fisheries. Stocking of CV waters with rainbow trout (*Oncorhynchus mykiss*) began as early as 1899, followed by brook trout (*Salvelinus fontinalis*) in 1900, and Yellowstone cutthroat trout (*Oncorhynchus clarkia bouvieri*) in 1967 (Randall 1978).

Recent management direction has reduced threats to CV grayling. Although grazing management changes on public and private lands combined with Refuge land acquisition have ameliorated threats on most Red Rock lakes tributaries, degraded conditions remain on some streams in the lower CV (USFWS 2009). McDonald Pond was converted back into a stream and its habitat restored from 2009-2016, Elk Springs Creek was reconnected directly to Upper Red Rock Lake (Upper Lake) in 2016, and plans are in place to remove at least one of the Picnic Creek impoundments to further restore connectivity and spawning habitat to Elk Springs Creek (USFWS 2009). Establishment of minimum instream flow reservations (FWP 1989, Kaeding and Boltz 1999), compact settlement between the Montana Reserved Water Rights Compact Commission and the Refuge (MCA 2000), Refuge acquisition of private lands, and changes in management practices on public and private lands have greatly reduced the threat of stream dewatering. The relative effect of non-native fishes, spawning habitat, and overwinter habitat on grayling is being directly assessed by the AMP and a Candidate Conservation Agreement with Assurances (CCAA) was implemented in 2018 to address potential threats (i.e., dewatering, riparian health, habitat fragmentation, entrainment in irrigation diversions) to grayling on private CV lands.

Objective 1: Conserve existing Centennial Valley Arctic grayling genetic diversity.

Genetic status: Genetic diversity of CV grayling, estimated as average expected heterozygosity (H_e) and allelic richness (A_R), is relatively high (DeHaan et al. 2013, Leary et al. 2015). Further, both H_e and A_R were largely stable through time, which indicates the population has been maintained by a relatively substantial effective population size (N_e; DeHaan et al. 2013, Leary et al. 2015), which is further corroborated by estimates of the effective number of breeders (N_b; Table 1). However, the consequences of recent demographic declines for A_R, H_e, and N_e are currently unknown. The magnitude of demographic declines has motivated the creation of a genetic reserve brood for CV grayling that ensures genetic redundancy in a setting removed from potential threats to the extant population. Importantly, there were significant allele frequency differences among grayling collected in Red Rock, O'Dell, and Long creeks; however, the magnitude of the differences was very small, and it cannot be determined if there are separate spawning populations or a single panmictic population without further research (Leary et al. 2015). Ongoing genetic monitoring is needed to assess population status and trend, and thus overall attainment of Objective 1.

The following activities were completed pursuant to this objective:

Genetic Monitoring: We evaluated two approaches of collecting samples of known age grayling to estimate N_b. Because many CV grayling move into Upper Lake, which is difficult to sample efficiently, within weeks of hatching, there is little opportunity to assess N_b of a cohort until they reach maturity and ascend tributaries to spawn. Each spawning run can be comprised of up to six cohorts that overlap in length distribution making assignment of age based on length impractical (Mogen 1996). To reliably assign tissue samples collected from spawning fish to cohort, both genetic and scale samples are collected from each captured grayling, scales are subsequently mounted and assigned age, and the corresponding tissue sample is then assigned to a cohort. The disadvantages of this approach are the time and expertise required, inherent uncertainties associated with ageing scales, and that a given cohort is not sampled until its members reach sexual maturity about three years after it is produced. However, age-0 and age-1 grayling do not overlap in length with each other or other ages and can be reliably assigned to cohort based solely on length (Mogen 1996). Therefore, we evaluated whether age-0 grayling could be effectively sampled in spawning tributaries prior to moving into Upper Lake or other rearing waterbodies as an alternative to collecting and aging scales of spawning fish to assign samples to cohort.

We attempted to collect age-0 grayling fry from Odell, Red Rock, Long, and West creeks in June of 2015. Streams were divided into 100-m reaches downstream of known or potential spawning habitat. Surveys were conducted by observing each reach for 20 minutes, counting total number of fry observed, collecting fry with small aquarium dip nets, and preserving them in 2 ml screw cap vials with 95% non-denatured ethanol. Because we anticipated both grayling and white sucker fry would be present, we attempted to only identify and collect grayling fry based on appearance and behavioral criteria provided by biologists experienced in identifying grayling fry in the field. Specific criteria included 1) presence of a relatively elongate dorsal fin with a shallow notch that will become the separation point for the adipose fin, 2) a large blunt head, large eyes, and a darker and slightly stouter body than sucker fry, 3) appearance in small groups of 1-3 fish associated with the stream margins, and 4) a recognizable wriggling motion against the current when seen from above (C. Kaya, S. Barndt, J. Mogen, pers. comm.).

Fry were collected from three of the sampled streams; no potential grayling fry were observed in Odell Creek. The number of fry collected in Red Rock, Long, and West creeks were 96, 64, and 19, respectively. Fry were stained and species was determined by up to three experts in larval fish identification using a dichotomous key. All 179 samples were confirmed to be white sucker fry and no grayling fry were collected during any of the sampling events. Therefore, we conclude that fry collection is not a viable sampling technique to capture grayling because fry species cannot be reliably determined in the field. N_b estimates will be most effectively derived from samples collected from spawning adults that are assigned to cohort using aged scales in the CV. Moreover, results from previous studies that relied on identification of grayling fry based on gross appearance in the field when white sucker fry were also present (e.g., Levine 2007) should be interpreted cautiously.

We collected tissue and scale samples from grayling spawning in Red Rock Creek from 2014-2018 to assign cohort and estimate N_b. Several scales were removed from the left side of the body between the lateral line and the dorsal fin and placed in an envelope. The scales were washed in the laboratory and three acetate slide impressions were made from three scales collected for each fish. Scales were aged using the Leica LAS Interactive Measurement module by two independent readers and, when differences in age occurred between readers, they assigned an agreed upon age. We further examined whether length-at-age measurements could be used to assign fish to age classes. The distances between annuli were measured along a transect from the focus to the anterior edge of the scale. Back-calculated lengths at ages of fish were determined by multiplying the length at captured by the proportional lengths between annuli and the total length of the transect used to measure each scale. Again, age-estimation will continue to require assigning age using scales, as length at age overlapped considerably for grayling older than age-1 (Table 2).

Tissue samples (0.25 cm^2) were collected from the pelvic fin and placed in 2 ml screw cap vials with 95% non-denatured ethanol. N_b was estimated using-cohort specific genetic data that were produced by the University of Montana Conservation Genetics Laboratory (Whiteley and Leary 2017). The number of effective breeders in the Red Rock Creek grayling population was relatively consistent from 2010-2014 (Table 1). The mean N_b over this time period was 216.8, and there were no clear differences in estimates across years, as confidence intervals for the N_b estimates overlap across all pair-wise combinations. Samples will be collected and N_b estimates generated for subsequent cohorts as they recruit to the spawning population.

Table 1. Genetic results from Red Rock Creek grayling 2010-2018 (R. Kovach unpublished data). Number of effective breeders was estimated for the cohort produced in a given year and all other metrics were estimated using a mixed-age sample collected in that year. Parenthesized sample sizes are the number of cohort-specific samples used for N_b estimation.

Year	Number of Samples	Expected Heterozygosity	Mean Allelic Richness	Number of Effective Breeders
2010	0 (34)	-	-	277 (97, inf.)
2011	228 (62)	0.802	13.15895	211 (118,721)
2012	100 (54)	0.793	12.98615	166 (74, inf.)
2013	0 (96)	-	-	227 (119, 986)
2014	81 (94)	0.761	12.30257	203 (104, 979)
2015	98	0.734	11.40283	NA
2016	133	0.739	11.35215	NA
2017	52	0.747	12.10146	NA
2018	228	0.749	11.94745	NA

Table 2. Mean back-calculated lengths at age (mm) of Arctic grayling captured in Red Rock Creek in 2013 and 2015.

Year	N	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7
2013	126	125.4	308.7	367.3	397.9	412.1	412.6	411.0
2015	106	132.7	275.8	349.4	381.5	411.2	422.2	407.0
Total mean	232	128.8	293.6	359.2	391.3	411.9	414.5	409.7
Standard Deviation		19.5	31.2	22.1	18.8	17.5	12.6	2.3
Minimum		81.4	204.7	271.5	328.0	368.0	392.0	407.0
Maximum		175.9	370.8	428.1	462.5	492.0	437.0	411.0

Genetic Reserve Brood Creation: We attempted to create genetic reserve broods for CV grayling in Elk and Handkerchief lakes between 2010 and 2018. These genetic reserves are specifically intended to reduce the risk of extinction of the CV genetic lineage by creating separate, isolated populations that conserve the existing genetic diversity of CV grayling and can serve as a brood source for future restoration efforts.

A CV grayling genetic reserve was created in Elk Lake beginning in 2010. This genetic reserve was intended to capture the extant genetic diversity in the CV grayling population in addition to restoring a native population. Grayling historically occupied Elk Lake, but a natural disruption of spawning tributary connectivity occurred. Although flow was intermittent, Narrows and Limestone creeks previously provided adequate spawning habitat to support the Elk Lake Arctic grayling population (Lund 1974). In the 1990s, continuous flow ceased to occur for a long enough period to provide adequate spawning habitat and the Elk Lake grayling population was extirpated; the last indigenous grayling was sampled in Elk Lake in 1994. This change was attributed to seismic activity and climate changes; both of these drainages are traversed by several faults in a seismically active area and precipitation has decreased through time (Gillilan and Boyd 2009). Synoptic flow measurements on Narrows Creek indicate the stream begins losing water about 1 mile from Elk Lake as it enters a fractured canyon. This threat was addressed by piping Narrows Creek past the losing reach and joining it with a spring about 200 yards above Elk Lake and restoring spawning habitat to this channel in 2011.

The Elk Lake genetic reserve population was founded using Red Rock Creek grayling. Although methods varied slightly among years, we generally collected gametes during electrofishing surveys on Red Rock Creek. Fish were spawned following a more robust adaptation of the guidelines suggested in the Big Hole Arctic Grayling Genetic Reserve Plan (Leary 1991); to maximize genetic diversity and minimize any deleterious effects of an individual on the fish it was crossed with, we attempted to spawn every female with two males and every male with two females when creating family groups. This was achieved by dividing the eggs of two females evenly between two containers then using a separate male to fertilize each container. A minimum of 25 pairs is desired to create populations that capture extant genetic diversity (Leary 1991) and we attempted to achieve this goal annually, rather than generationally. Eggs were stripped from females and were protected from sunlight throughout the spawning process. Within about two minutes of egg deposition, males were thoroughly dried proximal to the vent to avoid prematurely activating sperm and their milt was stripped onto eggs. A 0.75% saline solution was added to activate the sperm and prolong micropyle dilation and gametes were gently stirred and agitated for 30 seconds, which corresponds to the motility duration of sperm. Covered eggs sat for three to five minutes, were rinsed two to three times, and poured into a cooler to water harden. All water used generally originated from a hatchery, although clean, local freshwater was used in some instances. Following spawning, all embryos were water hardened for at least an hour in a closed cooler and were protected from sunlight before being moved. Embryos were enumerated by counting all embryos in about five 10 mL subsamples, averaging the results among subsamples, and extrapolating to the total volume of embryos collected. Remote site incubators (RSIs) were used to propagate grayling for all restoration and mitigation projects from 2010 to 2015, except in 2011 when hatchery-reared grayling were stocked into Elk Lake. Unless otherwise noted, all embryos were transported to RSIs within three hours of water hardening where they were left undisturbed for 24 to 72 hours. Embryos were then checked every one to three days and all dead embryos were counted and removed to reduce the spread of fungus to viable embryos. During some years, embryos were submerged in a 0.05% by volume (500 ppm) hydrogen peroxide bath for 15 minutes no more than once daily. No treatment occurred for three days following spawning and was halted when eggs were eyed, although the number of times treatment occurred varied among years. Once all embryos had hatched and fry had emigrated from RSIs, all remaining dead embryos and fry were counted and the cumulative total of dead embryos removed was subtracted from the estimated number of embryos initially placed in each RSI to calculate fry production and survival rate. Stocking occurred in Elk Lake to establish a genetic reserve brood for the CV, in Elk Springs Creek to re-establish a spawning population, and in Red Rock Creek to mitigate any negative effects of removing gametes from that population. Results of propagation efforts are described in Table 3.

We sampled Elk Lake each May since propagation began using five experimental gill nets, four trap nets, or both. Experimental gill nets were 125’ x 5’ with mesh sizes ranging from 0.75” to 2.5” and trap nets were 50’ with 0.5” mesh. Grayling were captured from 2012-2018, except in 2016, indicating RSI-produced fish survived to adulthood (Figure 2).

Table 3. Centennial Valley Arctic Grayling propagation results, 2010 to 2015.

Waterbody	Year	♀	♂	RSIs	embryos	fry	RSI survival
Elk Springs Creek	2010	22	60	10	33,200	25,420	77%
Elk Springs Creek	2011	10	10	10	70,956	57,548	81%
Elk Springs Creek	2012	39	27	10	69,200	47,100	68%
Elk Springs Creek	2013	34	34	7	32,772	16,067	49%
Elk Springs Creek	2014	14	14	5	56,000	50,616	90%
Elk Springs Creek	2015	17	11	9	32,542	19,316	60%
Elk Lake	2010	22	60	NA	123,000	7,161[a]	6%
Elk Lake	2011	25	21	19	139,616	51,238[b]	37%
Elk Lake	2012	39	27	20	127,728	94,743	74%
Elk Lake	2013	34	34	20	86,377	37,285[c]	37%
Red Rock Creek	2010	22	60	2	14,300	13,597	95%
Red Rock Creek	2011	35	31	2	5,300	3,700	70%

[a] embryos were hatched, reared, and stocked at 1-2" on 9/21/10 from Rose Creek State Hatchery

[b] embryos were eyed at Washoe State Hatchery then transported to RSIs

[c] embryos were eyed in Elk Springs Creek then transported to RSIs

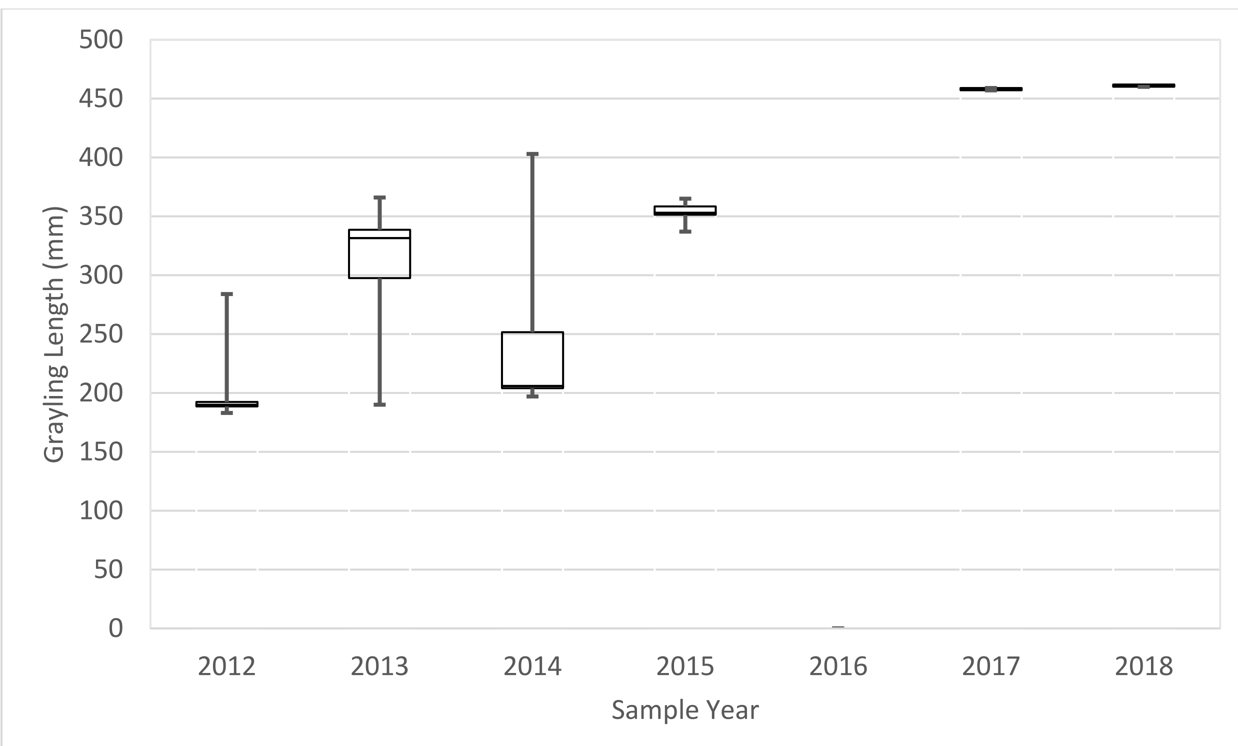

Figure 2. Elk Lake grayling lengths from netting surveys, 2012 to 2018. Boxes denote the 25th percentile, median, and 75th percentile, and whiskers describe the minimum and maximum length values.

The restored reach of Narrows Creek was visually surveyed one to eleven times during putative spawning period (May-June) each year to determine the maximum number of each species and redds from 2012 to 2018. Westslope cutthroat trout used the restored reach each year and no grayling were observed; however, a credible report of two spawning grayling was received after surveys ended in 2016 (Table 4). Differences in numbers of trout and redds are likely attributable to variation in flows, temperatures, and timing of surveys relative to peak spawning periods among years.

Table 4. Results of visual surveys in Narrows Creek, tributary to Elk Lake, in 2012-2018. Dash symbols (-) indicate sampling did not occur.

Year	Peak Number of Westslope Cutthroat	Peak Number of Trout Redds	Number of Grayling
2012	60	46	0
2013	22	27	0
2014	21	34	0
2015	-	-	-
2016	168	16	2*
2017	198	61	0
2018	18	18	0

* Grayling observed in 2016 by Audubon Society members

Grayling were successfully re-established in Elk Lake but there is no evidence natural reproduction has occurred in Narrows Creek, which is an essential aspect of reserve brood creation. When the highest densities of mature grayling were present (2014-2016), flows in Narrows Creek were relatively low and early; flows typically peaked in late April or early May and were less than 2 cfs. Lund (1974) observed successful grayling spawning in Narrows Creek when discharges were between 2 and 3 cfs in late May and our only observation of grayling spawning was on 5/27/16 when flows in Narrows Creek were high (3 cfs) because of recent precipitation. If the outlet of an existing pond in the headwaters of Narrows Creek was modified to control delivery of about 5 acre-feet of stored water, the hydrograph and timing described by Lund could be provided in most years (Sigler 2010). This pond is on land owned by the U.S. Forest Service, who estimated the cost of improvements to their specifications will exceed $250,000. Stocking of grayling in Elk Lake will be ceased until this improvement, or a less costly alternative, is implemented to reliably deliver adequate spawning flows.

An alternative genetic reserve brood outside of the CV is being created in Handkerchief Lake. The 51 acre Handkerchief Lake is located in Northwest Montana and previously contained Rainbow x Cutthroat hybrids and a robust population of self-sustaining nonnative grayling first stocked in 1954. The lake was chemically treated in 2016 as part of a multi-year drainage-wide effort to restore native Westslope Cutthroat (*Oncorhynchus clarkii lewisi*) and Bull Trout (*Salvelinus confluentus*) populations in 21 lakes within the South Fork of the Flathead River watershed. As part of MEPA, the public requested grayling stocking into Handkerchief Lake following hybrid trout removal to continue to provide a unique recreational fishery for this species. CV grayling were chosen as the donor source because of their conservation value and the need to create a genetic reserve brood outside of the CV.

Grayling stocked in Handkerchief Lake were offspring of fish spawned directly from Red Rock Creek. Five hundred and ninety CV grayling produced from 1:1 crosses of 26 females and 15 males in 2014 (N_b = 18.4) were being held at the Bozeman Fish Technology Center. About 500 of these fish were stocked in

Handkerchief Lake in 2017; however, about 100 died shortly thereafter (Table 5). The remaining 90 fish were genotyped and stocked into a private pond near Alder, MT and spawned in 1:1 crosses in 2018. They produced about 2000 eggs from 12 families, although only 700 fry resulted, and all were eaten by mink at the hatchery. A second wild spawn on Red Rock Creek in 2016 used 38 grayling in 2:2 crosses (N_b = 18.9) to produce 1400 fry, which were stocked into Handkerchief in 2017 (Table 5). Family composition and genetic diversity of stocked fish was described by Whiteley and Leary (2017). In 2018, five environmental DNA (eDNA) samples were collected at the inlet of Handkerchief Lake to determine whether grayling were attempting to spawn. No grayling DNA was found in the sample; however, timing may not have been consistent with the spawning period. Future monitoring will evaluate grayling presence by eDNA sampling the lake outlet and trap netting in the lake, in addition to more rigorous eDNA monitoring of the spawning inlet.

Table 5. Red Rock Creek grayling numbers stocked in Handkerchief Lake.

Year	Number of Grayling Stocked	Grayling Age
2017	500	3
2017	1400	1

Objective 2: Establish or maintain Arctic grayling spawning and/or refugia in at least two tributaries up and downstream of Upper Red Rock Lake and connectivity among tributaries.

To understand whether Objective 2 was being met and how to best prioritize conservation efforts, a better understanding of contemporary grayling distribution among and habitat condition within CV streams was needed. Survey results were used to prioritize specific tributaries for additional data collection or conservation measures that will result in attaining Objective 2. The following actions were completed pursuant to this objective.

CV Grayling distribution: The number of CV streams and lakes that were historically occupied by grayling is unknown. Comprehensive surveys using traditional methods to characterize fisheries resources of CV streams first occurred in 1951 (Nelson 1954). Earlier historic accounts and discrete collections of grayling provide evidence of occupancy (e.g., Evermann 1893, Henshall 1906); however, lack of mention does not indicate absence. The assumption that grayling historically occupied most suitable CV tributaries and downstream portions of the Red Rock and Beaverhead watersheds is generally accepted (Evermann 1893, Nelson 1954). Evidence exists that grayling resided in the CV year-round (Blair 1897); however, speculation during early propagation efforts (Henshall 1906) and aggregations of fish below Lima Dam following its closure in 1910 (Avare 1912) suggest grayling also migrated from downstream locations into the CV to spawn. Although the number of tributaries historically occupied by grayling is unknown, specific and recurrent mention of large numbers of spawning grayling in Elk Springs (Henshall 1902) and Red Rock (Nelson 1954) creeks suggest these streams historically supported the highest abundances and most frequent use among CV streams.

Although introduction of non-native rainbow (1899) and brook (1913 to 1915) trout and habitat degradation associated with development and use of natural resources occurred throughout the early 1900s, grayling remained relatively abundant and presumably widely distributed in the CV until a major decline in distribution occurred coincident with drought and chronic dewatering in the 1930s (Vincent 1962, Randall 1978). By 1930, at least 17,000 acres were being irrigated by diversion of water from all

CV tributaries upstream of Upper Lake (Deeds and White, Harding 1915). Although the Red Rock River was not diverted between Lower Red Rock Lake (Lower Lake) and Lima Reservoir, prolonged periods without measurable discharge occurred there in multiple years throughout the 1930s (USGS), which is suggestive of complete dewatering of all tributaries and resultant extirpation of grayling residing in them. By 1940, reports noted that a considerable decline in grayling distribution had occurred throughout the CV, that grayling had previously occurred in streams year-round but now only occupied Upper Lake outside of spawning periods, and that brook trout had become the most commonly encountered species in most streams (Vincent 1962, Randall 1978). Failure of grayling to return to previous distribution and abundances during the improved hydrologic conditions of the 1940s prompted the first extensive and focused fisheries survey of CV waters in 1951, which documented grayling in 11 streams and 2 lakes (Table 6; Nelson 1954). Between the 1950s and 1990s numerous planning efforts (e.g. Randall 1978, USFWS 1978, USFWS 1985, Unthank 1989) and some sampling (e.g. Lund 1974, Randall 1978, Peterson 1979) occurred but did not assess valley-wide distribution (Table 6). From 1996 to 1999, CV grayling distribution was reported to have declined to only two tributaries, Red Rock and Odell creeks, and two lake populations, Upper and Lower lakes; however, few other water bodies were extensively surveyed with sampling gears during spawning periods (Table 6; Mogen 1996).

Contemporary grayling distribution was assessed by surveying historically occupied streams from 2010 to 2012 with backpack, crawdad, or drift boat electrofishing (Table 6). Three 200-meter reaches were selected in each stream to optimally reduce false non-detection given occupancy and detection probabilities were expected to be less than 0.6 (Mackenzie and Royle 2005). A removal design was used such that sampling on a stream was halted if a grayling was captured at any site during any year and only streams where grayling were not found were re-sampled in multiple years.

Upper Lake, Elk Lake, and Lima Reservoir were also surveyed during this time period for research, evaluation of grayling population restoration, and routine monitoring, respectively. Upper Lake is a shallow (~1.8 meters), productive lake that provides the primary juvenile rearing and overwintering habitat for grayling; however, it has characteristics of a lake prone to winter kill (Davis 2016) and recent severe winters have coincided with large grayling population declines (Warren et al. 2018). Upper Lake was surveyed with 125’ x 5’ (0.75”-2.5” mesh) experimental gill nets and 50’ x 4’ (0.5” mesh) trap nets in early Fall of 2013 and 2014 to capture grayling for a telemetry study (Table 7). Lima Reservoir is located at the most downstream point of the Red Rock River in the CV and was created when the Lima Dam was completed at the western end of the valley. Lima Reservoir was surveyed with experimental gill nets in 2010 and trap nets in 2017. Two grayling, 272 and 348 mm, were captured in 2010 and one 207 mm grayling was captured in 2017 (Table 8). Although juvenile and adult grayling occupy Lima Reservoir, movements among the reservoir and streams and timing of use is unknown. Elk Lake sampling is described above associated with Objective 1.

Presence-absence electrofishing and gill netting surveys in 2010 to 2013 found grayling in seven streams and three lakes (Table 6). The grayling present in two of these waters, Elk Lake and Elk Springs-Picnic creeks, were the result of restoration actions. Additionally, reliable visual observations of grayling were made in West Creek in 2014, Narrows Creek in 2016, and Metzel Creek in 2017. Although Lower Lake and the Red Rock River downstream to Lima Reservoir were not sampled, grayling likely occupy them during at least parts of the year because they were observed up and downstream. As such, the contemporary CV grayling population is distributed from Lima Dam to Red Rock Creek and includes at least ten tributaries and three lakes during parts of the year.

Table 6. Perceived Centennial Valley Arctic grayling distribution through time. Grayling presence was documented by "X"; no mark indicates presence was not documented. Water bodies that were not surveyed during a specified period are denoted by "-".

Water body	Arctic grayling present			
	1950's	1970's	1990's	2010's
Red Rock Creek	X	X	X	X
Hell Roaring Creek	X	-		
Corral Creek	X	-		X
Antelope Creek	X	-		
Battle Creek	X	-	*	*
Elk Springs Creek	X			X
Picnic Creek	-	-		X
Tom Creek	X	X		X
East Shambow Creek	-	-	X	
Grayling Creek	-	-		
Odell Creek	X	X	X	X
Metzel Creek	X	-		X[a]
Long Creek	X			X
West Creek	X	-		X[b]
Narrows Creek	X	X		X[c]
Elk Lake	X	X		X
Upper Red Rock Lake	X	X	X	X
Lower Red Rock Lake	X	X	X	-
Lima Reservoir			-	X

* Battle Creek ceased to flow to Red Rock Creek and may have been previously maintained by diversion from Tom Creek

[a] Grayling were visually identified near the Fish Creek confluence by a retired fisheries biologist in 2017

[b] A grayling was visually identified by a BLM fisheries biologist in 2014

[c] Two grayling were observed spawning in Narrows Creek in 2016

Table 7. Upper Red Rock Lake Fall netting data in 2013 and 2014.

Sampling Year	Gear	Total Set Time (hours)	Grayling Caught	Grayling CPUE (grayling/hour)
2013	Trap Nets	359.3	4	0.011
2013	Gill Nets	74.3	15	0.202
2014	Gill Nets	171.4	44	0.257

Table 8. Lima Reservoir netting, 2010 and 2017.

Month	Year	Gear	Total Set Time (hours)	Grayling	Burbot	Westslope Cutthroat Trout	Rainbow X Cutthroat Hybrid	Brook Trout	White Sucker
Oct	2010	Gill Nets	108	2	1	0	27	0	233
June	2017	Trap Nets	285	1	70	1	0	3	2243
Sept	2017	Trap Nets	304	0	15	2	0	0	2836

Rapid stream assessment surveys (RASS), which characterize habitat conditions, were conducted in 2011 and 2012 for all streams in the CV. Barriers, connectivity, tributaries, irrigation infrastructure, fence lines, riparian habitat, in-stream habitat, and visual fish observations were documented, and overall stream condition assessed. Surveys were conducted by walking the entire length of each stream and taking notes, GPS points, and pictures of the aforementioned features. The RASS surveys documented over 1000 features across ~105 stream miles. Stream condition ranged from poor to excellent and potential connectivity issues were identified in 17 of the 22 stream surveyed (Table 9). Descriptions and feature details for each stream are listed in Appendix 1.

Table 9. Streams surveyed during Rapid Assessment Stream Surveys, 2011 and 2012.

Stream Name	Distance Surveyed (mi.)	Number of Features	Stream Condition	Connectivity Issues
Bean Creek	4.34	61	Excellent to Poor	Yes
Bear Creek	5.90	47	Okay to Poor	Yes
Clover Creek	10.24	95	Good to Okay	Yes
Curry Creek	2.27	27	Good to Poor	Yes
East Shambow Creek	0.22	24	Good	No
Elk Springs Creek	3.66	44	Good to Okay	Yes
Grayling Creek	0.99	54	Good	No
Hell Roaring Creek	1.65	23	Good to Okay	No
Long Creek	7.48	123	Excellent to Poor	Yes
Metzel Creek	3.29	85	Poor	Yes
Middle Creek	6.05	44	Good to Okay	Yes
Narrows Creek	0.78	7	Good	Yes
Odell Creek	3.74	118	Good	No
Peet Creek	5.39	62	Good	Yes
Picnic Creek	1.42	30	Good to Poor	Yes
Price Creek	4.97	53	Good	Yes
Red Rock Creek	7.59	118	Excellent to Okay	Yes
Red Rock River	30.90	72	Poor	No
Shambow Creek	1.36	14	Good to Okay	Yes
Tom Creek	1.33	19	Poor	Yes
West Creek	6.90	63	Good to Okay	Yes
Winslow Creek	0.73	5	Poor	Yes

Based on historical and contemporary distribution and habitat surveys, we prioritized Red Rock, Elk Springs, Long and West/Middle creeks for conservation actions to achieve Objective 2. The following activities were completed to provide spawning and/or refugia, establish connectivity, or evaluate present or inform future conservation actions.

Red Rock Creek: We characterized grayling spawning distribution, seasonal occupancy, and abundance to determine whether Red Rock Creek satisfied our conservation objective. Additionally, we assessed the effectiveness of using a two-pass mark-recapture electrofishing survey to estimate abundance of the spawning population. Abundance of spawning grayling in Red Rock Creek was traditionally estimated using mark-recapture surveys where fish were marked at a stationary weir and recaptured by electrofishing an upstream reach (Paterson 2013, Warren et al. 2018). The weir, which was operated by the FWS, is costly, time consuming, and logistically demanding to maintain. However, the capture of grayling in the weir provided unbiased information on the timing of fish movement upstream, which helped plan for the timing of the electrofishing survey(s). To plan for the absence of the weir we developed a model for the timing of grayling movement upstream in Red Rock Creek that we then validated to assess the feasibility of generating abundance estimates using electrofishing exclusively. This model was then used to inform the timing of electrofishing surveys so as to continue to generate reliable abundance estimates. We completed multiple electrofishing surveys in conjunction with the weir in 2016 and 2017 to assess environmental correlates of grayling movement.

We wrote a Baysian model that used a Poisson regression approach to estimate the number of grayling in the weir as a function of day of the year, stream discharge, and water temperature (details in Appendix 2). The number of fish in the trap on day *t* in year *y* ($F_{t,y}$) was modeled as:

$$\mathrm{F}_{t,y} \sim \mathrm{Poisson}(\lambda_{t,y}),$$

where the expected number of fish in the trap, λ_t, was a modeled as a function of covariates using a log link:

$$\log(\lambda_{t,y}) = \alpha + \beta_{doy}(\mathrm{doy}_{t,y}) + \beta_{doy^2}(\mathrm{doy}_{t,y}^2) + \beta_{dis}(\mathrm{dis}_{t-1,y}) + \beta_{dis^2}(\mathrm{dis}_{t-1,y}^2) + \beta_T(\mathrm{T}_{t-1,y}) + \log(N_y),$$

with doy_t corresponding to the day of the year, dis_{t-1} corresponding to the mean discharge (cfs) the previous day, and T_{t-1} corresponding to the mean stream temperature (F) the previous day. The last term, N, was the estimated population size in each year and was included as an offset to account for different expectation of fish in the trap from different-sized spawning runs. Results suggested grayling movement is strongly associated with warming stream temperatures on the ascending limb of the hydrograph (Table 10).

Table 10. Parameter estimates from Bayesian model for the number of fish in the trap as a function of day of the year (doy), stream discharge (dis) and stream temperature (T).

Parameter	Mean	95% CI
α	-2.899	-3.276, -2.532
β_{doy}	0.041	-0.070, 0.145
β_{doy^2}	-0.006	-0.012, -0.000
β_{dis}	0.085	0.058, 0.113
β_{dis^2}	-0.003	-0.004, -0.002
β_T	0.467	0.380, -.557

However, all of our covariates were highly collinear as they are all related to stream conditions that reflect spring melt and we caution against interpreting them alone. Our primary goal was to develop a predictive model. The model also had good predictive ability for the timing of grayling movement (and not the actual abundance in the trap, a result of the high variation in abundance through the years) when we validated it against other years not used to fit the model (e.g., Figure 3). In order to facilitate communication among staff responsible for survey logistics, we then put the model in a Shiny application on the web that automatically updates predictions for the following day using stream conditions and is freely during the late spring.

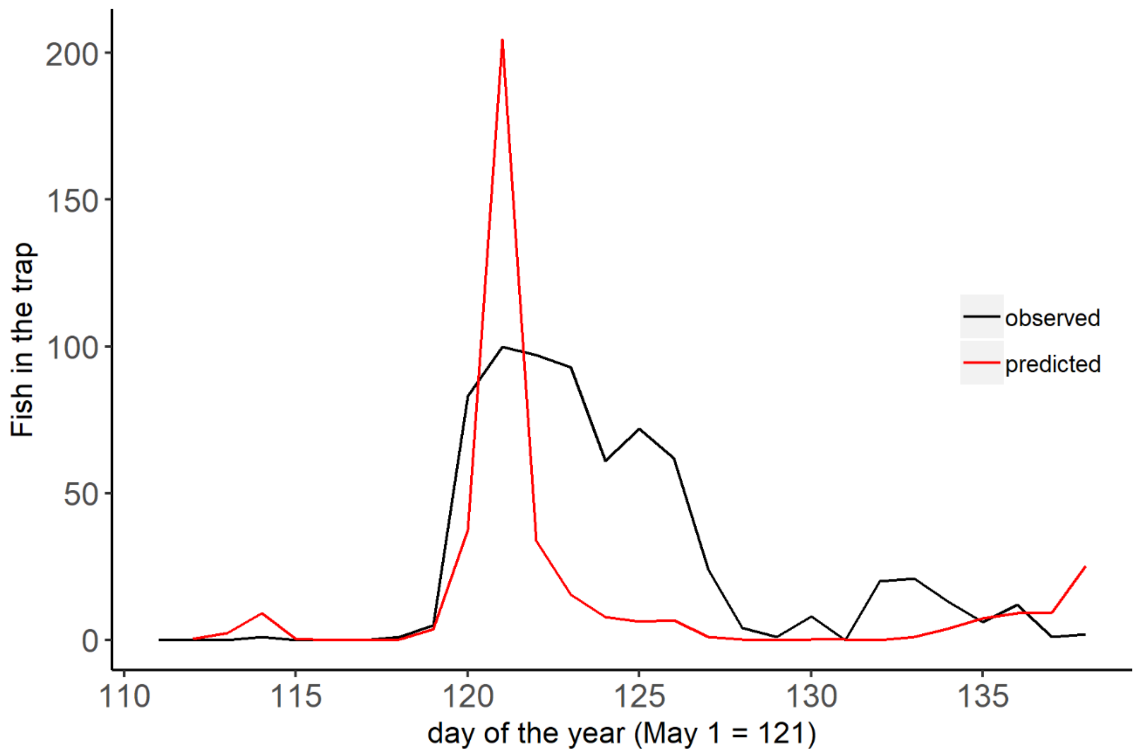

Figure 3. Predicted movement of fish through the trap (red line) compared to the number seen (black line) in 2015. The model was fit on data from 2016 and 2017, and this represents a test of the out-of-sample predictive ability of the model. Although the model incorrectly predicts abundance, it does correctly predict the peak of movement

Grayling distribution during the putative spawning run was determined by electrofishing the majority of Red Rock Creek each May from 2013 to 2015. Surveys typically began in Hellroaring Creek and continued downstream until lack of riffle-pool morphology precluded efficient sampling (RM ~2.2). Grayling were generally distributed across about 10 miles of Red Rock Creek each year (Figure 4). Maximum observed upstream distribution was about 14 miles from Upper Lake in 2013; however, reduced upstream grayling distribution in 2014 and 2015 was coincident with documented beaver dams, indicating potential barriers to upstream passage and habitat fragmentation (Figure 4). Although grayling were observed downstream to Upper Lake, it is likely these fish were migrating to or away from spawning areas given the paucity of spawning habitat downstream of RM 2.2 (Warren et al. 2019).

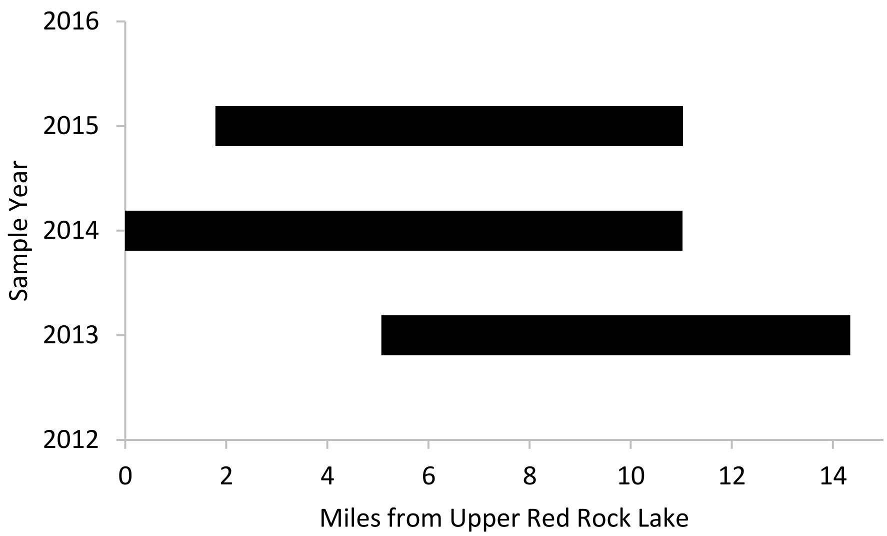

Figure 4. Distribution of grayling from Upper Red Rock Lake during the presumed spawning run in Red Rock Creek.

We determined grayling were present in Red Rock Creek throughout the summer in 2014. Four 200-meter sections were electrofished in July, August, and September to assess grayling presence. Grayling were present and distributed throughout Red Rock Creek during the summer at varied relative abundances among sections (Table 11). Grayling were previously thought to spawn in Red Rock Creek and immediately return to Upper Lake (i.e., adfluvial life history); however, grayling occupied Red Rock Creek well past spawning periods (May). Although we did not assess or document overwinter use, these results suggest CV grayling may exhibit both adfluvial and fluvial life histories. At a minimum, there is greater life history variation in CV grayling than previously recognized.

Table 11. Grayling presence in Red Rock Creek.

Section Name	Distance from Lake (miles)	Number of Grayling Present		
		15-Jul-2014	20-Aug-2014	15-Sep-2014
Upstream of Battle Creek	2.8	11	0	2
Nelson #1	5.4	1	0	0
Nelson #2	8.3	2	7	2
Nelson #3	10.3	3	0	1

Abundances of spawning grayling varied over the past 10 years (Figure 5). The highest abundances documented (2500) occurred in 2012 and near historic lows occurred in 2017. Likely population drivers have been described by Warren et al. (2019). Distributional and weir surveys indicated that most fish marked below the weir eventually moved above the weir, with the majority of spawners occupying the reach between Elk Lake Road (RM 5.5) and Corral Creek (RM 10.7). Analysis of electrofishing data from different combinations of subsections within this reach indicated it could be divided into two approximately equal sections, either section could be surveyed in a given year, and the resulting abundance estimate simply doubled to extrapolate to an abundance estimate for the entire stream. In 2016 and 2017, two electrofishing passes resulted in unbiased, but less precise abundance estimates than using electrofishing and the weir (Table 12). In 2018, only electrofishing surveys were used to estimate abundance, which resulted in the least precise estimate over the 25-year data set. However, there was a considerable savings in staff time for electrofishing (2 days) versus running the weir (25 to 60 days).

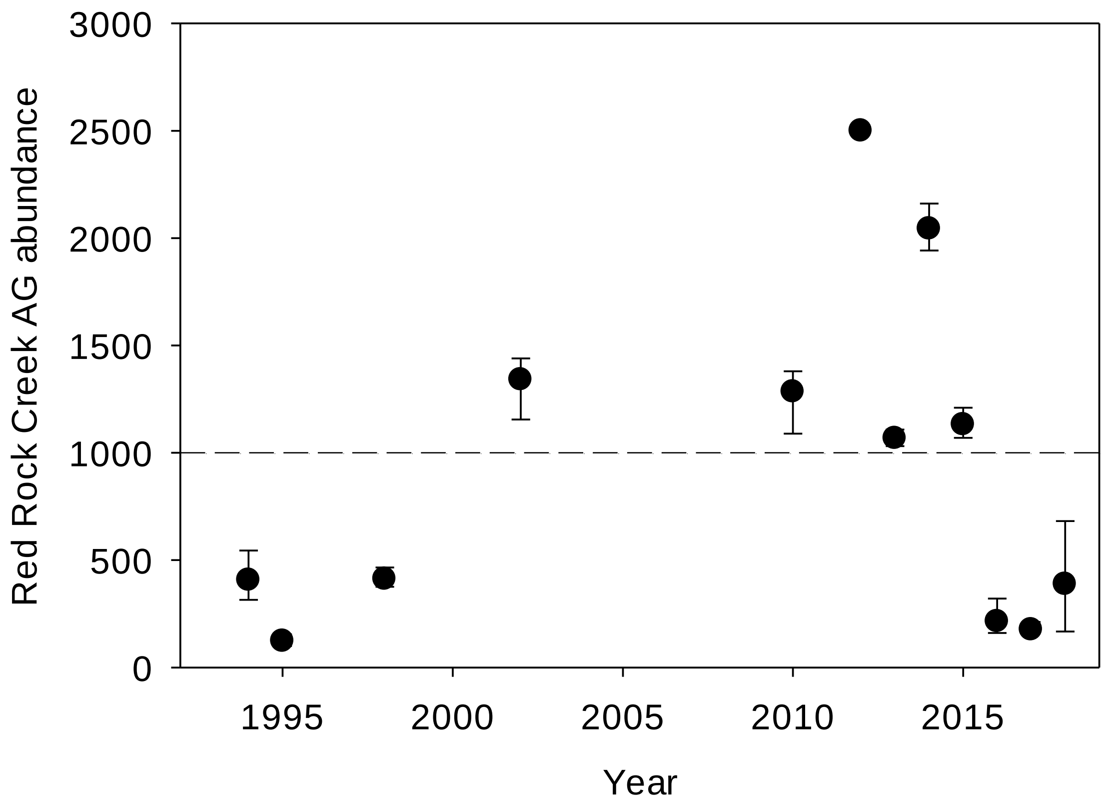

Figure 5. Abundance of spawning grayling in Red Rock Creek. Dashed line indicates the management goal for this stream.

Table 12. Abundance estimates generated with weir and electrofishing and electrofishing only. 95% confidence interval are shown in parenthesis.

Year	Weir mark & electrofishing recapture	Electrofishing mark & recapture
2016	214 (161, 321)	204 (130, 388)
2017	176 (159, 212)	184 (134, 234)

Elk Springs Creek: The Refuge restored connectivity to Elk Springs Creek between 2009 and 2016. Elk Springs Creek in the CV historically supported one of Montana's most prolific Arctic grayling spawning populations. Between 1898 and 1908 millions of eggs were taken from thousands of grayling by the U.S. Fish Commission to create new grayling fisheries and fuel the first Montana Arctic grayling conservation effort; however, the spawning habitat that supported this population was subsequently serially fragmented and degraded. Elk Springs Creek was diverted from its historic channel, which flowed directly into Upper Lake, into a shallow wetland marsh called Swan Lake by duck hunters in 1908. Although the Elk Springs Creek Arctic grayling spawning run crashed in 1909, it is unclear if it was caused by the aforementioned diversion into Swan Lake or the simultaneous closure of Lima Dam at the lower end of the CV. The stream was further fragmented and its spawning habitat degraded by an impoundment constructed in 1953 (MacDonald Pond) and an undersized and perched culvert that backwatered several hundred feet of stream installed during construction of Culver Road in 1965. The historically used spawning reach was further degraded by channelization occurring in 1955. Spawning Arctic grayling were resultantly extirpated from Elk Springs Creek for the past century. To restore connectivity to Elk Springs Creek, MacDonald Pond was drained in 2009, the undersized culvert on Culver Road removed in 2011, and the stream returned to its historic channel alignment and inlet in 2016 such that it bypasses Swan Lake and flows directly into Upper Lake. The effects of restored connectivity are being evaluated by a Montana State University graduate study.

FWP and the Refuge restored spawning habitat to the historically used 0.3 mile spawning reach of Elk Springs Creel that was degraded by MacDonald Pond. The dimensions and hydraulics of the channel that naturally colonized the post-impoundment lake bed could not adequately mobilize and sort gravels and flush lake-deposited fine sediment, resulting in a wide, shallow, silty channel unsuitable for spawning. In 2016, spawning habitat was restored by removing sediment deposited by MacDonald Pond, importing spawning gravels where needed, and narrowing the channel by 50 to 80%. Natural sinuosity was also restored to the channelized reach creating an additional 350 feet of stream. Completion of this project created 0.2 hectares of spawning habitat, which tripled the amount provided by restoring connectivity alone (Warren et al. 2019).

Efforts were made throughout restoration activities to reestablish graying in Elk Springs Creek using RSIs (Table 13). Movements of RSI-produced fry were characterized in Elk Springs Creek by the Refuge throughout the summer of 2014 using the methods described above for fry sampling. Unlike the aforementioned fry surveys on other CV streams, propagated grayling fry were readily distinguishable from sucker fry, which were first observed around July 11th, during this study. Elk Springs Creek was divided into nine 100-meter monitoring reaches; eight were distributed across the 5.3 miles between the headwater RSI location and inlet to Swan Lake and the ninth was located between Swan and Upper lakes. Grayling fry moved downstream throughout the upper half of the study reach within 3 days of emerging from RSIs; however, no fry were observed at lower sites until about 3 weeks post-emergence (Table 14). Several aggregations of 10 to 100 grayling fry were observed between Elk Lake Road and Swan Lake in July and August. No grayling fry were documented in the channel between Swan and Upper lakes, suggesting the potential for Swan Lake to serve as a barrier prior to reconnection.

Table 13. Grayling propagation summary in Elk Springs Creek, 2010 to 2015.

Year	RSIs	Embryos	Fry
2010	10	33,200	25,420
2011	10	70,956	57,548
2012	10	69,200	47,100
2013	7	32,772	16,067
2014	5	56,000	50,616
2015	9	32,542	19,316

Table 14. Elk Springs Creek Grayling fry distribution surveys, 2014.

Reach	First day fry observed	Total number fry observed
1	6/2/14	100
2	6/5/14	24
3	6/5/14	23
4	6/9/14	37
5	6/5/14	4
6	6/20/14	2
7	6/27/14	660
8	7/10/14	1
9	NA	0

Long, West, and Middle creeks: Long, West, and Middle creeks are high priorities for conservation due to their potential as grayling spawning and refugia tributaries below Upper Lake; however, these streams are located primarily on private land. The Centennial Valley Candidate Conservation Agreement with Assurances (CCAA) program was created in 2018 to incentivize management of private lands to remove potential threats to grayling. Potential threats to grayling on private lands, including streamflow targets and triggers, are well-described elsewhere (Brummond 2019, USFWS and MTFWP 2018). To help inform CCAA development and implementation, electrofishing surveys were conducted on Long, West, and Middle creeks between 2010 and 2018.

Grayling distribution in Long Creek was determined by electrofishing from the BLM boundary to the North Valley Road in 2017 and BLM lands in 2014 (9.4 total miles). Salmonids were primarily distributed between river miles 4.5 and 10.9 and grayling occupied about 3.4 miles of that reach (Figure 6).

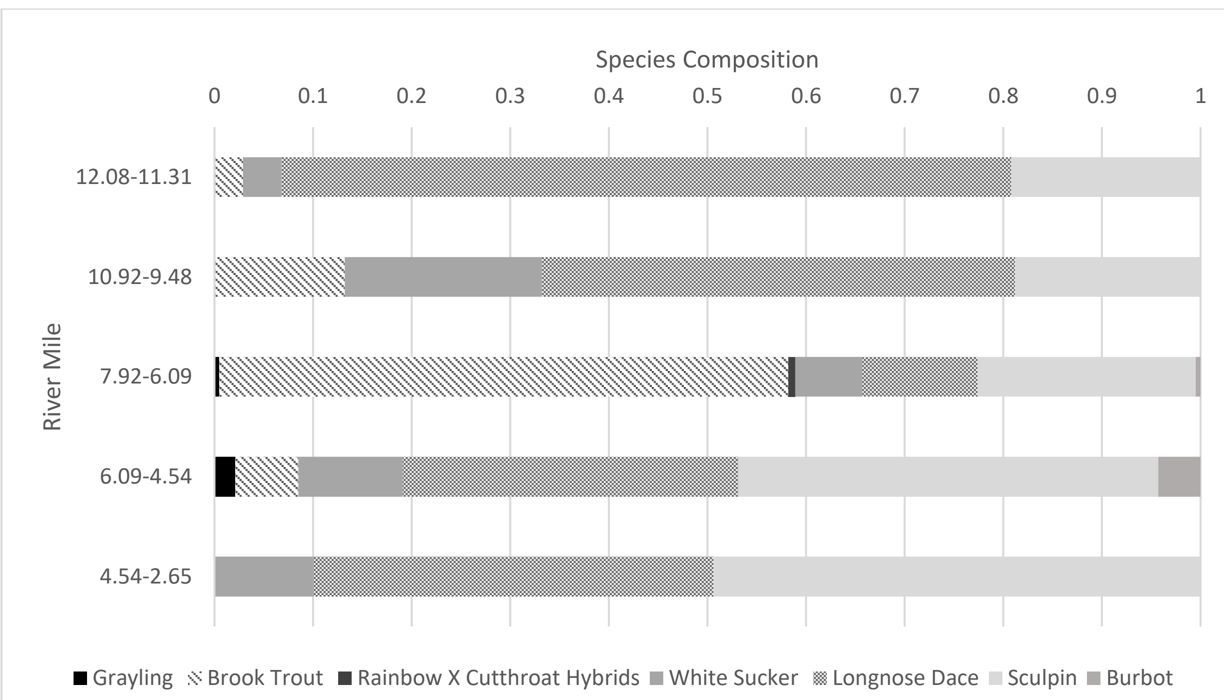

Figure 6. Proportional fish distribution in Long Creek electrofishing surveys 2014-2017.

Intensive electrofishing surveys of a Nature Conservancy habitat management and research project area on Long Creek occurred from 2010 to 2018. The Nature Conservancy acquired the area and changed agricultural use, primarily by reducing or eliminating riparian grazing, in 2010. Study sections corresponded to no management changes (Control), reduced grazing and installation of beaver mimicry structures (Passive/Beaver Mimicry), and intensive willow planting (Willow Transplant). The Passive and Willow Transplant sections were historically heavily grazed and potentially dewatered for agriculture. The Control section flows through a dense willow riparian area that had not received the grazing impact of the other two sections and habitat projects did not occur in the control section.

Twelve grayling were captured among the three reaches in 2010 and no grayling were found in 2011 or 2012; however, the three reaches were surveyed again in 2018 and five grayling were found. Brook trout were the most proportionally abundant species in the Control section; average proportion of the species composition was 0.55, although it varied from 0.22 to 0.88 among years (Figure 7). Grayling were captured in the Control reach in 2010 and 2018.

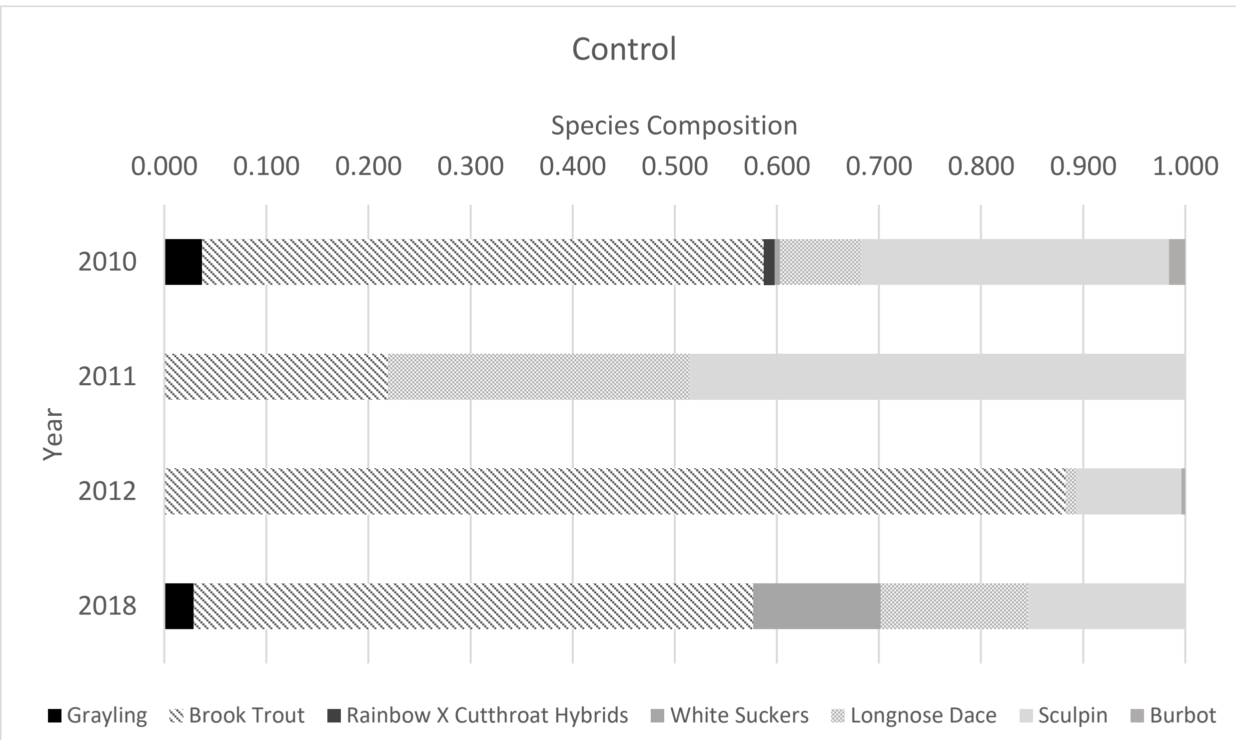

Figure 7. Long Creek Control Section species composition from 2010-2018.

The passive section was altered by the addition of beaver mimicry structures in 2016. The proportion of salmonids increased from 2010 to 2012, which is likely a result of reduced agriculture pressures; however, grayling were only captured in 2010. Following the installation of the mimicry structures, a transition from salmonid to catostomid species occurred (Figure 8). The increasing trend in proportion of salmonids in the other sections suggests beaver mimicry structures, and the resultant conversion of stream to impounded habitat, contributed to the decrease in salmonids and increase in catostomids.

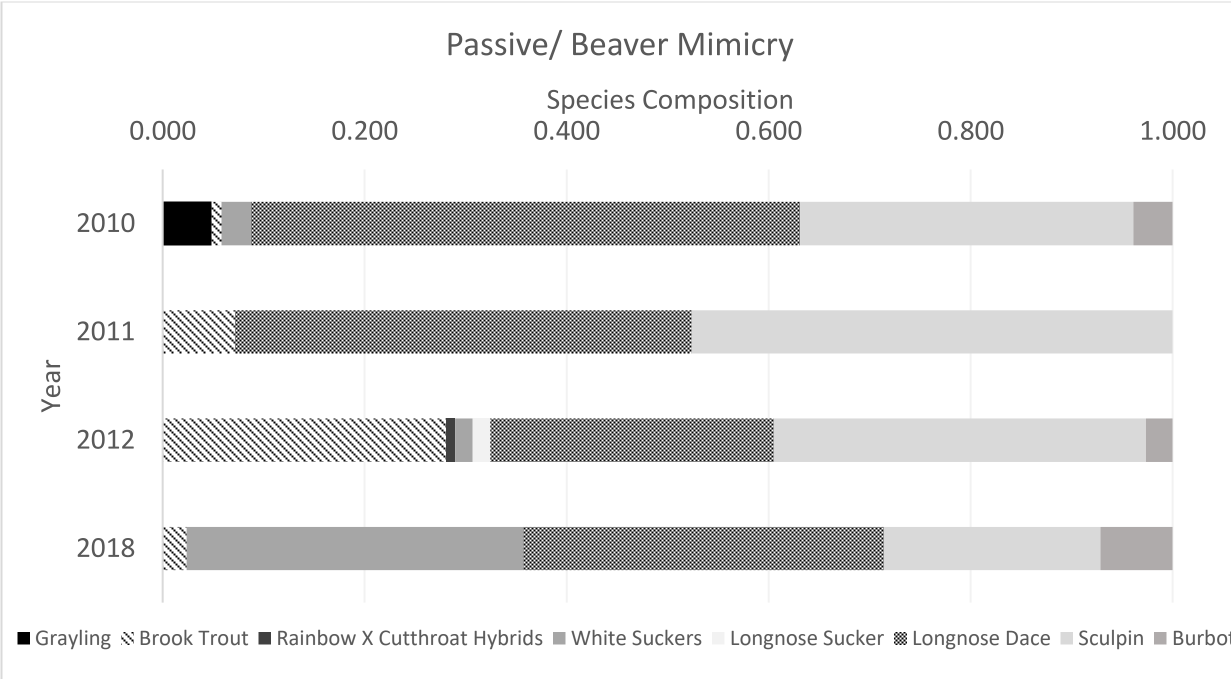

Figure 8. Long Creek Passive/Beaver Mimicry Section species composition from 2010-2018.

Willow recolonization was anthropogenically accelerated to more quickly improve habitat in the Willow Transplant reach. Similar to the Passive section, the proportion of salmonids increased from 2010 to 2012 (Figure 9). The proportion of salmonids decreased slightly from 2012 to 2018; however, previously absent grayling made up 14% of the 2018 species composition.

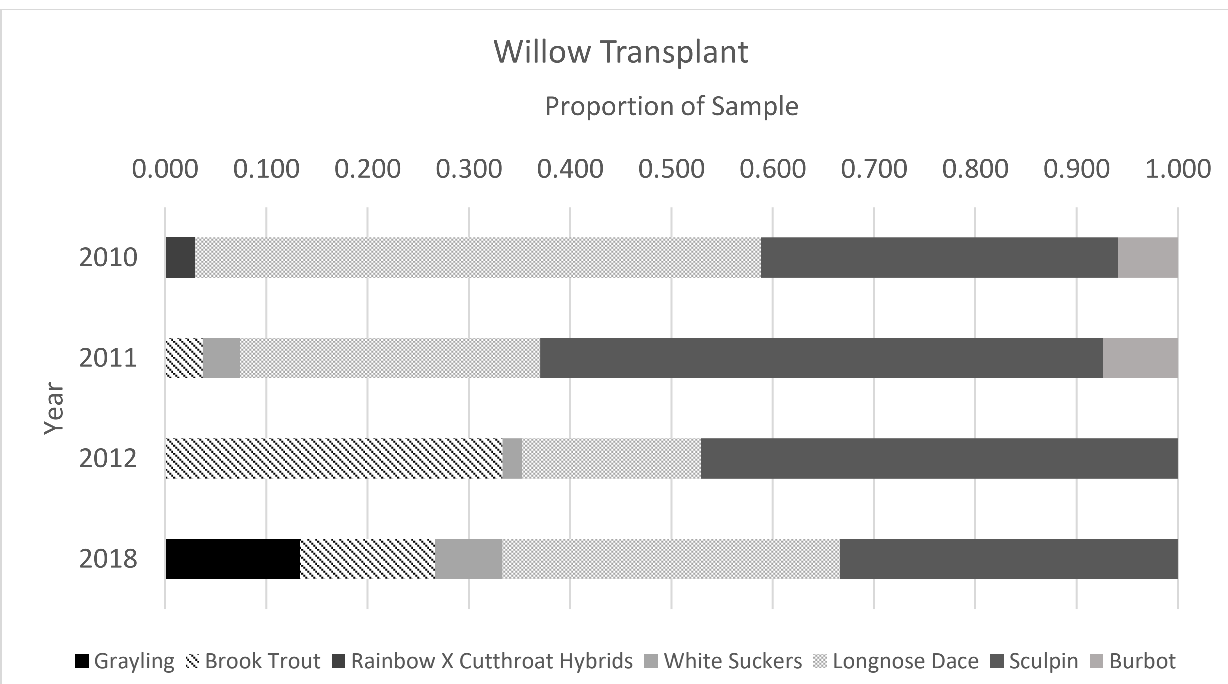

Figure 9. Long Creek Willow Transplant Section species composition from 2010-2018.

Grayling distribution in West and Middle creeks was assessed in 2017. West and Middle creeks offer potential spawning and temperature refugia for grayling in Lima Reservoir. An impassible headgate on Middle Creek and dewatering on West Creek presently disconnect portions of the streams; however, connectivity restoration efforts are underway. Backpack electrofishing occurred on West Creek from the North Valley Road to the Forest Service boundary and on Middle Creek from the confluence with West Creek to the Forest Boundary. Brook trout and sculpin were found throughout West and Middle creeks, but no grayling were captured. (Table 15).

Table 15. West and Middle Creek electrofishing surveys for grayling presence/absence.

Stream	Date	Section Length (mi.)	Grayling	Brook Trout	Rainbow x Cutthroat Hybrids	White Suckers	Sculpin
West	Jun-17	11.63	0	435	0	2	482
Middle	Jun-17	5.85	0	61	1	0	70

Irrigation ditches on West, Middle, and Long creeks were surveyed in 2016 and 2017 for entrained grayling to inform CCAA implementation. Entrainment occurs when grayling are trapped in ditches during irrigation season and are unable to return to the stream when irrigation ceases. Irrigation ditches were surveyed at the start and end of irrigation season by backpack electrofishing from the point of diversion to where defined channelized flow ceased. The number and length of ditches shocked varied due to survey timing and landowner water use (Table 16). No grayling were captured during entrainment surveys.

Table 16. Centennial Valley ditch monitoring for Arctic Grayling entrainment.

Stream Name	Date	Miles Electrofished	Number of Grayling
Long Creek Ditches	Jun-17	6.18	0
	Aug-17	2.62	0
	Jun-18	5.73	0
	Jun-18	2.49	0
West Creek Ditches	Jun-17	2.68	0
	Aug-17	2.52	0
	Jun-18	3.26	0
	Jun-18	0	0
Middle Creek Ditches	Jun-17	0.95	0
	Aug-17	1.99	0
	Jun-18	1.3	0
	Jun-18	0.14	0

Odell Creek: Odell Creek is a historic grayling spawning tributary that originates in the Centennial Mountains and flows ~12 miles into the southeast shore of Lower Lake. Spawning grayling were first reported in Odell Creek as early as 1906 and have been routinely observed throughout the last century (Gillin 2001). Historic threats to grayling spawning habitat in Odell Creek were sedimentation from land use on unstable soils, dewatering from irrigation, and beaver dams; however, riparian fencing and changes in water rights have reduced threats to Odell Creek. Fragmentation at beaver dams remain a potential threat to grayling, but Odell Creek is not currently prioritized for conservation actions. We conducted electrofishing surveys in Odell Creek that began at the South Valley Road and ended at the confluence with Shambow Creek, except the survey reach extended further downstream in 2016. The number of grayling captured decreased over the sampling period (Table 17); however, sampling efficiency also decreased as the presence of beaver dams increased. Sampling in 2016 was nearly impossible due to sampling inefficiency, therefore further sampling attempts have not been planned.

Table 17. Electrofishing sampling results of Odell Creek.

Sampling Date	Sampling Year	Number of Grayling Captured	Distance Shocked (miles)	Grayling CPUE (GR/mile)	Grayling Size Range (mm)
13-Jun	2012	34	1.4	24.29	376-434
5-Jun	2014	4	1.4	2.86	374-385
27-Jun	2016	1	1.79	0.56	376

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Appendix 1. RASS Descriptions and Feature Breakdowns

RASS stream features were separated into seven categories: natural barriers, manmade barriers, diversions, road crossings, miscellaneous land use, habitat, and fish and wildlife. Natural barriers included beaver dams, waterfalls, logjams, swamps, and cascades. Manmade barriers included impassible diversions, levees, perched/undersized culverts, and dewatering. Diversions were any form of irrigation diversion. Road crossings included culverts, fords, and bridges. Miscellaneous land use included fences, cattle grazing, cattle crossings, and water gaps. Habitat included good fish habitat, poor fish habitat, habitat changes, substrate type, tributary mouths, channel braids, riparian condition, and other various instream features. Fish and wildlife included observations of fry, number and species of fishes, and other wildlife.

Bean Creek (Figure 10): The East and West Fork of Bean Creek are located in forest areas and include good fish habitat. A potential low flow barrier exists at a culvert on the West Fork. The substrate in the Forks consists of gravel and cobble. The substrate changes once out of the forest to include more fines as cattle impacts become evident. The habitat becomes less suitable from the forest to the South Valley Road. Poor habitat and fine sediment characterize Bean Creek below the South Valley Road and the creek enters a pond at the lower end. Connectivity is good downstream until diversion systems below the pond cause dewatering issues.

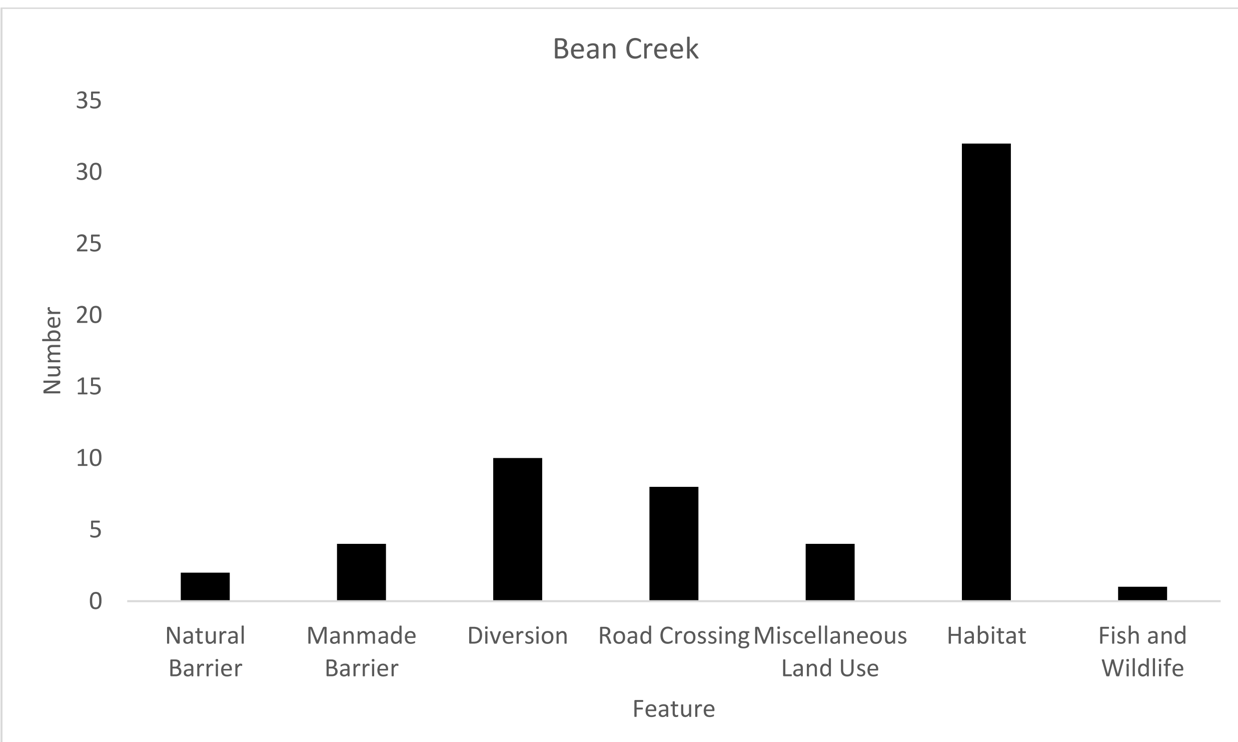

Figure 10. Bean Creek RASS features.

Bear Creek (Figure 11): Bear Creek is characterized by steep gradient, log jams, cascades, and cobble in the upper forested sections. Suitable fish habitat exists in the forested section and better fish habitat occurs when the gradient levels and the stream become more sinuous. Bear Creek enters a tight canyon and habitat resembles the upper section. Eroded banks, silted gravels, and channel widening begins at the forest boundary where cattle grazing occurs. Poor habitat and turbid water occurs when the creek reaches an undersized culvert at the South Valley Road. Flood irrigation complete dewaters the stream below the road.

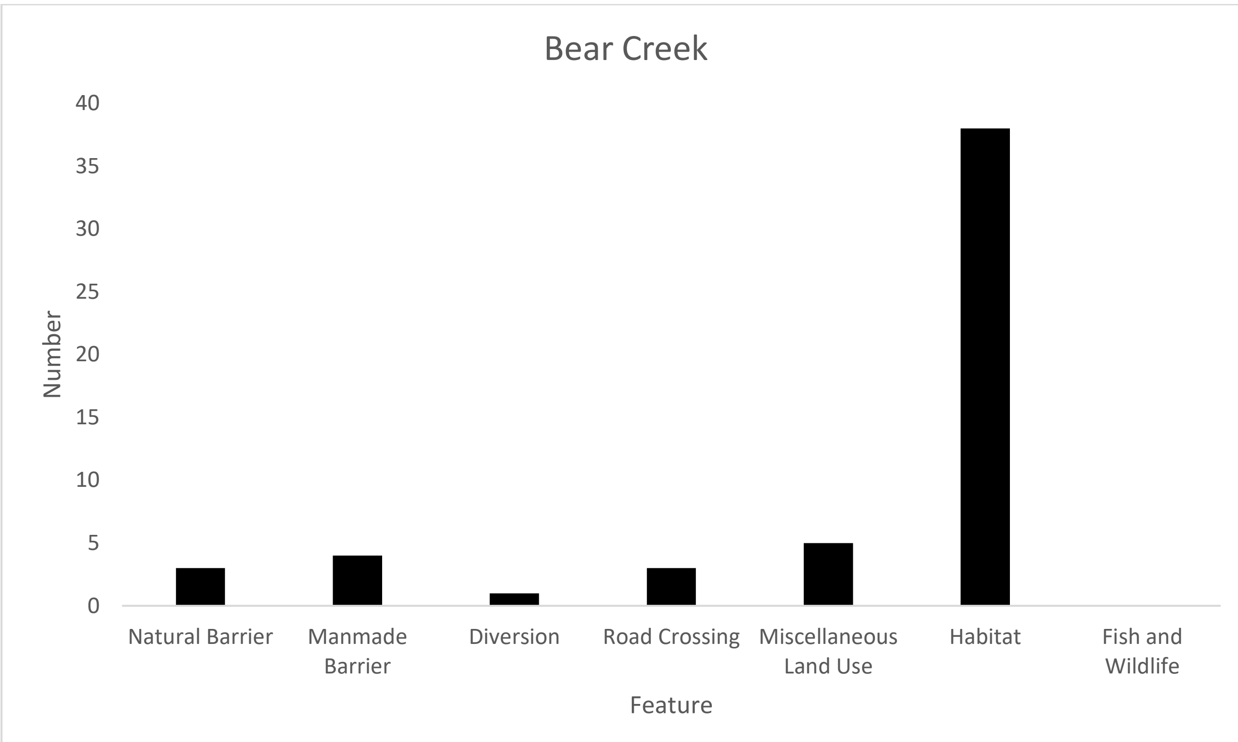

Figure 11. Bear Creek RASS features.

Clover Creek (Figure 12): The upper sections of Clover Creek are high gradient with good riparian areas, gravels, and a Westslope cutthroat population present. The lower portion of East Fork Clover Creek becomes more sinuous with good habitat and riparian buffers except within grazing areas. Grazing, beaver activity, and irrigation effects are more evident below the East Fork confluence. Silting problems and diversions continue throughout the stream to the mouth except for small areas of better habitat in fenced off areas below the road.

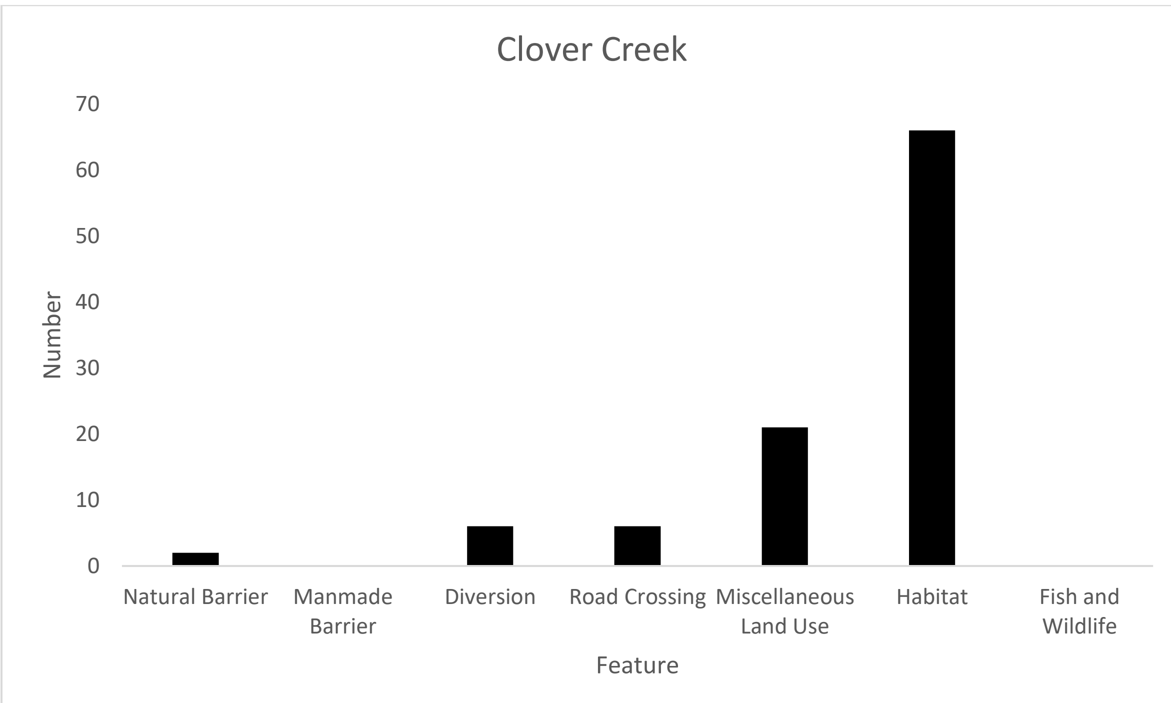

Figure 12. Clover Creek RASS features.

Curry Creek (Figure 13): Curry Creek is characterized by high gradient flows with cascades and abundant woody debris in the upper section. The section represents a natural stream with a healthy riparian area. However, high flow velocities and lack of pools in the upper section offer poor fish habitat. Moderate erosion and high banks occurs as the creek enters a burn area above the South Valley Road; however, habitat slightly improves below the road. Declines in habitat occur from erosion near a fence and riprap banks around a bridge. A natural barrier occurs when the channel ceases in a swamp.

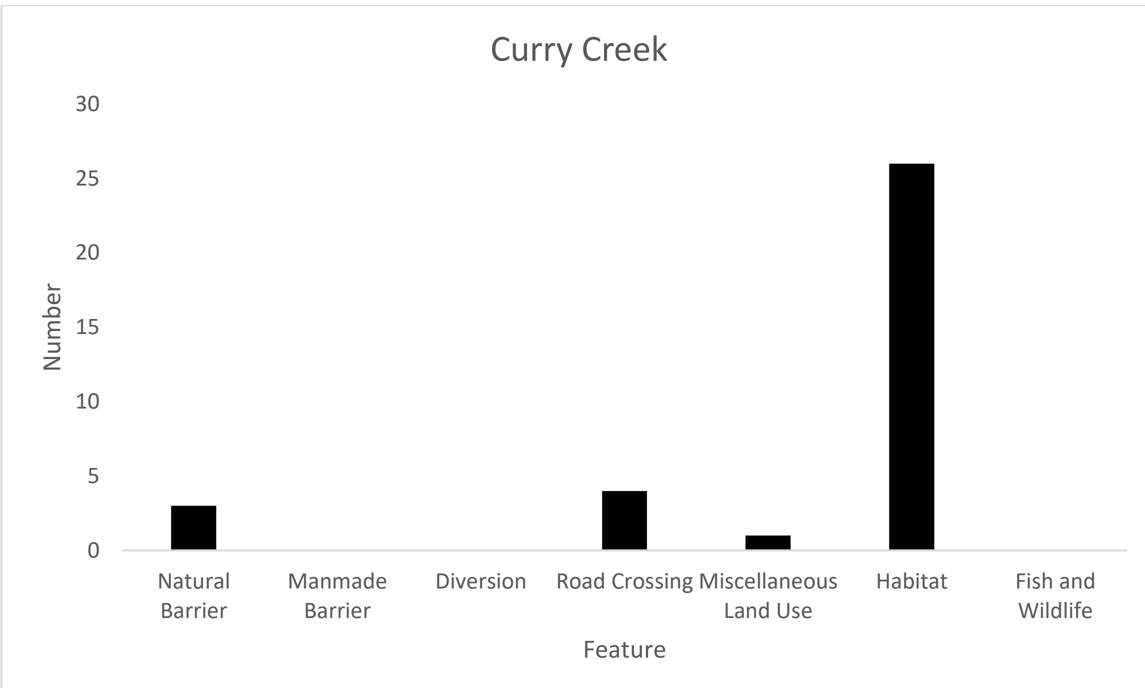

Figure 13. Curry Creek RASS features.

East Shambow Creek (Figure 14): RASS surveying began at the Shambow Pond levee which is a potential fish barrier. East Shambow Creek below the levee is characterized by good willow riparian and beaver activity. The beaver dams create good pool habitat where fish were observed. However, fine substrates from beaver dams result in poor spawning habitat. Good pool habitat continues until the willows end and the channel widens near the mouth of the creek at Upper Lake.

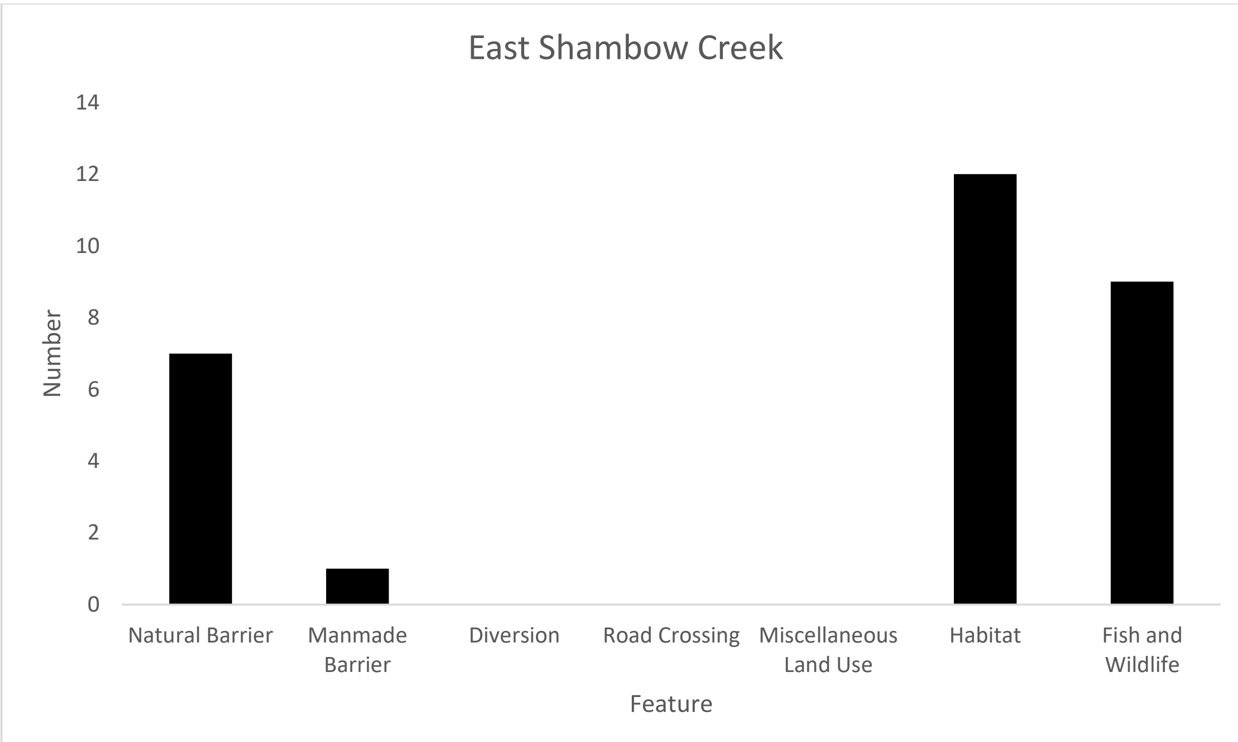

Figure 14. East Shambow Creek RASS features.

Elk Springs Creek (Figure 15): Elk Springs Creek originates in a grass choked channel flowing through dense willows. The channel flow and depth increases from seep tributaries. Elk Springs Creek is a continuous, shallow riffle through a grassy floodplain before it widens at the Old McDonald Pond culvert which is a potential barrier to upstream fish passage. Elk Springs Creek widens and shallows with poor substrate below the culvert. The channel gains sinuosity with deep pools on outside bends and cattle impacts become evident before the creek enters Swan Lake. The channel is uniform between Swan Lake and the mouth at Upper Lake.

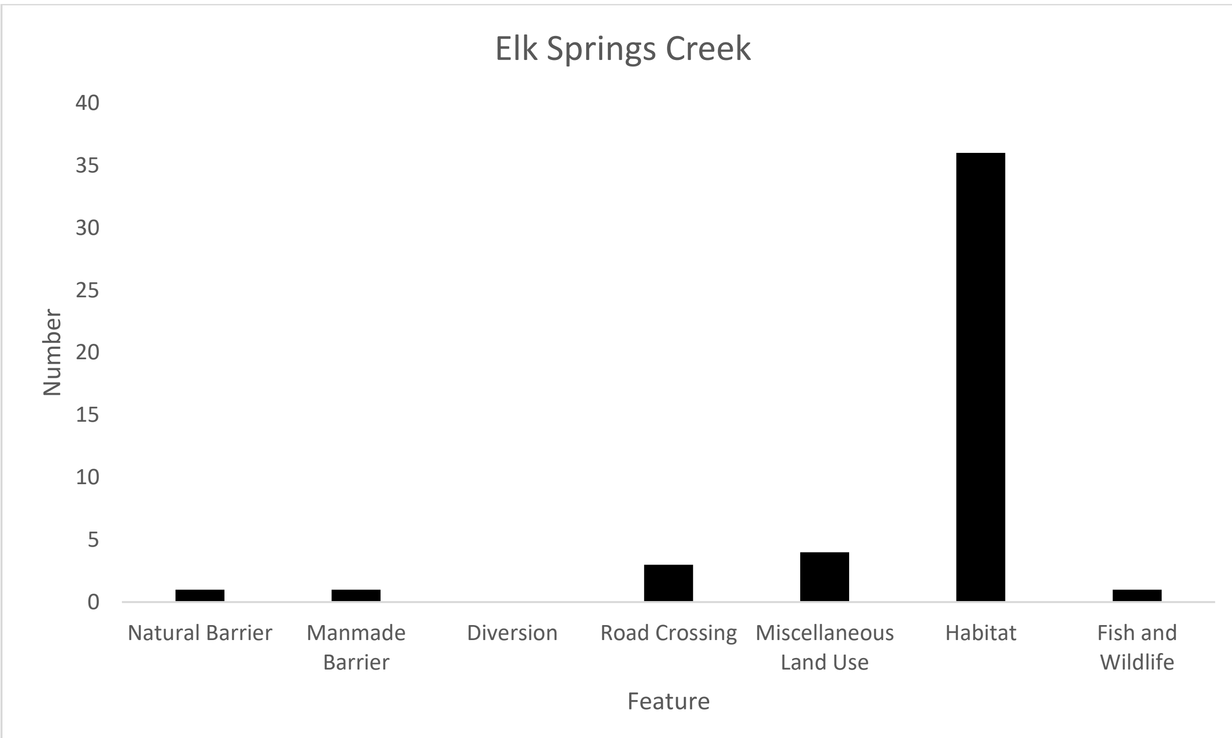

Figure 15. Elk Springs Creek RASS features.

Grayling Creek (Figure 16): Grayling Creek is formed by several springs and the channel quickly becomes wide and deep. A series a beaver dams and ponds are present on Grayling Creek. Potential spawning gravel exists between the beaver complex and a road culvert. Grayling Creek becomes sinuous, macrophyte choked, and silted from beaver activity as it flows through a grassy, willow floodplain. Undercut banks and better spawning habitat are present near the mouth of Grayling Creek.

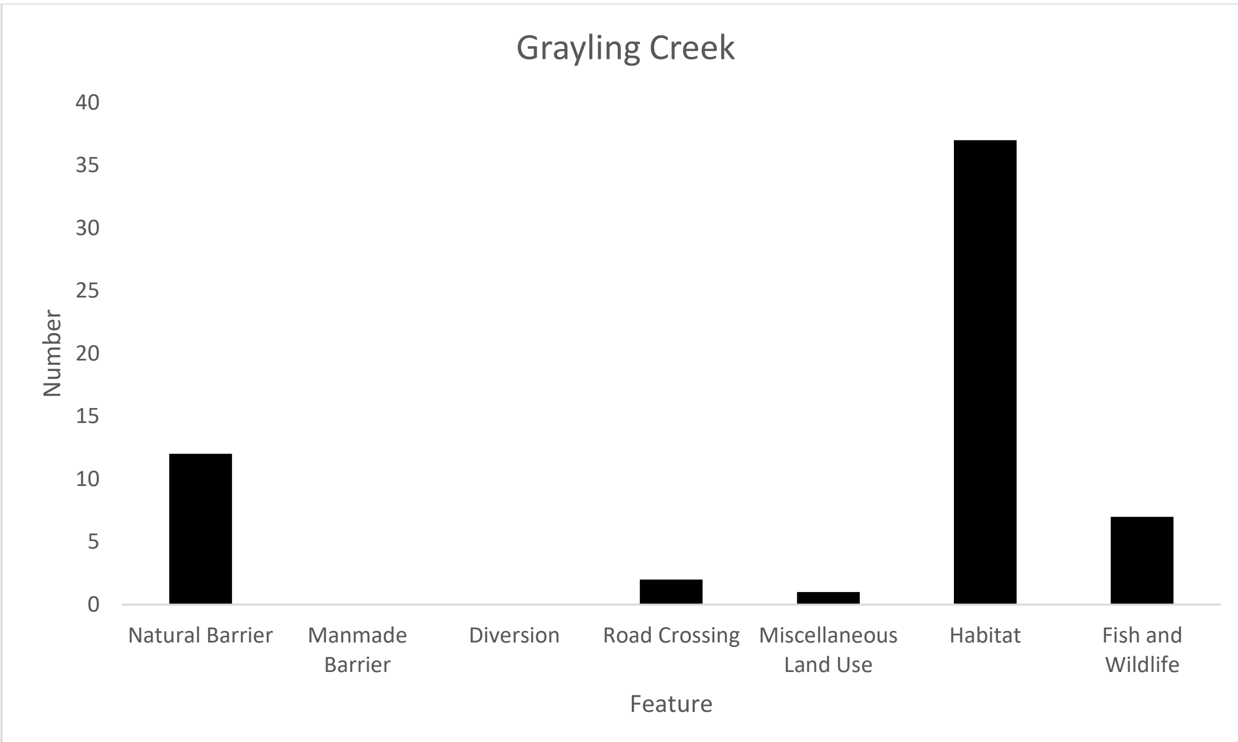

Figure 16. Grayling Creek RASS features.

Hell Roaring Canyon Creek (Figure 17): The upper, forested section of Hell Roaring Canyon Creek is high gradient with cobble substrate and good riparian habitat. The sections provides good spawning habitat. Side channels are present with some bank erosion before Hell Roaring Canyon Creek enters two culverts at the South Valley Road. Willow transplants, cobble substrate, and good pool habitat are present downstream of the road. Several inactive irrigation headgates exist below the road which don't present a threat to connectivity. The channel has a higher gradient with riffle-pool habitat before it enters a riprap bank stretch. Hell Roaring Canyon Creek becomes sinuous with gravel and silt substrate after the riprap bank. High eroded banks and a tributary confluence occur before the mouth at Red Rock Creek.

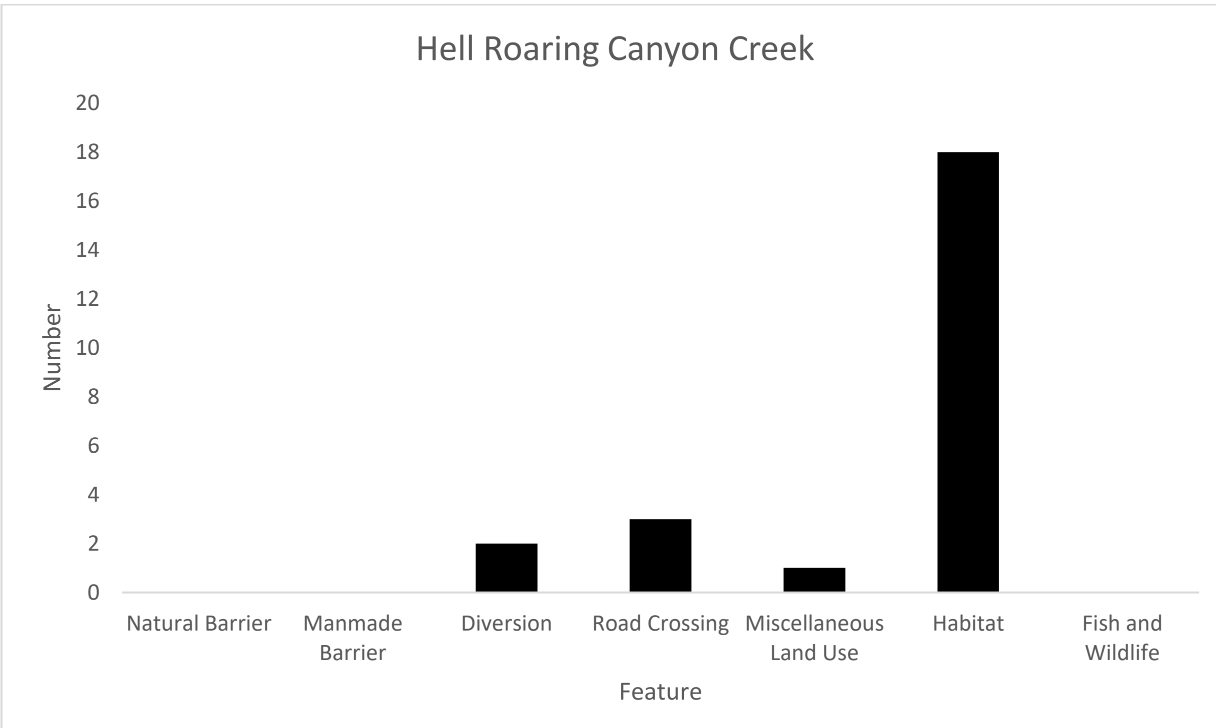

Figure 17. Hell Roaring Canyon Creek RASS features.

Long Creek (Figure 18): The upper portion of Long Creek is characterized by high amounts of beaver activity, high sedimentation, good riparian, and multi-channel habitat. The riparian and stream habitat quality varies between good and okay downstream and some beaver dams are potential barriers in low flows. Good habitat continues downstream but impacts of cattle grazing and headgates becomes evident. Riparian habitat improves on the TNC section of Long Creek and good spawning and pool habitat are present. The lower section before the mouth is characterized by high amounts of erosion, no riparian, and some pool habitat.

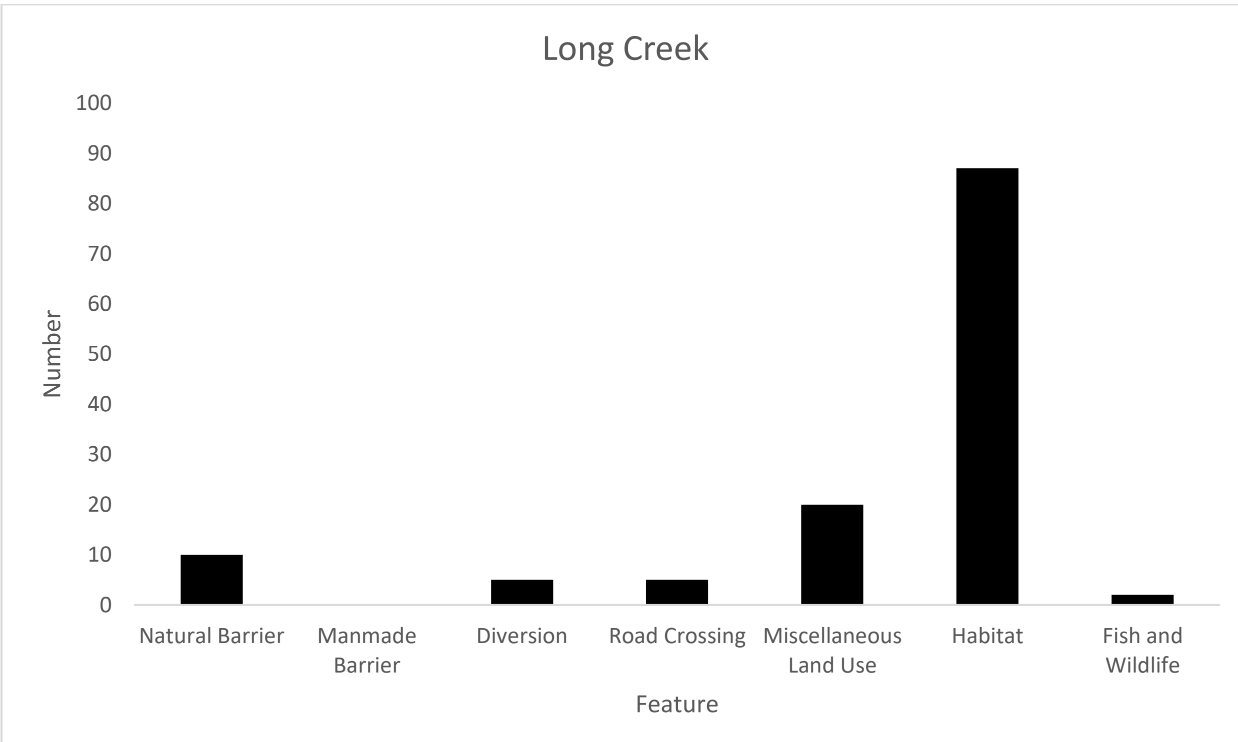

Figure 18. Long Creek RASS features.

Metzel Creek (Figure 19): The upper portion of Metzel Creek flows slightly sinuous through a grassy floodplain. The upper portions has a good riparian area; however, instream fish habitat is poor. An irrigation diversion and an undersized culvert are potential threats to fish movement in upper Metzel Creek. Metzel Creek becomes wide and shallow with bank erosion, undercut banks, and silt substrate below the North Side Road. The channel begins to narrow before it flows into Upper Lake.

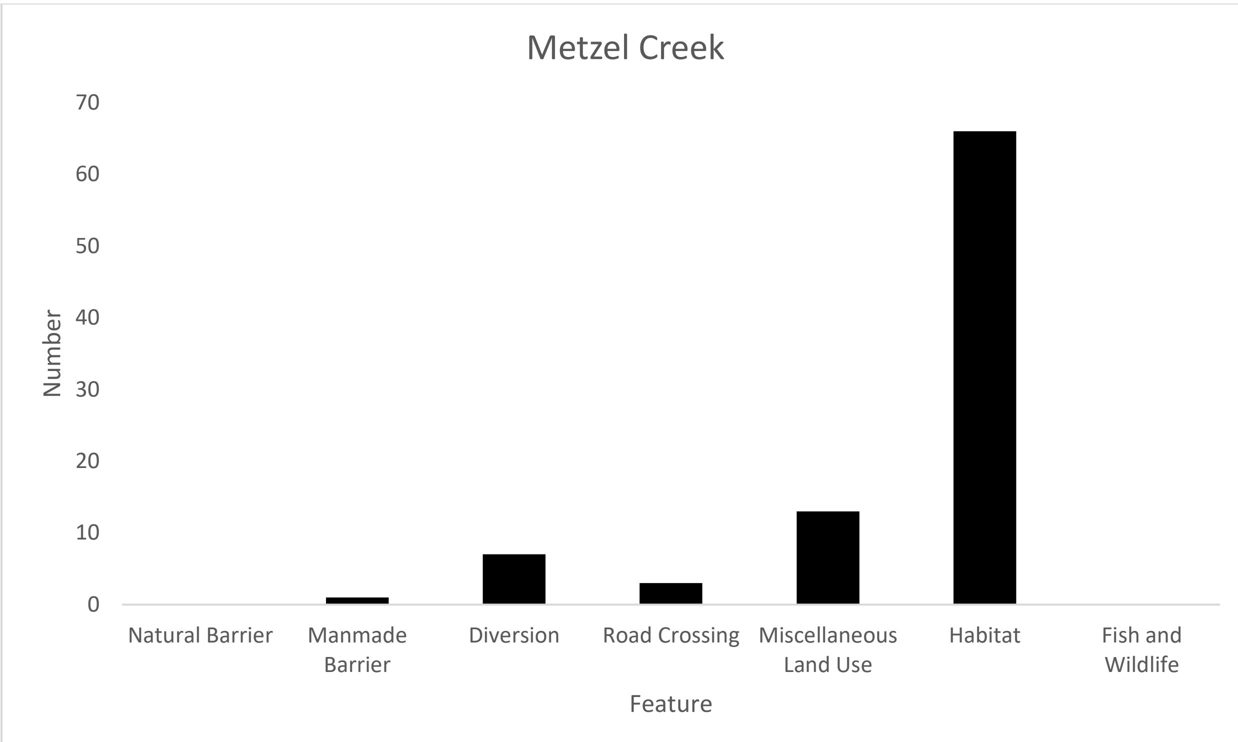

Figure 19. Metzel Creek RASS feature.

Middle Creek (Figure 20): The upper, forested section of Middle Creek is characterized by a high gradient and large woody debris. The gradient and wood create several cascades and drop pools that are potential fish barriers. The fish habitat is okay and there is no gravel for spawning. The habitat between the forest and the mouth has good fish habitat and riparian areas except for areas with cattle impacts. The lower section has some beaver activity and several irrigation diversions could result in low stream flows.

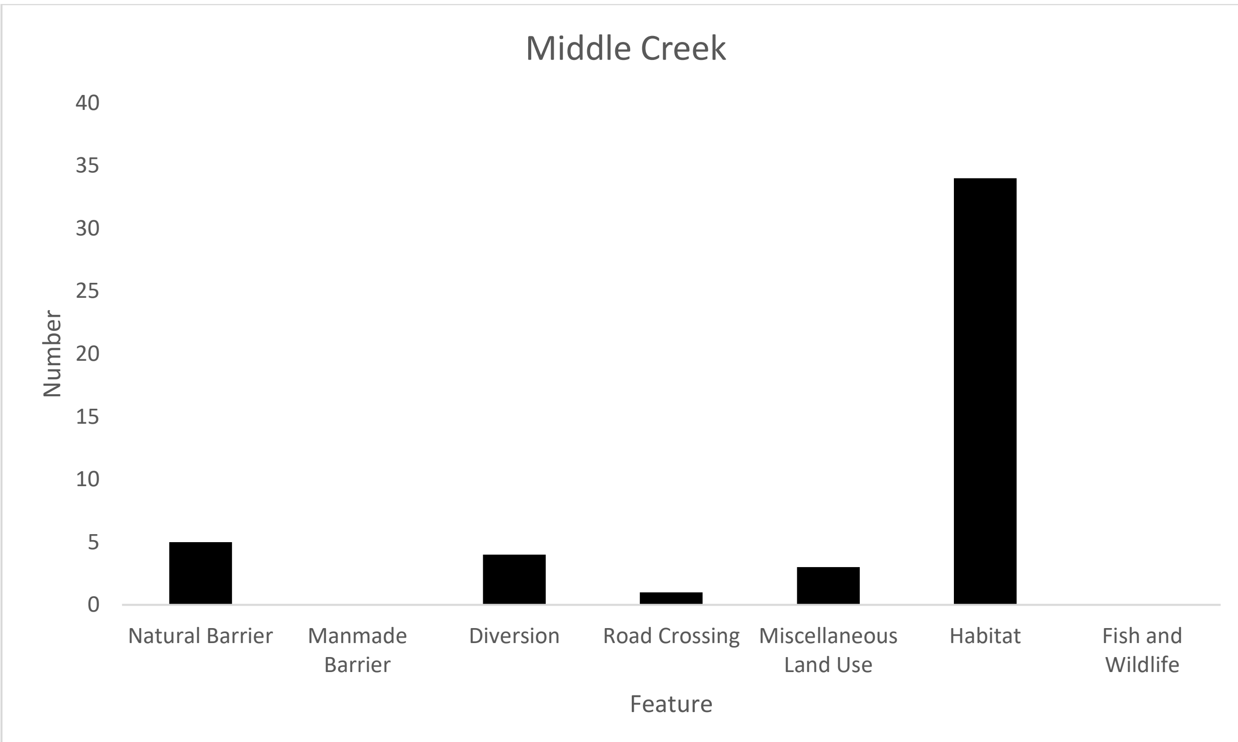

Figure 20. Middle Creek RASS features.

Narrows Creek (Figure 21): The upper and lower section of Narrows Creek are separated by a pond. The upper section is small with a good willow riparian habitat. The substrate contains gravel and cobble and woody debris is found in the creek. Habitat is similar in Narrows Creek just below the pond. Flows become subsurface in several spots which present a natural fish barrier. The creek flows out of the forest and through a culvert. The gradient decreases below the culvert. The riparian area transitions from willow to sedges and grasses in the lower section. The creek widens, flows decrease, and instream grasses are present near the mouth at Elk Lake.

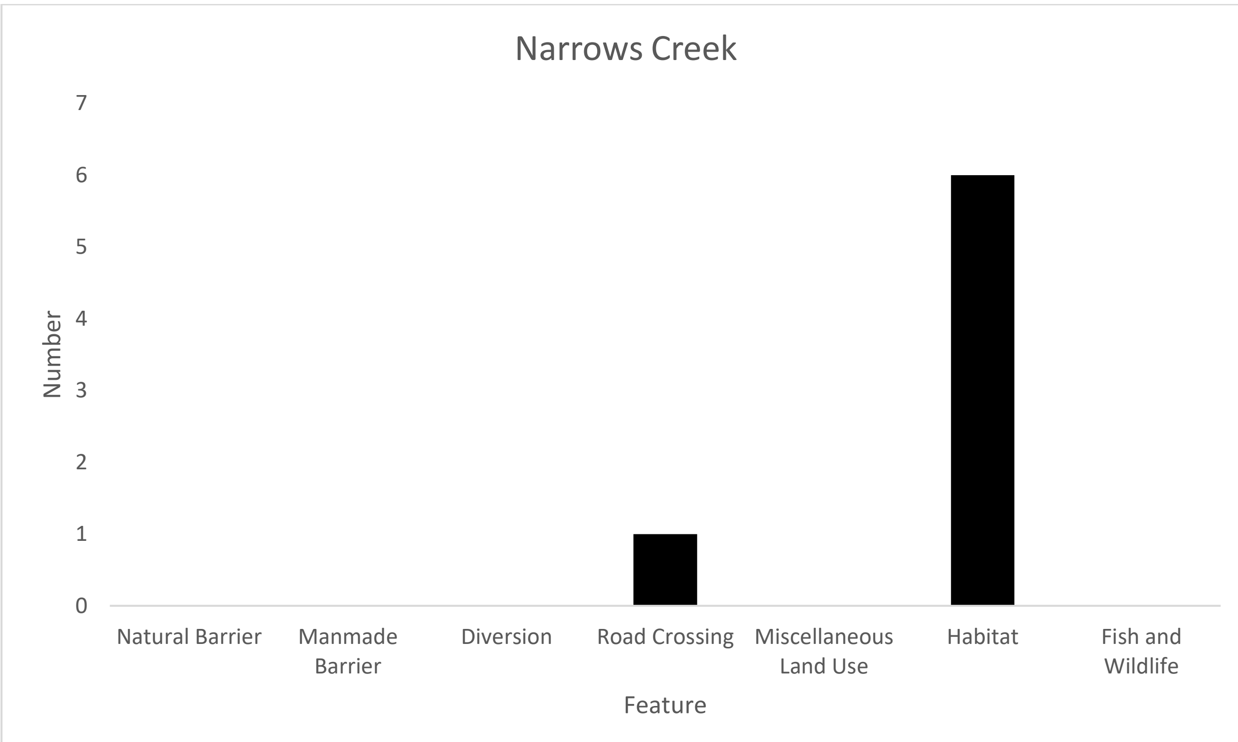

Figure 21. Narrows Creek RASS features.

Odell Creek (Figure 22): Odell Creek is formed by the East, Middle, and West Fork in forested habitat. The East Fork originates from a pond system at the headwaters where the substrate is silted in. The channel is small downstream near the mouth and the substrate changes to cobble. The Middle Fork is formed by a series of spring heads and is characterized by good gravel and woody debris. The West Fork has high gradient, braided channels with woody debris and cobble substrate. The high gradient and wood form drop pool habitat that are potential barriers. The Main Fork of Odell Creek is characteristic of high gradient, forested streams with primarily riffle and cobble habitat. Several small mountain streams, Lake Fork and Spring Creek, enter before Odell Creek exits the forest. The channel is similar to upstream with cobble and riffle habitat until it reaches the borrow pit of the South Valley Road. Flows are contained in the borrow pit for ~100 yards before riprap banks direct flow through a bridge. Odell Creek is sinuous with bank erosion, good gravels, and some willow riparian habitat below the road. The channel becomes wide, flat, and silty prior to reaching the delta at Lower Lake.

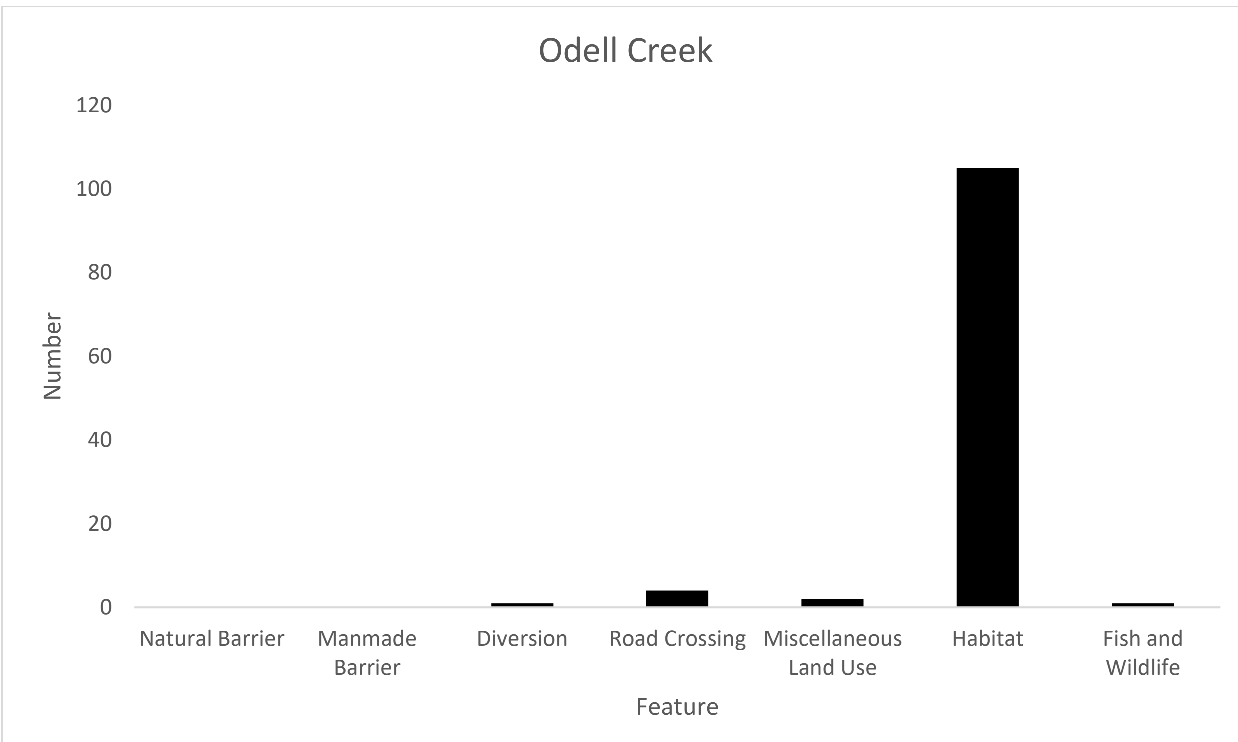

Figure 22. Odell Creek RASS features.

Peet Creek (Figure 23): The Middle Fork of Peet Creek is high gradient with cobble substrate, cascades, and good pools. Riparian and fish habitat in the Middle Fork are good. The West Fork of Peet Creek has similar characteristics and forms the main stem of Peet Creek at the confluence with the Middle Fork. The main stem has good riffle-pool habitat with cobble and gravel substrate. Cattle impacts result in erosive banks, silty substrate, and poor habitat downstream before the creek enters a pond. Peet Creek pours out of an impassable culvert and the East Fork of Peet Creek, which has good fish habitat that is threatened by erosions from cattle impacts, enters the stream. Peet Creek has good riffle-pool habitat in a willow corridor below the confluence with the East Fork. Peet Creek becomes wide and shallow when it leaves the willow corridor. The creek enters a series of irrigation diversions and a culvert at a road. The channel tightens up through a grassy meadow where cattle impacts are present before it enters another pond.

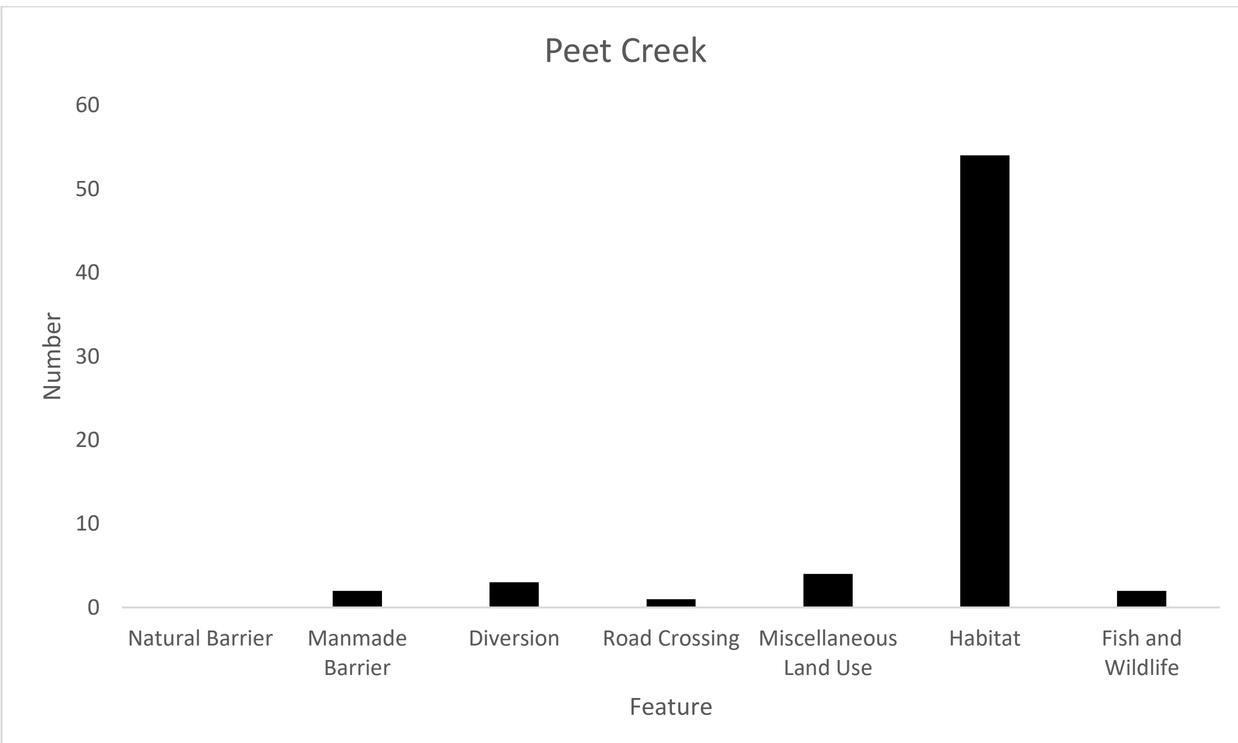

Figure 23. Peet Creek RASS features.

Picnic Creek (Figure 24): Picnic Creek begins at the culvert outlet of Culver Pond. The upper section has good spawning, riparian, and pool habitat. The habitat changes downstream to be more sinuous with smaller substrate. The channel becomes wider and shallower with macrophyte beds growing on the stream bottom. Picnic Creek gains velocity, tightens, and deepens with increased willow density, and larger substrate size before it enters Widgeon Pond. Picnic Creek is sinuous and silted in between Widgeon Pond and its confluence with Elk Springs Creek.

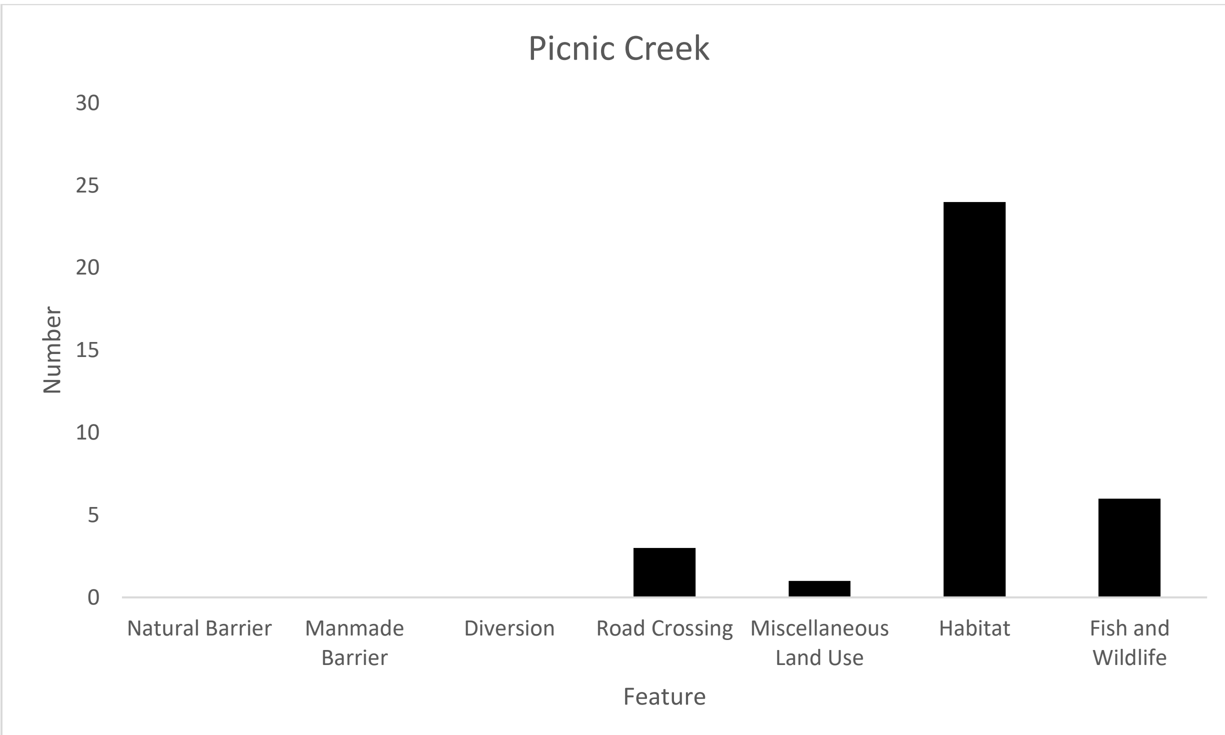

Figure 24. Picnic Creek RASS features.

Price Creek (Figure 25): The Upper end of West Fork of Peet Creek has two culverts that are potential barriers. The West Fork flows with high velocity through an open forest and habitat consists of cobble, woody debris, and plunge pools. The channel becomes wider with smaller substrate and some erosion as it flows towards a meadow. The channel narrows as the West Fork flows through the meadow. Erosion arises before the confluence with the East Fork. The East Fork of Price Creek consists of riffle-pool habitat with good spawning and willow riparian habitat. Erosion from cattle is present in some areas before the stream enters a series of beaver dams and ponds. The East Fork and West Fork confluence forms Price Creek. The main stem is sinuous through willows with a cobble and sand bottom. High, eroded banks are present on the outside bends. Price Creek flows through a large culvert and is diverted by a series of old headgates. The substrate transitions to silt as the channel splits and meets culverts at the South Valley Road.

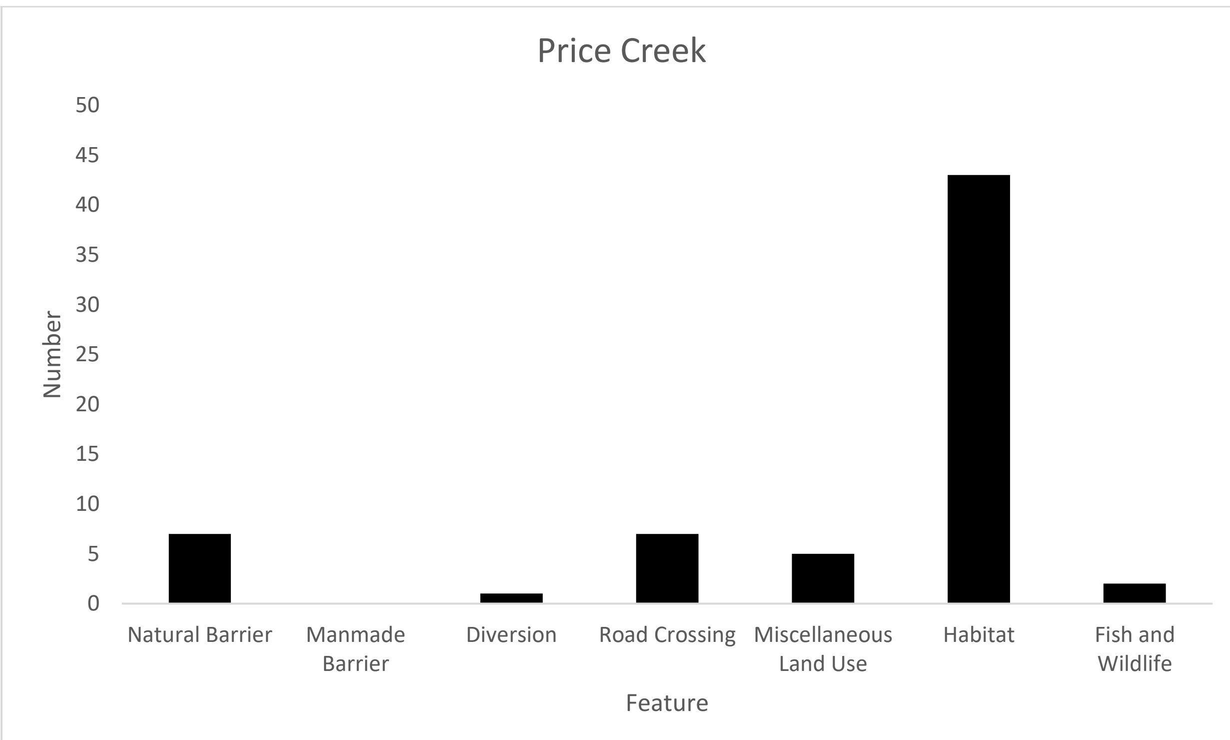

Figure 25. Price Creek RASS features.

Red Rock Creek (Figure 26): Red Rock Creek has some silt deposition on wide outside bends and bank erosion near the mouth of Corral Creek. The riparian is good throughout the upper sampling reach. The channel transitions to and maintains riffle-pool habitat with good spawning through a long stretch downstream. Outside bend erosion and inside bend silt deposition occur as the river flows further downstream. Red Rock Creek flows into a series of beaver dams. The beaver dams are natural barriers to fish movement and cause siltation of the streambed. Spawning gravels and riffle-pool habitat return downstream of the beaver activity. High bank erosion is common on outside bends as the creek moves downstream. Erosion continues and fines are deposited on wide outside bends and several instream bars on the lower stretch of Red Rock Creek. Lower Red Rock Creek has several beaver dams with high bank erosion between dams that lead to excessive sedimentation. Similar habitat continues until the mouth at Upper Lake.

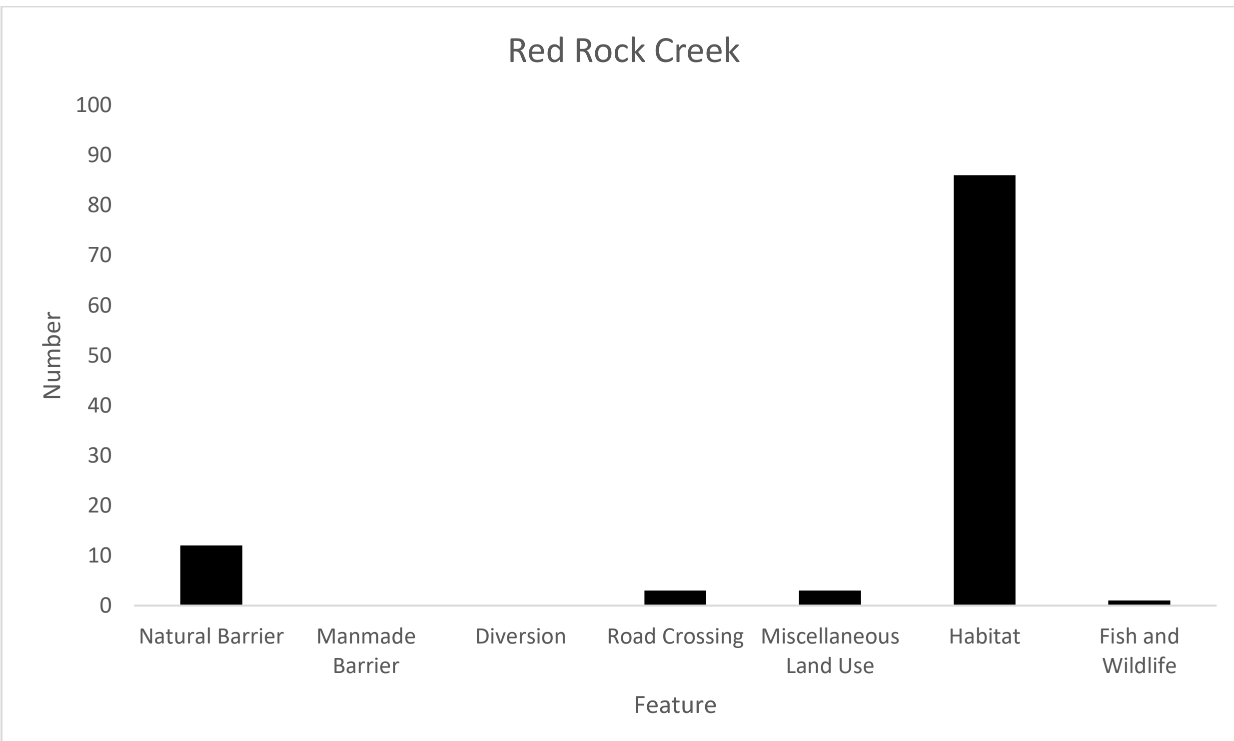

Figure 26. Red Rock Creek RASS features.

Red Rock River (Figure 27): Red Rock River flows through a dam structure on Lower Lake. The dam structure is not a barrier as it allows fish passage. Red Rock River is wide with no fish habitat. The riparian area consists of sedges, grasses, and bare banks. Erosion is prevalent on Red Rock River with numerous high cut banks. Sand and silt substrate is a result from erosion and low flow velocities. Cattle impacts and fence lines are common on Red Rock River. Limited riffle and pool habitat is available and channel uniformity occurs in most sections. The river has little to no fish habitat; however, it provides good connectivity for fish movement.

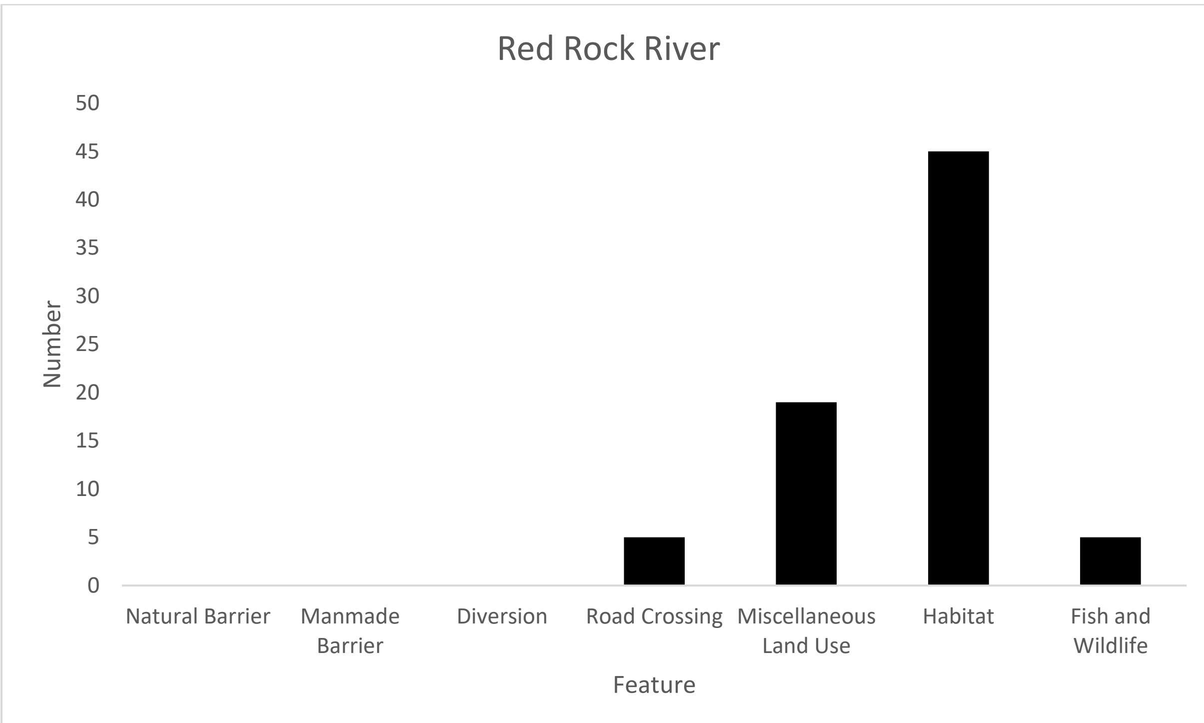

Figure 27. Red Rock River below Lower Red Rock Lake RASS features.

Shambow Creek (Figure 28): The upper section of Shambow Creek is a high gradient riffle with cobble substrate and the riparian consists of willows and sedges. A few pools exist downstream before the channel widens and escapes its banks. Shambow Creek enters a culvert that is a potential velocity barrier. The channel is more sinuous and fewer willows lead to eroding banks after the culvert. Bank stabilization increases as Shambow Creek enters a steep banked willow corridor. As the banks level out, the creek has a lower gradient, some spawning gravel, and good pool habitat until it flows into Odell Creek.

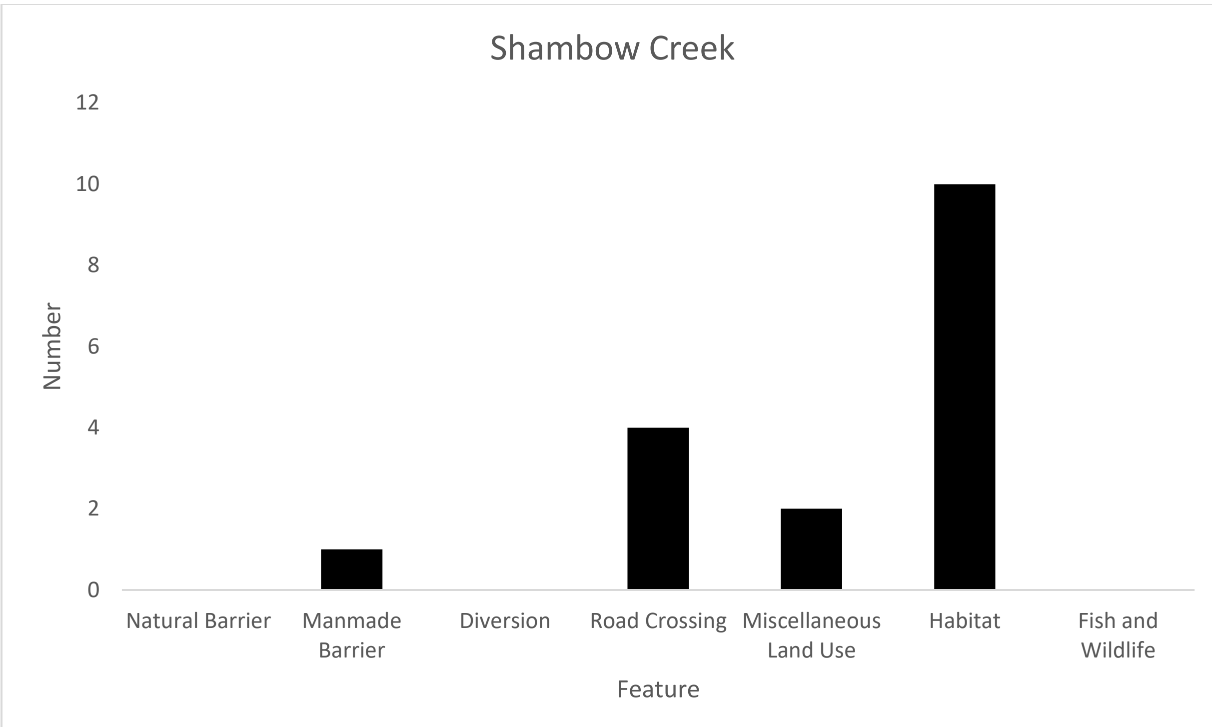

Figure 28. Shambow Creek RASS features.

Tom Creek (Figure 29): RASS surveys began where Tom Creek flows through an adequately sized culvert at the South Valley Road. Tom Creek has a straight channel with cobble/gravel substrate and a mature willow riparian. The channel leaves the willow riparian and becomes more sinuous. The substrate remains cobble/gravel and erosion starts on outside bends. Tom Creek flows back into a willow riparian where a beaver dam complex is located. The beaver dam complex is a barrier to fish movement and forms a sediment covered stream bottom. The channel exits the beaver complex and is characterized by good riffle-pool, spawning, and riparian habitat. Tom Creek straightens out through a sedge meadow and becomes deeper with a thick silt bottom. Tom Creek splits into multiple channels as it enters a marsh area prior to Upper Lake.

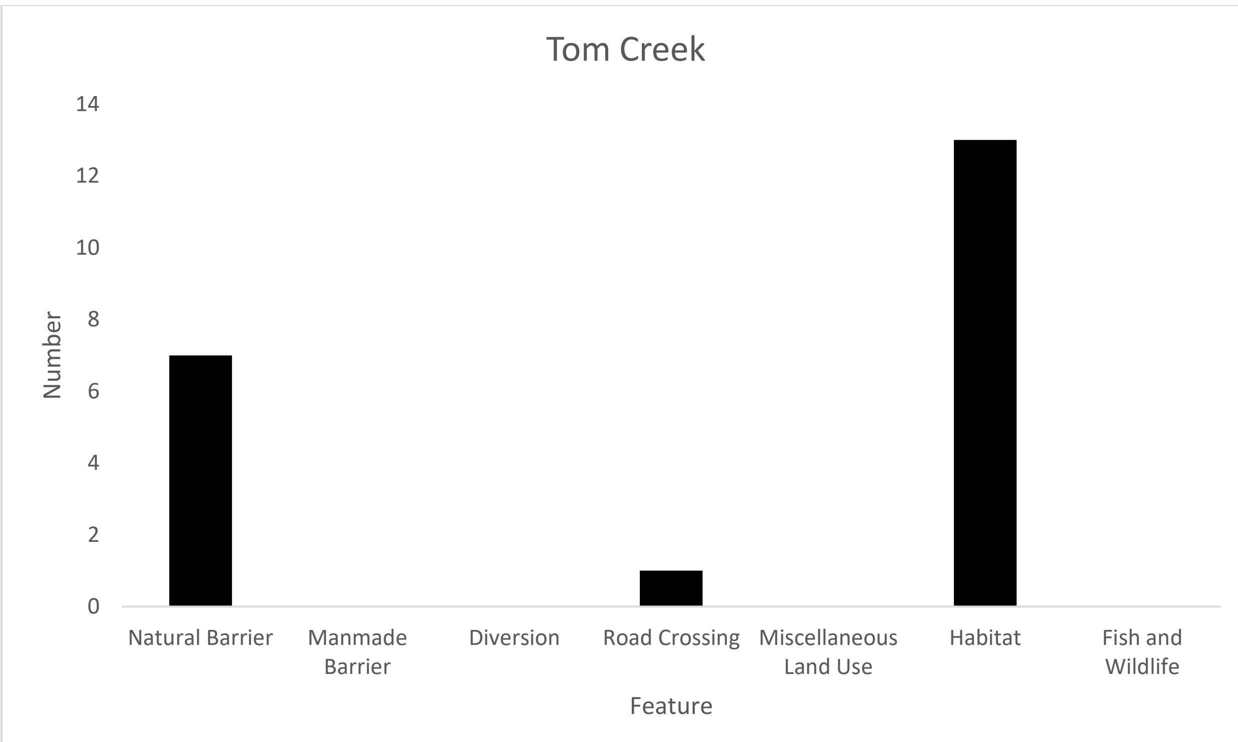

Figure 29. Tom Creek RASS features.

West Creek (Figure 30): The upper section of West Creek is high gradient through a willow riparian and contains large substrate. Several blown out beaver dams are present on the upper section. Gradient deceases as the stream flows downstream and spawning gravels become available. West Creek enters a series of diversion structures as it moves into pasture areas. The fish and riparian habitat remain good between diversion structures. The channel splits for a short distance and cattle impacts become evident. West Creek goes through an undersized culvert and good riffle-pool habitat begins. An irrigation diversion diverts most of the water from West Creek into a system of ditches. West Creek has little flow as it meanders through a grassy pasture. Erosions and stream widening from cattle is located in several spots before West Creek regains flow from the confluence with Middle Creek. Riffle-pool habitat with bank erosion is typical below the confluence. Several blown out beaver dams are located on the lower section of West Creek. The channel becomes more sinuous with less gradient and high, eroded banks as it nears the North Valley Road culvert, where flow is backed up.

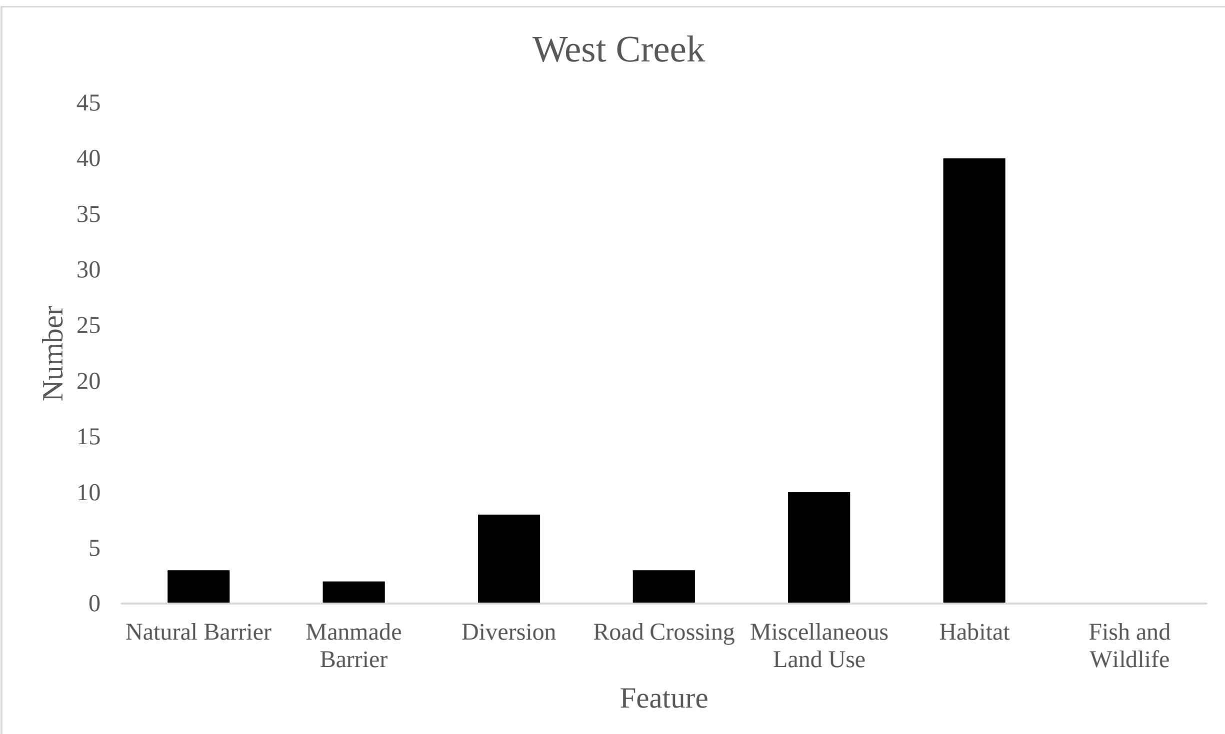

Figure 30. West Creek RASS features.

Winslow Creek (Figure 31): Lower Winslow Creek flows out of a levee that disconnects the creek. The channel sinuously flows through a grassy valley bottom. The banks are high and eroding from cattle impacts. The stream bottom is sediment covered with abundant macrophytes growing instream. Winslow Creek flows into Red Rock River; however, upstream irrigation in dry years could lead to dewatering.

Figure 31. Winslow Creek RASS features.

The raw RASS data has been compiled with photos and can be made available by contacting the Montana Fish, Wildlife, and Parks Dillon Field Office by phone at (406)-683-9310 or by email mattjaeger@mt.gov.

Appendix 2. Spawning model details: Our goal was to develop a predictive model that would inform management decisions regarding the timing of the electroshocking effort in Red Rock Creek in the absence of the fish weir. We used data from 2016 and 2017 to fit a Poisson regression model wherein the number of fish in the trap on day *t* in year *y* ($F_{t,y}$) was modeled as:

$$\mathrm{F}_{t,y} \sim \mathrm{Poisson}(\lambda_{t,y}),$$

where the expected number of fish in the trap, λ_t, was a modeled as a function of covariates using a log link:

$$\log(\lambda_{t,y}) = \alpha + \beta_{doy}(\mathrm{doy}_{t,y}) + \beta_{doy^2}(\mathrm{doy}^2_{t,y}) + \beta_{dis}(\mathrm{dis}_{t-1,y}) + \beta_{dis^2}(\mathrm{dis}^2_{t-1,y}) + \beta_T(\mathrm{T}_{t-1,y}) + \log(N_y),$$

with doy_t corresponding to the day of the year, dis_{t-1} corresponding to the mean discharge (cfs) the previous day, and T_{t-1} corresponding to the mean stream temperature (F) the previous day. Day of the year, discharge and temperature were first centered using day 130, 50 cfs, and 50 F prior to model fitting. Importantly, this is a panel approach to model estimation wherein the regression coefficients were shared between years (only the offset, N, was different), such that regression coefficients represent the average effect across years.

To complete the model specification, we used vague priors for all regression coefficients (Normal(μ = 0, σ^2 = 1000)) on the log scale. The model was fit using the package runjags (Denwood 2016) as the interface to JAGS 4.3.0 (Plummer 2017) in the R programming environment (R Core Team 2019). The MCMC algorithm was run for 50,000 iterations, the first 10,000 of which were discarded as burn-in. Convergence to the approximate posterior distribution was graphically assessed using traceplots. A simplification of the model statement in the JAGS language is given below.

```
model{
  for (i in 2:length.2016){
    log(lambda.2016[i]) <-  int + b_discharge*discharge.2016[i-1] +
b_discharge_sq*(discharge.2016[i-1]^2) + b_temp*temperature.2016[i-1] + b_doy*doy.2016[i] +
b_doy_sq*(doy.2016[i]^2) + log(offset.2016)
    counts.2016[i] ~ dpois(lambda.2016[i] )
  }
for (i in 2:length.2017){
    log(lambda.2017[i]) <-  int + b_discharge*discharge.2017[i-1] +
b_discharge_sq*(discharge.2017[i-1]^2) + b_temp*temperature.2017[i-1] + b_doy*doy.2017[i] +
b_doy_sq*(doy.2017[i]^2) + log(offset.2017)
    counts.2017 [i] ~ dpois(lambda.2017 [i] )
  }
int ~ dnorm(0, 0.001)
```

```
b_doy ~ dnorm(0, 0.001)

b_doy_sq ~ dnorm(0, 0.001)

b_discharge_sq ~ dnorm(0, 0.001)

b_discharge ~ dnorm(0, 0.001)

b_temp ~ dnorm(0, 0.001)

}
```