Survey of Fishes and Habitat of South Boulder Creek, Colorado, within City of Boulder Open Space and Mountain Parks Property

A Final Report

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EXECUTIVE SUMMARY

South Boulder Creek on City of Boulder Open Space and Mountain Parks property was surveyed in 2015-2016 to determine composition and patterns of distribution and abundance of fish. Stream discharge, water temperatures, and habitat were characterized at streamwide and site specific scales to identify factors limiting the fish community, and results were compared to the initial study of similar scope completed in 1996 by Bestgen and Kondratieff to assess changes that have occurred over the past 20 years.

Seven native and eight non-native species were collected in 29 samples at 15 sites during 2015 – 2016 sampling of South Boulder Creek. Native species were generally sporadic, less abundant than non-native species, and comprised 18.1% of total fish abundance across sites. This is a dramatic shift from 1996, where more than 80% of all fish collected were native taxa. Dominance of the fish community by non-native species was mainly due to the expansion and increased abundance of brown trout which accounted for 58.6% of all fish captured.

Native species were most common in more downstream reaches of South Boulder Creek, predominantly located between South Boulder Road and just downstream of Arapahoe Road. These species were most commonly associated with warmer water temperatures, backwater or off-channel habitat, and in proximity to complex microhabitat such as submerged vegetation or woody material.

The 2013 Colorado Front Range Flood may have affected the fish community and stream habitat of South Boulder Creek in several ways including mortality or displacement of fish, colonization of downstream reaches by non-native brown trout, scouring and removal of fine sediment, and alteration of local habitat features. Continued monitoring of South Boulder Creek is recommended in order to better define community dynamics and factors affecting the fish community and stream habitat.

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INTRODUCTION

Baseline survey data that describe species composition and relative abundance of aquatic biota and habitat conditions are necessary to assess the current status and health of an ecosystem. Survey data collected in a consistent manner over a long period (bio-monitoring) are necessary to determine if changes are occurring in biota relative to anthropogenic or natural changes in habitat or expansions and invasions by non-native fishes. Fishes are thought to be good indicators of the relative health of an aquatic ecosystem because they integrate effects of both site and watershed conditions and the magnitude of detrimental impacts may be manifest in the composition and abundance of these taxa. Alternatively, improvements in habitat quantity or quality, which include changes in water quantity and quality or improvements to stream passage, may benefit biota in streams. Species introductions and interactions may also affect community composition over time.

Assessments of fish, aquatic insects, and limited water quality parameters were made during a study conducted in South Boulder Creek in 1994 – 1995 (Bestgen and Kondratieff 1996). They concluded that at least three and perhaps as many as nine native fishes had been extirpated from South Boulder at the time of their study. Loss of nine native species constitutes a 50% reduction of fish community diversity, which the authors attributed to a number of interacting factors including in-channel diversions, channelization, reduced stream discharge, and altered sediment transport dynamics.

To determine if further changes to the aquatic community have occurred over time, we conducted a monitoring study similar to that completed in 1996. We re-sampled fishes and characterized stream habitat at the same monitoring sites that were used in 1994 – 1995. Comparison of data collected historically, and in 1994 – 1995 to that collected in 2014 (B.

Wright, Colorado Parks and Wildlife, personal communication) as well as 2015 – 2016, 20 years later, will permit assessment of the degree of change of the aquatic community in South Boulder Creek from effects such as installation of fish passage devices, floods in September 2013, and other changes that may have occurred since the mid-1990's. This assessment will provide context critical to understanding the current distribution and abundance of fishes in South Boulder Creek, which may aid and facilitate future management efforts.

MATERIALS AND METHODS

Study Area—South Boulder Creek forms it's headwaters in the Front Range Mountains southeast of the City of Boulder at greater than 3,000 m in elevation. It emerges from a mountain canyon near Eldorado Springs onto the valley floor, and from here runs northeast for approximately 13 km to its confluence with Boulder Creek (Figure 1). In this narrow transition zone from the mountain to the plains, streams are intermediate between high and low-gradient habitats and results in high habitat heterogeneity. Colorado transition zone streams historically featured high fish species diversity due to the dynamic gradient of habitat and the resulting presence of warmwater species, coldwater species, and glacial relict species - which in the South Platte Basin are obligated to the habitat types found only along the transition zone (Fausch and Bestgen 1997).

Hydrography in South Boulder Creek is modified by impoundment at Gross Reservoir approximately 12 km west of Eldorado Springs, and also by extensive water development through the transition zone, where nearly 100 ditches, pipelines, and reservoirs operate with a decreed rate total of over 5,000 cubic feet per second (cfs) of flow within the South Boulder

Creek drainage (Boulder County Transportation Department 2010). Because the only U.S. Geological Survey gauge (# 6729500) operates upstream of Eldorado Springs, detailed measurement of streamflow through the transition zone is not available. Measurements at this gauge shows the highest flows occurred from late April to early July, though the magnitude of the annual peak has declined over time, presumably due to increased capture of peak flows in upstream Gross Reservoir (Figure 2). Though less drastic, it also appears that baseflows during late fall, winter, and spring have increased slightly (Table 1).

Fish sampling and data analysis— Bestgen and Kondratieff (1996) sampled 15 locations along South Boulder Creek in 1994 – 1995, from upstream at the South Mesa Trailhead downstream to KOA Reservoir, to determine fish species composition, distribution, and abundance. In this study we replicated sampling at most of their locations to allow for comparative study. Sampling was foregone only at the most downstream site (15), located between the confluence to Boulder Creek and KOA Reservoir, due to challenges presented by property access and extensive habitat alteration from the September 2013 flood. To compensate for this, an additional site was sampled downstream of the fish passage structure placed at the McGinn Diversion, which is just downstream of the U.S. 36 Bridge crossing (numbered as Site 7b; Figure 1). Additionally, sampling at four sites (1, 2, 8, and 10; hereafter referred to as "sentinel sites") was completed on four separate occasions across seasons consistent with Bestgen and Kondratieff (1996), who found these sites best represented the transition between cool and warmwater habitat based on species richness (Table 2).

Fish sampling protocols outlined by Bestgen and Kondratieff (1996) were followed to enable reasonable comparisons between fish community surveys. This included use of a variety of gears including seines, dipnets, and a backpack electrofisher (Smith-Root 12-B) as needed to survey the taxa present within a reach. Effort was made to sample all different habitat types as each site including riffles, runs, and pools, as well as any other unique features present such as undercut banks, backwaters, or submerged vegetation and woody material. Electrofishing was conducted using a single backpack unit in a single-pass with a minimum of two netters. Sampling effort for all gear used was recorded to aid in estimating fish catch per unit of effort (CPUE). Captured fish were identified to species and counted, measured to the nearest mm total length (TL), and weighed. Occasionally subsamples of species (typically a minimum of 25) representing the range of fish sizes present were measured and weighed individually, while remaining individuals were counted and batch weighed to obtain mean individual weight. All fish were returned to the stream following sampling.

Fish community composition data, measured as species richness and abundance by site, were used to compare and contrast contemporary findings with those of previous studies of the South Boulder Creek fish community. Additionally, species composition and abundance were compared between sites sampled by Bestgen and Kondratieff (1996) to assess longitudinal trends in the fish community. This was accomplished using Bray-Curtis dissimilarity index (Bray and Curtis 1957) between select sites with the following equation:

$$bc_{ii'} = \frac{\sum_{j=1}^{J} |\, n_{ij} - n_{i'j}|}{n_{i+} + n_{i'+}}$$

where i and i' denotes sites, n_{ij} represents species counts by site, and n_{i+} represents site totals. Calculations were completed using the Vegan Community Ecology Package (Oksanen et al. 2005) in R statistical analysis software (v 3.2.2) The common practice of subtracting output values from one to transform the relationship into a representation of similarity was completed for ease of interpretation. Resulting values range from zero to one, such that values approaching one indicate greater similarity in species composition and abundance between two sites. Similarity was described at the four sentinel sites within and between 1996 and 2016 studies.

Habitat sampling and data analysis—Habitat assessment was completed consistent with methods outlined in the 1996 study. Measurements made for each study site included water temperature, conductivity, stream reach length, and average wetted width. Other qualitative notes about general habitat were also made. More detailed measurement was conducted at the four sentinel sites. Macrohabitat type (riffle, run, pool, or combinations of these) of the transect locality was recorded in order to estimate the relative amounts of each type in the reach. A Marsh-McBirney Flo-Mate meter was used to collect velocity and depth measurements at five equidistant points along 10 separate transects in the wetted channel between the upstream and downstream ends at each of the four sites. Substrate characteristics were assessed visually at these five points within each transect (50 points total per site) to generate an estimate of total substrate composition by site. Substrate composition was determined by classifying dominant or co-dominant substrate particle size in a circle within a 10 cm radius around the each point as using measurements outlined by Wentworth (1922) as follows; silt = 0.004 to 0.064 mm, sand = > 0.064 to 2 mm, gravel = > 2 mm to 64 mm, cobble = >64 mm to 127 mm, rubble = >127 mm to 256 mm, boulder = >256 mm. Maximum depth at each site, whether within a transect line or not, was also measured. Means and coefficients of variation (CV; = standard deviation/mean x 100) were calculated consistent with Bestgen and Kondratieff (1996) to enable adequate comparison of habitat measurements between studies and assess changes to habitat variability.

RESULTS

Species composition and abundance—A total of 3,166 fish specimens and seven native and eight non-native species were collected in 29 samples at 15 sites during 2015 – 2016 sampling of South Boulder Creek (Tables 2, 3, and 4). Results of sampling at each sample site are presented in Appendix I. We detected two fewer native taxa than Bestgen and Kondratieff (1996), and one fewer than 2014 sampling conducted by B. Wright of Colorado Parks and Wildlife (Wright 2014, unpublished data) (Table 5).

Native fishes were less abundant than non-native fishes and comprised 18.1% of total abundance across sites, and no taxa accounted for greater than 5% of total abundance (Table 6). This is a dramatic decline from 1996, where more than 80% of all fish collected were native taxa. Five species, all non-native, increased in abundance in this survey relative to 1996; brown trout, rainbow trout, cuttbow (cutthroat x rainbow trout hybrid), golden shiner, and bluegill. Longnose sucker and longnose dace were the most abundant and widespread native taxa collected in South Boulder Creek. Green sunfish were similarly widespread, but the least abundant among native fishes. Plains topminnow were similarly abundant, but were restricted to three sites predominantly in off-channel habitat. Creek chub, fathead minnow, and white sucker were neither abundant nor widespread. Central stoneroller was not collected in our sampling and appears to have been extirpated upstream of KOA Reservoir.

Similar to Bestgen and Kondratieff (1996) we captured eight non-native species in this study, but the composition differed as we did not capture pumpkinseed or black crappie, and instead found cuttbow and golden shiner. Our non-native species presence list matched that of Wright (2014) with the exception of their capture of goldfish and black crappie. Among the non-native species, brown trout and rainbow trout comprised 73.2% of all fish collected in 2015 –

2016 sampling. Brown trout was the most abundant species (58.6%), and was found at all sites that contained main channel stream habitat, which resulted in an expanded distribution from 2014 sampling. Length frequency data recorded from representative sub-samples of brown trout showed a wide range of size classes were present at each of the four seasonally sampled sentinel sites (Figures 3 and 4). Rainbow trout were also relatively widespread, but were not collected downstream of Site 10 at Baseline Road. Golden shiner, largemouth bass, bluegill, and western mosquitofish were found in relatively low abundance. Largemouth bass was the only relatively widespread of these species, and was predominantly found in or associated with close proximity to impounded water.

Longitudinal zonation—Bestgen and Kondratieff (1996) found the South Boulder Creek fish community to be separated into three distinct longitudinal zones, with abrupt changes in community composition linked to the South Boulder Road and Valmont Diversions, above Site 8 and below Site 11, respectively. We observed a shift in community zonation relative to 1996, most notably in the reaches upstream of Site 8 (Table 7). At the most upstream sites 1 and 2, the fish community was similar to 1996 in that it remained relatively species depauperate and dominated by cold and coolwater species. However, similar to Wright (2014) we found warmwater species, green sunfish and largemouth bass, first appeared in the main channel as far upstream as Site 4, near the Shearer Diversion. Downstream of here, warmwater species were present at every other site, with highest native species richness at Sites 8 and 11 (n = 5) below South Boulder Road and above the Valmont Diversion, respectively. All seven native species encountered in this study were detected between Sites 8 and 11, however, the majority of specimens were captured in off-channel habitats, and many were rare or absent in main channel habitat.

Downstream of Site 11 and the Valmont Diversion, the fish community was simplified similar to upstream reaches, and fish abundance was relatively low overall. Brown trout remained the dominant species, followed by creek chub. The remaining species captured (largemouth bass, white sucker, and bluegill) were all found in very low density. Site 14 harbored large numbers of juvenile bass, sunfishes, and carp in the western arm of KOA reservoir, but to the west of the bike path plains topminnow, western mosquitofish, and golden shiner were captured. We did not conduct sampling below KOA Reservoir, but this location supported the greatest species richness of any site in 2014, a large increase from the 3 species detected in this reach in 1996.

Spatial and temporal community trends—Bray-Curtis similarity indices underscored the changes in both species composition and abundance of the fish community in South Boulder Creek since the mid 1990's (Table 8). Similarity between the most upstream (1 and 2) and downstream (8 and 10) sentinel sites in 1996 was very low (mean = 0.13, range = 0.09 – 0.19), indicating a clear separation between the two habitat types and the taxa they supported. Similarity was moderate between both Sites 1 and 2 (0.45) and Sites 8 and 10 (0.53). Alternatively, 2016 index values showed a much greater similarity between the upstream and downstream sentinel sites (mean = 0.65, range = 0.61 – 0.68), as well as between Sites 1 and 2 (0.78), and Sites 8 and 10 (0.63). Comparison of site similarity between 1996 and 2016 sites was low for all four sentinel sites (mean = 0.18, range = 0.10 – 0.25).

Habitat at sample sites—Site 1 (sentinel) was sampled on four occasions during this study, and detailed habitat measurements were taken in August 2016 (Tables 2 and 9). This site began at the footbridge near the South Mesa Trailhead parking lot, and proceeded upstream 115 m above a channel-spanning water diversion structure. The habitat was largely composed of riffle and run habitat from the footbridge crossing upstream to the base of the diversion dam. Above the diversion was a large pool with silt substrate over gravel, and transitioned into a wide, shallow riffle upstream. The most prominent habitat feature in the stretch below the diversion dam was a moderately large aggregation of woody material captured by a tree on the right bank. A lower velocity scour consistently harbored adult trout during each sampling event. Maximum depth at this site was 0.79 m below the diversion, and 1.4 m in the pool above it. Relative to 1996, this site appears to have widened, increased in velocity (Table 9), and may be the result of slightly higher flows throughout the year. Aside from a single longnose sucker, this fish community at this site was comprised solely of trout.

Site 2 (sentinel) was adjacent to the Lafayette Water Treatment Plant, beginning approximately 30 m upstream of a river-right fence line, and proceeding upstream for 135 m. This site was also sampled on four occasions, with habitat measurements taken in August 2016. This site appears to have changed relative to 1996, when it was characterized as wide, shallow, and without significant overhead canopy. The most notable change at this site was the maximum depth increase from approximately 0.5 m in 1996 to over 1 m in 2016. This was from a large undercut on the left bank below a shallow braided riffle in the middle portion of the reach. This scour hole contained large numbers of trout, and many rainbow trout on every visit to the site, and likely functions as overwinter habitat. Substrate was dominated by rubble, cobble, and gravel, with sporadic boulders through the lower portion of the reach. Trout were the only fish captured at this site.

Site 3 was a small gravel pit pond just west of the South Boulder Creek Trailhead parking lot. When sampled in August, the wetted area of the pond was 16 x 18 m, and the area had receded several m compared to earlier in the year. The wetted area was mostly silt and mud over gravels, with thick submerged vegetation. Dipnets captured plains topminnow and green sunfish, and many more topminnow were visible than were captured. Sampling was somewhat limited in an attempt to limit disturbance of sediments which may have resulted in water quality issue (low dissolved oxygen) for resident fish. Little appears to have changed at this site over the past two decades.

Site 4 began immediately above the Shearer Diversion and proceeded upstream for approximately 100 m, and sampled once in August. This reach was fairly wide and shallow, with little habitat complexity and similar maximum (0.6 m) and average depth (0.4 m). Substrate was dominated by cobble and rubble, and overhanging willow on the right bank provided the most significant cover for fish. Trout dominated this site, as opposed to 1996 when only longnose dace and longnose sucker were captured. These species along with green sunfish were present, but in low numbers.

Site 5 began approximately 80 m below and upstream to the Shearer Diversion, and sampled once in August 2016. Substrate, channel, and habitat characteristics were similar to that of Site 4, with the addition of one large, deep scour hole near the bottom of the reach. This was also noted as the most prominent habitat feature in 1996 sampling. The maximum depth here increased to nearly 1 m, and was associated with an outflow to the pond complex just to the west of Sites 4 and 5. There were many large trout in this location, along with largemouth bass that presumably moved into the main channel from the pond complex.

Site 6 was about 40 m below the South Boulder Canyon fish passage structure that was not present during 1996 sampling. The lower end of the site consisted of large boulders and rubble, with a moderate gradient that contained only trout. A wide gravel and sand mixed riffle led up to the base of the passage structure, where a very large deep pool was located. The depth of the pool was not measured but was estimated to be greater than 2 m, and consequently was not efficiently sampled, resulting in few fish captured. Several longnose dace were captured in the riffle below the large pool, but all other fish were brown trout.

Site 7 was 50 m upstream of the US Highway 36 Bridge and proceeded upstream for 85 m, and sampled once in August 2016. Habitat consisted of relatively homogenous straight riffle-run sequences with little overhead canopy, and substrate composed of rubble and cobble. There were a few deeper portions of runs on the right bank that provided shade and slightly deeper water for the trout captured in this reach. Habitat degradation in this reach described by Bestgen and Kondratieff (1996) remains evident as there were few pools, and no large individuals were captured in our sampling.

Site 7b was new to this study with the construction of the fish passage structure at the McGinn Diversion structure. The site began 85 m downstream of the structure, which is just downstream of the US Highway 36 Bridge. Substrate was composed mostly of cobble and rubble, with few boulders scattered throughout the mostly riffle and run sequences. Log structures placed on the left bank of this reach during 2011-2012 instream habitat improvements were successful in creating small backwater habitats that were used by trout. Longnose dace and longnose sucker were slightly more numerous at this site and utilized higher velocity main channel habitats. A group of 15 adult longnose sucker were captured in December in the run below the passage structure entry, but it is unknown if passage was attempted by these fish. There were two small meanders that created erosion around tree roots not far below the passage structure that were occupied by trout, and could potentially serve as overwinter habitat for larger-bodied individuals.

Site 8 (sentinel) began directly above a water diversion dam located approximately 250 m downstream of South Boulder Road, and proceeded upstream 160 m. Fish were sampled on four occasions across all seasons, and detailed habitat measurements were taken in August 2016. This site has a densely vegetated riparian area and canopy, and remained well shaded, especially during spring and summer months. The dense vegetation has provided several inputs of woody material that are used as cover, especially by juvenile trout. During 2016 an effort was undertaken to remove large Crack willow in this reach that will certainly change canopy cover in years to come. This reach is composed of run habitat, but a large relatively shallow pool is present at the downstream end that inundates a grassy shoreline on the left bank. This was the only location that plains topminnow were observed and captured in main channel habitat during August 2016 sampling. In the middle of the reach there is a small connection to a storm drainage return channel (locally known as the Viele Channel) that contains an off-channel pool that contains high numbers of topminnow, along with many golden shiner and some creek chub. This pool is situated below a rock gabion that acts as in-stream barrier located approximately 20 m upstream of the main channel connection. The pool is a cobble substrate overlain by silt, and water level fluctuated throughout the year. Main channel substrate was mostly rubble, cobble, and gravel, with sand and silt often present at channel margins. There is a very narrow chute towards the top end of this reach that harbored many adult trout, including several of the largest individuals captured during this study. This was the deepest location in the reach (0.8 m), with high velocity that created an undercut bank. The mean and variability of channel width both have increased relative to 1996. Higher native species richness is likely related to increased habitat diversity and warmer water temperature relative to sites upstream of South Boulder Road.

Site 9 was a small off-channel pond connected by overflow to a drainage canal and South Boulder Creek just east of the East Boulder Recreation Area. The habitat was dense cattail with thick duckweed and filamentous algae in the few open water areas, and thick silt substrate. Minnow traps were deployed at this site in August but did not capture fish. Several juvenile largemouth bass were captured near the inflow adjacent to the bike path, and likely originated from the recreation area ponds. Plains topminnow likely is no longer found at this site, but sampling and direct observation was difficult because of dense vegetation and algae.

Site 10 (sentinel) was located upstream from the Baseline Road Bridge near the Bobolink Trailhead to 160 m upstream. Fish were sampled on four occasions across all seasons, and detailed habitat measurements were taken in August 2016. Habitat consisted mostly of runs, with two small riffles on the downstream end, and a large pool near the middle of the reach that accounted for an increase in sand and silt substrate relative to the other sentinel sites. This pool had a maximum depth of 1 m and contained many large trout and longnose suckers. The habitat seems to have changed little since 1996 sampling, with similar channel width and depth, and canopy cover. This site was formerly the most upstream extent of central stoneroller and the only capture location of orangespotted sunfish, neither of which were captured in 2016 sampling. This site had the same species richness as Site 8, the two highest in the study, but fewer native species were captured. Longnose dace were more common here than at Site 8, and were found in the slightly more abundant riffle habitat. Flows were lower during March and November sampling, emphasizing the importance of the pool habitat in sustaining larger bodied fish at this site.

Site 11 was from the pool upstream of the Valmont Diversion upstream to the Arapahoe Road Bridge, approximately 75 m. Silt and sand were the dominant substrate, and much of the reach was slow flowing due to the large impounded pool upstream of the diversion, which was difficult to sample due to heavy silt deposition and depth greater than 1.5 m. There was dense mature canopy in the middle of the reach, but was open near the upstream end. Brown trout along with few longnose sucker and green sunfish were the only species captured in the main channel. A storm drain that emptied into a concrete lined "backwater" pool directly below Arapahoe Road that was much warmer than the main channel contained many white sucker, creek chub, and was the only location fathead minnow were captured during the study. Golden shiner and bluegill were also found in this storm drain pool. Conductivity in this pool was extremely high (1,600 microsiemens/cm^2) relative to the rest of the study area (45 – 200 microsiemens/cm^2), presumably due to runoff from roadways.

Site 12 was located in the floodway downstream of the Valmont Diversion and was sampled once during August. The reach was approximately 300 m upstream of KOA reservoir and about 100 m in length. The stream was very shallow averaging 0.2 m, and varied in width from 3 to 9 m. Substrate was a mix of gravel and sand, with silt-bottomed run and pool habitat interspersed. The riparian and overhead cover was dense, and juvenile brown trout less than 90 mm in length dominated the fish community. In a short pool section near the upstream end of the reach 22 creek chub were captured, the highest total of any site during the study.

Site 13 was also in the floodway, 150 m upstream of KOA Reservoir, and sampled once in August. Habitat was generally the same as for Site 12, but lacked any small pool sections and no creek chub were captured. Brown trout were again dominant, with several larger (200 mm) individuals captured. Bestgen and Kondratieff (1996) found common carp had moved into this reach during their sampling, but we did not observe this. The floodway was actively flowing with a 30 m channel width when sampled in 1996, and it is possible this still occurs during higher flows.

Site 14 was the west arm of KOA Reservoir, both to the east and west of the trail crossing. The eastern side (in the reservoir) was sampled in August, while the western side was sampled in November when dense algae and vegetation was reduced. In the eastern sample rocky rip-rap shoreline gave way to silt over gravel, with dense mats of submerged vegetation. Seining captured juvenile largemouth bass, bluegill, and green sunfish. Adult common carp were observed, but not captured. West of the trail the drainage area was very dense cattail that could not be sampled, but seining was performed in open water just to the east of the 55th Street Bridge. The habitat was boulder rip-rap covered in algae, with dense submerged vegetation. Many small fish were observed, but seining was made difficult due to difficult footing. We confirmed the presence of plains topminnow, as well as western mosquitofish, the only location they were observed. Mosquitofish appeared to be more numerous, but capture efficiency was limited. Golden shiner and juvenile largemouth bass were also captured.

DISCUSSION

Species composition and abundance—The South Boulder Creek fish community has changed since the mid 1990's from one numerically dominated by native taxa, to dominance by non-native taxa. In terms of abundance, brown trout represented the largest increase in abundance, increasing from less than 1% of the total abundance in 1996 to nearly 60% during our study (Table 3). Conversely, the greatest decline in any species was that of native fathead minnow and longnose sucker. These two species comprised 47% of all fish captured in 1996 (23.5% each), but declined to 5.8% of total abundance in 2016. This is a particularly curious observation for fathead minnow, as they are tolerant of a wide range of habitat and water quality conditions, and commonly displace other small bodied fishes where they are found, but in our study were only found in one location, down from six sites in 1996. Along with the concurrent increase in brown trout and decrease in fathead minnow and longnose sucker, creek chub abundance decreased from almost 10% of total abundance in 1996 to approximately 2% in 2016.

In their 1996 report, Bestgen and Kondratieff stated, "the effects of non-native fishes on native forms are unknown in South Boulder Creek". Our findings suggest the effects have manifest in homogenization of the fish community, as supported by the changes in Bray-Curtis similarity values within and between years (Table 8). Both species richness and abundance are incorporated into these index values, and the change to higher similarity between sentinel sites in 2016 is driven both by the expanded distribution and dramatically increased abundance of brown trout throughout South Boulder Creek, as well as the greatly reduced abundance or loss of other taxa, such as central stoneroller and orangespotted sunfish. Density of the dominant non-native species in 1996, rainbow trout, remained relatively unchanged between 1996 and 2016. Brown trout are a desirable sport fish, and are commonly stocked and then reproduce to form sustaining populations. The result of their increased abundance can be their eventual dominance over other salmonids via competition for space and resources (Fausch and White 1981), and versatility in habitat selection (Heggenes 2002). Furthermore, proliferation of brown trout in South Boulder Creek may directly contribute to reduced abundance of native species by increased predation or by facilitating trophic cascades that reduce quantity or availability of food sources (Cowan and Peckarsky 1994; Townsend 1996). Causal mechanisms for brown trout proliferation in South Boulder Creek are uncertain, and we speculate on possible influences below.

Changes in habitat characteristics from the mid 1990's may have influenced the increased distribution and abundance of brown trout in South Boulder Creek. Both mean and maximum depth increased at each of the four sentinel sites from 1996 to 2016 habitat sampling (Table 8), which likely indicates increased depth stream-wide and more over-winter habitat for trout species. Greater variation in depth was also observed at Site 2, which could explain the large increase in trout abundance in this reach. This general trend in increased depth throughout the study area may be a result of scouring from the September 2013 flood, which may have also served to clean fine sediment from reaches creating higher quality trout habitat (Harvey et al. 2009). Additionally, water temperatures remained cool throughout all seasons and at both upstream and downstream sentinel sites (Figure 5). Decreased temperatures relative to the mid-1990's may have contributed to a greater abundance trout than native fishes. Finally, two notable fish passage structures were installed between South Boulder Road and South Foothills Parkway at the McGinn and South Boulder Canyon Diversions since the 1996 study by Bestgen and Kondratieff, and may have facilitated movement and increased distribution and abundance of trout in this section of South Boulder Creek. Artificial barriers are a common management strategy to segregate and conserve native fish populations (Novinger and Rahel 2003), and it is possible that the construction of these structures may have indeed facilitated downstream expansion (Colorado Parks and Wildlife 2012).

Following their expansion into new reaches, the life history of brown trout may have further facilitated their dominance. Brown trout spawn in the fall, and newly hatched fish emerge in the spring, whereas rainbow trout typically spawn during the spring and young emerge from gravels in the summer. The net result is that young brown trout are larger through their first summer of life, and may have a competitive advantage (e.g. Fausch and White 1986). This ecological interaction may have also been exacerbated by changes in hydrology. Slightly higher base flows during fall and winter (Table 1) could conceivably inundate more spawning gravels in shallow riffle habitat increasing reproductive success of brown trout. Increased base flows may also create more usable stream area for juvenile and adult brown trout. For example, Wolff et al. (1990) noted that increasing minimum flows in a regulated Wyoming stream from 1 to 5.5 cfs resulted in two to six-fold increases in brown trout abundance. Furthermore, continued decreases in the annual hydrograph peak could dampen the potential displacement or mortality of young brown trout during high flows (Harvey 1987, Jensen and Johnsen 1999).

Historic flooding in September 2013 may have played a direct role in the expansion of brown trout into downstream reaches as well. For example, brown trout were found in low density in the floodway upstream of KOA Reservoir and below Valmont Reservoir in sampling completed by Colorado Parks and Wildlife in both 2000 (n=36) and 2002 (n=1), but were found in higher densities during post-flood sampling in 2014 (n=332) (Colorado Parks and Wildlife 2016, unpublished data), numbers similar to what we observed in this study. Stream salmonid density, including young-of-year fish, has been found to increase following catastrophic flood events in other systems (Roghair et al. 2002; George et al. 2015), and flushing of fine sediments and habitat scouring from flooding may have enabled successful reproduction and recruitment to occur in this reach of South Boulder Creek (e.g., Ortlepp and Mürle 2003). Flooding may have also dispersed fishes from upstream locations such as the Walker Ranch downstream of Gross Reservoir, a popular sport fishery for brown and rainbow trout, throughout lower reaches of South Boulder Creek, and those that survived were able to colonize and proliferate in downstream habitats. Indeed, capture of many brown trout < 100 mm TL in this reach during August 2016 sampling suggests successful reproduction has occurred. Water temperature is a probable limiting factor for brown trout in South Boulder Creek. Temperatures measured during the middle of the afternoon in mid-August at the lowermost occupied Sites 12 and 13 were 20.8ºC and 21.7 ºC, respectively, values below the critical thermal maximum (CTM) of brown trout (Lee and Rinne 1980); temperature was much lower in more upstream study locations (Figure 5).

September 2013 flooding may have also negatively affected growth and survival of brown trout in South Boulder Creek. Length data from representative sub-samples of brown trout showed that catches were comprised primarily of three year classes, with fewer large three-plus year old fish captured, particularly at more upstream Sites 1 and 2 (Figures 3 and 4). The reduced number of larger individuals may be the result of reduced survival of early life stages of brown exposed to 2013 flooding (Jensen and Johnson 1999). However, the observed patterns may simply be the natural age-class structure for brown trout in South Boulder Creek as dictated by density dependent processes (Lobon-Cervia 2007). Without a long term data collection program, we cannot identify apparent gaps or shifts in interannual length-frequency data that would provide insight to age class structure, growth, and survival trends, and therefore can only speculate on these aspects of brown trout population dynamics in South Boulder Creek.

Plains topminnow assessment—Plains topminnow is a Tier 1 Species of Greatest Conservation Need (SCGN) in Colorado Parks and Wildlife's 2015 State Wildlife Action Plan, and is the only fish species with a SCGN status currently present in South Boulder Creek. The species does not have a state statutory listing (i.e. Endangered or Threatened) as declines in its global distribution are a recent occurrence (Pasbrig et al. 2012). Plains topminnow in South Boulder Creek is near the western extent of their distribution, and has apparently declined subsequent to the Bestgen and Kondratieff (1996) study. They documented plains topminnow at six of the 14 sampling locations. In 2016, the species was found at only three of these six locations. Two sites are isolated ponds (Sites 3 and 14), and the third is Site 8, both in the pool in the Viele Channel, and the lower portion of the main channel in summer.

The proliferation of western mosquitofish is believed to be a key factor in the recent decline of plains topminnow across its native range (Lynch and Roh 1996, Pasbrig et al. 2012). Certainly, the increased distribution of western mosquitofish in the South Platte Basin of Colorado has been coincident with declining distribution of plains topminnow. Western mosquitofish were present in both studies. Bestgen and Kondratieff (1996) found the species only downstream of KOA Reservoir, though we did not sample this location. Since that study, their distribution within this particular section of South Boulder Creek has increased only slightly in an upstream direction. They were present just upstream of their original location at one additional site in our study – the Southwest arm of KOA Reservoir, the only site they co-occurred with plains topminnow.

Overall, the distribution of western mosquitofish has been relatively static for the last 20 years. This may be attributable to the number of physical barriers present just upstream of their original location in South Boulder Creek; the section of stream surrounding KOA Reservoir is heavily fragmented by manmade structures that either serve as grade control or divert water. Keeping a physical barrier intact upstream of KOA Reservoir may be an integral piece of managing the non-native species to prevent its advancement into upstream habitats. The relatively isolated nature of the present plains topminnow populations serves as both a benefit and hindrance to the overall conservation of the species in South Boulder Creek. As a result of being isolated, these populations are protected from invasion by western mosquitofish; however, gene flow among plains topminnow populations resulting from immigration and emigration is non-existent in this system.

Conclusions—Completion of this study has led to several conclusions regarding the fish community and habitat of South Boulder Creek, listed below. These conclusions will be useful for directing future research needs and possibly management actions to conserve native fishes in the transition zone of South Boulder Creek.

1) The South Boulder Creek fish community has shifted from one dominated by native cool and warmwater species to one predominantly comprised of coldwater, non-native species.
2) Brown trout have become the most numerically dominant species in South Boulder Creek
3) Native fish were most numerous in reaches of South Boulder Creek downstream of South Boulder Road, and commonly associated with warmer water temperatures, off-channel habitats, and complex in-stream structure.
4) Magnitude of peak runoff flows in late spring and early summer have decreased, and base flows in late fall and early winter have increased relative to previous time periods examined.

Recommendations—We offer the following research recommendations that may lead to increased understanding of factors limiting native fish populations in the transition zone of South Boulder Creek. Increasing understanding of limiting factors may illuminate additional management activities that may enhance the conservation of these populations.

The shift in the South Boulder Creek fish community to one predominantly comprised of coldwater, non-native species warrants concern for the persistence of native taxa that depend on transition zone stream habitat. It remains unclear if these changes are a temporary response to 2013 flooding, short-term shifts in water temperature and flows, or are more permanent in nature. If permanent, the prevailing trends suggest continued expansion by brown trout and reductions in the native fish community are probable, and the potential for localized extirpations of native taxa exists. Considering these factors, we recommend the following:

1) Continued monitoring of fish and habitat at established sampling locations.

Long term monitoring plans would elucidate interannual trends in species distribution and abundance and provide better insight into factors limiting the continued persistence of native taxa. Additionally, given their declining status within the state and throughout their range, particular emphasis should be placed on the monitoring of known plains topminnow populations to ensure their persistence in South Boulder Creek. We believe additional sampling of adjacent water bodies is also warranted to provide a more comprehensive understanding of status of plains topminnow and other fish species throughout the South Boulder Creek drainage.

2) Establish streamflow and water temperature monitoring stations at more locations in South Boulder Creek.

Gauging is currently restricted to the U.S. Geological Survey gauge near Eldorado Springs (# 06729500), and is upstream of many water diversion and return locations in South Boulder Creek. Monitoring flow and temperature in closer proximity to reaches where native fish are more abundant would provide valuable information to better manage for their benefit, and clarify interannual distribution or abundance trends relative to differing water years (i.e. high flow versus drought years).

3) Preservation or enhancement of existing warm backwater and off-channel habitats most frequently used by native species.

For example, the Viele Channel is an important location for plains topminnow located in an area where off-leash dog use is high. Fencing off this small pond habitat may be useful to impede dogs and humans from disturbing sediments and altering water quality through summer breeding months.

4) Creation of new habitat to benefit native fish.

This may include creation of aforementioned backwater and off-channel habitat that are seasonally connected to the main channel, or instream features such as shallow side channels or braids. Creation of such habitat features may be a viable option to increase abundance of native taxa that could be tested with continued monitoring.

5) Monitor non-native fish populations to track dispersal patterns.

These efforts should include any waterways connected to South Boulder Creek, either perennially or seasonally. Western mosquitofish regularly displace plains topminnow, and their expansion would threaten the persistence of plains topminnow in the drainage. Additionally, Brown trout have established and become dominant in more downstream reaches of South Boulder Creek, and pose threat to the continued decline or loss of native species in these reaches. Long term monitoring may provide information helpful in understanding population dynamics and management of brown trout in South Boulder Creek.

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Table 1. Mean monthly discharge (m^3/s; ft^3/s in parentheses) records for South Boulder Creek, near Eldorado Springs (gauge # 06729500) from two post-impoundment time periods (1956 – 1993 and 1994 – 2015).

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1956 – 1993	0.20 (7)	0.22 (8)	0.25 (9)	1.25 (44)	4.10 (145)	7.35 (260)	3.65 (129)	1.45 (51)	0.80 (28)	0.40 (14)	0.35 (12)	0.20 (7)
1994 – 2015	0.26 (9)	0.27 (10)	0.52 (18)	1.35 (48)	4.30 (152)	6.16 (218)	2.93 (103)	1.27 (45)	0.77 (27)	0.68 (24)	0.41 (14)	0.53 (19)
% diff	+0.06 (2)	+0.1 (2)	+0.27 (9)	+0.10 (4)	+0.20 (7)	-1.19 (42)	-0.72 (26)	-0.18 (6)	-0.03 (1)	+0.3 (10)	+0.06 (2)	+0.33 (12)

Table 2. Site numbers (OCP = off-channel pond), UTM coordinates (DS = downstream terminus, US = upstream terminus, E = Easting, N = Northing), length (meters), dates of visits, and total number of visits for 2015 – 2016 survey of South Boulder Creek.

Site	DS (E, N)	US (E, N)	Length (m)	Visit dates	Total visits
1	477825, 4421070	477772, 4420990	115	12/4/15; 4/27/16; 8/11/16*; 11/9/16	4
2	479820, 4423019	479719, 4422951	135	12/4/15; 4/27/16; 8/11/16*; 11/9/16	4
3 (OCP)	479731, 4423367	NA	NA	8/11/16	1
4	480605, 4424145	480595, 4424048	100	8/18/16	1
5	480610, 4424230	480599, 4424155	80	8/18/16	1
6	480919, 4424765	480927, 4424721	40	8/18/16	1
7	481077, 4425531	481051, 4425448	85	8/18/16	1
7b	481140, 4425732	481117, 4425654	85	12/3/15; 8/18/16	2
8	481186, 4426477	481168, 4426315	160	12/3/15; 3/16/16; 8/16/16*; 11/10/16	4
9 (OCP)	481364, 4427015	NA	NA	8/12/16	1
10	481606, 4427782	481606, 4427629	160	12/15/15; 3/14/16; 8/16/16*; 11/10/16	4
11	481701, 4429506	481678, 4429433	75	8/12/16	1
12	481550, 4430385	481567, 4430289	100	8/12/16	1
13	481529, 4430528	481545, 4430478	50	8/12/16	1
14 (OCP - KOA arm)	481103, 4430689	NA	NA	8/12/16	1
14 (OCP - 55th St)	480985, 4430454	NA	NA	11/10/16	1

*Indicates habitat measurements were taken on this date, results outlined in Table 9

Table 3. List of fish species collected during the 2015-2016 survey of South Boulder Creek, Colorado, on City of Boulder Open Space property, their status (N = native (n = 7), I = introduced [n=7]), frequency of occurrence at sites (N = 15 possible), and in collections (N = 29 possible), and percent abundance in all samples (% of 3,166 total specimens collected); + indicates more specimens observed but not captured at some sites.

Taxa		**Occurrence**				
Common Name	**Scientific Name**	**Status**	**Sites**	**Collections**	**N**	**Percent Abundance**
brown trout	*Salmo trutta*	I	12	25	1,856	58.6
rainbow trout	*Oncorhynchus mykiss*	I	8	21	463	14.6
longnose sucker	*Catostomus catostomus*	N	7	13	140	4.4
golden shiner	*Notemigonus crysoleucas*	I	3	5	129	4.1
longnose dace	*Rhinichthys cataractae*	N	7	13	117	3.7
plains topminnow	*Fundulus sciadicus*	N	3	5	115	3.6
creek chub	*Semotilus atromaculatus*	N	3	5	73	2.3
largemouth bass	*Micropterus salmoides*	I	6	8	68	2.1
white sucker	*Catostomus commersonii*	N	3	3	53	1.7
fathead minnow	*Pimephales promelas*	N	1	1	44	1.4
bluegill	*Lepomis macrochirus*	I	4	6	37	1.2
green sunfish	*Lepomis cyanellus*	N	8	13	35	1.1
cuttbow*	*O. clarkii x mykiss*	I	6	9	21	0.7
western mosquitofish	*Gambusia affinis*	I	1	1	15	0.5

* cutthroat trout x rainbow trout hybrid (*Oncorhynchus clarkii x O. mykiss*)

Table 4. Sites where fish species were captured in South Boulder Creek, Colorado, on City of Boulder Open Space property, 2015-2016. Species arranged in order of total abundance across all samples. Sites correspond to localities on Figure 1.

Common Name	Scientific Name	Sites where collected
brown trout	*Salmo trutta*	1, 2, 4, 5, 6, 7, 7b , 8, 10, 11, 12, 13
rainbow trout	*Oncorhynchus mykiss*	1, 2, 4, 5, 7, 7b, 8, 10
longnose sucker	*Catostomus catostomus*	1, 4, 5, 7b, 8, 10, 11
golden shiner	*Notemigonus crysoleucas*	8, 11, 14
longnose dace	*Rhinichthys cataractae*	4, 5, 6, 7, 7b, 8, 10
plains topminnow	*Fundulus sciadicus*	3, 8, 14
creek chub	*Semotilus atromaculatus*	8, 11, 12
largemouth bass	*Micropterus salmoides*	5, 9, 10, 11, 12, 14
white sucker	*Catostomus commersonii*	11, 12, 13
fathead minnow	*Pimephales promelas*	11
bluegill	*Lepomis macrochirus*	10, 11, 13, 14
green sunfish	*Lepomis cyanellus*	3, 4, 7, 7b, 8, 10, 11, 14
cuttbow*	*Oncorhynchus spp.*	1, 2, 4, 5, 8, 10
western mosquitofish	*Gambusia affinis*	14

* cutthroat trout x rainbow trout hybrid (*Oncorhynchus clarkii x O. mykiss*)

Table 5. Comparison of fishes collected in South Boulder Creek by Hendricks (1950), Li (1968), Propst (1982), Bestgen and Kondratieff (1996), Wright (2014), and this study. Fishes found just downstream in Boulder Creek are presented for comparison and data are from the above mentioned sources as well as from Juday (1904) and Ellis (1914). A single species list was derived from the different studies regardless of the number of collections made (one or many), but were usually from one or two localities.

	Taxa	Hendricks (1950)	Li (1968)	Propst (1982)	Bestgen, Kondratieff (1996)	Wright (2014)	Haworth, Bestgen (2016)
Native	bigmouth shiner	X					
	blacknose shiner						
	central stoneroller	X		X	X	X	
	common shiner	X					
	creek chub	X	X	X	X	X	X
	cutthroat trout						
	fathead minnow			X	X	X	X
	green sunfish			X	X	X	X
	hornyhead chub						
	Iowa darter						
	Johnny darter			X			
	lake chub						
	longnose dace	X	X	X	X	X	X
	longnose sucker	X	X	X	X	X	X
	northern redbelly dace						
	orangespotted sunfish				X		
	plains topminnow			X	X	X	X
	white sucker	X		X	X	X	X
Non-native	black crappie				X	X	
	bluegill			X	X	X	X
	brown trout				X	X	X
	common carp				X	X	X
	cuttbow*					X	X
	golden shiner					X	X
	goldfish					X	
	largemouth bass			X	X	X	X
	pumpkinseed				X		
	rainbow trout			X	X	X	X
	western mosquitofish				X	X	X
	Number of native species	7	3	9	8	8	7
	Number of non-native species	0	0	3	8	10	8
	% native species captured	100	100	75	50	44	47

* cutthroat trout x rainbow trout hybrid (*Oncorhynchus clarkii x O. mykiss*)

Table 6. List of fish species collected during 1994-1995, 2014, and 2015-2106 sampling of South Boulder Creek, Colorado, from South Mesa Trailhead to Boulder Creek Confluence, their status (N = native, I = introduced), the number of sites at which they were present (15 possible), their overall percent abundance at all sites, and change (+/-) from 1996 to 2016.

Taxa			**1996 Abundance**		**2014 Abundance**		**2016 Abundance**		**Change from 1996 to 2016**
Common Name	**Scientific Name**	**Status**	**No. Sites**	**Percent**	**No. Sites**	**Percent**	**No. Sites**	**Percent**	**(+/-)**
black crappie	*Pomoxis nigromaculatus*	I	1	<0.01	1	0.02	-	-	-
bluegill	*Lepomis macrochirus*	I	3	0.10†	5	1.10	4	1.20	+
brown trout	*Salmo trutta*	I	4	0.80	11	23.96	12	58.60	+
central stoneroller	*Campostoma anomalum*	N	2	5.80	1	0.02	-	-	-
common carp	*Cyprinus carpio*	I	2	†	1	0.06	-	†	NA
creek chub	*Semotilus atromaculatus*	N	5	9.40	5	14.25	3	2.30	-
cuttbow*	*Oncorhynchus spp.*	I	-	-	1	0.02	6	0.70	+
fathead minnow	*Pimephales promelas*	N	6	23.50	2	0.06	1	1.40	-
golden shiner	*Notemigonus crysoleucas*	I	-	-	2	0.24	3	4.10	+
goldfish	*Carassius auratus auratus*	I	-	-	1	0.02	-	-	NA
Green sunfish	*Lepomis cyanellus*	N	5	1.20	8	3.18	8	1.10	-
Largemouth bass	*Micropterus salmoides*	I	5	5.30†	7	6.42	6	2.10	-
longnose dace	*Rhinichthys cataractae*	N	8	7.80	6	19.12	7	3.70	-
longnose sucker	*Catostomus catostomus*	N	8	23.50	7	7.60	7	4.40	-
plains topminnow	*Fundulus sciadicus*	N	6	8.40†	3	1.71	3	3.60†	-
pumpkinseed	*Lepomis gibbosus*	I	2	0.60	-	-	-	-	-
rainbow trout	*Oncorhynchus mykiss*	I	7	10.30	8	10.32	8	14.60	+
western mosquitofish	*Gambusia affinis*	I	1	0.60†	2	0.04	1	0.50†	-
white sucker	*Catostomus commersonii*	N	5	2.70	5	11.85	3	1.70	-

* cutthroat trout x rainbow trout hybrid (*Oncorhynchus clarkii x O. mykiss*)

† indicates visual encounters not included in total species abundance

Table 7. Comparative table of species richness (presented as number of species collected) for each study site in sampling completed by Bestgen and Kondratieff (1994-1995), Wright (2014), and Haworth and Bestgen (2015-2016).

Site	**No. Species Present**		
	1994-1995	**2014**	**2015-2016**
Site 1	4	2	4
Site 2	3	2	3
Site 3	2	2	2
Site 4	2	4	6
Site 5	3	6	6
Site 6	*	*	2
Site 7	4	5	4
Site 7b	*	*	5
Site 8	12	11	9
Site 9	1	2	1
Site 10	11	8	8
Site 11	5	9	9
Site 12	5	5	4
Site 13	3	6	3
Site 14	4	3	3
Site 15	3	12†	*

*Site not sampled during study

† High species richness likely influenced by proximity to Boulder Creek confluence

Table 8. Bray-Curtis similarity indices for sites sampled in multiple seasons during 1996 and 2016 surveys. Top (1996) and middle (2016) tables represent site similarity based on species composition and abundance within years at South Mesa Trailhead (Mesa, Site 1), Lafayette Water Treatment Plant (Lafayette, Site 2), South Boulder Road (South Boulder, Site 8), and Baseline Road (Baseline, Site 10). The lowermost table represents similarity at sites between the 1996 and 2016 surveys. Values approaching one represent greater similarity between fish communities, with those approaching zero being more dissimilar.

1996 Sites	Mesa (1)	Lafayette (2)	South Boulder (8)
Lafayette (2)	0.45	*	*
South Boulder (8)	0.19	0.16	*
Baseline (10)	0.09	0.10	0.53

2016 Sites	Mesa (1)	Lafayette (2)	South Boulder (8)
Lafayette (2)	0.78	*	*
South Boulder (8)	0.64	0.66	*
Baseline (10)	0.68	0.61	0.63

Site	Mesa (1)	Lafayette (2)	South Boulder (8)	Baseline (10)
	0.10	0.21	0.25	0.17

Table 9. Summary of habitat measure made at South Mesa Trailhead (Mesa, Site 1), Lafayette Water Treatment Plant (Lafayette, Site 2), South Boulder Road (South Boulder, Site 8), and Baseline Road (Baseline, Site 10) sites in South Boulder Creek. Figure 1 presents site localities. Habitat variables stream width (m), depth (m), velocity (m/s) (those as mean, range, coefficient of variation [CV], substrate (% composition within site), maximum depth (m), and dominant macrohabitat type (riffle-run (RiRu), run (Ru), run-pool (RuPo)), were summarized from data collected at ten transects within the site. Transects were spaced at upstream intervals corresponding to two stream widths; habitat data were collected at five points along each transect. Percent substrate composition at sites was determined by classifying dominant or co-dominant substrate particle size in a circle within a 10 cm radius around the habitat point as follows; silt (si) = 0.004 to 0.064 mm, sand (sa) = > 0.064 to 2 mm, gravel (G) = > 2 mm to 64 mm, cobble (C) = >64 mm to 127 mm, rubble (R) = >127 mm to 256 mm, boulder (B) = >256 mm.

Site	Stream Width	Depth	Velocity	Maximum depth	Habitat type	Substrate composition					
						Si	Sa	G	C	R	B
Mesa (1)	10.1 (7.3 – 12.1) 16.1	0.29 (0.04 – 0.62) 48.4	0.43 (0.0 – 1.0) 62.2	1.4	RiRu	3.6	9.1	20.0	29.1	32.7	5.5
Lafayette (2)	8.8 (5.9 – 12.6) 23.6	0.31 (0.06 – 0.98) 62.4	0.45 (0.01 – 1.16) 71.7	1.2	RiRu	0.0	7.0	31.6	22.8	33.3	5.3
South Boulder (8)	6.4 (2.1 – 10.5) 35.8	0.31 (0.14 – 0.58) 34.8	0.24 (0.01 – 0.77) 60.7	0.83	Ru	3.7	9.3	33.3	25.9	24.1	3.7
Baseline (10)	5.3 (4.6 – 7.6) 16.7	0.25 (0.06 – 0.59) 51.9	0.26 (0.0 – 0.74) 66.6	1.0	RuPo	5.5	10.9	18.2	25.5	34.5	5.5

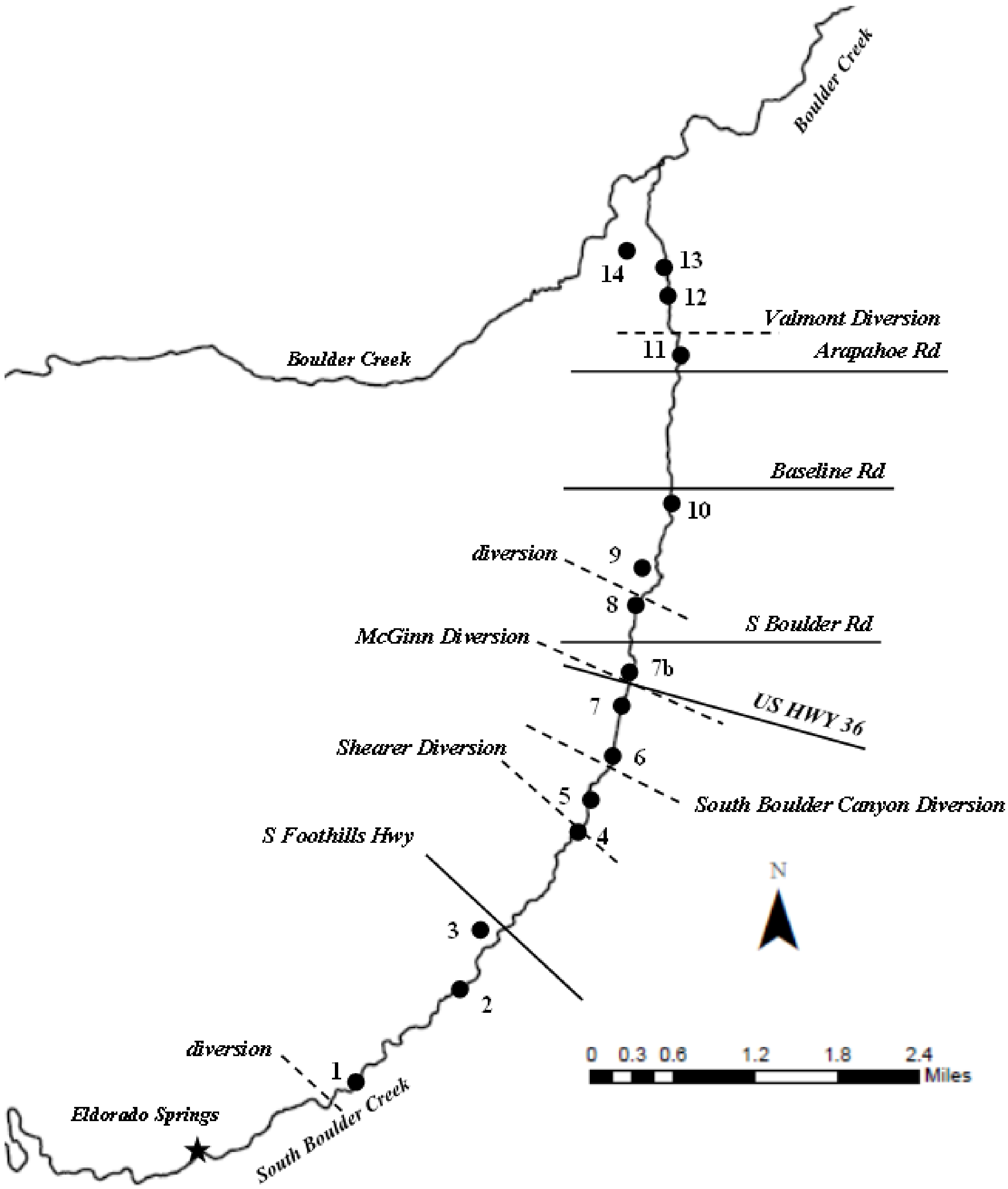


Figure 1. The South Boulder Creek study area. Filled circles and corresponding numbers represent sampling localities. Solid lines represent major roadway crossings associated with the study area, dashed lines represent diversion structures relevant to sampling locations.

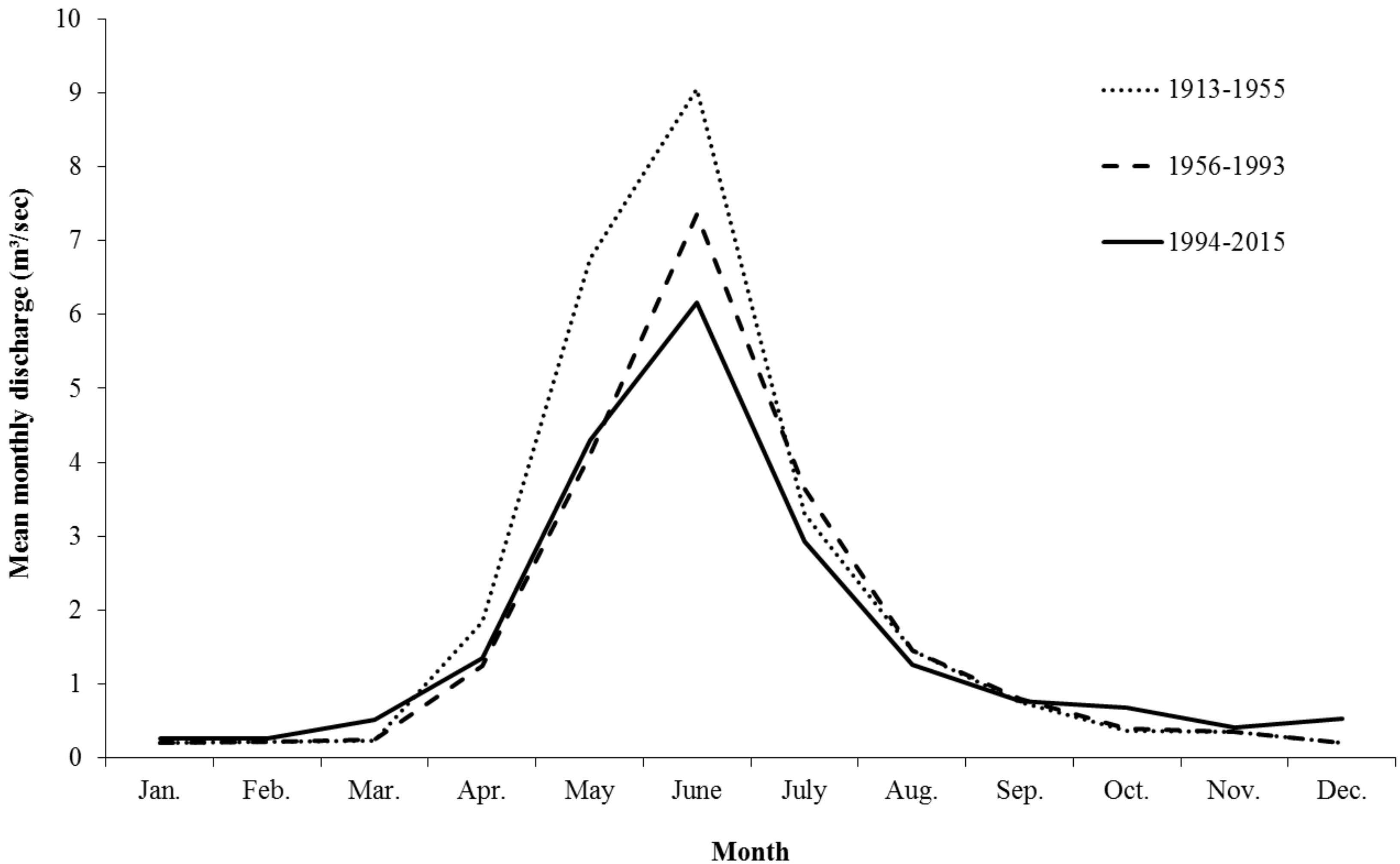
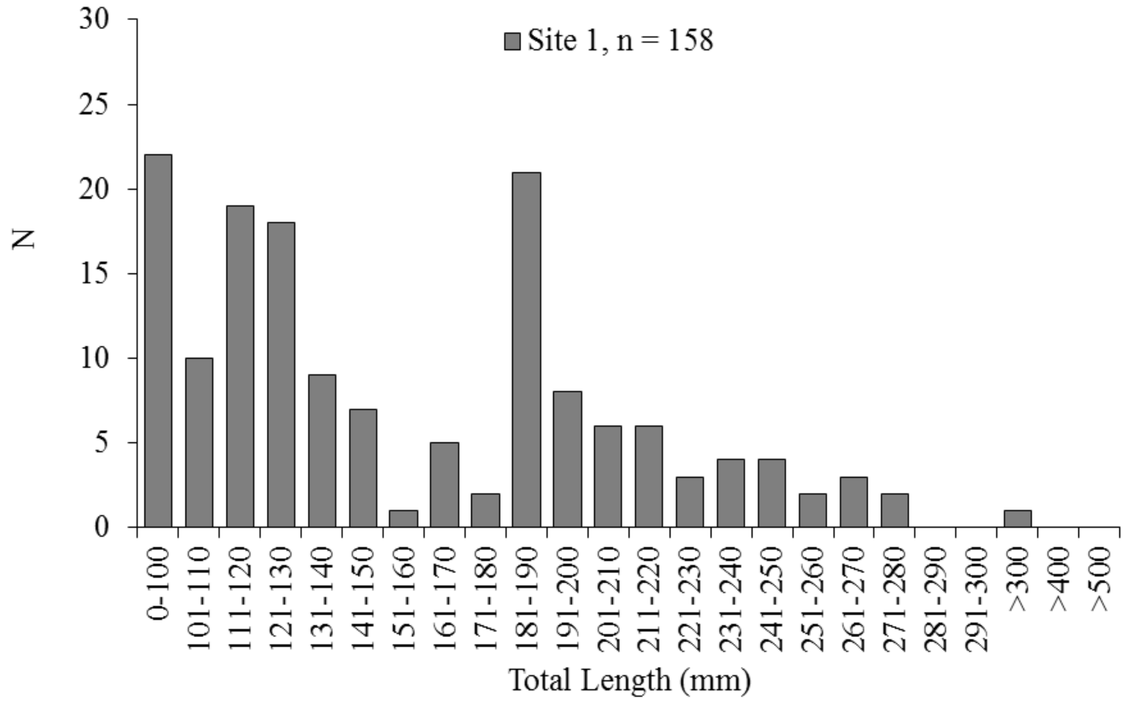


Figure 2. Mean monthly stream discharge records for South Boulder Creek, near Eldorado Springs (U.S. Geological Survey gauge # 06729500) for pre-impoundment (1913 – 1955) and two post-impoundment periods (1956 – 1993 and 1994 – 2015). Numerous diversions dramatically affect stream flow downstream of this gauge, especially in winter months.



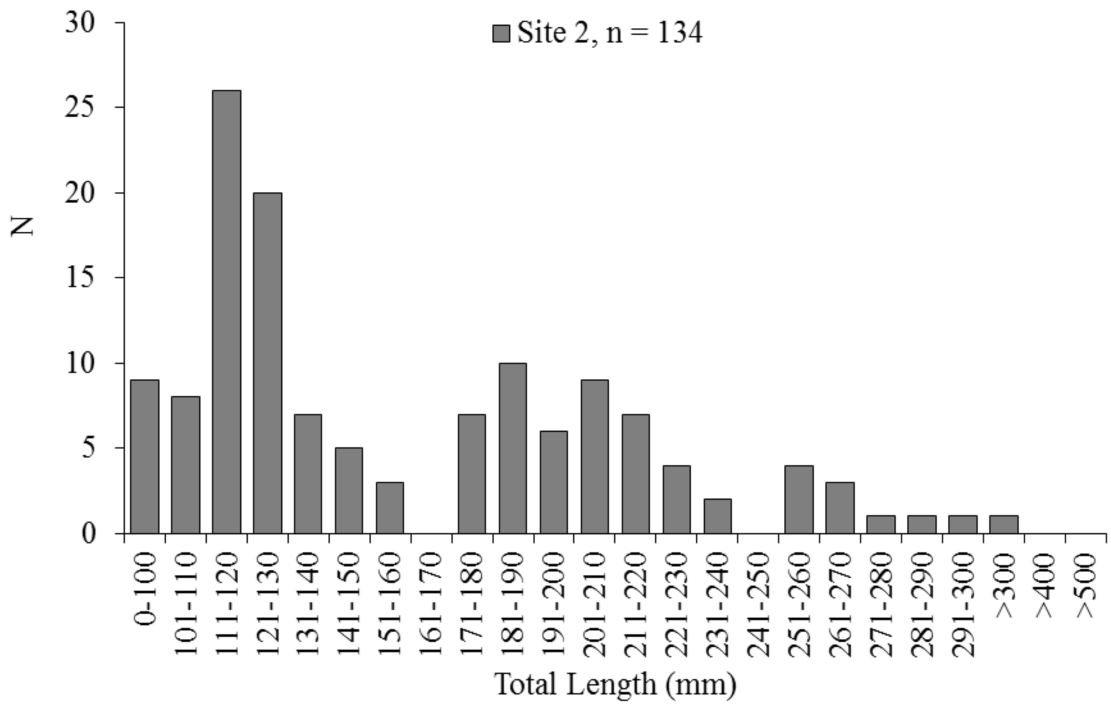
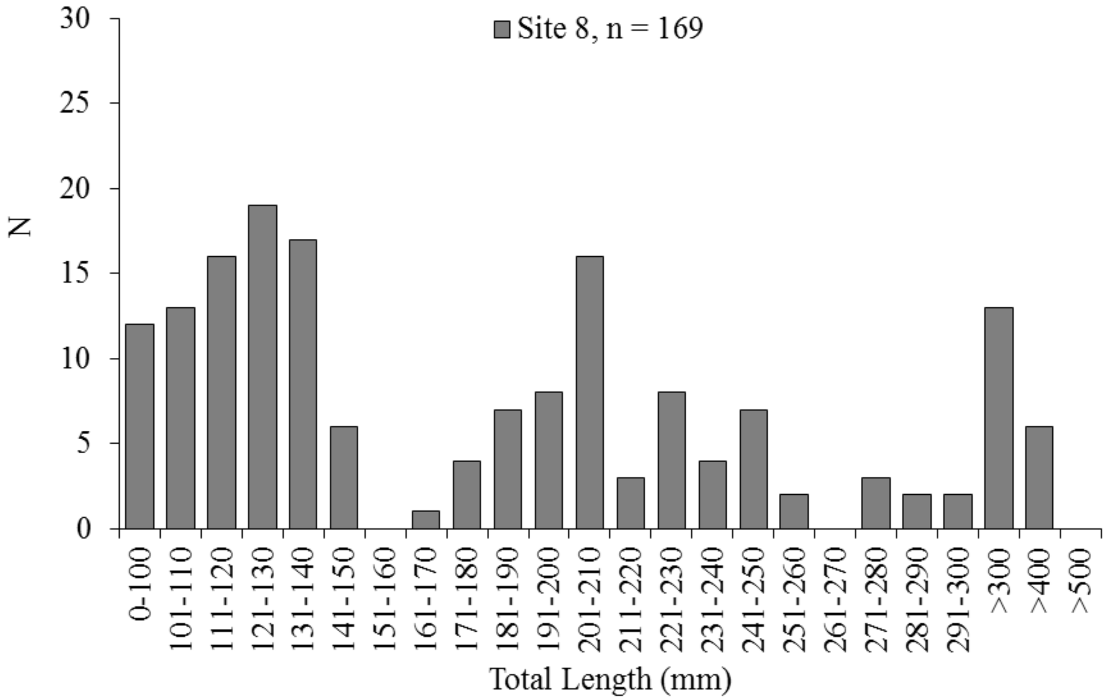


Figure 3. Length frequency data (N = number of fish in each length grouping) of brown trout sub-sampled from fish captured in fall 2015, and spring, summer, and fall 2016 at upstream Sites 1 (South Mesa) and 2 (Lafayette).



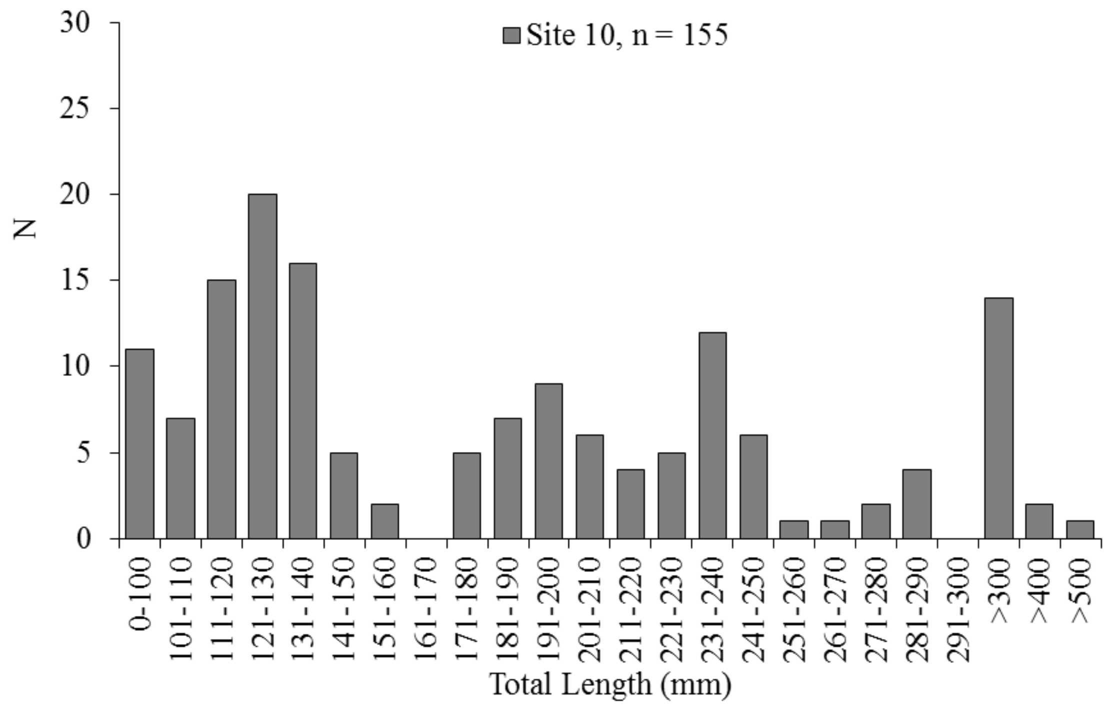


Figure 4. Length frequency data (N = number of fish in each length grouping) of brown trout sub-sampled from fish captured in fall 2015, and spring, summer, and fall 2016 at downstream Sites 8 (South Boulder) and 10 (Baseline).

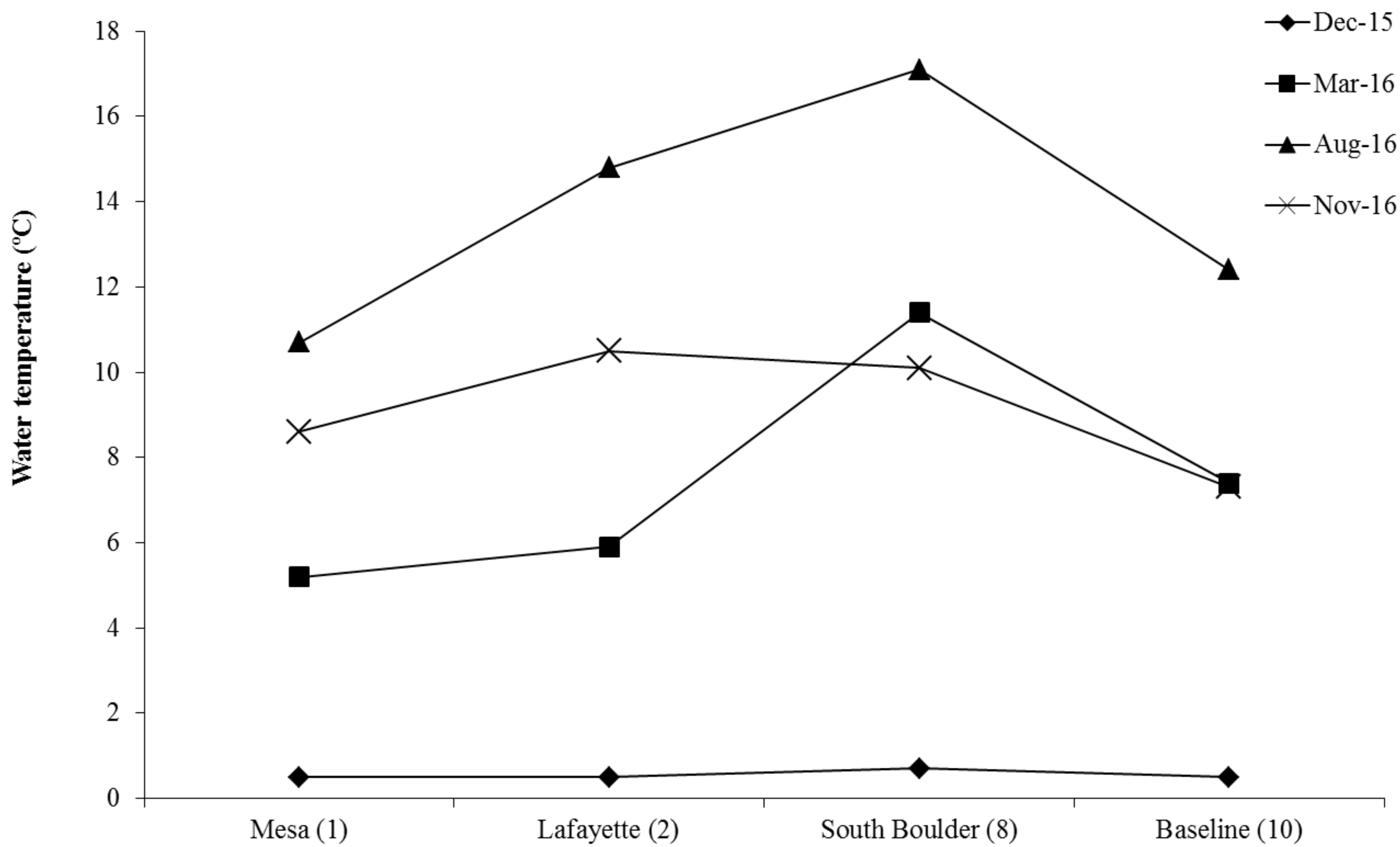


Figure 5. Water temperature (ºC) at each of the four seasonally sampled sites in South Boulder Creek at South Mesa Trailhead (Mesa, Site 1), Lafayette Water Treatment Plant (Lafayette, Site 2), South Boulder Road (South Boulder, Site 8), and Baseline Road (Baseline, Site 10).

APPENDIX I

South Boulder Creek Fish Community Survey

Site 1: Colorado, Boulder County, South Boulder Creek, South Mesa Trailhead, upstream of footbridge for 0.15km.
M.R. Haworth, E.R. Kluender
4 December 2015

	Abundance	
Common name	(No.)	(%)
brown trout	88	94.6
rainbow trout	3	3.2
rainbow x cutthroat trout hybrid	1	1.1
longnose sucker	1	1.1
Totals	93	100.0

M.R. Haworth, RAP, CMF, MMD
27 April 2016

	Abundance	
Common name	(No.)	(%)
brown trout	44	95.7
rainbow trout	2	4.3
Totals	46	100.0

M.R. Haworth, E.R. Kluender
11 August 2016

	Abundance	
Common name	(No.)	(%)
brown trout	56	88.9
rainbow trout	9	11.1
Totals	65	100.0

M.R. Haworth, E.R. Kluender, A.M. Hink
9 November 2016

	Abundance	
Common name	(No.)	(%)
brown trout	127	91.4
rainbow trout	12	8.6
Totals	139	100.0

Site 2: Colorado, Boulder County, South Boulder Creek, 0.3 km upstream of CO State Highway 93, adjacent to LaFayette Water Treatment Plant.
M.R. Haworth, E.R. Kluender
4 December 2015

	Abundance	
Common name	(No.)	(%)
brown trout	66	72.5
rainbow trout	25	27.5
Totals	91	100.0

M.R. Haworth, RAP, CMF, MMD
27 April 2016

	Abundance	
Common name	(No.)	(%)
brown trout	39	81.3
rainbow trout	9	18.7
Totals	48	100.0

M.R. Haworth, E.R. Kluender
11 August 2016

	Abundance	
Common name	(No.)	(%)
brown trout	29	63.0
rainbow trout	17	37.0
Totals	46	100.0

M.R. Haworth, E.R. Kluender
9 November 2016

	Abundance	
Common name	(No.)	(%)
brown trout	136	57.6
rainbow trout	98	41.5
rainbow x cutthroat trout hybrid	2	0.8
Totals	236	100.0

Site 3: Colorado, Boulder County, South Boulder Creek, pond at South Boulder Creek West trailhead, just west of CO State Highway 93.
M.R. Haworth, E.R. Kluender
11 August 2016

Common name	Abundance (No.)	(%)
plains topminnow	7	87.5
green sunfish	1	12.5
Totals	8	100.0

Site 4: Colorado, Boulder County, South Boulder Creek, about 1.1 km downstream of CO State Highway 93, 0.2 km upstream of Shearer headgate.
M.R. Haworth, E.R. Kluender, S.R. Finley
18 August 2016

Common name	Abundance (No.)	(%)
brown trout	44	61.1
rainbow trout	16	22.2
longnose dace	5	6.9
rainbow x cutthroat trout hybrid	4	5.6
green sunfish	2	2.8
longnose sucker	1	1.4
Totals	72	100.0

Site 5: Colorado, Boulder County, South Boulder Creek, about 1.3 km downstream of CO State Highway 93, and 0.2 km downstream of Shearer headgate.
M.R. Haworth, E.R. Kluender, S.R. Finley
18 August 2016

Common name	Abundance (No.)	(%)
brown trout	45	48.4
rainbow trout	22	23.7
largemouth bass	11	11.8
longnose sucker	9	9.7
longnose dace	3	3.2
rainbow x cutthroat trout hybrid	3	3.2
Totals	93	100.0

Site 6: Colorado, Boulder County, South Boulder Creek, 40 m downstream of South Boulder Canyon headgate.
M.R. Haworth, E.R. Kluender, S.R. Finley
18 August 2016

Common name	Abundance (No.)	(%)
brown trout	16	72.7
longnose dace	6	27.3
Totals	22	100.0

Site 7: Colorado, Boulder County, South Boulder Creek, an 80 m section beginning 60 m upstream of U.S. Highway 36.
M.R. Haworth, E.R. Kluender, S.R. Finley
18 August 2016

Common name	Abundance (No.)	(%)
brown trout	55	64.7
rainbow trout	28	32.9
green sunfish	1	1.2
longnose dace	1	1.2
Totals	85	100.0

Site 7b: Colorado, Boulder County, South Boulder Creek, 100 m downstream of McGinn Diversion headgate.
M.R. Haworth, K.R. Bestgen, E.R. Kluender
3 December 2015

Common name	Abundance (No.)	(%)
brown trout	47	55.3
rainbow trout	19	22.3
longnose sucker	15	17.6
green sunfish	2	2.4
longnose dace	2	2.4
Totals	85	100.0

M.R. Haworth, E.R. Kluender, S.R. Finley
18 August 2016

Common name	Abundance (No.)	(%)
brown trout	152	69.4
rainbow trout	37	17.0
longnose dace	20	9.1

longnose sucker	6	2.7
green sunfish	4	1.8
Totals	219	100.0

Site 8: Colorado, Boulder County, South Boulder Creek, 0.4 km downstream of South Boulder Rd.
M.R. Haworth, K.R. Bestgen, E.R. Kluender
3 December 2015

	Abundance	
Common name	(No.)	(%)
brown trout	44	65.6
rainbow trout	20	29.9
green sunfish	2	3.0
rainbow x cutthroat trout hybrid	1	1.5
Totals	67	100.0

M.R. Haworth, E.R. Kluender, RAP
16 March 2016

	Abundance	
Common name	(No.)	(%)
brown trout	75	51.5
rainbow trout	42	28.7
green sunfish	10	6.8
plains topminnow	6	4.1
longnose sucker	4	2.7
golden shiner	4	2.7
rainbow x cutthroat trout hybrid	3	2.1
creek chub	1	0.7
longnose dace	1	0.7
Totals	146	100.0

M.R. Haworth, E.R. Kluender
16 August 2016

	Abundance	
Common name	(No.)	(%)
brown trout	92	38.8
plains topminnow	56	23.6
golden shiner	51	21.5
rainbow trout	11	4.6
longnose dace	10	4.2
longnose sucker	7	2.6

creek chub	7	2.6
green sunfish	3	1.2
Totals	237	100.0

M.R. Haworth, E.R. Kluender, C.M. deVlaming
10 November 2016

Common name	Abundance (No.)	(%)
brown trout	137	48.9
golden shiner	55	19.6
plains topminnow	42	15.0
rainbow trout	34	12.1
rainbow x cutthroat trout hybrid	4	1.4
longnose sucker	3	1.1
creek chub	3	1.1
longnose dace	1	0.4
green sunfish	1	0.4
Totals	280	100.0

Site 9: Colorado, Boulder County, gravel pit pond off of west side of South Boulder Creek, directly northeast of the East Boulder Recreation Area.
M.R. Haworth, E.R. Kluender
12 August 2016

Common name	Abundance (No.)	(%)
largemouth bass	3	100.0
Totals	3	100.0

Site 10: Colorado, Boulder County, South Boulder Creek, Bobolink Trailhead, upstream of Baseline Rd. for 165 m
M.R. Haworth, E.R. Kluender
15 December 2015

Common name	Abundance (No.)	(%)
brown trout	99	80.5
longnose dace	13	10.5
rainbow trout	9	7.3
longnose sucker	2	1.7

Totals	123	100.0

M.R. Haworth, W.H. Keeley, RAP
14 March 2016

	Abundance	
Common name	(No.)	(%)
brown trout	116	56.0
longnose dace	39	18.8
longnose sucker	30	14.5
rainbow trout	15	7.3
bluegill	4	1.9
green sunfish	3	1.5
Totals	207	100.0

M.R. Haworth, E.R. Kluender
16 August 2016

	Abundance	
Common name	(No.)	(%)
brown trout	98	67.1
longnose sucker	25	17.1
rainbow trout	15	10.2
longnose dace	4	2.7
rainbow x cutthroat trout hybrid	2	1.5
bluegill	1	0.7
largemouth bass	1	0.7
Totals	146	100.0

M.R. Haworth, E.R. Kluender, C.M. deVlaming
10 November 2016

	Abundance	
Common name	(No.)	(%)
brown trout	132	69.5
longnose sucker	22	11.6
rainbow trout	20	10.6
longnose dace	12	6.3
rainbow x cutthroat trout hybrid	1	0.5
bluegill	1	0.5
largemouth bass	1	0.5
green sunfish	1	0.5
Totals	190	100.0

Site 11: Colorado, Boulder County, South Boulder Creek, Valmont Reservoir Diversion upstream 0.1 km to Arapahoe Rd.
M.R. Haworth, E.R. Kluender
12 August 2016

	Abundance	
Common name	(No.)	(%)
brown trout	50	22.4
white sucker	50	22.4
fathead minnow	44	19.7
creek chub	40	17.9
longnose sucker	15	6.7
golden shiner	14	6.3
bluegill	4	1.8
green sunfish	3	1.4
largemouth bass	3	1.4
Totals	223	100.0

Site 12: Colorado, Boulder County, South Boulder Creek, approximately 0.3 km upstream of KOA Reservoir, downstream of Valmont Reservoir Diversion.
M.R. Haworth, E.R. Kluender
12 August 2016

	Abundance	
Common name	(No.)	(%)
brown trout	49	63.6
creek chub	22	28.6
largemouth bass	5	6.5
white sucker	1	1.3
Totals	77	100.0

Site 13: Colorado, Boulder County, South Boulder Creek, approximately 0.2 km upstream of KOA Reservoir, downstream of Valmon Reservoir Diversion.
M.R. Haworth, E.R. Kluender
12 August 2016

	Abundance	
Common name	(No.)	(%)
brown trout	20	87.0
white sucker	2	8.7
bluegill	1	4.3
Totals	23	100.0

Site 14: Colorado, Boulder County, northwest arm of KOA Reservoir, east of bikepath.
M.R. Haworth, E.R. Kluender
12 August 2016

	Abundance	
Common name	(No.)	(%)
largemouth bass	42	60.0
bluegill	26	37.1
green sunfish	2	2.9
Totals	70	100.0

M.R. Haworth, E.R. Kluender, C.M. deVlaming
10 November 2016

	Abundance	
Common name	(No.)	(%)
western mosquitofish	15	57.7
golden shiner	5	19.2
plains topminnow	4	15.4
largemouth bass	2	7.7
Totals	26	100.0