Yellowstone Cutthroat Trout Monitoring in Spread Creek, Wyoming

2013 Annual Progress Report

By

Robert Al-Chokhachy
Research Fisheries Biologist
U.S. Geological Survey
Northern Rocky Mountain Science Center
Bozeman, MT
ral-chokhachy@usgs.gov

Jeffrey Kershner
Center Director
U.S. Geological Survey
Northern Rocky Mountain Science Center
Bozeman, MT

Patrick Uthe
Graduate Research Assistant
Montana Cooperative Fishery Research Unit
Montana State University
Bozeman, MT

Executive summary

The Upper Snake River represents one of the largest remaining strongholds of Yellowstone cutthroat across its native range. Understanding the effects of restoration activities and the diversity of life-history patterns and factors influencing such patterns remains paramount for long-term conservation strategies. In 2011, we initiated a project to quantify the success of the removal of a historic barrier on Spread Creek and to evaluate the relative influence of different climate attributes on native Yellowstone cutthroat trout and non-native brook trout behavior and fitness. Our results to date have demonstrated the partial success of the dam removal with large, fluvial Yellowstone cutthroat trout migrating up Spread Creek to spawn, thus reconnecting this population to the greater Snake River metapopulation. Our sampling, however, has also demonstrated considerable entrainment within the existing diversion indicating the need for screening to prevent both juvenile and adult Yellowstone cutthroat trout and other native species from perishing in the diversion system.

Early indications from mark-recapture data demonstrate considerable differences in life-history and demographic patterns across tributaries within the Spread Creek drainage. Our results highlight the diversity of life-history patterns of resident and fluvial Yellowstone cutthroat trout with considerable differences in seasonal and annual growth rates and behavior across populations. Continuing to understand the factors influencing such patterns will provide a template for prioritizing restoration activities in the context of future challenges to conservation (e.g., climate change).

Acknowledgements

This research and monitoring continues to be a collaborative effort with volunteers from multiple groups assisting in field data collection. We would especially like to thank Jim Broderick and the Jackson Hole Chapter of Trout Unlimited, numerous volunteers from the Jackson Hole Chapter of Trout Unlimited, Rob Gipson, Tracy Stephens, and Brian Hines (Wyoming Game and Fish), US Forest Service, Chad Whaley and Sue Consolo Murphy (National Park Service), and the US Fish and Wildlife Service. Funding for this research was provided by the U.S. Geological Survey – Priority Ecosystems Science Program, the Jackson Hole OneFly Foundation, the University of Wyoming-NPS Research Grant opportunity, and donations from the Jackson Hole Trout Unlimited Chapter .

Introduction

Yellowstone cutthroat trout are an integral part of natural ecosystems across their native range as a key resource for terrestrial and avian species and a recreational resource with strong socioeconomic values (Gresswell and Liss 1995; Wengeler et al. 2010). Relative to their historic distribution and abundance, Yellowstone cutthroat trout have experienced considerable declines as a result of habitat fragmentation and degradation and the introduction of non-native species (Gresswell 2011). Ultimately, understanding how anthropogenic-related disturbances influence Yellowstone cutthroat trout is an important step in prioritizing future restoration and directing management and conservation efforts.

In addition to current limiting factors, Yellowstone cutthroat trout are likely to be significantly influenced by global climate change, particularly given the narrow thermal tolerances of this species (Williams et al. 2009). However, the large elevational and latitudinal gradients suggest the effects of global climate change are likely to vary considerably across basins (Al-Chokhachy et al. 2013). Major basins across the intermountain West have experienced a consistent decrease in summer discharge and increase in stream temperatures over the past 50 years (Isaak et al. 2012). The concurrent effects on biotic factors such as non-native species distributions (Wenger et al. 2011a; 2011b) and macroinvertebrate prey (Harper and Peckarsky 2006) will also play a major role in shaping future cutthroat trout distributions. While there has been work describing how climate change may influence spatial patterns of salmonids (e.g., Wenger et al. 2011), there continues to be a paucity of information linking salmonid life-history patterns and demographic rates to climate factors.

To address the conservation and management needs of Yellowstone cutthroat trout, we initiated a research project in 2011 to understand the effects of habitat fragmentation and climate change. This work is conducted through collaboration with Wyoming Game and Fish biologists in Jackson, WY and with considerable support from the Jackson Hole Trout Unlimited Chapter. The specific objectives of this project are to: 1) Monitoring the Yellowstone cutthroat trout population connectivity and spawning locations of migratory Yellowstone cutthroat trout after the removal of the historic dam; 2) Evaluate the extent of entrainment of juvenile and adult Yellowstone cutthroat trout in the diversion ditch created at the new site. The current diversion is not screened, and quantifying the extent of entrainment is critical for identifying the overall success of this project and identifying future needs; 3) Identify how stream temperature, stream flows, and food availability influence life-history characteristics of Yellowstone cutthroat trout; and 4) Quantify Yellowstone cutthroat trout demographic and vital rates across different portions of the stream network in the Spread Creek drainage, and how these factors differ with and without non-native brook trout (*Salvelinus fontinalis*).

Study site

The study area for this research includes portions of the stream network within the Spread Creek drainage in northwestern Wyoming (Figure 1). Spread Creek is a relatively large drainage with over 200 km of fish-bearing streams. Prior to 2010, an impassible barrier (Figure 1) in the form of a diversion dam existed approximately 7.2 km upstream from the confluence with the Snake River. In the fall of 2010, collaborative efforts by state and federal agencies and Trout Unlimited helped remove this barrier and reconnect the Spread Creek drainage with the Upper Snake River.

Spread Creek hosts a variety of native fishes in addition to Yellowstone cutthroat trout, including bluehead sucker (*Catastomus discobolus*), Utah sucker (*C. ardens*), longnose dace (*Rhinichthys cataractae*), mottled sculpin (*Cottus bairdii*), and Paiute sculpin (*C. beldingi*). Non-native brook trout also exist in the Spread Creek drainage

Methods

Fish sampling

Our study area included portions of Spread Creek, South Fork Spread Creek, Grouse Creek, Leidy Creek, and Rock Creek. All of the tributary reaches that were sampled in 2012 were resampled in 2013. Some of the reaches in Spread Creek that had been sampled in 2012 were not re-sampled in 2013 due to time constraints (Figure 2).

Similar to 2012, fish sampling consisted of a summer and fall component in the tributaries and a single summer event in South Fork Spread Creek and mainstem Spread Creek. Summer sampling in the tributaries began the first week of July and was completed the third week of July. Fall sampling was conducted from October 5 to October 11. South Fork Spread Creek and Spread Creek were sampled between July 29 and August 16. Fish were captured exclusively with backpack electrofishing units in the tributaries and a combination of electrofishing and angling in Spread Creek and South Fork Spread Creek. We conducted one-pass surveys in the majority of the sample sites. However, to estimate capture efficiency, we block netted (20-mm mesh) and conducted 3-pass electrofishing surveys in 3 reaches in each tributary. No three pass surveys were conducted in Spread Creek or South Fork Spread Creek during 2013.

Once captured, individuals were placed in a stream-side holding container and identified to species. For all non-salmonids and salmonids <80 mm, we recorded lengths and weights and immediately returned individuals to the stream. We anesthetized all salmonids >80 mm with a diluted solution of clove oil, recorded length and weight measurements, and inserted passive integrated transponder tags (PIT-tags; half duplex, Oregon RFID) ventrally and anterior to the pectoral fins. For all salmonids between 80 and 120 mm we inserted 12 mm PIT-tags and fish >120 mm we used 23 mm PIT-tags. We inserted PIT-tags into a small insertion (2-4 mm) made with a scalpel. After tagging, we placed all fish in a flow-through recovery tank placed in the stream channel. Once fish regained equilibrium, we used hand nets to return fish to slow-water sections within the sampled reach.

Salmonid biomass

Average salmonid biomass was estimated for Grouse, Leidy, and Rock Creeks. Abundance estimates in each reach were adjusted based on the average capture efficiency per stream that was estimated from the three pass electrofishing events (see results section). The mean weight of fish in each reach was multiplied by the corrected abundance estimates to derive an estimate of total biomass per reach. Total reach biomass was divided by the volume of the reach. Reach volume was estimated using average width from three width measurements at each reach and the average depths from the July flow measurements. Reach biomass estimates were averaged across all sites within each stream.

Summer growth

Growth was estimated for all individuals recaptured during the fall sampling event. Daily relative growth rate was calculated using the equation

$$G=[(W_t - W_0) / (W_0 \times t)] \times 100,$$

where G is daily relative growth rate, W_t is mass at recapture, W_0 is mass at initial capture, and t is time between capture and recapture.

Movement and capture-recapture

Prior to fish sampling, we installed passive instream antennae adjacent to the formal diversion structure on Spread Creek and at the mouths of Grouse, Leidy, and Rock Creeks. Each antennae array, including the one postitioned in the irrigation canal, consisted of two channel-wide loops.. Having multiple loops in each channel allows for quantifying directionality of fish movement. A half duplex reader (Oregon RFID multiplexor) was uesd to record movments at each antennae. The system at the old diversion site was powered by two solar panels, which together with the reader and rechargeable batteries were located between the current diversion structure and the Spread Creek Channel. Antennae located in the tributaries were powered by a single solar panel each.

After completion of fish sampling, we used mobile PIT-tag antennae to provide recapture information and information regarding movement for all PIT-tagged individuals. We used continuous surveys in each of the three tributaries. We conducted the mobile surveys using 2 -3 portable antennae, which included hoop antennae (~0.3 m diameter) attached to a pole and mobile rectangular PVC frames (1 m x 3 m). During the mobile surveys, we covered the entire stream channel in a manner analogous to backpack electrofishing. Movement distances were calculated in ArcMap10.1 with the Network Analyst function. Movement estimates represent the distance from the midpoint of the sampling reach where the fish was tagged to the point where it was detected. The estimates have a maximum resolution of 50m so any movement estimate less than that is considered within reach movement.

Entrainment within the diversion structure

During 2012 we conducted opportunistic sampling events in the diversion ditch on July 30 and August 16. During this period electrofishing methods were used to collect all fish observed in the ditches downstream of the diversion structure on Spread Creek. All fish were weighed and measured and transported to Spread Creek. Additional surveys were completed by GTNP biologists and WGF biologists (not included).

Temperature and streamflow

We deployed continuous stream temperature loggers at numerous locations in the study area. Temperature loggers consisted of a combination of Onset Pendants and Onset V2 temperature loggers. In addition to temperature loggers, we deployed pressure-transducers to continuously measure stream flow height (i.e., stage) and develop stage-discharge relationships. We installed the pressure transducers in Rock Creek, Leidy Creek, Grouse Creek, SF Spread Creek and NF Spread Creek above the confluence, and at the site of the historic diversion structure on Spread Creek. Pressure transducers in tributaries were deployed at a site near the mouths and at a site above the top site on each stream. A temperature logger was deployed at the midpoint of each of the three tributaries. Pressure transducers were placed in a perforated 5 cm PVC pipe, partially buried in the substrate and attached to rebar. To establish stage-discharge relationships, we measured discharge at each location during the summer and fall. To avoid losing pressure transducers due to ice, we removed the pressure transducers in early November, and will replace these prior to the spring runoff.

Food availability

Food availability was measured bi-weekly at a fixed sampling site (located between the mouth and the lowest site on each creek) from July through August in Grouse, Leidy, and Rock Creeks. Each sampling event consisted of a morning sample starting at one hour after sunrise and an evening sample starting at one hour prior to sunset. This regimen was chosen to capture the beginning of the crepuscular increase in drift density that is an important feeding period for salmonids**.**

Two drift nets (25 x 45cm, 500 µm) were deployed adjacent to the thalweg of a fast-water channel unit. Nets remained in the channel for one hour to maximize the volume of water sampled without risking backflow due to clogging. Nets were deployed at least 2cm off the substrate to prevent benthic macroinvertebrates from crawling into the nets. Nets were always deployed so that the tops were above the water surface to capture drifting terrestrial invertebrates. Flow and water depth were measured directly after setting the nets and prior to retrieving them. These measurements were used to calculate the volume of water sampled over the hour. The contents of the nets were transferred to storage jars and preserved with 95% ETOH. In order to account for differences in total energy available due to differences in invertebrate community composition among the streams, samples from 2012 were identified to the taxonomic level of order and then dried in an oven at 103°C for four hours (Mason et al. 1983). Energy content was estimated using dry mass-energy equivalents (Curry et al. 1993). There was a strong correlation between total energy estimated from order-specific caloric content and total dry mass of the sample (R^2 = 0.999). Therefore, drift samples from 2013 were oven dried and weighed without partitioning taxonomic groups.

Results

Fish sampling.— We sampled 63 reaches totalling 8,263 m during the 2013 summer field season. The estimated capture efficiency was 0.677 in Grouse Creek, 0.726 in Leidy Creek, and 0.719 in Rock Creek (Table 1).During the fall, the 49 tributary reaches were resampled. During the summer sampling a total of 34 brook trout and 192 Yellowstone cutthroat trout were captured in the tributaries (i.e., Grouse Creek, Leidy Creek, and Rock Creek). Seven brook trout and 41 Yellowstone cutthroat trout were recaptured (i.e., had previously been implanted with a PIT-tag). We implanted an additional 27 brook trout and 138 cutthroat trout with PIT tags. In South Fork Spread Creek and Spread Creek we captured 12 brook trout and 117 cutthroat trout. Six cutthroat trout were recaptured. Twelve of the brook trout and 111 cutthroat trout were implanted with tags and released. During the fall sampling season we captured 48 brook trout and 283 cutthroat trout in the tributaries. Of these, 14 brook trout and 49 Yellowstone cutthroat trout were recaptured individuals. We implanted an additional 30 brook trout and 193 Yellowstone cutthroat trout with PIT tags.

In 2012, we captured the first documented brook trout in Leidy Creek during the fall sampling. In 2013 we captured two brook trout during summer sampling and three additional fish during fall sampling. The invasion of brook trout appears to be from a source population in nearby Grouse Creek (see below).

Since 2011, we have captured a total of 1,754 Yellowstone cutthroat trout and 268 brook trout (Figure 3). The average length of all Yellowstone cutthroat trout captured is 157 mm (range = 25 – 457 mm) and the average length of all brook trout is 142 mm (range = 46 – 313 mm). Size distributions varied among the tributaries during both sampling seasons (Figures 4,5,6), and as expected, sizes of fish within tributaries were considerably smaller than those observed in SF Spread Creek and Spread Creek Sample sites (Figure 8).

Salmonid biomass.— Biomass varied considerably across streams and years (Table 2). In 2013, the estimated average biomass was 11.7 g/m^3 in Grouse Creek, 5.14 g/m^3 in Rock Creek, and 7.69 g/m^3 in Leidy Creek. In general, we found the lowest biomass in Leidy Creek and considerable variability between years in Grouse Creek and Rock Creek, where 2013 biomass was considerably lower than observed in 2012.

Summer growth.— We estimated growth over the summer growing season for 12 trout in Leidy Creek, 15 trout in Rock Creek, and 13 trout (8 brook trout, 5 Yellowstone cutthroat trout) in Grouse Creek. Average relative growth rates varied among streams and between years (Figure 9). In general, brook trout in Grouse Creek consistently demonstrated higher growth rates when compared to Yellowstone cutthroat trout in each of the other tributaries. In 2012, there were no signifcant differences between growth rates of brook trout and Yellowstone cutthroat trout in Grouse Creek, nor between cutthroat trout in Grouse and Leidy Creeks. Yellowstone cutthroat trout in Rock Creek had significanty lower growth rates than observed in both Grouse and Leidy Creeks.

There were no significant differences in growth rates of cutthroat trout across the three tributaries in 2013. Growth rates of brook trout in 2013 were significantly greater than Yellowstone cutthrroat trout in Grouse Creek. Cutthroat trout in Grouse Creek exhibited significantly lower growth rates in 2013 than in 2012. Cutthroat trout in Leidy Creek also had a decrease in growth rates from 2012 to 2013, but this was not significant. In Rock Creek, cutthroat trout had significantly higher growth rates in 2013 than in 2012.

Movement and capture-recapture.— The antennae on Spread Creek were installed on April 23, but were dislodged during runoff and re-installed on June 18. They were removed on October 30; at that time we found that the solar panels used to power our antennae were stolen. As a result, we discovered a non-recoverable error in the tag reader upon removal that precluded us from downloading the detection history for 2013. Given the stolen property and loss of data, we have contacted GTNP to move the placement of this antennae system to the bridge area where Highway 89/91 crosses Spread Creek to avoid further vandalism.

During the periods of operation in 2011 (July 20th – October 31st) and 2012 (May 17th – Oct 31st) we oberved the highest downstream movements during August and October, but downstream movements also occurred during July (Figure 10). Yellowstone cutthroat trout displayed emigration distances from >21 km (Figure 11) including individuals tagged in tributaries (Figure 12). While the majority of PIT-tagged fish emigrated from tagging locations in Spread Creek (Figure 12), the presence of relatively large migrations suggest the headwater tributaries to Spread Creek are part of the Snake River metapopulation.

Given the loss of data during 2013, we combined the lengths of PIT-tagged fish (2011-current) migrating downstream past the antennae at the historic dam location with the lengths of fish entrained within the diversion ditch (2012-2013) to assess the lengths of known emigrants past the historic dam location. We pooled these data given the assumption that fish entrained in the diversion were migrating downstream. Our results indicated Yellowstone cutthroat trout emigration during the summer and early fall in Spread Creek includes a variety of age classes, including age-0 fish (<70 mm) with the highest emigration of age 1-2 fish (100 – 150 mm; Figure 13). Emigration of larger (>200 mm) Yellowstone cutthroat trout likely includes individual migrating downstream post spawning events and larger fish, emigrating for the first time.

During 2013 the antennae on Grouse and Leidy Creeks were installed on March 18 and remained operational through the end of October, while the antennae on Rock Creek were installed on May 21 and remained operational through the end of October. In general, we found the highest movement into and out of Grouse Creek across years, with Leidy Creek demonstrating the least amount of movement and considerable variability across years in Rock Creek (Figures 14, 15). In 2013 there was a substantial difference in the number of fish detected moving over the antennae in each stream. There were 57 fish (44 cuthroat and13 brook trout) detected in Grouse Creek, 24 fish (22 cutthroat and 2 brook trout) detected in Leidy Creek, and 32 fish detected in Rock Creek. Frequency of detections differed across months and across streams (Figure 15). Cutthroat trout movements in Grouse Creek peaked in July and October and fish consistently moved throughout the summer. Movements in Rock Creek peaked in July then remained low for the remainder of the season. Leidy Creek had the fewest tag detections and demonstrated no clear seasonal pattern.

When considering the stream of origin (i.e., where individual fish were initially marked), we found considerable differences across tributaries. The stream of origin of trout detected moving into or out of Leidy and Grouse Creeks was more diverse than in Rock Creek (Figure 16,17) suggesting a panmictic population of Yellowstone cutthroat trout. Of particular interest was the movement of Yellowstone cutthroat trout marked in the NF Spread Creek into Leidy Creek and individuals from Grouse and Leidy Creek moving between tributaries. We also found individual brook trout marked in Grouse Creek moving into Leidy Creek in 2013.

The origin of emigrants from each tributary appeared to vary considerably across streams and years (Figures 18, 19). Within tributaries, most emigrants originated in the lower 10% of the stream lengths in 2013 (Figure 19). However, we found emigrated from a broad distribution of reaches in Grouse Creek and Rock Creek. Our results also documented considerable differences across years, however, we acknowledge such differences may largely be driven by the sample size of existing PIT-tagged fish in the population, which increased considerably in 2013.

Mobile surveys

We surveyed a total of 16 km with mobile PIT-tag readers in 2013 (Figure 20). No mobile sampling was conducted in Spread Creek and South Fork Spread Creek in 2013 in order to increase sampling effort in the tributaries and due to the lower overall capture during these extensive surveys in previous years. The mobile surveys in the tributaries were conducted at the end of June, July, August, and October.

Overall, we detected 490 different trout for a total of 804 detections over the course of all mobile tracking events. Monthly displacement distances were different across seasons and streams (Figure 21). The range of movement in Rock Creek declined considerably after high flows subsided in July, but trout in Leidy and Grouse Creeks continued to exhibit variable mobility throughout the summer and fall. Yellowstone cutthroat trout in Grouse Creek were more mobile than brook trout except for the fall interval when they exhibited very similar movement patterns. Brook trout movement distances are likely influenced by fall spawning migrations.

Entrainment within the diversion structure.—Sixteen Yellowstone cutthroat trout (median length = 225 mm; range = 112 – 375 mm) were captured and transported to lower Spread Creek (Figure 22) during the two days of sampling the diversion structures. One of the fish entrained in 2013 was a Yellowstone cutthroat trout originally marked in 2012 in Spread Creek between the Highway 89/91 bridge and the confluence with the Snake River. The original length during marking in April 2012 was 325 mm (395 g) and the length at recapture was 375 mm (607 g). Given the origin of tagging in lower Spread Creek, the entrainment of this fish clearly documents the return of Yellowstone cutthroat trout from the Snake River to spawn in Spread Creek, thus demonstrating the success of the removal of the historic dam. In addition to cutthrout trout we captured four longnose dace and one sucker.

The data from 2013 combined with the data from 2012 indicate a considerable portion of juvenile and adult Yellowstone cutthroat trout continue to be entrained in the diversion structure (Figure 23). Our results support the need for designing and implementing a screen at the diversion to prevent entrainment and provide unimpeded migration from the Snake River into Spread Creek.

Temperature and streamflow.— Stream temperatures and stream discharge were considerably different between 2012 and 2013 (Figure 24). Average August stream discharge in Spread Creek (above the diversion structure) during 2013 (2.32 m^3/s) was higher than in 2012 (1.68 m^3/s); during September this pattern was more pronounced as 2013 discharge (1.89 m^3/s) was much higher than in 2012 (1.07 m^3/s; Table 3). Average stream temperatures in Spread Creek in August in 2012 (13.7°C) were similar in 2013 (13.9)°C.

Across the three tributaries, we observed considerable differences in discharge during 2012 and 2013 (Figure 25). Stream discharge was highest in Leidy Creek in 2012 and 2013. Discharge in Grouse Creek was higher than in Rock Creek in 2012, but was very similar during 2012. Average summer discharge (July through September) was lower in 2013 than in 2012 for Leidy and Grouse Creeks, but higher in 2013 than in 2012 in Rock Creek (Table 4). Stream temperatures were similar in Rock and Grouse Creeks and slightly cooler in Leidy Creek during both years (Figure 26), but we observed substantial differences in the lapse rates (i.e., how temperatures change within changing elevations: Table 5). Upper Grouse creek demonstrated the lowest stream temperatures across all sites in 2012 and 2013.

Food availability.— We collected four morning and evening samples during July and August in Rock, Leidy, and Grouse creeks in 2013. There were few biologically relevant or statistically signifcant differences between the drifting biomass of invertbrates during the summer months across the three streams (Figure 27). In Leidy Creek the average invertebrate biomass in the drift was 0.18 mg/m^3 (SD = 0.10) in the morning and 0.26 mg/m^3 (SD = 0.12) in the evening during 2012 and was 0.55 mg/m^3 (SD= 0.58) in the morning and 0.39 mg/m^3 (SD=0.14) in the evening during 2013. In Grouse Creek, the average drifting biomasss was 0.14 mg/m^3 (SD = 0.12) in the morning and 0.50 mg/m^3 (SD = 0.53) in the evening during 2012 and was 0.30 mg/m^3 (SD= 0.15) in the morning and 0.67 mg/m^3 (SD=0.35) in the evening during 2013. In Rock Creek, the average drifting biomasss was 0.15 mg/m^3 (SD = 0.10) in the morning and 0.20 mg/m^3 (SD = 0.14) in the evening during 2012 and was 0.24 mg/m^3 (SD= 0.08) in the morning and 0.16 mg/m^3 (SD=0.07) in the evening during 2013.

References

Curry, R.A., S. Allen, M.G. Fox, and G.E. Morgan. 1993. Growth and food of young-of-the-year brook charr, Salvelinus fontinalis, in lake and creek environments. Environmental Biology of Fishes 37: 131-138.

Dunham, J. B., G. Chandler, B. Rieman, and D. Martin. 2005. Measuring stream temperature with digital data loggers: a user's guide. Gen. Tech. Rep. RMRSGTR-150WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p.

Elliott, J. M, and M. A. Hurley. 1995. The functional relationship between body size and growth rate in fish. Functional Ecology 9, 625–627.

Al-Chokhachy, R., J. Alder, S. Hostetler, R. Gresswell, and B. Shepard. 2013. Thermal controls of Yellowstone cutthroat trout and invasive fishes under climate change. Global Change Biology 19(10).

Gresswell, R. E. 2011. Biology, Status, and Management of the Yellowstone Cutthroat Trout. North American Journal of Fisheries Management 31(5):782-812.

Gresswell, R. E., and W. J. Liss. 1995. Values associated with management of Yellowstone cutthroat trout in Yellowstone National Park. Conservation Biology 9(1):159-165.

Wengeler, W. R., D. A. Kelt, and M. L. Johnson. 2010. Ecological consequences of invasive lake trout on river otters in Yellowstone National Park. Biological Conservation 143(5):1144-1153.

Wenger, S. J., D. J. Isaak, J. B. Dunham, K. D. Fausch, C. H. Luce, H. M. Neville, B. E. Rieman, M. K. Young, D. E. Nagel, D. L. Horan, and G. L. Chandler. 2011. Role of climate and invasive species in structuring trout distributions in the interior Columbia River Basin, USA. Canadian Journal of Fisheries and Aquatic Sciences 68(6):988-1008.

Williams, J. E., A. L. Haak, H. M. Neville, and W. T. Colyer. 2009. Potential Consequences of Climate Change to Persistence of Cutthroat Trout Populations. North American Journal of Fisheries Management 29(3):533-548.

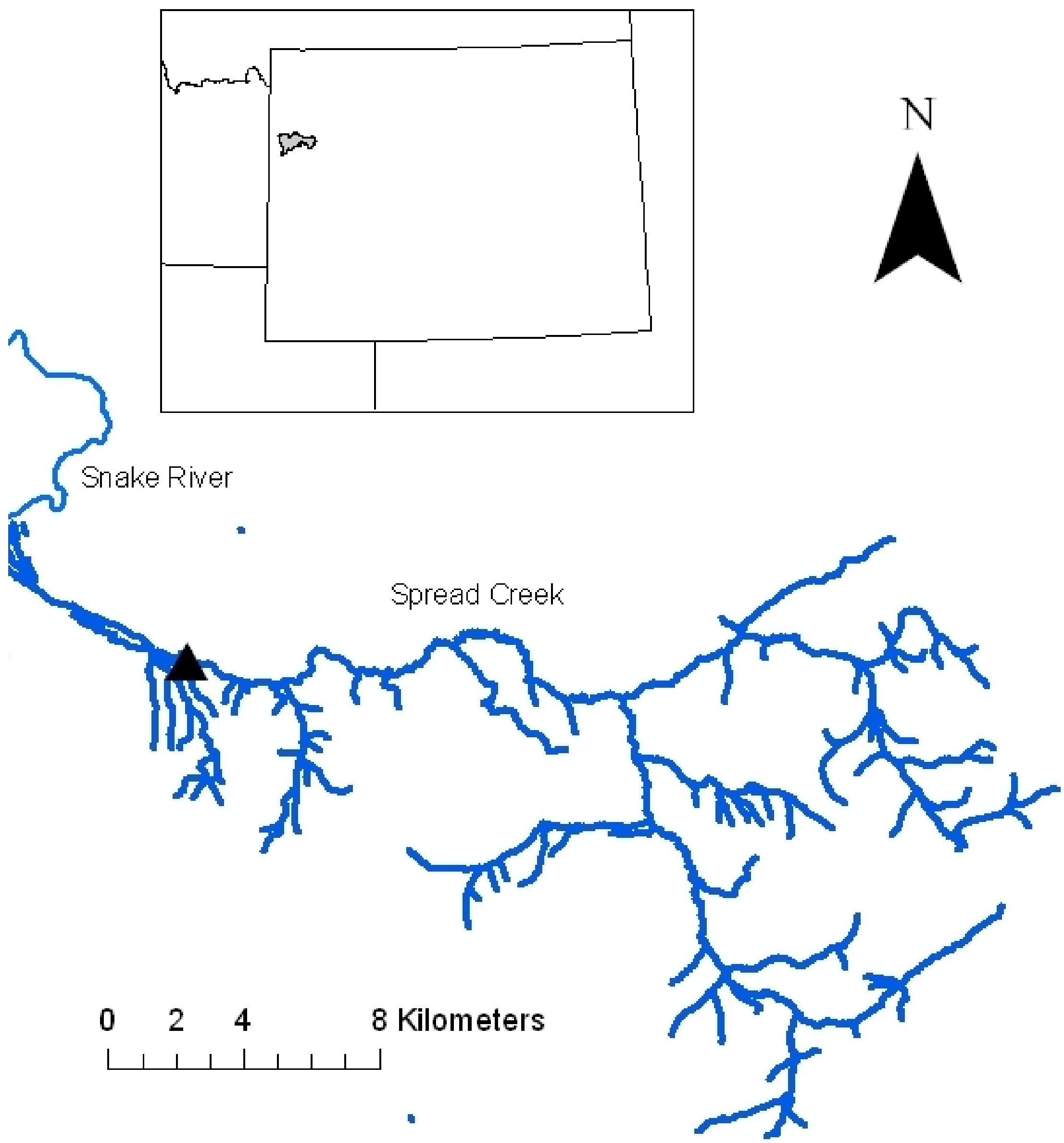

Figure 1. The location of the Spread Creek drainage in Wyoming and the stream network and former diversion dam (black triange) location in the drainage.

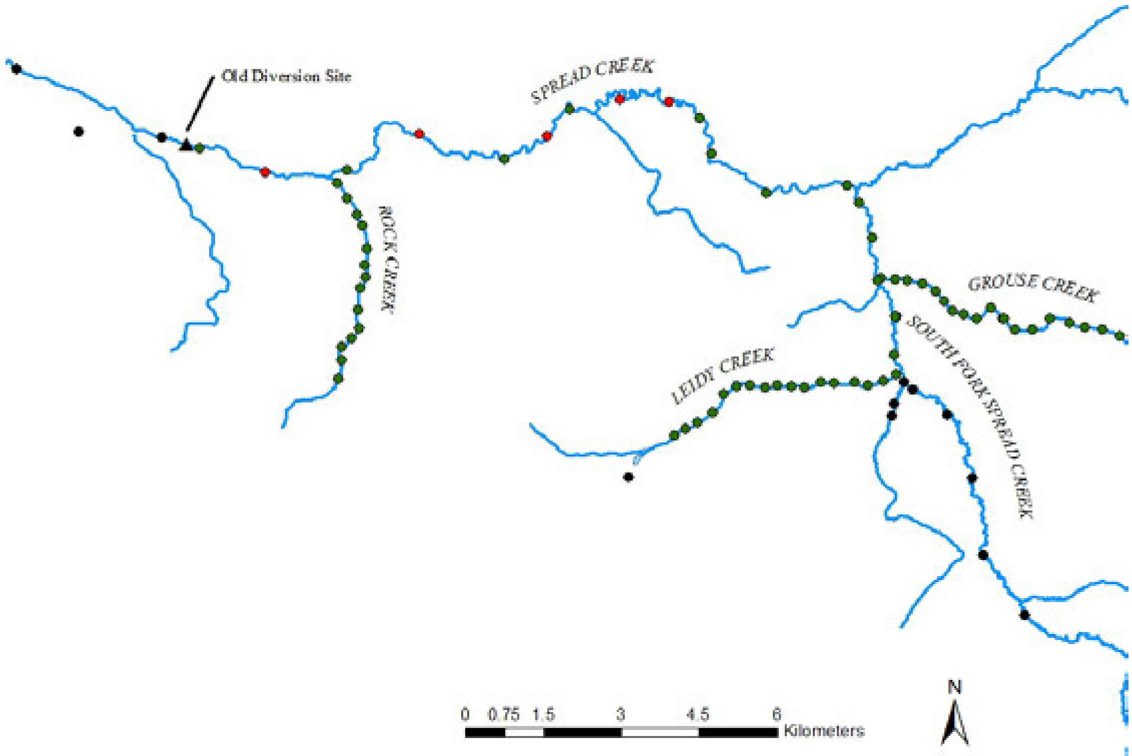

Figure 1. A map illustrating the sites sampled in 2013 (green circles), sites that were only sampled in 2011 (black circles), and sites sampled in 2012 that were not re-sampled in 2013 (red circles).

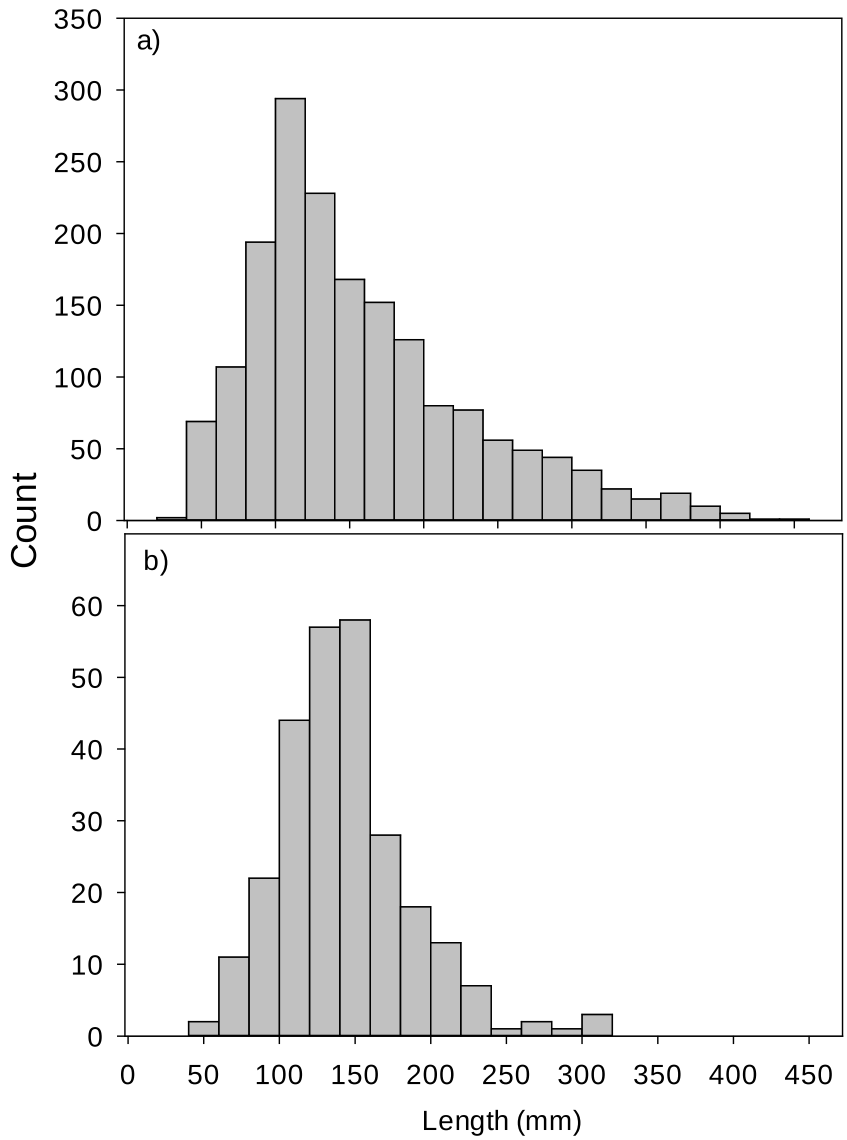

Figure 6. Length-frequency histograms of all Yellowstone cutthroat trout (a) and brook trout (b) captured in all sampling reaches and seasons in the Spread Creek study area from 2011 to 2013.

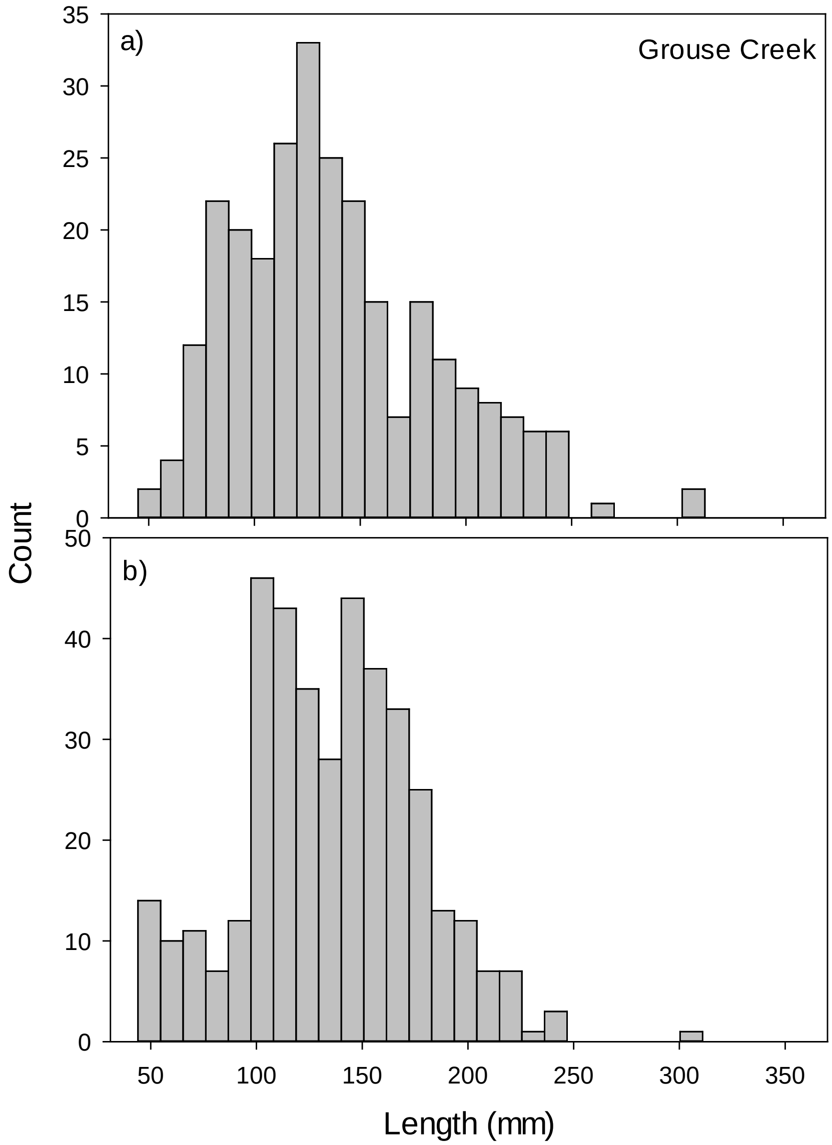

Figure 4. Length-frequency histograms for Yellowstone cutthroat trout captured in Grouse Creek during the summer (a) and fall (b) sampling seasons (2012-2013).

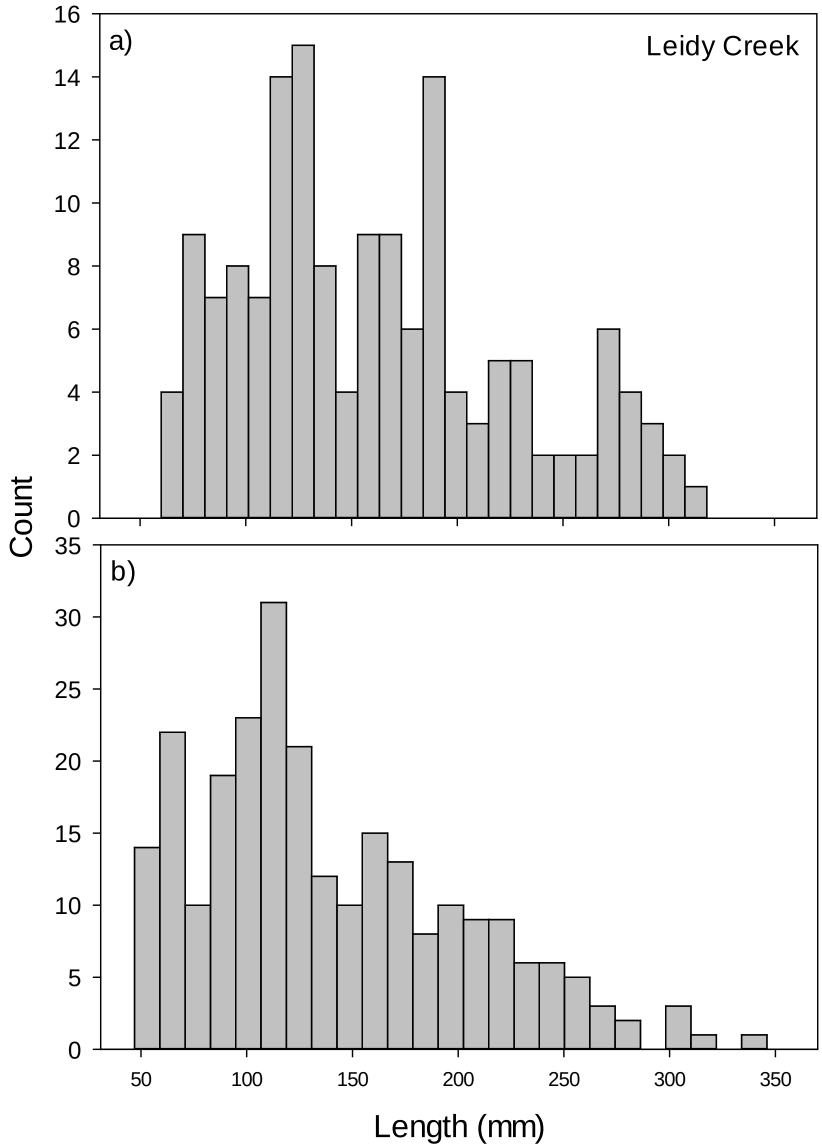

Figure 5. Length-frequency histograms for Yellowstone cutthroat trout captured in Leidy Creek during the summer (a) and fall (b) sampling seasons (2012-2013).

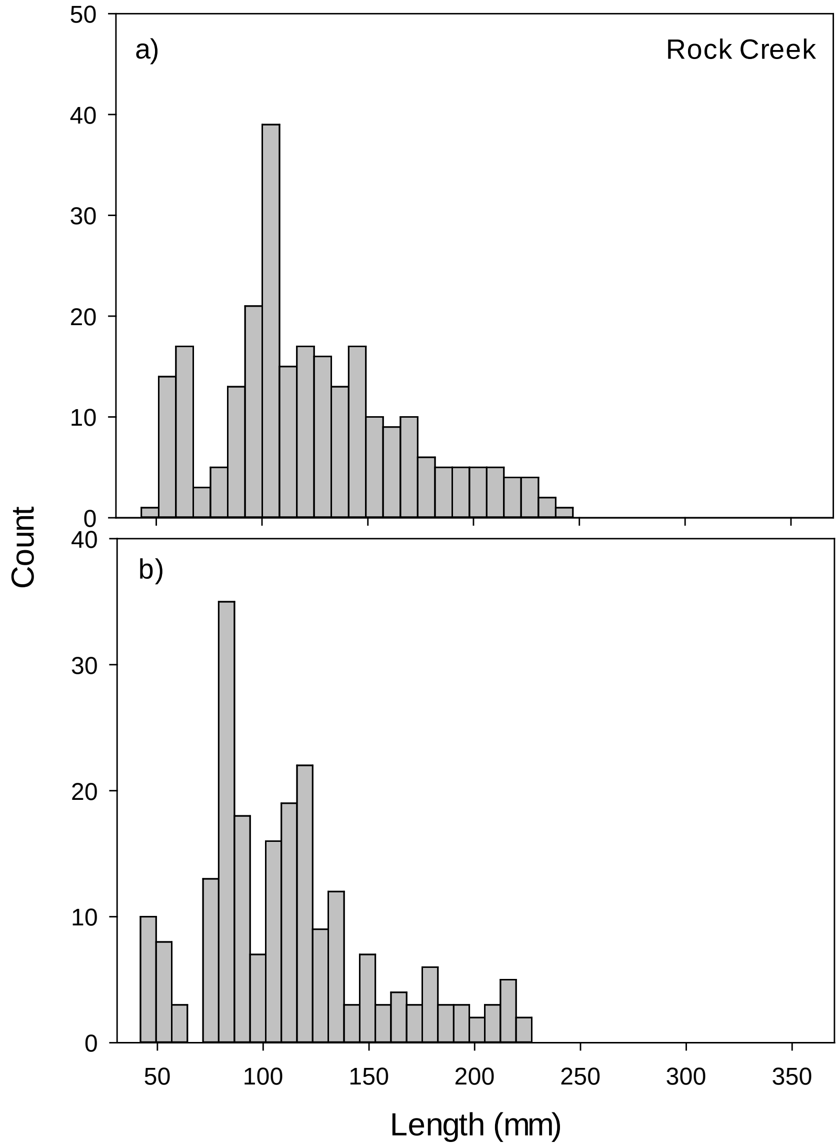

Figure 6. Length-frequency histograms for Yellowstone cutthroat trout captured in Rock Creek during the summer (a) and fall (b) sampling seasons (2012-2013).

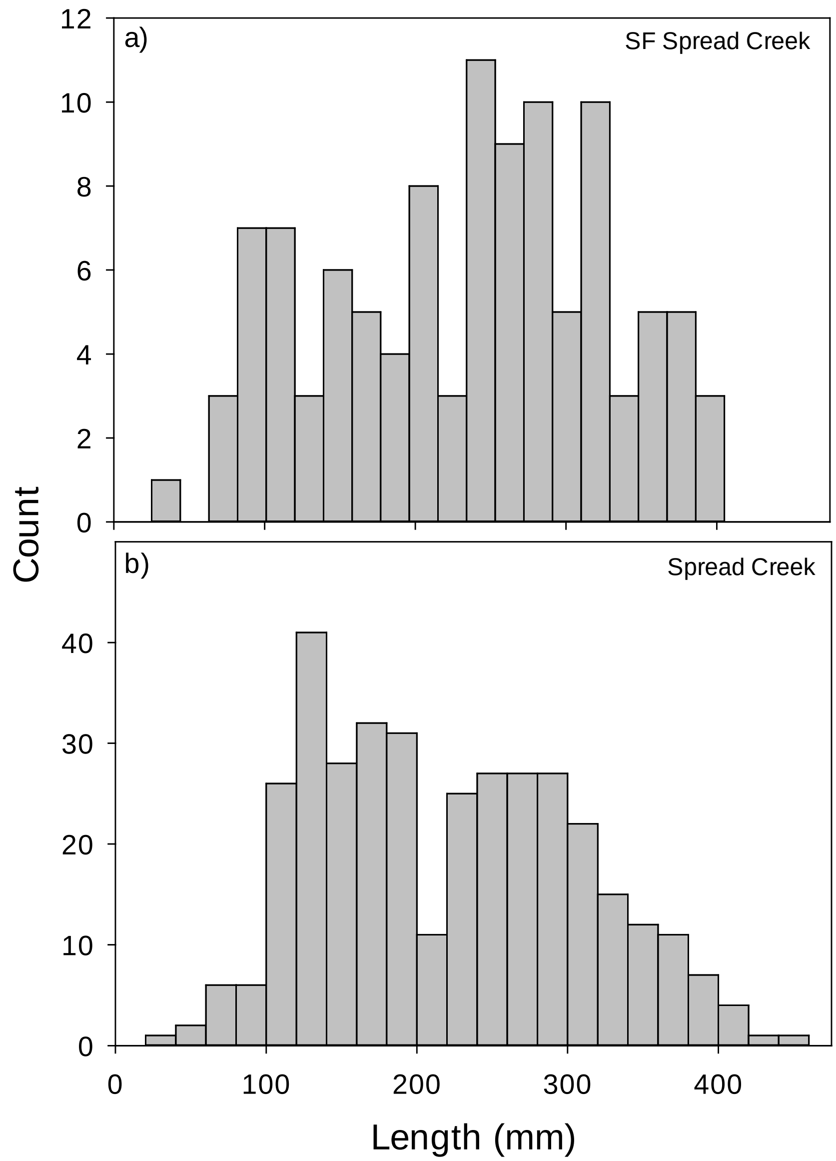

Figure 7. Length-frequency histograms of all Yellowstone cutthroat trout captured in South Fork Spread Creek (a) and the mainstem Spread Creek (b) from 2011 to 2013.

Table 1. Estimated capture efficiencies (p) from the three-pass electrofishing events in 2013.

	Reach	p	Standard Error
Grouse Creek	3	0.615	0.211
	5	0.667	0.384
	8.5	0.75	0.154
Leidy Creek	1	1	n/a
	5	0.8	0.205
	11	0.377	0.106
Rock Creek	1	0.5	0.173
	5	0.824	0.103
	7	0.833	0.168

Table 2. The average (standard deviation) salmonid biomass (g/m^3) in each stream during the summer of 2012 and 2013.

	2012	2013
Grouse Creek	19.02 (10.3)	11.69 (8.47)
Leidy Creek	6.83 (10.8)	7.69 (11.08)
Rock Creek	14.15 (10.77)	5.14 (5.3)

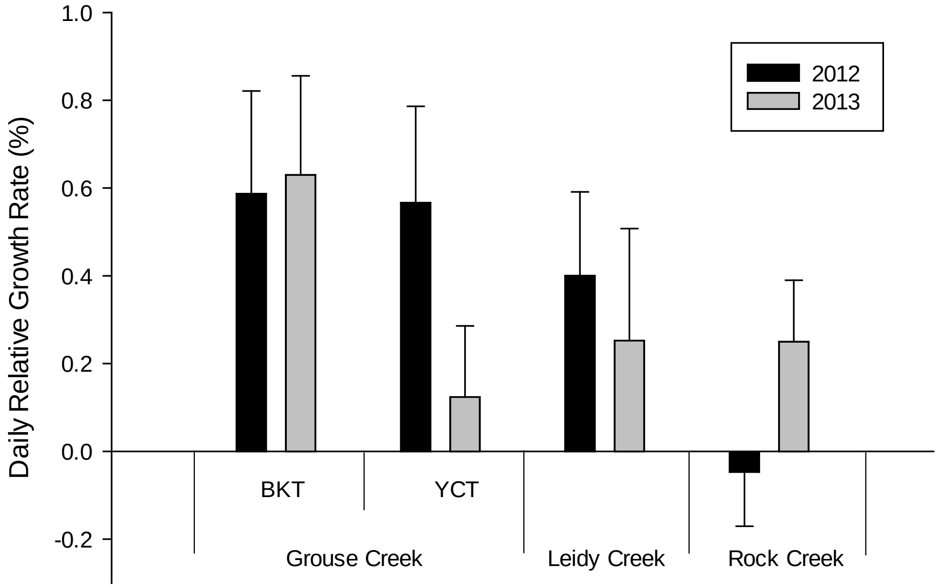

Figure 9. Average relative growth rates in Grouse, Leidy, and Rock Creeks during the summer through fall periods for 2012 and 2013. Error bars represent 95% confidence intervals.

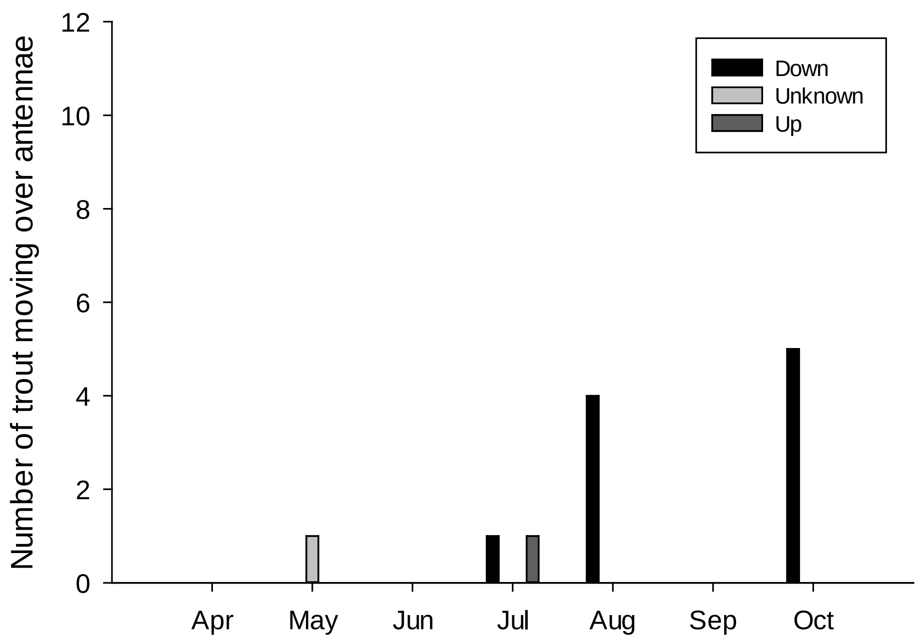

Figure 10. Number of tagged Yellowstone cutthroat trout moving over the stationary antennae at the old diversion site in 2012.These data represent counts of the last known detection of a unique tag number. No brook trout were detected.

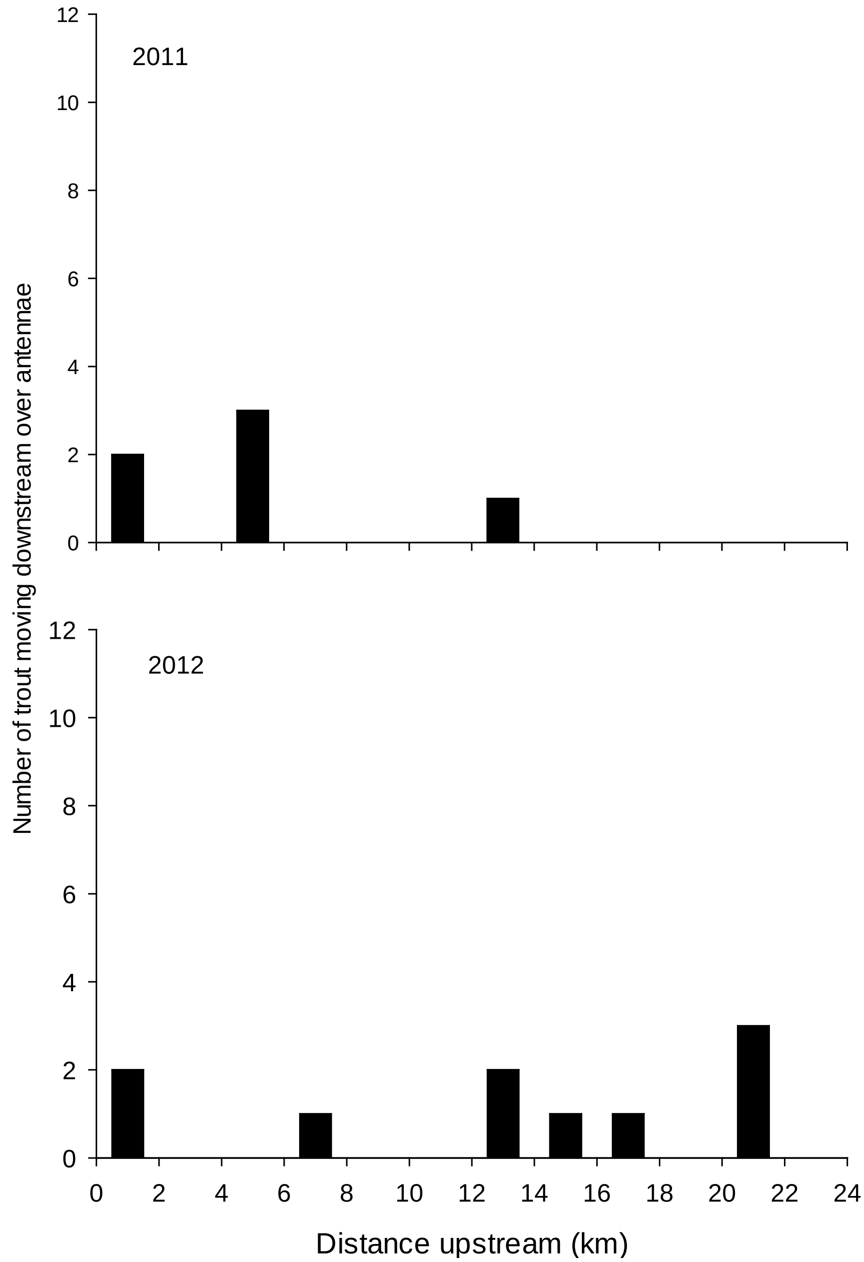

Figure 11. Histogram illustrating the tagging locations (i.e., distance upstream) of PIT-tagged Yellowstone cutthroat trout emigrating from Spread Creek in 2011(top) and 2012 (bottom) past the historic dam location.

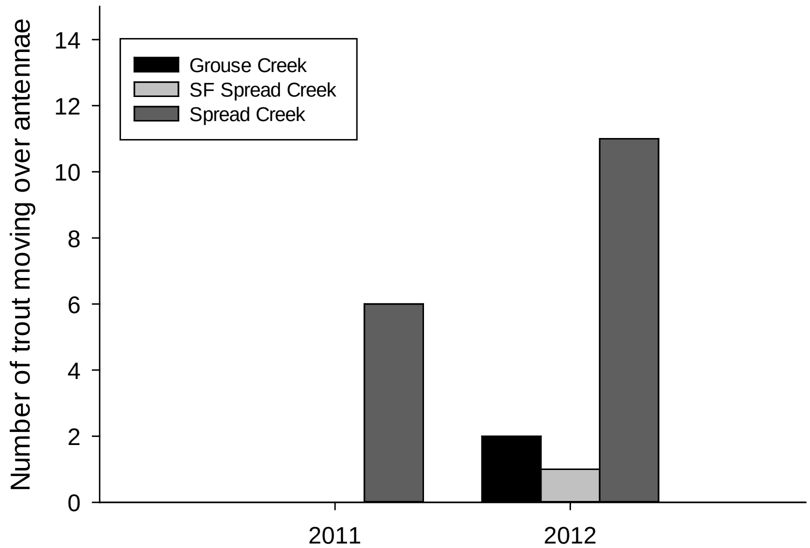

Figure 12. Stream of origin of tagged Yellowstone cutthroat trout detected moving over the stationary antennae at the old diversion location in 2011 and 2012. Note that no brook trout were detected.

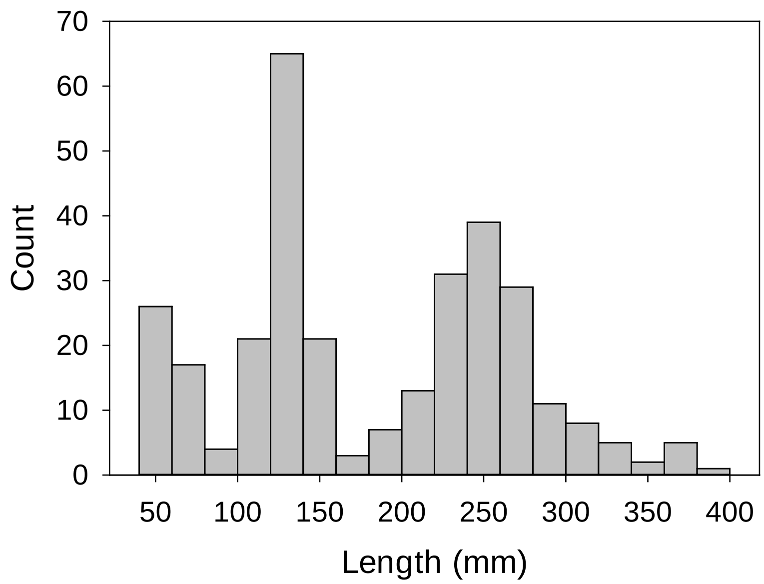

Figure 13. Length-frequency histogram of Yellowstone cutthroat trout detected moving downstream past the PIT-tag antennae at the historic dam site (2011-2012) and salvaged from the diversion ditch during opportunistic sampling events (2012-2013).

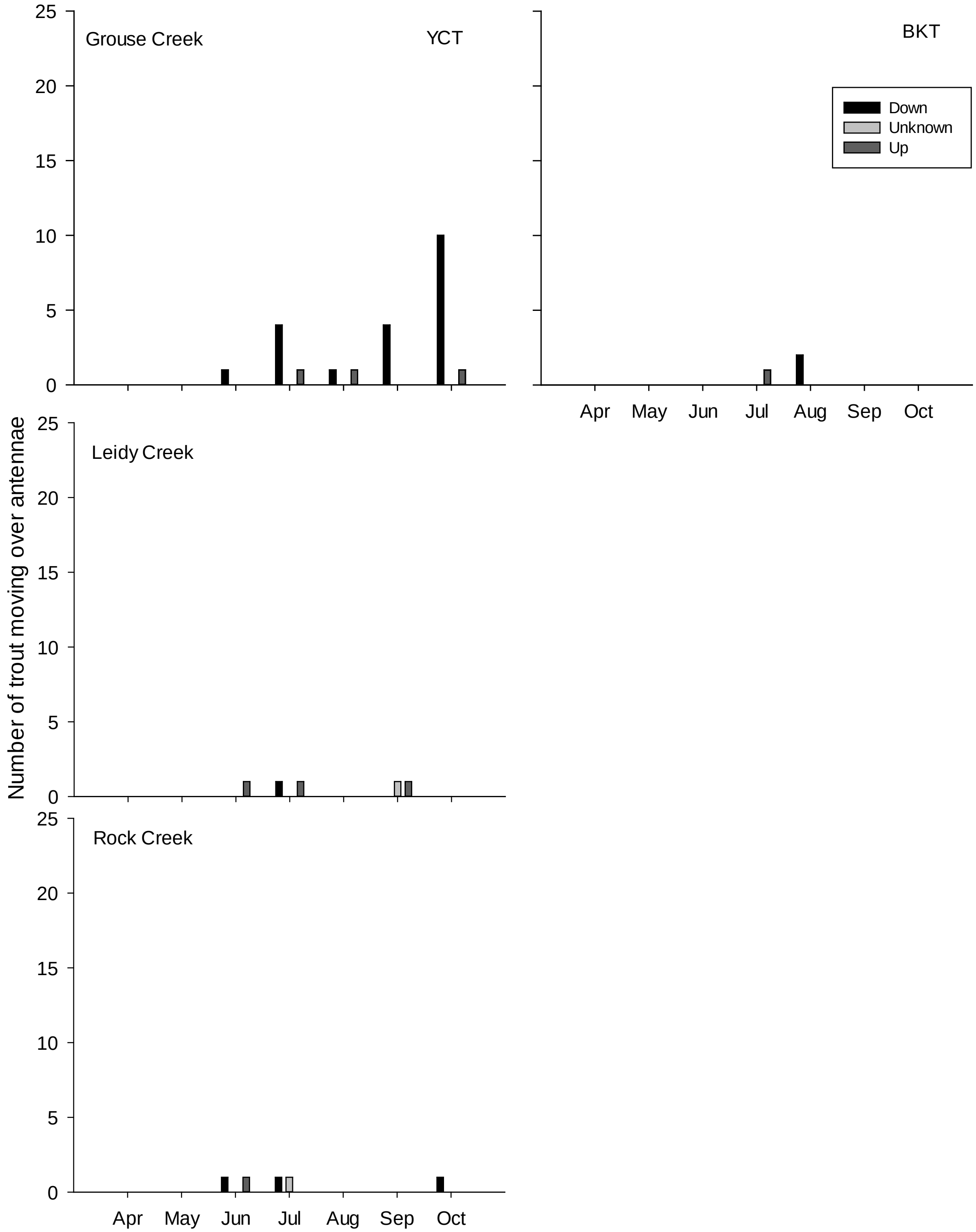

Figure 14. Number of tagged trout moving over the stationary antennae by month in 2012. Plots are arranged by stream (horizontally) and species (vertically). Note that no brook trout were detected in Leidy Creek or Rock Creek. These are counts of the last known detection of a unique tag number.

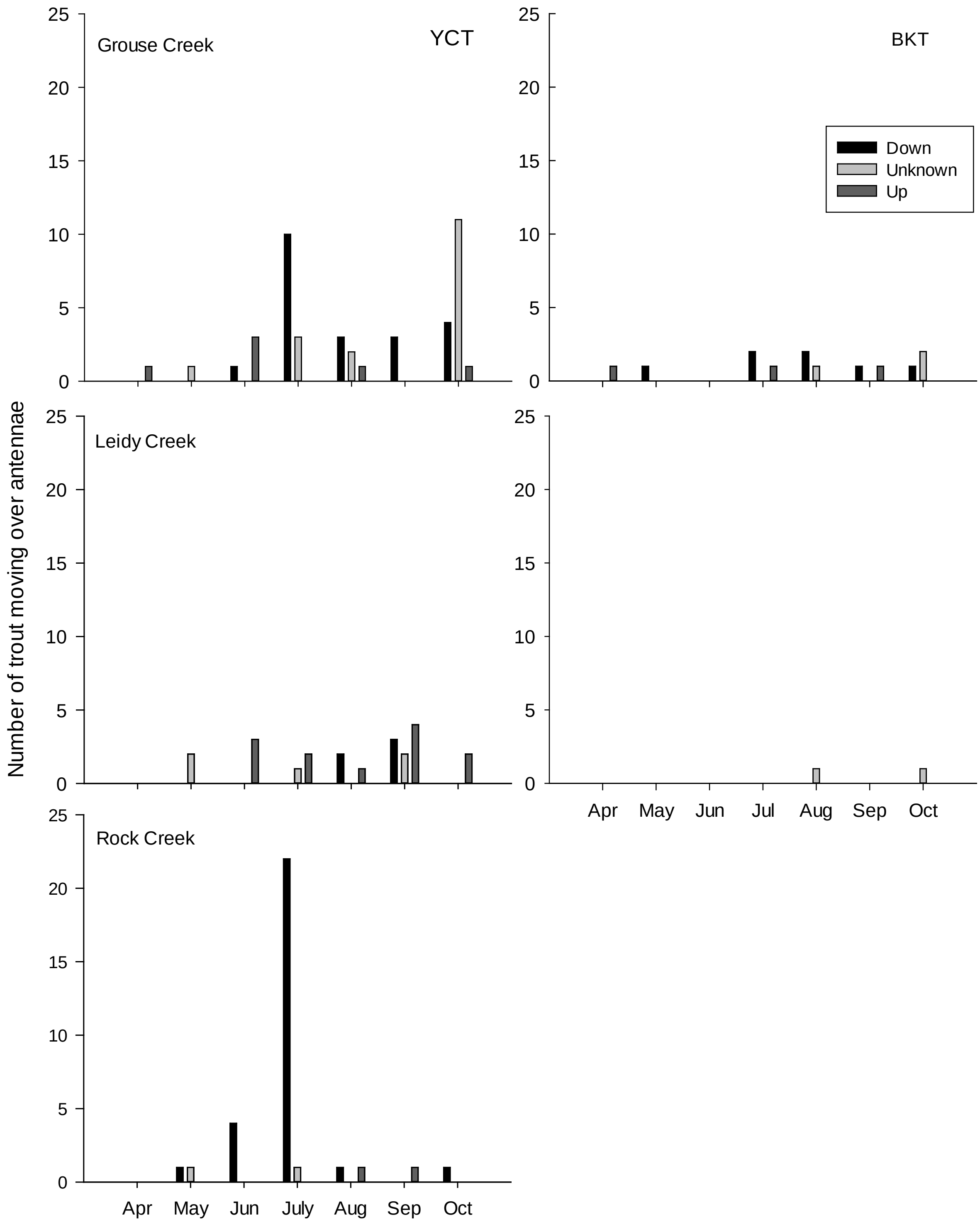

Figure 15. Number of tagged trout moving over the stationary antennae by month in 2013. Plots are arranged by stream (horizontally) and species (vertically). Note that no brook trout have been detected in Rock Creek. These are counts of the last known detection of a unique tag number.

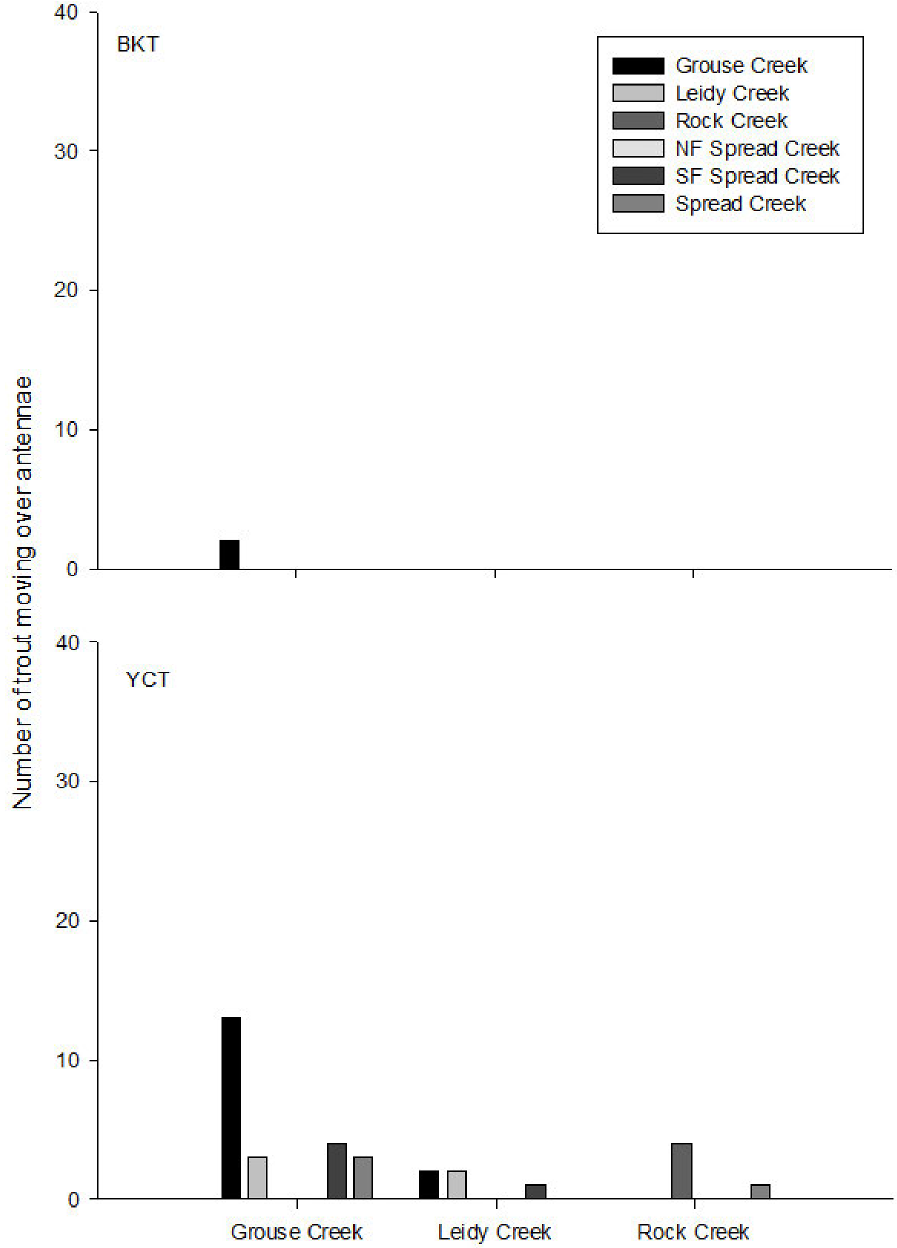

Figure 16. Stream of origin of tagged trout detected moving over the stationary antennae in 2012. Note that no brook trout were detected in Leidy Creek or Rock Creek.

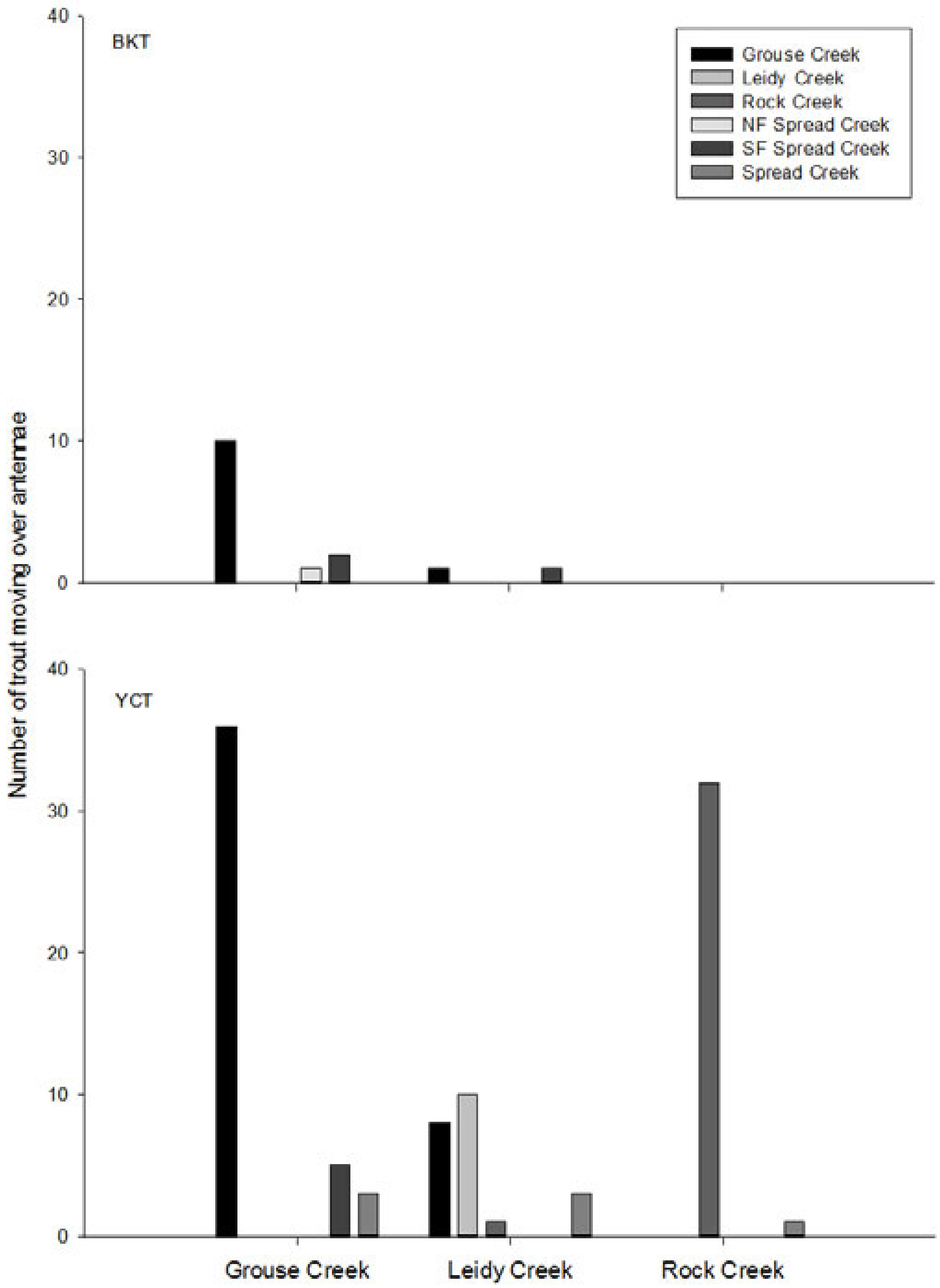

Figure 17. Stream of origin of tagged trout detected moving over the stationary antennae in 2013. Note that no brook trout were detected in Rock Creek.

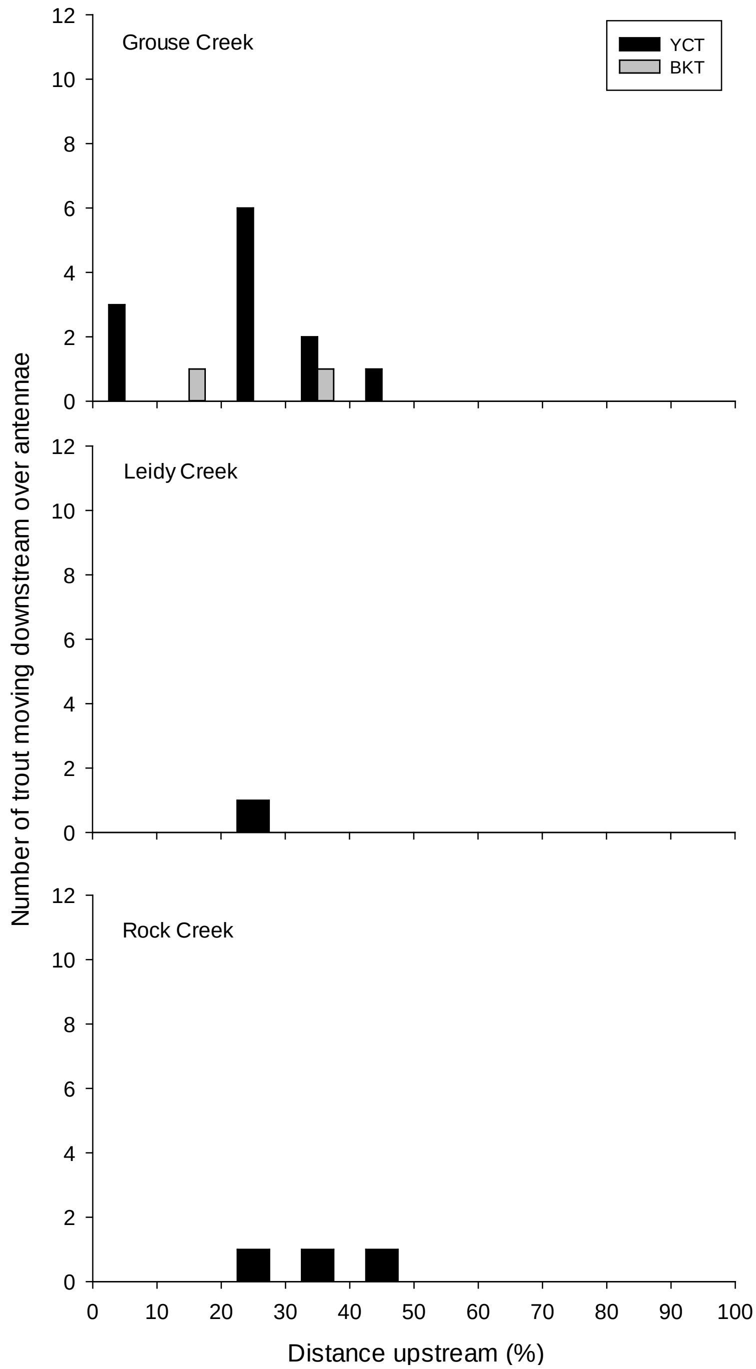

Figure 18. Histogram of tagging locations of PIT-tagged emigrants moving past the fixed antennae at the mouth of each tributary in 2012. Location is the percent of total stream length upstream from the mouth for Grouse Creek (sample length = 5.7 km), Leidy Creek (sample length = 5.4 km), and Rock Creek (sample length = 4.5 km).

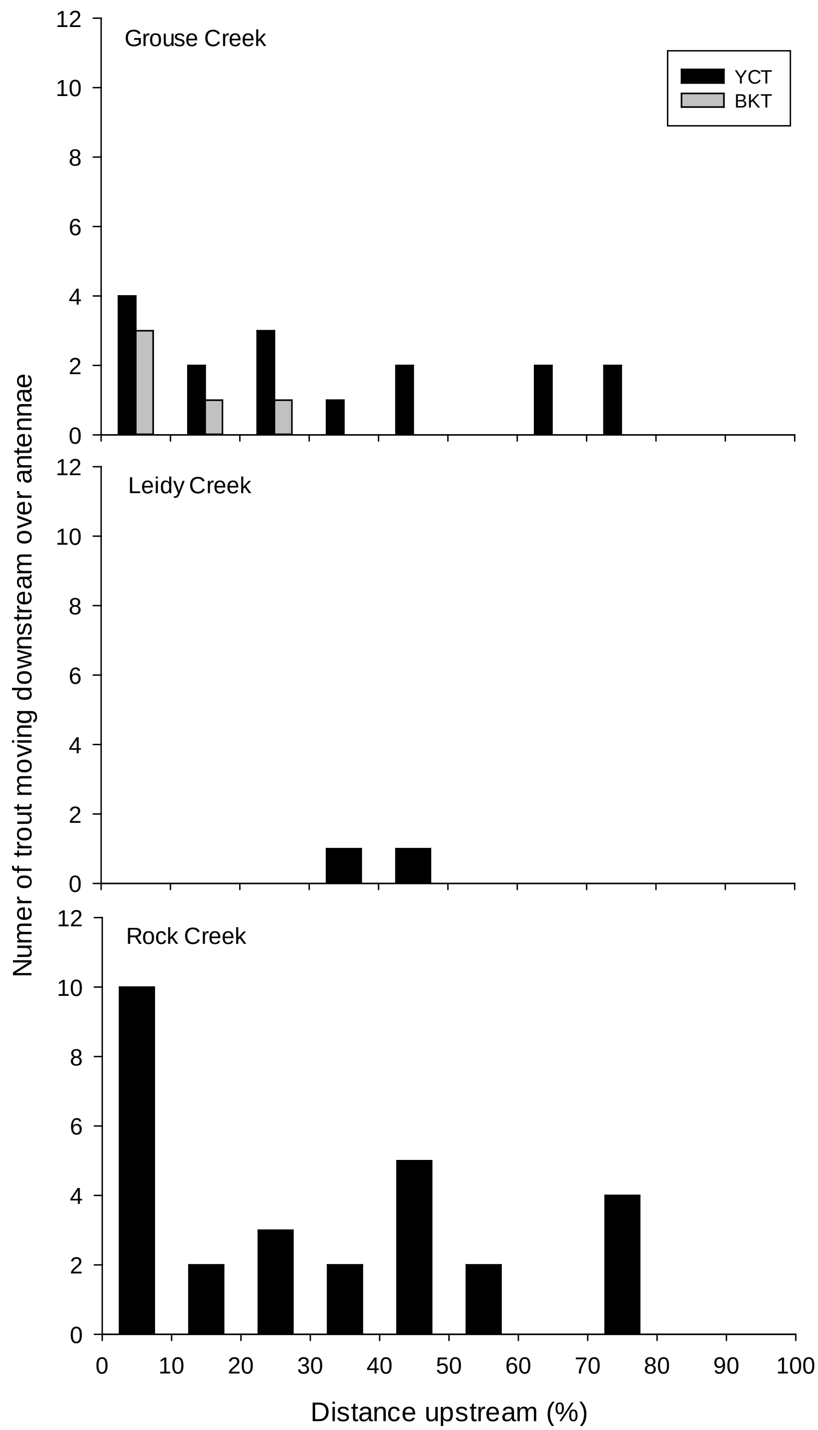

Figure 2. Histogram of tagging locations of PIT-tagged emigrants moving past the fixed antennae at the mouth of each tributary in 2013. Location is the percent of total stream length upstream from the mouth for Grouse Creek (sample length = 5.7 km), Leidy Creek (sample length = 5.4 km), and Rock Creek (sample length = 4.5 km).

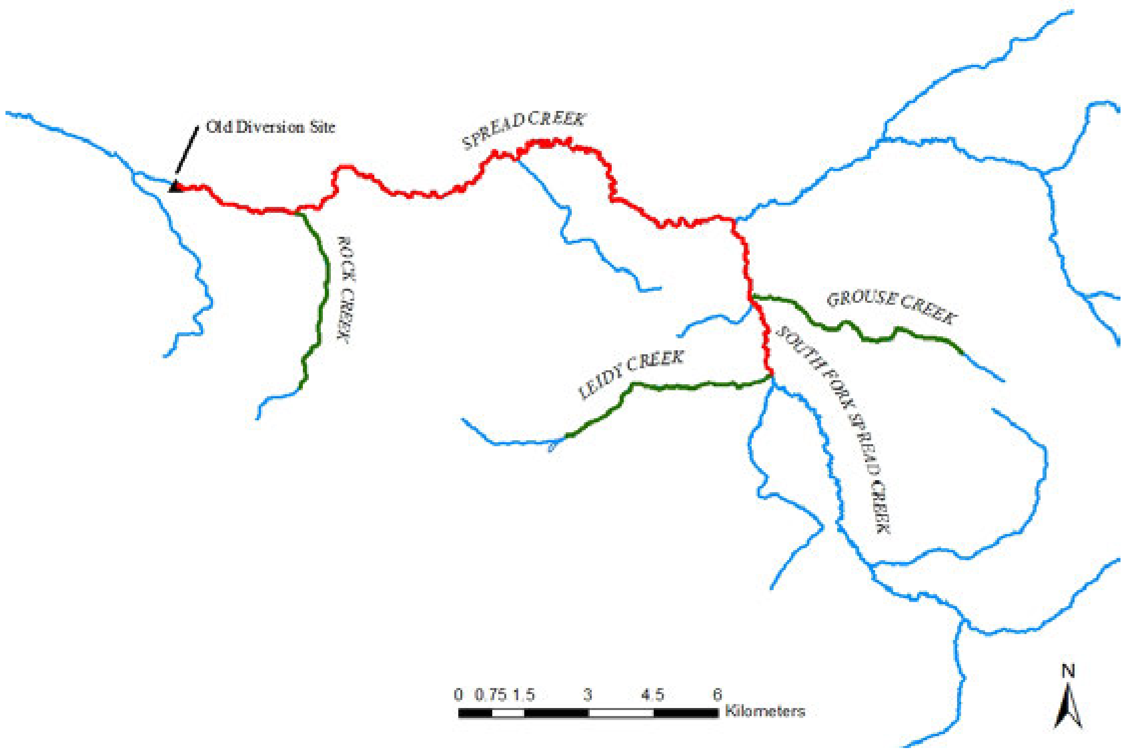

Figure 20. Extent of mobile PIT-tag surveys during the 2013 field season (green) and reaches from 2012 that were not sampled in 2013 (red). Grouse, Leidy, and Rock Creeks were sampled with mobile PIT-tag equipment in June, July, August, and October of 2013.

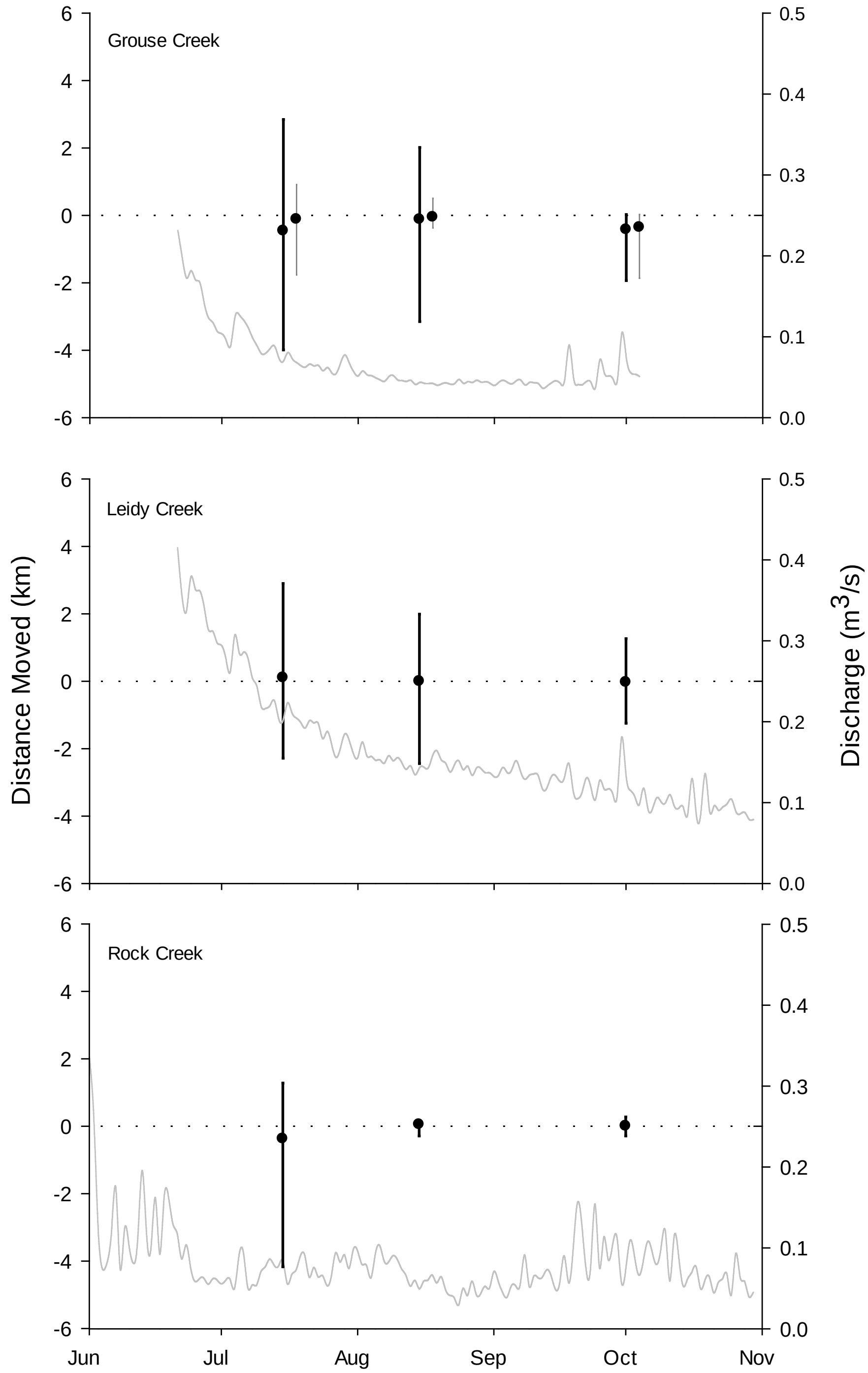

Figure 21. Monthly displacement distances (left y- axis) of Yellowstone cutthroat trout (black vertical lines) and brook trout (dark grey) and mean daily discharges (right y-axis) in 2013. The circles represent the mean displacement distance during the interval and the vertical lines represent minimum and maximum distances moved; negative values represent distances moved downstream and positive values represent distances moved upstream. Note that the fall movement interval is from September to November.

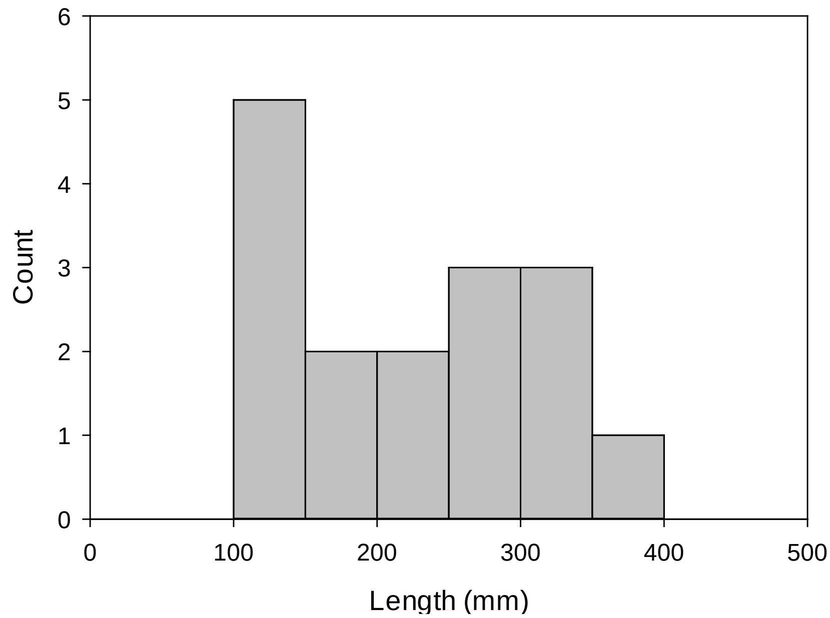

Figure 22. A histogram of the count and length of Yellowstone cutthroat trout entrained and captured in the diversion sediment trap and diversion ditches during the two sampling occasions on July 30 and August 16, 2013.

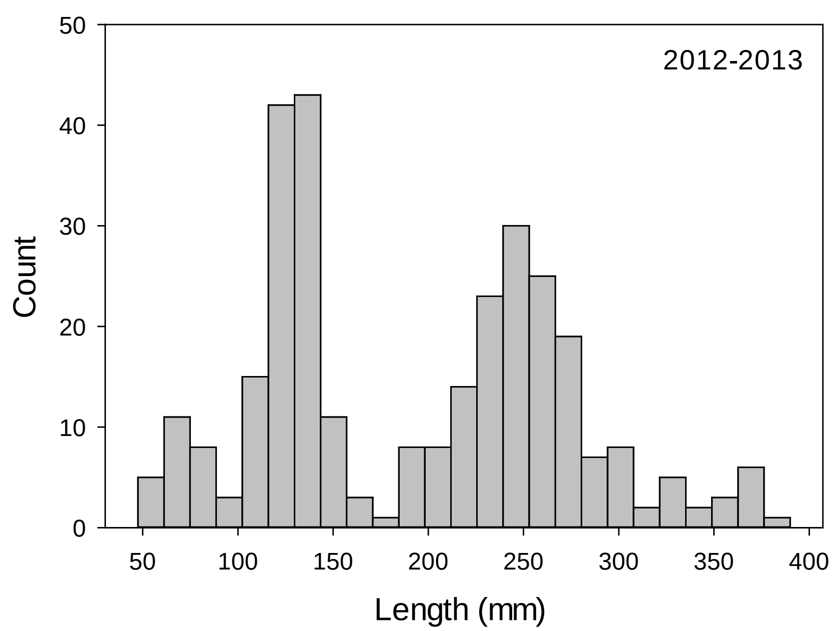

Figure 23. Length-frequency histogram of Yellowstone cutthroat trout entrained and salvaged from the diversion ditch during opportunistic sampling events in 2012 and 2013.

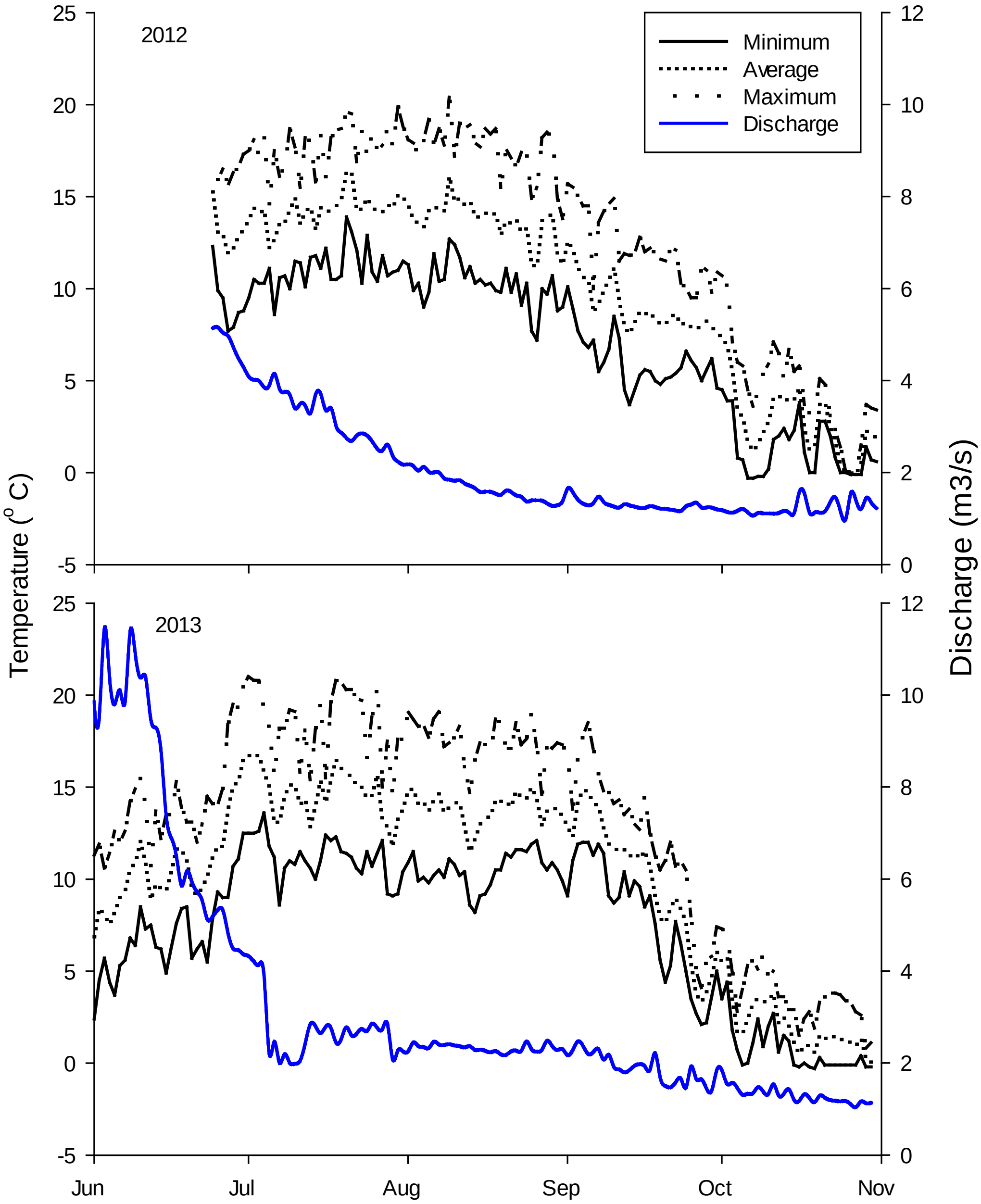

Figure 3. The minimum, average, and maximum daily temperatures and the daily average discharge estimates for 2012 (top) and 2013 (bottom) above the diversion structure on Spread Creek, WY. In 2012, the logger was not installed until June 24.

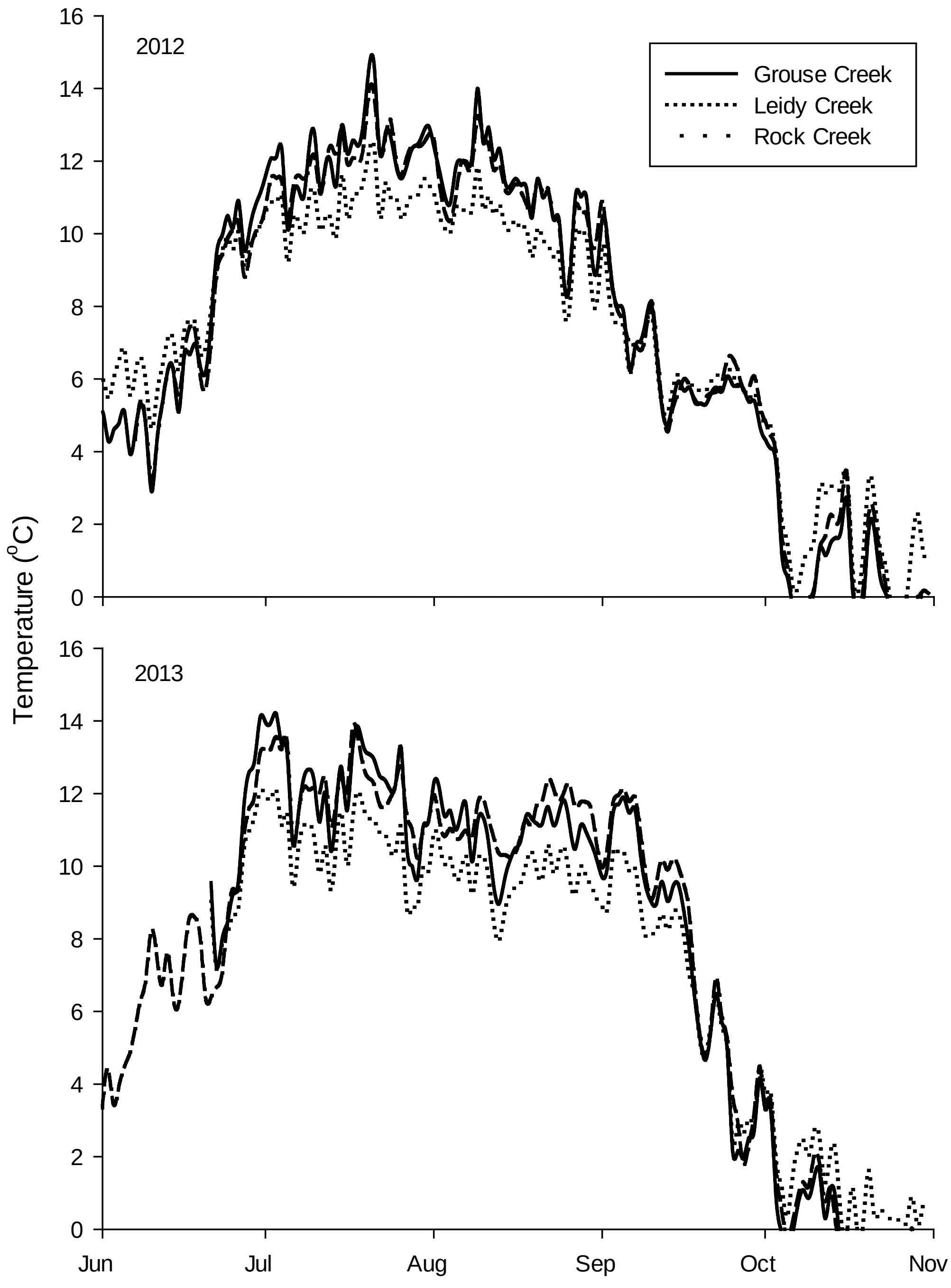

Figure 4. Average daily temperatures in the three tributaries during 2012 (top) and 2013 (bottom).

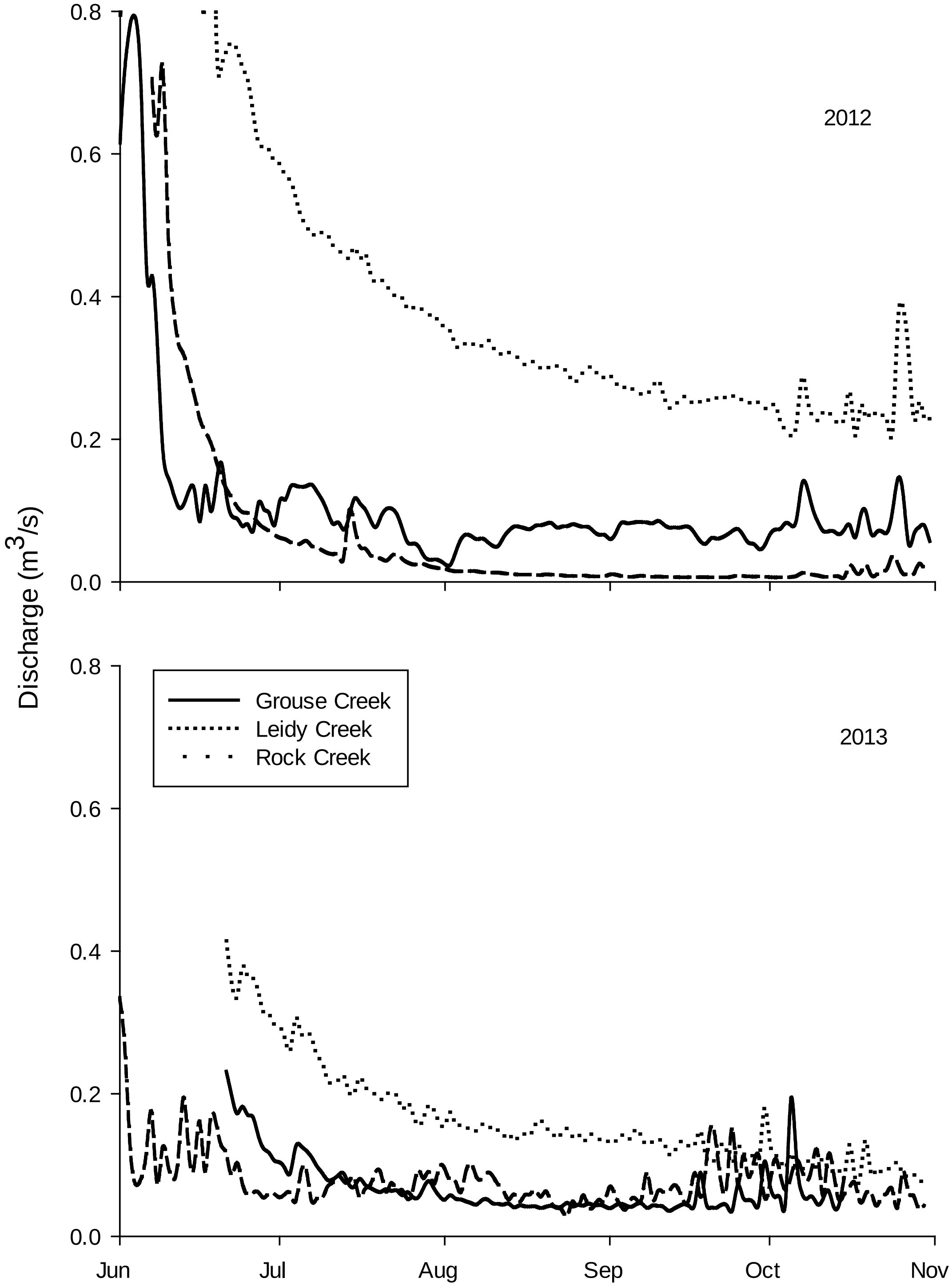

Figure 26. Average daily discharge in the three tributaries in 2012 (top) and 2013 (bottom).

Table 3. The average (Standard deviation) discharge (m^3/s) for Spread Creek above the diversion structure for August and September in 2011, 2012, and 2013.

	August	September
2011	2.61 (0.86)	1.69 (0.34)
2012	1.68 (0.41)	1.07 (0.19)
2013	2.32 (0.16)	1.89 (0.35)

Table 4. The average (Standard deviation) discharge (m^3/s) for Grouse, Leidy, and Rock Creeks during the period of July through September in 2012 and 2013.

	2012	2013
Grouse Creek	0.08 (0.02)	0.06 (0.02)
Leidy Creek	0.34 (0.09)	0.17 (0.05)
Rock Creek	0.02 (0.02)	0.07 (0.02)

Table 5. The maximum average weekly temperature (MWAT), maximum weekly average maximum temperature (MWMT), and the overall instantaneous maximum temperature (MDMT; as per Dunham et al. 2005) (Celsius) for locations within Spread Creek in 2012 and 2013.

	MWAT		MWMT		MDMT	
	2012	2013	2012	2013	2012	2013
Lower Grouse Creek	13.2	13.6	18.3	19.6	19.4	20.5
Upper Grouse Creek	7.4	8.8	10.8	14.1	11.2	14.6
Lower Leidy Creek	11.5	11.6	16.7	17.5	17.7	18.4
Upper Leidy Creek	15.5	16.7	16.9	18.4	17.9	19.2
Lower Rock Creek	12.9	12.7	16.2	16.6	17	17.8
Upper Rock Creek	12.5	12.7	15.0	17.6	18.4	18.7
SF Spread Creek	12.9	13.2	16.8	18.2	17.9	19.9
NF Spread Creek	11.6	12.0	16.7	17.4	18.3	19.3
Spread Creek	15.1	15.6	18.7	20.2	20.4	21.0

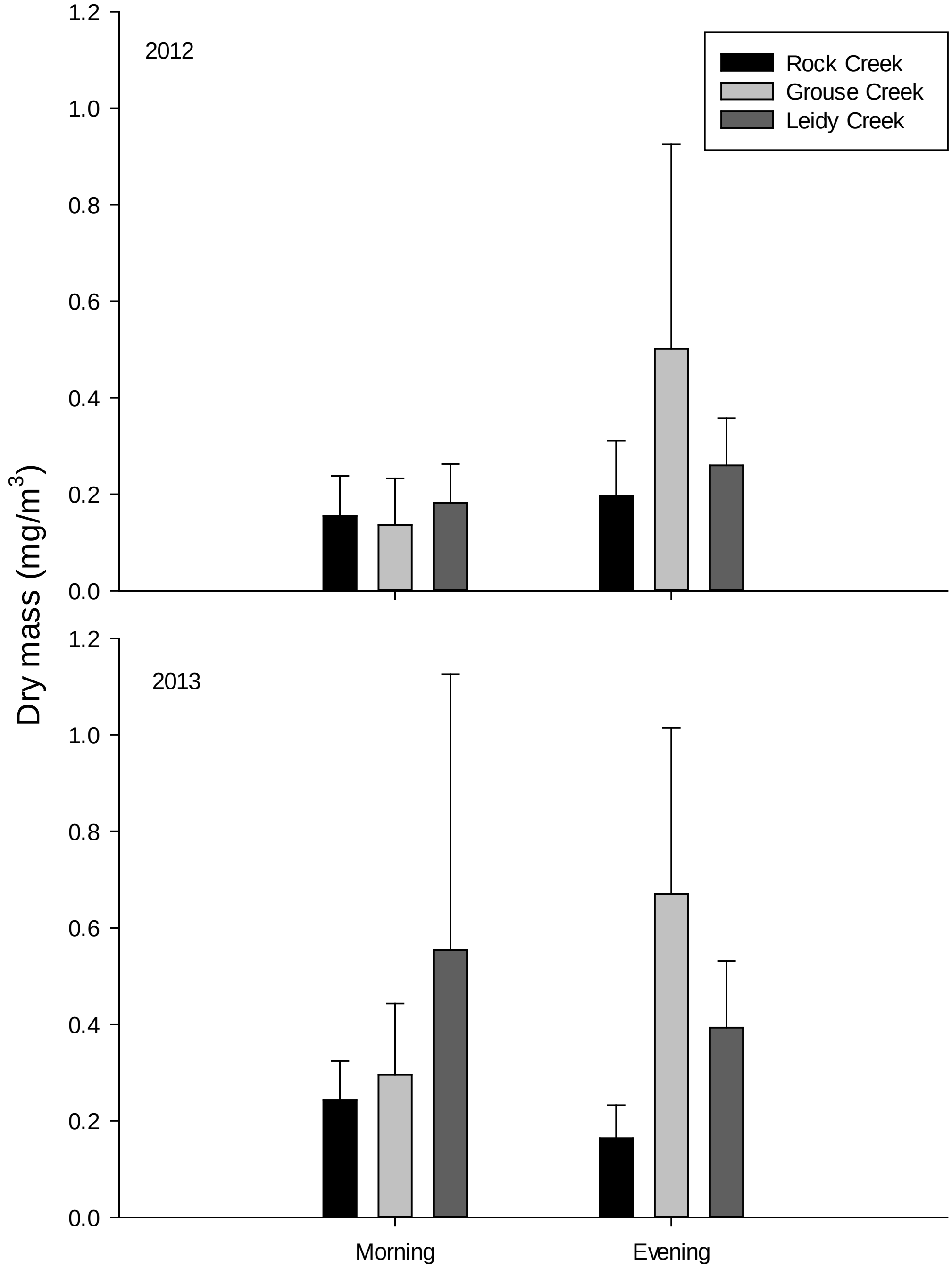

Figure 5. Average dry mass of invertebrates drifting in the water column during the morning and evening sampling events in the three tributaries in 2012 (top) and 2013 (bottom). Error bars represent 95% confidence intervals.

Appendix

Figure 1A. A picture showing how drift nets were deployed for food availability sampling.