National Park Service
U.S. Department of the Interior

Science Report NPS/SR—2024/157
https://doi.org/10.36967/2304877

Fisheries Inventories at Rocky Mountain National Park to Inform Cutthroat Trout Conservation and Recreational Angling Decision Post-fire

Field crews sampling at an unburned (left) and burned (right) site in 2021 at Rocky Mountain National Park.
NPS / YOICHIRO KANNO

Fisheries inventories at Rocky Mountain National Park to inform cutthroat trout conservation and recreational angling decision post-fire

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Please cite this publication as:

Kanno, Y., and D. Preston. 2024. Fisheries inventories at Rocky Mountain National Park to inform cutthroat trout conservation and recreational angling decision post-fire. Science Report NPS/SR—2024/157. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2304877

NPS 121/194118, July 2024

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Abstract

The Cameron Peak Fire and East Troublesome Fire of 2020 were the two largest wildfires in Colorado history. They burned approximately 9% of the Rocky Mountain National Park, raising a concern for trout populations that currently support recreational fishing and success of on-going and future efforts to conserve native trout populations. We inventoried habitat characteristics and biological communities at 19 sites in summer of 2021 and a subset of 11 sites in summer of 2022 to characterize wildfire impacts on aquatic resources, with the focus on characterizing trout population responses. There was much site-to-site variation in the trout population responses, but when averaged across sites using Bayesian hierarchical models, trout abundance significantly decreased in 2021 relative to pre-fire abundance, and the decrease was more evident in smaller trout (75-125 mm total length) than in larger trout (> 125 mm). From 2021 to 2022, trout abundance generally increased, although the increase was statistically significant only in small trout. Although pre-fire data were lacking for benthic macroinvertebrates, their abundance and composition was comparable between burned sites and those outside the fire perimeter, indicating that prey availability to trout was not limited. Our results show that trout abundance decreased post-fire, but trout populations were not eradicated and are likely in a recovery phase. These data cannot be used to argue for stocking trout to sustain recreational fisheries or discontinuing native trout conservation actions including the Poudre Headwaters Project.

Acknowledgements

This project was funded by the NPS Inventory and Monitoring Division Inventory Program.

Grant NO: P21AC11242-00

NPS Research Permit #: ROMO-2021-SCI-0026, ROMO-2022-SCI-0023

Introduction

In 2020, the two largest wildfires in Colorado history burned in and adjacent to the Rocky Mountain National Park (ROMO) burning approximately 9% of the park area. The Cameron Peak Fire burned 208,913 acres and the East Troublesome Fire burned 193,812 acres in the state (Colorado Division of Fire Prevention and Control, 2023). Both were late-season fires with the Cameron Peak Fire starting on August 13 and the East Troublesome Fire on October 14, 2020. These fires apparently impacted not only the terrestrial but also the aquatic environment. Fish kills were reported on both the east and west sides of the Continental Divide, raising a concern for aquatic resources in ROMO.

Wildfire affects streams via changes in water quality, sediment, thermal and flow regimes (Hauer & Spencer, 1998; Silins et al., 2014). These abiotic alterations then affect aquatic biota including algae, benthic macroinvertebrates, and fish (Dunham et al., 2003; Malison & Baxter, 2010; Bixby et al., 2015). Stream ecosystems generally recover from wildfire impacts over time (Dunham et al., 2003; Mihuc & Minshall, 2005), but the magnitude of initial impacts and recovery speed depend on fire severity (Jackson et al., 2012), geography (Verkaik et al., 2015; Yeung et al., 2018), and frequency of disturbances (e.g., post-fire floods) (White et al., 2022). Impacts of high-elevation wildfire such as the Cameron Peak Fire and East Troublesome Fire are relatively little known (Preston et al., 2023), motivating this current inventory effort.

In this study, we surveyed habitat characteristics and biological communities at 19 sites in summer of 2021 and a subset of 11 sites in summer of 2022 to characterize wildfire impacts on aquatic resources. We were primarily interested in trout population structure and abundance, which were compared to available pre-fire data. In addition, we collected information on physical habitat, water quality, algae and benthic macroinvertebrates because wildfire effects are complex (Dunham et al., 2003) and this array of data helps assist identifying ecological mechanisms that affect aquatic top predators (i.e., trout).

Park Resource Management Issues

Rocky Mountain National Park harbors current and future recovery habitat for state and federally listed cutthroat trout (*Oncorhynchus clarkii*) and highly valued recreational fishing opportunities. Quantifying wildfire effects on stream ecosystems and trout populations is needed for ROMO to decide whether (1) ongoing conservation actions should continue including the Poudre Headwaters Project, which is part of the Settlement Agreement with the US Forest Service and the Water Supply and Storage Company to restore the largest meta-population of greenback cutthroat trout (*O. c. stomias*) in its native range in Colorado, (2) recreational fishing should be regulated, and (3) waters should require trout stocking or will naturally recover via trout immigration from connected populations.

The greenback cutthroat trout is listed as state and federally threatened and is the Colorado State Fish. The Colorado River cutthroat trout is a state species of concern and two distinct lineages occur in the burned areas of ROMO. The Cameron Peak Fire burned most of the Hague Creek drainage, which is a part of the ongoing Poudre Headwaters Project to restore a greenback cutthroat trout meta-population. The burned area also supports recreational fishing targeting primarily non-native brook trout (*Salvelinus fontinalis*). Approximately 8% of ROMO visitors engage in fishing, which would total an estimated 360,000 anglers based on the annual visitation of 4.5 million people.

Permits

This study was conducted in accordance with the conditions stipulated in Permit Number ROMO-2021-SCI-0026 and ROMO 2022-SCI-0023. The study was conducted in accordance with protocols approved by the National Park Service Institutional Animal Care and Use Committee (NPS IACUC Project Name CO_ROMO_Kanno_Trout_2021.A2) and Colorado State University Institutional Animal Care and Use Committee (IACUC Protocol Number 1505 and 1539).

Methods

Sample Design

Fieldwork was conducted during the base flow conditions in August and September of 2021 and 2022 to characterize short-term impacts of the wildfires that had occurred in 2020. Our primary sampling occurred in 2021, when we sampled 19 sites (1,615-2,800 m in elevation) in ROMO (Table 1). Fifteen of the 19 sites were within the burn perimeter, and the other four sites (Big Thompson 3, Cascade 1, Poudre 1, & Poudre 3) were just outside the burn perimeter (Figure 1). Sixteen sites with pre-fire trout data were selected and they represented all sites with pre-fire trout data in ROMO. Colorado 9 & 10 and North Inlet were added as new sites, despite lack of pre-fire trout data, because fish kills had been reported in 2020. In 2022, we sampled a subset of 11 sites because additional funding was provided by the Rocky Mountain Conservancy (Table 1). In both years, we collected biological data (fish population, benthic macroinvertebrate community, and chlorophyll-a) and habitat data (width, length, UTM coordinates, qualitative assessment of burn severity, canopy cover, water temperature, pH, and dissolved oxygen). In 2021, we additionally collected data on substrate, conductivity, turbidity, nutrients, and eDNA samples. We compared site-specific and overall trout abundance between pre- and post-fire, and between 2021 and 2022 at 15 of the 19 sites where pre-fire trout abundance data had been collected by the US Fish and Wildlife Service (C. Kennedy, *unpublished data*) and Colorado State University (Y. Kanno, *unpublished data*) (Figure 1). Biotic and abiotic data are submitted along with this report in Excel files following the NPS I&M format style. Two main files are included, one containing data on fish and environmental variables and the second containing data on benthic macroinvertebrates. Our data analyses focus on trout population patterns. We also provide summary statistics and figures conveying macroinvertebrate community structure. Data for the environmental variables are included in the datasets but not analyzed.

Table 1. List of study sites in or near the burn perimeter. Colorado 9, Colorado 10, and North Inlet are new survey sites without any pre-fire trout population data. Hague 4 was excluded from the pre- versus post-fire trout abundance analysis because physical removals of non-native brook trout by electrofishing had occurred as a management strategy to conserve sympatric cutthroat trout at this site. Pre-fire data were collected by US Fish and Wildlife Service (USFWS) and Colorado State University (CSU).

Site	UTM Zone	Easting	Northing	Inside Burn Perimeter	Pre-fire Data	Pre-fire Data Collected by	Post-fire Data
Big Thompson 3	13T	442206	4467913	Adjacent	2014, 2015	FWS	2021, 2022
Cascade 1	13T	440208	4486123	Adjacent	2016, 2019	FWS & CSU	2021, 2022
Cascade 2	13T	438027	4486386	Yes	2016	FWS	2021
Colorado 9	13T	427747	4460718	Yes	NA	NA	2021
Colorado 10	13T	427789	4459047	Yes	NA	NA	2021
Fern	13T	443052	4466097	Yes	2017	FWS	2021, 2022
Hague 1	13T	439164	4485383	Yes	2019	CSU	2021, 2022
Hague 2	13T	439951	4484776	Yes	2019	CSU	2021, 2022
Hague 3	13T	441111	4484941	Yes	2019	CSU	2021, 2022
Hague 4	13T	442238	4483872	Yes	2006, 2013, 2016, 2018	FWS	2021
Hazeline 1	13T	440083	4484525	Yes	2012	FWS	2021, 2022
Hazeline 2	13T	439922	4484752	Yes	2004, 2012, 2016, 2018, 2019	FWS & CSU	2021, 2022
Mummy Pass	13T	441388	4485645	Yes	2009, 2019	FWS & CSU	2021, 2022
North Inlet	13T	432024	4456703	Yes	NA	NA	2021
Onahu 2	13T	428105	4463342	Yes	2012	FWS	2021
Poudre 1	13T	437539	4483125	Adjacent	2019	CSU	2021
Poudre 3	13T	434801	4478087	Adjacent	2019	CSU	2021, 2022
Poudre 5	13T	437448	4485042	Yes	2010	FWS	2021, 2022
Tohahutu	13T	430494	4456690	Yes	2012	FWS	2021

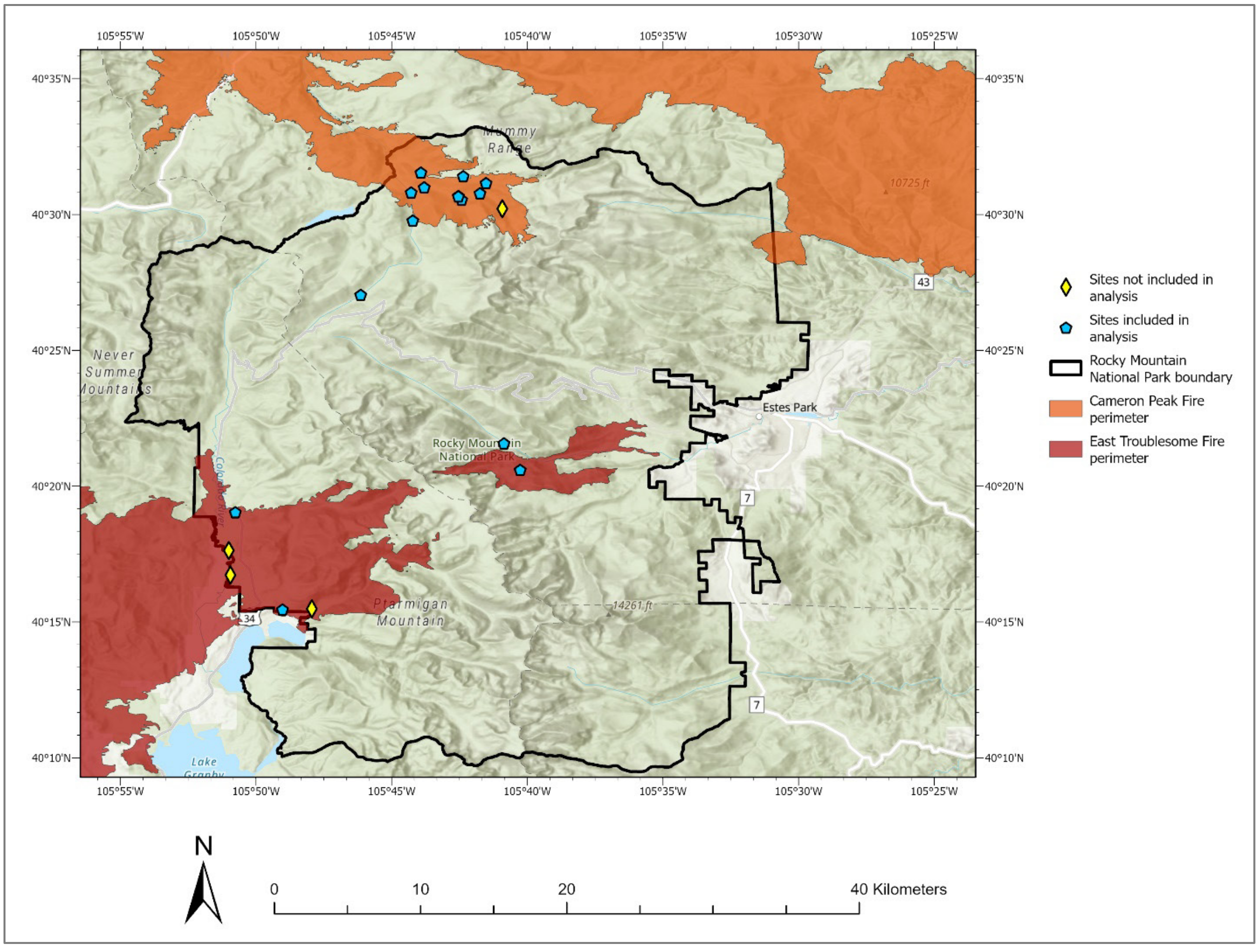

Figure 1. Locations of 19 Rocky Mountain National Park sites surveyed in 2021 and/or 2022. Four sites were not included in analysis of pre- versus post-fire trout abundance because three were new sites lacking pre-fire data (Colorado 9, Colorado 10, and North Inlet) and one site (Hague 4) had been subject to physical removals of non-native brook trout by electrofishing to conserve cutthroat trout and abundance data did not represent natural population dynamics.

Survey Methods

Backpack electrofishing units (Model LR-24, Smith-Root Inc., Vancouver, WA) were used to collect fish population data. Two-pass electrofishing removal sampling was conducted for approximately 100 m in each site, but the site length differed depending on the location of geomorphic breaks (e.g., cascades, pools). Four-pass removal sampling was conducted in Hague 2 in 2022 because more trout were caught in the second pass than in the first pass and additional passes were needed for estimating fish abundance via depletion. The number of backpack electrofishing units was scaled with stream width, and up to 3 units were used per site. Electrofishing settings were adjusted to minimize fish injuries and mortalities (450-600 V, 30-60 Hz, 15-25% duty cycle). Upon capture, fish were measured for total length (mm) and weight (g) in 2021 and for total length in 2022. All fish were identified to species and returned to the site of capture alive.

Site length was measured by stretching a tape or using a range finder. Stream width was measured at every 10 m, where three depth measurements were recorded at each transect (¼, ½, and ¾ widths). Canopy cover was measured using a spherical densiometer at the center of the stream channel at every 20 m. Substrate composition was characterized by measuring the size of 100 randomly selected samples using a gravelometer (Wildco, Yulee, FL). Water temperature, pH, dissolved oxygen, and conductivity were measured in the stream channel using a multiparameter meter (Model ProQuatro, YSI Inc., Yellow Springs, OH). Turbidity was measured by collecting three replicate water samples by avoiding stagnant waters using a turbidometer (Hanna Instruments, Woonsocket, RI). Riparian burn severity was measured using a modified version of the Compositive Burn Severity Index (Lutes et al., 2006). This approach incorporated visual estimates of burn severity within 1 m of the stream edge based on the percentages of burned duff, alive trees (green), scorched trees (brown), torched trees (black), tree canopy mortality, and vegetation regeneration. Grab water samples were collected in the thalweg and were sent to the Colorado State University's EcoCore Analytical Service for quantifying nitrate and ammonium concentrations. Nitrate and ammonium were measured using an OI Analytical 3700 Automated Chemistry Analyzer (O.I. Analytical, College Station, Texas) following methods EPA 353.2 and DIN 38406 (Lipps et al., 2023). We collected environmental DNA samples inside the electrofishing reach and farther upstream following the protocols detailed in Carim et al. (2015). We filtered 5L of water to collect each sample while carefully avoiding cross-sample contamination. Environmental DNA samples were submitted to the NPS I&M Program at the completion of the 2021 summer field season.

Benthic macroinvertebrates were sampled in riffle habitat by collecting three (in 2021) or five (in 2022) replicated Surber samples (0.09 m^2 in area, 248 µm mesh each). Samples were identified, typically to family level, in the laboratory. A subset of macroinvertebrates of each taxon within each Surber sample (n = 10) were measured for total body length (mm). Relative values of chlorophyll-a in periphyton were obtained using techniques based on EPA Method 445 (Arar & Collins, 1997). Three rocks were randomly collected and periphyton from the top surface of each rock was scraped using a toothbrush. The resulting slurry was collected into a tray and transferred into a 50 mL conical vial. The surface area of each rock was traced on a data sheet to scale the periphyton values by the area sampled. Periphyton samples were kept in the dark in a cooler with ice until they were transported to the laboratory. In the laboratory, a subsample of the periphyton suspension was filtered onto a GFF glass microfiber filter and then frozen at -5°C. To extract chlorophyll-a, the filter was soaked in 90% buffered acetone for 5 hrs. The extract was then analyzed on an Aquafluor Handheld Fluorometer (Turner Designs, Sunnyvale, CA), using 90% acetone to dilute the sample if needed. The resulting values are expressed as relative chlorophyll fluorescence, with higher values being indicative of greater quantities of chlorophyll extracted per unit rock sampled.

Analysis Methods

We tested whether trout abundance changed before and after wildfires to evaluate the magnitude of fire impacts, and between 2021 and 2022 to evaluate post-fire recovery, using an *N*-mixture model (Royle, 2004). This analytical framework incorporates spatiotemporal variation in capture probability and uses this information to estimate trout abundance at each site. In addition, we fit this hierarchical model to make inferences on how trout abundance changed over time when averaged across study sites. A total of four sites were removed from the analysis because three sites were new sites lacking pre-fire data (Colorado 9, Colorado 10, and North Inlet) and physical removals of brook trout occurred in several years before fire (NPS, pers communication) to assist a cutthroat trout population at Hague 4, which precludes unbiased characterization of trout abundance (Table 1). As a result, we used trout count data from the remaining 15 sites to investigate whether trout abundance changed over time.

Three metrics of abundance were used to test fire impacts on and recovery of trout populations. They were small trout (75-125 mm TL), large trout (> 125 mm TL), and total abundance (small trout + large trout). All trout species size-classes were combined. We refer to our removal sampling data as $y_{i,j,t}$ to indicate trout count for site *i*, pass *j*, and time period relative to fire *t* (1 = pre-fire; 2 = first year post-fire [2021]; and 3 = second year post-fire [2022]). To modify the conventional *N*-mixture model to accommodate our removal sampling design, our observation model was:

$$y_{i,j,t} \sim Binomial\ (N_{i,t},\ p_{i,t}) \qquad \text{for 1}^{\text{st}} \text{ pass } (j=1)$$

$$y_{i,j,t} \sim Binomial\ (N_{i,t} - \textstyle\sum_{1}^{j-1} y_{i,j,t}\ ,\ p_{i,t}) \qquad \text{for 2}^{\text{nd}} \text{ and subsequent pass } (j>1)$$

where $N_{i,t}$ represents imperfectly observed abundance at site *i* in time period *t* and $p_{i,t}$ is the capture probability of individuals per electrofishing pass at site *i* in time period *t*. Only individuals that were not captured in the first electrofishing pass ($N_{i,t} - y_{i,1,t}$) were available for capture in the second pass, and the equation above incorporates the one site with four electrofishing passes to ensure depletion (i.e., Hague 2 in 2022). Capture probability, $p_{i,t}$, was assumed to be constant between electrofishing passes but vary between pre-fire and post-fire (2021 & 2022) because some of the pre-fire data were not collected by the current field crew (i.e., $p_{.,1} \neq p_{.,2} = p_{.,3}$). Furthermore, we assumed that capture probability could depend on two covariates. Specifically, trout would be more readily captured later in the season when flows are lower and in streams with narrower widths. Thus, we modeled capture probability as a function of stream width and day-of-the-year on the logit scale:

$$logit\ (p_{i,t}) = \beta 0_t + \beta 1 \times day_{i,t} + \beta 2 \times width_{i,t}$$

where $\beta 0_t$ is the mean capture probability at period *t*, β_1 is the effect of day-of-the-year, and β_2 is the effect of stream width on capture probability. This specification assumes that mean capture probability differed before and after fire, but the effects of day-of-the-year and stream width would not change within each time period. Day-of-the-year and stream width were standardized by mean and then divided by standard deviation so that the effect sizes of these two covariates were comparable.

We modeled spatiotemporal variation in abundance:

$$N_{i,t} \sim Poisson\ (\frac{l_{i,t}}{100} \lambda_{i,t})$$

$$\log{(\lambda_{i,t})} = \alpha 0_i + \alpha 1_i \times Y2021_i + \alpha 2_i \times Y2022_i$$

where $l_{i,t}$ is the electrofishing sampling length for site *i* and period *t*, and $\lambda_{i,t}$ is the trout density per 100 m for site *i* and period *t*. This approach accounted for the fact that sampling lengths varied among sites. The intercept term, $\alpha 0_i$, is the pre-fire trout abundance at site *i*, $\alpha 1_i$ is the difference in trout abundance in 2021 relative to the pre-fire abundance at site *i*, and $\alpha 2_i$ is the difference in trout abundance in 2022 relative to the pre-fire abundance at site *i*. $Y2021_i$ and $Y2022_i$ are binary indicators where their values were 1 if sampling occurred at site *i* in 2021 and 2022, respectively, or 0 otherwise.

In addition, site-level trout abundance before fire ($\alpha 0_i$) and in 2021 ($\alpha 1_i$) and 2022 ($\alpha 2_i$) was modeled as random effects to make inferences on how trout abundance changed over time when all sites were combined:

$$\alpha 0_i \sim Normal\ (\alpha 0.mu,\ \alpha 0.sd)$$

$$\alpha 1_i \sim Normal\ (\alpha 1.mu,\ \alpha 1.sd)$$

$$\alpha 2_i \sim Normal\ (\alpha 2.mu,\ \alpha 2.sd)$$

where $\alpha 0.mu$ is the pre-fire trout abundance per 100 m averaged across study sites and $\alpha 0.sd$ is the standard deviation among the sites, $\alpha 1.mu$ is the difference in trout abundance in 2021 relative to the pre-fire abundance averaged across study sites and $\alpha 1.sd$ is the standard deviation among the sites, and $\alpha 2.mu$ is the difference in trout abundance in 2022 relative to the pre-fire abundance averaged across study sites and $\alpha 2.sd$ is the standard deviation among the sites.

The *N*-mixture models were analyzed with a Bayesian approach using a Markov chain Montel Carlo method in Program JAGS (Plummer, 2017) called from Program R (R Core Team, 2023) with the jagsUI package. Diffuse priors were used throughout. Posterior distributions of parameters were characterized by taking every 5th sample from 10,000 iterations of four chains after a burn-in period of 5,000 iterations (8,000 total posterior samples). Model convergence was checked by ensuring that the R-hat statistic was < 1.1 for all parameters (Gelman & Hill, 2007). To test whether trout abundance changed before and after fire when all sites were considered, we characterized posterior samples of $\alpha 1.mu$ to compare trout abundance across sites in 2021 to the pre-fire abundance, $\alpha 2.mu$ to compare trout abundance across sites in 2022 to the pre-fire abundance, and $\alpha 2.mu - \alpha 1.mu$ to compare trout abundance across sites between 2021 and 2022. We considered these quantities to be statistically significant when > 90% of posterior samples were negative (decreased abundance over time) or positive (increased abundance). To test whether trout abundance changed over time at each site, we characterized percent changes in abundance at each site *i* ($N_{i,.}$) and similarly declared statistical significance based on whether their 90% credible intervals overlapped 0. Finally, the effects of day-of-year and stream width on trout capture probability were considered statistically significant when their 90% credible intervals did not overlap 0.

Trout abundance was estimated differently between the Bayesian analyses above and site narratives. The Bayesian analyses are more integrative in the sense that all sites were analyzed simultaneously, which means that this approach allowed us to infer temporal trends when all sites were considered together and data from other sites could influence local trout abundance estimates. Trout abundance was estimated site-by-site using a Zippin removal estimator, and this was necessary for the four sites lacking pre-fire data.

Results

Trout Abundance

Overall Patterns Across Sites

When sites were pooled for overall patterns in the Bayesian hierarchical models, abundance decreased significantly in large trout (> 125 mm TL), small trout (75-125 mm TL), and all trout in 2021 compared to pre-fire abundance (Figure 2). Prior to fire, an average of 39 large trout (90% Credible Interval [CI] = 26, 58) occurred per 100 m reach, but a post-fire average was 20 large trout (90% CI = 7, 48). In small trout, a pre-fire average was 25 individuals (90% CI = 14, 44) per 100 m, and in 2021 an average of 4 individuals (90% CI = 1, 15) occurred per 100 m. These data indicated that small trout decreased more severely than large trout in the first year after fire, relative to pre-fire abundance. Pre-fire total abundance (small + large trout) was 68 individuals (90% CI = 43, 105) per 100 m, and total abundance in 2021 was 25 individuals (90% CI = 8, 64). Thus, total trout abundance before fire averaged approximately 2.7 times greater than that in 2021.

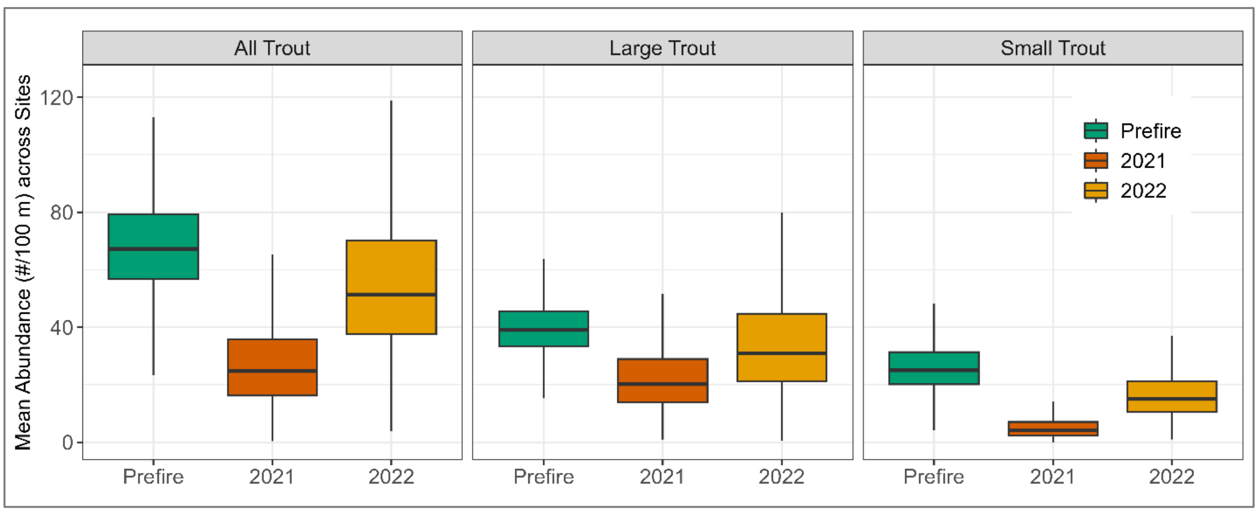

Figure 2. Boxplots of posterior samples of trout abundance per 100m averaged across study sites before fire, and after fire (2021 and 2022), estimated in Bayesian *N*-mixture models. Analysis was conducted for large trout (> 125 mm TL), small trout (75-125 mm TL) and all trout (large and small trout combined). Horizontal lines indicate median values, boxes indicate interquartile ranges (IQR: ranges of Q1 [25th percentile] and Q3 [75th percentile]), and whiskers indicate Q1 – 1.5*IQR and Q3 + 1.5*IQR.

In 2022, trout abundance generally increased from 2021, but the increase was statistically significant only in small trout (75-125 mm TL) (Figure 2). At the same time, average abundance of large and all trout in 2022 did not significantly differ from pre-fire conditions, showing signs of trout population recovery between 2021 and 2022. Average abundance of small trout in 2022 was still significantly lower than pre-fire abundance, indicating that trout population responses to wildfires depend on body size. In 2022, trout abundance per 100 m averaged 31 large trout (90% CI = 11, 82), 15 small trout (90% CI = 6, 36), and 53 total trout (90% CI = 23, 120). This meant that large trout abundance in

2022 was 1.6 times greater, small trout abundance was 3.8 times greater, and total trout abundance was 2.1 greater than that in 2021.

Site-Specific Patterns

Despite the overall temporal patterns, there was much site-to-site variation in trout population responses to wildfire (Table 2; Table 3; Figure 3). Compared to pre-fire abundance, large trout (> 125 mm TL) decreased significantly at five sites (Fern, Hague 2, Hazeline 2, Ohanu 2, & Tonahutu), but increased significantly at five sites (Cascade 1, Hague 1, Poudre 1, Poudre 3, & Poudre 5) in 2021. Abundance of small trout (75-125 mm TL) decreased significantly at 12 sites in 2021, but increased significantly at three sites (Cascade 1, Mummy Pass & Poudre 3), again showing that small trout abundance decreased disproportionately in the first year after fire. When large and small trout were combined, post-fire total abundance decreased significantly in 2021 at nine sites (Big Thompson 3, Cascade 2, Fern, Hague 1, Hague 2, Hague 3, Hazeline 2, Onahu 2, & Tonahutu), but increased significantly at three sites (Cascade 1, Mummy Pass, & Poudre 3). Taken together, trout abundance decreased significantly from pre-fire to 2021 at five sites (Fern, Hague 2, Hazeline 2, Ohahu 2, & Tonahutu) of the 15 sites analyzed, no matter how trout body size classes were defined.

Trout abundance significantly increased from 2021 to 2022 at approximately half of 11 sites surveyed in both years (Table 2). During this period, large trout abundance increased significantly at four sites (Hague 2, Hazeline 1, Hazeline 2, & Mummy Pass) and decreased at one site (Big Thompson 3); small trout abundance increased at five sites (Fern, Hague 2, Hague 3, Hazeline 2, & Poudre 5) and did not decrease at any site; and total trout abundance increased at five sites (Fern, Hague 2, Hazeline 1, Hazeline 2, & Mummy Pass) and decreased at one site (Big Thompson 3). When comparing 2022 trout abundance to pre-fire abundance, directions of changes were mixed. Specifically, large trout abundance increased at 4 sites, decreased at 3 sites, and did not significantly change at 4 sites; small trout abundance increased at 3 sites, decreased at 6 sites, and did not significantly change at 2 sites, and total trout abundance increased at 4 sites, decreased at 5 sites, and did not change at 2 sites (Table 2). These data indicated that trout population recovery was common from 2021 to 2022, and by 2022 trout abundance approached pre-fire abundance at many sites.

Table 2. Changes in trout abundance at each of the 15 sites analyzed in the Bayesian *N*-mixture models. Statistically significant increases are when > 90% posterior samples of the differences in trout abundance over time are positive and significant decreases are when > 90% of the posterior samples are negative (see Table 3). Otherwise, trout abundance did not change over time. This same information is also presented in Figure 3 above.

	From Pre-fire to 2021			From Pre-fire to 2022			From 2021 to 2022		
Site	**All**	**Large**	**Small**	**All**	**Large**	**Small**	**All**	**Large**	**Small**
Big Thompson 3	Decreased	No change	Decreased	Decreased	Decreased	Decreased	Decreased	Decreased	No change
Cascade 1	Increased	Increased	Increased	Increased	Increased	Increased	No change	No change	No change
Cascade 2	Decreased	No change	Decreased	NA	NA	NA	NA	NA	NA
Fern	Decreased	Decreased	Decreased	Decreased	Decreased	Decreased	Increased	No change	Increased
Hague 1	Decreased	Increased	Decreased	Decreased	No change	Decreased	No change	No change	No change
Hague 2	Decreased	Decreased	Decreased	No change	No change	No change	Increased	Increased	Increased
Hague 3	Decreased	No change	Decreased	Decreased	Decreased	Decreased	No change	No change	Increased
Hazeline 1	No change	No change	Decreased	Increased	Increased	Decreased	Increased	Increased	No change
Hazeline 2	Decreased	Decreased	Decreased	Decreased	No change	Decreased	Increased	Increased	Increased
Mummy Pass	Increased	No change	Increased	Increased	Increased	Increased	Increased	Increased	No change
Onahu 2	Decreased	Decreased	Decreased	NA	NA	NA	NA	NA	NA
Poudre 1	No change	Increased	Decreased	NA	NA	NA	NA	NA	NA
Poudre 3	Increased	Increased	Increased	Increased	Increased	Increased	No change	No change	No change
Poudre 5	No change	Increased	Decreased	No change	No change	No change	No change	No change	Increased
Tonahutu	Decreased	Decreased	Decreased	NA	NA	NA	NA	NA	NA

Table 3. Posterior median percent changes (90% credible intervals) in trout abundance at each of the 15 sites analyzed in the Bayesian *N*-mixture models from pre-fire to 2021, from pre-fire to 2022, and from 2021 to 2022. All trout combined abundance of large (> 125 mm TL) and small (75-125 mm TL) trout. This same information is also presented in Table 2 and Figure 3 above. An asterisk (*) indicates sites where trout were not captured in 2021 but were captured in 2022. The upper limit of 90% credible intervals is not shown for small trout in Fern from pre-fire to 2022 and in Hazeline 1 from pre-fire to 2021 and 2022 because no small trout were captured at these sites in either year and credible intervals could not be reliably estimated; we considered that small trout abundance decreased significantly during these time periods at these sites (Table 2).

	From Pre-fire to 2021			From Pre-fire to 2022			From 2021 to 2022		
Site	**All**	**Large**	**Small**	**All**	**Large**	**Small**	**All**	**Large**	**Small**
Big Thompson 3	-28 (-49, -2)	6 (-27, 50)	-65 (-86, -21)	-88 (-94, -79)	-87 (-95, -75)	-83 (-94, -64)	-83 (-92, -69)	-88 (-95, -75)	-51 (-85, 50)
Cascade 1	107 (64, 162)	73 (29, 131)	193 (96, 338)	109 (66, 163)	61 (20, 116)	223 (122, 378)	1 (-20, 28)	-8 (-32, 27)	10 (-23, 59)
Cascade 2	-42 (-58, -20)	-5 (-35, 40)	-81 (-91, -62)	NA	NA	NA	NA	NA	NA
Fern	-99 (-100, -94)	-97 (-100, -90)	-98 (-100, -88)	-84 (-92, -71)	-96 (-100, -86)	-47 (-75, NA)	Inf *	NA	Inf *
Hague 1	-26 (-43, -3)	39 (1, 89)	-50 (-70, -17)	-37 (-53, -17)	29 (-5, 75)	-69 (-81, -52)	-15 (-34, 7)	-7 (-30, 22)	-39 (-65, 5)
Hague 2	-83 (-93, -64)	-70 (-88, -31)	-98 (-100, -81)	-26 (-54, 21)	2 (-43, 92)	-54 (-79, 3)	339 (112, 922)	247 (64, 716)	Inf *
Hague 3	-68 (-81, -48)	-29 (-61, 24)	-98 (-100, -89)	-70 (-81, -53)	-57 (-77, -23)	-74 (-88, -48)	-5 (-47, 75)	-39 (-69, 20)	Inf *
Hazeline 1	44 (-37, 195)	60 (-30, 237)	-92 (-100, NA)	353 (172, 656)	438 (211, 827)	-60 (-95, NA)	215 (47, 650)	234 (58, 678)	NA
Hazeline 2	-98 (-100, -92)	-97 (-100, -90)	-97 (-100, -77)	-30 (-51, -5)	-23 (-47, 6)	-55 (-83, -3)	Inf *	Inf *	Inf *
Mummy Pass	42 (17, 72)	25 (-4, 60)	92 (41, 161)	90 (60, 126)	125 (84, 177)	44 (5, 99)	34 (8, 65)	80 (40, 136)	-25 (-48, 8)
Onahu 2	-59 (-68, -49)	-50 (-64, -30)	-58 (-71, -40)	NA	NA	NA	NA	NA	NA
Poudre 1	21 (-4, 53)	83 (39, 138)	-70 (-84, -48)	NA	NA	NA	NA	NA	NA
Poudre 3	103 (63, 152)	88 (49, 139)	201 (78, 429)	99 (60, 149)	98 (56, 153)	93 (9, 254)	-2 (-19, 19)	6 (-14, 30)	-36 (-62, 5)
Poudre 5	-5 (-24, 19)	44 (12, 87)	-74 (-86, -55)	-2 (-21, 24)	24 (-6, 63)	-24 (-52, 22)	4 (-16, 28)	-15 (-31, 7)	195 (67, 450)
Tonahutu	-98 (-100, -92)	-96 (-99, -88)	-98 (-100, -88)	NA	NA	NA	NA	NA	NA

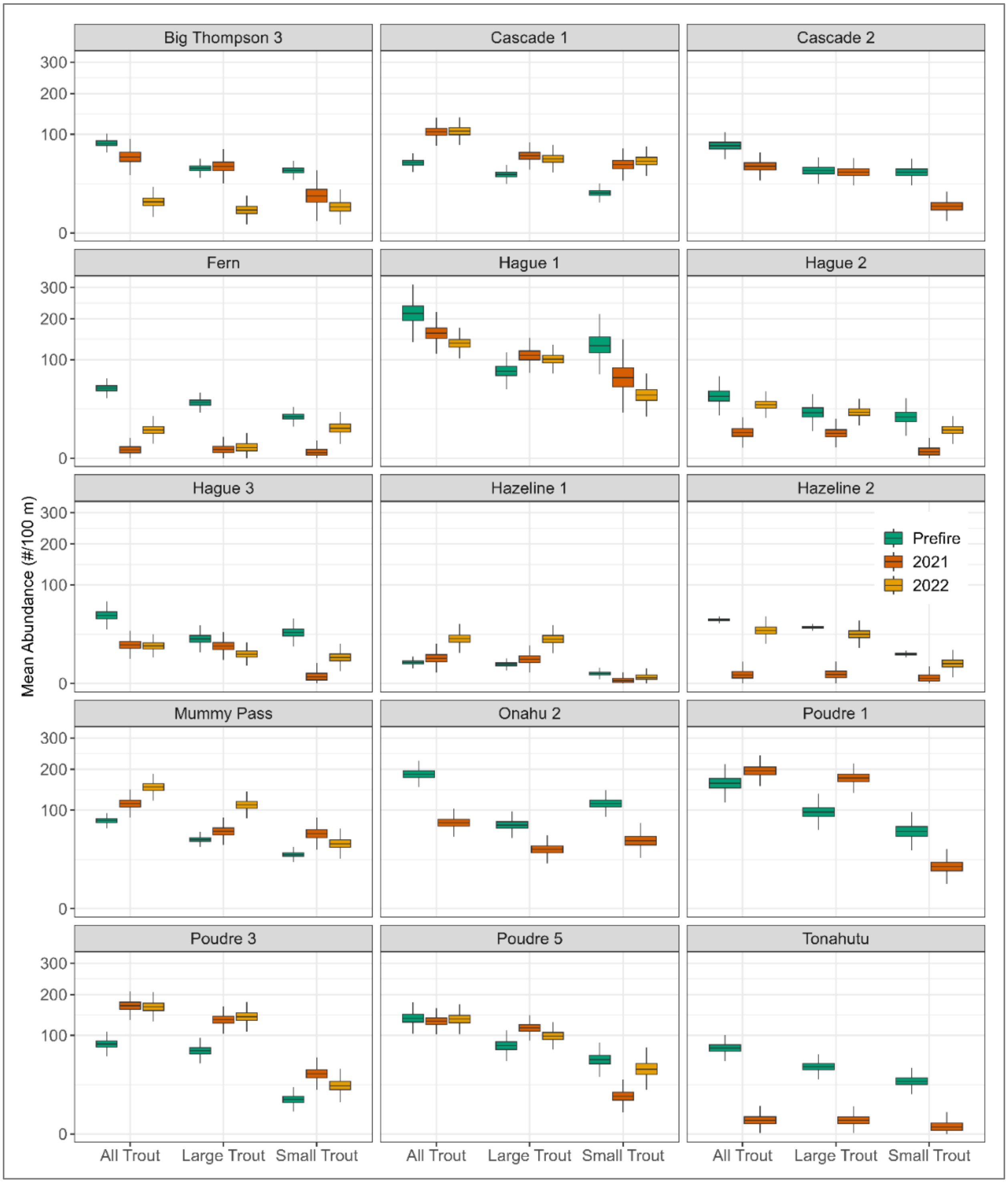

Figure 3. Boxplots of posterior samples of trout abundance per 100m in each study site before fire, and after fire (2021 and 2022), estimated in Bayesian *N*-mixture models. Analysis was conducted for large trout (> 125 mm TL), small trout (75-125 mm TL) and all trout (large and small trout combined). Horizontal lines indicate median values, boxes indicate interquartile ranges (IQR: ranges of Q1 [25th percentile] and Q3 [75th percentile]), and whiskers indicate Q1 – 1.5*IQR and Q3 + 1.5*IQR. This same information is also presented in Table 2 below.

Trout Capture Probability

The mean capture probability of trout per electrofishing pass before fire was estimated to be 0.65 (90% CI = 0.61, 0.69) in large trout, 0.63 (90% CI = 0.58, 0.68) in small trout, and 0.64 (90% CI = 0.60, 0.67) when large and small trout were combined, showing that capture probability did not depend on trout body size considered. After fire (2021 & 2022), the mean trout capture probability per pass was estimated to be 0.72 (90% CI = 0.69, 0.75) in large trout, 0.47 (90% = 0.37, 0.56) in small trout, and 0.67 (90% CI = 0.64, 0.70) when large and small trout were combined. As predicted, trout capture efficiency significantly increased in narrower stream reaches and later in the season in most cases. The mean effect of day-of-the-year ($\beta 1$) on the logit scale was 0.51 (90% CI = 0.38, 0.63) in large trout, 0.39 (90% CI = 0.25, 0.54) in small trout, and 0.48 (90% CI = 0.38, 0.58) in all trout combined. The mean effect of stream width ($\beta 2$) on the logit scale was -0.20 (90% CI = -0.31, -0.10) in large trout, -0.39 (90% CI = -0.59, -0.22) in small trout, and -0.27 (90% CI = -0.37, -0.17) in all trout combined. This translated, for example, that the mean capture probability of all trout combined post-fire was 0.56 on August 2 (mean – 1SD) and 0.77 on September 8 (mean + 1SD) and was 0.73 in a 2.4-m wide stream (mean – 1SD) and 0.61 in a 7.3-m wide stream (mean + 1SD).

Benthic Macroinvertebrates

We detected at least 51 unique taxa of benthic macroinvertebrates. The number of detected taxa per site varied from 22 (North Inlet) to 37 (Cascade 1), and the mean taxonomic richness was 28.4 across all 19 sites (SE = 0.99). In total, we identified 67,245 benthic macroinvertebrate individuals from all sites combined. Densities of all taxa combined ranged between 19,586 invertebrates per square meter (Fern) to 739 invertebrates per square meter (Tonahutu) (mean = 7,007 invertebrates per square meter across all sites). Diptera or Ephemeroptera were the most abundant orders at each site (Figure 4). Densities of all taxa at each site, as well as densities of the most abundant six orders (Coleoptera, Diptera, Ephemeroptera, Oligochaeta, Plecoptera, & Trichoptera) are shown in Figure 4.

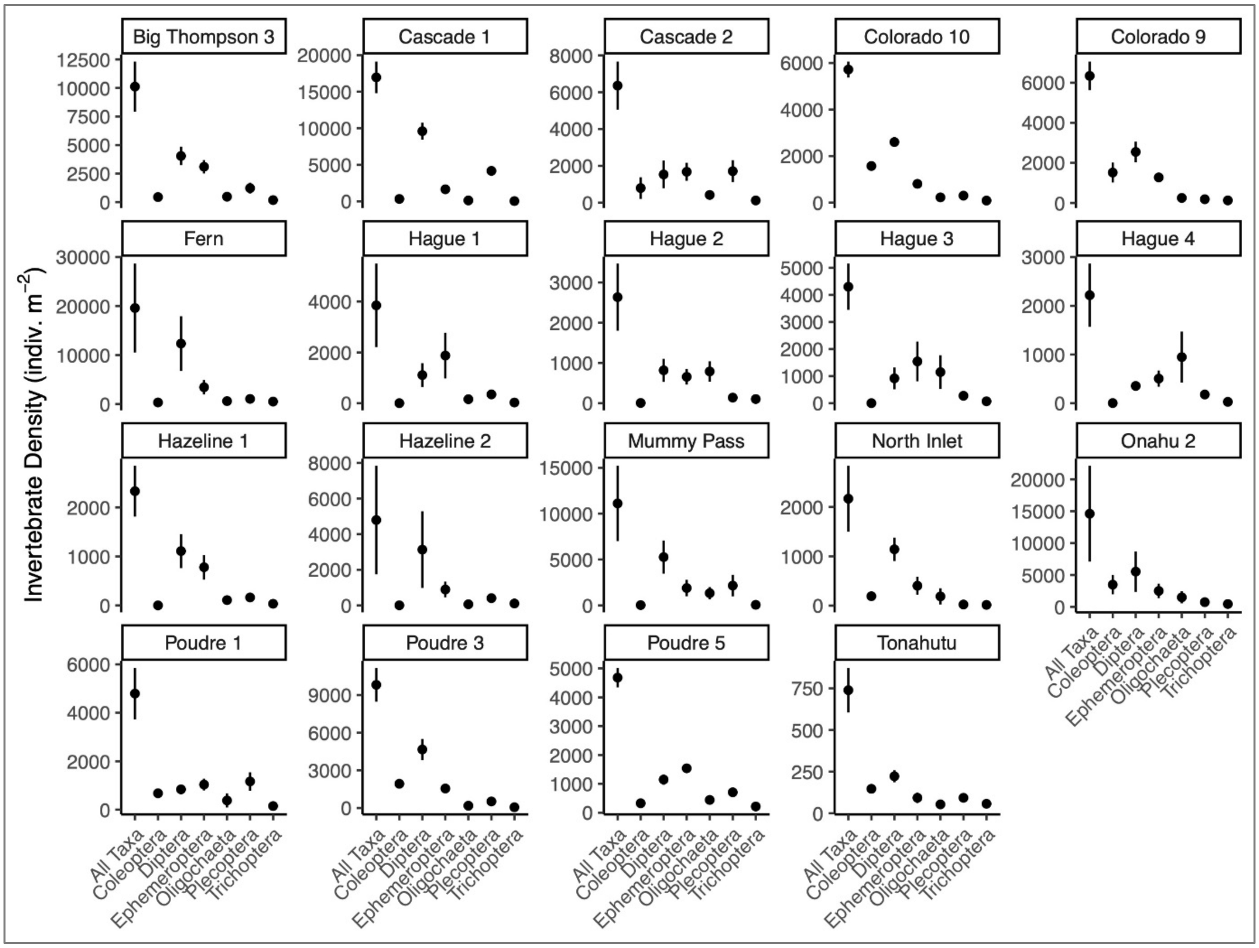

Figure 4. Densities of benthic macroinvertebrates sampled at 19 study sites in Rocky Mountain National Park in summer of 2021. Points indicate mean values (± 1 standard error). Note the difference in the y-axis limits across panels. Means are based on three replicate Surber samples collected at each site. The x-axes display densities of all invertebrate taxa, followed by the most commonly encountered orders: Coleoptera (beetles), Diptera (flies), Ephemeroptera (mayflies), Oligochaeta (annelid worms), Plecoptera (stoneflies), and Trichoptera (caddisflies).

The four sites outside of the fire perimeter (Big Thompson 3, Cascade 1, Poudre 1, & Poudre 3) did not have consistently higher total macroinvertebrate densities than the other 15 sites inside the fire perimeter (Figure 4). The highest observed total densities were at Fern, Onahu, Mummy Pass, Big Thompson 3, and Cascade 1 (Figure 4). Some of the lowest observed densities, however, were at sites within the burn perimeter, including Tonahutu, North Inlet, Hazeline 1, and Hague 4 (Figure 4).

We did not observe strong shifts in macroinvertebrate density over time at the seven sites sampled in both 2021 and 2022. Three sites showed a modest increase in density, while four showed a modest decrease (Figure 5). The four sites within the burn perimeter (Fern, Hazeline 1, Mummy Pass, & Hague 1) did not show strong shifts in macroinvertebrate density between the two years.

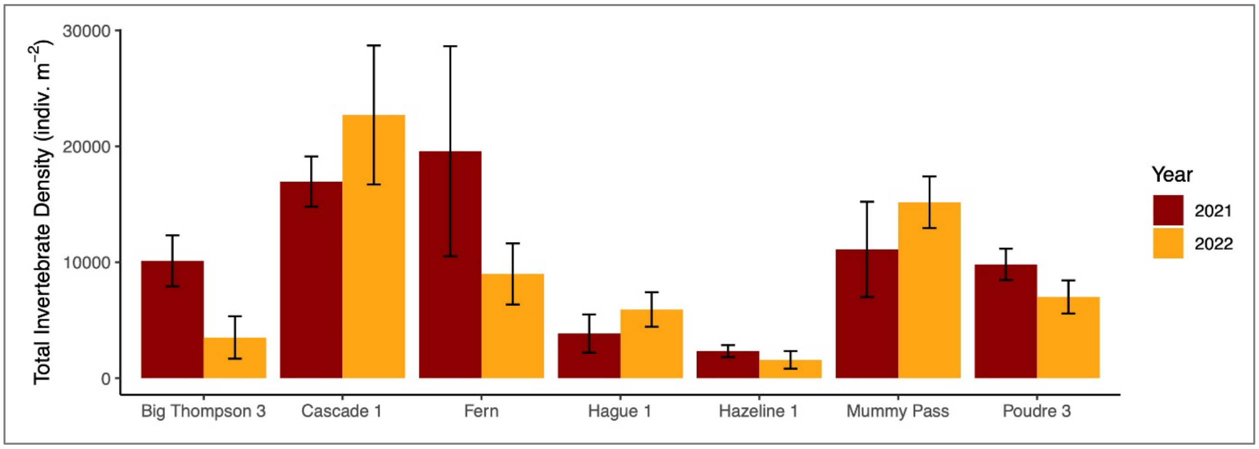

Figure 5. Densities of all benthic macroinvertebrates combined from 7 study sites in Rocky Mountain National Park sampled in both summer of 2021 (brown) and summer of 2022 (orange). Bars show means of three (2021) and five (2022) Surber samples collected at each site (+/- 1 standard error).

Conclusions

Trout abundance generally decreased in 2021 relative to pre-fire abundance but increased from 2021 to 2022, indicating a short-term impact of wildfire on these important park resources as well as signs of recovery in just two years post-fire. This pattern was more evident in small trout (75-125 mm TL) than in large trout (> 125 mm TL), showing that wildfire impacts depend on trout body size. However, our data cannot discern whether such size-dependent responses are due to differential trout mortalities immediately after fire or trout movement subsequently. Overall, our inventory data suggest that trout populations are recovering from wildfire, and these data cannot be used to argue for stocking trout to sustain recreational fisheries or discontinuing native trout conservation actions including the Poudre Headwaters Project. It is also notable that wildfire impacts on trout populations and their recoveries differed from site to site, and management actions, if needed, should be devised based on site-specific conditions and trajectories post-fire.

All sites that were sampled had populations of benthic macroinvertebrates, suggesting that invertebrates were recovering after wildfire or that disturbance was not strong enough to eliminate their populations into summer of 2021. Effects of fire and subsequent erosion were likely site-specific and variable across the study area. Many macroinvertebrates are also able to readily colonize streams after disturbance, particularly for flying taxa. A similar study in Arapaho-Roosevelt National Forest near Rocky Mountain National Park observed a slight decrease in macroinvertebrate density after the Cameron Peak Fire, but no major shift in macroinvertebrate biomass or taxonomic composition (Preston et al., 2023). The results of our sampling in ROMO indicate potentially similar results, with most sites showing macroinvertebrate densities in the thousands per square meter. Trout are generalist predators and are able to consume all of the observed macroinvertebrate orders at the study sites, as well as terrestrial prey that were not quantified in our surveys (Wipfli, 1997; Nakano et al., 1999). The relative abundances of different prey in their diets will vary due to seasonal changes in prey availability, as well as trout foraging behavior (Dunham et al., 2000; Saunders & Fausch, 2012).

Securing adequate person power for fieldwork was critical to the success of our inventory effort. Some of our sites, such as Big Thompson 3, Hague 4, and Mummy Pass, were not easily accessible. We typically surveyed 1-2 sites daily and our sampling was conducted by a crew of 5-7 people with each member carrying heavy loads on their shoulders. In our experience, fisheries inventories in the remote high-elevation terrain require dedicated personnel and it is often not reasonable to rely on volunteers, although some volunteers participated in our sampling. We are grateful that sufficient funding was provided to hire seasonal student employees for this project. Comparable levels of funding will be needed for any future inventory effort, which will be important to quantify trout responses to wildfire over longer temporal extents, particularly at sites where trout recovery was not documented in this current inventory.

Once again, the nature of this fieldwork in the remote and rugged terrain limits the number of study sites logistically, but any future inventory effort should consider including unburned sites as a control to quantify wildfire effects on trout populations. Our current design focused on burned sites, particularly those sites with pre-fire trout population data. Thus, our approach builds upon a “before-after” wildfire sampling design. The before-after-control-impact design provides more robust statistical inferences, and adding a handful of unburned sites (e.g., 5-6 sites = 3-4 additional field days) could provide more useful information on how these highly valued aquatic resources in ROMO respond to and recover from wildfire.

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Appendix A - Summary Table of Environmental Variables Measured in 2021 and 2022

Table 4. Mean values for dissolved oxygen (DO), pH, water temperature, canopy cover above the reach, riparian tree mortality (within 1 meter of stream), riparian regrowth (within 1 meter of stream), reach length, reach width and reach area. Values are means from 19 sites in 2021 and 11 sites in 2022.

	Year of Survey	
Variable	**2021**	**2022**
Number of sites	19	11
DO (mg/L)	8.4	7.6
pH	7.3	7.3
Water Temp. (C)	11.8	12.8
Canopy Cover (%)	9.1	4.0
Riparian Tree Mortality (%)	19.7	40.0
Riparian Regrowth (%)	66.6	82.3
Reach Length (m)	133.8	104.6
Reach Width (m)	6.2	4.4
Reach Area (square meters)	706.0	462.0

Appendix B - Summary of Trout Population Data at Each of the 19 Study Sites

Big Thompson 3 Site

Survey date: 08/20/2021 & 08/04/2022

Site coordinates (UTM; latitude/longitude): 13T 442206 4467913; 40.35978, - 105.681

Access: From the Fern Lake Trailhead parking area. Walked on the trail past the “Pool”. The trail goes uphill from there. At the first sharp switchback, we hiked an unclearly marked trail that headed west to cross over Spruce Creek. Hiked up to a saddle above the Black Pool. Strolled downhill to the site. Access was very challenging due to many downed trees.

Burn severity (based on **USFS BAER map** and qualitative visual inspection on our own): Low

Species: All Cutthroat Trout

Site description: Hillsides burned. Vegetation in riparian zone within 3 m appeared only lightly burned, but most riparian trees and understory vegetation were alive (Figure 6 and Figure 7). The stream reach included a split channel with a run/pool/riffle combo and had many fallen logs, which came from a combination of beetle kill and fire. Average stream width was 10.1 m and depth was 49 cm. Stream gradient was moderate (5-6 %). Substrate was a mix of boulder, cobble, pebble, gravel, and sand. At the time of the 2021 survey, DO = 83.8 %, water temperature = 9.8 ℃, pH = 6.65, conductivity = 15.1 µs/cm and turbidity was relatively low. Canopy cover was relatively high (well shaded). Undercut banks and large wood provided good habitat for trout. Fish abundance was modest, but electrofishing was efficient overall (Figure 8). All fish were Cutthroat Trout, and young of year (YOY) were present (2-3 cm in body length). Trout density was approximately much lower in 2021 compared to 2015, and size distribution shifted toward larger individuals. Trout abundance remained low in 2022.

Figure 6. Big Thompson 3 site location photo.

Figure 7. Big Thompson 3 example specimen photo.

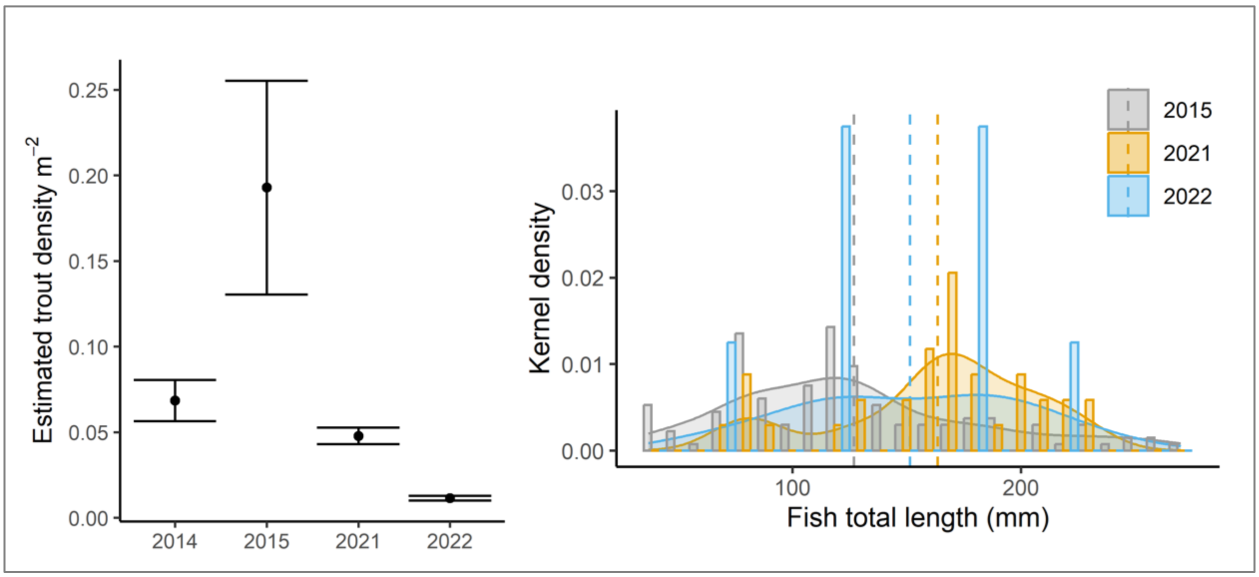

Figure 8. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2014 & 2015), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year including the most recent pre-fire survey (2015), and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by the US Fish and Wildlife Service.

Cascade 1 Site

Survey date: 08/17/2021 & 08/27/2022

Site coordinates (UTM; latitude/longitude): 13T 440208 4486123; 40.52368, -105.706

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, and then headed up the Mummy Pass Trail. Took a left turn on the Mirror Lake Trail to locate the Cascade Creek. From there, hiked downstream through a meadow area.

Burn severity: None

Species: All Brook Trout

Site description: Reach was in the upper meadow section. We saw no evidence that the riparian habitat was burned, including the meadow and surrounding forests within 300 m (Figure 9). The only visible burned scar was much farther downstream and near the top of the hillside. Riparian vegetation was mostly willows with some tall grasses and a few small lodgepole pines. No visible ash in stream. Stream reach was a simple, narrow channel with a combination of very narrow riffles (< 1 m wide) and some wider (3-5 m) pool sections interspersed. Average stream width was 1.9 m and depth was 37 cm. Stream gradient was moderate (3-4 %). Substrate was mostly cobble/boulder mix with some gravel and fine substrate at meanders. A high amount of moss, macrophytes, and periphyton coated the substrates. At the time of the 2021 survey, DO = 80.9 %, water temperature = 12.2 °C, pH = 7.37, conductivity = 12.1 µs/cm, and turbidity was relatively low. There was no canopy cover. The reach had many undercut banks with grassy overhangs and cascades into deeper pools, so it appeared to be very good trout habitat. Aquatic macroinvertebrates were abundant. Trout abundance was approximately 3-fold higher compared to 2019, and fish sizes were similar (Figure 10). Trout abundance was comparable between 2021 and 2022.

Figure 9. Cascade 1 site photo.

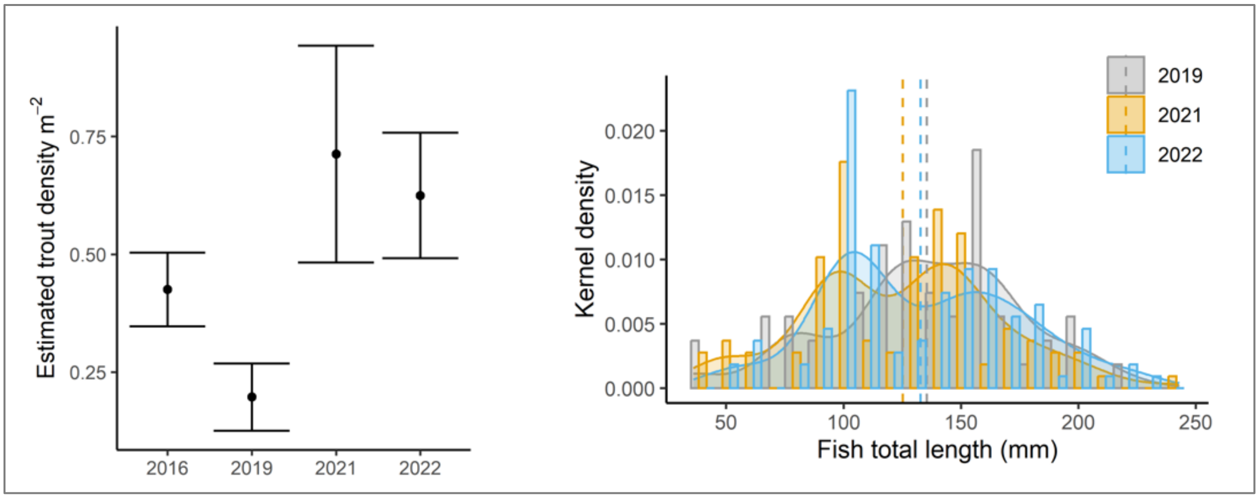

Figure 10. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2016 & 2019), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year including the most recent pre-fire survey (2019), and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by Colorado State University.

Cascade 2 Site

Survey date: 08/16/2021

Site coordinates (UTM; latitude/longitude): 13T 438027 4486386; 40.52589, -105.732

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, and then the Mummy Pass Trail. After the Desolation Campsite, headed north off trail.

Burn severity: Low

Species: All Brook Trout

Site description: Riparian vegetation consisted of willows and grasses interspersed with stands of lodgepole (Figure 11). Most vegetation was largely unburned, though one bank had burned trees ~5 m from riparian edge. Overall, this site appears lowly impacted by fire, with no ash deposition in the stream. Stream reach is a sinuous channel with mostly riffle/run habitat and a few pools. Average stream width was 2.7 m and depth was 26 cm. Gradient was modest (2-3 %). Substrate was mostly larger cobble with some finer substrates. There were good amounts of periphyton/algae on substrate, and aquatic macroinvertebrate communities looked abundant with high species richness. At the time of the 2021 survey, DO = 66.8 %, water temperature = 11.8 °C, pH = 6.72, conductivity = 13.8 µs/cm, and turbidity was relatively low. Canopy cover was moderate (some shade). Pools were not very big or deep, but this reach appeared good trout habitat with grass overhanging some undercut banks and large boulders for habitat structure. Channel was narrow, so we used 1 shocker. Fish were all Brook Trout, with several large individuals (Figure 12). Trout size distribution shifted toward larger individuals in 2021, compared to 2016 (Figure 13).

Figure 11. Cascade 3 site photo.

Figure 12. Cascade 2 example specimen photo – brook trout.

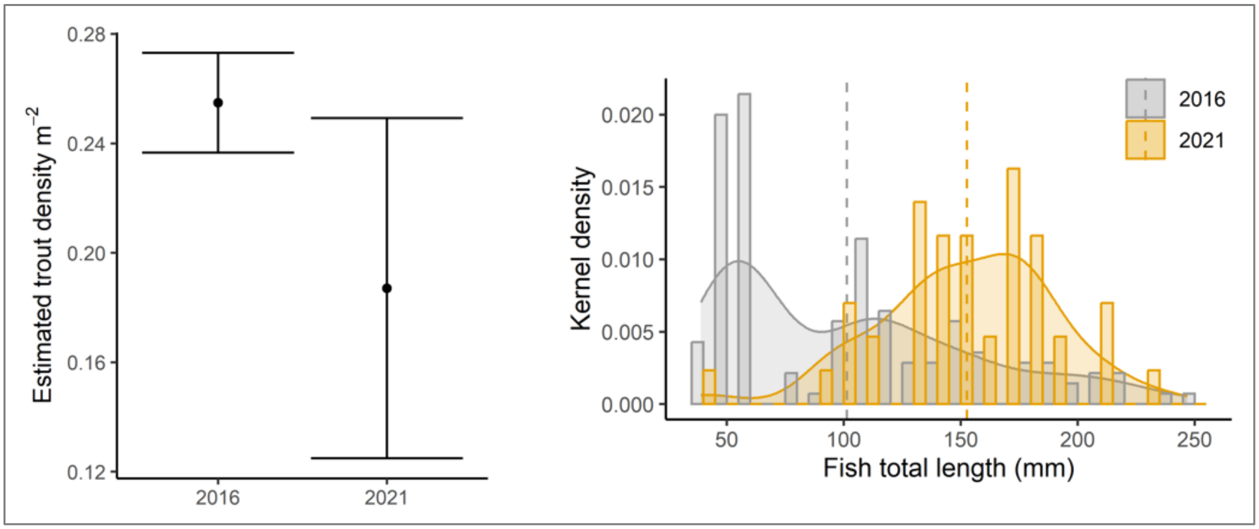

Figure 13. (Left) Trout density estimated post-fire (2021) and pre-fire (2016), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by the US Fish and Wildlife Service.

Colorado 9 Site

Survey date: 08/13/2021

Site coordinates (UTM; latitude/longitude): 13T 427747 4460718; 40.29384, -105.850

Access: Parked on the shoulder of Route 34 and headed straight west through a burned area to access the site. The site is located just upstream of the confluence with Onahu Creek.

Burn severity: Moderate

Species: Brown Trout, 2 Brook Trout, Longnose Sucker, and Mottled Sculpin

Site description: Reach was located in a meadow/mixed-stand area with grassy vegetation (Figure 14). The severely burned portion of the forest is downstream (trees severely burned as we walked toward the stream), but the reach itself shows only moderate impact of fire (a few small trees within 10 m of stream burned lightly brown). Outer banks appeared unstable with evidence of scouring. There was a very small amount of ash on the stream bottom. Stream reach was a meandering simple channel with deep, lateral-scour pool habitat and some shallow riffle/runs. Average stream width was 8.2 m and depth was 76 cm. Gradient was modest (2-3 %). Substrate was mostly small cobbles and pebbles with a high amount of algal growth on the benthos. At the time of the 2021 survey, DO = 70.1 %, water temperature = 17.2 °C, pH = 7.73, conductivity = 73.1 µs/cm, and turbidity was moderate. Canopy cover was very low. Overall, this reach appeared to be great trout habitat, with very deep pools below runs, undercut banks, large wood, and abundant aquatic macroinvertebrates. The pools held several large Brown Trout, and we also observed Brook Trout, Mottled Sculpin, and Longnose Sucker. Electrofishing was challenging in the deep pools. We caught more fish in the 2nd

pass than in the 1st pass and did not do the 3rd pass because we had started releasing fish back to the stream. Estimated trout density is therefore uncertain, but biomass is certainly high at this site, and the size distribution spanned a wide range up to 400 mm (Figure 15).

Figure 14. Colorado 9 site photo.

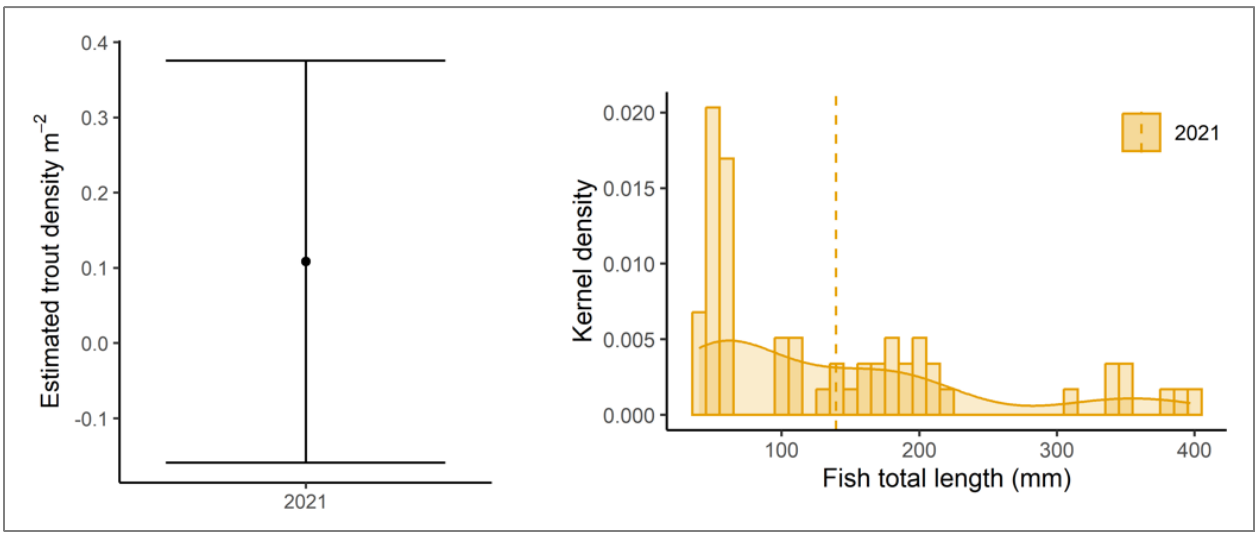

Figure 15. (Left) Trout density estimated in 2021, with 95% confidence intervals based on 2-pass depletion. See site description above for notes regarding electrofishing. (Right) Relative trout size distribution in 2021, and the vertical dashed line shows the mean length. This was a new site, so comparisons to previous years are not available.

Colorado 10 Site

Survey date: 08/13/2021

Site coordinates (UTM; latitude/longitude): 13T 427789 4459047; 40.27879, -105.849

Access: From the Sun Valley Trailhead parking area at Route 491. Near the Winding River Resort Campground. The site is upstream of Route 491, past what appeared to be a house on the private property.

Burn severity: Moderate

Species: Brown Trout, Longnose sucker

Site description: Riparian vegetation was mixed with unburned grasses and small trees (Figure 16). On river left, some trees were burned brown (but not blackened), but river right did not burn. On the left bank, vegetation started to grow back. There was a small amount of ash in the stream. Overall the reach looked minimally impacted by fire. Stream reach had some split channels that meandered with a mixture of riffles, runs, and deep pools. Average stream width was 13.2 m and depth was 66cm. Large wood was abundant and log jams were present at the top of the reach, in the reach, and farther downstream. Gradient was low (1-2%). Substrate was mostly small cobble, gravel, and sand. At the time of the 2021 survey, DO = 74.5 %, water temperature = 14.2 ℃, pH = 8.16, conductivity = 61.5 µs/cm, and turbidity was moderate. There was no canopy cover. Overall, this reach appeared to contain great trout habitat (deep pools below runs, pools with large wood) and good amounts of aquatic macroinvertebrates. According to Mary Kay, fish kill had been observed at this site. However, fish biomass was high including a wide size range of Brown Trout, including individuals over 400 mm (Figure 17 and Figure 18). Many YOY (1-3 cm) were observed in side channels, and many Longnose Sucker were caught.

Figure 16. Colorado 10 site photo.

Figure 17. Colorado 10 example specimen photo - brown trout.

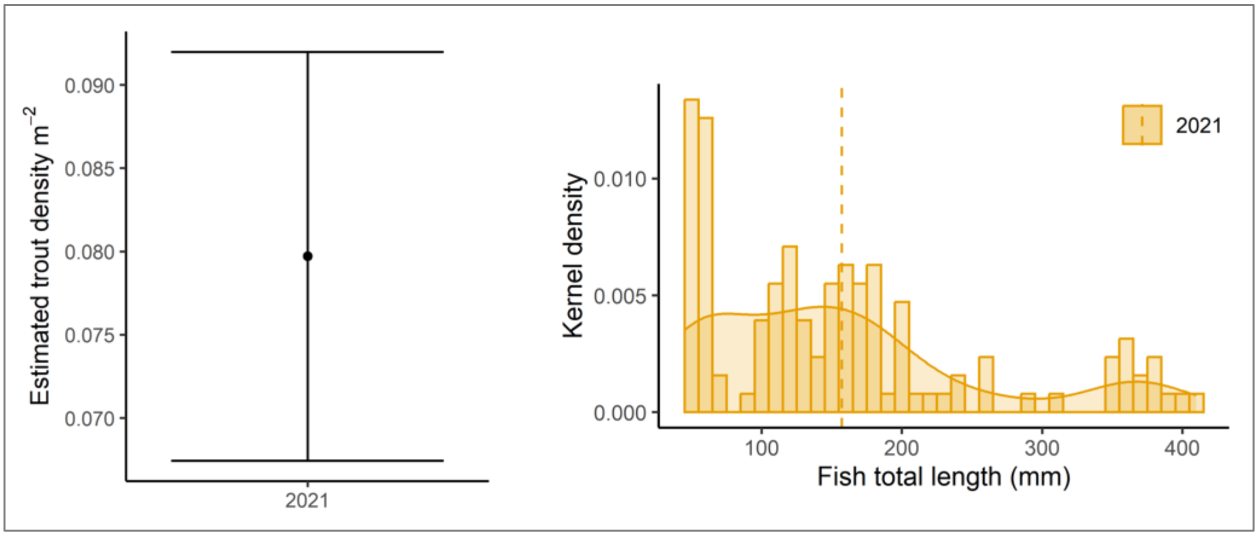

Figure 18. (Left) Trout density estimated in 2021, with 95% confidence intervals based on 2-pass depletion. (Right) Relative trout size distribution in 2021, and the vertical dashed line shows the mean length. This was a new site, so comparisons to previous years are not available.

Fern Site

Survey date: 08/27/2021 & 08/01/2022

Site coordinates (UTM; latitude/longitude): 13T 443052 4466097; 40.34348, -105.671

Access: From the Fern Lake Trailhead parking area. Walked on the trail past the "Pool". Continued to hike upstream toward the Fern Lake past the Fern Falls. The site is located approximately halfway between the Fern Falls and the Marguerite Falls.

Burn severity: High

Species: No fish in 2021 and Cutthroat Trout in 2022

Site description: The riparian area was severely burned with completely blackened trees and understory vegetation coming back but not quite fully (Figure 19). Ash deposition in stream was high and accumulated along banks and within substrate in channel. The stream reach was a simple channel with a mix of riffles, small waterfalls (~1 m high), and some pools formed by trees that fell into the river. Average stream width was 4.6 m and depth was 36 cm. Gradient was relatively high (5-6%). Substrate was a mix of sand/gravel in pools and large cobble/boulders in riffles. At the time of the 2021 survey, DO = 87.8 %, water temperature = 14.2 °C, pH = 7.23, conductivity = 16.4 µs/cm, and turbidity was moderate. There was complete mortality of the canopy due to fire. Overall, stream habitat appeared adequate but not optimal for trout due to high gradient and flow rates and lack of undercut banks or overhanging riparian vegetation. Aquatic macroinvertebrate communities looked good, however. The reach was located upstream of a very large waterfall (>10 m) that likely acts as a barrier for upstream dispersal of trout. Electroshocking started at a channel-spanning log and ended where a series of cascades started. In 2021, we did not catch any fish by electrofishing but visually confirmed YOY Cutthroat Trout in a side channel. Trout were caught in 2022 (Figure 20 and Figure 21).

Figure 19. Fern site photo.

Figure 20. Fern site example specimen photo - cutthroat trout fry.

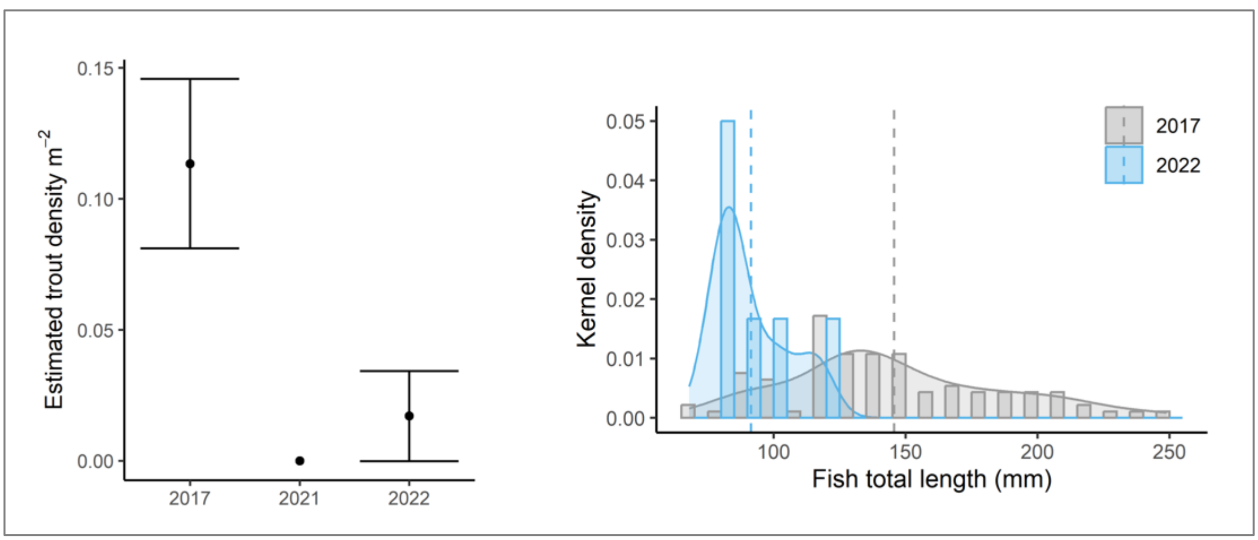

Figure 21. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2017), with 95% confidence intervals based on 2-pass depletion. No fish were caught in 2021. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by the US Fish and Wildlife Service.

Hague 1 Site

Survey date: 08/09/2021 & 08/12/2022

Site coordinates (UTM; latitude/longitude): 13T 439164 4485383; 40.51687, -105.730

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, and then the Mummy Pass Trail. Once a large meadow area of Hague Creek opened, we walked in the meadow to access this site.

Burn severity: Low

Species: All Brook Trout

Site description: Meadow/riparian area did not burn. Site is surrounded by a large meadow (Figure 22). Trees on both hillsides burned severely. There is a small amount of ash deposition in the stream and stream banks that likely washed down from upstream burned areas, but water was clear. The stream reach was a meandering channel with a mix of riffle and pool habitat including side pools with very muddy substrate and deep pools at the bends. Average stream width was 10.2 m and depth was 48 cm. Gradient was relatively low (2-3%). Substrate was mostly cobble, gravel, and sand. At the time of the 2021 survey, DO = 78.3 %, water temperature = 12.3 °C, pH = 7.45, conductivity = 26.2 µs/cm, and turbidity was low. There were no trees or canopy cover over the stream. Undercut banks with grassy overhangs and deep pools likely provide excellent trout habitat. Electrofishing seemed efficient and we captured YOY. Many fish came from backwater and side channel. Trout size distribution in 2021 shifted toward larger individuals compared to 2019 (Figure 22 and Figure 23). Trout abundance increased slightly from 2021 to 2022.

Figure 22. Team conducting sampling at Hague 1 site.

Figure 23. Hague 1 example specimen photo - brook trout.

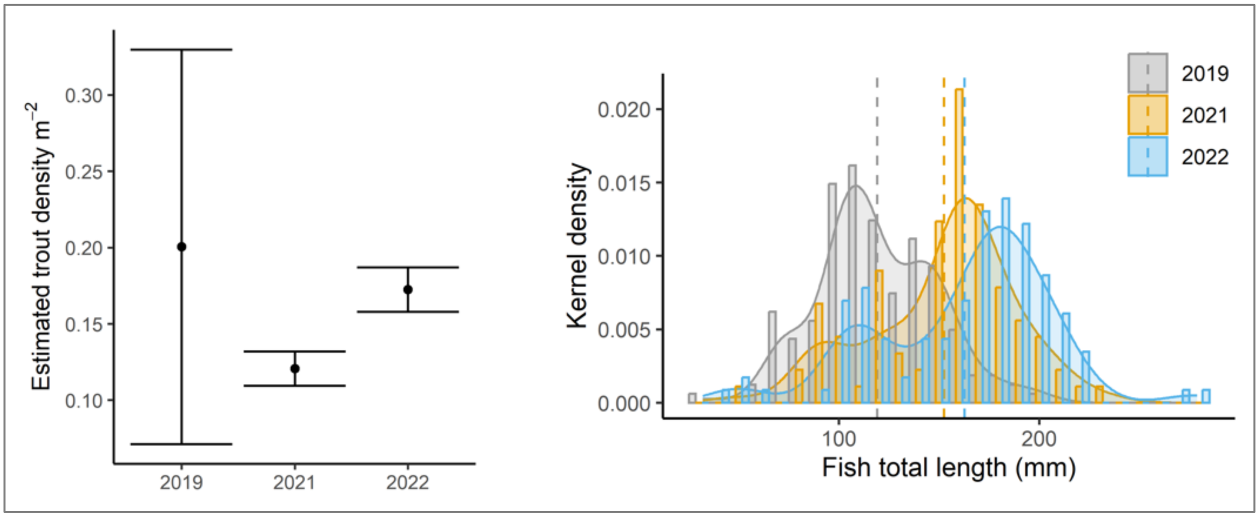

Figure 24. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2019), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by Colorado State University.

Hague 2 Site

Survey date: 08/09/2021 & 08/08/2022

Site coordinates (UTM; latitude/longitude): 13T 439951 4484776; 40.51153, -105.709

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, and then the Mummy Pass Trail. Once a large meadow area of Hague Creek opened, we walked along the perimeter of the meadow to access this site, located just upstream of the confluence with Hazeline Creek.

Burn severity: Moderate

Species: All Brook Trout

Site description: The riparian area was mostly grassy with some willows and interspersed trees (Figure 25). Riparian area had some signs of burn and regrown vegetation but did not burn severely. The broader surrounding landscape was burned severely. There did not appear to be much ash deposition on the benthos stream except in back eddies/ stagnant side-pools. The reach was a simple channel with mostly swift riffles/cascades and only a few small pockets of pool-like habitats. Flows were very swift throughout much of the reach. Average stream width was 6.0 m and depth was 45 cm. Gradient was relatively high (5-6%). Substrate included many large boulders and cobble. At the time of the 2021 survey, DO = 68.9 %, water temperature = 12.9 ℃, pH = 8.05, conductivity = 27.1 µs/cm, and turbidity was relatively high. Canopy cover almost entirely open. Aquatic macroinvertebrate abundance appeared high. We started electrofishing just upstream of the confluence with Hazeline Creek. Complex habitat and swift flow made capturing fish very challenging, though habitat did not look optimal for trout either with minimal pool habitat. We collected just six Brook Trout individuals in 2021, and size distribution shifted toward mostly large individuals, except for a few YOY that were present (Figure 26). Trout abundance increased in 2022 to a level comparable to pre-fire (2019).

Figure 25. Hague 2 site photo.

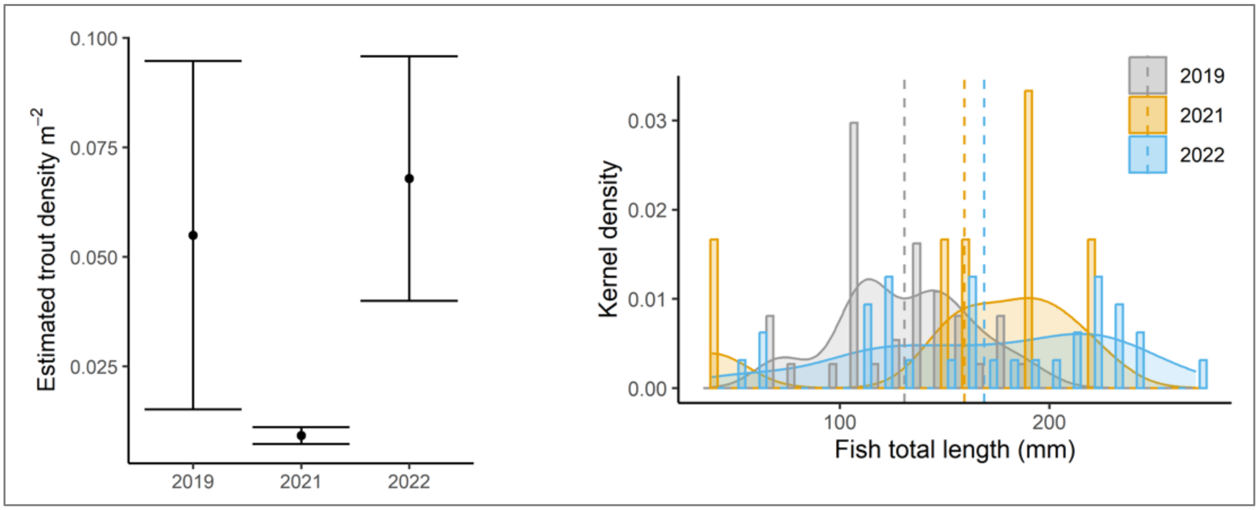

Figure 26. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2019), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by Colorado State University.

Hague 3 Site

Survey date: 08/10/2021 & 08/09/2022

Site coordinates (UTM; latitude/longitude): 13T 441111 4484941; 40.39027, -110.370

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, and then the Mummy Pass Trail. Once a large meadow area of Hague Creek opened, we walked along the perimeter of the meadow to access the site.

Burn severity: Low

Species: All Brook Trout

Site description: The stream reach ran through a large meadow upstream of the confluence with Mummy Pass Creek (Figure 27). The riparian vegetation and surrounding meadow were regrown with evidence of low grass shrub burn. The hillsides burned severely with very little regrowth. Site overall was similar to Hague 1. There was ash deposition in the stream, including ash mixed in with finer substrates, especially in the pools and side channels, but the water looked clear. Reach was a meandering channel with some splits around grassy mounds and had deep, lateral pools. Average stream width was 5.7 m and depth was 56 cm. Substrate was very mobile and dominated by cobble, pebbles, and gravel. At the time of the 2021 survey, DO = 77.9 %, water temperature = 12.7 °C, pH = 6.74, conductivity = 27.6 µs/cm, and turbidity was moderate. Canopy cover was completely open. Overall, the habitat looked great for fish with several deep pools, undercut banks, and overhanging grasses. Aquatic macroinvertebrates looked abundant. We did not catch as many fish as expected, but we caught several large Brook Trout. YOY were present. Estimated trout density in 2021 was much lower compared to 2019, and size distribution shifted toward larger individuals (Figure 28). Trout abundance was nearly comparable between 2021 and 2022.

Figure 27. Hague 3 site photo.

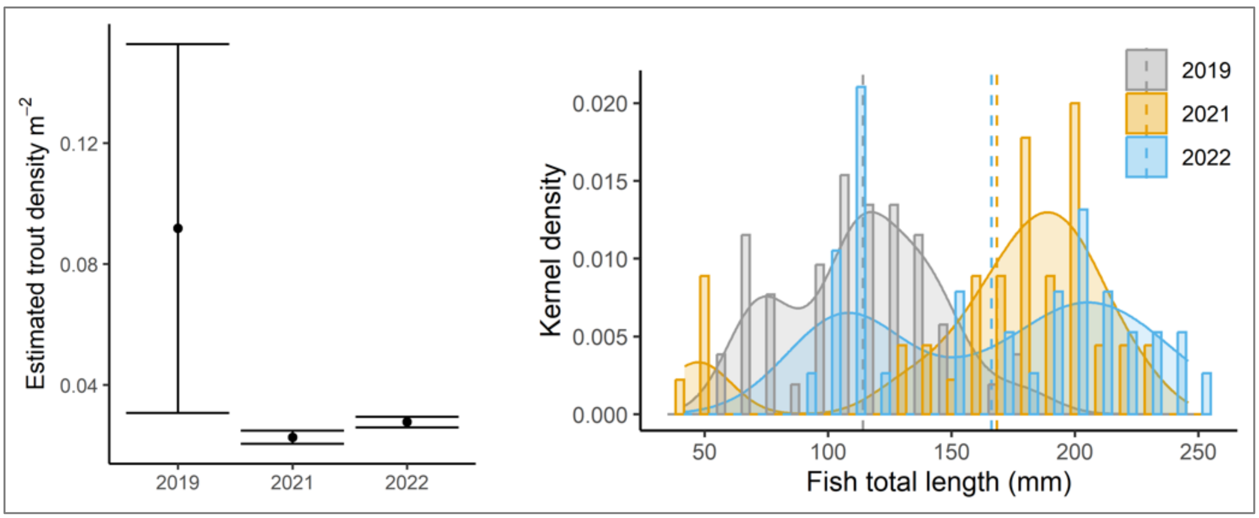

Figure 28. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2019), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by Colorado State University.

Hague 4 Site

Survey date: 08/11/2021

Site coordinates (UTM; latitude/longitude): 13T 442238 4483872; 40.50355, -105.682

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, and then the Mummy Pass Trail. Once a large meadow area of Hague Creek opens up, we walked along the perimeter of the meadow on the river right (facing downstream). Upstream of Hague 3, we crossed the river and walked on along the perimeter of the meadow on the river left.

Burn severity: Moderate

Species: No fish were caught

Site description: Mechanical removal of Brook Trout had been conducted in surveys prior to 2021. The full reach we surveyed was 815 m in length. The surrounding forest was heavily burned, except for a few unburned trees (Figure 29). Grasses and other small vegetation appeared to have been burned and regrown. Black branches showed signs of burn up to the water edge. Hillsides were burned severely on either side of the meadow, and the area just upstream of the 815-m reach was forested and severely burned up to the streamside. There was also ash deposition within the finer sediments in stream. Reach was a narrow, braided channel with many shallow riffles, pools with undercut banks, and more complex habitat (e.g., run/cascade/step). There were a few lateral scour pools in the downstream section. Average stream width was 3.3 m and depth was 34 cm. Despite being in a meadow, gradient was high (5-6%). Substrate was a mix of boulder/cobble in the upstream, higher-gradient section and cobble/pebble in the downstream section. At the time of the 2021 survey, DO = 77.1 %, water temperature = 10.1 °C, pH = 8.00, conductivity = 23.7 µs/cm, and turbidity was low. Canopy cover was completely open. The macroinvertebrate communities look healthy. There were many areas where habitat looked great for trout, but no fish were caught (Figure 30). A few 1-2 cm YOY were observed in the side channel. There might be a dispersal barrier (fast waterfall/cascade) just downstream of the reach.

Figure 29. Hague 4 site photo.

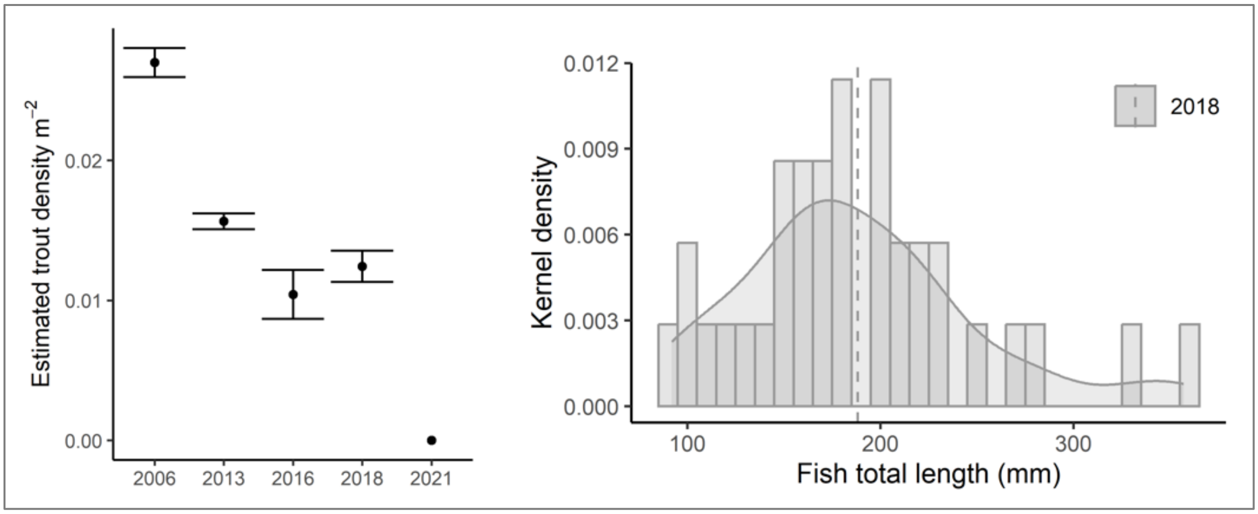

Figure 30. (Left) Trout density estimated post-fire (2021) and pre-fire (2006-2018), with 95% confidence intervals based on 2-pass depletion. No fish were caught in 2021. (Right) Relative trout size distribution in the most recent pre-fire survey (2018), and the vertical dashed line shows the mean length. Pre-fire data were collected by the US Fish and Wildlife Service.

Hazeline 1 Site

Survey date: 08/10/2021 & 08/08/2022

Site coordinates (UTM; latitude/longitude): 13T 440083 4484525; 40.50928, -105.707

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, and then the Mummy Pass Trail. Once a large meadow area of Hague Creek opened, we walked along the perimeter of the meadow to access this site. From the confluence with Hague Creek, we walked upstream along Hazeline Creek.

Burn severity: High

Species: All Brook Trout

Site description: Reach was in a severely burned forest with almost entirely torched trees and a high degree of duff/litter burn up to the stream edge (Figure 31). Soil in the hill on both sides were unstable due to burn, and many burned trees had fallen into the stream channel. There was some regrowth of understory vegetation along the streamside but not much. Ash deposition in the stream coated many of the rocks in slower flowing areas. Reach was a complex channel (chutes/cascades/steps) with many large boulders and log jams, so there were many fast-flowing sections but still a few pockets of slower flow. Average stream width was 6.6 m and depth was 30 cm. Stream gradient was very high (>10 %, some areas >20 %). Substrate was a mix of bedrock and boulders. At the time of the 2021 survey, DO = 85.3 %, water temperature = 8.8 °C, pH = 7.74, conductivity = 18.8 µs/cm, and turbidity was low. Canopy cover was completely open due to complete canopy mortality. Aquatic macroinvertebrates seemed healthy, though, including mayflies, stoneflies, and caddis. There was a decent amount of periphyton on rocks too. Habitat included some good pools with large wood, and looked decent for trout, despite high gradient and swift flows. Most fish caught were from pockets of pools. No Cutthroat Trout were observed, only Brook Trout in both 2021 and 2022 (Figure 32). Smaller fish (<150 mm), including YOY, were not observed in either year. Trout abundance increased from 2021 to 2022.

Figure 31. Hazeline 1 site photo.

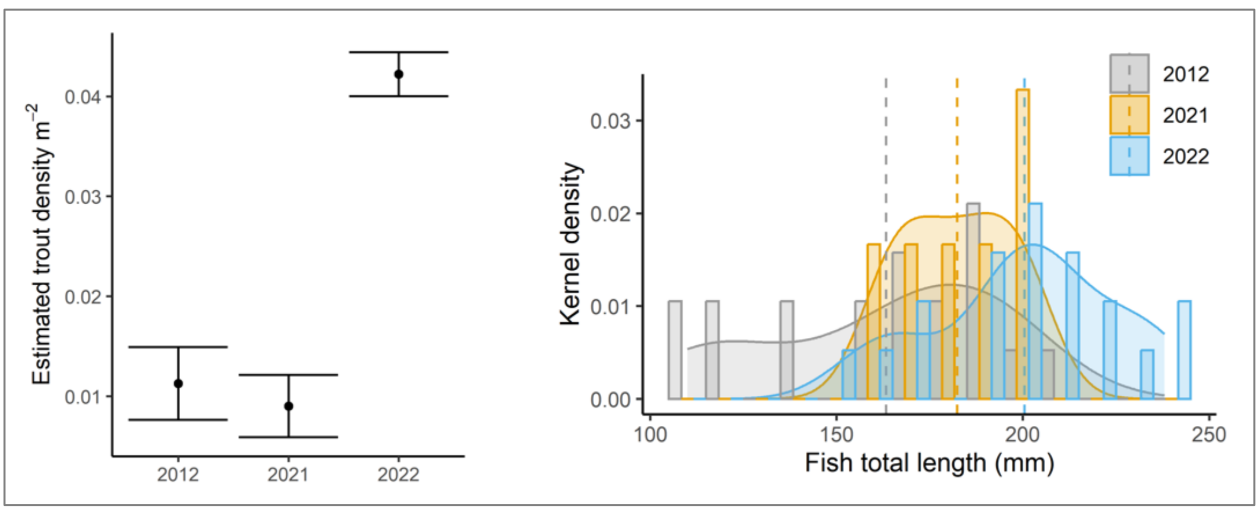

Figure 32. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2012), with 95% confidence intervals based on 2-pass depletion. (Right) Relative trout size distribution between years, and the vertical dashed line shows the mean length. Pre-fire data were collected by the US Fish and Wildlife Service.

Hazeline 2 Site

Survey date: 08/10/2021 & 08/09/2022

Site coordinates (UTM; latitude/longitude): 13T 439922 4484752; 40.51131, -105.709

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, and then the Mummy Pass Trail. Once a large meadow area of Hague Creek opened, we walked along the perimeter of the meadow to access this site, located just upstream of the confluence with Hague Creek.

Burn severity: Moderate

Species: No fish were caught

Site description: Streamside vegetation may have burned but appeared to be growing back well and riparian shrubs and grasses seemed mostly intact (Figure 33). Most of the streamside trees did not appear burned, except a few slightly burned stands (needles intact but brown). Upper half of reach is much more burned (several scorched trees and duff/litter burn). There was not much ash deposition in stream except some areas along banks. Reach was a simple, narrow channel with cascades and pools. Average stream width was 4.5 m and depth was 30 cm. Stream gradient was high (5-6%). Substrate was a mix of mostly boulder and cobble. At the time of the 2021 survey, DO = 82.4 %, water temperature = 7.5 ℃, pH = 7.96, conductivity = 19.3 µs/cm, and turbidity was low. Canopy cover was very low with some canopy mortality. Habitat did look okay for trout and was similar to Hague 2 but narrower in width and there were not many slow pockets of water or undercut banks. We caught no fish in either pass in 2021. One fish was observed visually but was missed. Given the narrow width, we used 1 shocker but it was outputting fine (confirmed by hand), and many bugs in the nets, so shocking was likely efficient. No YOY were present. However, we caught Brook Trout in 2022 and its density was comparable to pre-fire years (2012, 2016 & 2018) (Figure 34).

Figure 33. Hazeline 2 site photo.

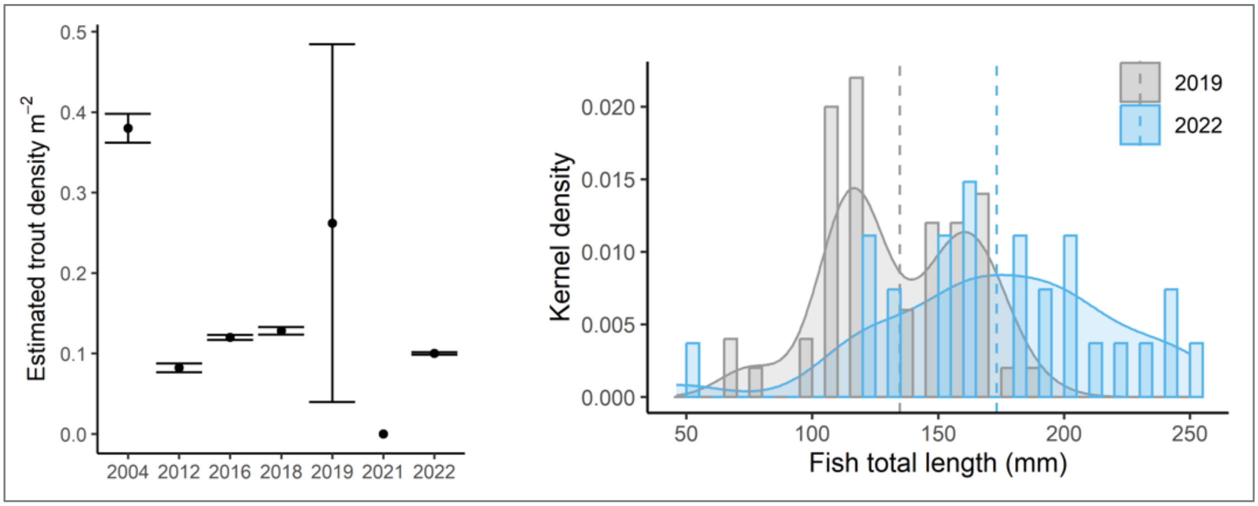

Figure 34. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2004-2019), with 95% confidence intervals based on 2-pass depletion. No fish were caught in either pass in 2021. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by Colorado State University.

Mummy Pass Site

Survey date: 08/17/2021 & 08/27/2022

Site coordinates (UTM; latitude/longitude): 13T 441388 4485645; 40.51946, -105.692

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, and then headed up the Mummy Pass Trail. The site is located near the Mummy Pass Creek Campsite.

Burn severity: Moderate

Species: All Brook Trout

Site description: The upstream river left had some scorched and torched trees, but the rest of the riparian area, which was mostly meadow, did not look burned (Figure 35). The areas that were burned did not seem to burn up to the stream edge. There did not appear to be much if any ash deposition in the stream, even in the side pools and stagnant areas. Reach was a meandering, simple channel with a mix of riffles and pools. Average stream width was 2.3 m and depth was 27 cm. Stream gradient was low (2-3%). Substrate was a mix of mostly cobble with boulder, gravel, and sand. At the time of the 2021 survey, DO = 80.3 %, water temperature = 8.3 °C, pH = 7.44, conductivity = 18.6 µs/cm, and turbidity was low. Canopy cover was mostly open. The aquatic macroinvertebrates looked healthy; in particular, there were many midges (Simuliidae and Chironomidae). There were also high amounts of periphyton growth on the substrate. This reach appeared to be great habitat for trout, with several nice pools and undercut banks with overhanging grasses. Estimated trout density was approximately 3-fold higher in 2021 compared to 2019, but size distribution was similar with a slight shift toward larger individuals (Figure 36). Trout density and population size structure were comparable between 2021 and 2022.

Figure 35. Mummy Pass site.

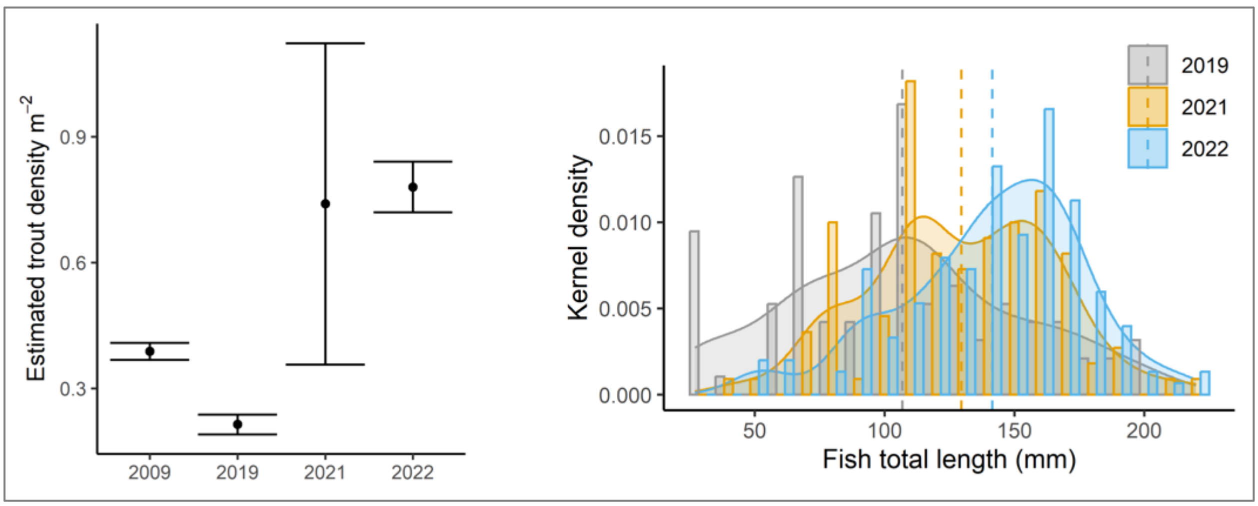

Figure 36. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2009 & 2019), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by Colorado State University.

North Inlet Site

Survey date: 08/06/2021

Site coordinates (UTM; latitude/longitude): 13T 432024 4456703; 40.25803, -105.799

Access: From the North Inlet Trailhead parking area. Hiked east on the trail along the RMNP boundary. The trail turns to northeast and the site is located where the river approaches close to the trail.

Burn severity: Moderate

Species: Brook Trout, Brown Trout, and Mottled Sculpin

Site description: The surrounding landscape was substantially burned with several torched and fallen trees and regrowth of tall grasses in the riparian area (Figure 37). Ash deposition in the stream was high and accumulated along banks and covered many of the rocks/sediment. The middle of stream had less ash but ash was still present within finer sediment. Reach was a simple, wide channel with mostly deep pools and almost no riffle habitat. There was one big jam of large burned trees and unburned branches at bottom of the reach. Average stream width was 9.7 m and depth was 74 cm. Stream gradient was very low (1-2 %) with slow velocity. Substrate was mostly small gravel and cobble with some large boulders. At the time of the 2021 survey, DO = 75.0 %, water temperature = 13.5 ℃, pH = 6.54, conductivity = 20.4 µs/cm, and turbidity was moderate. Canopy cover was completely open. Overall, this appeared good trout habitat with several deep pools and undercut banks with overhanging grasses. Estimated fish density was low compared to other sites, likely because stream area was very large (Figure 38). Size distribution was composed of mostly small individuals (<100 mm) but ranged up to ~275 mm.

Figure 37. North Inlet site photo.

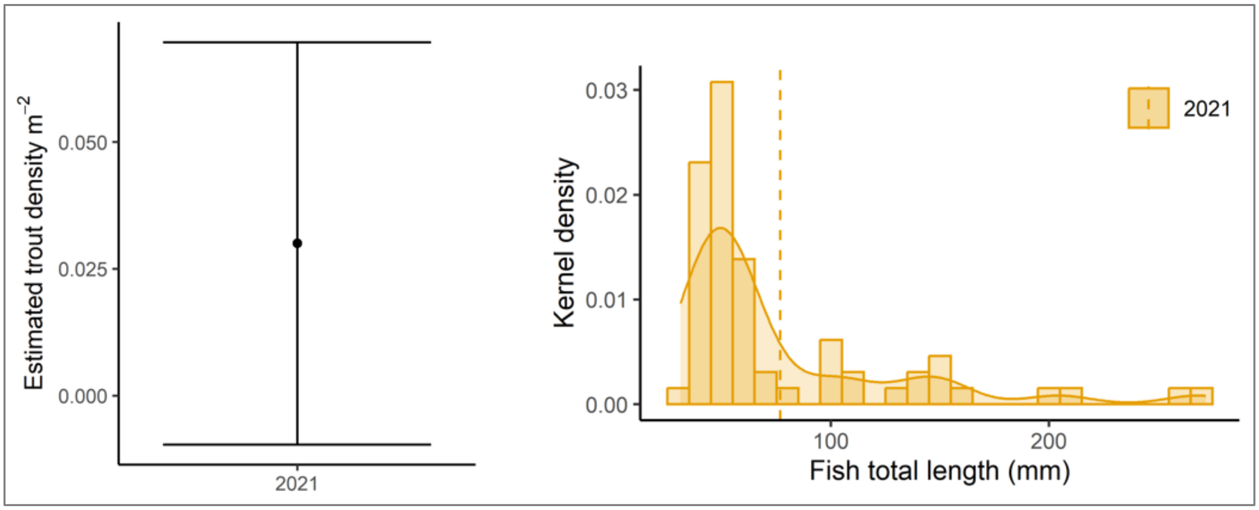

Figure 38. (Left) Trout density estimated in 2021, with 95% confidence intervals based on 2-pass depletion. (Right) Relative trout size distribution in 2021, and the vertical dashed line shows the mean length. This was a new site, so comparisons to previous years are not available.

Onahu 2 Site

Survey date: 08/13/2021

Site coordinates (UTM; latitude/longitude): 13T 428105 4463342; 40.31751, -105.846

Access: Parked on the Onahu Creek Trailhead parking area. Walked along Route 34, and the site is located downstream of Route 34. The upstream end of the site is the road crossing with Route 34.

Burn severity: Low

Species: Brook Trout, Brown Trout, and Mottled Sculpin

Site description: There was some evidence of fire burning riparian branches, but limited (Figure 39). Some trees were burned nearby, but most trees were not burned and still alive or affected by beetles. Shrubs and grasses had grown back. Site looked nearly identical pre-fire and was likely minimally impacted by fire, other than very small amounts of ash and small charred wood in some of the pools. Stream was a narrow, simple channel with a mixture of riffles and small pools with small wood. Average stream width was 4.2 m and depth was 31 cm. Stream gradient was moderate (3-4%). Substrate was a mixture of cobble and pebble. At the time of the 2021 survey, DO = 83.8 %, water temperature = 9.8 °C, pH = 6.65, conductivity = 15.1 µs/cm, and turbidity was relatively low. Canopy cover was moderate. The reach had high habitat heterogeneity and included pools with undercut banks and overhanging grass, making it great trout habitat. We observed a good mix of Brook and Brown Trout (more Brook Trout), including YOY and a wide range of sizes except for very large individuals. Overall, the reach was a very productive habitat, including high amounts of aquatic macroinvertebrates. Estimated fish density was approximately half of the 2012 estimate (Figure 40).

Figure 39. Onahu 2 site photo.

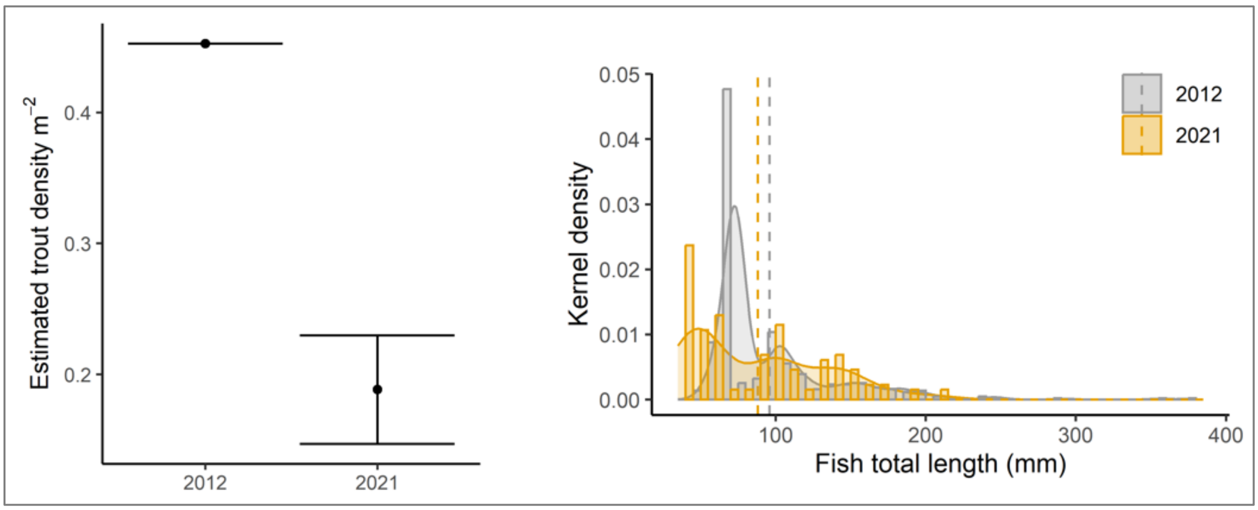

Figure 40. (Left) Trout density estimated post-fire (2021) and pre-fire (2012), with 95% confidence intervals based on 2-pass depletion. No fish > 75 mm were caught in pass 2 in the 2012 survey, leading to no estimated error. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by the US Fish and Wildlife Service.

Poudre 1 Site

Survey date: 09/10/2021 (pictures not available)

Site coordinates (UTM; latitude/longitude): 13T 437539 4483125; 40.49648, -105.737

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, past the confluence with Hague Creek. The site was in an open meadow.

Burn severity: Low

Species: All Brook Trout

Site description: Site was just upstream of a burned area, but the site itself did not burn. Riparian area was mostly meadow with grasses, willows, and other vegetation. Reach was a simple channel with ~30% pool and the rest was riffle/cascade habitat. Average stream width was 6.4 m and depth was 33 cm. Stream gradient was moderate (3-4%). Substrate was a mix of boulder, cobble, pebble, gravel, and sand. The reach was also characterized with high amounts of algae on the substrate. At the time of the 2021 survey, DO = 73.0 %, water temperature = 18.4 °C, pH = 6.57, conductivity = 44.6 µs/cm, and turbidity was moderate. Canopy cover was completely open. Electrofishing started at a riffle/cascade complex and ended after a bend. Flow was low, but wide enough for 3 shockers. There were higher than usual mortalities, likely due to high temperatures. We caught a very high number of Brook Trout, including large individuals (>200 mm). YOY were also present. Trout size distribution shifted toward larger individuals in 2021 compared to 2019 (Figure 41).

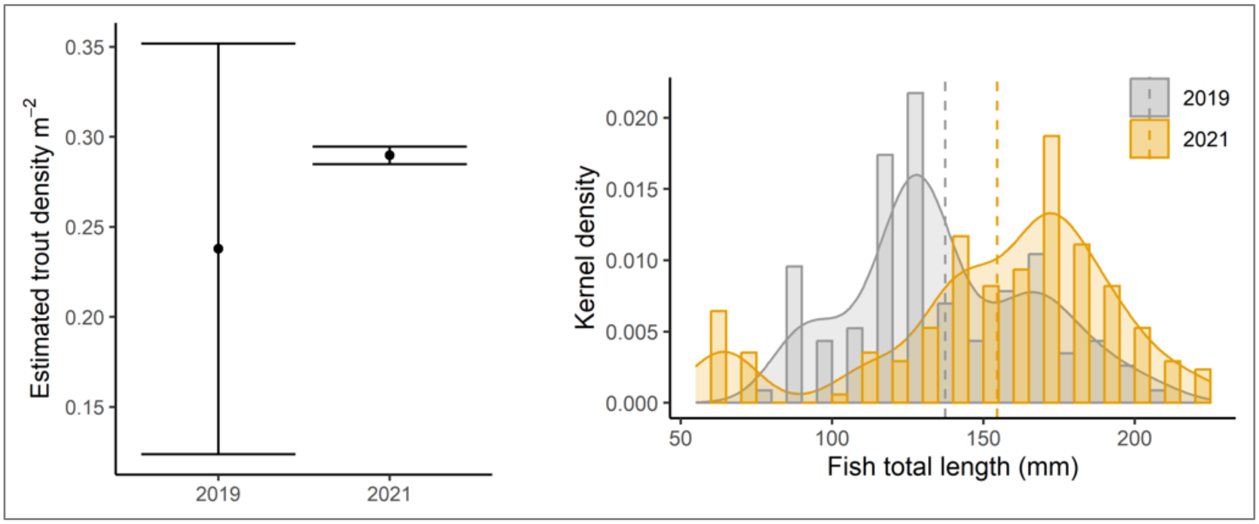

Figure 41. (Left) Trout density estimated post-fire (2021) and pre-fire (2019), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by Colorado State University.

Poudre 3 Site

Survey date: 08/19/2021 & 08/03/2022

Site coordinates (UTM; latitude/longitude): 13T 434801 4478087; 40.45089, -105.769

Access: From the Cache La Poudre Trailhead parking area on Route 34 near Poudre Lake. Walked down the trail to access this site.

Burn severity: None

Species: All Brook Trout

Site description: The reach runs through meadow with no trees or large vegetation within close proximity (Figure 42). There seemed to be no impact of fire at all – no visible ash, no burned vegetation nearby, and surrounding meadow and forests not burned at all. Reach was a simple, meandering channel with mostly riffles but ~30% pool habitat. Average stream width was 3.8 m and depth was 22 cm. Stream gradient was moderate (3-4%). Substrate was mostly cobbles and pebble. At the time of the 2021 survey, DO = 82.2 %, water temperature = 8.1 ℃, pH = 7.28, conductivity = 42.0 µs/cm, and turbidity was moderate. Canopy cover was completely open. Brook Trout were very abundant here. The pools had some undercut bank with overhanging small vegetation, and these habitats held many trout (>15). There were many mayflies and midges as well. Estimated trout density was nearly twice as high in 2021 compared to 2019, but size distribution was similar (Figure 43 and Figure 44). Trout abundance increased from 2021 to 2022.

Figure 42. Poudre 3 site photo.

Figure 43. Poudre 3 example specimen photo - brook trout.

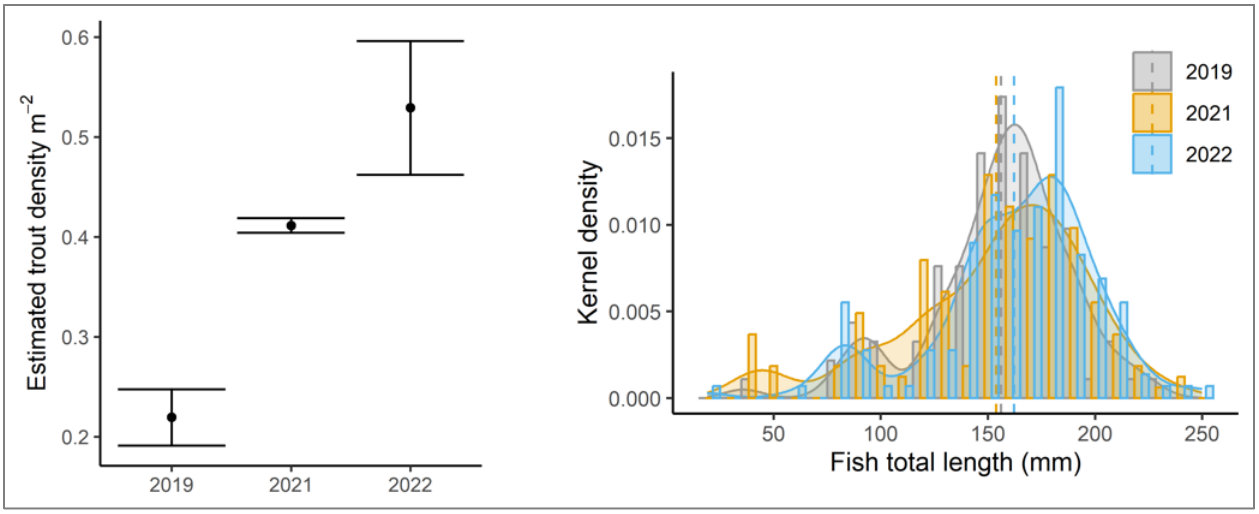

Figure 44. (Left) Trout density estimated post-fire (2021 & 2022) and pre-fire (2019), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by Colorado State University.

Poudre 5 Site

Survey date: 09/10/2021 & 08/12/2022

Site coordinates (UTM; latitude/longitude): 13T 437448 4485042; 40.51374, -105.738

Access: From the Corral Creek Trailhead parking area. Walked down the Corral Creek Trail and crossed the new bridge over the La Poudre Pass Creek. Walked upstream on the Poudre River Trail, past the confluence with Hague Creek. The site was downstream of what appeared to be impassable waterfalls for fish.

Burn severity: High

Species: Brook Trout (except one individual of Cutthroat Trout)

Site description: Riparian trees burned up to the stream channel on both banks, and ash was visible on the stream channel margin (Figure 45). Understory vegetation was coming back in burned areas. The reach was a simple channel and contained a mix of run, pool, and riffle habitats, with pools occupying 15-20% of surface area. Average stream width was 7.8 m and depth was 31 cm. Stream gradient was low (2-3%). Substrate was a primarily boulder, cobble, and pebble. At the time of the 2021 survey, DO = 86.6 %, water temperature = 6.5 °C, pH = 7.01, conductivity = 35.0 µs/cm, and turbidity was moderate. Canopy cover was almost entirely open with high canopy mortality due to fire. A large waterfall was located about 50-100 m upstream of the electrofishing section. Electrofishing started above a cascade and ended below another cascade. Flow was low in 2021, but the stream was wide enough to require 3 backpack shocking units. Brook Trout were abundant and showed a range of sizes (>200 mm) in both years. In 2021, YOY were present in the channel margin and had reached 4-5 cm as it neared the summer growing season. We caught one Cutthroat Trout in

2021. Estimated fish density was high, especially considering the large stream area, and size distribution included many intermediate-sized fish with both large and small individuals as well (Figure 46). Trout abundance was comparable between 2021 and 2022.

Figure 45. Poudre 5 site photo.

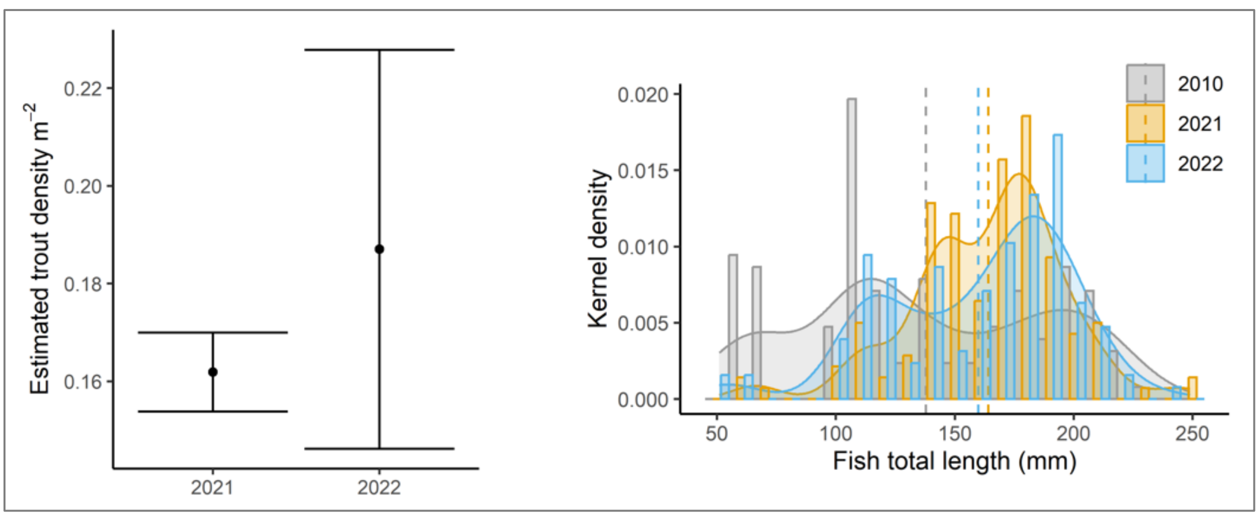

Figure 46. (Left) Trout density estimated post-fire (2021 & 2022), with 95% confidence intervals based on 2-pass depletion. The most recent pre-fire survey (2010) was a single-pass survey, so 2-pass estimation could not be used for density estimates. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by the US Fish and Wildlife Service.

Tonahutu Site

Survey date: 08/06/2021

Site coordinates (UTM; latitude/longitude): 13T 430494 4456690; 40.25779, -105.817

Access: From the Tohahutu Trailhead parking area. Followed the trail approximately 200-300 m.

Burn severity: Moderate

Species: Brook Trout. Two Rainbow Trout were caught outside of reach

Site description: Riparian area directly adjacent to stream was mostly forested and did not look burned, but areas 20-50 m from the reach were severely burned (Figure 47). There were high amounts of suspended sediment mixed with ash. Ash had accumulated in areas on the stream bank. Sediment seemed quite mobile. Reach was a single channel with very complex habitat and swift flows in some sections. Many large boulders and log jams created a sequence of riffles, runs, cascades, and pools. Average stream width was 6.5 m and depth was 51 cm. Stream gradient was high (6-7%). Substrate was a mix of boulder, cobble, pebble, and some finer sediments. At the time of the 2021 survey, DO = 81.5 %, water temperature = 12.4 °C, pH = 7.95, conductivity = 36.6 µs/cm, and turbidity was very high. Water was so turbid that eDNA filters became clogged quickly. Canopy cover was relatively high (well shaded) as there was limited canopy morality in the riparian area, most of which was due to beetle kill rather than fire. Despite high gradient and swift flows, the habitat looked okay for trout, but we caught few fish (Figure 48). In 2021, only four trout were caught in pass 1 and no fish were caught in pass 2 (Figure 49). Two Rainbow Trout were caught in shocking outside of the reach.

Figure 47. Tonahutu site photo.

Figure 48. Tonahutu site example specimen photo - rainbow trout.

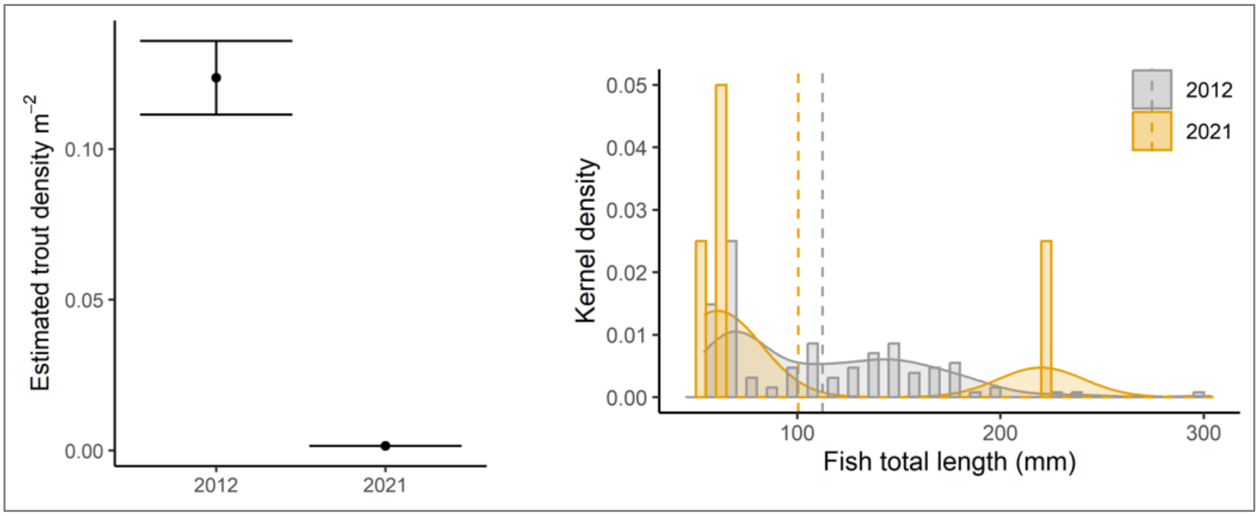

Figure 49. (Left) Trout density estimated post-fire (2021) and pre-fire (2012), with 95% confidence intervals based on 2-pass depletion. More narrow confidence intervals result when relatively few fish were caught in pass 2. (Right) Relative trout size distribution by year, and the vertical dashed line shows the annual mean total length. Pre-fire data were collected by the US Fish and Wildlife Service.

Appendix C - JAGS Code for Analysis of Trout Count Data.

The same information is submitted as an R file.

```
model{


  # Priors
  for (t in 1:2){  # 1 = before, 2 = after (2021 & 2022)
    mean.p[t] ~ dunif(0.3, 1)       # mean capture probability
    b0[t] <- log(mean.p[t]/(1-mean.p[t])) # convert to logit
scale
  }
  b1 ~ dnorm(0, 0.001)   # day-of-year effect on capture
probability
  b2 ~ dnorm(0, 0.001)   # stream width effect on capture
probability


    # site random effects on abundance
    for (j in 1:nSites){
      a0[j] ~ dnorm(a0.mu, a0.tau)       # mean abundance before
fire
      a1[j] ~ dnorm(a1.mu, a1.tau)       # year effect (2021) -
1st year post-fire
      a2[j] ~ dnorm(a2.mu, a2.tau)       # year effect (2022) -
2nd year post-fire
    }
    ## hyper-parameters
    a0.mu ~ dnorm(0, 0.001)
    a0.tau <- 1 / (a0.sd * a0.sd)
    a0.sd ~ dunif(0, 5)       # dgamma(0.001, 0.001)


    a1.mu ~ dnorm(0, 0.001)
    a1.tau <- 1 / (a1.sd * a1.sd)
    a1.sd ~ dunif(0, 5)       # dgamma(0.001, 0.001)


    a2.mu ~ dnorm(0, 0.001)
```

```
    a2.tau <- 1 / (a2.sd * a2.sd)
    a2.sd ~ dunif(0, 5)       # dgamma(0.001, 0.001)


  # Likelihood

  ## Before fire
  for(i in 1:n){
    N[i] ~ dpois(lambda[i] * reachLength[i]/100) # lambda = log
abundance in 100 m
    log(lambda[i]) <- a0[site[i]] + a1[site[i]]*Y2021[i] +
a2[site[i]]*Y2022[i]

    ## Capture
      y[i,1] ~ dbin(p[i], N[i])                              #
e-fish pass 1
      y[i,2] ~ dbin(p[i], N[i] - y[i,1])
   # e-fish pass 2
      y[i,3] ~ dbin(p[i], N[i] - y[i,1] - y[i,2])
   # e-fish pass 3
      y[i,4] ~ dbin(p[i], N[i] - y[i,1] - y[i,2] - y[i,3])
   # e-fish pass 4

      # the next two lines may help logit models to converge
(Schaub & Kery 2012)
      p[i] <- 1/(1 + exp(-lp.lim[i]))
      lp.lim[i] <- min(999, max(-999, lp[i]))
      lp[i] <- b0[time[i]] + b1 * day[i] + b2 * width[i] # time 1
= before, 2 = after (2021 & 2022)

    ## Compute expected pass 1 count
      y.exp[i] <- p[i] * N[i]
  }


  # Derived quantity
```

```
    ## overall mean difference between 2021 and 2022
    diff.21_22.overall <- a2.mu - a1.mu

    ## mean abundance in 2021 and 2022
    post2021.a0.mu <- a0.mu + a1.mu
    post2022.a0.mu <- a0.mu + a2.mu

    for (i in 1:nSites){
      ## site-specific difference between 2021 and 2022
      diff.21_22.site[i] <- a2[i] - a1[i]
      ## site-specific abundance in 2021 and 2022
      post2021.a0.site[i] <- a0[i] + a1[i]
      post2022.a0.site[i] <- a0[i] + a2[i]
    }
}
```

Appendix D - Taxon List of Benthic Invertebrates Encountered in Surber Samples (from 2021 and 2022 combined)

Table 5. Taxon list of benthic invertebrates encountered in Surber samples (from 2021 and 2022 combined). The columns show invertebrate Order, Family, the number of Sites where that taxon was detected (out of 19), and the total number of individuals observed. Individuals without a Family listed were only identified to Order.

Order	Family	Sites	Total Individuals
Anomopoda	–	10	97
Bivalvia	Cyrenidae	1	1
Bivalvia	Sphaeriidae	5	790
Coleoptera	Amphizoidae	1	1
Coleoptera	Dytiscidae	3	4
Coleoptera	Elmidae	18	4049
Coleoptera	Staphylinidae	2	2
Collembola	–	7	28
Copepoda	–	14	745
Diptera	–	19	604
Diptera	Athericidae	2	6
Diptera	Ceratopogonidae	19	989
Diptera	Chironomidae	19	26923
Diptera	Culicidae	1	1
Diptera	Dixidae	4	5
Diptera	Empididae	16	121
Diptera	Pediciidae	5	9
Diptera	Psychodidae	1	1
Diptera	Simuliidae	18	3969
Diptera	Tipulidae	15	35
Ephemeroptera	–	8	151
Ephemeroptera	Ameletidae	12	97
Ephemeroptera	Baetidae	19	6174
Ephemeroptera	Ephemerellidae	19	2568
Ephemeroptera	Heptageniidae	19	3976
Ephemeroptera	Leptophlebiidae	17	1415
Hemiptera	–	15	64
Hemiptera	Saldidae	2	2
Isopoda	Asellidae	1	1
Nematoda	–	16	95
Oligochaeta	–	19	3637

Table 5 (continued). Taxon list of benthic invertebrates encountered in Surber samples (from 2021 and 2022 combined). The columns show invertebrate Order, Family, the number of Sites where that taxon was detected (out of 19), and the total number of individuals observed. Individuals without a Family listed were only identified to Order.

Order	Family	Sites	Total Individuals
Ostracoda	–	16	1564
Plecoptera	–	8	685
Plecoptera	Chloroperlidae	18	996
Plecoptera	Leuctridae/Capniidae	14	132
Plecoptera	Nemouridae	18	3407
Plecoptera	Perlidae	9	29
Plecoptera	Perlodidae	19	1231
Plecoptera	Pteronarcyidae	2	8
Thysanoptera	–	17	107
Trichoptera	–	15	100
Trichoptera	Brachycentridae	14	136
Trichoptera	Chloroperlidae	1	1
Trichoptera	Glossosomatidae	15	176
Trichoptera	Hydropsychidae	13	70
Trichoptera	Hydroptilidae	13	44
Trichoptera	Lepidostomatidae	4	33
Trichoptera	Limnephilidae	6	113
Trichoptera	Philopotamidae	1	3
Trichoptera	Polycentropodidae	15	138
Trichoptera	Psychomyiidae	1	3
Trichoptera	Rhyacophilidae	15	167
Trichoptera	Uenoidae	5	8
Tricladida	–	9	36
Trombidiformes	–	19	1497

National Park Service
U.S. Department of the Interior

Science Report NPS/SR—2024/157
https://doi.org/10.36967/2304877

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1201 Oakridge Drive, Suite 150
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NPS 121/194118, July 2024