April 2025

Madison River Drainage 2188 Project Monitoring Report 2024

To:
Northwestern Energy-Environmental Division
11 East Park Street
Butte, MT 59701

By:
Travis Lohrenz, Jenna Sirmon, Keith Wellstone, Matt McCormack, and Matt Jaeger
Montana Fish, Wildlife & Parks
Region 3 Fisheries
1400 South 19th Avenue
Bozeman, MT 59718

Contents

Introduction

Montana Fish, Wildlife & Parks (FWP) monitors the fisheries in the Madison River Drainage to determine potential effects from operations at Hebgen and Madison dams. This work is funded through an agreement with NorthWestern Energy (NWE), the owner and operator of the dams. The agreement between FWP and NWE is designed to assist NWE in meeting the terms and conditions of the Federal Energy Regulatory Commission (FERC) license issued to NWE in 2000 to operate hydropower systems on the Madison and Missouri rivers (FERC 2000). This license includes Hebgen and Madison dams (Figure 1) and seven dams on the Missouri River collectively referred to by FERC as the 2188 Project. The 2188 license details requirements NWE must follow to operate the dam and hydropower facilities on the Madison and Missouri Rivers.

NWE entered a 10-year Memorandum of Understanding (MOU) with state and federal resource management agencies to provide annual funding to implement 2188 license requirements for the protection, mitigation, and enhancement (PM&E) of fisheries, recreation, and wildlife resources. The MOU established Technical Advisory Committees to collectively allocate annual funding to implement PM&E programs and the provisions of the 5-year fisheries and wildlife PM&E plans using adaptive principles. The Madison Fisheries Technical Advisory Committee (MadTAC) comprised of representatives from NWE, FWP, the U.S. Fish & Wildlife Service (USFWS), the U.S. Forest Service (USFS), and the U.S. Bureau of Land Management (BLM) is responsible for the allocation of funds to address fisheries issues related to operations of the Hebgen and Madison Dams under the 2188 license.

This report summarizes work completed by FWP in 2024 with funding provided by the MadTAC to address requirements of the 2188 license, specifically Articles 403, 408, 409, 412, and 419 that pertain to the Madison River fishery. Work included 1) fish abundance estimates in the Madison River, 2) assessment of fish populations in Hebgen and Ennis reservoirs, 3) limnological evaluation of Hebgen reservoir, 4) evaluation of the effects of the 2021 Hebgen gate failure on upper Madison River fisheries 5) conservation and restoration of Arctic Grayling populations, 6) conservation and restoration of Westslope Cutthroat Trout (WCT) populations, 7) evaluation of opportunities for the enhancement of mainstem and tributary habitats, and 8) evaluation of the effects of river flows on side channel habitat.

Study Area

The Madison River originates in Yellowstone National Park at the confluence of the Gibbon and Firehole rivers and flows north for 180 miles through Southwest Montana to its confluence with the Missouri River near Three Forks, Montana. The Madison transitions from a narrow, forested river valley in the headwaters to a broad valley bounded by the Madison and Gravelly mountain ranges south of Ennis. North of Ennis the river flows through a steep canyon for 11 miles before it transitions into a broad alluvial valley bottom where it joins the Jefferson and Gallatin rivers, forming the Missouri River (Figure 1).

Two dams impound the Madison River: Hebgen Dam forms Hebgen Reservoir, and Madison Dam forms Ennis Reservoir (Figure 1). Hebgen Reservoir is operated as a water storage facility to control inflow to the downstream Madison Dam, which is a power-generating facility. Madison and Hebgen dam operations are coordinated to provide year-round flows at or above required minimum instream flows and below required maximum rates of flow change; while also mitigating thermal issues in the Madison River below Madison Dam by delivering pulsed flows (Figure 1).

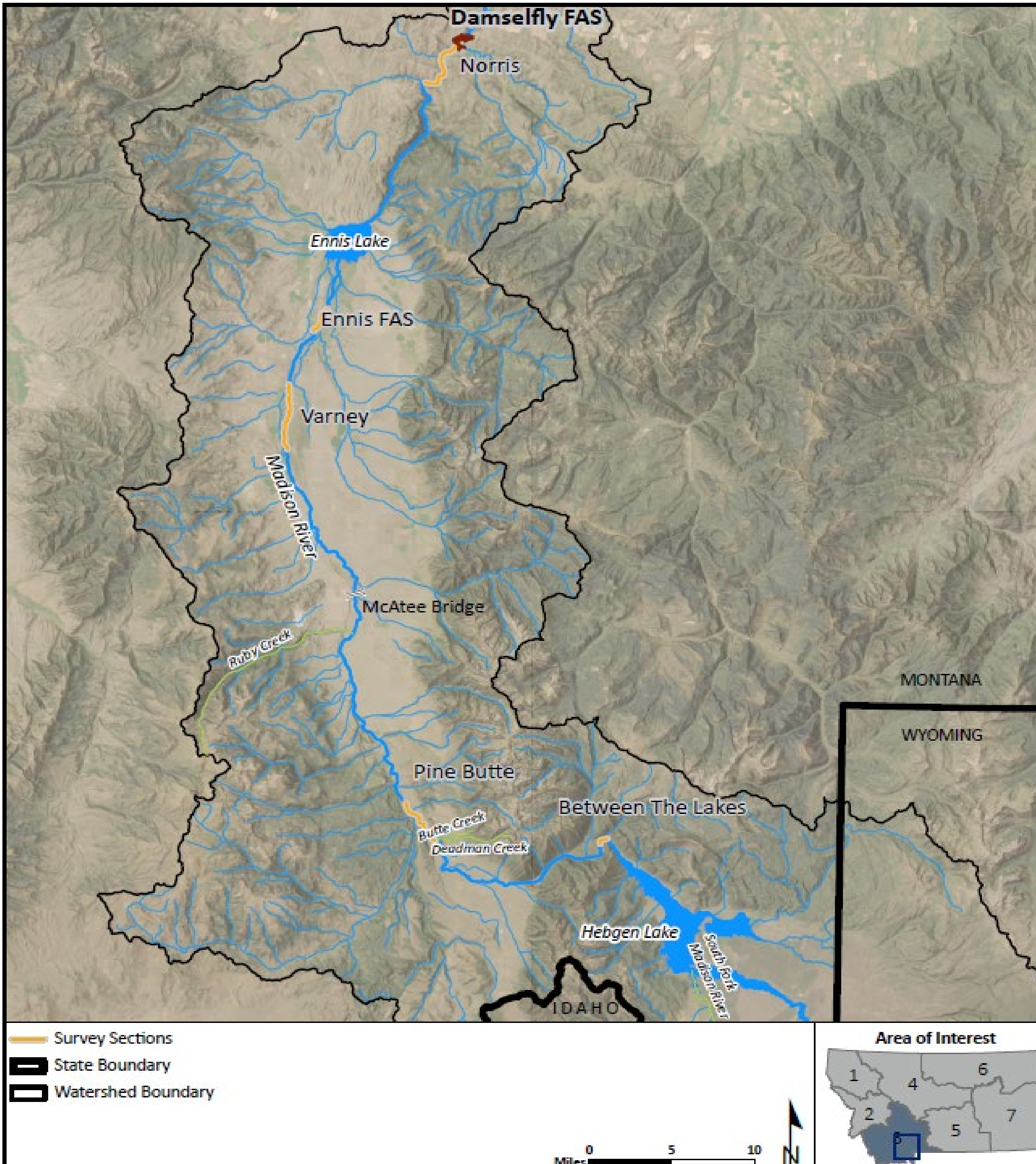

Figure 1. Locations of NWE dams on the Madison River (FERC Project 2188), FWP annual abundance estimate sections, Ennis and Hebgen Lakes, and project areas discussed in this report.

Monitoring and Projects

Article 403-River Discharge:

Article 403 of the 2188 Project FERC license specifies operational conditions, including minimum and maximum instream flows in various sections of the Madison River. NWE must maintain a minimum flow of at least 150 cfs in the Madison River below Hebgen Dam (gage no. 6-385) and limit the change in the outflow from Hebgen to no more than 10% per day. Additionally, a minimum flow of 600 cfs at Kirby Ranch (USGS gage no. 6-388) and 1100 cfs at USGS gage no. 6-410 below the Madison Dam must be maintained. Flows at Kirby Ranch are limited to a maximum of 3500 cfs under normal conditions to minimize erosion of the Quake Lake outlet. These license requirements necessitated the establishment of the permanent flow gage at Kirby Ranch. FWP and NWE monitor river discharge to avoid deviations from operational conditions.

Deviations from Article 403 occurred below Hebgen Dam and at Kirby Ranch on November 30, 2021. The deviations resulted from a broken component on the Hebgen Dam gate that resulted in a 43% change in Madison River discharge between Hebgen and Quake lakes and reduced flows at Kirby Ranch to 395 cfs for approximately 48 hours. To assess the potential impacts of the Hebgen Dam gate failure on the Madison River fishery, a monitoring plan developed by MadTAC and the preparation of a literature review to evaluate the potential effects of low flows were approved by FERC on August 18, 2022. Monitoring completed by FWP and NWE in 2024 is summarized in Appendix A.

Article 408-1) Effects of Project Operations on Hebgen Reservoir Fish Populations:

FWP monitors the Hebgen Reservoir fish assemblage with annual spring gill netting surveys to assess the effects of project operations on the fishery (Figure 1). Significant changes in the fish assemblage would warrant a review of project operations to address identified issues. We set ten multi-panel, experimental gillnets in Hebgen Reservoir in 2024. Catch-per-unit-effort (CPUE) was calculated as the average number of each species per net night:

$$\frac{C}{E}$$

where C represents the total number of fish and E represents one net night. Catch-per-unit-effort was calculated using catches from both floating and sinking nets. Brown Trout CPUE was calculated from sinking gill nets, and Rainbow Trout CPUE was calculated from floating gill nets to account for behavioral differences of each species.

The mean CPUE of total trout (Brown Trout and Rainbow Trout combined) in Hebgen Reservoir appears stable or slightly decreasing. Standardized gillnetting shows a decrease in CPUE from 23 trout/net in 2023 to 21 trout/net in 2024 and remains above the long-term average of 19 trout (Figure 2). The CPUE of Brown Trout was similar in 2023 (17.25 trout/net) and 2025 (16.75 trout/net) and exceeds the management goal of 15.5 Brown Trout/net. Rainbow Trout CPUE decreased from 6 trout/net in 2023 to 4.2 trout/net in 2024 which remains below the management goal of 7.5 Rainbow Trout/net. The mean length of Brown Trout increased from 456 mm in 2023 to 466 mm in 2024, remaining above than long-term average of 446 mm (Figure 3). The mean length of Rainbow Trout increased from 404 mm in 2023 to 426 mm in 2024, which is above the long-term average of 405 mm (Figure 3). Eighty-five percent of the Brown Trout captured in gill nets were ≥ 406 mm, and 56 % of the Rainbow Trout captured were ≥ 406 mm.

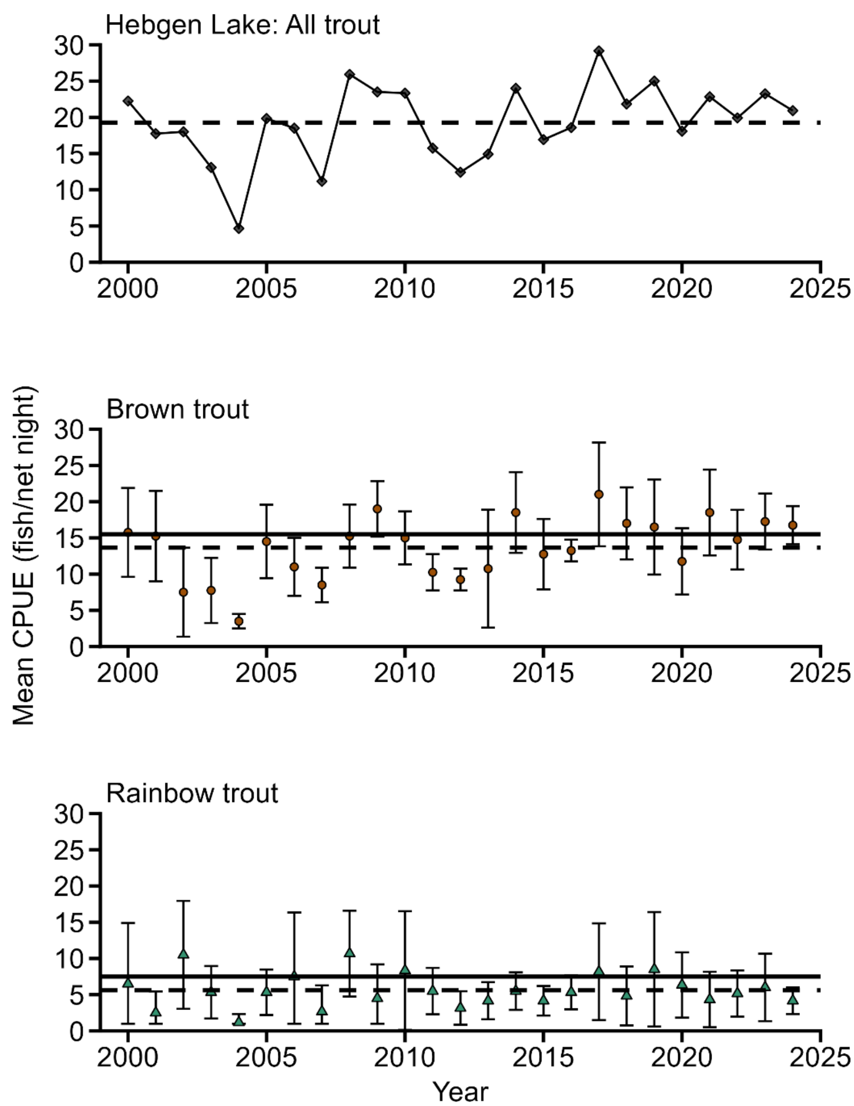

Figure 2. Mean catch-per-unit-effort (CPUE) of all trout combined (black diamonds), Brown (brown circles) and Rainbow Trout (green triangles) captured in Hebgen Reservoir from 2000 to 2024. Solid lines represent management goals, dashed lines represent the long-term average CPUE from 2000 to 2024, and error bars represent standard deviations for each year.

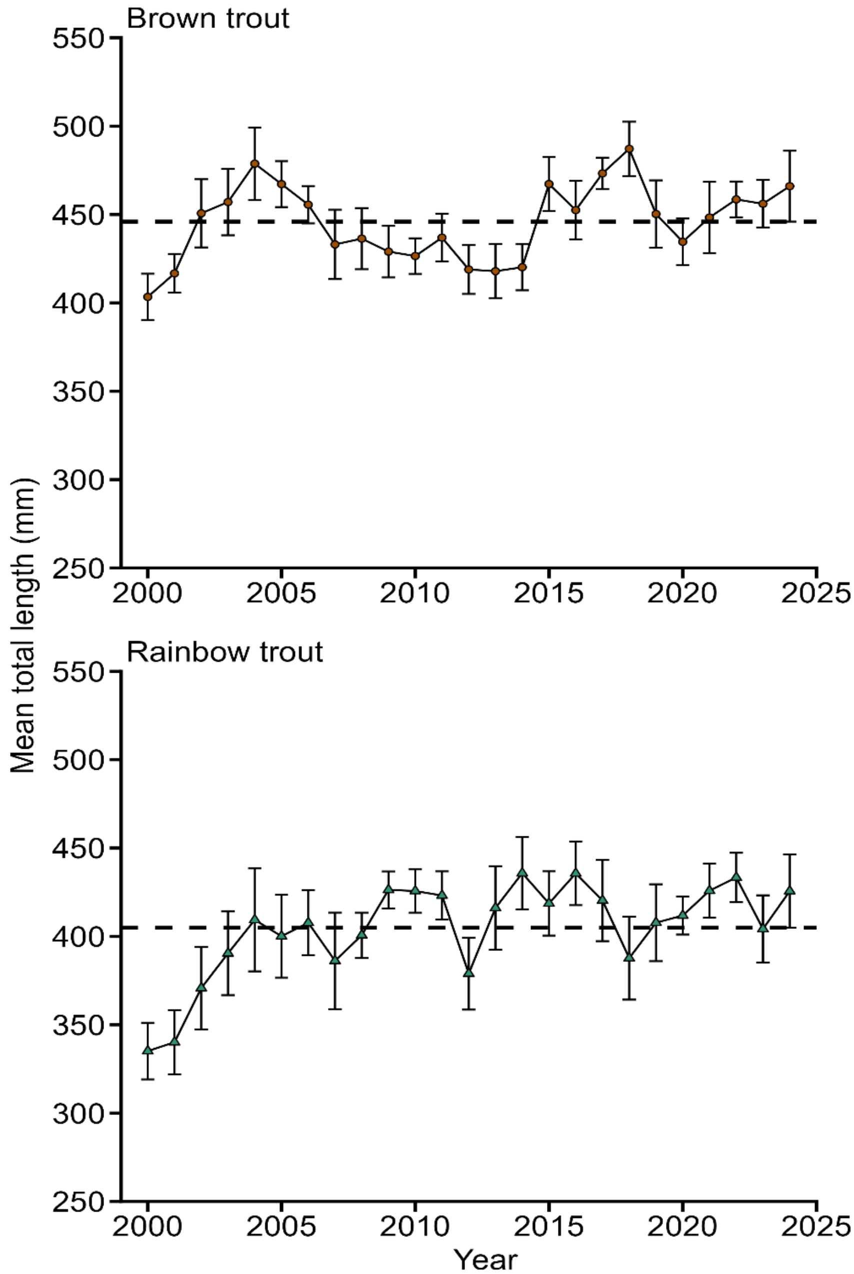

Figure 3. Mean total length (mm) of Brown (brown circles) and Rainbow Trout (green triangles) captured in Hebgen Reservoir from 2000 to 2024. The dashed lines represent the long-term average total length from 2000 to 2024, and error bars represent 95% confidence intervals for each year.

Article 412–1) Effects of Project Operations on Ennis Reservoir Fish Populations:

FWP historically monitored the Ennis Reservoir fish assemblage with biannual fall gill netting surveys on odd years. New gill net locations were established in 2021 to increase sampling efficacy while eliminating gill net sets in shallow habitats with poor capture efficiencies. In 2024, the fourth consecutive year with new net locations, we set six multi-panel, experimental gill nets in Ennis Reservoir. FWP continues to analyze data to establish management goals for the Brown and Rainbow Trout fisheries. Although FWP will assess long-term trends using data collected with the new sampling approach, much uncertainty will exist with such comparisons until additional data using the new gill net sets are available. Taking that into consideration, the mean CPUE of total trout, Brown Trout, and Rainbow Trout were above the long-term averages (Figure 4). Total trout CPUE increased from 13 trout/net in 2023 to 18 trout/net in 2024. The mean total length of Brown Trout decreased from 430 to 419 mm, still exceeding the long-term average of 399 mm. The mean total length of Rainbow Trout decreased from 390 to 370 mm which is below the long-term average of 376 mm (Figure 5).

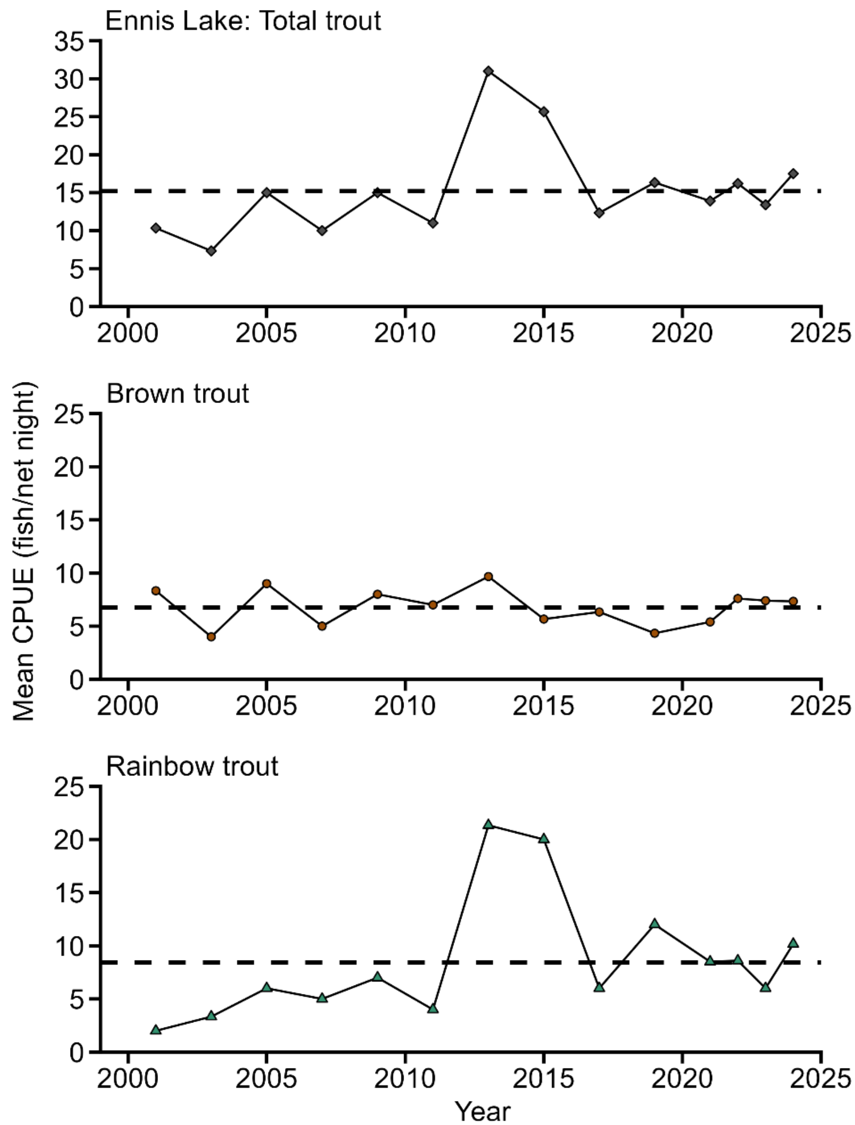

Figure 4. Mean catch-per-unit-effort (CPUE) of total (black diamonds), Brown (brown circles) and Rainbow Trout (green triangles) captured in gill nets set in Ennis Reservoir from 2001 to 2024. Brown and Rainbow Trout mean CPUE and were calculated using all nets set from each year.

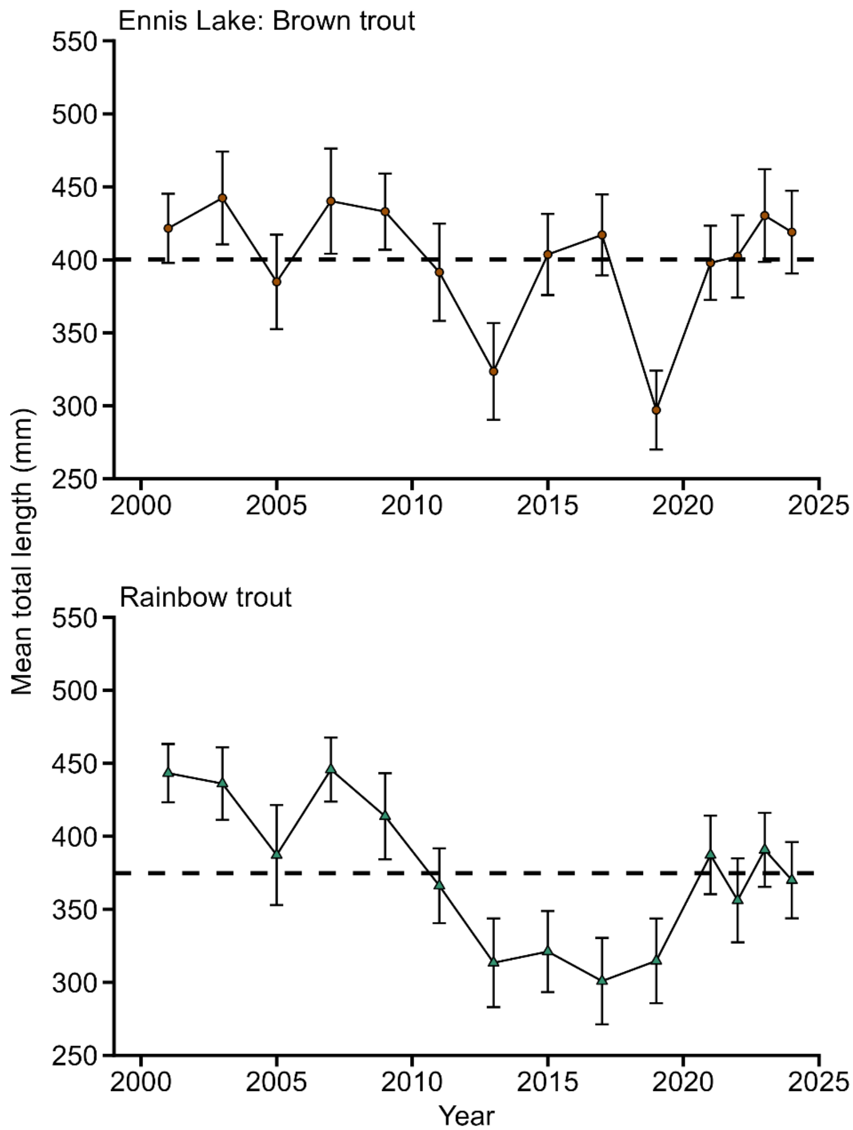

Figure 5. Mean total lengths (mm) of Brown (brown circles) and Rainbow Trout (green triangles) in Ennis Lake from 2001 to 2024. Dashed black lines represent the long-term average total lengths of each species and vertical bars represent the 95% confidence intervals for mean lengths each year.

408-3) Reservoir Draw Down Effects on Fish:

The interactions between Hebgen Reservoir elevation and operations, trophic status, and the trout populations were assessed annually by FWP from 2006-2020. Sampling occurred in June, July, and August, because these months correspond with the emigration of juvenile trout from natal tributaries to Hebgen Reservoir and their recruitment to the fishery may be influenced by reservoir conditions at the time of emigration (Watschke 2006, Clancey and Lohrenz 2007, Clancey and Lohrenz 2008, Clancey and Lohrenz 2009). Reservoir elevation may influence juvenile trout growth and recruitment by altering the amount of shoreline habitat and zooplankton abundances. Fluctuating reservoir elevations can impoverish the plankton assemblage through the loss of nutrients, which could limit forage for juvenile trout until they can switch to macroinvertebrates or piscivory (Axelson 1961, Haddix and Budy 2005). Hebgen Reservoir has a full pool elevation of 6534.87 feet (msl) and license article 403 requires NWE to maintain reservoir elevations between 6530.26 feet and 6534.87 feet from June 20 through October 1 and reach full pool elevation by late June or early July. Given the narrow operational range and similarity in reservoir conditions among years, limnological sampling was moved to a biannual schedule in 2020 or when reservoir elevations are outside of normal operational ranges.

FWP conducted limnological sampling at nine established sites on Hebgen reservoir in 2024. Sampling consisted of measuring light penetration into the water column with a Secchi disk and vertical zooplankton tows to evaluate zooplankton community densities. Secchi depths were recorded as the distance (in meters) between the water surface and the point in the water column where the disk becomes indiscernible. Zooplankton samples were collected by towing a 153-micron mesh (1 micron = 1/1,000th millimeter) plankton net vertically through the entire water column at one meter/second. Samples were rinsed and preserved in a 95% ethyl alcohol solution for enumeration and identification. Zooplankton were identified to groups (cladocera or copepoda) and the densities of each sample were calculated.

There was a statistical difference in zooplankton densities between June and July (Figure 6; ANOVA, $p=0.014$) and between June and August (Figure 6; ANOVA, $p=0.017$); however, there was no difference in densities between July and August (Figure 6; ANOVA, $p>0.05$). Copepoda comprised 69% of the sample in June, 75% in July, and 84% in August. Cladocera comprised 31%, 25%, and 26% of the samples respectively. No relationships between trophic status, zooplankton abundance, or trout and zooplankton abundances have been identified under the current reservoir operation criteria; however, zooplankton abundances were different among years in June, July, and August (Figure 7; ANOVA, $p < 0.05$). Therefore, FWP recommends continuing limnological sampling every other year and in years when departures from normal operations occur.

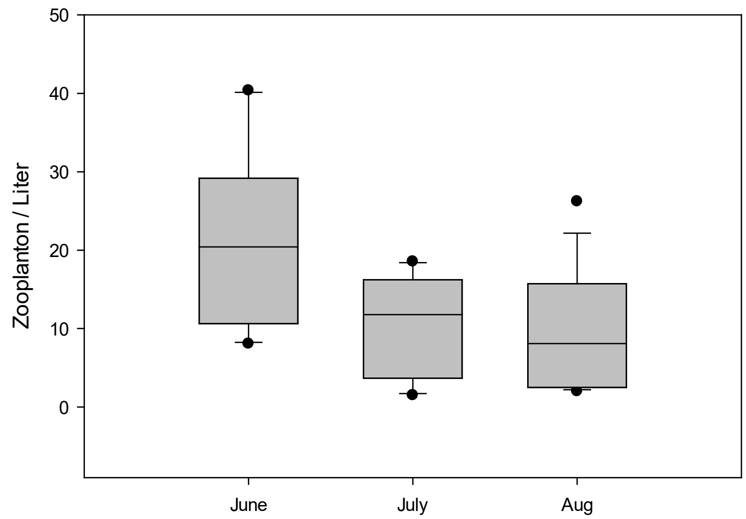

Figure 6. Total zooplankton abundance in June, July, and August 2024. Within each box, horizontal black lines denote median values; boxes extend from the 25th to the 75th percentile of each group's distribution of values, vertical lines denote the 5th and 95th percentile of each group’s distribution of values, and black dots are observations beyond those percentiles.

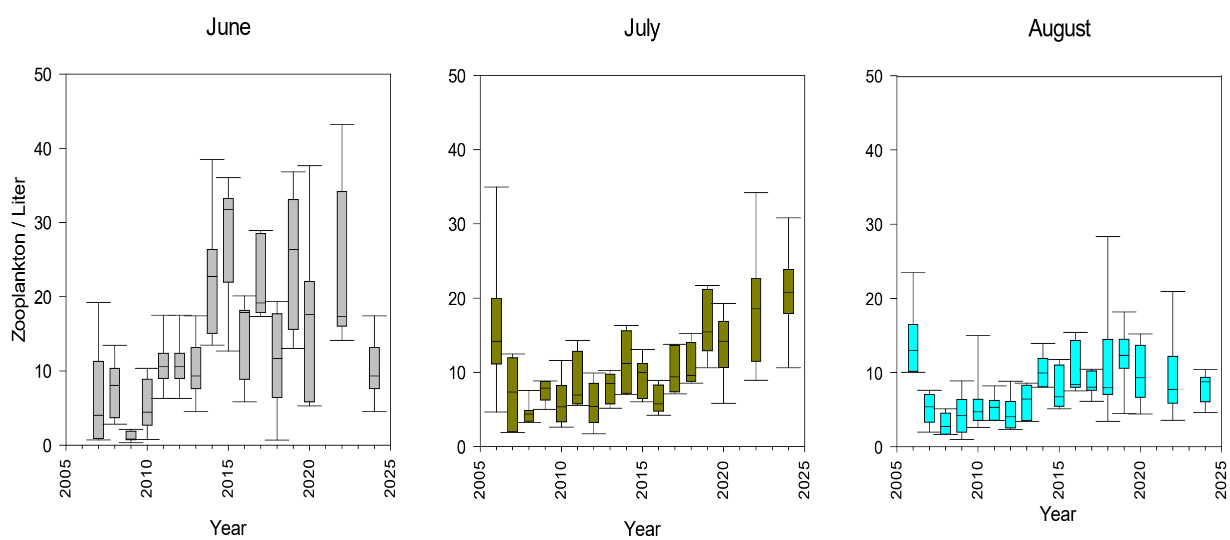

Figure 7. Total zooplankton abundance among months June, July, and August 2006-2024. Within each box, horizontal black lines denote median values; boxes extend from the 25th to the 75th percentile of each group's distribution of values, and vertical lines denote the 5th and 95th percentile of each group’s distribution of values.

408-4) Monitor the Effects of Modified Project Operations on Upper Madison River Fish Populations-Madison River Fisheries Assessment:

Montana Fish, Wildlife & Parks monitors Rainbow and Brown Trout abundances in three long-term monitoring sections of the Madison River to evaluate the influence of modified project operations at Hebgen and Madison dams on the trout fisheries. This report is limited to a discussion of potential influences of project operations; however, other potential population drivers (e.g., angling pressure, disease) are hypothesized to be influential and thus are evaluated independently by FWP. Crews conducted mark-recapture surveys in three long-term monitoring sections (Pine Butte, Varney, and Norris; Figure 8) to estimate trout abundances. Trout were collected by electrofishing from a drift-boat mounted, mobile anode system. Trout captured in the initial sampling events (marking runs) were anesthetized, weighed (g), measured to total length (mm), marked with a fin clip, and released. Crews conducted additional sampling events (recapture runs) 7 – 10 days after the marking runs. Trout captured on the recapture runs were measured to total length, examined for existing fin clips, and weighed (if not a recapture). Length-class specific abundance estimates were generated for Brown and Rainbow Trout using an R-based, proprietary FWP fisheries database and analysis tool. Capture histories for the recapture events were generated for each trout *i* where y_i = 0 represented a trout that was not a recapture and y_i = 1 represented a trout that was a recapture. We modeled this binary outcome using a generalized linear model with a Bernoulli distribution and a logit link function:

$$y_i \sim Bernoulli(p_i)$$

where p_i represents the detection probability for fish *i*. We compared four models for p_i:

1) Null model: $$logit(p_i) = \beta_0$$

2) Length linear: $$logit(p_i) = \beta_0 + \beta_1 length.bin_i$$

3) Length quadratic $$logit(p_i) = \beta_0 + \beta_1 length.bin_i + \beta_2 length.bin_i^2$$

4) Length quadratic fixed intercept: $$logit(p_i) = -5 + \beta_1 length.bin_i + \beta_2 length.bin_i^2$$

We used Aikike's information criterion to determine the best-fitting model (Akaike 1998) and predicted detection probabilities (p_I) for each length bin *i* using weighted model averages. We summed the abundance estimates for each length bin to estimate total abundance ($\widehat{N}$). Abundance estimates were standardized to stream mile:

$$\frac{\widehat{N}}{L}$$

where L represent the section length.

FWP developed management goals for total trout abundances (trout ≥ 252 mm [≈ 10”]) and size structure (percentages of trout ≥ 252 mm that are also ≥ 406 mm (≈ 16”]; Table 1) for each of the long-term sampling sections using the 66th percentiles of data collected over a twenty-year period from 2000 – 2020. Evaluating PM&E (Protection, Mitigation, and Enhancement) activities and management actions (e.g., flushing flows) in the context of these goals provides a better understanding of how they influence the Madison River trout fishery relative to other potential population drivers.

We calculated total trout abundances for fish ≥ 252 mm and the proportion of trout ≥ 406 mm in each section to evaluate whether management goals (Table 1) for each section were met.

Table 1. Montana Fish, Wildlife & Parks management goals for trout abundances and size structures in three long-term monitoring sections of the Madison River.

	Management goals	
Site	Abundance (trout ≥ 252 mm /mile)	Proportion of trout ≥ 252 mm that are also ≥ 406 mm
Pine Butte	2,300	25%
Varney	1,200	35%
Norris	2,500	15%

Abundance management goals were not met for any section in 2024. Abundances of trout per mile ≥ 252 mm increased slightly in the Pine Butte and Varney sections but decreased to historic lows in the Norris section (Figure 8). Proportional size structure goals for fish ≥ 406 mm were met in the Pine Butte and Norris sections (Figure 9); however, low capture probabilities for larger trout in the Pine Butte section may have biased abundance estimates resulting in a higher calculated proportion of trout ≥ 406 mm.

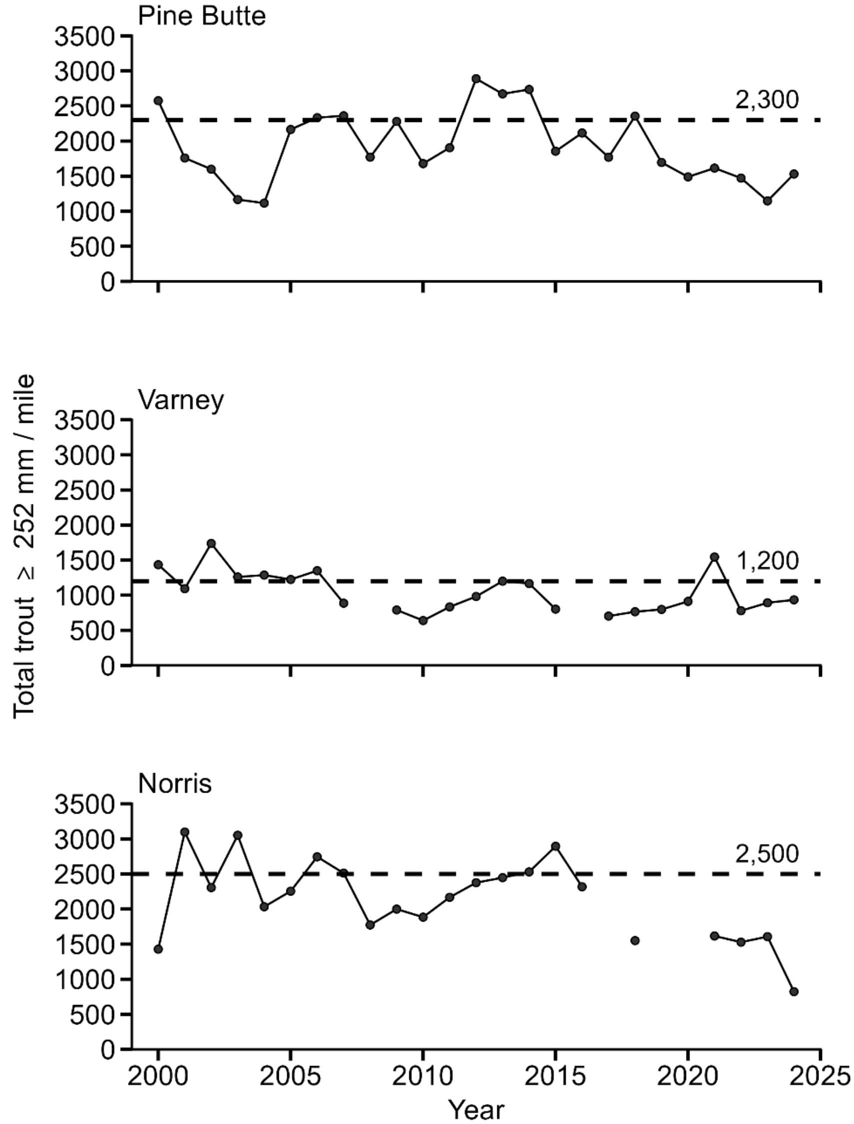

Figure 8. Estimated abundance of all trout ≥ 252 mm (~ 10") in three long-term monitoring sections of the Madison River. Black dashed lines represent the management goals for trout abundance in each section.

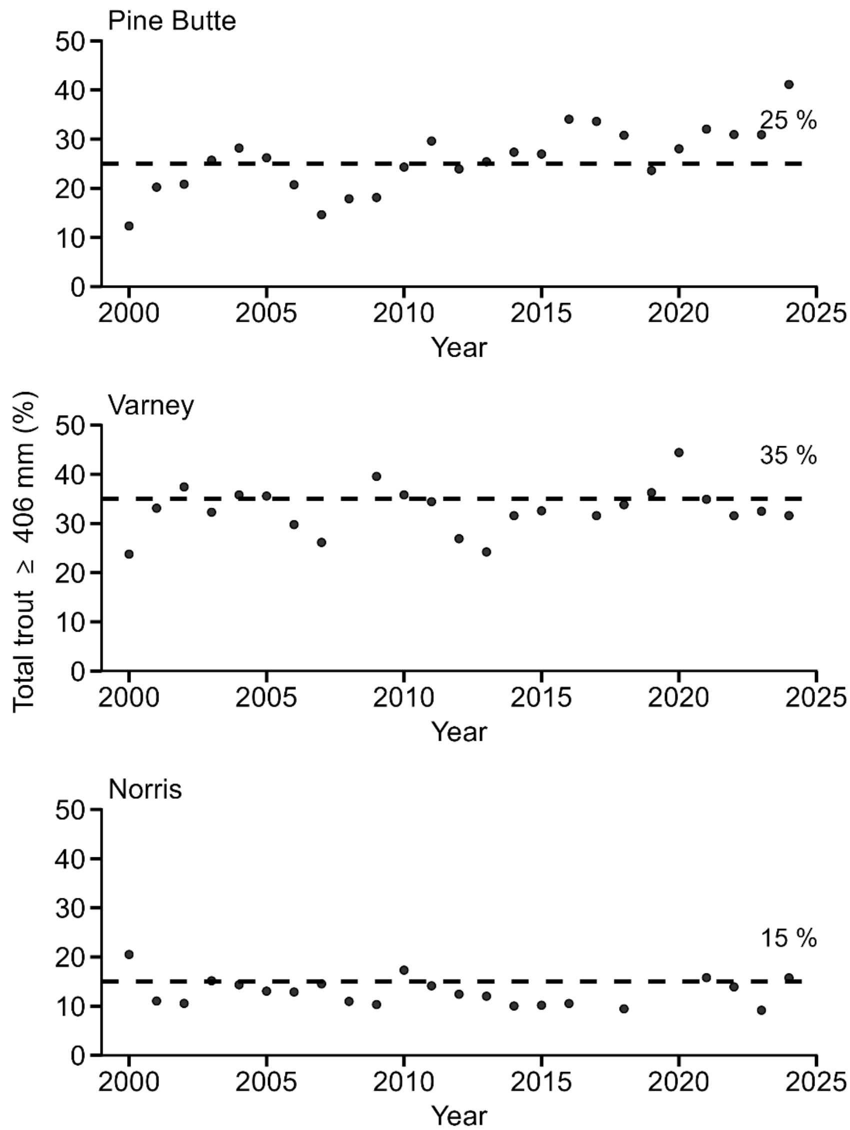

Figure 9. Percentage of ≥ 252 mm trout that are ≥ 406 mm (≈16") in three long-term monitoring sections of the Madison River. Black dashed lines represent the management goals for trout size structure in each section.

Pine Butte

The estimated abundance of Rainbow Trout ≥ 152 mm in Pine Butte increased from 1340 trout/mile in 2023 to 2848 trout/mile in 2024 (Figure 10), exceeding the 25-year average. Younger age classes comprised a large proportion of the 2024 population, with a high occurrence of Rainbow Trout ≤ 252 mm in our catch (Figure 11). The abundance of Brown Trout ≥ 152 mm in Pine Butte increased from 1257 trout/mile in 2023 to 2066 trout/mile in 2024, meeting the 25-year average (Figure 10). The high proportion of Brown Trout ≤ 252 mm observed in 2023 likely led to strong recruitment in 2024; similarly, the high proportion of Brown Trout ≤ 252 mm observed in 2024 suggests that another strong year class recruited to the sampling gear (Figure 11), which may result in increased numbers of larger trout in subsequent years.

Varney

The abundance of Rainbow Trout ≥ 152 mm has exceeded the 25-year average since 2020 and increased from 1,574 trout/mile in 2023 to 1,950 trout/mile in 2024 (Figure 10). An increase in the proportion of Rainbow Trout ≤ 252 mm from 2023 to 2024 indicates a strong year class recruited to the sampling gear (Figure 12), which may result in increased numbers of large trout in subsequent years. Brown Trout abundances decreased slightly below the 25-year average from 1,610 trout/mile in 2023 to 1,425 trout/mile in 2024 (Figure 10); however, the increase in the total abundance trout ≥ 252 mm suggests good survival of previous year classes (Figure 12).

Norris

Abundances of trout ≥ 152 mm remain at historic lows in Norris (Figure 10). The estimated abundance of Rainbow Trout ≥ 152 mm declined from 1,248 trout/mile in 2023 to 473 trout/mile in 2024. The truncated length-frequency histograms of Rainbow Trout in recent years (Figure 13) indicate a decline in Rainbow Trout recruitment and survival compared to the 2000s and 2010s. Brown Trout abundance decreased from 680 trout/mile in 2023 to 496 trout/mile in 2024 (Figure 10). Length frequencies of Brown Trout suggest some recruitment is occurring, but abundance estimates indicate an overall decline in the population compared to the 25-year averages (Figures 8 and 11). Overall, these results indicate the need for management intervention to improve recruitment of Rainbow and Brown Trout in the Norris Reach. Projects that improve spawning habitat or increase habitat complexity and refuge for age 0 and 1 trout should be prioritized.

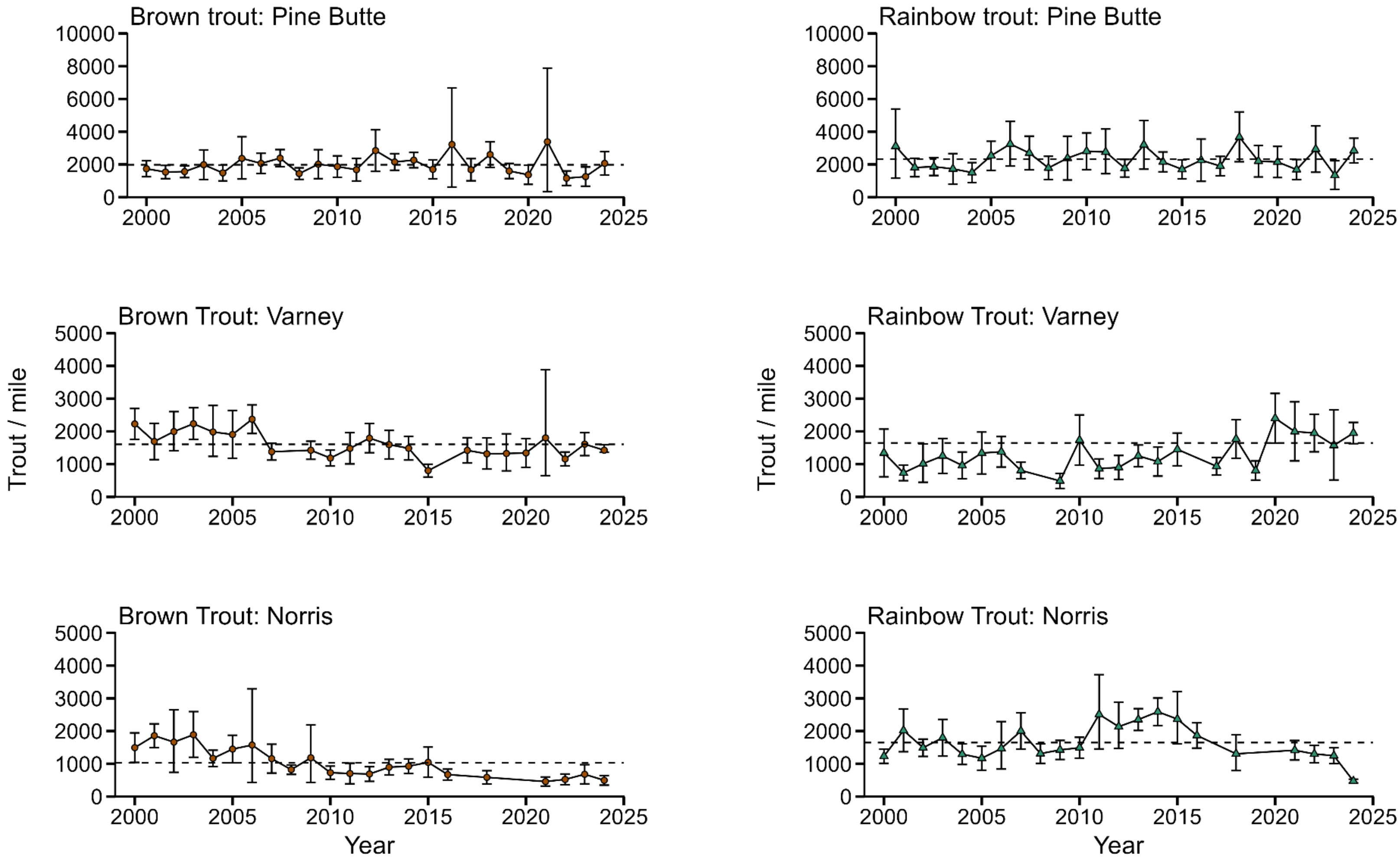

Figure 10. Estimated abundances of Brown (brown circles) and Rainbow Trout (green triangles) ≥ 152 mm (~ 6") in the three long-term sampling sections of the Madison River. Dashed lines represent the long-term average trout abundance (2000 to 2024), and error bars represent 95% confidence intervals. *We used 200 mm as the minimum size to calculate trout abundances in the Norris reach in 2024.

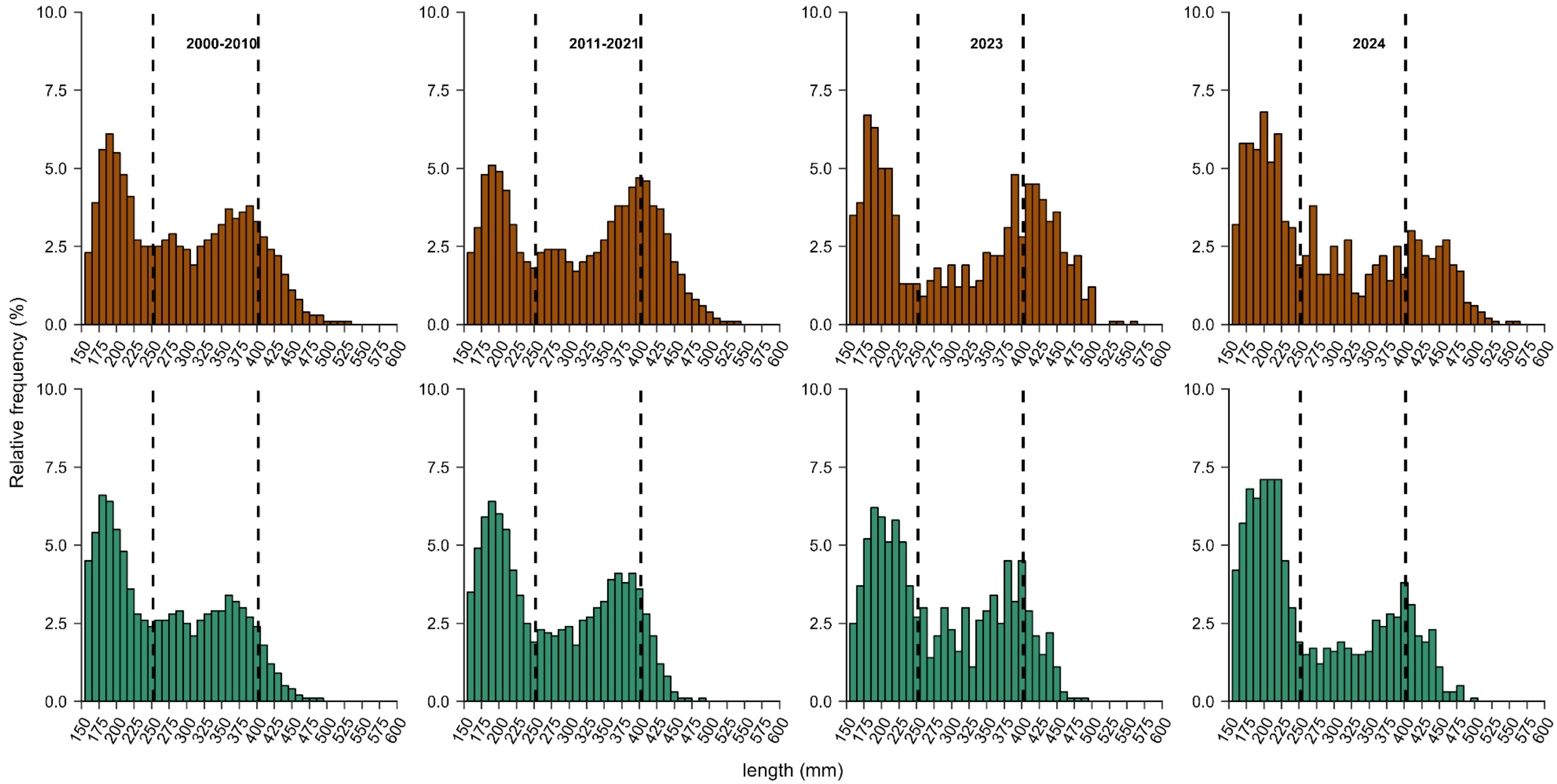

Figure 11. Length frequency histograms of Brown (brown bars) and Rainbow Trout (green bars) ≥ 152 mm (≈ 6”) captured in the Pine Butte Section of the Madison River. Black dashed lines delineate 252 mm (≈10”) and 406 mm (≈ 20”).

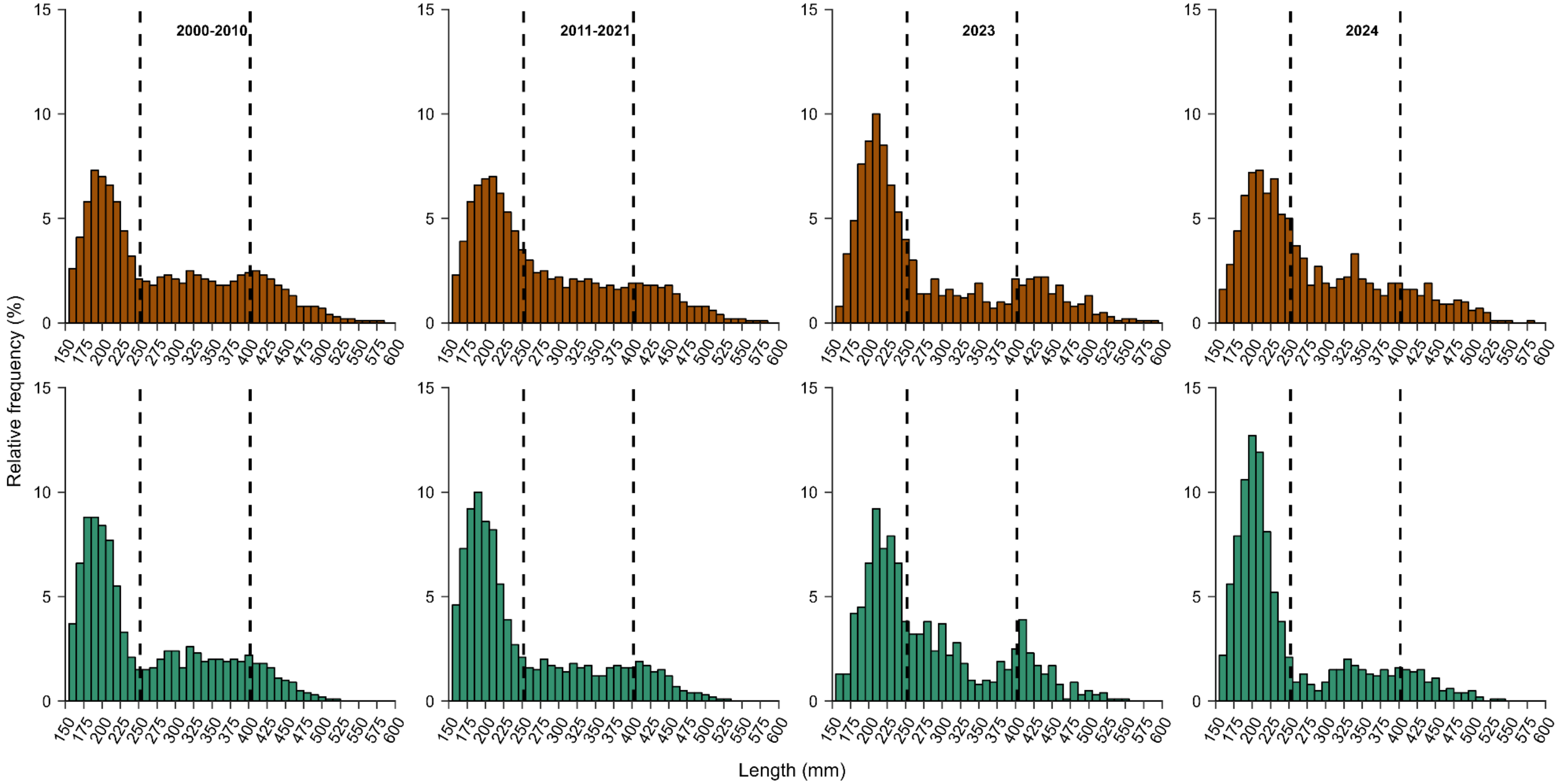

Figure 12. Length frequency histograms of Brown (brown bars) and Rainbow Trout (green bars) ≥ 152 mm (≈ 6”) captured in the Varney Section of the Madison River. Black dashed lines delineate 252 mm (≈10”) and 406 mm (≈ 20”).

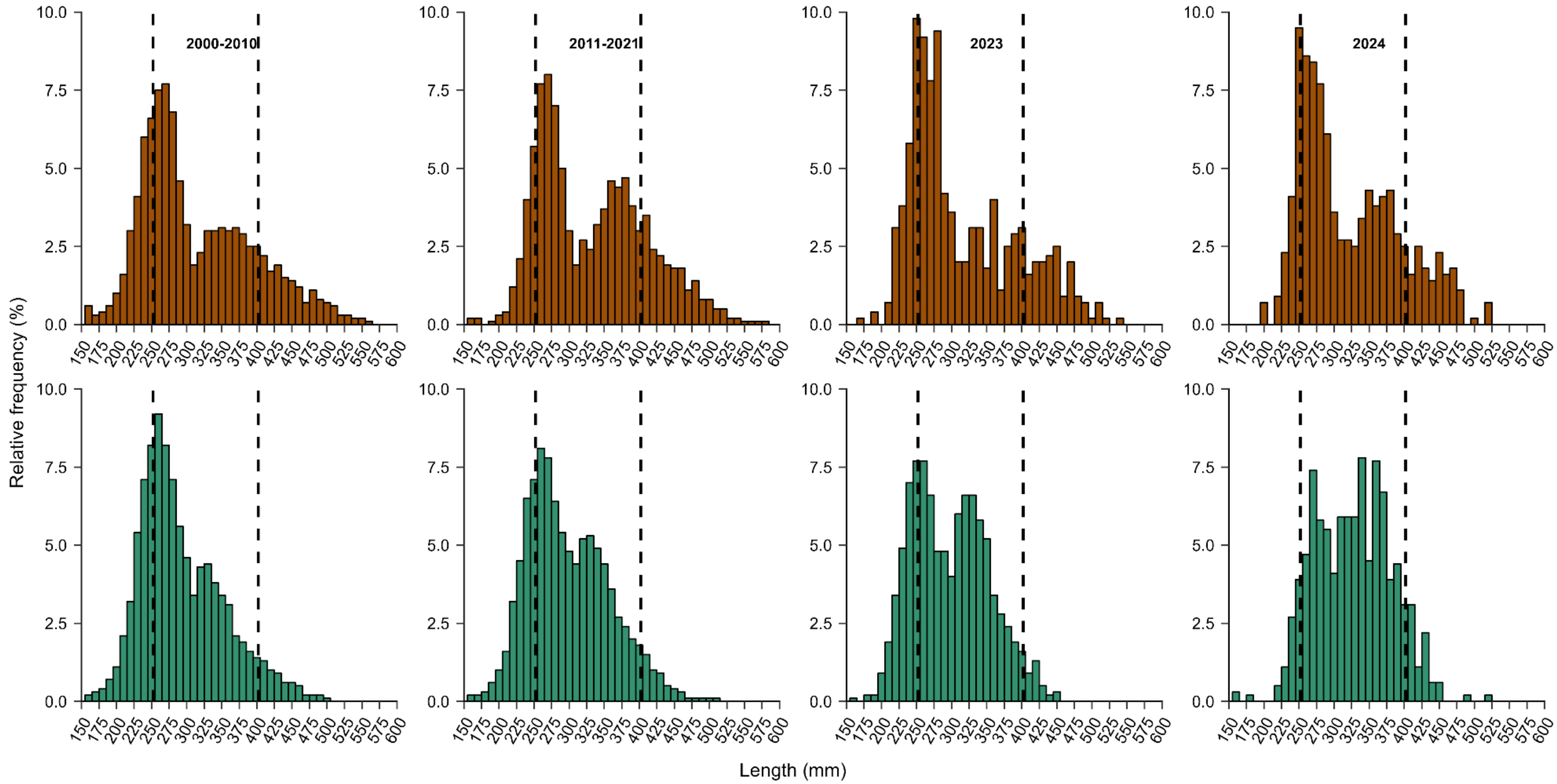

Figure 13. Length frequency histograms of Brown (brown bars) and Rainbow Trout (green bars) ≥ 152 mm (≈ 6”) captured in the Norris Section of the Madison River. Black dashed lines delineate 252 mm (≈10”) and 406 mm (≈ 20”).

408-7) Monitor Species of Special Concern; Madison Arctic Grayling; Westslope Cutthroat Trout:

Opportunities to recover, conserve, and expand native fish distributions are regularly pursued by FWP and partner agencies. NWE is committed to implementing PM&E measures under Articles 408, 409, and 412 of the 2188 FERC License from Hebgen Reservoir to Three Forks, Montana to mitigate adverse effects to native fish species associated with Madison Project operations (FERC 2000).

Goals and objectives for the conservation and re-establishment of viable Arctic Grayling populations are defined in The Upper Missouri River (UMR) Arctic Grayling Conservation Strategy (MAGWG 2022). The strategy calls for the establishment of two viable grayling populations in Hebgen Reservoir and its tributaries. Previous efforts to re-establish populations in the Madison River below Hebgen Dam have been unsuccessful, potentially due to high densities of Brown Trout in spawning and rearing tributaries. However, the removal of nonnative fish from Grayling Creek and the Gibbon River and low densities of resident Brown Trout in the upper South Fork Madison, all tributaries to Hebgen Reservoir, provide opportunities for the re-establishment of viable populations in the Madison River drainage. Reintroduction efforts will require using a minimum of 500,000 grayling eggs/year from fish of primarily Madison genetic ancestry for 3-5 consecutive years.

Reintroduction efforts in the South Fork Madison River fell below the minimum stocking goal (500,000 eggs/year) for Arctic Grayling in 2024. Due to highly variable spawning in Rogers Lake, eggs were instead collected from Park Lake and 218,000 embryos of Centennial genetic ancestry were stocked into Black Sands Spring, a tributary to the South Fork Madison. In addition, FWP repeated an experiment to evaluate differences in Arctic Grayling embryo survival between two stocking methods: remote site incubators (RSIs) (Figure 14) and simulated broadcast spawning. The complete study design and the 2024 results are described in Appendix B.

Figure 14. Remote site incubators (RSIs) and broadcast pens used to stock Arctic Grayling embryos in Black Sands Springs, a tributary to the South Fork Madison, in 2024.

FWP's Statewide Fisheries Management Plan calls for the protection and reintroduction of WCT conservation populations (i.e., populations with less than 5% hybridization by nonnative fish) to 20% of historically occupied waters (Montana Statewide Fisheries Management Program and Guide 2018). To help facilitate and direct WCT conservation efforts, several state, federal, and nongovernment agency partners formalized the Westslope Cutthroat Trout Conservation Strategy for the Missouri Headwaters of Southwest Montana in 2022 (Jaeger et al. 2022). The strategy identifies the current status and conservation actions needed to protect and restore WCT to 20% of historically occupied tributaries in each of the nine subbasins that comprise the Missouri Headwaters: Ruby, Big Hole, Beaverhead, Gallatin, Madison, Jefferson, Red Rock, Boulder, and Upper Missouri rivers.

Revised assessments of WCT conservation populations in the Madison River sub-basin suggest they currently inhabit 14% of historically occupied tributaries and only 23% of the identified populations are considered secure (isolated from nonnative fishes, typically by a physical barrier, have a population >2,500 fish >75mm, and occupy enough habitat to ensure long-term persistence). Northwestern Energy MadTAC funding was used in 2024 to update Ruby Creek population demographics, construct a wooden barrier on Elk Creek to protect a core WCT population, transfer at-risk WCT populations to the North Fork of Spanish Creek, and coordinate and implement a decision matrix for future WCT expansion projects in the Madison sub-basin.

FWP estimated Ruby Creek WCT population abundance by conducting 100-meter depletion estimates using a backpack electro-fisher at low, middle, and high sampling locations within the drainage. Successive electrofishing passes were conducted until the number of fish captured during a pass was 50% or less than the number collected during the previous pass. Fish collected during each pass were held in separate live cars below the sampling reach. Once sampling criteria were met, all fish were enumerated, measured (mm), and a fin clip was taken for genetic analysis. Estimates were produced by using an R-based proprietary FWP fisheries database and analysis tool.

WCT average abundance in Ruby Creek is 21 fish / 100 m (95% CI: 14,19). The Ruby Creek WCT population is estimated at 2,534 fish in approximately 7.5 miles of habitat and therefore deemed secure (Jaeger et al. 2022; Figure 15). Translocations from Last Chance and Wally McClure creeks to Ruby Creek significantly increased genetic diversity and fitness (Feuerstein 2021). Although a translocation from Poison Creek was originally planned for 2024, genetic results showed WCT in Poison Creek are more closely aligned with WCT west of the Continental Divide and no translocations from any donor streams to Ruby Creek occurred in 2024.

Figure 15. A Westslope Cutthroat Trout captured during Ruby Creek population surveys.

A wooden barrier on Elk Creek was constructed in the fall of 2024 with MadTAC funding. The barrier protected 8 miles of habitat for a core WCT population occupying the headwaters of the Elk Creek drainage (Figure 16). The barrier will allow FWP to coordinate and implement a piscicide treatment project to remove the threat of hybridization and competition with nonnative salmonids beginning in August of 2025.

Figure 16. Elk Creek fish barrier construction completed in October 2024.

In 2016, NWE committed funding to the North Fork of Spanish Creek native fish restoration project. Environmental DNA (eDNA) sampling throughout the North Fork of Spanish Creek drainage confirmed that the 2022 treatment had been successful in eradicating Eastern Brook Trout from the system and additional treatments were unnecessary. In 2024, FWP and Turner Enterprises personnel translocated 72 WCT from Greenhorn Creek and 5 WCT from Garrotts Creek into the mainstem of the North Fork of Spanish Creek and 19 WCT from Wildhorse Creek into Big Brother Lake. Since 2023, 251 WCT have been transferred into the North Fork of Spanish Creek drainage.

In 2024, FWP coordinated the evaluation of streams in the Madison sub-basin previously identified as potential candidates for the implementation of conservation efforts to restore WCT to 20% of their historic distribution (Table 2). Conservation actions to restore WCT to 20% of historic distribution typically involves nonnative fish removal projects followed by repopulating WCT from donor streams. Currently, 88 miles of WCT restoration is needed to meet the objective of 20% historic distribution (292.2 miles).

Nine streams were evaluated as candidates for WCT expansion projects (i.e., fish removal and WCT repopulation) by FWP, Beaverhead-Deerlodge National Forest, Custer-Gallatin National Forest, Yellowstone National Park, and Turner Enterprises (Table 3). Habitat suitability, stream isolation, and social impacts was assessed in each stream. Habitat suitability was defined by a minimum of 5 miles of stream length that supports 2500 fish > 75mm. Stream length was measured from the potential barrier location to the upstream distribution of fish using GIS. Field staff identified upstream fish distribution using presence/absence electrofishing surveys. A minimum of three 100-meter depletion estimates low, middle, and high in the drainage were completed using a backpack electrofisher and one to two netters working in an upstream direction (Figure 17). Depletion passes continued until the number of fish captured was 50% or less of the initial pass within the section. Fish species, total length (mm), pass captured, and upstream/downstream GPS coordinates were recorded. Total expected population size was calculated by averaging depletion estimates and extrapolating to stream length. Stream discharge, habitat quality, and potential to conserve other native species were also determined. Stream discharge was measured at baseflow conditions near the potential barrier location using a flow meter. Habitat quality was characterized using professional judgement by describing presence of overwintering habitat (i.e., pool depth), floodplain connectivity, riparian vegetation, livestock impacts, spawning habitat, and stream velocities. Potential to conserve other native species included describing available Arctic Grayling and Western Pearlshell habitat using mapping tools, field observations, and historic datasets. Suitable Arctic Grayling habitat was defined by low gradient (<1%), at least 8-10 cfs, and/or being connected to a pond/lake (Hubert et al. 1985; Anderson 2019). Western Pearlshell habitat was defined as low gradient and at least 2 meters of stream width (Stagliano 2010).

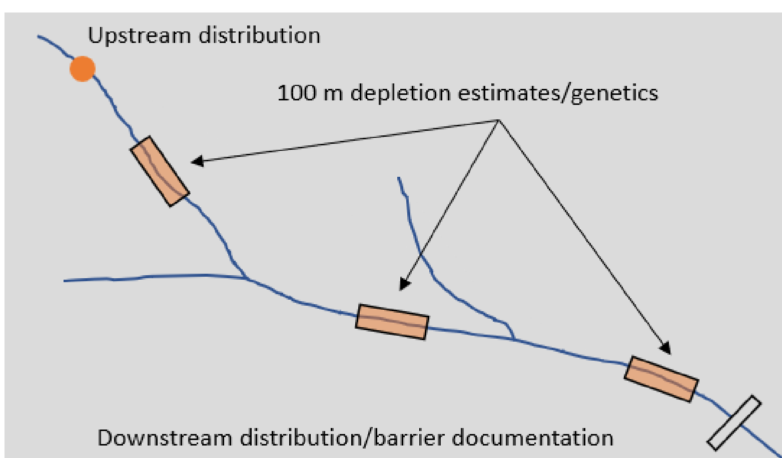

Figure 17. Example of WCT sampling sites in candidate stream.

Table 2. Table of habitat measurements collected on WCT expansion candidate streams. Total stream miles from barrier to upper fish distribution, average fish per 100 meters with 95 CI in (), total fish distribution (# of fish), discharge (cfs at baseflows), and potential to conserve other native species (Arctic Grayling and Western Pearlshell) (Y = Yes, N = No).

Stream	Total miles	Average fish/100m	Fish Distribution	Discharge	Conserve other native species
Elk River	22.9	20 (18, 22)	3154	14.5	Y
Gazelle Creek	12	65 (57, 74)	9413	7	N
Papoose Creek	3.7	25 (22, 28)	1488	14.1	N
Pole Creek	13	71	7100	3	Y
Red Canyon Creek	3.5	3	169		N
Standard Creek	7	48 (39,58)	4183	13.5	N
Watkins Creek	5	33 (29,37)	1593		N
WF Denny Creek	3.7	11 (7,14)	695		N
Grayling Creek	46.7	56	6944	48	Y

Restoration potential was evaluated based on identifying suitable fish passage barrier locations, barrier cost, cost per WCT restored, and describing treatment feasibility. Suitable locations were defined as having a narrow valley floor to minimize barrier span, stream gradient that allowed for at least a 6 foot drop in elevation at the barrier, and a single thread channel. Barrier locations were recorded using GPS. Barrier type (wood, concrete, culvert) and estimate of barrier cost based on previous projects was assessed. Cost per WCT was estimated based on total population size divided by the estimated barrier cost. Cost per WCT should be interpreted with caution until updated barrier costs are updated during contractor field visits in 2025. Treatment feasibility was ranked low, medium, or high based on professional knowledge and experience from piscicide projects. Stream miles, number of tributaries and lakes, topography, off-channel water, road/trail access, sportfish management, and landowner support were considered. Streams characterized as "low" to "medium" feasibility typically had greater than 10 stream miles, multiple tributaries, lakes, limited to no road and trail access, steep gradient, and large areas of off-channel water that require backpack spraying. Streams that have "high" feasibility generally had less than 10 stream miles, few tributaries (≤3), ample road and trail access, no lakes, easily navigable terrain, and small areas of backpack spraying.

Table 3. Summary of restoration potential data collected on WCT expansion project candidate streams. Barrier location (lat/long), Landowner (of potential barrier site), Barrier Type (concrete, wood, culvert), Barrier Cost, Cost per WCT restored (Barrier cost / total fish distribution).

Stream	Barrier Location	Landowner	Barrier Type	Barrier Cost	Cost per WCT Restored
Elk River	44.805900 -111.685211	USFS	Concrete	$500,0000	$158.53
Gazelle Creek	44.885806 -111.586665	USFS	Culvert	$44,000	$4.67
Papoose Creek	None	NA	NA	NA	NA
Pole Creek	45.599360 -111.532750	Turner	Wood	$60,000	$8.45
Red Canyon Creek	None	NA	NA	NA	NA
Standard Creek	44.895813 -111.669256	USFS	Wood	$60,000	$14.34
Watkins Creek	TBD	USFS	TBD	TBD	TBD
WF Denny Creek	None	NA	NA	NA	NA
Grayling Creek	44.803480 -111.130293	NA	Concrete	$500,000	$29.45

Finally, broad public support is necessary for successful WCT conservation. Each candidate stream was evaluated for social impacts such as but not limited to landowner support, angling opportunity, interference with sportfish management, and formal Wilderness designation. FWP personnel and partners will expand on the candidate stream list in 2025 and seek public input in 2026.

Article 409- 3) Fish habitat enhancement both in mainstem and tributary streams:

With the development of Hebgen Dam in 1917, gravel sources to replenish downstream spawning habitats were greatly diminished. The 1959 earthquake and subsequent landslide that impounded the Madison River provided a new source of gravel; however, the river has since incised through the material left by the slide leaving it largely inaccessible under normal dam operations. The scarcity of spawning gravel sources is exacerbated by the loss of existing gravel in Ennis Reservoir due to the frequent capacity of the river to mobilize the D50 of the active streambed 59 to 364 days a year, a process that typically only occurs 7 to 14 days a year in unregulated systems (Pioneer Technical Services 2022).

Complex habitat features such as islands can serve as reservoirs of gravel for the replenishment and creation of spawning habitat; the passive edges of islands and side channels provide areas of reduced velocity where spawning gravels are retained, and fish can find refugia from predators and temperature extremes. Habitat or cover (e.g., boulders, large woody debris, undercut banks) have been correlated with trout abundance (Binns and Eiserman 1979; Varley and Gresswell 1988; Molony 2001). The influence of mainstem Madison River habitat features (boulders, islands, and side channels) on trout abundance showed a suggestive positive relationship between island and side channel density and the abundance of trout >16" (Lohrenz et al. 2021). Although the relationship between these features and juvenile trout was not investigated, relative abundances young-of-the-year and Age-1 salmonids are frequently linked to complex habitats like islands and side channels because they are commonly used for rearing and overwintering (Meehan, W. R. 1991; Swales et al. 1986).

FWP and NWE are pursuing a side channel reconnection project between Lyons Bridge and the Varney FAS and island construction near the Warm Springs FAS. Both projects will help mitigate the loss of spawning habitat and improve habitat conditions for fish production and recruitment to the mainstem fishery.

Madison River side channel development

On July 31 and August 1, 2024, FWP, NWE, and Geum Environmental Consulting Inc. (Geum) representatives surveyed 15 potential side channel reconnection and development sites along the Madison River from Lyons Bridge FAS to Varney Bridge FAS. Surveyed sites were classified as Tier 1, Tier 2, or Tier 3, with Tier 1 sites having the highest potential for reconnection and Tier 3 the lowest (Table 4). Of the 15 sites evaluated, 6 were classified as Tier 1, 7 as Tier 2, and 2 as Tier 3. Nine sites (6 Tier 1, and 3 Tier 2) are scheduled for additional surveying in 2025 to determine if appropriate-sized substrate for spawning is present at depths required for channel reactivation. FWP anticipates implementation of a channel reconnection project in 2026 or 2027.

Table 4. A classification matrix used to identify and prioritize side channel reconnection and development sites from Lyons Bridge FAS to Varney Bridge FAS by Tier.

Tier 1	Tier 2	Tier 3
Existing woody vegetation	Limited woody vegetation	Dry
Surface water or saturated soils	Limited wetland, mostly dry	High elevation relative to the river channel
Low elevation relative to the river channel	Possible reconnection to the river at both upstream and downstream ends	Major excavation
Minimal excavation	Moderate excavation	

Norris Island and Habitat Enhancement

The Norris Reach is a single-thread channel with interspersed islands undergoing a gradual reduction in area (Figure 18). From 1995 to 2021 an estimated net loss of 0.1 acres of island margin habitat has occurred in the Norris reach (Pioneer Technical, 2021). Continued erosion and shrinking of the island margins have led to an overall reduction in habitat heterogeneity and quality.

In 2024, MadTac allocated funding for the Norris Island and Habitat Enhancement project. The project is intended to improve overall conditions for fish production and recruitment in the reach by constructing a new island and side channel habitat (Figure 19). Project construction will occur in the fall of 2025. FWP initiated pre-project data collection in 2024 and is finalizing a monitoring plan to evaluate fish response to the project. FWP anticipates monitoring the project through 2028.

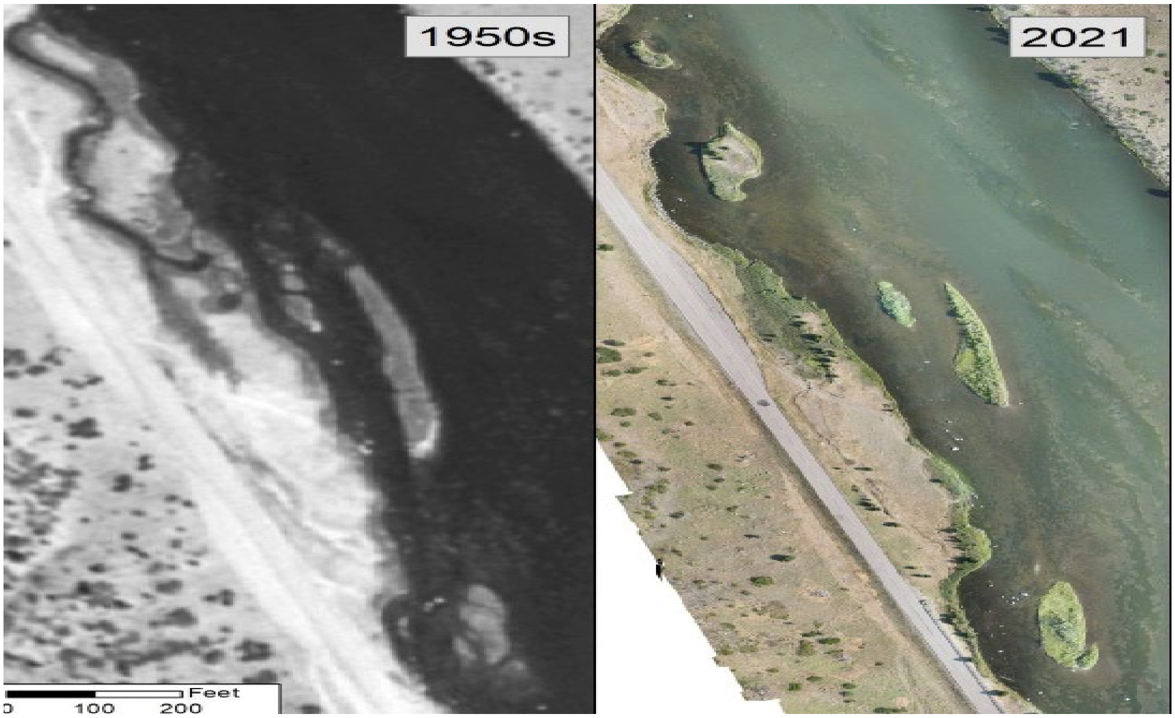

Figure 18. Comparison of island loss from the 1950s and 2021 in the Norris reach (Pioneer Technical 2021).

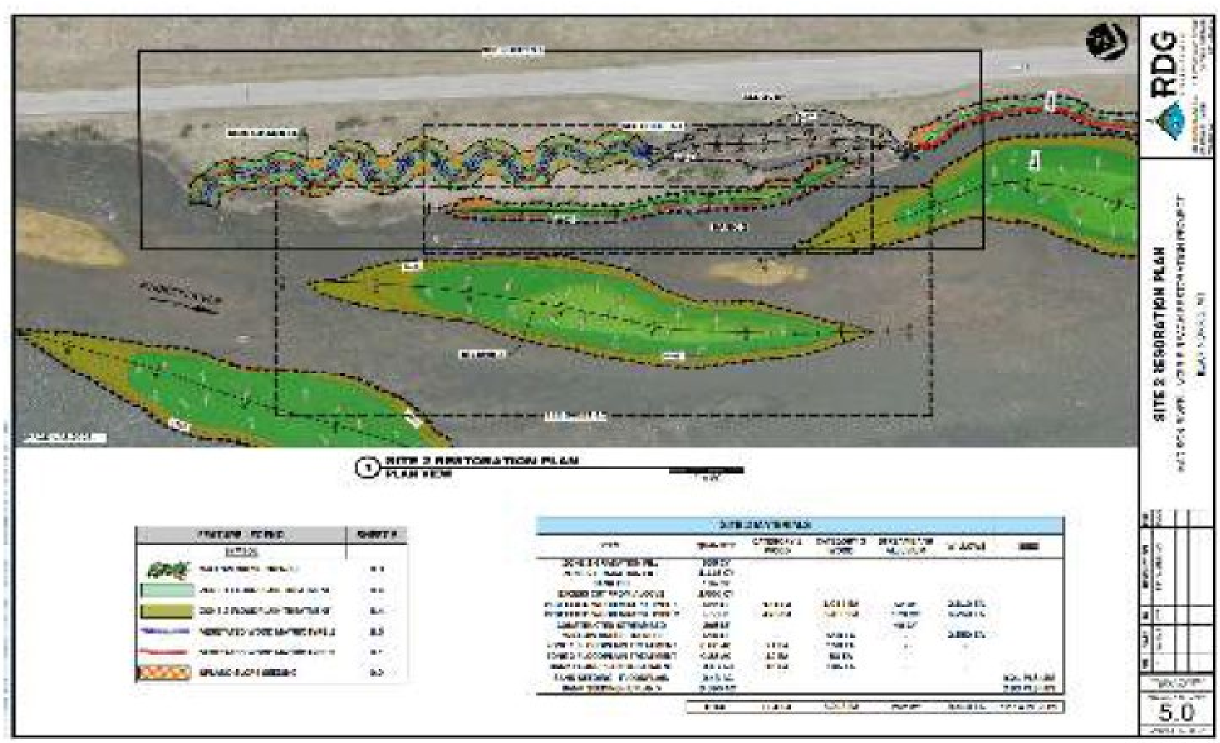

Figure 19. Norris Island and habitat enhancement design (RDG 2024).

Article 413-Pulsed Flows

Temperature affects all aquatic organisms and fish species have specific thermal ranges that are optimal for their persistence. Exposure to extreme temperatures for extended durations can be lethal to fish. In 1988, a fish kill occurred in the Lower Madison River when temperatures reached 82.5°F. FWP and NWE have since implemented monitoring programs to mitigate the effects of high-water temperatures on fish. FWP has monitored water and air temperatures throughout the Madison River basin from upstream of Hebgen Reservoir to the mouth of the Madison River at Headwaters State Park since 1993 (Figure 20). Temperature data is used by FWP for implementing angling restrictions to reduce adult trout mortality during periods of thermally induced stress. Angling restrictions are implemented when the daily maximum water temperature is ≥ 73°F for three consecutive days. Additionally, to mitigate high water temperatures and reduce the risk of a thermally induced fish kill in the Lower Madison River, NWE implemented the Madison Decision Support System (DSS) program. The Madison DSS program is designed to predict a pulse volume of water that will limit thermal heating sufficiently to keep maximum daily water temperatures ≤ 80°F at Sloan and avoid the 82.5°F lethal thermal limit of resident fish in the Lower Madison River. The Madison DSS consists of two methods to determine a pulse volume to be delivered to the Lower Madison River: a thermo-dynamic physics model (physics model) and a manual protocol. Pulsed flows are triggered when the water temperature at the Madison (Ennis) Powerhouse is 68°F or higher and the predicted air temperature at the Sloan Station (River Mile 17) near Three Forks, MT for the following day is 80°F or higher. NWE enters the maximum water temperature recorded at the McAllister USGS gage and the next day's forecasted maximum air temperature at Three Forks to the manual protocol and the physics model to derive the volume of the pulse needed for the following day (Table 5). NWE determines the larger derived pulse of the two methods and directs operations to release that volume the following day from 6:00 am to noon. The timing of the release is designed to allow for the travel time of the water to arrive in the lower Madison River near Sloan Station during the late afternoon when daily solar radiation is greatest.

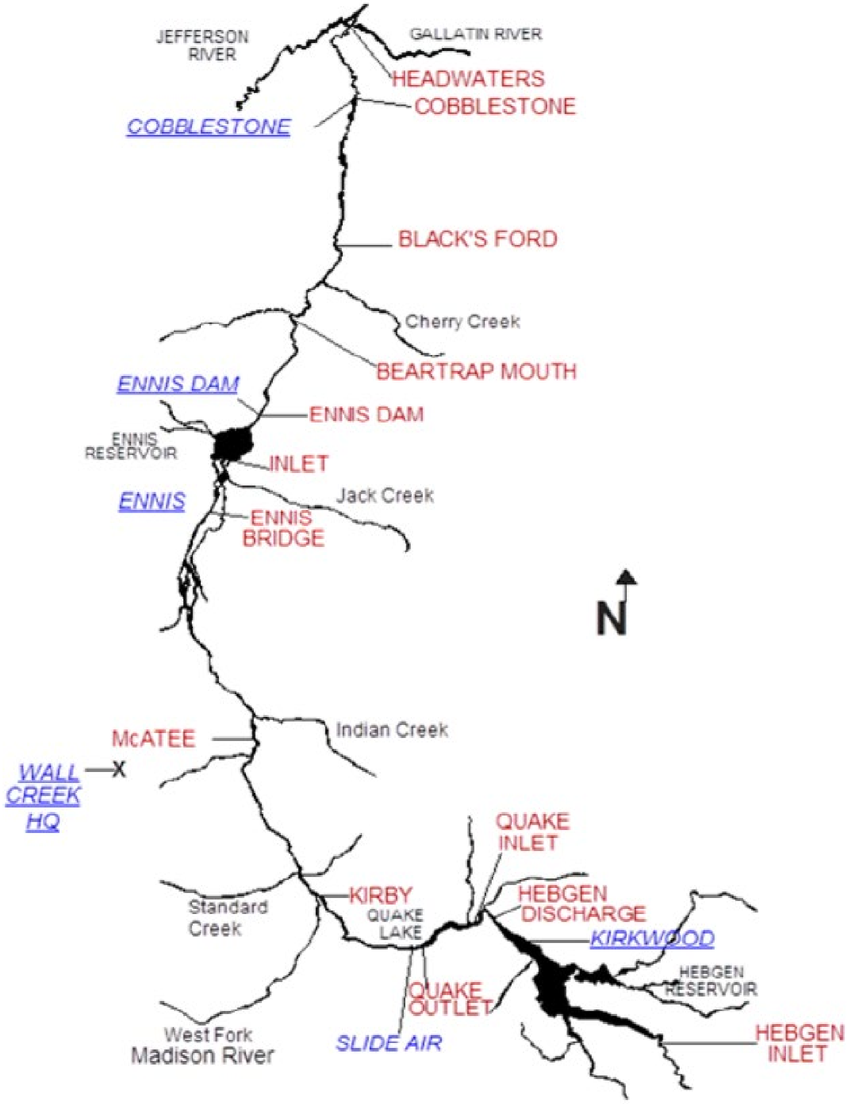

Figure 20. FWP temperature monitoring sites. Air temperature monitoring sites are blue and underlined; water temperature monitoring sites are red.

Table 5. Madison DSS Manual Protocol (Northwestern Energy 2020).

Maximum powerhouse release temperature (°F) at the Madison DSS website or USGS McAllister gage on or after 8:30 p.m.	Predicted maximum air temperature (°F) at Sloan Gage the following day and corresponding pulse flows (cfs).		
	75.0—84.9	85.0—94.9	≥ 95.0
68.0—68.9	1150	1150	1400
69.0—69.9	1150	1400	1600
70.0—70.9	1150	1600	2000
71.0—71.9	1400	1600	2100
72.0—72.9	1450	1800	2400
73.0—73.9	1600	2100	2800
74.0—74.9	1800	2600	3000
≥ 75.0	2600	3200	3200

Daily maximum temperatures were ≥ 73°F at the lower river monitoring sites, Blacks Ford and Cobblestone, for 47 and 53 days, respectively (Table 6). Since 2000, maximum daily water temperatures at the Blacks Ford monitoring site have been ≥ 73°F an average of 46 times a year causing FWP to regularly implement restrictions that prohibited angling from 2 p.m. to 12 a.m. during summer months.

In 2024, there were 40 calls for a pulse flow, but only 31 resulted in operational changes to accommodate a pulse flow. Maximum daily water temperatures reached 79.8°F at Sloan Station on July 23. Downstream of Sloan Station at the Cobblestone FAS water temperatures reached or exceeded 80°F on July 16 and 23. (Table 6; Figure 21). Pulse flows have been implemented an average of 28 days since 2015 and have been effective at moderating maximum daily water temperatures and preventing the occurrence of a thermally induced fish kill in the lower river (Figure 22).

Table 6. Maximum and minimum temperatures (˚F) recorded at monitoring sites in the Madison River Drainage, 2024. The mean temperature is the mean daily temperature ± 95% confidence intervals (CI). Days ≥ 73˚F are the number of days daily maximum temperatures were at or exceeded 73˚F, and days ≥ 80˚F are the number of days daily maximum temperatures were at or exceeded 80˚F. NA denotes that temperature data was unable to be recovered.

Site	Max ◦F	Min ◦F	Mean daily temperature ±95% CI	Days ≥ 73◦F	Days ≥ 80◦F
Hebgen inlet	78.3◦	40.8◦	59.9◦ ±0.2◦	42	0
Hebgen discharge	66.2◦	37.0◦	53.2◦ ±0.3◦	0	0
Quake Lake inlet	NA	NA	NA	NA	NA
Quake Lake outlet	64.3◦	37.2◦	52.6◦ ±0.3◦	0	0
Kirby Bridge	70.0◦	35.2◦	53.0◦ ±1.1◦	0	0
McAttee Bridge	NA	NA	NA	NA	NA
Ennis Bridge	NA	NA	NA	NA	NA
Ennis Reservoir inlet	NA	NA	NA	NA	0
Madison Dam	74.2◦	43.3◦	60.3◦ ±0.2◦	14	0
Bear Trap Mouth	NA	NA	NA	NA	NA
Blacks Ford	79.6◦	42.3◦	59.6◦ ±1.0◦	41	0
Cobblestone	80.4◦	39.8◦	60.5◦ ±0.3◦	42	2

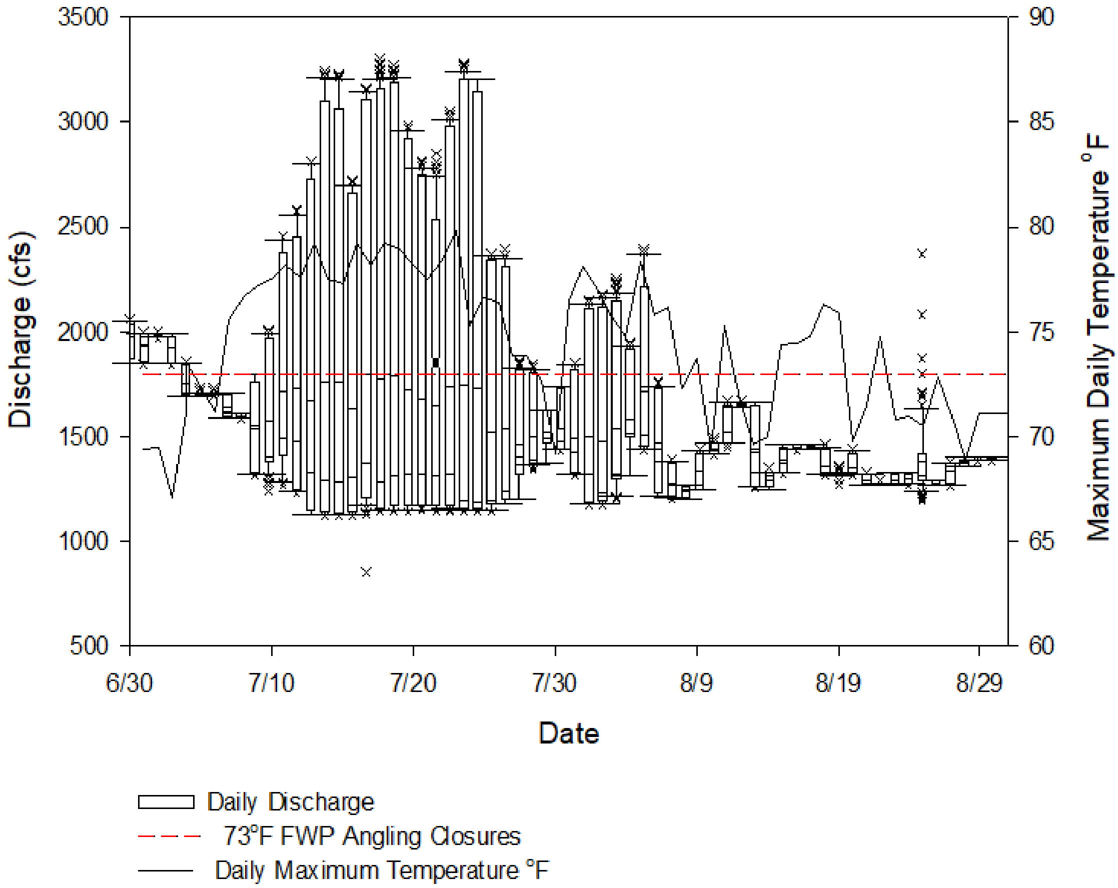

Figure 21. Daily distribution of discharges (left axis) collected every 15 minutes from July 1-Aug 31, 2024 (pulse flow season) at USGS gage # 6-410 and daily maximum water temperature at Sloan (right axis). Boxes extend from the 25th to the 75th percentile and whiskers are the 5th and 95th percentile. Horizontal black lines are the median values of the groups' distribution and horizontal red lines are the mean values of the groups' distribution. X's are values outside the 5th and 95th percentiles. The red dashed line denotes the 73°F maximum used by FWP to implement angling closures.

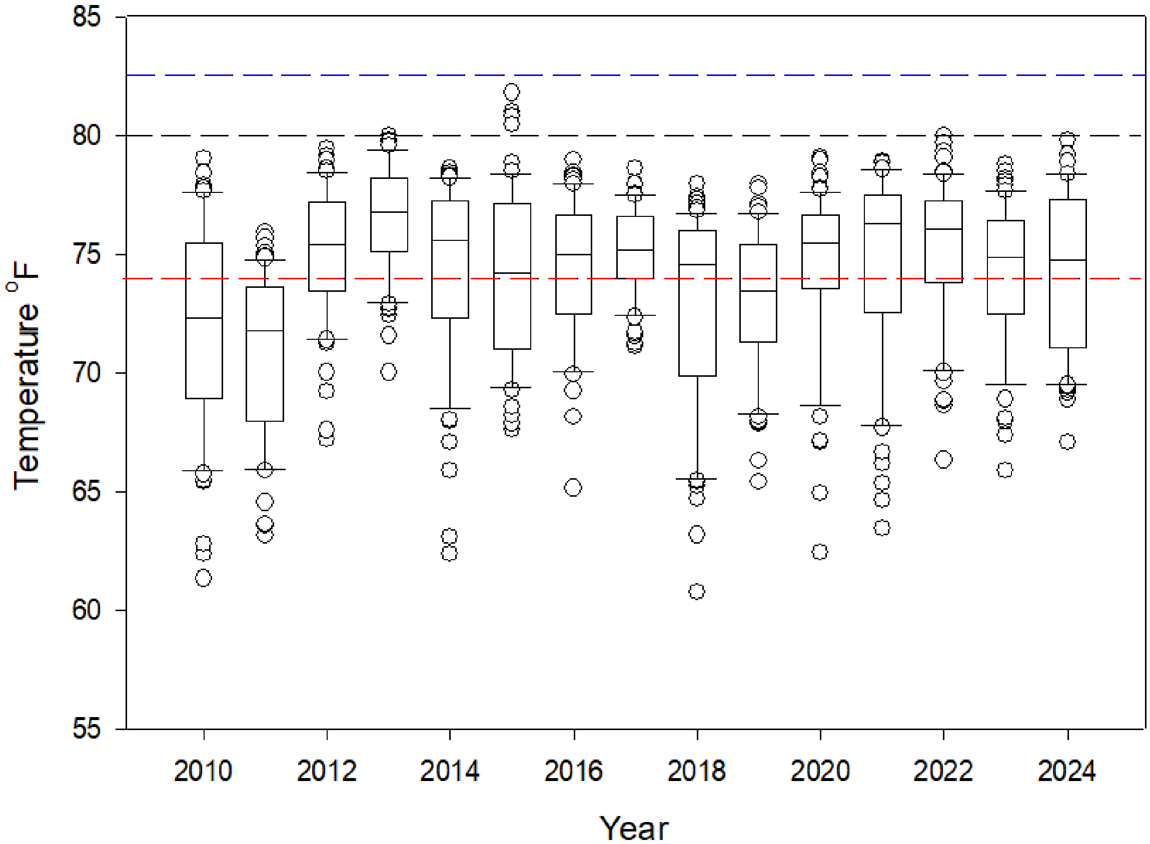

Figure 22. Distribution of daily maximum water temperatures at Sloan from July 1-August 31 from 2010-2024. Boxes extend from the 25th to the 75th (interquartile range) percentile, whiskers are the 5th and 95th percentile and circles are values beyond the 5th and 95th percentiles. The red dashed line denotes the 73°F threshold used by FWP to implement angling restrictions, the black line is the 80°F NWE pulse flow temperature ceiling goal for the lower river, and the blue dashed line denotes the lethal temperature for fish in the lower Madison River of 82.5°F.

FWP's implementation of angling restrictions and NWE's pulse flow program appear to be effective in limiting thermally induced fish mortality in the lower river; pulse flows have kept summertime water temperatures below lethal thermal limits for trout. However, a negative correlation between the abundances of age-1 and age-2 Rainbow Trout and the frequency of pulses has been observed (Lohrenz et al. 2022). This may be attributable to the lack of habitat complexity in the Norris reach that would provide velocity refugia (Lohrenz et al. 2022). Per recommendations, FWP and NWE plan to implement a project to improve habitat complexity and diversity in the Norris reach in 2025 (Lohrenz et al. 2023). FWP advocates for the continuation of the NWE pulse flow program.

Article 419-Coordinate and Monitor Flushing Flows:

Article 419 of the 2188 FERC license requires NWE to develop and implement a plan to coordinate and monitor flushing flows in the Madison River downstream of Hebgen Dam. A flushing flow should be large enough to mobilize substrates and produce scour in some locations and deposition in other locations. This is a natural occurrence in unregulated streams and rivers that maintains and creates spawning, rearing, and foraging habitats for fish as well as providing fresh mineral and organic soil for terrestrial vegetation and other wildlife needs (Poff et.al 1997; Reiser, Ramey, and Wesche 1990). Impoundments such as dams interrupt the natural hydrograph of rivers and high flow events responsible for replenishing and cleaning spawning gravels are often reduced in magnitude and duration. These effects may be exacerbated by operational parameters the owner or operators of the dam prefer or must comply with. Streambed embeddedness and excessive amounts of fines (particles ≤ 0.84 mm) in spawning gravels can adversely affect the survival of embryos and the emergence of fry by inhibiting the delivery of oxygenated water and reducing the amount of interstitial space required for development (McNeil and Ahneil 1964; Kondolf 2000). Accordingly, a goal to maintain ≤ 10% fines in the upper Madison River and ≤ 15% in the lower Madison River was established with the understanding that releasing a flushing flow from Hebgen Dam has limited influence on sediment mobility in the lower Madison River. This goal was selected because these targets are known to provide suitable conditions for salmonid spawning.

Operational constraints for Hebgen Reservoir outflow and reservoir elevation limit implementation, magnitude, and duration of a flushing flow. These constraints 1) limit discharge at USGS gage no. 6-388 (Kirby gage) to no more than 3500 cubic feet per second (cfs) to limit erosion of the Quake Lake outlet, 2) limit changes in the outflow from Hebgen Dam to no more than 10% per day for the entire year, and 3) require that snowpack and runoff forecasts allow for the filling of Hebgen to a minimum elevation of 6532.26^{ft} msl by June 20. Snowpack conditions and runoff forecasts for the spring of 2024 prevented NWE from making operational changes at Hebgen Dam to accommodate a flushing flow. Instead, water was conserved in Hebgen Reservoir to meet the required volumes for the 2024 pulse flow season and minimum elevation requirements.

Flushing flow and spawning gravel recruitment:

Since 2002, evaluation of the efficacy of flushing flows to recruit spawning gravels and maintain fine sediment thresholds under current operational constraints has occurred through annual sediment core sampling at four established monitoring sites representative of stream conditions present in the upper (Kirby and Ennis) and lower (Norris and Greycliff) Madison River. Appropriate substrate for sampling was identified by conducting spring and fall redd surveys at each monitoring location. Areas where redds typically occurred contained gravels ranging in size from 10-60 mm with minimal amounts of organic debris and sediment. Core samples from these areas were collected in 2024 with a 12-inch McNeil core sampler manually drilled into the substrate to a depth of 8”. Substrate from within the 12” x 8” area was removed, dried, and sorted using a sieve method. The percentage composition of the sample was calculated according to particle size. The results from annual core sampling provide an index of relative spawning habitat suitability (Kleinshmidt 2022). There is no statistical difference in the % fines ≤ 0.84 mm between years when a flushing flow was and was not implemented (Lohrenz et al. 2021; Kleinshmidt 2022). This is consistent with the findings of a 2021 study that examined sediment transport, storage, and spawning gravel recruitment within the range of flows allowed under the current operational conditions (Pioneer Technical Services 2022). The results indicated normal, non-flushing flows can mobilize particles of the active streambed layer that are ≤ D_{50} 59 to 364 days a year and that a flushing flow is not needed to transport spawning gravels (Pioneer Technical Services 2022). Core sample data and results from 2024 will be reported by NWE.

Flushing flow and riparian plant community maintenance and regeneration:

Riparian plant communities are influenced by fluvial processes. These processes are often disrupted on regulated streams through manipulation of the timing and magnitude of high-water events. In unregulated river systems, high flows typically occur in early summer coinciding with the release of wind and water-dispersed seeds from riparian plant species. Seed germination and seedling establishment occur in areas of fresh alluvial deposition created during high flows, which are critical to the establishment of riparian species, such as cottonwood and willows. The timing of high flows is also critical to riparian plant recruitment. Cottonwoods, for example, disperse their seeds from roughly the end of May through the end of July. Natural or contrived high flows outside of this window would not likely support cottonwood recruitment. Due to its lack of hydrologic complexity as a predominately single-thread channel and operational constraints, processes that support riparian regeneration and expansion are limited throughout much of the Madison River. However, suitable conditions for riparian regeneration and expansion do occur in reaches of the river characterized by multi-thread, high-complexity channels that dissipate stream energy and create depositional areas during high flows, such as Varney and Greycliff (Figure 24).

In 2023, FWP, NWE, and Geum personnel floated the Varney reach (Figure 24) to assess whether the timing and magnitude of flushing flows, under current operational constraints, were adequate for cottonwood and willow establishment and maintenance along the Madison River. Geum Environmental Consulting concluded that a flushing flow of 6200 cfs every five to ten years coinciding with the timing of riparian plant seed dispersal would sustain and promote the regeneration of riparian plant communities along the Madison River (Figure 23; Parker, 2024). This information is being used along with recent sediment transport and habitat evaluations to help inform MadTac about whether a flushing flow would be beneficial, given year-specific conditions and expected magnitude and duration.

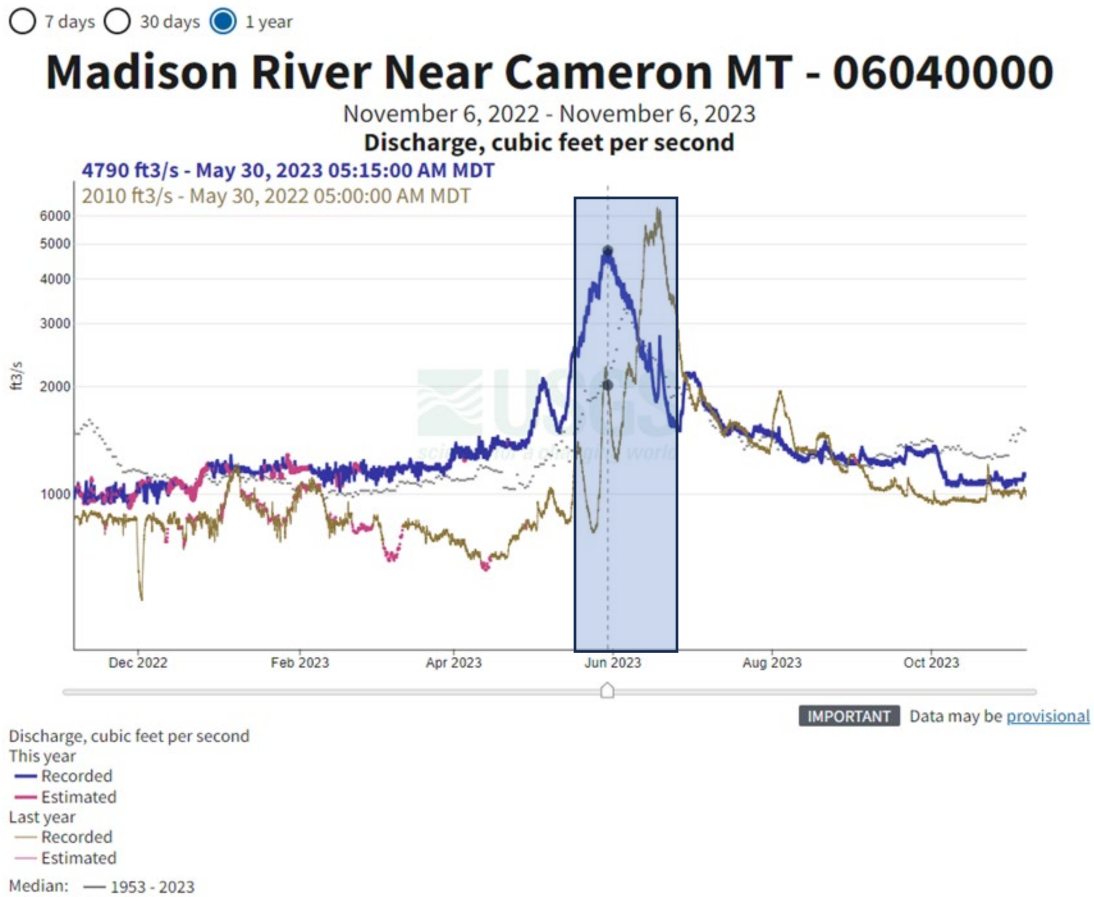

Figure 23. Hydrograph from USGS gage number 6-400 showing discharge (cfs) for 2022(red line) and 2023 (blue line). The blue box depicts the recruitment "window" for riparian plant species.

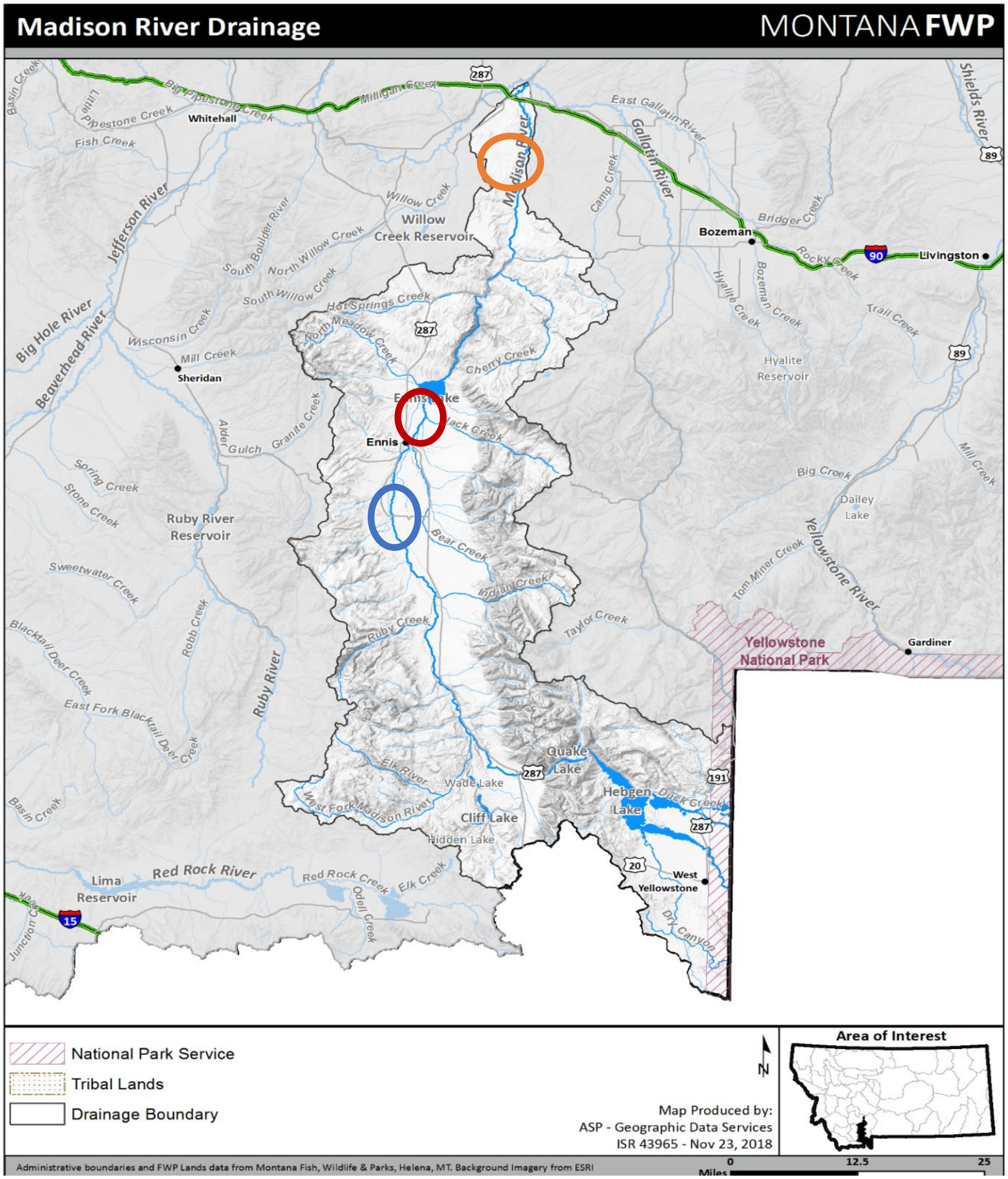

Figure 24. Reaches of the Madison River where riparian surveys and flushing and nonflushing flow side channel habitat evaluations were conducted in 2023-2024. The blue circle is Varney, the red circle is the Channels, and the orange circle is Greycliff.

River flows and side channel habitat

Flushing flows in regulated systems are often designed to provide sediment maintenance and not channel and habitat maintenance (e.g., development of side channels, pools, undercut banks, etc.). In many instances, the normal flow regime is adequate to mobilize sand and gravel in the active streambed of the main river channel, and a flushing flow is not warranted (Kondolf 1996; Pioneer Technical 2022). The flushing flow evaluation conducted by Pioneer Technical (2022), showed discharges of ≥600 cfs were adequate to mobilize the D_{50} of the active streambed in the Varney and Greycliff reaches 365 days a year, which suggests that even without the implementation of a flushing or pulse flow, base flows would be capable of mobilizing gravel of sufficient size for spawning and keep them relatively free from sediment. However, these calculations only applied to the main river channel and were specific to spawning habitat maintenance within the active layer.

While the focus of the flushing flow program has largely been on the maintenance of spawning gravels and pulse flows for thermal mitigation in the mainstem lower river, monitoring was initiated by FWP in 2023 and continued in 2024 to discern how discharges associated with flushing flows and pulse flows affect side channel habitats. Side channels can be important to the survival of salmonids, as they can contain spawning gravels close to habitats with reduced discharge such as pools, cobbles, and woody debris commonly used by young-of-the-year and age-1 trout for rearing. Monitoring in 2023 characterized the effects of a flushing flow and the pulsed flow season on side channel habitat, whereas 2024 monitoring evaluated the effects of peak (non-flushing flow) and pulse flow discharges.

To assess effects on physical habitat features of side channels (i.e. riffles and pools) in the absence of a flushing flow, FWP replicated riffle elevation and residual pool measurements at the 17 upper river monitoring sites established in 2023; ten sites were in the Varney reach and seven in the Channels reach (Figure 24). Riffle elevation and residual pool measurements associated with peak discharge (spring runoff) were taken pre-runoff on May 3, 2024, and post-runoff on June 24, 2024, and to assess pulsed flows on June 24, 2024 (pre-pulse flow) and on August 25, 2024 (post-pulse flow). Scour and deposition at each location were assessed by surveying streambed elevations at riffles and measuring residual pool depths. Riffle elevation measurements were made with a stadia rod and laser level by comparing a benchmark above bank full elevation on a streambank to the riffle crest marked by a steel pin (installed using a post pounder) that remained in the stream for the field season. Changes in streambed elevation after spring runoff were calculated by subtracting measurements recorded June 24 post-spring runoff from those recorded May 3 pre-spring runoff, and for pulse flow measurements recorded August 25 post-pulse flow from measurements recorded pre-pulse flow on June 24. Similarly, residual pool depth was measured from the streambed at the deepest part of the pool located immediately upstream from a riffle selected for monitoring relative to its benchmark with a stadia rod and laser level, and changes in residual pool depth were calculated by subtracting post spring runoff measurements from pre-spring runoff measurements and post-pulse flow pre-pulse flow measurements.

Calculated changes in riffle elevations and residual pool depths after spring runoff from the Varney and Channels reaches were combined and a paired t-test ($\alpha = 0.05$) was used to test whether changes in riffle crest elevations and residual pool depths were significantly different between the 2023 flushing flow and the 2024 spring runoff or the 2023 and 2024 pulse flow seasons.

A z-test (α = 0.05) was used to test whether the proportion of riffles and pools exhibiting scour and deposition differed between the 2023 flushing flow and 2024 spring runoff, and between the 2023 and 2024 pulse flow.

The 2023 flushing flow occurred from May 28 -May 31 when flows at the Varney gage (USGS no. 6-400) were at 4840 cfs (Figure 25). In 2024, a peak discharge of 3530 cfs was recorded at the Varney gage on June 8 (Figure 25). The difference in peak discharge between 2023 and 2024 was 1310 cfs (Figure 25). Flows of ≥600 cfs are required to mobilize the D_{50} of the active substrate layer of the streambed in the main channel, on average this occurs 357 days a year in the Varney reach (Pioneer Technical, 2022).

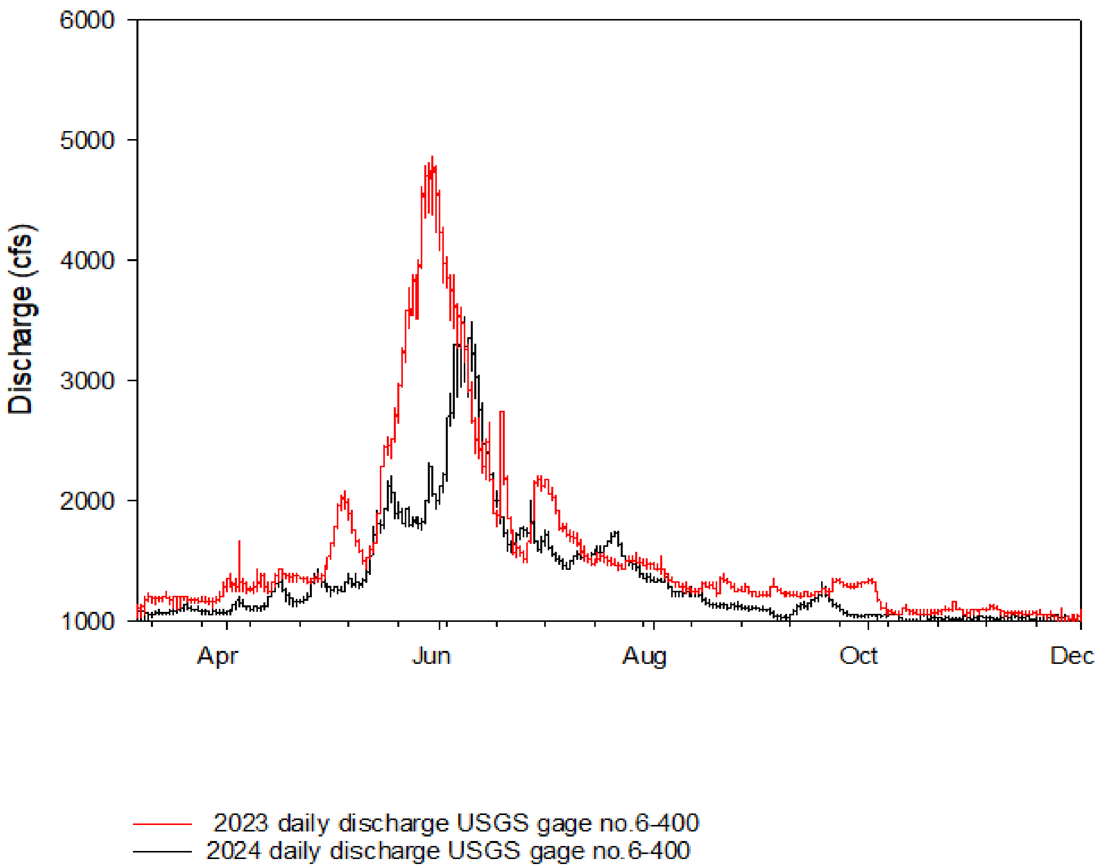

Figure 19. Daily distribution of discharges collected every 15 minutes from March 7-Dec 31, 2023 and 2024 for Varney (USGS gage no. 6-400).

The 2023 flushing flow induced scour in 53% of riffles and 53% of pools and deposition within 47% of riffles and 41% of pools. In total, scour (0.10-0.80 ft) occurred at 9 riffles and deposition (0.02-1.30 ft) at 8 riffles among reaches (Table 4). Residual pool depth increased (0.10-0.80 ft) at 9 locations and decreased (0.20-1.80 ft) at seven locations (Table 4).

The 2024 spring runoff induced scour in 53% of riffles and 58% of pools, and deposition in 47% of riffles and 41% of pools. In total, scour (0.06-0.42 ft) occurred at 9 riffles and deposition (0.01-0.20 ft) at 8 riffles among reaches (Table 7). Residual pool depth increased (0.05-0.60 ft) at 10 locations and decreased (0.01-0.91ft) at 7 locations (Table 7). In general, mean riffle scour, riffle deposition, pool scour, and pool deposition were higher after the 2023 flushing flow than those observed after spring runoff in 2024 (Table 7).

There were significant differences in riffle deposition (*P* =0.05), riffle scour (*P* =0.02), and pool deposition (*P* =0.03) detected between 2023 flushing flow and 2024 spring runoff flows (Table 7). No significant difference in pool scour was detected between the flushing and spring runoff flows (Table 7).

There was no significant difference in the proportion of riffles that exhibited scour or deposition between the 2023 flushing flow and the 2024 spring runoff. Likewise, there was no significant difference in the proportion of pools that exhibited scour or deposition between the 2023 flushing flow and 2024 spring runoff.

Table 7. Bed scour and deposition following the 2023 flushing flow and 2024 runoff at side channel riffles and pools in the Varney and Channels reach by monitoring location, riffle scour (ft), riffle deposition (ft), pool scour (ft), and pool deposition (ft). Mean scour and deposition at riffles and pools; *P* value from paired t-test at α=.05.

	Riffle scour (ft)		Riffle deposition (ft)		Pool scour (ft)		Pool deposition (ft)	
Location	Flushing Flow	Spring Runoff	Flushing Flow	Spring Runoff	Flushing Flow	Spring Runoff	Flushing Flow	Spring Runoff
V1	0.20	0.11	0.00	0.00	0.50	0.11	0.00	0.00
V2	0.80	0.00	0.00	0.03	0.00	0.08	0.00	0.00
V3	0.20	0.06	0.00	0.00	0.70	0.17	0.00	0.00
V4	0.10	0.12	0.00	0.00	0.20	0.14	0.00	0.00
V5	0.00	0.33	0.50	0.00	0.00	0.12	0.80	0.00
V6	0.40	0.42	0.00	0.00	0.40	0.20	0.00	0.00
V7	0.00	0.08	0.30	0.00	0.80	0.05	0.00	0.00
V8	0.00	0.00	0.30	0.03	0.00	0.16	0.60	0.09
V9	0.80	0.00	0.00	0.01	0.00	0.00	0.30	0.00
V10	0.00	0.00	0.40	0.10	0.20	0.00	0.00	0.18
C1	0.00	0.00	0.30	0.04	0.00	0.60	0.20	0.00
C2	0.00	0.00	0.02	0.20	0.00	0.00	0.50	0.23
C3	0.30	0.00	0.00	0.07	0.10	0.00	0.00	0.52
C4	0.50	0.08	0.00	0.00	0.30	0.26	0.00	0.00
C5	0.20	0.07	0.00	0.00	0.20	0.00	0.00	0.03
C6	0.00	0.00	1.30	0.06	0.00	0.00	1.80	0.91
C7	0.00	0.12	0.50	0.00	0.00	0.00	0.50	0.01
Mean	0.21	0.08	0.21	0.03	0.20	0.17	0.27	0.11
P value	0.05		0.02		0.36		0.03	

The 2023 pulse flows induced scour in 18% of riffles and 6% of pools and deposition within 71% of riffles and 88% of pools. In total, scour (0.01-0.20 ft) occurred at four riffles and deposition (0.05-0.50 ft) at 14 riffles among reaches (Table 8). Residual pool depth increased (0.01-0.30 ft) at two locations and decreased (0.06-0.40) at 18 locations (Table 8).

The 2024 pulse flows induced scour in 41% of riffles and 24% of pools and deposition within 53% of riffles and 35% of pools. In total, scour (0.03-0.23 ft) occurred at seven riffles and deposition (0.01-0.51 ft) at six riffles (Table 8). Residual pool depth increased (0.02-0.27 ft) at four locations and decreased (0.09-0.91) at 5 locations (Table 8).

No significant differences in riffle scour, riffle deposition, pool scour, or pool deposition were detected between the 2023 and 2024 pulse flow seasons (Table 8).

There was no significant difference in the proportion of riffles that exhibited scour or deposition between the 2023 and 2024 pulse flow and no significant difference in the proportion of pools that exhibited scour between the 2023 and 2024 pulse flow; however, there was a significant difference in the proportion of pools that exhibited deposition between the 2023 and 2024 pulse flow (*P*<001).

Table 8. Bed scour and deposition following the 2023 and 2024 pulse flows at side channel riffles and pools in the Varney and Channels reach by monitoring location, riffle scour (ft), riffle deposition (ft), pool scour (ft), and pool deposition (ft). Mean scour and deposition at riffles and pools; *P* value from paired t-test at α=.05.

	Riffle scour (ft)		Riffle deposition (ft)		Pool scour (ft)		Pool deposition (ft)	
Location	2023 Pulse Flow	2024 Pulse Flow	2023 Pulse Flow	2024 Pulse Flow	2023 Pulse Flow	2024 Pulse Flow	2023 Pulse Flow	2024 Pulse Flow
V1	0.00	0.00	0.30	0.11	0.00	0.00	0.20	0.00
V2	0.00	0.00	0.20	0.09	0.00	0.00	0.30	0.00
V3	0.00	0.07	0.20	0.00	0.00	0.00	0.30	0.00
V4	0.00	0.17	0.30	0.00	0.00	0.08	0.20	0.00
V5	0.00	0.00	0.50	0.17	0.00	0.00	0.40	0.00
V6	0.00	0.00	0.50	0.51	0.00	0.00	0.30	0.00
V7	0.00	0.00	0.30	0.01	0.30	0.00	0.00	0.00
V8	0.00	0.03	0.00	0.00	0.00	0.00	0.30	0.09
V9	0.00	0.00	0.30	0.09	0.00	0.00	0.10	0.00
V10	0.20	0.08	0.00	0.00	0.00	0.27	0.30	0.18
C1	0.00	0.21	0.30	0.00	0.00	0.00	0.30	0.00
C2	0.00	0.23	0.20	0.00	0.00	0.02	0.30	0.23
C3	0.00	0.00	0.10	0.00	0.00	0.00	0.20	0.52
C4	0.60	0.04	0.00	0.00	0.00	0.00	0.20	0.00
C5	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00
C6	0.00	0.00	0.10	0.33	0.00	0.13	0.10	0.91
C7	0.10	0.00	0.00	0.14	0.00	0.00	0.20	0.01
Mean	0.05	0.05	0.19	0.11	0.02	0.03	0.22	0.23
P value	0.46		0.06		0.33		0.46	

The 2023 flushing flow had a greater capacity to mobilize the coarse streambed within side channels than the 2024 spring runoff. Riffle deposition was significantly greater following the flushing flow. This is likely due to higher flows and the increased capacity to transport and redistribute substrates loosened by scour. Scour can loosen compacted streambed surfaces and reduce the fine sediment in spawning habitat and in the interstices between cobbles often occupied by juvenile trout (Raleigh et al. 1984; Klemetsen et al. 2003). Factors such as the magnitude and duration of flow and the amount and size of bedload particles dictate the redistribution and deposition of spawning gravel and sediments (Hames et. al 1996; Duncan and Ward 1985). Reiser and Bjornn (1991) noted that changing water velocities associated with changing streamflow generally affect the area of riffles more than pools. Similarly, there was a significant difference in the amount of deposition observed in pools between the flushing flow and the 2024 spring runoff. Again, this was likely due to the increased capacity of higher flows to transport and redistribute substrates. We did not observe a significant difference in pool scour between the flushing flow and the 2024 runoff; however, average pool scour was greater during the 2023 flushing flow and was likely beneficial for trout. Modifications of pool depth can affect available cover, thermal refugia, and areas of reduced velocity for juvenile trout (Raleigh et al. 1984; Klemetsen et al. 2003).

Assessments of riffle and pool measurements made at the end of August for 2023 and 2024 suggest that flows during the pulse flow season are not sufficient to induce a significant change in side channel habitats in the upper river. The difference in the proportion of pools that exhibited deposition during the 2023 pulse flow season may be a function of more material becoming part of the active layer from the loosening of the coarse stream bed associated with the flushing flow scour in 2023.

Our analysis shows the effects of a flushing flow on side channel habitats are greater than those produced by spring runoff or discharges during the pulse flow season. These differences were evident even though the 2023 flushing flow had a relatively low peak discharge; flushing flows had 20% to 25% higher peaks in 2011, 2018, and 2020 (Lohrenz et al. 2023). Based on our findings and the findings of Geum (2024), FWP suggests implementing a flushing flow in years when year-specific conditions allow for the timing of a flushing flow to coincide with riparian seed dispersal and reach discharges of approximately 6,000 cfs at the Varney gage (Figure 17). FWP also recommends that annual MadTac discussions about flushing flow implementation continue, and implementation only be considered if there is a certainty that pulse flow and drought management needs can be met.

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Appendix A

Madison River Fishery Monitoring related to the Hebgen Dam Gate Failure

Compliance Report 2024

Prepared by

Travis Lohrenz, Jenna Sirmon, Keith Wellstone, Matt McCormack and Matt Jaeger

For

NorthWestern Energy

Introduction

On November 30, 2021, a mechanical failure of the Hebgen Dam gate resulted in an abrupt decrease in the stage of the Madison River. Madison River flows between Hebgen Dam and Quake Lake declined 370 cfs, from 648 cfs to 278 cfs, within 15 minutes (Figure 1). The decline was more protracted in the 13-mile reach downstream of Quake Lake to Lyons Bridge (Figure 1), with flows decreasing 381 cfs, from 780 cfs to 399 cfs in roughly 48 hours. The rate and volume of water reduction resulted in deviations from NorthWestern Energy's (NWE) Project 2188 Article 403 requirements to: (1) maintain…, a continuous minimum flow of 600 cfs at USGS Gauge No. 6-388 near the Kirby Ranch; and (3) limit changes in the outflow from Hebgen Dam to no more than 10 percent per day for the entire year.

Figure 2. Map of the Madison River and the areas affected by the Hebgen Dam gate failure on November 30, 2021. The areas of focus for monitoring are highlighted in red.

Observed impacts to the fishery immediately following gate failure were greatest between Hebgen Dam and Quake Lake where numerous Brown Trout redds along channel margins (Figure 2) and in side channels were dewatered and adult and juvenile salmonids and sculpins became stranded in disconnected side channels and pools (Figure 3). Below Quake Lake to Lyons Bridge, some Brown Trout redds in shallow side channels were partially dewatered and juvenile salmonids and sculpin were stranded; however, no stranding of adult fish was observed in this reach. There was minimal change in the river stage downstream of Lyons Bridge to the town of Ennis and no dewatered Brown Trout redds or stranded fish were observed in this reach during initial surveys (Figure 1).

Figure 3. A Brown Trout redd in the Madison River between Hebgen Dam and the Quake Lake inlet that became dewatered following the rapid reduction in flow and stage during the Hebgen gate failure.

Figure 4. Juvenile salmonids and Rocky Mountain Sculpin salvaged from a dewatered side channel of the Madison River between Hebgen Dam and Quake Lake inlet following the rapid reduction in flow and stage during the Hebgen gate failure.

Plan to assess impacts:
To assess the long-term impacts of the Hebgen Dam gate failure to the Madison River fishery the Madison Technical Advisory Committee, comprised of NWE, Montana Fish, Wildlife & Parks (FWP), United States Forest Service, United States Fish and Wildlife Service, and the Bureau of Land Management suggested the following monitoring plan (Table 1), which was approved by The Federal Energy Regulatory Commission (FERC) on August 18, 2022.

To date, FWP has completed prescribed monitoring (tasks #1-5) and continues to pursue the development of tributary habitat improvement projects as well as an alternative analysis and preliminary engineering report to evaluate the feasibility of implementing projects to improve spawning habitat, gravel recruitment, and embryo survival within the affected reach of the mainstem Madison River as prescribed in task # 6 (Table 1).

This report summarizes the ongoing monitoring tasks completed from 2022 through 2024 to evaluate the effects of the Hebgen Gate failure on Madison River fish populations.

TABLE 1. PRESCRIBED MONITORING PLAN FOR THE MADISON RIVER FISHERY AND TASK PROGRESS.

Monitoring Plan	Progress
1. Continue developing population estimates in the Pine Butte section (a longstanding electrofishing survey area) on an annual basis to gain information on species ratios and to track cohorts;	***Completed 2022-2024 -Ongoing***
2. Conduct backpack electrofishing surveys in the side channels and margins of the mainstem Madison River (but possibly as far downstream as Kirby) to determine the presence or absence of young-of-the-year (YOY), 1-, and 2-year-old salmonids during the summer of 2022;	***Initiated in 2022 and completed***
3. Conduct electrofishing surveys between Hebgen Dam and Quake Lake to determine catch-per-unit-effort (C/f) and population structure information (provided that electrofishing remains safe in swift currents) in 2022 and 2025; and,	***Completed 2022-2024 -Ongoing***
4. Conduct fall redd counts in the Madison River between Hebgen Dam and Quake Lake to identify and document key areas of fish use from 2022 through 2025; and,	***Completed 2022-2024 -Ongoing***
5. Preparation of a literature review to evaluate whether impacts from the low flow event could have resulted in a total loss of the population or an individual age class; and,	***Initiated in 2022 and completed***
6. Development of mitigation measures to benefit the Madison River fishery, with a focus on improving embryo or young-of-the-year survival, developing or enhancing spawning habitat, and/or protecting key habitats from Hebgen Dam to Lyons Bridge (e.g., tributary habitat improvement, an alternative analysis and preliminary engineering report to evaluate alternatives to improve spawning habitat, gravel recruitment, and embryo survival within the affected reach of the mainstem Madison River) will be developed.	***Ongoing***

1) Pine Butte Cohort Recruitment and Species Ratios

FWP estimated trout abundances using mark-recapture techniques in the Pine Butte monitoring section to evaluate the influence of modified project operations at Hebgen Dam and the gate failure (Figure 1). Trout were collected by electrofishing from a drift boat-mounted mobile anode system. Fish captured in the initial trip (marking run) were weighed in grams and their length measured to the nearest millimeter, marked with a fin clip, observed for hooking scars, and released to redistribute. After seven days, FWP conducted a second trip (recapture run) where fish were examined for marks, measured, and unmarked fish weighed. Species ratios and length-specific mark-recapture log-likelihood closed population abundance estimates by age group were generated and standardized to stream mile for Brown and Rainbow Trout using an R-based proprietary FWP fisheries database and analysis tool. Age classifications were adopted from scale data previously summarized for the Madison River fishery as follows: age 1 (152.0mm-276.9mm), age 2 (277.0mm-376.9mm), and age 3+ (>377mm) (Vincent 1973).

All cohorts of Rainbow and Brown trout have been observed since 2022; however, the proportional composition and abundance of juvenile Brown Trout in the Pine Butte section were relatively low in 2022 and 2023. The proportion of age 1, 2, and 3+ Brown Trout in 2022 were below the 25th percentile, with the cohort that were age 0 during the gate failure (age 1 in 2022 and age 2 in 2023) having the lowest proportional composition in the past 20 years. The low proportion of age 2 Brown Trout observed in 2023 translated into a lower observed proportional representation of age 3+ Brown Trout in 2024. However, proportional representation of adult Brown Trout is similar to or better than previous years; the proportion of age 3+ Brown Trout in 2022 was similar to the 25th percentile and above the 75th percentile in 2023 and at the 20-year median in 2024, suggesting that the number older fish present in the 3+ cohort are buffering the low number of recruits from the age 2 class. The proportion of age 2 Rainbow Trout in 2023 were below the 25th percentile; however, this same cohort was proportionally above the 75th percentile in 2022, suggesting it was not adversely affected by the gate failure.

Table 2. Comparison of the percent composition of Brown Trout (LL) and Rainbow Trout (RB) for the 2022 through 2024 total combined trout estimate and the total combined trout estimated 20-year median and 25th and 75th percentiles by age group in the Pine Butte section. Values with * are below the 25th or above the 75th percentile.

	Age 1			Age 2			Age 3+		
Species	2022	2023	2024	2022	2023	2024	2022	2023	2024
Brown Trout	14%*	21%	26%*	5%*	4%*	3%*	9%*	25%*	13%
Rainbow Trout	52%*	38%	44%*	9%	6%*	7%	10%	7%	7%
Brown Trout 20-year median	21% (19%, 25%)			8% (7%, 11%)			14% (10%, 17%)		
Rainbow Trout 20-year median	35% (31%, 41%)			10% (8%, 14%)			6% (5%, 10%)		

Overall abundances of age 1 Brown Trout were below the 20-year average in 2022 and 2023 but rebounded to an above-average level in 2024. Age 2 Brown Trout overall abundance has remained below the 20-year average in each of the past three years; however, age 3+ Brown Trout abundances were above the 20-year average in 2023 and 2024. (Figure 4). The high abundance of age 1 Brown Trout observed in 2021 did not translate into a strong age 2 class in 2022; however, the age 1 estimate obtained in 2021 should be interpreted cautiously because of sampling difficulties that year. The gate failure may have influenced the age 1 abundance estimates in 2022 – 2023 as observed abundances of age 1 Brown Trout in 2024, embryos in 2022 the first year after the gate failure, were above the 20-year average. The low abundance of age 1 Brown Trout observed in 2022, the cohort anticipated to be most affected by the Hebgen gate failure, translated to similarly low abundances of age 2 Brown Trout in 2023 and the low abundance of age 1 Brown Trout in 2023, embryos in the gravel during the 2021 gate failure, similarly resulted in low abundances of age 2 Brown Trout in 2024. However, age 2 Brown Trout abundances have been below the twenty-year average since 2018, and age 3+ Brown Trout abundances have been near the 20-year average suggesting that other factors may also be influencing recruitment to age 2. All cohorts of Rainbow Trout except for age 1 were below average in 2024. The 2022 age 1 cohort, which would have likely been most affected by the gate failure, translated to a slightly lower number of Age 2 fish in 2023, but adult Rainbow Trout in 2024 remain near the 20-year average and similar to the 2023 estimate (Figure 4).

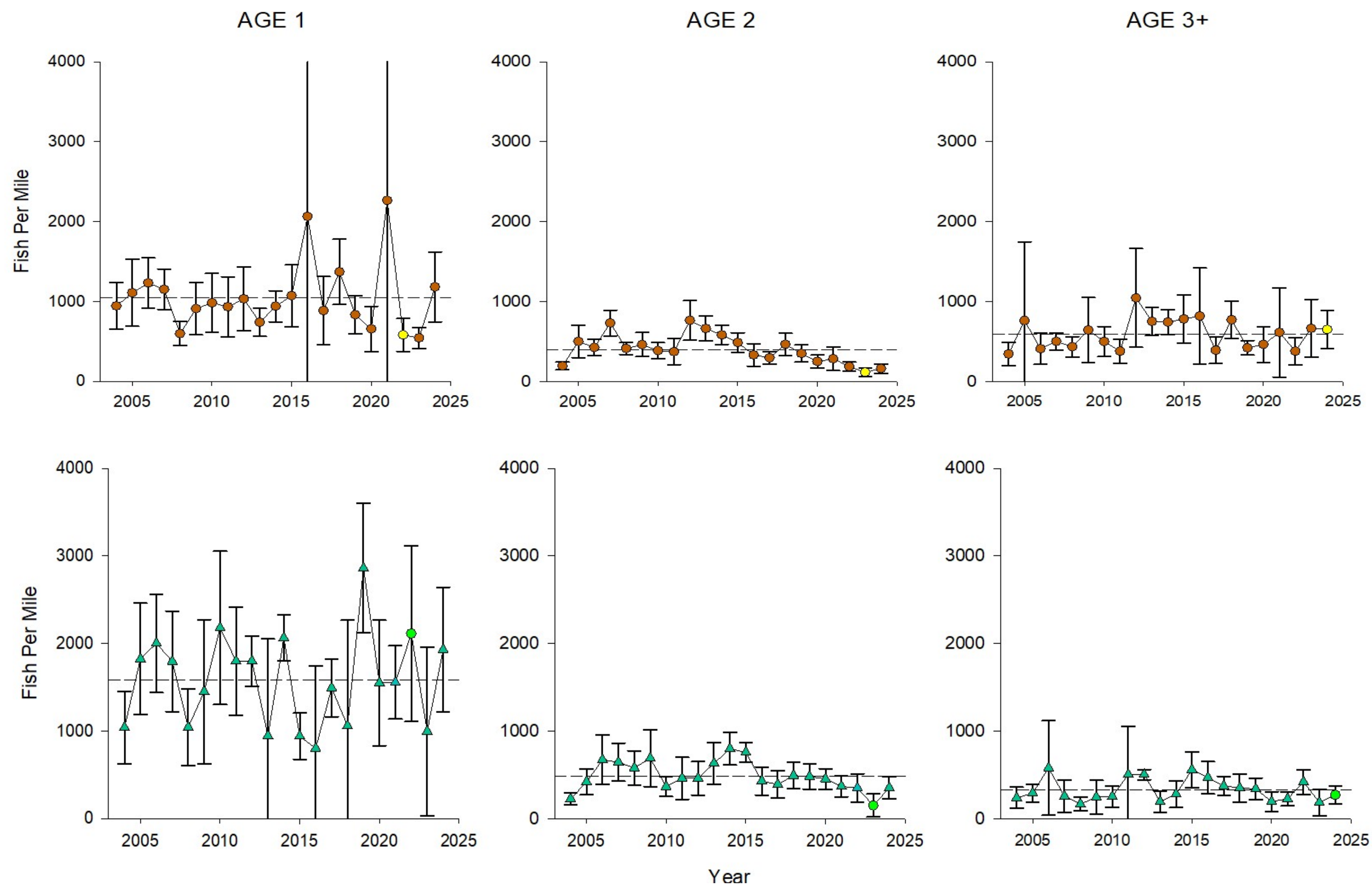

Figure 4. The estimated abundances of Brown and Rainbow Trout by age group in the Pine Butte monitoring section. The dashed lines are the 20-year averages (2004-2024), and the error bars are the 95% confidence intervals. Top panel (Brown Trout) and bottom panel (Rainbow Trout), yellow marker and blue marker represent the cohort that would have been affected by the 2021 Hebgen gate failure.

2) Juvenile Salmonid Presence Absence Survey

Presence/Absence surveys were completed in 2022 and confirmed that YOY and juvenile salmonids persisted in habitats throughout the reaches of the river most affected by the Hebgen Dam gate failure. Brown Trout YOY were present in 90% of the side channels sampled in June and 95% in July 2022, while YOY Rainbow Trout were present in 90% of the side channels sampled in July 2022. Rainbow Trout YOY absence from the June sample is attributable to emergence timings described by Downing (2001) and resulted in clear size differentiation between Brown and Rainbow Trout YOY; Brown Trout YOY were on average 20mm longer than Rainbow Trout YOY. Age 1 Brown (70% and 75%) and Rainbow Trout (80% and 40%) were present in the majority of side channels during both sampling periods. Age 2 Brown (15% and 35%) and Rainbow trout were present in (10% and 35%) of the side channels sampled. No Mountain Whitefish YOY were observed, age 1 Mountain Whitefish were present in 5% and 20% of side channels, and age 2 Mountain Whitefish were present in 5% of side channels in the respective sampling periods (Lohrenz et. al 2022).

3) Catch-per-unit effort survey of the Madison River between Hebgen Dam and the Quake Lake inlet

FWP performed a catch-per-unit (C/f) survey to collect population structure information for salmonid species in the Madison River between Hebgen Dam and the Quake Lake inlet on September 10, 2024. Fish were collected by electrofishing from a drift boat-mounted mobile anode system. Captured fish were weighed in grams and measured to the nearest millimeter. The sampling section length was used as the measure of effort and age-specific C/*f* estimates of relative abundance were generated and standardized to stream mile for Brown and Rainbow Trout, and Mountain Whitefish using an R-based proprietary FWP fisheries database and analysis tool.

Catch-per-unit-effort sampling between Hebgen Dam and Quake Lake continues to show lower relative abundances for all fish species and age classes than anticipated, which may be a direct result of the swift and deep river conditions present throughout the section; sampling efficiencies were low and not directly estimated or corrected for. Rainbow Trout and Mountain Whitefish comprised the majority of the fish sampled in 2022, 2023, and 2024. Brown Trout were at low relative abundances in all years (Table 3). The paucity of Brown Trout observed in the section may be attributable to the lack of habitat features such as undercut banks and large woody debris throughout the sampling reach. As reported previously, YOY, age 1, and age 2 Brown and Rainbow Trout were present in the side channels between Hebgen Dam and Quake Lake; however, only mainstem habitats were sampled during the C/*f* survey (Lohrenz et.al. 2022).

Table 3. Catch per unit effort (C/*f*) per mile by age group in millimeters for Brown Trout (LL), Rainbow Trout (RB), and Mountain Whitefish (MWF) below Hebgen Dam to the Quake Lake inlet.

	Age 1			**Age 2**			**Age 3+**		
Species	2022	2023	2024	2022	2023	2024	2022	2023	2024
LL	1	0	0	0	0	0	5	4	2
RB	28	4	82	12	6	34	15	27	34
MWF	4	39	34	5	82	53	70	57	34

Data collected in 2024 suggested the age 1 MWF and Rainbow Trout cohort of 2022 recruited well to the age 3+ in 2024 (Table 3). Brown Trout numbers have been similar between years (Table 3). C/f surveys will continue to be conducted through 2025 and compared to subsequent surveys to assess the potential effects of the Hebgen gate failure. However, general sampling conditions, normal fluctuations in abundances, and the lack of prior data in this section may make statistically linking future observations to the gate failure difficult. Electrofishing surveys in large rivers inherently produce abundance estimates with notable uncertainty (i.e., relatively large confidence intervals for abundance estimates), which inhibits our ability to statistically detect and attribute population changes to the dam failure. Estimated Brown and Rainbow trout abundances of fish 152 mm (~6") or greater in the Pine Butte Section fluctuated on average 28% and 31%, respectively, from year-to-year since 2000. If the trout population downstream of Hebgen Dam has similar variation as the population in the Pine Butte Section, the low and uncertain efficiency associated with C/f sampling may mask potential influence of the dam failure in this reach. However, observed trends in long-term sampling reaches elsewhere that are influenced by similar environmental conditions found downstream of Hebgen Dam may be used to help explain deviations in abundances in the new monitoring section from what might be expected based on conditions in future years (i.e., are the trout populations between the lakes exhibiting different trends than tailwaters elsewhere in SW Montana).

4) Fall Redd Counts

FWP continued Brown Trout redd counts in the Madison River between Hebgen Dam and Quake Lake to identify and document key areas utilized by Brown Trout for spawning. River discharge at the time redd counts were conducted was 724 cfs (measured at the USGS 06038500 Grayling gage below Hebgen Lake). Redd counts were done by walking in an upstream direction and visually identifying streambed disturbances consistent with redd morphology (Gallagher et al. 2007). A typical redd consists of a defined pit where gravel was excavated with a mound of gravel (tail spill) immediately downstream of the pit (Figure 5). GPS coordinates were recorded and redd locations were mapped using Google Earth (Figure 6).

Figure 5. Brown Trout spawning in a side channel of the Madison River between Hebgen Dam and the Quake Lake inlet Fall 2024.

Figure 6. Locations of redds identified in the Madison River between Hebgen Dam and the Quake Lake inlet. The blue dots are redds observed in 2022,yellow dots are redds observed in 2023, and red dots are redds observed in 2024. The size of the dot is a general representation of redd density (i.e., the larger the dot the greater the number of redds at that location).

Similar to redd counts in 2022 and 2023, side channel habitats were used most by Brown Trout for spawning in the Madison River between Hebgen Dam and the Quake Lake inlet in 2024 (Figure 6; Table 3). The proportion of redds observed in all years has been greatest in side channel habitat (Table 6). However, in 2023 a slight increase in the proportion of mainstem redds was observed. The increase was likely due to greater discharge being released from Hebgen Dam (834 cfs, November 9, 2023) than in 2022 or 2024 (689 cfs, November 15, 724 cfs October 21) an average difference of 127.5 cfs, which based upon the wetted perimeter and discharge relationship curve for the Madison River below Hebgen Dam is approximately 1.0 acres of nearshore habitat that would have been wetted in 2023 (FWP 1989). The high concentration of redds within side channels may be a function of higher quality habitat and more suitable water velocities. Gravels selected for redd construction typically have a median diameter ⩽ 10% of the female’s body size and can be easily excavated (Chambers et. al 1955; Kondolf and Wolman 1993). While side channel habitats had the potential to be dewatered and disconnected during the 2021 gate failure, egg mortality was likely low because flows were restored within 44 hours. Literature reviewed by Dukovcic et al. (2022) suggested trout eggs early in development can withstand 1-5 weeks of complete dewatering as long as the relative humidity in the gravel remains fairly high. This is consistent with the findings of the 2022 side channel survey where numerous Brown Trout YOY were observed.

Table 4. The proportion of Brown Trout (LL) redds observed by year and habitat type. Discharge (Q) cfs at the time of counts.

Year	Q (cfs)	Proportion of LL redds in Main stem	Proportion of LL redds Side channel
2022	689	8%	92%
2023	834	18%	82%
2024	724	6%	94%

6) Development of Mitigation Measures to Benefit the Madison Fishery

FWP and NorthWestern Energy have identified and are pursuing three projects that would increase the availability of spawning habitat and improve embryo or young-of-the-year survival in the affected reach of the river from Hebgen Dam to Lyons Bridge.

Olliffe Creek

In 2022 a habitat improvement project was identified, Olliffe Creek, a Madison River tributary (Figure 7), to improve Brown Trout spawning and rearing habitat. In its current condition, the upstream reaches of Olliffe are sediment-laden and over-widened due to past livestock management practices. FWP and NorthWestern Energy have completed a restoration design (Appendix A) and are negotiating with the landowner about project implementation.

In addition to the potential for upstream enhancement, FWP is working to improve passage for Madison River fish into Olliffe Creek. Large beaver complexes (Figure 8) at the confluence of Olliffe Creek and the Madison River appear to limit fish passage. In 2023, 150 Brown Trout in Olliffe Creek were implanted with PIT tags (passive integrated transponder) to track their movement to the Madison River. Of the 150 tagged fish only one was recorded at the confluence of Olliffe Creek and the Madison River. Additionally, no large Brown Trout redds indicative of a river fish were observed during Brown Trout redd counts in Olliffe Creek in the Fall of 2023. Brown Trout redds observed were consistently small and more representative of a resident fish.

In July 2024, FWP consulted with a riparian ecologist and FWP beaver specialist to evaluate if breaching the existing beaver complex would be a viable option to increase connectivity and fish passage between Olliffe Creek and the Madison River. Both agreed that breaching the beaver dams would be detrimental to the existing wetland and beavers would quickly rebuild the structures, requiring continual maintenance to sustain fish passage. Construction of a channel to bypass the beaver complex (Figure 9). was recommended as an alternative to increase connectivity and fish passage. Upon this recommendation, FWP has engaged with the landowner for implementation, obtained a preliminary channel construction bid, completed a wetland delineation, and is pursuing a final channel design.

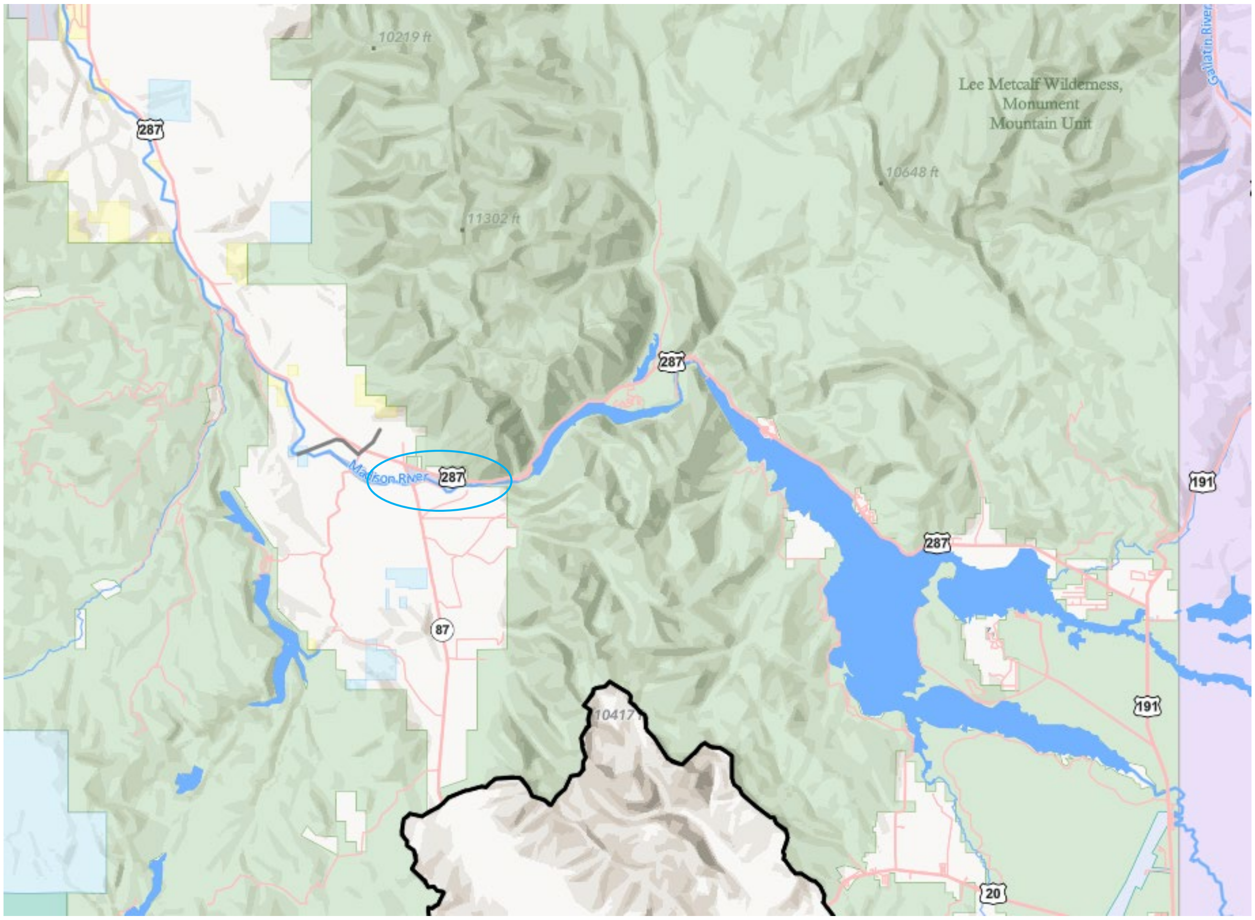

Figure 7. Olliffe Creek tributary (highlighted in red) an area of focus of FWP and NWE efforts to increase spawning and rearing habitat and passage for Madison River trout. Area within the blue circle is the section of the Madison River surveyed for potential flood plain and side channel reconnection for the purpose of improving spawning gravel recruitment and spawning and rearing habitat within the reach.

Figure 8. Beaver Dam complex at the confluence of Olliffe Creek and the Madison River limits fish passage.

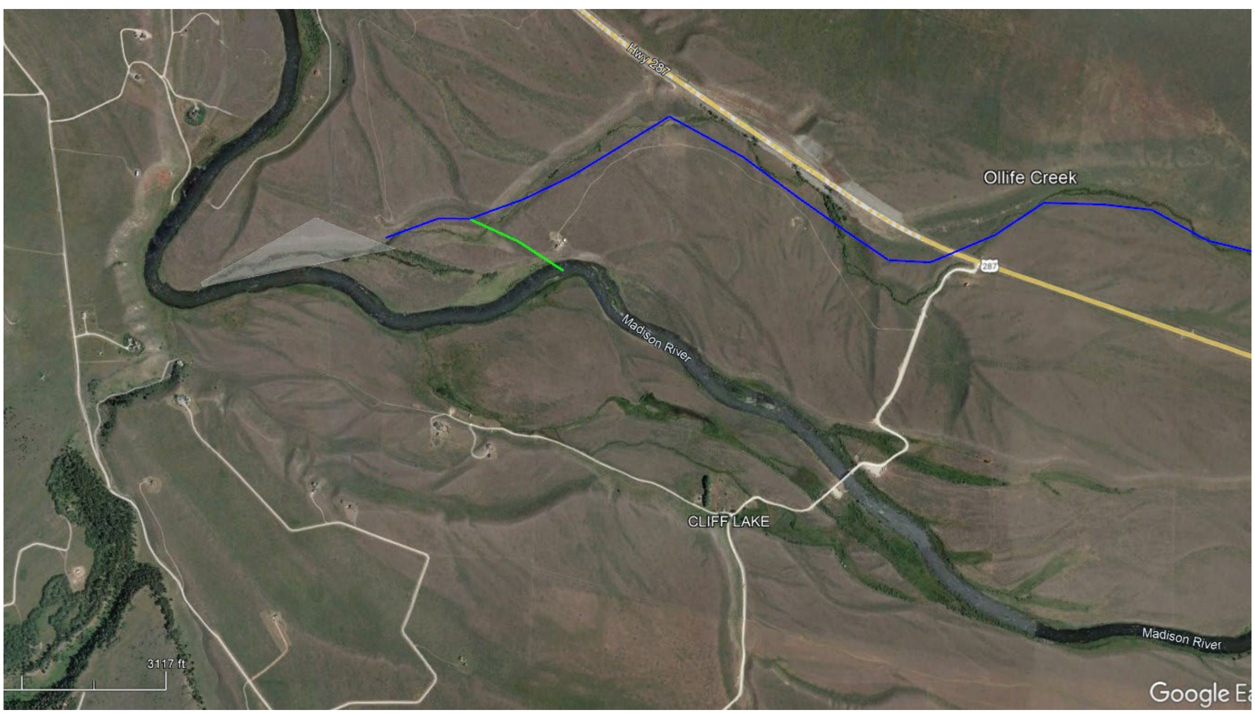

Figure 9. illustrates the Beaver Dam complex at the confluence of Olliffe Creek and the Madison River. The blue line represents Olliffe Creek, while the light green line indicates the proposed location of the bypass channel.

Alternatives Analysis

On July 25, 2024, FWP and NorthWestern Energy representatives, met with a contractor for an initial survey of the Madison River, below Quake Lake to Three Dollar Bridge (Figure 7), to evaluate the feasibility of implementing projects to improve spawning habitat, gravel recruitment, and embryo survival in the reach. A feasibility report recommending options for potential projects will be delivered in 2025; however, a decision on project implementation will likely not occur until 2026.

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Appendix B

Arctic Grayling- Remote Site Incubator vs Simulated Broadcast Spawning Study

Introduction

Throughout the Mountain West, RSIs (Remote Site Incubators) have been used to introduce salmonid embryos into waters in remote locations. They provide developing embryos with shelter and increase survival rates (Shepard et al. 2021). However, RSI deployment is labor intensive and their success has varied widely among species (Haugen et al. 2000; Magee et al. 2006; Anderson 2016; Anderson 2019). Arctic Grayling embryos are placed in RSIs at a relatively high density but are highly susceptible to fungus, which can spread rapidly causing mortality. This can be mitigated by removing infected embryos, adjusting flow, and repositioning the egg basket but the labor requirements are extensive and additional handling of embryos could be detrimental to their survival. Unlike other salmonids that dig a nest in the streambed for embryos to develop, Arctic Grayling are broadcast spawners and their embryos are dispersed in the water column where they eventually settle into the interstices of the stream bed. The dispersal of embryos likely reduces the probability of fungal infection compared to when they are concentrated in RSIs. Given the time constraints and varied success of stocking Arctic Grayling with RSIs, an alternative method may be appropriate. One method to reduce the labor required and increase survival rate for Arctic Grayling embryo introduction is to simulate embryo dispersal as it occurs during spawning.

Our study compared the survival rates of stocked Arctic Grayling embryos using RSIs and a simulated broadcast spawning method. Our goal was to determine if simulated broadcast spawning is a viable alternative to RSIs for stocking Arctic Grayling embryos.

Study Area

Black Sands Springs is located in Custer Gallatin National Forest at an elevation of roughly 9000 ft and flows through approximately 1 mile of lodgepole pine (Pinus contorta) forest and riparian plant assemblages before joining the South Fork Madison, which flows into Hebgen Reservoir near West Yellowstone (Figure 1). Black Sands Springs is a low-gradient stream with a year-round flow of 18.7 cfs (Montana Fish, Wildlife & Parks 1989) and was selected for grayling restoration because of the low densities of resident nonnative trout and overall habitat characteristics that were identified as important to fluvial Arctic Grayling by Hubert et al. (1985) and Kaya (1992), such as constant water temperature, low-velocities, and the presence of gravel substrate for spawning.

Figure 1. Aerial view of Arctic Grayling reintroduction in Black Sands Spring (yellow dot).

Methods

To evaluate Arctic grayling embryo survival to emergence rates, 5 RSIs and 5 simulated broadcast spawning net pens were used in Black Sands Springs. RSIs were installed following Rupert et al. (2007) with additional fry trap boxes attached (Figure 2). The simulated broadcast spawning method used 4 ft x 2 ft x 3 ft rectangular net pens constructed with T-posts anchored to the stream bottom, 1/32" mesh, and a fry trap attached to the downstream end (Figure 2). Arctic grayling spawning has been observed in areas with spawning gravels ranging from 2-64 mm, stream velocities of 0.75-3 ft/s, stream depths of 0.5-3 ft, areas with 25% fines (< 3mm) or less, and stream temperatures ranging from 40-55 °F (Hubert et al. 1985; Anderson 2019). Site selection for the broadcast spawning net pens was determined based on Arctic grayling spawning suitability criteria described by Hubert et al. (1985) for velocity, depth, temperature, and substrate size. Location of RSIs within Black Sands Springs was limited to the headwaters of Black Sands Springs due to design constraints (i.e., elevation drop needed for adequate flow). Water temperature was recorded within each RSI and broadcast net pens.

Arctic Grayling eggs were obtained from Rogers Lake and held until eye up (approximately 1 week from spawning) at Anaconda fish hatchery. Arctic Grayling egg numbers were estimated by volume (750 eggs per fluid ounce) using hatchery methods (Piper et al. 1983; personnel communication hatchery manager). Approximately 13,000 Arctic Grayling eggs were placed in each RSI and simulated broadcast net pen. Fry trap boxes were checked daily, and emergent fry were enumerated and released. Survival rates were estimated by totaling the number of Arctic Grayling fry observed from each RSI and net pen during the hatching period (end of May until the second week of June) and dividing by the initial number of viable embryos.

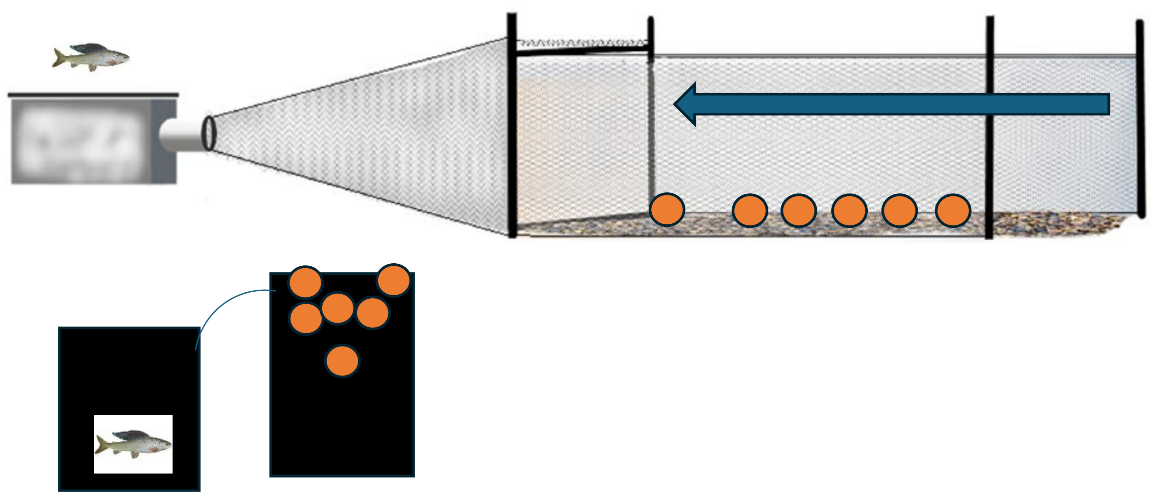

Figure 2. Diagram of experimental design. Top picture depicts broadcast pen set up. Bottom picture depicts remote site incubator (RSI). Orange circles show location of initial egg placement, blue arrow indicates direction of flow. Fry trap boxes are shown with fish picture.

Results

A Mann-Whitney Ranked Sum Test (α=0.05) was used to determine significant differences in total survival between years and within years. A Mann-Whitney Ranked Sum Test (α=0.05) was also used to test for significant differences in survival between stocking methods within years.

Overall survival rates in 2024 were significantly higher than survival rates in 2023 (*P* = 0.003, Figure 3). The median survival rate in 2024 was 0.101 and 0.0001 in 2023 (Figure 3). Survival rates between spawning methods were significantly different in 2024 (P = 0.01), but not in 2023 (P = 0.43, Figure 4). The median survival rate of RSIs was 0.28 and the broadcast method was 0.01 in 2024 and the median survival rate for RSIs was 0.008 and the broadcast method was 0.003 in 2023. Due to a small sample size (n < 30), results should be interpreted cautiously.

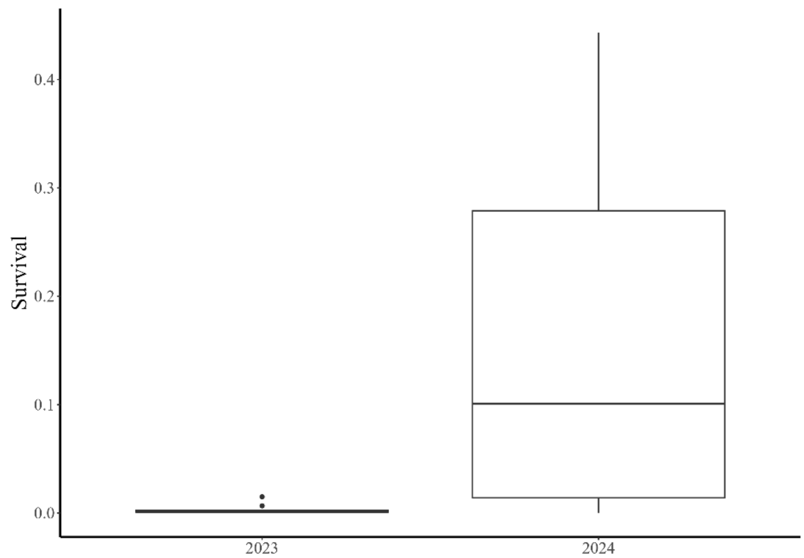

Figure 3. Survival rates of Arctic Grayling embryos to fry emergence between years. Median values are displayed with solid line and box whiskers are 95% confidence intervals. Dots are outliers.

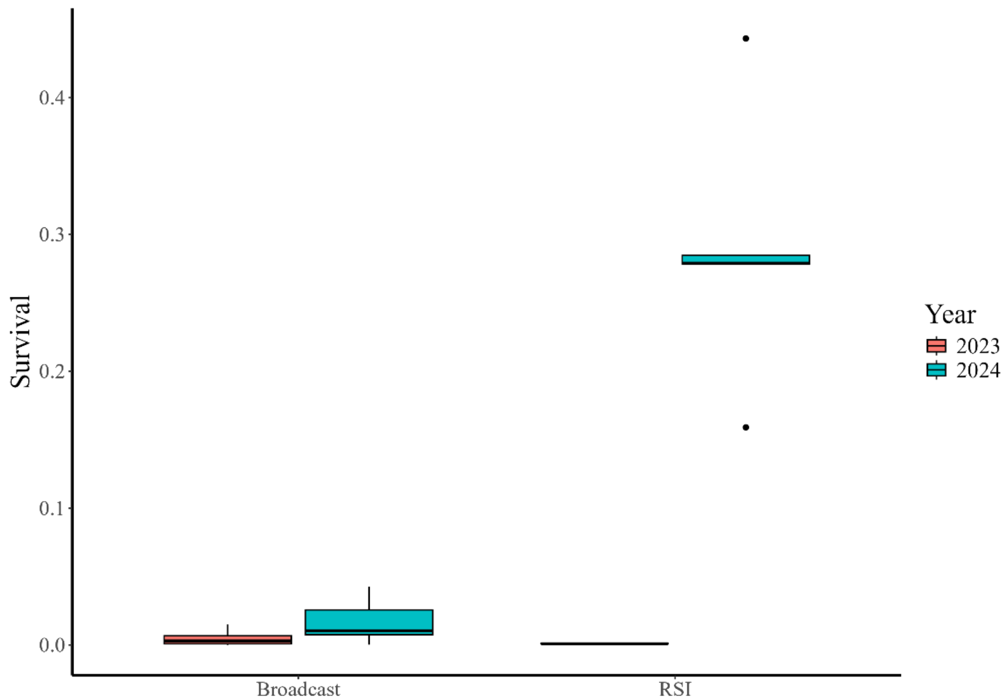

Figure 4. Survival rates of Arctic Grayling embryos to fry emergence in 2024 (blue) and 2023 (red) by spawning method (Broadcast or RSI). Median values are displayed with solid line and box whiskers are 95% confidence intervals. Dots are outliers.

Discussion

The difference in survival rates between years is likely attributable to embryo quality. In general, embryo condition was of higher quality in 2024 than in 2023 with a lower prevalence of fungus and dead embryos (FWP staff, personnel communication). Embryo survival during the eye-up period at the Anaconda hatchery was estimated to be 75% in 2024 and ≤ 40% in 2023 (Figure 5, Montana FWP Hatchery, personnel communication 2024). Hatchery personnel are refining methods to improve embryo quality for future stocking events.

Differences in survival rates between spawning methods in 2024 is difficult to interpret because we suspect that the ability to detect fry within the broadcast pens has caused us to underestimate survival. Arctic Grayling fry are highly visible within the RSI capture buckets, but their detection in the broadcast pens is hindered by the substrate bottom and the size of the pen. In addition, interaction between other factors such as natural predation (i.eg., sculpin, invertebrates) and escapement from nets could also be biasing inference. In 2025, FWP personnel will try to address detection issues by developing a test to determine the probability of detection in the net pens.

Figure 5. Arctic Grayling embryos at Anaconda-Washoe Hatchery in 2024.

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