NorthWestern Energy
Delivering a Bright Future

NWE-2188-4338

Ms. Kimberly D. Bose
Secretary
Federal Energy Regulatory Commission
888 First Street, NE
Washington, DC 20426

December 13, 2023

Re: NorthWestern Energy (NorthWestern) filing Updated Five Year (2024 thru 2028) Madison River Fisheries Plan per Project 2188 License Articles 408, 409 and 412

Dear Secretary Bose,

The September 27, 2000 Order Issuing New License[1] for the Missouri-Madison Hydroelectric Project (FERC #2188) required a plan for protection, mitigation and enhancement (PM&E) of fisheries resources and habitat in the Madison River and its tributaries from Hebgen Reservoir to Three Forks (92 FERC 61,261). The Plans[2,3,4] that were originally submitted and approved by FERC in December 2001 encompass three segments of the river corridor as listed below with the correlating license articles, is collectively referred as the "Project 2188 Madison River Fisheries Plan". It has been updated every five years since.

Article 408 – Hebgen Reservoir and upper Madison River

Article 409 – Hebgen Dam to Madison Reservoir

Article 412 – Madison Reservoir and the lower Madison River

NorthWestern, in consultation with state and federal agencies and conservation groups, has been implementing the current Project 2188 Madison River Fisheries Plan (2019 thru 2023). NorthWestern provides annual funding and employs a formal consultation framework through a voluntary Memorandum of Understanding (MOU) with the resource agencies which supports four Technical Advisory Committees (TACs) that implement fisheries, wildlife, habitat, and water quality PM&E measures. These collaborative efforts have resulted in significant fisheries and river habitat conservation projects with local, state and national recognition.

---

[1] 92FERC 61,261
[2] 97FERC 62,210
[3] 97FERC 62,211
[4] 97FERC 62,217

Northwestern herein provides in Exhibit I an Updated Project 2188 Madison River Fisheries Plan for the 2024 thru 2028 period. This updated Plan will continue to provide important PM&E measures and coordination with agencies on conservation measures for Madison River fisheries and habitat resources.

Also included is Exhibit II, summary progress reports on PM&E measures implemented under the current (2019-2023) Project 2188 Madison River Fisheries Plan.

Northwestern has consulted with the US Forest Service, US Fish and Wildlife Service, Montana Department of Fish, Wildlife and Parks, and the US Bureau of Land Management on the Updated (2024 thru 2028) Project 2188 Madison River Fisheries Plan. Signatures of approval for this Plan from these agencies appear on the following page.

Sincerely,

Mary Gail Sullivan

Director, Environmental and Lands

CC: Andy Welch, NWE
John Tabaracci, NWE
Jon Hanson, NWE
Dale Olson, USFS
Matt Jaeger, MFWP
James Boyd, USFWS
Chris Boone, BLM

Northwestern Energy has consulted with agencies in the preparation and filing of this Updated Five-Year (2024 thru 2028) Project 2188 Madison River Fisheries Plan per License Articles 408, 409 and 412. As signed below, the following agencies agree with this Updated Plan described above and attached in Exhibit I:

By:

Title: Fisheries Division Administrator

Representing Montana Department of Fish, Wildlife and Parks

Date: 11/22/23

By: JACOB MARTIN Digitally signed by JACOB MARTIN Date: 2023.11.29 13:46:42 -07'00'

Title: Acting Field Supervisor

Representing U.S. Fish and Wildlife Service

Date: November 29, 2023

By: Dale Olson

Title: Madison District Ranger

Representing U.S. Forest Service

Date: 11/21/2023

By: RUTH MILLER Digitally signed by RUTH MILLER Date: 2023.12.11 12:00:55 -07'00'

Title: Deputy State Director, Resources and Planning

Representing U.S. Bureau of Land Management

Date: December 11, 2023

Exhibit I

Updated Project 2188

Madison River Fisheries Plan

2024 thru 2028

FIVE YEAR PLAN (2024-2028) TO PROTECT, MITIGATE AND ENHANCE MADISON RIVER FISHERIES FROM HEBGEN RESERVOIR TO THREE FORKS

Prepared By:

NorthWestern Energy

November

2023

5-year Plan - ARTICLE 408

The Project 2188 License requires NWE to submit for Commission approval updated fisheries plans for implementing specific mitigation and enhancement measures and post-licensing evaluation and monitoring for the Madison River from Hebgen Reservoir to Three Forks. The plan is required to include a schedule for implementing the following actions for Hebgen Reservoir and the upper Madison River:

1. Monitor the effects of modified project operations on Hebgen Reservoir fish populations

The effects of modified project operations on Hebgen Reservoir fish populations will be assessed by conducting annual gillnet surveys in standardized locations. These annual surveys have been conducted by MFWP each spring since 1971 and provide the best indicator of relative change in Hebgen Reservoir fish assemblages and how they may be influenced by modified project operations. Biological data collected includes the number of fish caught by species, length, weight size distribution of selected species, and relative abundance. When problems are identified, PM&E measures will be undertaken to address them.

2. Evaluate the potential to enhance tributary spawning to increase the contribution of natural reproduction to the Hebgen Reservoir fishery

Hebgen Reservoir tributaries are being assessed to determine the feasibility of establishing or enhancing spawning runs of native and non-native fish. Tributary qualities being assessed include fish use, presence or absence of barriers, potential for flow enhancement through irrigation system improvements, water temperatures, and spawning and rearing habitat quality and quantity.
The primary conservation strategy for Madison River Arctic grayling is to establish viable populations in at least two Hebgen Reservoir tributaries. There will be a focus on restoring Arctic Grayling in the South Fork Madison River and supporting ongoing restoration in Grayling Creek and the Gibbon River.
When opportunities are identified, PM&E measures will be developed to address them.

3. Monitor the effects of the proposed reservoir drawdown regime on macrophytes reservoir fisheries, and limnological conditions (e.g., effects on spawning habitat, egg/larvae survival, and refuge habitat for juveniles)

The effects of reservoir drawdowns, whether scheduled or because of emergency operations, on the Hebgen fishery will be monitored with established gillnetting surveys. If reservoir elevations occur that violate license parameters, additional monitoring may be developed and conducted to assess the impact on macrophytes and juvenile fish.
When problems are identified, PM&E measures will be undertaken to address them.

4. Monitor the effects of modified project operations on upper Madison River fish populations

The effects of modified project operations on upper Madison River fish populations will be assessed by conducting electrofishing surveys in the Pine Butte and Varney study sections and monitoring river discharge and temperature. MFWP has surveyed these reaches each fall since 1967, Biological data collected includes the number of fish caught by species, length , weight, disease information, and size distribution of selected species.. This data will be used to develop estimates of abundance by size and age, and to determine distribution, health, and habitat needs of the fish assemblage. These surveys will be used to evaluate the effects of modified project operations and other impacts to the fishery and to prioritize and evaluate the effectiveness of mitigation and enhancement measures. Additional study sections and monitoring approaches may be developed if the long-term trend sections do not provide adequate inference. River discharge will be monitored by the Kirby and Varney USGS stream gages and water temperature by thermographs placed throughout the upper river.

When problems are identified, PM&E measures will be developed to address them.

5. Monitor the effects of spring flow fluctuations on spawning success in the upper Madison River as related to possible dewatering of redds during low flow and redd destruction during high flow

The effects of spring flow fluctuations on spawning success in the upper Madison River will be assessed by conducting electrofishing surveys in the Pine Butte and Varney study sections and habitat inundation surveys in complex reaches. Comparison of cohort specific abundance estimates will be used to evaluate spawning success and effectiveness of mitigation and enhancement measures. If flow conditions allow, surveys will be conducted in complex reaches to determine at what discharges redds and juvenile trout habitat become dewatered.

When problems are identified, PM&E measures will be undertaken to address them.

6. Evaluate the potential to enhance tributary spawning to increase the contribution of natural reproduction to the upper Madison River fishery

Madison River tributaries are being assessed to determine the feasibility of establishing or enhancing spawning populations of native and non-native fish. There will be a focus on restoring Westslope Cutthroat Trout populations in accordance with the FWP Westslope Cutthroat Trout Conservation Strategy for the Missouri Headwaters of Southwest Montana. Otolith michrochemistry will be used to guide restoration efforts for Brown and Rainbow Trout within the mainstem Madison and tributary streams; tributary enhancement will be emphasized in reaches with relatively high tributary use (Varney Bridge to Ennis Reservoir) and mainstem spawning enhancement projects (e.g., side channel reconnection, increased recruitment of spawning substrate) will be evaluated in reaches with predominately mainstem spawning (Quake Lake to Varney Bridge). Tributary qualities being assessed include presence of barriers, potential for flow enhancement through irrigation system improvements, discharge, climate resilience, and spawning and rearing potential.

When opportunities are identified, PM&E measures will be developed to address them.

7. Monitor fish species of special concern (i.e., Arctic grayling and westslope cutthroat trout).

Native fish species are being monitored and projects developed to secure, recover, and expand their populations. FWP has developed and is implementing conservation strategies for Arctic Grayling and Westslope Cutthroat Trout. The primary conservation strategy for Madison River Arctic grayling is to establish viable populations in at least two Hebgen Reservoir tributaries. Efforts to re-establish populations in South Fork of the Madison River, Gibbon River, and Grayling Creek are being undertaken and evaluated. The conservation goal for Westslope Cutthroat Trout is to ensure long-term self-sustaining persistence by restoring secured populations to 20% of their historic distribution. Westslope Cutthroat Trout have been protected or re-established in about 16% of historically occupied Madison River tributaries by isolating them from non-native fish with the cooperation of private landowners and federal agencies. Emphasis will be placed on protecting at-risk conservation populations and establishing new populations in previously occupied tributaries. When projects are identified, PM&E measures will be undertaken to complete them.

8. Monitor ice erosion on reservoir shoreline habitats in Hebgen Reservoir to assess the rate of erosion under the new operating regime and determine if erosion is directly or indirectly affecting fish populations

This is being completed under the Project 2188 Article 402 Plan. There are no plans in the next five years for specific fisheries monitoring related to Hebgen Reservoir erosion.

5-year Plan - ARTICLE 409

The Project 2188 License requires NWE to submit for Commission approval updated fisheries plans for implementing specific mitigation and enhancement measures and post- licensing evaluation and monitoring for the Madison River from Hebgen Reservoir to Three Forks. The plan is required to include a schedule for implementing the following tasks for the Madison River from Hebgen Dam to Madison Reservoir. The plan is to include, but not be limited to:

1. Stream structure enhancements (to provide holding water for larger fish) between McAtee Bridge and Varney in the upper Madison River.

This item has been determined to not likely have measurable improvements to the fishery. Analysis has determined that the addition of boulders would not benefit the fish population in this section of the Madison River (2012 and 2022 Annual Report). Other structure enhancements are not planned during this 5 year timeframe.

2. River bank enhancements (undercuts and vegetative cover) in the upper and lower Madison River to enhance brown trout habitat.

River bank and riparian enhancements and restoration are addressed in item 3 below.

3. Fish habitat enhancement both in main stem and tributary streams, including enhancement for all life stages of fishes.

An increased focus on improving spawning and rearing habitats within the mainstem Madison River and its tributaries is anticipated for the 2024-2028 timeframe. Otolith microchemistry will be used to guide restoration efforts for Brown and Rainbow Trout within the mainstem Madison or tributary streams; tributary enhancement will be emphasized in reaches with relatively high tributary use (Varney Bridge to Ennis Reservoir) and mainstem spawning enhancement projects (e.g., side channel reconnection, increased recruitment of spawning substrate) will be evaluated in reaches with predominately mainstem spawning (Quake Lake to Varney Bridge). In the lower Madison, an emphasis will be placed on creating island habitats to enhance spawning and rearing habitat. Madison River tributaries are being assessed for restoration potential and to determine the feasibility of establishing or enhancing spawning runs of Brown and Rainbow trout from the Madison River. Qualities being assessed include stream discharge, water temperature, the presence of barriers, the potential for stream flow enhancement through irrigation system improvements, and spawning and rearing potential.

When projects are identified, PM&E measures will be developed to implement them.

4. Purchasing water leases.

Madison River tributaries have been assessed for the potential to enhance spawning and rearing habitat and recruitment of trout to the Madison River. Qualities assessed include presence of barriers, the potential for flow enhancement through irrigation system improvements, and spawning and rearing potential. There is the potential to pursue water rights lease agreements with private parties for conversion to instream flows. Water conservation measures for Indian Creek will be prioritized.

5. Improving or replacing stream culverts.

PM&E measures will be implemented as specific projects are identified.

6. Inclusion or exclusion of fish barriers.

This PM&E measures will be implemented as specific projects are identified, including but not limited to screening, irrigation needs, and fish losses by entrainment to canals. Installation of fish barriers will occur as prescribed by the Westslope Cutthroat Trout Conservation Strategy for the Missouri River Headwaters of Southwest Montana.

7. Purchasing fishing access.

PM&E measures will be implemented as specific projects are identified.

8. Promotion or enhancement of wilderness fisheries.

Agencies and NWE have determined that this element is unnecessary as there are no direct or peripheral impacts to wilderness fisheries by operation of the Madison hydro- facilities.

5-year Plan - ARTICLE 412

The Project 2188 License requires NWE to submit for Commission approval updated fisheries plans for implementing specific mitigation and enhancement measures and post- licensing evaluation and monitoring for the Madison River from Hebgen Reservoir to Three Forks. The plan is required to include a schedule for implementing the following PM&E measures for Madison Reservoir and the lower Madison River:

1. Monitor the effects of modified project operations (including pulsed flows) on Madison Reservoir and lower Madison River fish populations.

The effects of modified project operations on Madison Reservoir fish populations will be assessed by conducting gillnet surveys in standardized locations in alternate years. These historic surveys were modified in 2021 by FWP and provide the best indicator of relative change in Madison Reservoir fish assemblages and how modified project operations may influence them. Biological data collected includes the number of fish caught by species, length and weight characteristics, size distribution of selected species, and relative abundance.

The effects of modified project operations on lower Madison River fish populations will be assessed by conducting electrofishing surveys in the Norris study section and monitoring river discharge and temperature. MFWP has surveyed this reach each spring since 1967. Biological data collected includes the number caught by species, length and weight characteristics, the size distribution of selected species, and disease information. This data will be used to estimate abundance, age distribution, health, and habitat needs of the fish assemblage. These surveys will be used to evaluate the effects of modified project operations, such as pulsed flows, and to prioritize and evaluate the effectiveness of mitigation and, enhancement measures. Additional study sections and monitoring approaches may be developed if the long-term trend section does not provide adequate inference. River discharge will be monitored by the McCallister USGS stream gage and water temperature by the McCallister and Sloan gages and thermographs placed throughout the lower river.

When problems are identified, PM&E measures will be undertaken to address them.

2. Monitor ice erosion on reservoir shoreline habitats in Madison Reservoir to assess the rate of erosion under the new operating regime and determine if erosion is directly or indirectly affecting fish populations.

When problems are identified, PM&E measures will be undertaken to address these problems.

3. Evaluate the macrophyte community in Madison Reservoir relative to changes in the reservoir drawdown regime.

Monitoring of age 0 fish has previously been compared to gross changes in the macrophyte density and location. Beach seining or electrofishing was being conducted in macrophyte areas to obtain gross estimates of juvenile fish populations. Due to fish sampling challenges around heavy macrophyte growth and minimal long-term changes to the fish assemblage, further evaluations are not scheduled for the duration of this fishery plan.

When problems are identified, PM&E measures will be undertaken to address these problems.

4. Protect and aid the recovery of threatened and endangered fish species and other aquatic species of special concern, including Arctic grayling, in Madison Reservoir and the lower Madison River.

The Madison River presently has no Endangered Species Act (ESA) listed fish species. Native fish species are being monitored and projects are being developed to secure, recover, and expand populations. FWP has developed and is implementing conservation strategies for Arctic Grayling and Westslope Cutthroat Trout. The primary conservation strategy for Madison River Arctic grayling is to establish viable populations in at least two Hebgen Reservoir tributaries; no grayling conservation activities are planned for the Madison Reservoir or lower Madison River over the next five years. The conservation goal for Westslope Cutthroat Trout is to ensure long-term self-sustaining persistence by restoring secured populations to 20% of their historic distribution. Westslope Cutthroat Trout have been protected or re-established in about 16% of historically occupied Madison River tributaries by isolating them from non-native fish with the cooperation of private landowners and federal agencies. No Westslope Cutthroat Trout conservation activities are planned for the Madison Reservoir or lower Madison River over the next five years. When projects are identified, PM&E measures will be undertaken to complete them.

5. Provide initial supplementation of spawning gravels within the Madison bypass reach.

This element has been evaluated and determined unnecessary due to the persistent high abundance of fish in the Bypass reach and the documented fish movement out of the Bypass reach for spawning. If problems are identified, PM&E measures will be undertaken to address these problems.

6. ***Monitor the effectiveness of spawning gravel supplementation within the bypass reach and make annual replacements as needed.***

Same as number 5 above.

7. Monitor fish and invertebrate population dynamics in the bypass reach in response to new minimum flows.

Same as number 5 above. Bypass invertebrates have not been monitored.

8. Monitor flushing flow needs in the Madison River near Ennis, Norris, and Greycliff in 2002 and every 5 years thereafter for the term of the License

Conducting annual population estimates in the lower Madison River to monitor population abundance and assess the effectiveness of mitigation and enhancement measures.

See Project 2188 License Article 419 Plan. When problems are identified, PM&E measures will be undertaken to address these problems.

9. Evaluate the potential to enhance tributary spawning to increase the contribution of natural reproduction to the lower Madison River fishery.

The lower Madison River has few tributaries of significant size, which limits the ability to enhance tributary spawning. Tributaries such as Hot Springs Creek, Rey Creek, Elk Cr, and others will be further investigated to determine restoration opportunities to enhance tributary spawning. However, the creation of habitat features such as islands to enhance mainstem spawning and rearing in the lower Madison River will be prioritized over the next five years. As additional restoration activities are identified they will be supported as appropriate by the Madison TAC.

When problems are identified, measures will be taken to address the problems.

10. Monitor fish populations in the lower Madison for evidence of chronic effects of long-term exposure to high temperatures and, if found, prescribe and carry out appropriate mitigation.

Water and air temperature are monitored throughout the lower Madison River annually. Data are collected from late-April through early-October each year. Gross evaluation of the historic fish growth characteristics of two, three, and four year old Rainbow and Brown trout in the lower Madison River was compared to similar information from the population in the upper river where chronic temperatures are not a problem, and no significant difference in growth characteristics was found.

When problems are identified, PM&E measures will be undertaken to address these problems.

Exhibit II

Summary Progress Reports on PM&E Measures

2019 thru 2023

2019 – 2023 Five Year Madison River Fisheries Summary

Article 403: Madison River discharge

- Deviations from Article 403 occurred below Hebgen Dam and at Kirby Ranch on November 30, 2021 as a result of a broken component on the Hebgen Dam gate, which 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. The literature review suggested the gate failure at Hebgen dam is unlikely to have caused catastrophic damage to the Madison River fishery or total loss of fish populations or individual age classes and that juvenile Brown Trout, Rainbow Trout, Mountain Whitefish, and Rocky Mountain Sculpin likely had the highest mortalities, followed by adults and salmonid eggs. Initial monitoring confirmed that there was no catastrophic damage to the Madison River fishery or total loss of fish populations or individual age classes and subsequent monitoring will be needed to assess cohort-specific effects on young-of-the-year fish and embryos. Monitoring completed by FWP and NWE in 2022 is summarized in Appendix A and FWP's review of literature relevant to the gate failure is described in Appendix B of the 2022 annual report.

Article 408-1: Effects of project operations on Hebgen Reservoir fish populations

- Brown trout abundances in Hebgen Reservoir have been stable the past five years during spring gill netting efforts while Rainbow Trout abundances slightly declined during that same time. Abundances of both species remain near the long-term averages. The mean lengths of both species captured in gill nets slightly increased in recent years. Monitoring completed by FWP is summarized in each annual report and data from the past five years is included in the 2022 annual report.

- About 85% of anglers interviewed during the 2020 creel survey indicated they were "satisfied" or "very satisfied" with the overall fishing experience on Hebgen Reservoir. The catch rates and lengths of fish caught by anglers in 2020 was higher than those of anglers interviewed during a similar creel survey in 2000.

Article 408-3: Reservoir Draw Down Effects on Fisheries

- Contemporary Hebgen Reservoir operations appear to have little influence on limnology and trout abundance. No statistically significant relationships ($P \geq 0.05$) were observed between reservoir elevation and zooplankton abundance, trophic status, or trout abundance or between zooplankton and trout abundances. Moreover, the minimal mean fluctuation in reservoir elevation below full pool during the summer and the narrow operational range from June 20 - October 1 reduces the likelihood of observing and describing interannual variability among these factors; no relationships exist or are expected under contemporary operations because conditions are similar each year. This analysis was summarized in the 2020 annual report.

- There was no statistical difference in zooplankton densities between the months of June and July or between July and August (ANOVA, $p>0.05$). However, there was a difference in densities between June and August (ANOVA, $p=0.037$). 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 (ANOVA, $p < 0.05$). Therefore, FWP recommends continuing limnological sampling occur every other year and in years when departures from normal operations occur. This analysis was summarized in the 2022 annual report.

Article 408-4: Monitor the effects of modified operations on Upper Madison Fish Populations

- Although abundances of Rainbow Trout ≥ 152 mm (≈ 6") in the Pine Butte and Varney sections were above the long-term averages in 2022, Brown Trout abundances in each long-term section as well as Rainbow Trout abundances in the Norris Section remain near historical lows. The size structures of Rainbow and Brown Trout in the Norris Section indicate decreased juvenile recruitment and adult survival in recent years. Monitoring completed by FWP is summarized in each annual report and data from the past five years is included in the 2022 annual report.

- The influence of habitat features (boulders, islands, side channels) in the mainstem Madison River on fish abundances was evaluated using aerial imagery and historic electrofishing data. Our modeling approach was focused on assessing the influence of stream characteristics (boulder, side-channel, and island density) on fish abundance, while allowing for extra variation from random year effects and a robust negative binomial model for fish abundance. The model had two key components: a model to estimate fish abundances using the mark-recapture data, and a model for the estimated fish abundance as a function of stream characteristics (boulder density, islands, and side channels). Boulder density was highest in Pine Butte (400 boulders/mile) followed by Norris (248 boulders/mile) and Varney (16 boulders/mile). Overall, the Varney Section had the greatest densities of islands and side channels with 10 islands/mile and 4 side channels/mile. Norris had the lowest island density among all sections with 4 islands/mile and similar side channel density to Pine Butte. The abundance of trout showed considerable variation among length groups, among section sub-stops, within sub-stops, and among years (Table 3; Figures 21 and 22). Within section variation in abundance of > 10" and > 16" trout across sub-stops and years were lowest in Pine Butte and highest in the Varney section and sub-stop abundances differed among years in each section. Variation in trout abundances were not related to boulder densities; however, a suggestive positive relationship existed between abundance of trout > 16" and island and side channel densities. We found no evidence that addition of boulder and side channels will influence overall abundances of Madison River trout > 10", although increasing side channel or island density may increase abundances of large trout > 16". This analysis was summarized in the 2021 annual report.

- During 2012-2015 and 2017 water was released from the surface of Hebgen Reservoir as repairs to the outlet structure used for mid-reservoir release was completed. On average, mean daily water temperatures were 2.0 ◦F higher in the Pine Butte monitoring sections during surface release than pre or post surface release (ANOVA F=129.9; df=2.0; P<0.05). No significant differences existed in mean daily water temperatures in the Varney or Norris sections among surface release and pre or post surface release periods. No significant difference was observed in the estimated abundance of age-1 Brown or Rainbow trout between mid-reservoir and surface release; however, there was an increase in the proportion of fish ≥406 mm that was marginally significant at time t (*t*-test, $P=0.06$) and statistically significant at time t-1 (*t*-test, $P=0.03$) during years of surface release in the Pine Butte monitoring section. A significant negative relationship between surface release and W*r* of age-1 trout in the Pine Butte monitoring section at time t and t-1 (*t*-test $P<0.01$). The observed increase in the proportion of fish ≥406 mm during periods of surface release in the Pine Butte section suggest surface release may be a viable management action to regularly meet management goals for large trout, although the concurrent decline in juvenile W*r* is problematic. This analysis was summarized in the 2020 annual report.

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

- Arctic Grayling**:** Arctic Grayling reintroduction occurred in several Madison River tributaries between 2014 and 2020. Introductions were carried out by placing embryos in remote site incubators and allowing them to hatch and fry to enter the stream. While there has been limited success in recovering young-of-year grayling in some streams following emigration from RSIs, they have failed to recruit to older age classes. Arctic Grayling introduction efforts for the next 3-5 consecutive years will focus on Hebgen Reservoir and its tributaries where FWP plans to introduce 1,000,000 eggs and fry from populations of primarily Madison ancestry. This work is summarized in 2021 and 2022 annual reports.

- Barriers were installed to protect extant Westslope cutthroat trout populations from non-native fish in Wall, Pine Butte, and Deadman's creeks. A barrier was constructed and piscicide project completed to restore WCT to the North Fork of Spanish Creek. Ongoing restoration of WCT of aboriginal Madison drainage origin to Ruby Creek occurred. This work is summarized in 2018-2022 annual reports.

Article 409- 3: Fish habitat enhancement both in the main stem and tributary streams

- FWP conducted an otolith microchemistry study and established fishery management goals to guide and prioritize restoration potential and need in the mainstem and tributary streams. Nearly half of the Rainbow and Brown Trout analyzed from the Pine Butte Section originated in tributaries. Similar tributary contributions were observed for Brown Trout collected near Varney and Valley Garden, but only 25% of the Rainbow Trout from those areas originated in tributaries. The situation was much more complex in the lower Madison River where downstream habitats, the Jefferson, Gallatin, and Missouri rivers, contributed about 33% of the Brown Trout and 66% of the Rainbow Trout included in the study. About 25% of the Rainbow and Brown Trout in the lower Madison River originated in tributaries with relatively low mainstem contributions compared to the upper Madison River. This work is summarized in 2022 annual reports.

- From 2005 to 2009, stream restoration efforts on O'Dell Creek narrowed stream channels, increased stream sinuosity, lowered streambank elevation, and increased stream channel water surface elevations. FWP completed electrofishing monitoring in six sections following restoration and again in 2021 to assess Brown Trout abundance and size structure. Fewer and larger fish were captured in 2021 and median lengths and weights were statistically significantly different among years in all sections. Overall, it appears that restoration activities, such as deepening and narrowing the channel as well as increasing discharge, enhanced conditions for and increased abundance of large adult fish after initially improving abundances of younger fish. This analysis was summarized in the 2021 annual report.

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

- New gill net locations were established on Ennis Reservoir in 2021 to provide better coverage of the reservoir while eliminating gill net sets that often had poor capture efficiencies in shallow habitats. Sampling will occur annually for at least three consecutive years to provide data that can be used to establish management goals for the Rainbow and Brown Trout fisheries. The mean catch-per-unit-effort of Brown Trout and Rainbow Trout were near the long-term averages in 2021 and 2022 as were the mean lengths of Brown Trout (402 mm [≈ 16”]) and Rainbow Trout (356 mm [≈ 14.0”]). This analysis was summarized in the 2022 annual report.

Article 413-Pulse Flows

- FWP evaluated the effect pulsed flows delivered by the Madison Decision Support System (DSS) program had on the fishery. General linear models (linear regression) were used to determine whether negative correlations existed between abundances of age-3+ Rainbow and Brown Trout and the number of days water temperatures were ≥ 73° F, age-1, age-2, and age 3+ Rainbow and Brown Trout and average pulse change, and between age-1, age-2 Rainbow and Brown Trout and the number of days a pulse flow occurred in the Norris section. There was no correlation between the abundances of age-1 or age-2 Rainbow or Brown Trout at t-1 or t-2, or age-3+ Rainbow or Brown Trout at t-2 and average pulse flow change. Additionally, no correlation was found between the number of days water temperatures were ≥ 73° F and the abundance of age-3+ Rainbow or Brown Trout at t-1. The abundances of age-1 or age-2 Brown Trout and the number of days a pulse flow occurred at t-1, t-2 were not correlated; however, there were significant negative correlations between age-1 Rainbow Trout and the number of pulse flows at a t-1 ($R2 = 0.22$; $P = 0.04$) and age 2 Rainbow Trout at t-2 ($R2 = 0.54$; $P = 0.05$). Statistical results suggest that FWP’s implementation of angling restrictions and the pulse flow program are effective in limiting thermally induced mortality in the lower river. This analysis was summarized in the 2022 annual report.

Article 419-Coordinate and Monitor Flushing Flows

- FWP evaluated whether flushing flows under current operational constraints are beneficial or detrimental to fish recruitment and survival using FWP abundance estimates from three long-term monitoring sections (Pine Butte, Varney, and Norris) and USGS hydrograph data from 2000 to 2020. Fish abundances were positively correlated with longer duration high flow events but not with flushing flow occurrence or peak flows. FWP whether a flushing flow was able to induce localized scour and pool maintenance at boulders, transport sediment and maintain pools and riffles in side channels, and recruit gravel from stream banks in the mainstem. Monitoring of stream bed mobilization with scour chains in the mainstem at NWE monitoring sites in the Ennis and Norris sections were consistent with findings since 2014 that have shown no substantial scour or fill occurring at these sites during flushing flows. However, monitoring suggests that flushing flows may beneficially maintain and enhance habitats associated with geomorphic features such as boulders or those found in side channels where increased flows in conjunction with smaller channel dimensions can more efficiently mobilize stream bed materials. This analysis was summarized in the 2021 annual report.

2019 Madison River Drainage 2188 Project Monitoring Report

to

Northwestern Energy

Environmental Division

Butte, MT

By

Travis Lohrenz, Nick Larson, and Mike Duncan

Montana Fish, Wildlife & Parks

INTERNET WEB PAGES CITED IN THIS REPORT, OR OF LOCAL INTEREST
(In alphabetical order)

Aquatic Nuisance Species Task Force	www.anstaskforce.gov
Madison River Foundation	www.madisonriverfoundation.org
Lower Madison River Monitoring page	www.madisondss.com/madison.php
Montana Fish, Wildlife, & Parks	www.fwp.mt.gov
Northwestern Energy	northwesternenergy.com
Stop Aquatic Hitchhikers	http://stopaquatichitchhikers.org
Quake Lake bathymetric map	http://fwp.mt.gov

FWP personnel took all photos in this report unless otherwise credited.

Contents

This page intentionally left blank

Executive Summary

There were ten monitoring activities or projects completed in the Madison river basin pursuant to the 2188 project FERC license articles in 2019. Long-term abundance monitoring for rainbow and brown trout in the two established sections of the upper Madison River was conducted. Estimated abundances of brown and rainbow trout declined below 20-year averages in the upper Madison River. Water temperature was monitored at 12 sites and air temperature at 6 sites; results are displayed in Appendix A1-A3. The average length of rainbow trout captured during annual Hebgen Reservoir fisheries assessment remained above long-term averages at 16.3 inches. Additionally, the proportion of rainbow trout over 14 inches has increased noticeably since 2005. Zooplankton density in Hebgen Reservoir was monitored and temporal trends are displayed in this report. Ennis Reservoir gillnet catch trends showed a decrease in Utah chub and an increase in rainbow trout. A stream restoration project to improve fish habitat and ranch operations was initiated on South Meadow Creek, a tributary to Ennis Reservoir. 65,000 Arctic grayling eggs were introduced into Madison River tributaries as part of the Madison Artic grayling re-introduction plan. A migration barrier was constructed in Tepee Creek for possible reintroduction of westslope cutthroat trout. Redd counts and core sampling were conducted at established monitoring sites in the Madison River.

Introduction

Montana Fish, Wildlife & Parks (FWP) has conducted studies in the Madison River Drainage to assess the effects of hydropower operations at Hebgen and Ennis dams on fisheries since 1990 (Byorth and Shepard 1990, Clancey 1995, Clancey 1996, Clancey 1997, Clancey 1998a, Clancey 1999, Clancey 2000, Clancey and Downing 2001, Clancey 2002, Clancey 2003, Clancey 2004, Clancey and Lohrenz 2005, Clancey 2006, Clancey 2007, Clancey 2008, Clancey and Lohrenz 2009, Clancey and Lohrenz 2010, Clancey and Lohrenz 2011, Clancey and Lohrenz 2012, Clancey and Lohrenz 2013, Clancey and Lohrenz 2014, Clancey and Lohrenz 2015, Moser and Lohrenz 2016, Moser and Lohrenz 2017). This work has been funded through an agreement with the owner and operator of the dams. The dams were owned by Montana Power Company (MPC) until 1999 and then PPL Montana until November 18, 2014, when they were purchased by Northwestern Energy (NWE). The original agreement between FWP and MPC to fund this work was designed to anticipate Federal Energy Regulatory Commission (FERC) relicensing requirements for MPC's hydropower system on the Madison and Missouri rivers. This includes Hebgen and Ennis dams, as well as seven dams on the Missouri River collectively referred to by FERC as the 2188 Project (Figure 1). In 2000 the FERC issued NWE a license to operate the 2188 Project for 40 years (FERC 2000). The license details the terms and conditions NWE must meet, including fish, wildlife, recreation protection, mitigation, and enhancement measures. NWE has convened committees with annual budgets and authority to spend mitigation funds to address fisheries, wildlife, water quality, and recreation issues pursuant to license requirements. The Madison Fisheries Technical Advisory Committee (MadTAC) is composed 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).

This report summarizes work FWP completed in 2019 with funding provided by the MadTAC to address license requirements of FERC project 2188. Work included 1) fish abundance assessments in the Madison River, 2) assessment of fish populations in Hebgen and Ennis reservoirs, 3) conservation and restoration of Arctic grayling populations, 4) conservation and restoration of westslope cutthroat trout populations, and 5) enhancement and restoration of tributary streams.

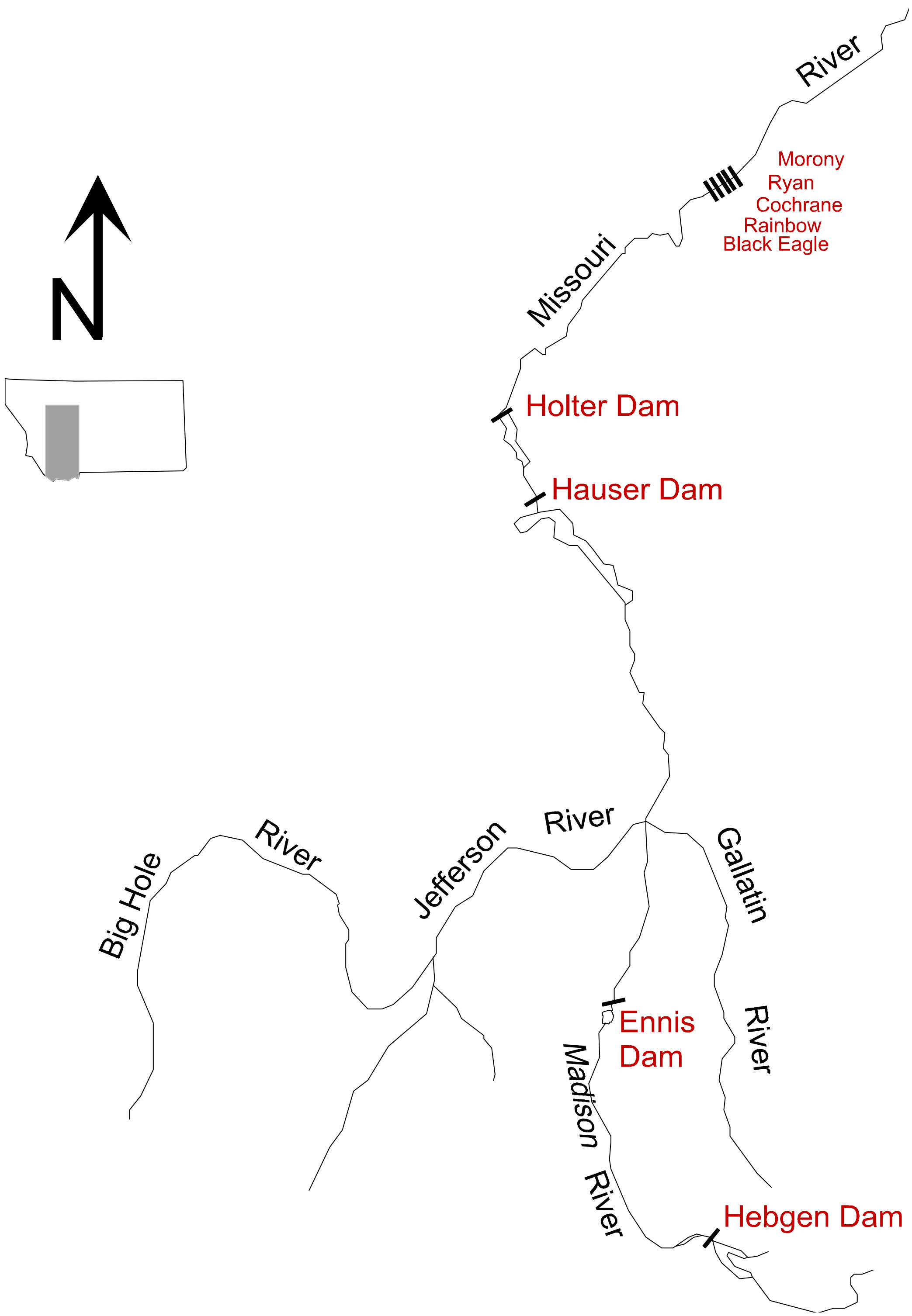


Figure 1. - Locations of NWE dams on the Madison and Missouri rivers (FERC Project 2188)

Article 403 – River Discharge

Minimum and maximum instream flows in various sections of the Madison River are mandated in Article 403 and in Condition No. 6 of the FERC license to NWE. Specifically, Condition 6 in its entirety states: "*During the operation of the facilities authorized by this license, the Licensee shall maintain each year a continuous minimum flow of at least 150 cfs in the Madison River below Hebgen Dam (gage no. 6-385), 600 cfs on the Madison River at Kirby Ranch (USGS gage no. 6-388), and 1,110 cfs on the Madison River at gage no. 6-410 below the Madison development. Flows at USGS gage no. 6-388 (Kirby Ranch) are limited to a maximum of 3,500 cfs under normal conditions excepting catastrophic conditions to minimize erosion of the Quake Lake spillway. License requirements also require the :Establish[ment] a permanent flow gauge on the Madison River at Kirby Ranch (USGS Gauge No. 6-388).* FWP and NWE continue to jointly monitor river flows to avoid deviations from operational conditions. NWE conducted a leakage test of the Madison Dam September 11-13 per FERC requirements. FWP was notified of the test and granted consent. Minimum flow requirements at USGS gage no 6-410 were maintained during the test and flow was maintained in the bybass reach directly below the dam at 104cfs, 24cfs more than the 80cfs instantaneous minimum maintenance flow requirement for the time period July1-March 31. No deviation from the conditions for flow requirements in article 403 occurred.

Article 408- 1) Effects of project operations on Hebgen Reservoir fish populations; 3) Reservoir draw down effects on fish; 4) Monitor the effects of modified project operations on upper Madison River fish populations 7) Monitor species of special concern.

Hebgen Reservoir Fisheries Assessment

FWP conducts annual gillnetting in Hebgen Reservoir using 125-foot variable mesh experimental gillnets to monitor trends in reservoir fish assemblages for the purpose of assessing the effects of project operations. Gross changes in reservoir fish assemblage trends would warrant a review of and potential change to project operations to address identified issues. Sampling yielded 1,277 fish (Table 1). Utah chub comprised 65.7% of the sample, brown trout 17.5%, rainbow trout 10.9%, and mountain whitefish 5.9%, respectively. Utah chub are the most abundant fish species in Hebgen Reservoir and have comprised the majority of fish sampled during annual gillnetting since its inception (Figure 2). Brown trout relative abundance and mean length have trended slightly upward since 2014. The mean number per net of brown trout sampled in gill nets has ranged from 2.3/net in 2001, to 12.5/net in 1999 (Figure 3). The number/net of mountain whitefish decreased to 2.8/net from 4.4/net observed in 2018 (Figure 4). Average length of rainbow trout sampled has remained fairly stable since 2010, ≥16.0. This is an approximate 1.5- inch increase in average length from those observed in the mid 90's through the early 2000's, ≥ 14.5 inches. Rainbow trout per/net was the highest observed since hatchery supplementation of the Hebgen rainbow trout fishery was halted by FWP with a mean 5.5/net (Figure 5). Based upon current trend data no recommendations to NWE for a change in project operations is warranted.

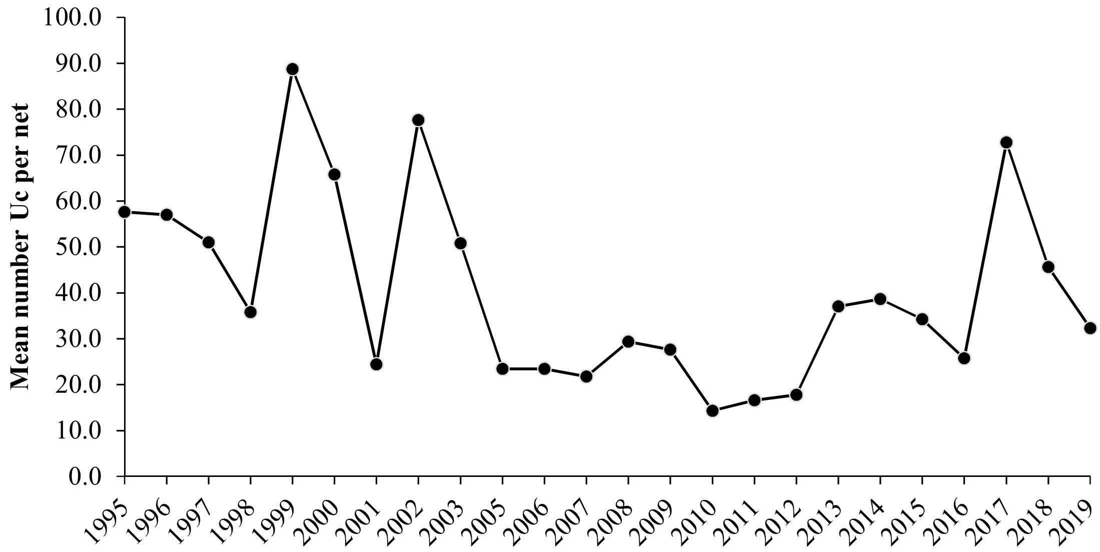


Figure 2 . Mean number of Utah chub (Uc) per net 1995-2019.

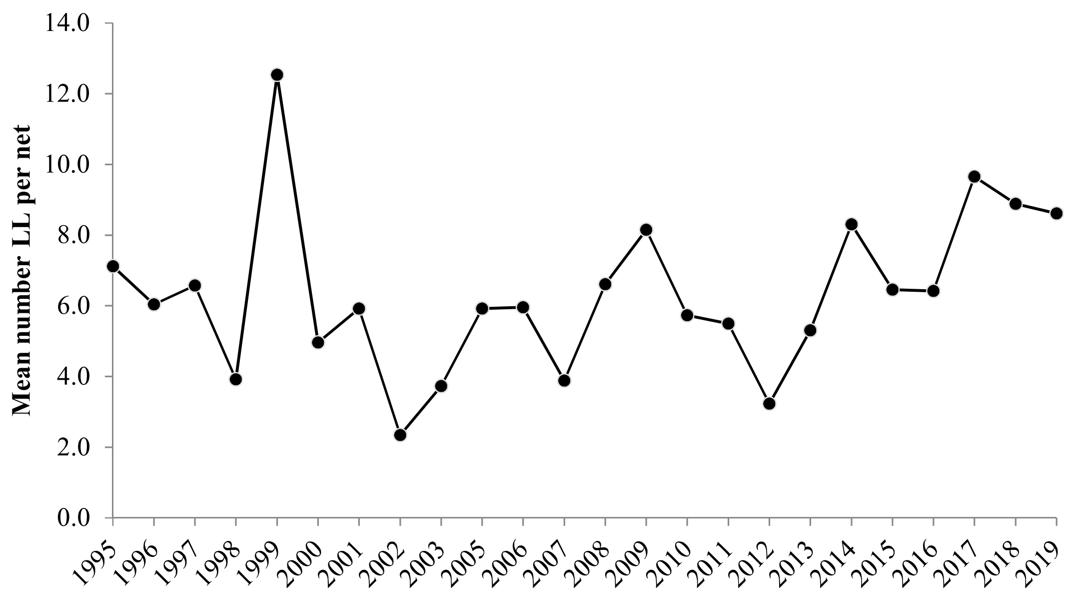


Figure 3 . Mean number of brown trout (LL) per net 1995-2019.

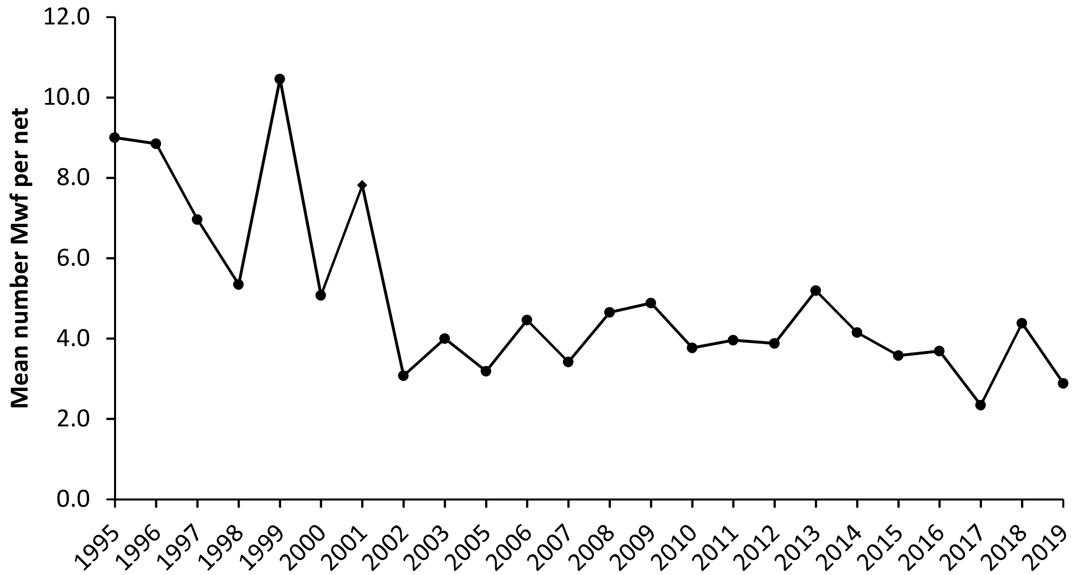


Figure 4 . Mean number of mountain whitefish (Mwf) per net 1995-2019.

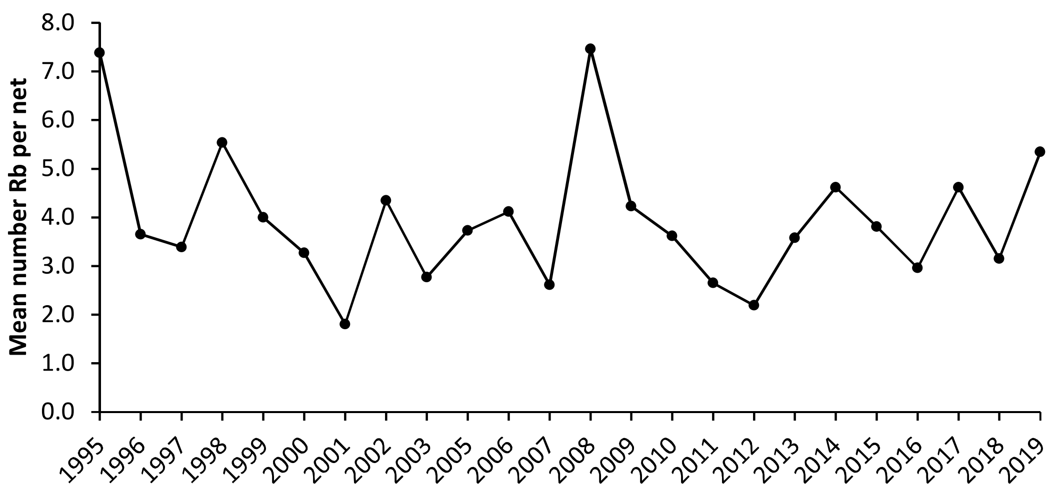


Figure 5 . Mean number of rainbow trout (Rb) per net 1995-2019.

Table 1.- Hebgen Reservoir rainbow trout, brown trout, mountain whitefish, Utah chub catch per unit effort (C/*f*) ± SE, mean length, mean length tested at 95% confidence (CI), mean weight, mean weight tested at 95% confidence.

Species	C/*f* number per net	Mean length	Upper 95% CI	Lower 95% CI	Mean weight	Upper 95% CI	Lower 95% CI
Rainbow trout	5.5±1.4	16.3	16.4	16.3	1.54	1.55	1.53
Brown trout	8.6±2.3	17.6	17.6	17.5	1.91	1.92	1.90
M.whitefish	2.8±0.83	16.0	16.1	15.9	1.67	1.83	1.50
Utah chub	32.3±7.6	10.3	10.4	10.2	0.45	0.45	0.45

Hebgen Reservoir Trophic Status

FWP began monitoring the trophic status of Hebgen Reservoir in 2006 while investigating potential limiting factors to wild rainbow trout recruitment to the Hebgen Reservoir fishery and if any potential change to operational guidelines, such as reservoir draw down, could affect reservoir productivity. Monitoring of Hebgen Reservoir trophic status consists of taking secchi disk measurements in conjunction with zooplankton tows to establish a Trophic State Index number (TSI) (Carlson 1977).

A Secchi disk is used to measure light penetration (in meters) into the Hebgen Reservoir water column. Secchi depths are recorded as the distance from the water surface to the point in the water column where the disk colors became indiscernible.

Monthly zooplankton tows are conducted at nine established sites on Hebgen Reservoir to evaluate plankton community densities and composition. Plankton samples are collected with a Wisconsin® plankton net with 153-micron mesh (1 micron = 1/1,000th millimeter) towed vertically through the entire water column at one meter per second. Tows are taken preferably at locations with a minimum depth of 10 meters. Samples are rinsed and preserved in a 95% ethyl alcohol solution for enumeration. Zooplankton are identified to groups, cladocera or copepoda, and densities from each sample are calculated.

Applying the Trophic State Index (TSI) (Figure 6) developed by Carlson (1977), Hebgen Reservoir has been classified as oligotrophic-mesotrophic for all years monitoring has occurred. The highest mean TSI score and zooplankton abundances for years data are available occurs in the month of June (Figure 7).

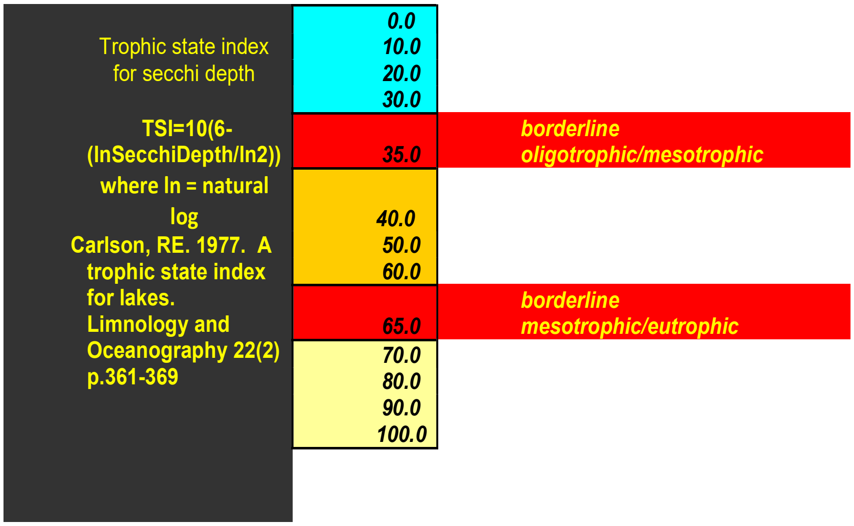


Figure 6. - Trophic State Index (TSI) developed by Carlson (1977).

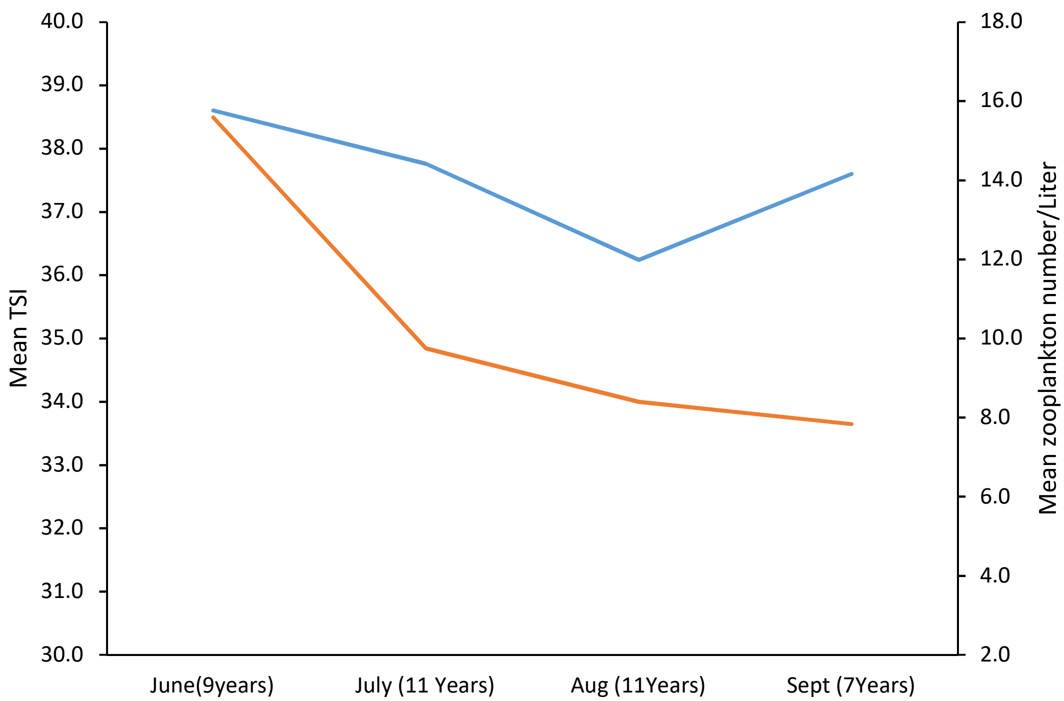


Figure 7. Mean TSI scores and zooplankton abundance by month for years data exists. The blue line is TSI and red line is zooplankton abundance.

Zooplankton group abundance varied by month and trends in total abundance show peak densities occurring in late spring and early summer (Figure 8). Mean abundance in June samples was 17.4 individuals/L, the highest density observed during the year with copepoda constituting 57% and cladocera 43% of the sample. Copepoda was the dominant zooplankton group observed in samples throughout the sampling period; July (64%), August (65%), respectively.

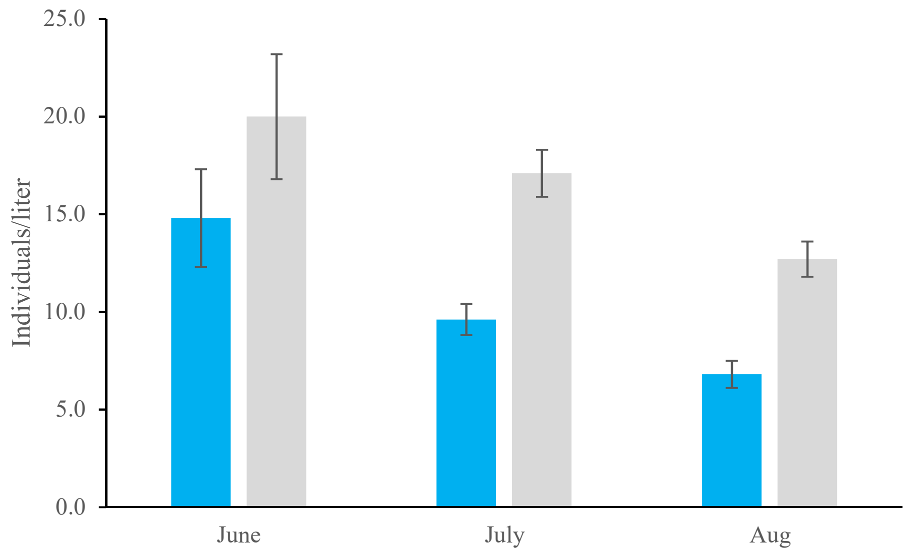


Figure 8. - Mean Cladocera and copepoda abundance (zooplankton/liter) reservoir wide June-Aug 2019. Cladocera are represented by blue column and copepoda gray column. Error bars are 95% confidence interval.

Primary productivity in Hebgen Reservoir may be limited by elevation and residence time Johnson and Martinez (2000). With a full pool elevation of 6,534.87 feet, Hebgen Reservoir may be more characteristic of a high elevation lake with a short growing season allowing for relatively few days of primary production. Additionally, increases in discharge from Hebgen could affect the duration nutrients required for primary production stay in the reservoir. No changes to project operations have been considered at this time but monitoring will continue.

Madison River Fisheries Assessment

FWP conducts abundance estimates annually in two established monitoring sections in the upper Madison River to evaluate fish abundance and the influence of project operations and mitigation and enhancement measures (PM&E) on them.

Electrofishing from a drift boat mounted mobile anode system (Figure 9) is the principle method used to monitor trout abundances in the Madison River.

Figure 9. - Mobile anode electrofishing (shocking) in the Norris section of the Madison River.

Fish captured for abundance estimates are weighed and measured, observed for hooking scars, marked with a fin clip, released, and allowed to redistribute for at least ten days. A recapture run is conducted after the ten days. During the recapture run, fish are observed for marks administered during the marking run, lengths are taken on marked fish, and length and weights are recorded on fish that do not exhibit a mark.

Estimated abundances of brown and rainbow trout ≥ 152 mm (≈ 6") declined below the 20-year averages in the upper Madison River in 2019 (Figure 10). In the Pine Butte Section, estimated brown and rainbow trout abundances declined by about 40% from 2018 to 2019. The estimated abundance of brown trout was 1,600 trout/mile in 2019, which is 80% of the 20-year average.

The estimated abundance of rainbow trout decreased to 2,201 trout/mile in that same reach, which is 93% of the 20-year average for that section. Estimated abundances of brown trout in the Varney Section remained relatively stable at 1,325 fish/mile, which is 81% of the 20-year average for that reach. Estimated abundances of rainbow trout declined by 55% to 805 fish/mile, which is 72% of the 20-year average. The Norris Section, which is downstream of Ennis Lake, was not sampled in 2019.

Estimated abundances of small brown (Figure 11a) and rainbow (Figure 11b) trout have generally increased in the Pine Butte Section since 2014. However, the estimated abundances of brown (Figure 11c) and rainbow (Figure 8d) trout > 277 mm (> 11") have declined during that same time period. These trends indicate that recruitment of age-0 fish appears to remain high, but mortality of age-2 and older fish has increased for unknown reasons. Estimated abundances of small rainbow trout varied from year-to-year in the Varney Section (Figure 12b) whereas small brown trout illustrated a similar trend to those observed in the Pine Butte Section with increasing abundances since 2014 (Figure 12a). Low estimated abundances of large fish were observed for both species the last several years in the Varney Section (Figure 12c, d), which suggests increasing mortality of large brown and rainbow trout in the Varney Section since 2014. A shift in the size structure of those populations is also evinced by the length frequency histograms from the Pine Butte and Varney sections (Figures 13 and 14). Despite relatively high estimated abundances of age-1 brown and rainbow trout in both sections compared to the 10-year mean, estimated abundances of age-2 and older fish, which are typically fish ≥ 277 mm, remained low in 2019. Although brown and rainbow trout ≥ 500 mm have historically composed a small percentage of the catch in the Pine Butte and Varney sections, those fish became increasingly rare during 2018 and 2019 sampling efforts. FWP will assess whether changes in abundances are associated with 2188 project operations and if operational changes should be considered in the future.

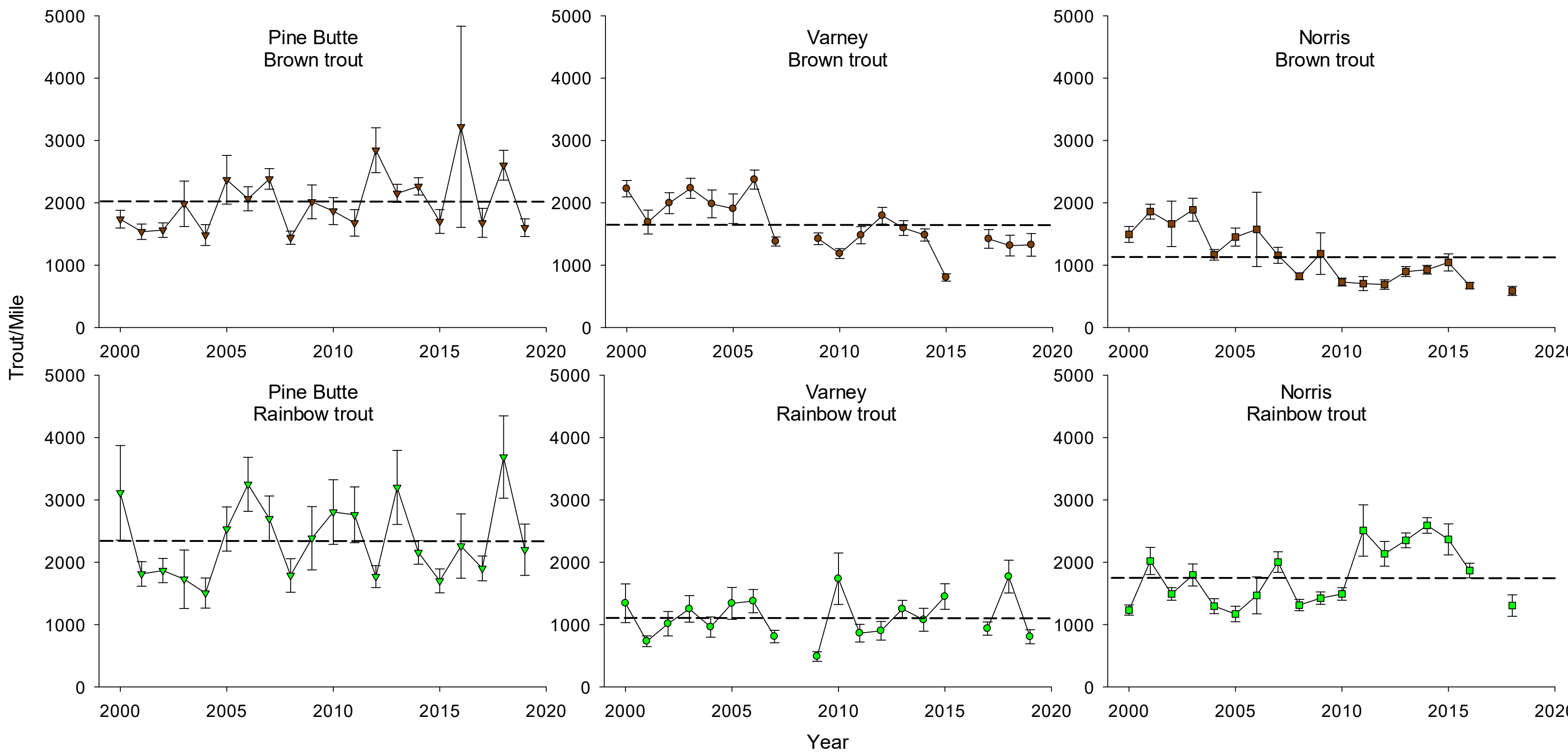


Figure 10. -Estimated abundances of brown (brown squares) and rainbow (green circles) trout ≥ 152 mm (≈ 6”) captured in the three long-term sampling sections of the Madison River. Dashed lines are the 20-year averages of estimated abundances and error bars are the 95% confidence intervals for each sampling event.

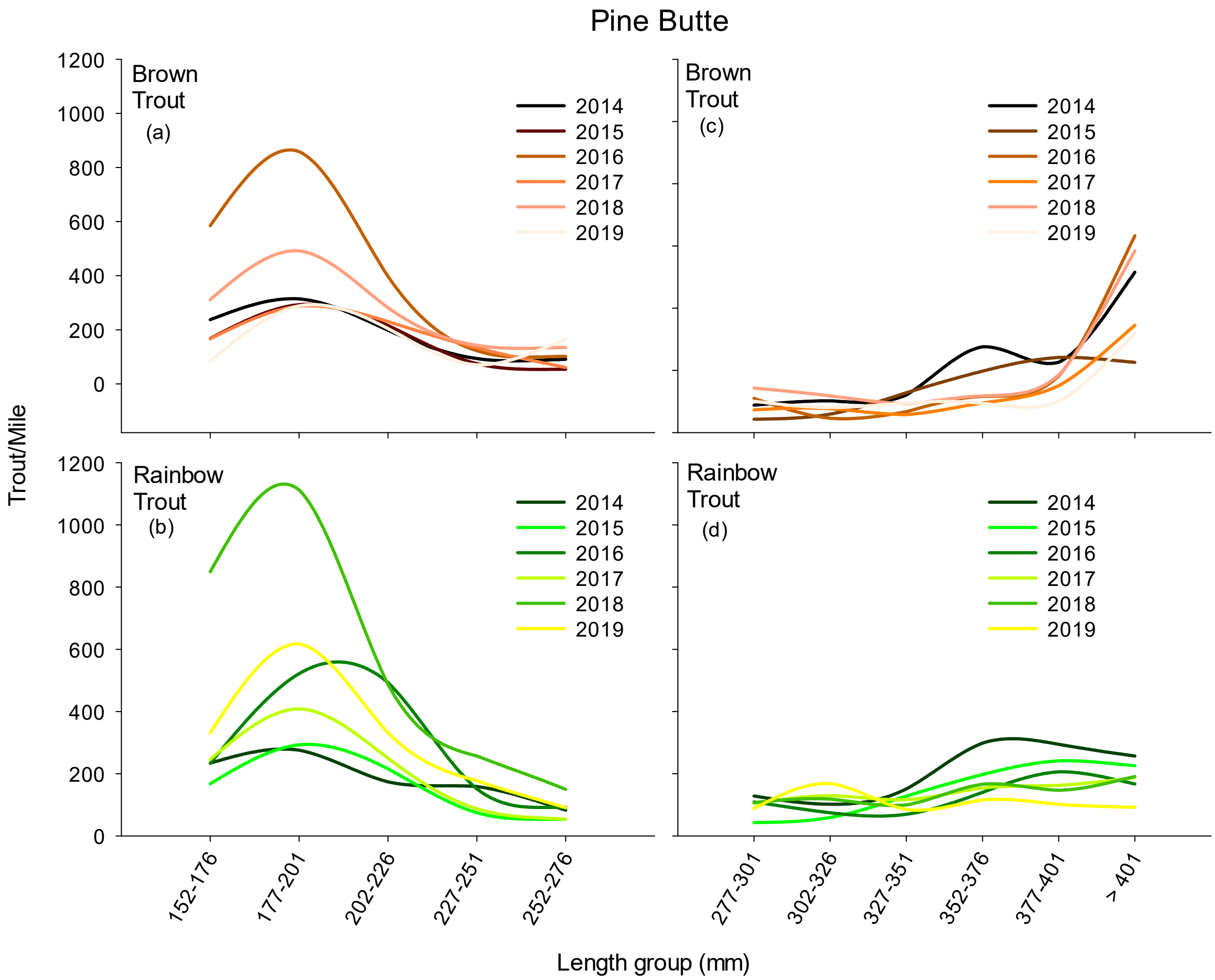


Figure 11. - Estimated abundances of brown and rainbow trout in the Pine Butte Section of the Madison River. A nearest neighbor function was used to smooth the line between years.

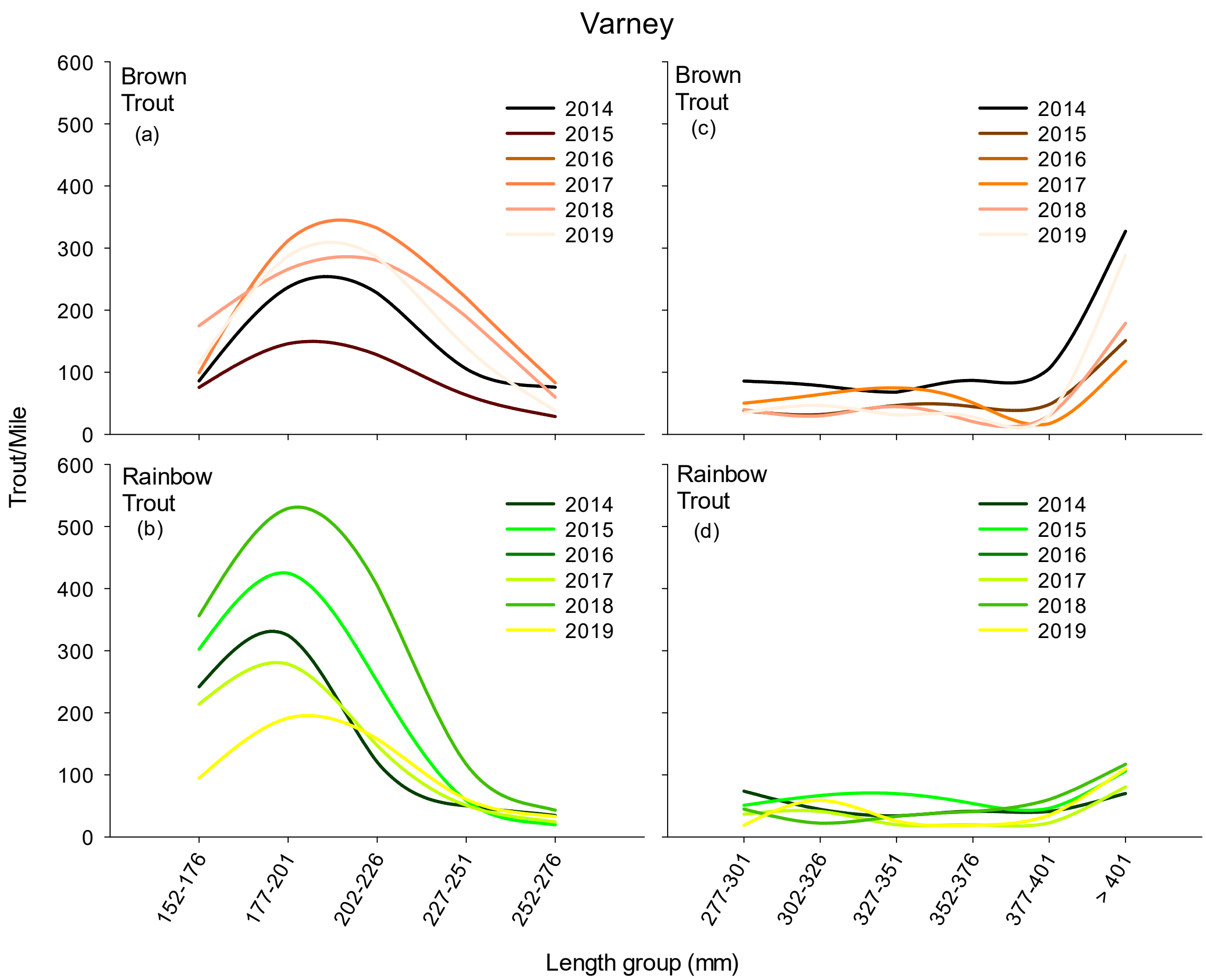


Figure 12.- Estimated abundances of brown and rainbow trout in the Pine Butte Section of the Madison River. A nearest neighbor function was used to smooth the line between years.

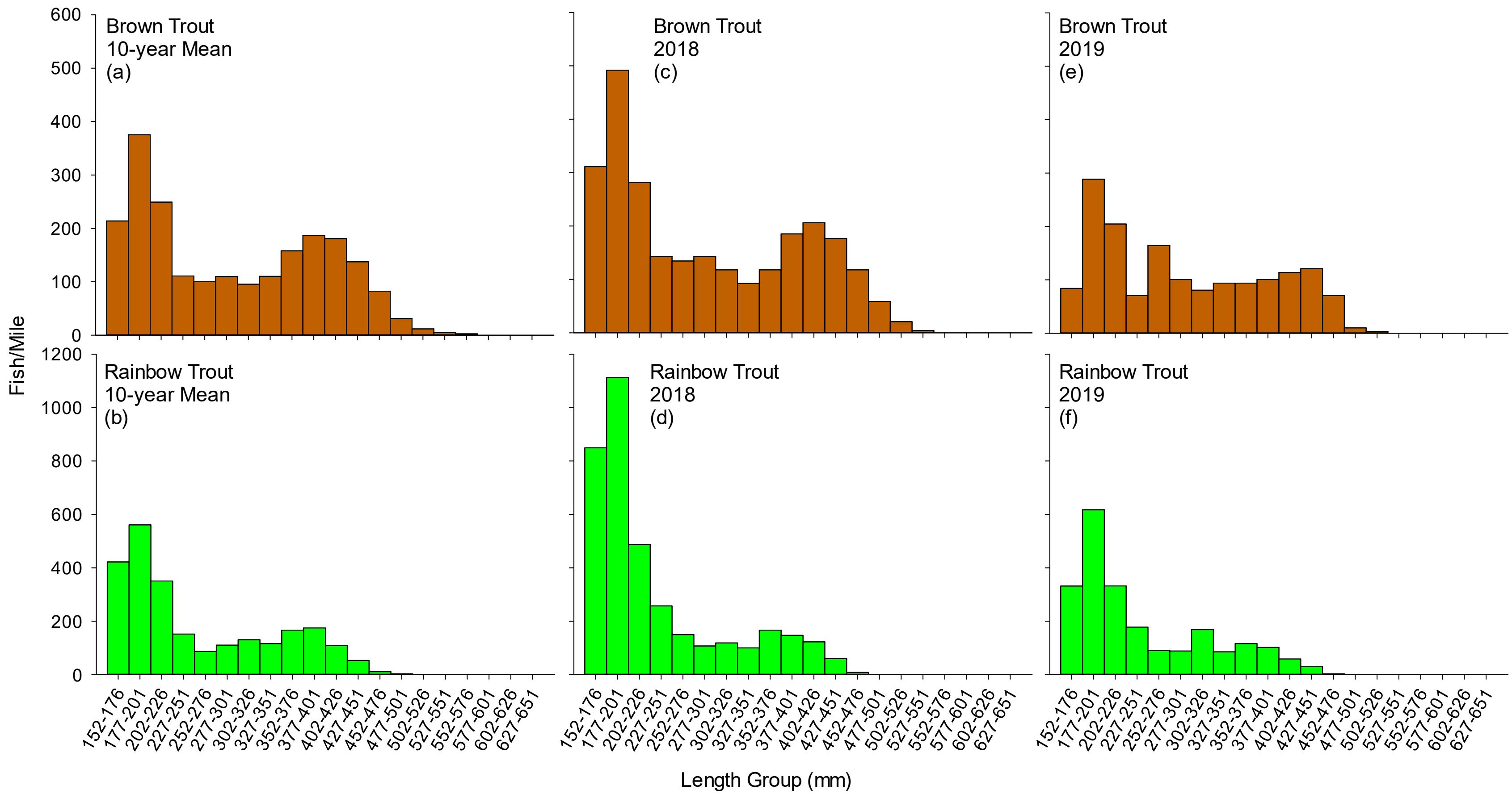


Figure 13. Length frequency histograms of brown and rainbow trout ≥ 152 mm (≈ 6") captured in the Pine Butte Section of the Madison River.

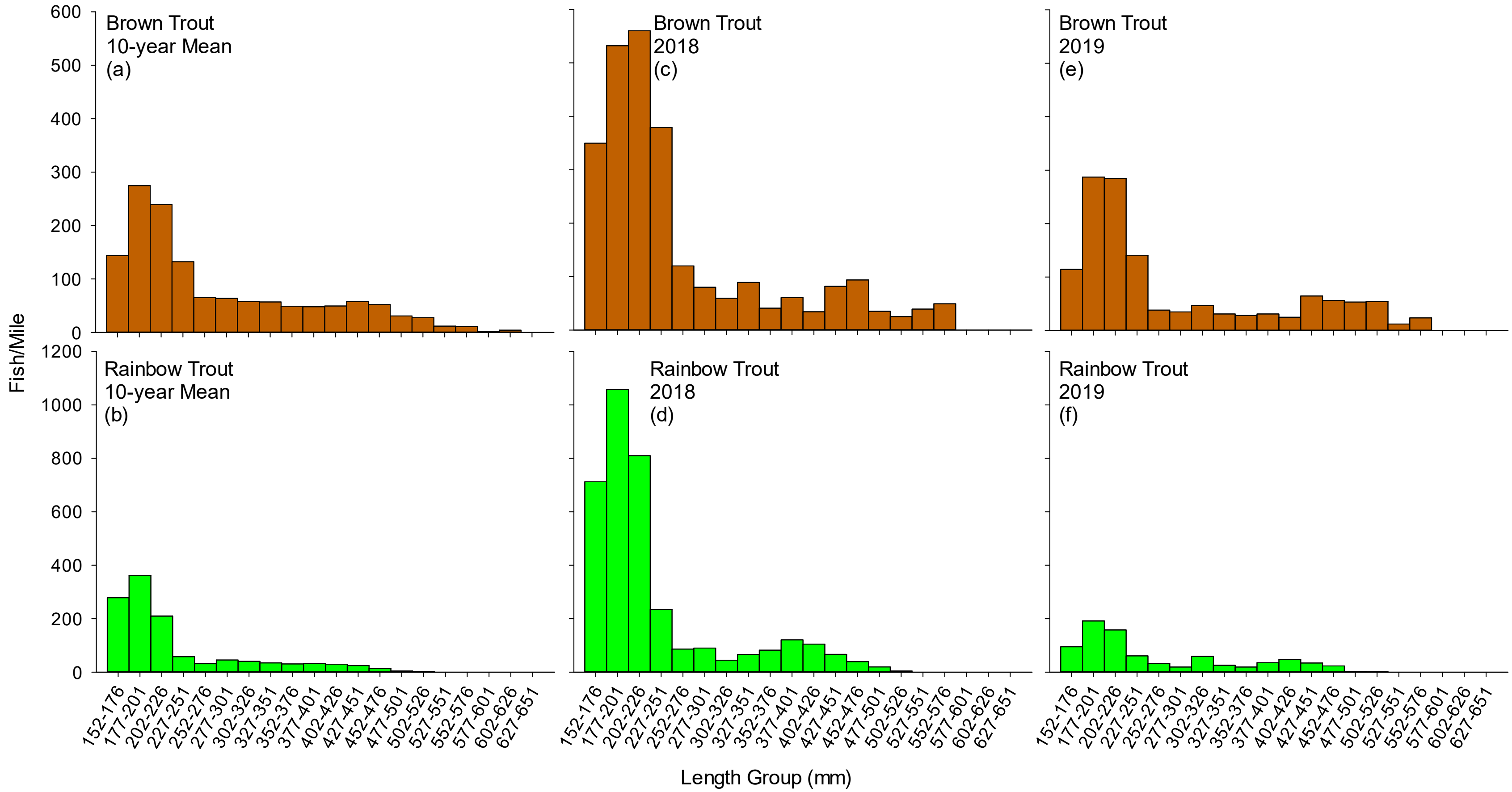


Figure 14. Length frequency histograms of brown and rainbow trout ≥ 152 mm (≈ 6") captured in the Varney Section of the Madison River.

Monitor Species of Special Concern; Madison Artic Grayling; Westslope Cutthroat Trout

Opportunities to recover, conserve, and expand native fish species distribution are continually being pursued by FWP and partner agencies. Due to habitat loss and impacts to native fish species, such as Artic grayling and westslope cutthroat trout, associated with the operations of the Madison Project NWE is committed to providing funding for PM&E measures under Articles 408, 409, 412 the 2188 FERC agreement form Hebgen Reservoir to Three Forks Montana (FERC 2000) .

Arctic grayling introductions in the Madison Drainage began in May 2014 (Clancey and Lohrenz, 2015) to re-establish viable Arctic grayling populations in formerly occupied waters or at sites where their populations are diminished. Sixty-five thousand Arctic grayling eggs, from the Green Hollow pond located on the Flying D Ranch (Gallatin drainage), were introduced at three sites in the Madison Drainage through Remote Site Incubators (RSIs) (Figure 15). Introduction sites were Odell Spring Creek- Granger Ranch (15,000), Odell Spring Creek- Longhorn Ranch (45,000) and Blaine Spring Creek (10,000) (Figure16). Water temperature data for the duration of incubation and emergence is displayed in Table 2.

Figure 15. - Arctic grayling remote site incubators at Odell Spring Creek-Granger Ranch

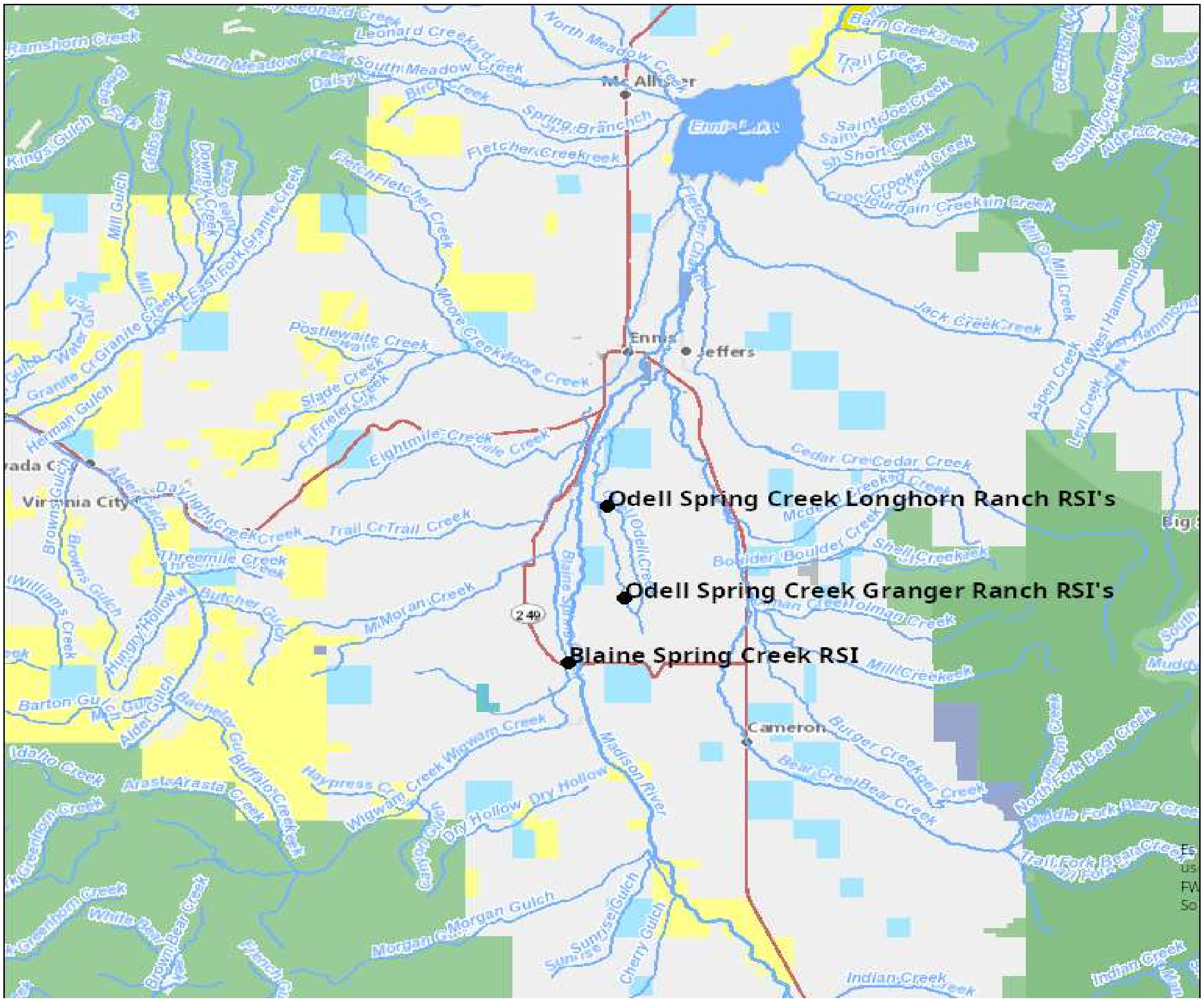


Figure 16.- Location of Artic grayling introductions 2019.

Table 2. - Water temperature characteristics and approximate date of last emergence at Madison Drainage Arctic grayling RSI introduction sites, 2019. Eggs were placed into the RSIs at Odell Spring Creek -Granger Ranch, Odell Spring Creek- Longhorn Ranch, and Blaine Spring Creek on May 22.

RSI site	Mean water temperature ◦F	Temperature range ◦F	Approximate date of last emergence
Odell Spring Creek- Granger Ranch	51.5	48.7-54.1	June 2
Odell Spring Creek- Longhorn Ranch	50.3	49.0-52.1	June 9
Blaine Spring Creek	-	-	June 2

Limited success of Arctic grayling introductions in the Madison drainage to date effected a review of the current introduction approach. Introduction sites were revisited and a list of habitat features, potentially beneficial and limiting to introduction success, was developed (Appendix A- Table 8). Additionally, angler reports of grayling capture locations were cross referenced with proximity of introduction sites and sites where juvenile grayling have been sampled(Appendix A-Table 8). Given the relatively small numbers of eggs introduced at sites where grayling have been recovered and after considering habitat, FWP will focus introduction efforts at those sites and increase the quantity of eggs introduced.

The state of Montana's Fisheries Management Plan calls for the protection and reintroduction of WCT trout with less than 10% non-native fish hybridization (i.e., conservation populations) to 20% of historically occupied waters (Montana Statewide Fisheries Management Program and Guide). The MadTAC has granted funding to FWP to pursue these conservation efforts under Articles 408, 409, and 412 of the 2188 project FERC license.

Funds granted by MadTAC to FWP and CGF were used to construct a migration barrier with explosives above a natural falls in Tepee Creek, a tributary to Grayling Creek near Hebgen reservoir. The CGF explosives crew blasted and removed a bedrock formation immediately below an existing waterfall and associated plunge pool (Figures 17-18). The channel modification has decreased the depth of the downstream plunge pool and increased the height of the waterfall by the corresponding height. FWP and CGF crews will revisit and evaluate the barrier in 2020, at that time a decision will be made as to whether or not to remove non-natives from the seven miles of the main stem and unnamed tributaries above the barrier and reintroduce genetically pure WCT.

Figure 17.- Custer-Gallatin National Forest explosives crew preparing to blast bedrock to enhance fall on Tepee creek for a migration barrier. Photo courtesy of Allison Stringer Custer-Gallatin National Forest Service.

Figure 18.- Tepee creek enhanced waterfall after blasting of bedrock and removal of plunge pool. Photo courtesy of Allison Stringer Custer-Gallatin National Forest Service.

Wall Creek is occupied by a WCT conservation population of >95% genetic purity. Currently, non-native rainbow trout are able to ascend Wall Creek and hybridize with individuals in the WCT population. To prevent further introgression of the Wall Creek WCT population, FWP in partnership with the Beaverhead-Deerlodge National Forest, requested and was granted funding from the MadTAC for the survey and design of a migration barrier that would secure 7.5 to 8.0 miles of WCT occupied waters in the Wall Creek drainage (Figure 19). During the 2019 and 2020 funding cycles MadTAC granted $120,000 in cost share funding for the construction of the barrier. Other funding sources include Montana Future Fisheries ($40,000), USFS ($10,000), and the Western Native Trout Initiative WNTI ($9,488). An additional funding source has shown interest and construction of the barrier is anticipated for August 2020.

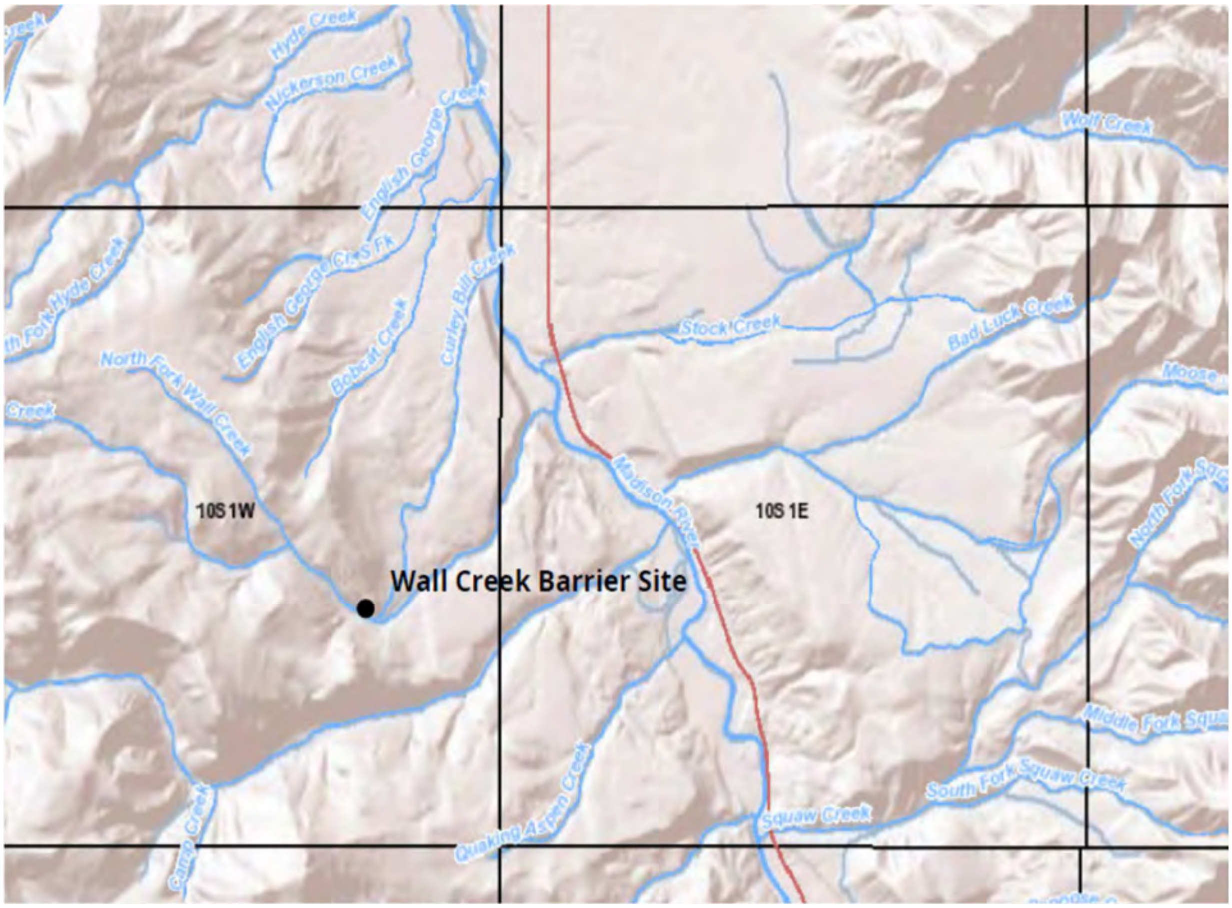


Figure 19. -Location of Wall Creek barrier.

Article 409- 3) Fish habitat enhancement both in main stem and tributary streams

South Meadow Creek

Flow augmentation and habitat degradation in tributary streams can have adverse effects on Madison River water quality and fish populations. Article 409 sub-article 3 stipulates that PM&E measures will be taken to address these issues as they are identified.

In 2012 the Madison Watershed Coordinator identified and initiated a project to rebuild irrigation infrastructure and re-establish the riparian corridor along a reach of South Fork Meadow Creek, a tributary to Ennis Reservoir (Figure 20). Stream corridor rehabilitation was promoted by fencing a 30-foot zone on each side of the stream to eliminate livestock access to the stream banks. The removal of the constant stress of livestock access along the stream banks, stimulated the growth and recovery of grasses and willows that stabilize the riparian soil and reduce sediment input from raw stream banks.

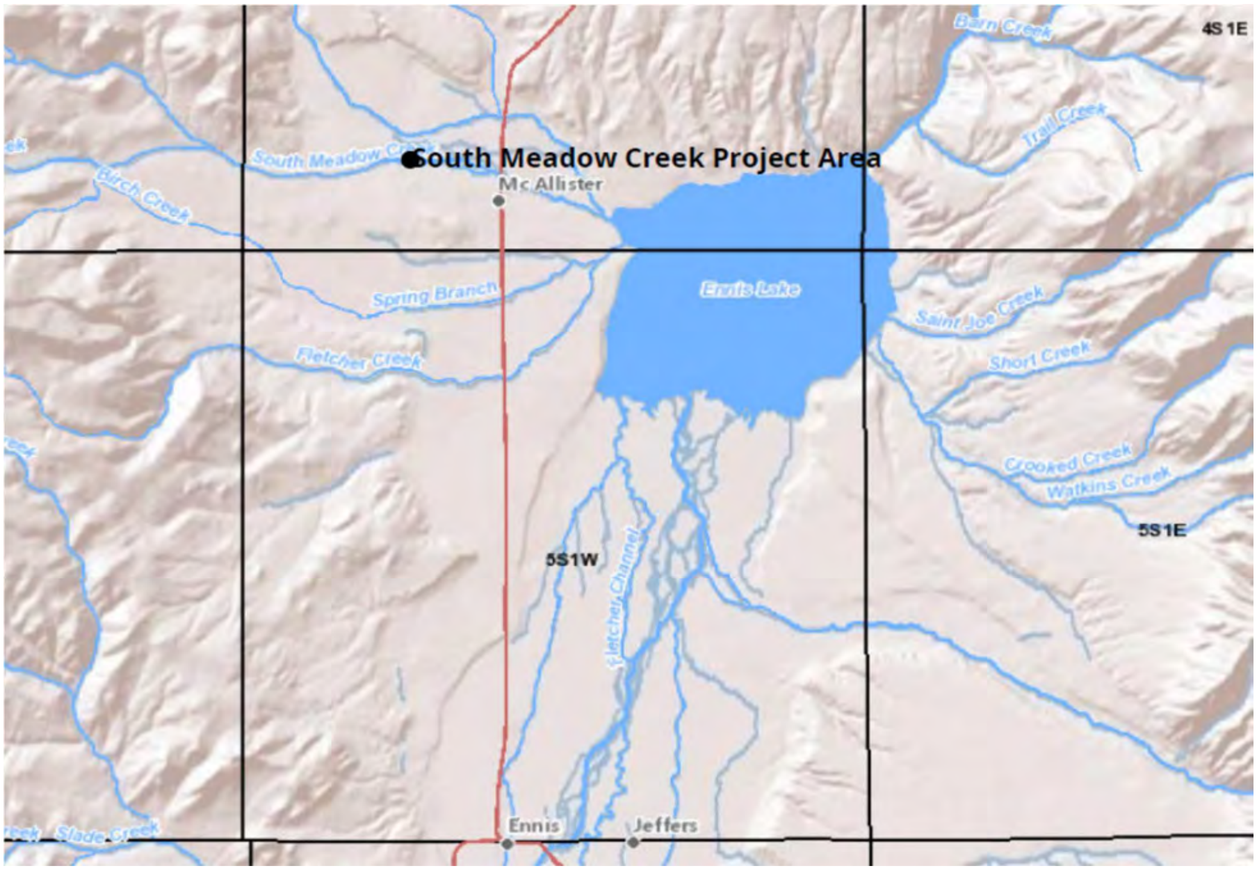


Figure 20.- Location of South Meadow Creek Project.

McNeil Resources of Townsend, MT was commissioned by FWP in 2018, with funds granted by the Mad TAC, to evaluate and develop a design to enhance fish habitat in a 1000' reach of South Meadow Creek that is within the 2012 project area. A previous landowner straightened this reach of stream, likely for water conveyance. The channel straightening resulted in loss of instream habitat such as pools and spawning gravels. Additionally, the section of stream was disconnected with the historic flood plain. Material removed from the stream was deposited in a berm along the stream bank, preventing water during high flows access to the flood plain which is needed to irrigate riparian vegetation (Figures 21-22).

Figure 21.- Aerial view of project reach showing channel straightening-Photo courtesy of Madison Conservation District.

Figure 22. -Berm material removed to reconnect flood plain.

Design objectives for the reach were : 1) provide adequate pool habitat in times of low water, 2) Develop and retain adequate spawning gravels at pool tail outs, 3) Add sinuosity to the reach to dissipate stream energy during high flow events, 4) reconnect the flood plain bench on the North side of the stream to promote riparian recovery, 5) bring the stream width back to appropriate dimensions, 6) improve cattle operations.

Rehabilitation of the reach began in November. Flood plain elevation was re-established, which will ensure irrigation of riparian plant species and prevent flooding of the landowners calving pasture. After re-establishment of the flood plain elevation, structures were incorporated into the stream to provide pool habitat in low water conditions and promote deposition of spawning gravels at pool tail outs. Additionally, stream channel size was brought back to appropriate dimensions by extending the bank toe and revegetating with sod mats (Figures 23-24). Construction continued until freezing conditions forced operations to halt. The project will resume and be completed in April 2020.

Of note neighboring landowners upstream have expressed interest in pursuing similar measures to improve stream conditions.

Figure 23.- Placement of instream structure for pool development.


Figure 24. -Portion of stream below a pool structure that was narrowed.

Article 412 – 1) Monitor the effects of project operations (including pulsed flows) on Ennis Reservoir and the lower Madison River fish populations

Ennis Reservoir Fisheries Assessment

Ennis Reservoir was gillnetted in October to assess trends in reservoir fish populations pursuant to article 412-1. A total of 240 fish were sampled in 2019; Utah chub comprised 39% of the sample, white sucker 41%, brown trout 13%, and rainbow trout 7%, respectively.

Mean length and weight of rainbow trout sampled has trended downward over the last decade; however, the number per net increased from 4/net in 2017 to 12/net in 2019. (Table 3). Brown trout mean length and weight was the lowest observed since 2013 (Table 4).

Supplementation of the Ennis Reservoir rainbow trout fishery ended in 1994 and has been managed by FWP as a wild trout fishery since that time.

Table 3 -.Ennis Reservoir rainbow trout catch per unit effort (C/*f*) ± SE, mean length, mean length tested at 95% confidence (CI), mean weight, mean weight tested at 95% confidence.

Year	C/*f* number per net	Mean Length	Upper 95% CI	Lower 95% CI	Mean weight	Upper 95% CI	Lower 95% CI
2003	3.0 ± 0.9	17.2	17.6	16.7	1.79	1.91	1.67
2005	4.0 ± 2.8	15.3	16.1	14.4	1.59	1.75	1.43
2007	3.3 ± 1.6	17.6	17.9	17.2	1.62	1.68	1.56
2009	2.3 ± 1.9	16.3	17.1	15.5	1.74	1.93	1.55
2011	2.7 ± 1.8	14.4	15.0	13.9	1.32	1.43	1.21
2013	21.0 ± 7.5	12.3	12.6	12.0	0.87	0.89	0.85
2015	13.3 ± 5.4	12.6	12.9	12.3	0.93	0.96	0.90
2017	4.0 ± 2.2	11.8	12.5	11.2	0.75	0.83	0.67
2019	12.0 ± 5.2	12.4	12.7	12.0	0.84	0.87	0.81

Table 4.- Ennis Reservoir brown trout. catch per unit effort (C/*f*) ± SE, mean length, mean length tested at 95% confidence (CI), mean weight, mean weight tested at 95% confidence.

			95% CI for mean length			95% CI for mean weight	
Year	C/*f* number per net	Mean Length	Upper bounds	Lower bounds	Mean weight	Upper bounds	Lower bounds
2003	3.6 ± 0.5	17.4	18.1	16.7	2.13	2.34	1.92
2005	9.0 ± 4.5	15.2	15.7	14.6	1.50	1.57	1.43
2007	5.0 ± 1.2	17.3	18.2	16.5	2.45	2.65	2.25
2009	5.3 ± 2.9	17.1	17.5	16.6	1.77	1.87	1.67
2011	7.0 ± 1.7	15.4	16.0	14.8	1.73	1.85	1.61
2013	9.7 ± 2.2	12.7	13.2	12.2	0.94	1.00	0.88
2015	5.6 ± 2.7	15.9	16.4	15.4	1.71	1.81	1.61
2017	6.3 ± 2.8	16.4	16.9	16.0	1.60	1.68	1.52
2019	4.3 ± 1.2	11.7	12.2	11.2	0.70	0.78	0.62

Pulse Flows

Article 413 of the FERC license mandates NWE monitor and mitigate thermal effects in the lower river (downstream of Ennis Reservoir). In coordination with agencies, the company has developed and implemented a remote temperature monitoring system and a 'pulsed' flow system to mitigate high water temperatures. Real-time or near real-time meteorological and temperature monitoring is conducted to predict water temperature the following day, which determines the volume of discharge that is necessary for thermal mitigation. Pulsed flows are triggered when 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. The volume of water released in the pulse is determined by how much the water and/or air temperature exceeds the minimum thresholds (Table 5). The increase in water volume in the lower river reduces the peak water temperature that would occur at the 1,100 cubic-feet-per-second (cfs) base flow. Discharge from Ennis Dam is increased in the early morning so that the greatest volume of water is in the area of Black's Ford and downstream during the late afternoon when daily solar radiation is greatest. The increased volume of water reduces the peak water temperature in the lower river reducing the potential for thermally induced fish kills. Discharge from Hebgen Dam typically does not fluctuate on a daily basis during pulse flows but is occasionally adjusted to increase or decrease the volume of water going into Ennis Reservoir, where daily fluctuations in the lower river are controlled. In total there were 32 calls for a pulse flow releases in 2019, however only 10 actual pulse releases were needed as natural discharge was more than the predict pulse (NorthWestern Energy 2020). Table 6 gives summary statistics for years when pulse flows were conducted on the Madison River.

Table 5.- Criteria for Pulse Flow (Northwestern Energy 2020)

Today's maximum power- house release temperature at the Madison DSS website or USGS McAllister gage on or after 8:30 p.m.	Tomorrow's predicted maximum air temperature (◦F) and corresponding pulse flows (cfs). Look up predicted high air temperature for the next day at Sloan Station near Three Forks, MT.		
	>=75 and < 85	>=85 and < 95	>=95 and < 105
Greater than or equal 68 to and less than 69	1150	1150	1400
Greater than or equal to 69 and less than 70	1150	1400	1600
Greater than or equal to 70 and less than 71	1150	1600	2000
Greater than or equal to 71 and less than 72	1400	1600	2100
Greater than or equal to 72 and less than 73	1450	1800	2400
Greater than or equal to 73 and less than 74	1600	2100	2800
Greater than or equal to 74 and less than 75	1800	2600	3000
Greater than 75	2600	3200	3200

Table 6 . Summary statistics for years in which pulse flows were conducted on the Madison River. 1/ As of October 1st each year **2/** Hebgen full pool is 6534.87 msl. The FERC license requires NWE to maintain. Hebgen pool elevation between 6530.26 and 6534.87 from June 20 through October 1.

Year	Hebgen Oct1 pool elevation[1/]	Feet below full pool	Feet of Hebgen draft due to pulsing	Number of days pulsing occurred	Feet of Hebgen draft to meet 1,100 cfs minimum McAllister gauge
2000	6531.21	3.66	0.61	29	3.05
2001	6530.53	4.34	0.05	13	4.29
2002	6530.46	4.41	0.70	18	3.71
2003	6528.59	6.28	2.68	39	3.60
2004	6532.07	2.80	0.28	12	2.52
2005	6531.52	3.35	0.30	17	3.05
2006	6530.86	4.01	1.74	15	2.27
2007	6526.05	8.82	2.12	43	6.70
2008	6524.84	10.03	0.00	0	10.03
2009	6533.02	1.85	0.03	8	1.82
2010	6531.50	3.37	0.00	3	3.37
2011	6534.04	0.83	0.00	0	0.83
2012	6532.00	2.87	0.00	0	2.87
2013	6531.07	3.80	1.70	35	2.10
2014	6532.73	2.14	0.06	42	2.08
2015	6531.97	2.90	0.48	11	2.42
2016	6530.41	4.46	1.00	26	3.46
2017	6532.62	2.25	1.66	36	0.59
2018	6531.54	3.33	0.67	36	2.66
2019	6531.18	3.69	0.08	10	3.61

Temperature Monitoring

Temperature affects all living organisms and fish species have specific thermal ranges that are optimal for their persistence. While FWP initiated temperature monitoring to aid with the development of the pulse flow program, water temperature monitoring is relevant to all of the 2188 articles and is affected by PM&E activities enacted under those Articles.

Water temperature was recorded at 12 sites and air temperature at six sites throughout the Madison River basin from upstream of Hebgen Reservoir to the mouth of the Madison River at Headwaters State Park (Figure 25). Each of the Tidbit™ temperature loggers recorded over 40,000 temperature points in Fahrenheit from late April through early September. Air temperature recorders were placed in areas that were shaded from solar radiation 24 hours per day.

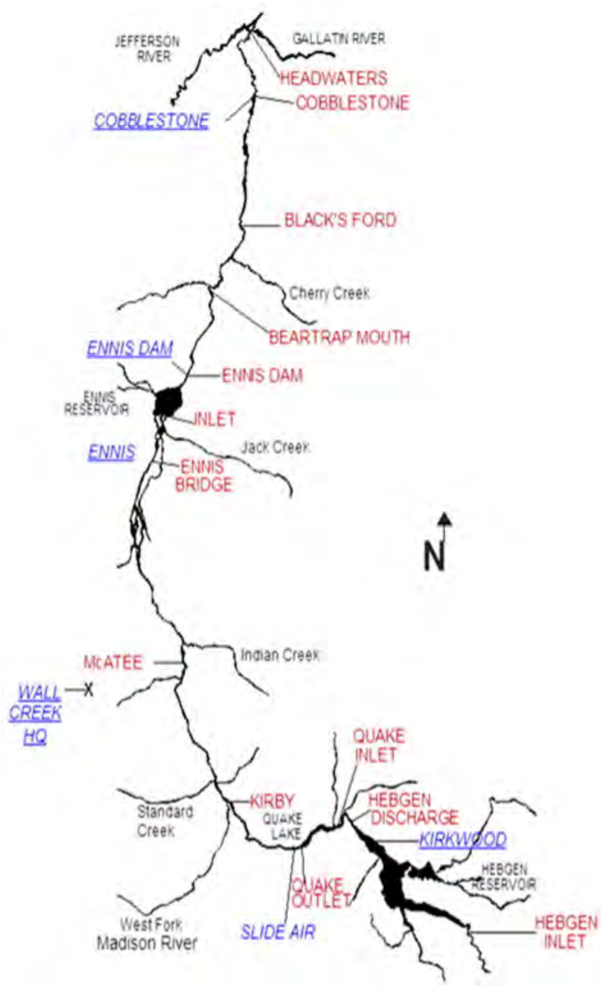


Figure 25. - Locations FWP temperature monitoring sites. Air temperature monitoring sites are blue and underlined; water temperature monitoring sites are red.

Table 7 summarizes the data collected at each location. Appendix A2 contains comparisons of annual maximum temperatures at selected adjacent monitoring sites and Appendix A3 contains annual maximum temperature longitudinal profiles illustrating the maximum water temperature recorded at each river monitoring site since 1997. It is important to note that the maximum temperatures at each site throughout the river did not all occur on the same day in any year, and that the maximum temperature at any given site may have occurred on more than just one day in a year. Water temperature recorders were not recovered at every site in some years, or the data was not recoverable because of recorder failure, but for years where data are available notable patterns occur:

- For all 17 years where data are available, maximum water temperature at the Hebgen Inlet site is higher than maximum water temperature at the Hebgen discharge site
- For 20 of 21 years where data are available, maximum water temperature at the Quake Inlet site is higher than maximum water temperature at the Quake outlet site
- Since 1995 maximum water temperatures were recorded in July at the Kirby and McAtee sites. In both instances, the maximum temperature occurred in early July, before daylength shortened and summertime air temperatures were moderated.
- The Ennis Reservoir Inlet site annually exhibits the highest maximum water temperature of the seven sites between Hebgen Dam and Ennis Reservoir
- In 20 of the 24 years where data are available, maximum water temperature at the Ennis Dam site is lower than at the Ennis Reservoir Inlet site
- Maximum water temperatures at all sites downstream of Ennis Dam typically are about 5º F warmer than at Ennis Dam
- Maximum water temperature at Blacks Ford has been successfully attenuated by pulse flows conducted to prevent thermal related fish kills; the last fish kill occurred in 1988.
- In 2015, thermal maxima for the recorded period (1994 to present) was recorded at the Kirby, Wall Creek Bridge and McAtee sites and at every monitoring site from Ennis Dam to Cobblestone. Below Ennis Dam, maximum temperatures equaled or exceeded 80º F at every site except Ennis Dam. In every instance, the maximum temperature occurred in early July, before summer air temperatures moderated.

Table 7.- Table showing maximum, minimum and mean temperatures (ºF) recorded at locations in the Madison River Drainage, 2019. Air and water temperature data were recorded from April 22 –September 22. Temperature graphs for each location are in Appendix A-1.

Deployment	Site	Max	Min	Mean
Water	Hebgen inlet	75.4	42.8	60.1
	Hebgen discharge	65.1	37.7	53.8
	Quake Lake inlet	64.9	37.3	53.1
	Quake Lake outlet	63.8	37.6	52.7
	Kirby Bridge	69.5	35.9	53.2
	McAtee Bridge	69.9	34.0	53.9
	Ennis Bridge	71.2	35.0	55.9
	Ennis Reservoir Inlet	74.7	42.9 (late deployment	57.1
	Ennis Dam	72.4	39.5	60.1
	Bear Trap Mouth	76.4	39.0	60.3
	Blacks Ford	77.9	38.0	59.3
	Cobblestone	79.1	39.1	60.8
	Headwaters S.P. (Madison mouth)	NA	NA	NA
Air	Kirkwood	89.8	14.3	53.3
	Slide	NA	NA	NA
	Wall Creek HQ	93.2	14.3	56.7
	Ennis	92.2	17.0	57.6
	Ennis Dam	100.0	28.8	63.9
	35 MPH Corner	84.6	24.4	60.0
	Cobblestone	97.1	13.5	59.8

419-Coordinate and monitor flushing flows

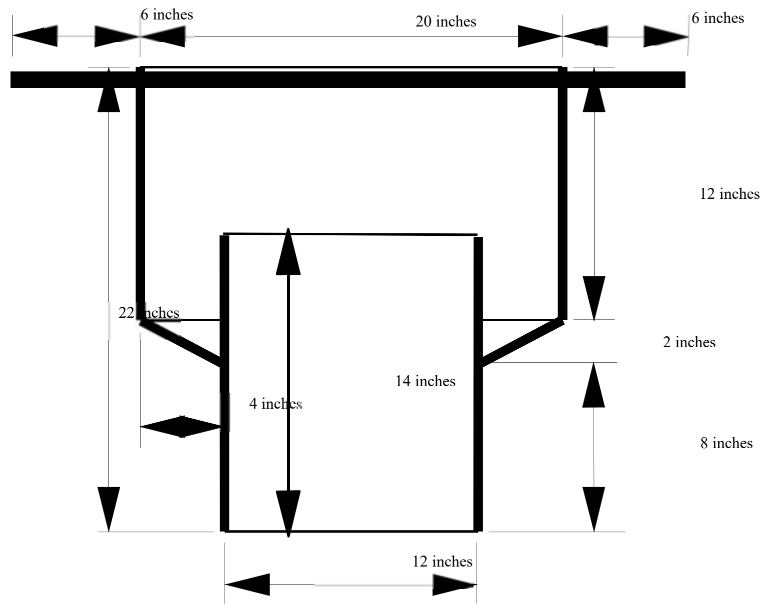
Article 419 of the FERC license requires that NWE develop and implement a plan to coordinate and monitor flushing flows in the Madison River downstream of Hebgen Dam. A flushing flow must be large enough to mobilize streambed materials and produce scour in some locations and deposition in other locations. This is a natural occurrence in unregulated streams and rivers, and renews spawning, rearing, and food producing areas for fish, as well as providing fresh mineral and organic soil for terrestrial vegetation and other wildlife needs.

Core Sampling and Redd Counts

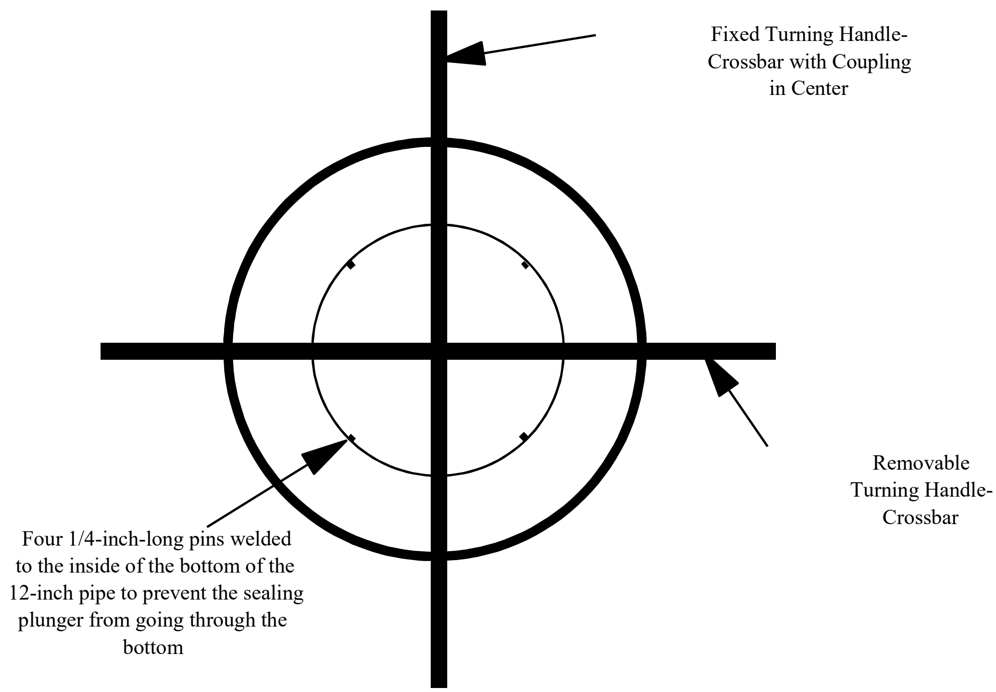
FWP assists NWE annually with core sampling to evaluate the composition of substrates from the riverbed at known salmonid spawning areas (Figure 26). Core samples provide information about fines that can be tied to channel changing flows and whether a flushing flow should be initiated to reduce the amount of fine sediments in spawning gravel.

Core samples are collected with a 12" McNeil core sampler (Figure 27). The core sampler is drilled into the substrate to a depth of 8." Substrate from within the 12"x 8" area is collected, dried, and sorted using a sieve method. Percent composition of the substrate sample according to size is then calculated.

Figure 26.- Redd at the Norris redd counting and core sampling site.



Cross-Section



Top View

Figure 27-. Schematic of 12-inch diameter substrate sampler, modeled after the original 6-inch diameter sampler developed by McNeil and Ahnell (1964).

Results from core sampling have shown flushing flows when they are initiated to be fairly ineffective. The last flushing flow occurred in 2018. Conditions in upper Madison River are relatively stable with little change in sediment deposition. Fredle index numbers – a measure of embeddedness of substrate - remain above five for all but one site on the upper Madison. The number of fines <0.84 mm in the lower river are continuously higher than those values observed in the upper river. Fredle index numbers have trended noticeably downward in the lower Madison over the last ten years (Figure 28) (R2 Resource Consultants 2018). Samples taken in 2018 and 2019 are still being analyzed by a contractor hired by NWE. Data collected through 2017 is in Table 8 and trends for median % fines are in Figure 29 (R2 Resource Consultants 2018).

Table 8. Upper Madison River % fines <.84mm median value ± standard deviation (SD), lower Madison River % fines <.84mm median value ± SD, NWE flushing flow event, peak flow in cubic feet per second (CFS) at USGS gage 06041000.

Year	Upper Madison River % fines <.84 mm median ±SD	Lower Madison River % fines <.84mm median ± SD	NWE flushing flow	Peak Flow CFS USGS gage 0604100
1995	6.6 ±4.4	15.9 ±5.4		7360
1996	5.8 ±1.2	8.3 ±4.5		7980
1997	7.4 ±3.9	9.8 ±4.5		7910
1998				6820
1999				5500
2000				4450
2001				2460
2002	3.7 ±1.5	9.6 ±4.1	No	5180
2003	8.6 ±3.2	10.0 ±5.7	No	4670
2004	7.6 ±2.7	10.7 ±5.2	No	3440
2005	6.9 ±4.1	13.5 ±8.0	No	4470
2006	9.7 ±3.7	13.5 ±5.0	Yes	5390
2007	5.1 ±2.5	8.5 ±4.0	No	3400
2008	5.4 ±2.9	9.7 ±4.8	Yes	5390
2009	9.3 ±3.2	12.4 ±11.7	No	4050
2010	7.0 ±5.3	11.9 ±5.7	No	5540
2011	10.1±3.4	13.8 ±8.2	Yes	7100
2012	6.8 ±7.2	15.9 ±5.4	No	4810
2013	5.8 ±2.1	18.8 ±18.7	No	2850
2014	8.4 ±3.4	22.9 ±13.7	No	5560
2015	8.3 ±6.1	12.6 ±8.3	No	4490
2016	7.1 ±4.0	14.7 ±10.2	No	3180
2017	7.9 ±2.4	11.7 ±5.7	No	4520

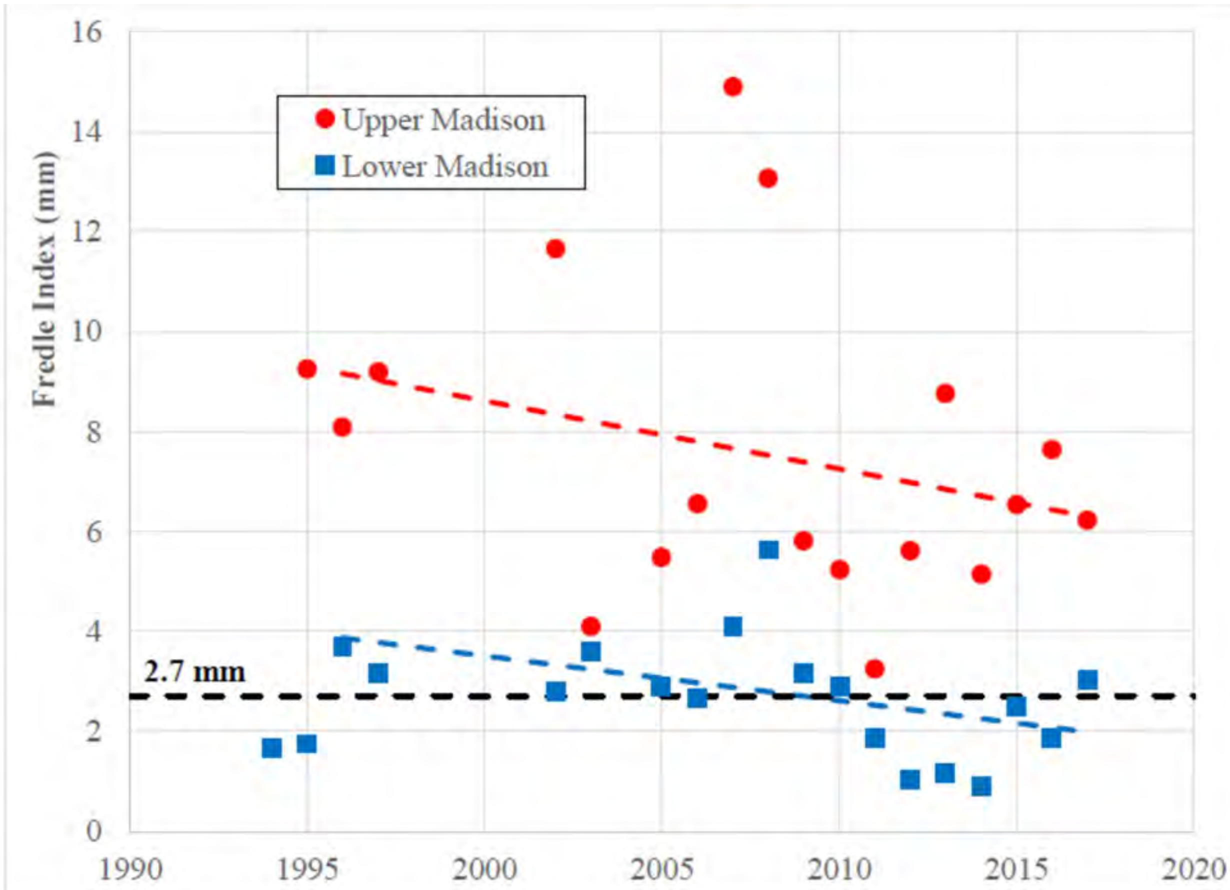


Figure 28. Median annual Fredle Index, trend lines developed for the Madison River from data available since 1996 (R2 Resource Consultants).

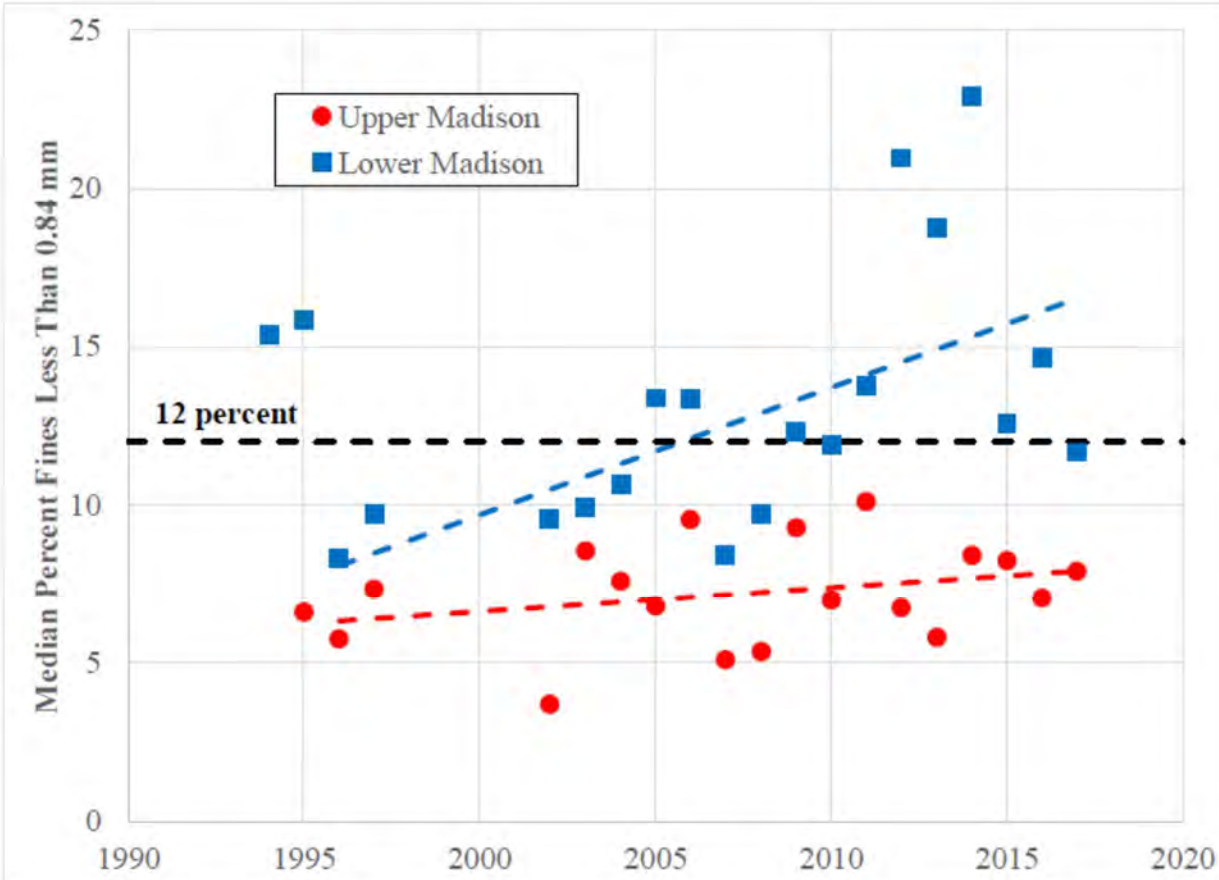


Figure 29. Median annual percent fines less than 0.84 mm, trend lines developed for the Madison River from data available since 1996 (R2 Resource Consultants).

MadTAC funding has been granted to other agencies or groups to initiate and conduct projects that adhere to the FERC license articles. Their accomplishment reports are in Appendix A4.

LITERATURE CITED

Byorth, P. and B. Shepard. 1990. Ennis Reservoir/Madison River Fisheries Investigations. Montana Fish, Wildlife, & Parks Final Report to Montana Power Company. 90 pages.

Carlson, R.E. 1977. A Trophic State Index for Lakes. Limnology and Oceanography 22(2): 361-369.

Clancey, P. 1995. Madison River/Ennis Reservoir Fisheries. 1994 Annual Report to Montana Power Company, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. May 1995.

Clancey, P. 1996. Madison River/Ennis Reservoir Fisheries. 1995 Annual Report to Montana Power Company, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. February 1996.

Clancey, P. 1997. Madison River/Ennis Reservoir Fisheries. 1996 Annual Report to Montana Power Company, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. March 1997.

Clancey, P. 1998a. Madison River/Ennis Reservoir Fisheries. 1997 Annual Report to Montana Power Company, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. June 1998.

Clancey, P. 1999. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 1998 Annual Report to Montana Power Company, Environmental Division, Butte, and Turner Enterprises, Inc., Gallatin Gateway, from Montana Fish, Wildlife, & Parks, Ennis. April 1999.

Clancey, P. 2000. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 1999 Annual Report to PPL Montana (formerly Montana Power Company), Environmental Division, Butte, and Turner Enterprises, Inc., Gallatin Gateway, from Montana Fish, Wildlife, & Parks, Ennis. April 2000.

Clancey, P. 2002. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2001 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. June 2002.

Clancey, P. 2003. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2002 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. March 2003.

Clancey, P. 2004. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2003 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. May 2004.

Clancey, P. and T. Lohrenz. 2005. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2004 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. April 2005.

Clancey, P. 2006. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2005 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. June 2006.

Clancey, P. 2007. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2006 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. June 2007.

Clancey, P. 2008. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2007 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. July 2008.

Clancey, P. 2012. Environmental Assessment for the Reintroduction of Native Westslope Cutthroat Trout in Ruby Creek by Removal of Non-native Rainbow Trout with Electrofishing and Rotenone, 43 pages. Montana Fish, Wildlife, & Parks, Ennis. May 2012.

Clancey, P. 2014. Southwest Montana Arctic Grayling Reintroductions Environmental Assessment. 25 pages. Montana Fish, Wildlife & Parks, Ennis. January 2014.

Clancey, P. and D. Downing. 2001. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2000 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. April 2001.

Clancey, P. and T. Lohrenz. 2009. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2008 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. August 2009.

Clancey, P. and T. Lohrenz. 2010. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2009 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. June 2010.

Clancey, P. and T. Lohrenz. 2011. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2010 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. May 2011.

Clancey, P. and T. Lohrenz. 2012. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2011 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. May 2012.

Clancey, P. and T. Lohrenz. 2013. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2012 Annual Report to PPL Montana, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. May 2013.

Clancey, P. and T. Lohrenz. 2014. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2013 Annual Report to PPL Montana, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. May 2014.

Clancey, P. and T. Lohrenz. 2015. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2014 Annual Report to PPL Montana/Northwestern Energy, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. February 2015.

Federal Energy Regulatory Commission. 2000. Order Issuing New License, Project No. 2188-030. Issued September 27, 2000.

Graham, R.J. 1955. Biology of the Utah chub in Hebgen Lake, Montana. Master's thesis. Montana State University.

Johnson, B. and P. Martinez. 2000. Trophic economics of lake trout management in reservoirs of differing productivity. North American Journal of Fisheries Management. 20: 127-143.

Johnson, J. 1988. Environmental assessment of plans to restore Strawberry Reservoir fishery. Utah Division of Wildlife Resources No 87-14. Salt Lake City, Utah.

Montana Fish, Wildlife, & Parks. 1999. Memorandum of Understanding and Conservation Agreement for Westslope Cutthroat Trout in Montana. May 1999.

Montana Fish, Wildlife, & Parks. 2004. FA+. Montana Fish, Wildlife, & Parks, Information Services Unit, Bozeman.

Montana Fish, Wildlife, & Parks. 2007. Memorandum of Understanding and Conservation Agreement for Westslope Cutthroat Trout and Yellowstone Cutthroat Trout in Montana. July 2007.

Montana Fish, Wildlife, & Parks. 2019. 2019-2027 Statewide Fisheries Management Plan. 446-447.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-species in the United States. Ecological Economics, 2005 (Vol. 52) (No. 3) 273-288.

R2 Resource Consultants, Inc. Flushing flow needs in the Madison River 2013 through 2017 streambed and aquatic invertebrate monitoring results and comparison with results from 1994 through 2012. 4-7 and 4-8.

Sloat, M.R., B.B. Shepard, and P. Clancey. 2000. Survey of tributaries to the Madison River from Hebgen Dam to Ennis, Montana with an emphasis on distribution and status of westslope cutthroat trout. Report to Montana Fish, Wildlife, & Parks, Helena, Montana. 165 pages.

Teuscher D. and C. Luecke. 1996. Competition between kokanees and Utah chub in Flaming Gorge Reservoir, Utah-Wyoming. Transactions of the American Fisheries Society. 125:505-511.

Appendix A

Summary of Ennis Reservoir sampling 1995 - 2018 Habitat Evaluation of Introduction Sites and Egg Numbers Introduced at Sites since 2014

Table 9.-Ennis Reservoir Arctic grayling sampling, date and species sampled

Date	AG	MWF	LL	Rb
7/27/95	12	177	4	0
9/1/95	23	89	4	0
6/18/96	0	6	1	2
7/22/96	0	0	0	0
8/22/96	0	0	1	0
8/20/97	1	0	3	0
10/27/97	0	5	0	0
9/4/98	0	0	0	0
9/22/99	2	34	0	0
11/2/00	0	14	3	0
8/29/01	0	0	0	0
10/2/02	1	2	4	0
10/6/03	0	2	3	1
9/28/04	1	9	96	0
9/27/05	0	11	19	5
11/5/07	0	0	0	0
9/29/08	0	0	3	1
10/1/09	0	0	139	30
10/22/09	1	5	0	0
10/6/10	0	0	1	0
10/3/11	0	4	9	5
10/9/13	0	3	1	3
10/29/14	0	1	0	0
9/30/15	0	19	1	1
10/5/2016	0	2	2	6
10/3/2017	0	0	2	2
10/9/18	0	26	27	9
2019	No sampling occurred			

Species abbreviation AG-Arctic grayling ,MWF-mountain whitefish, LL-brown trout, and Rb-rainbow trout.

Table 10. Grayling introduction site habitat evaluation. Habitat features of introduction sites beneficial or potentially limiting to recruitment.

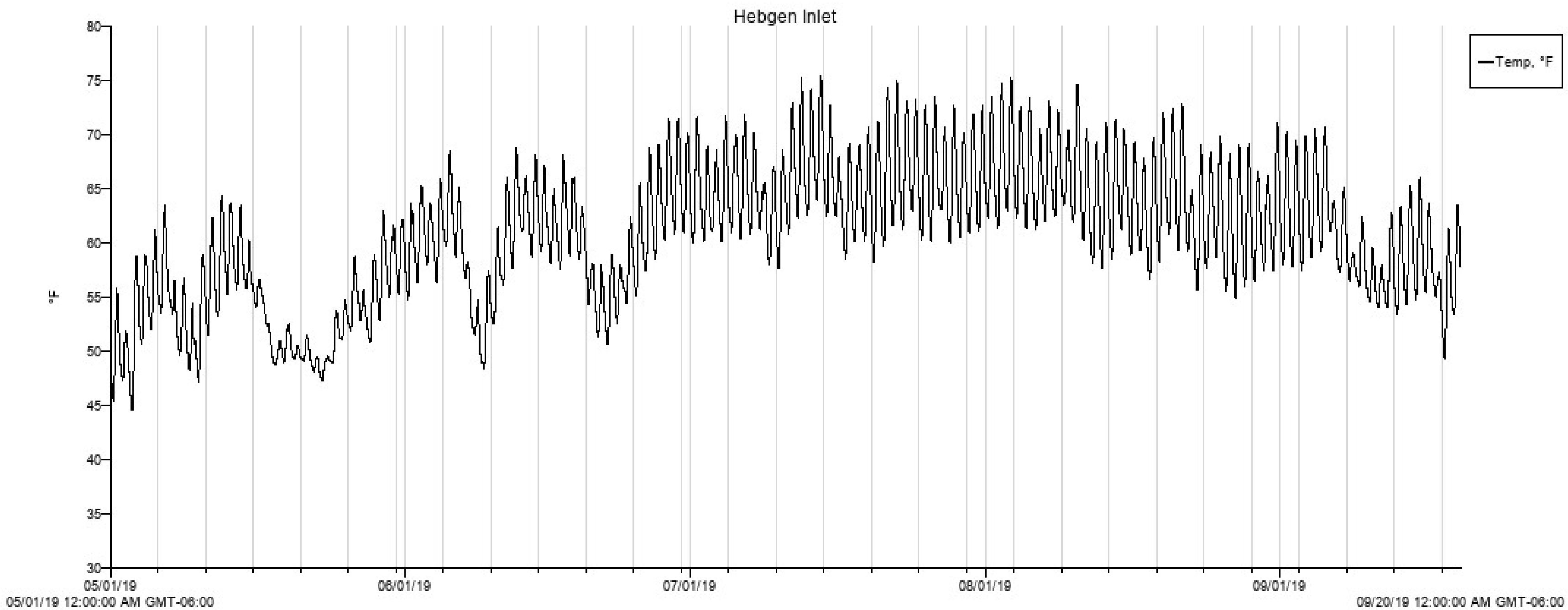
	Habitat Features	
Introduction Site	Beneficial	Potentially limiting
Odell Spring Creek-Granger Ranches	Back waters for rearing Stream margins with appropriate velocity for rearing Deep pools	Water velocity Spawning substrate size Brown Trout abundance Area of spawning substrate available Length of pools Sediment Lack of macrophytes
Odell Spring Creek-Longhorn Ranch	Pool length and depth Spawning substrate more abundant Deep pools	Water velocity Spawning substrate size Brown Trout abundance Area of spawning substrate available Sediment Lack of macrophytes
Blaine Spring Creek	Rearing habitat Spawning substrate size and quantity Macrophytes	Pools with depth Brown Trout abundance
Moore Creek	Well-developed pools with length and depth Spawning substrate of appropriate size and area Velocity Stream margins with appropriate velocity for rearing	Proximity to reservoir Sediment Few back waters for rearing

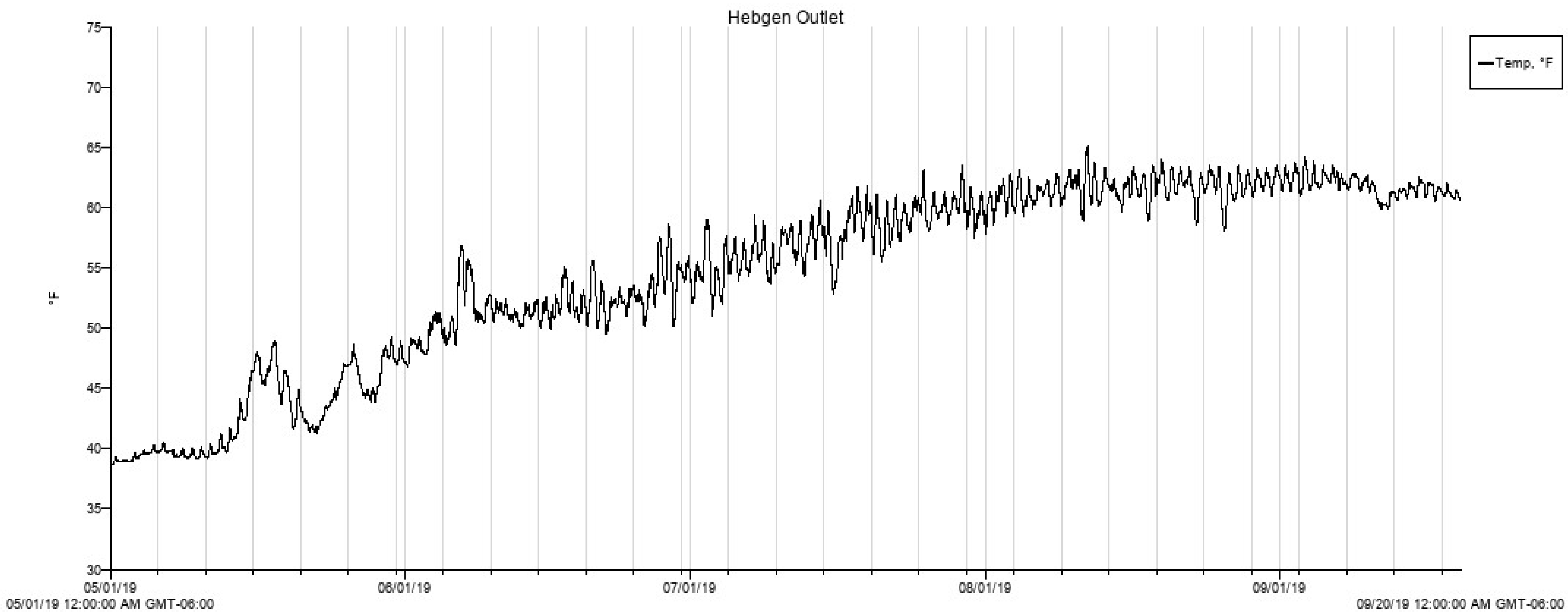
Table 11.-Arctic grayling introductions number of eggs at each introduction site and year, and if any were recovered or reported.

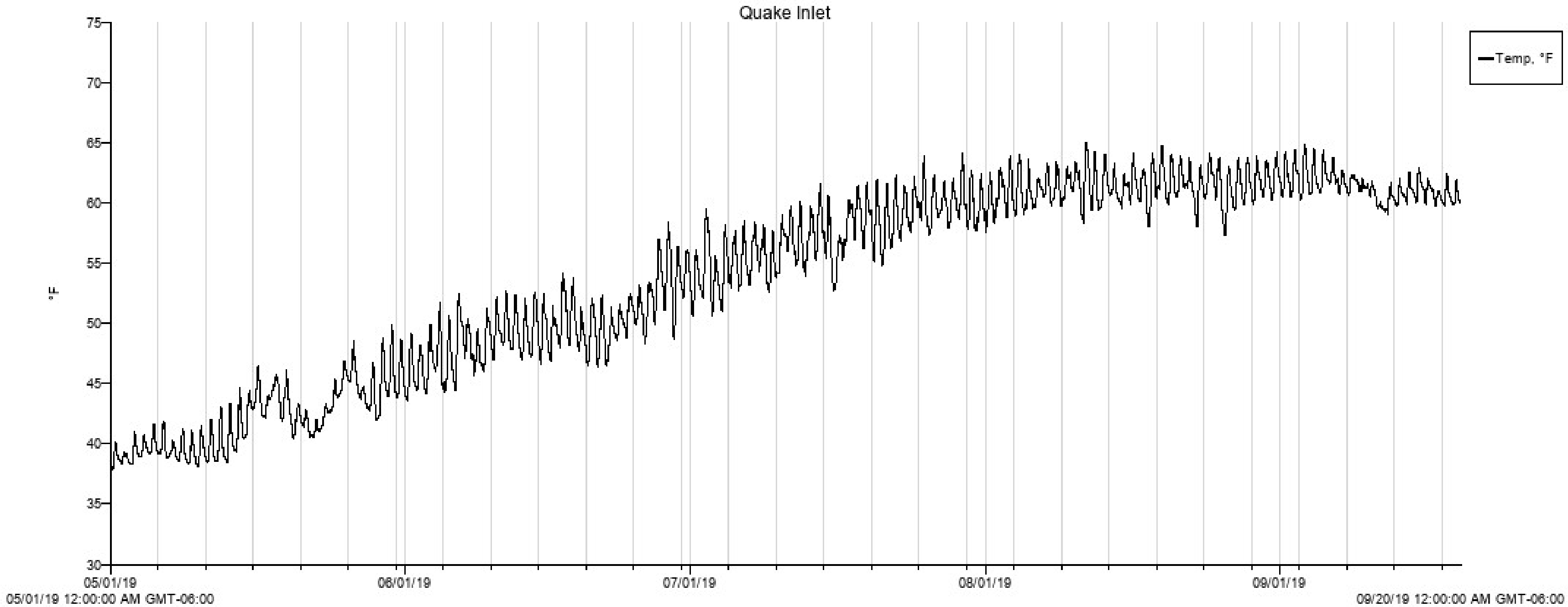
				Year				
Introduction site	2014	2015	2016	2017	2018	2019	Sub total	Grayling recovered/reported
Odell Spring Creek Granger Ranches		36,000		32,000	60,000	15,000	143,000	None
Odell Spring Creek Longhorn Ranch						45,000	45,000	None
Blaine Spring Creek Granger Ranches		15,000	5,000	1,000	42,000	10,000	73,000	Angler report 2 AG at 8-mile FA 2017, Angler report 1 AG at Burnt Tree Hole FA 2019
Moore Creek Valley Garden Ranch		5,000	5,000	20,000			30,000	Two juvenile AG recovered in 2015 angler report AG in Fletcher Channel 2016
West Fork Madison Upper	1,200							None
West Fork Madison Middle	10,000	30,000	5,000				45,000	One young of the year recovered 2015 sampling
Lake Creek		13,000	27,000	5,000			45,000	None
Denny Creek				5,000	2,000		7,000	None

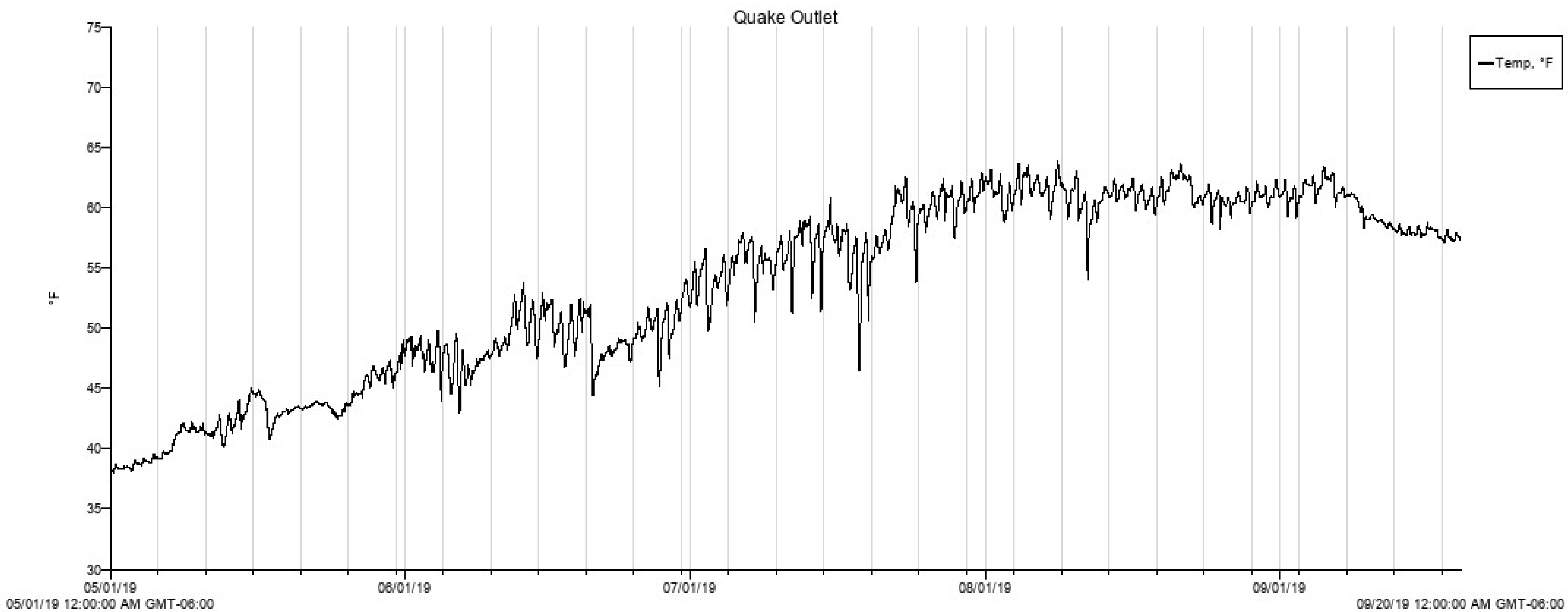
Appendix A1

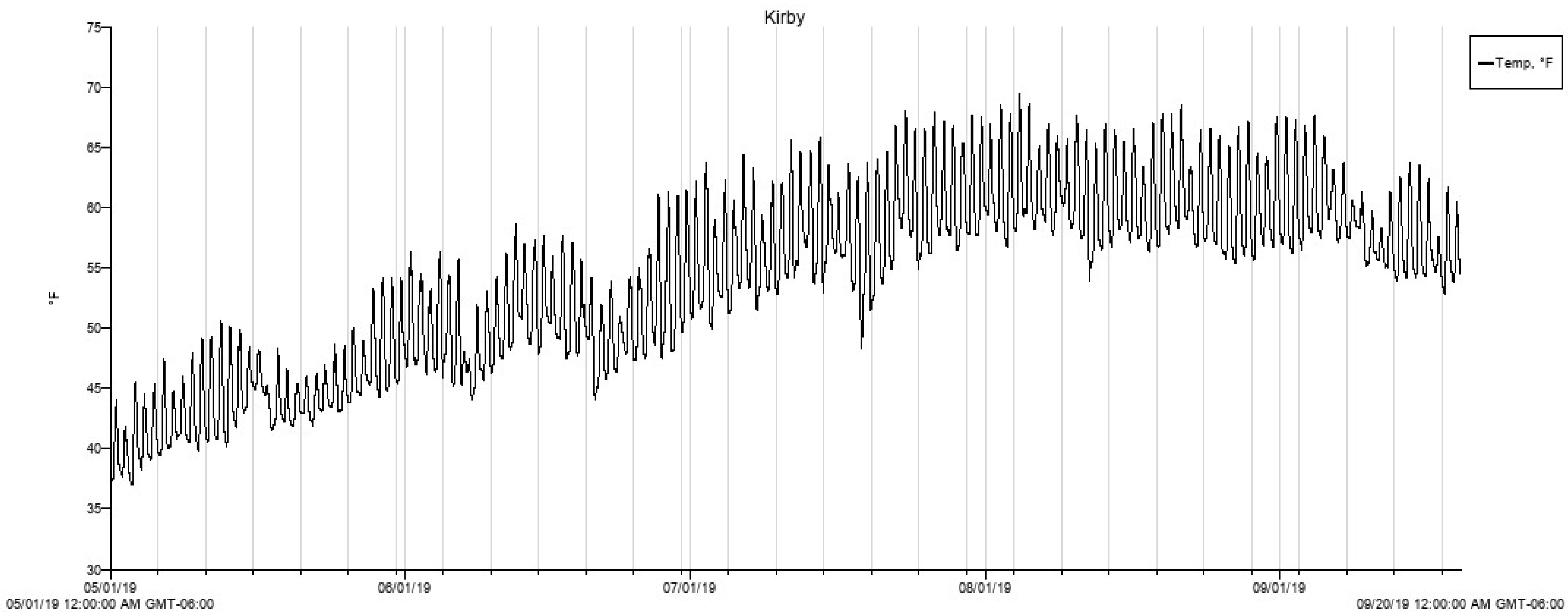
Temperature recordings from Madison River monitoring sites
2019
See Figure 11 for locations

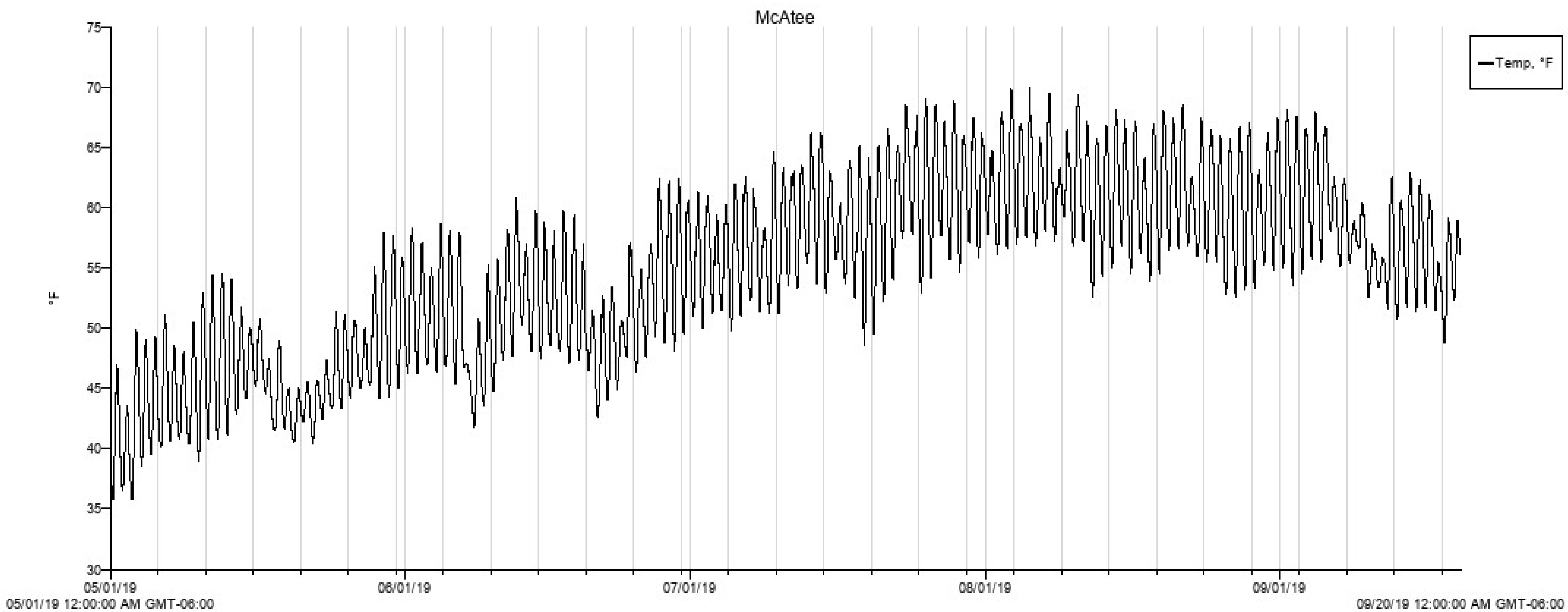


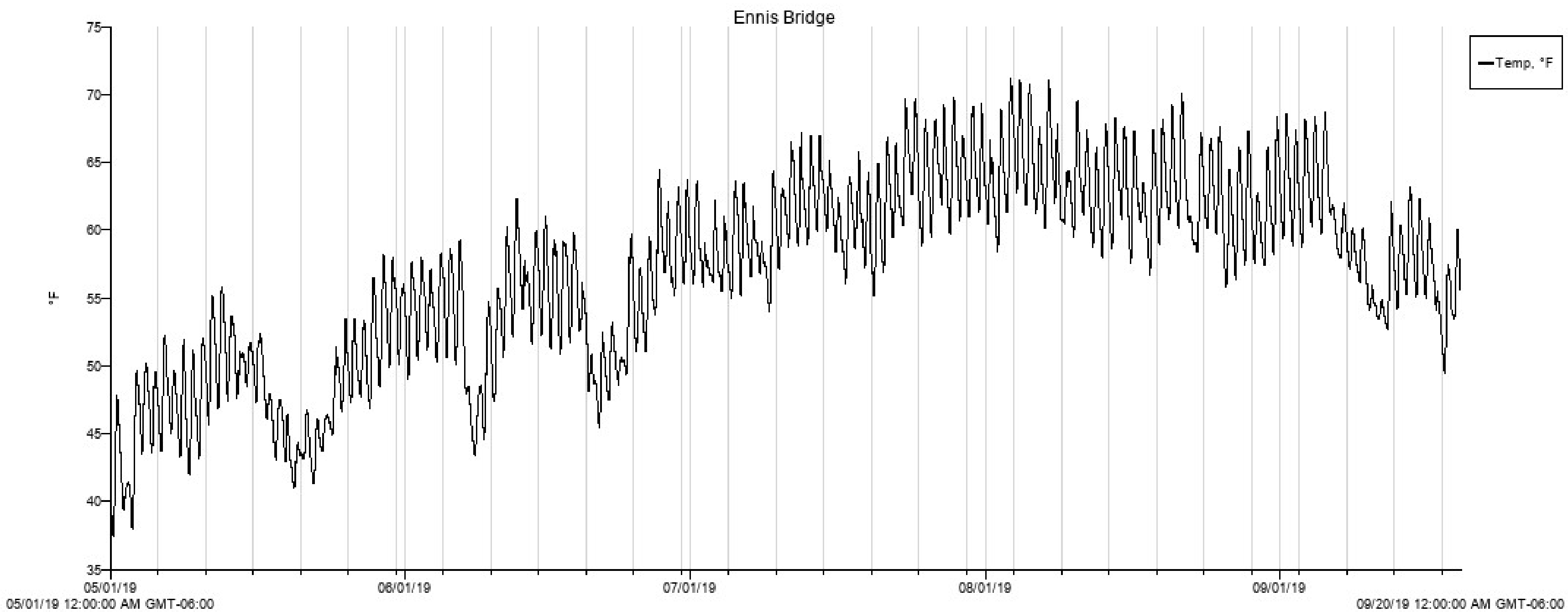

Hebgen Outlet
Temp, °F
°F
75
70
65
60
55
50
45
40
35
30
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00

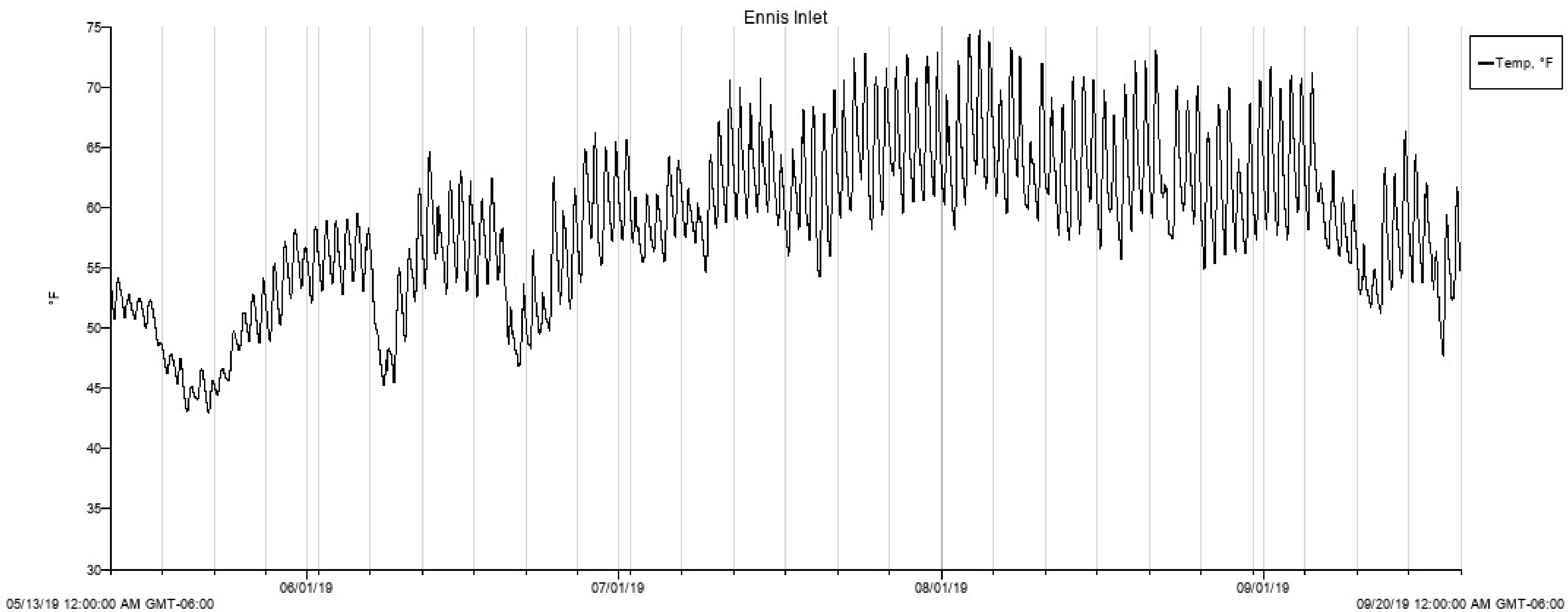

Quake Inlet
—Temp, °F
°F
75
70
65
60
55
50
45
40
35
30
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00

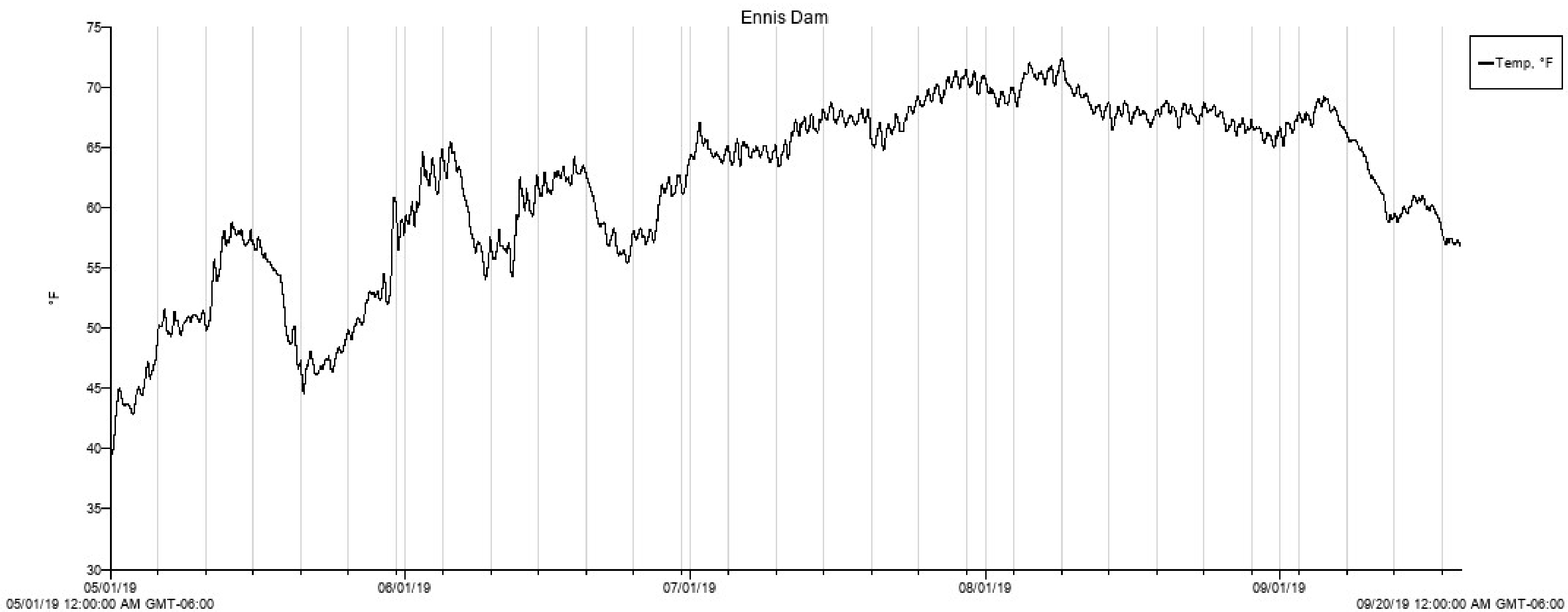

Quake Outlet
Temp, °F
°F
75
70
65
60
55
50
45
40
35
30
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00

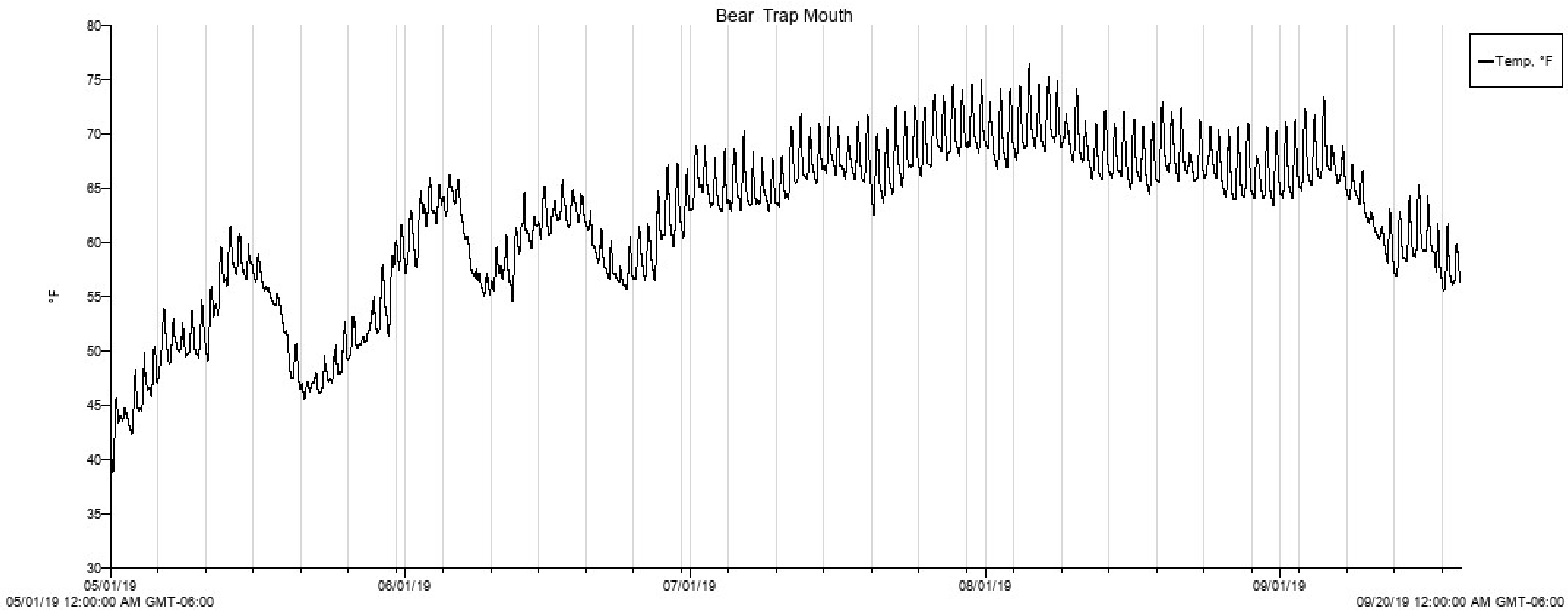

Kirby
Temp, °F
°F
75
70
65
60
55
50
45
40
35
30
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00

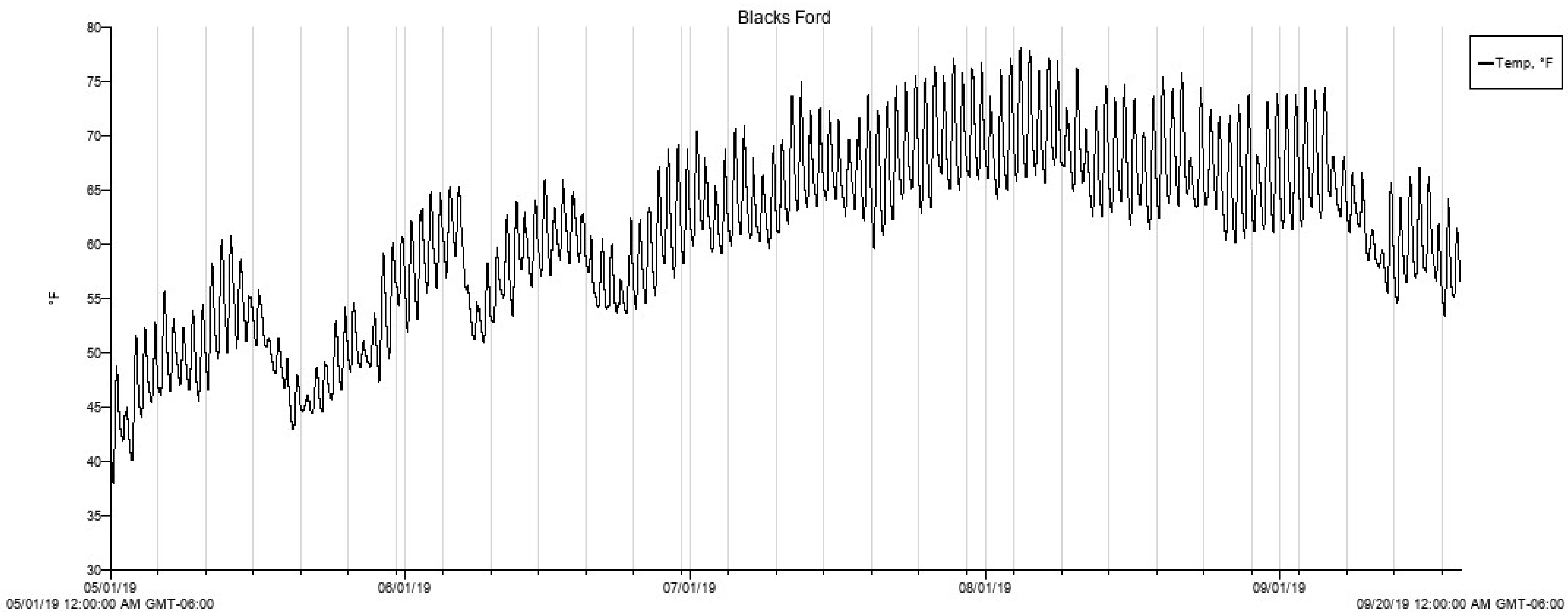

McAtee
Temp, °F
°F
75
70
65
60
55
50
45
40
35
30
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00


Ennis Bridge
Temp, °F
°F
75
70
65
60
55
50
45
40
35
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00

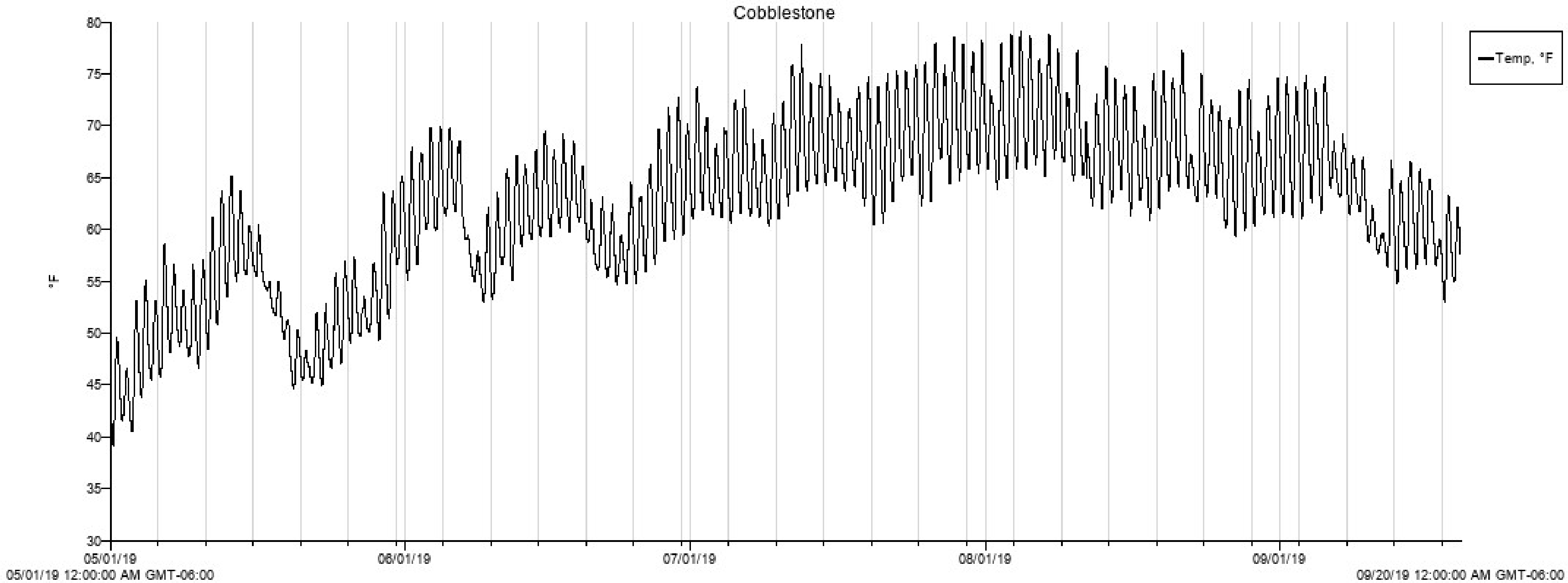

Ennis Inlet
Temp, °F
°F
75
70
65
60
55
50
45
40
35
30
05/13/19 12:00:00 AM GMT-06:00
06/01/19
07/01/19
08/01/19
09/01/19
09/20/19 12:00:00 AM GMT-06:00


Ennis Dam
Temp, °F
°F
75
70
65
60
55
50
45
40
35
30
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00


Bear Trap Mouth
Temp, °F
°F
80
75
70
65
60
55
50
45
40
35
30
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00



Blacks Ford
Temp, °F
°F
80
75
70
65
60
55
50
45
40
35
30
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00


Cobblestone
Temp, °F
°F
80
75
70
65
60
55
50
45
40
35
30
05/01/19
06/01/19
07/01/19
08/01/19
09/01/19
05/01/19 12:00:00 AM GMT-06:00
09/20/19 12:00:00 AM GMT-06:00

Appendix A2

Comparison of maximum annual water temperatures at selected Madison River monitoring sites

1997 - 2019

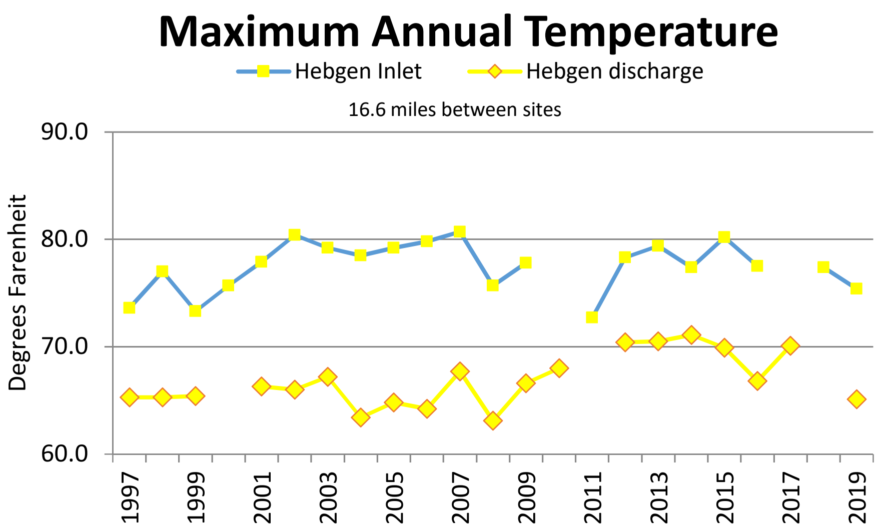
See Figure 11 for locations

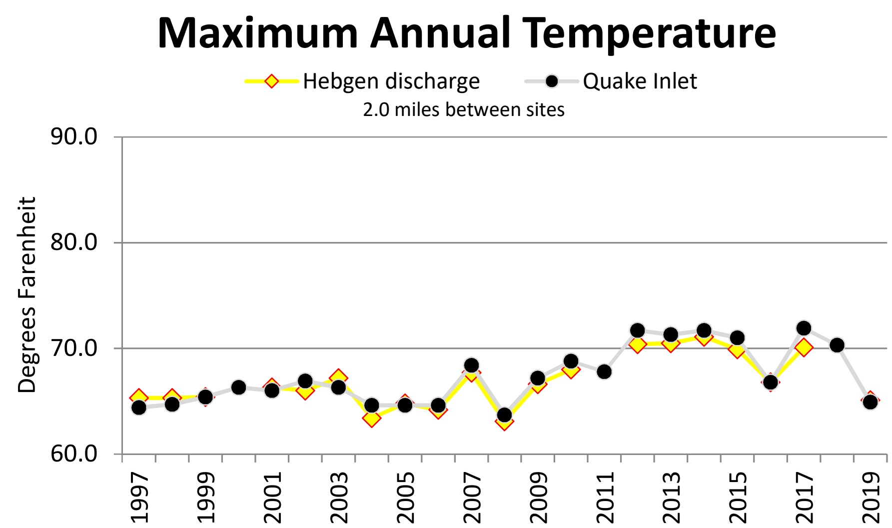
NOTES:

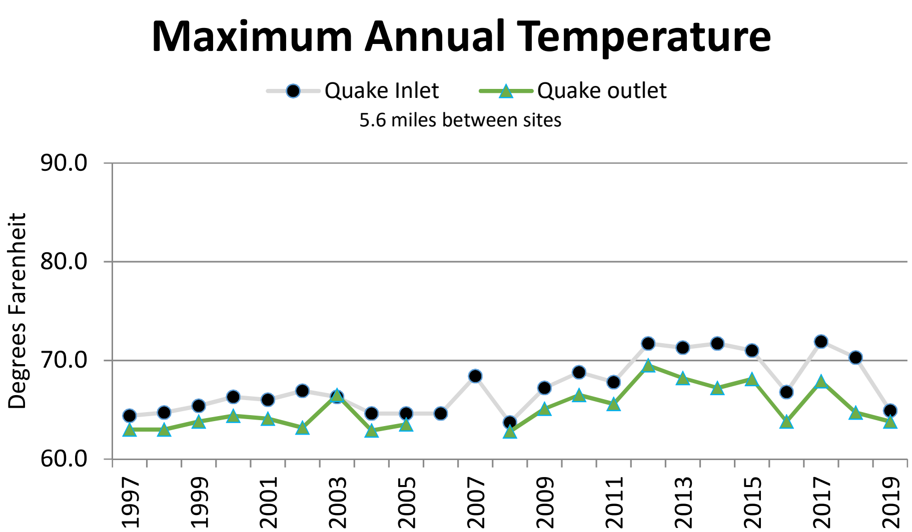
- Recorders at some locations were not recovered some years

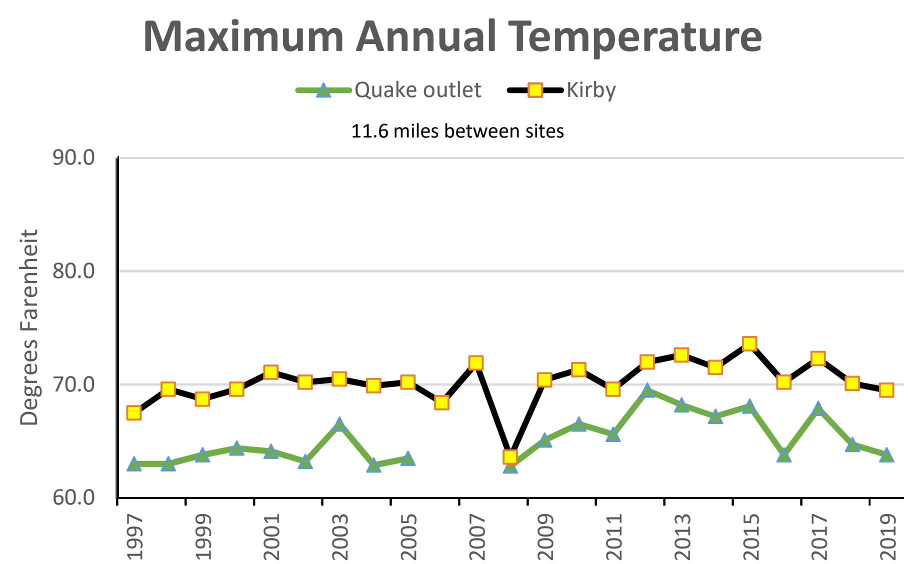
- It is important to note that the maximum temperatures at each site throughout the river did not all occur on the same day in any year, and that the maximum temperature at any given site may have been attained on more than just one day in a year

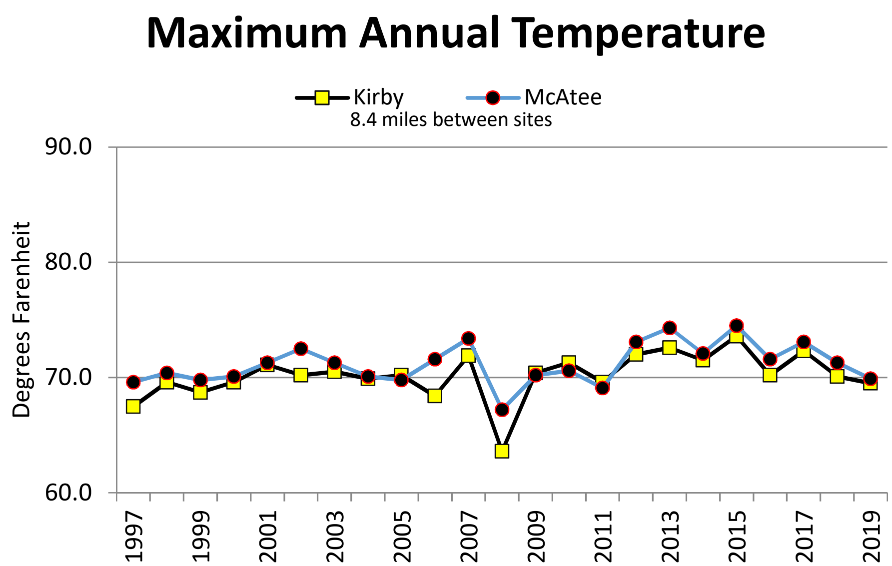
- Pulse flows were conducted out of Ennis Reservoir annually from 2000 – 2007, in 2009, and 2013 - 2019.

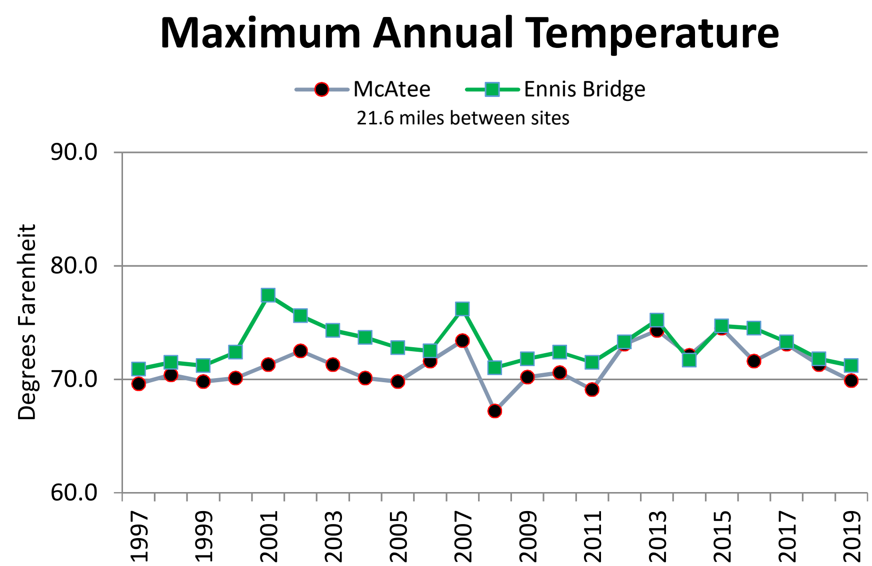

Maximum Annual Temperature
Hebgen Inlet
Hebgen discharge
16.6 miles between sites
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

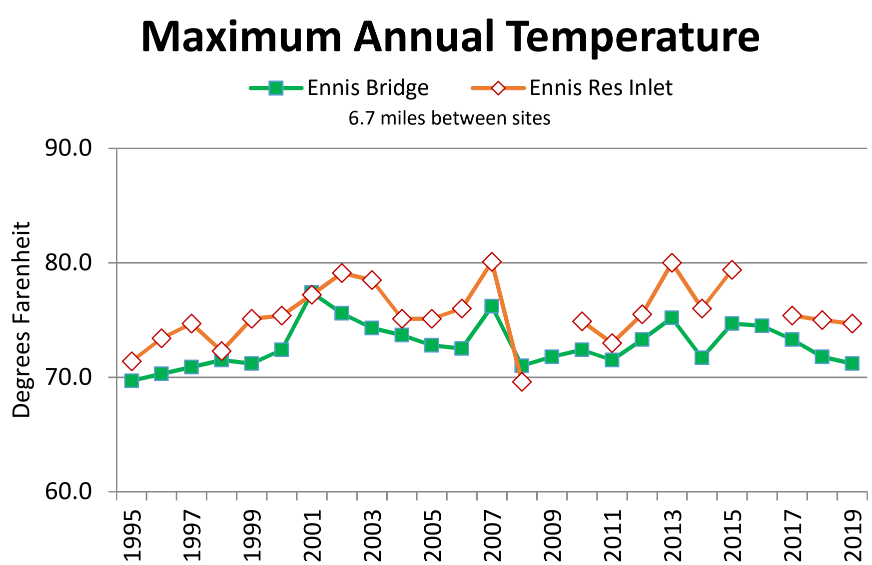

Maximum Annual Temperature
Hebgen discharge
Quake Inlet
2.0 miles between sites
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

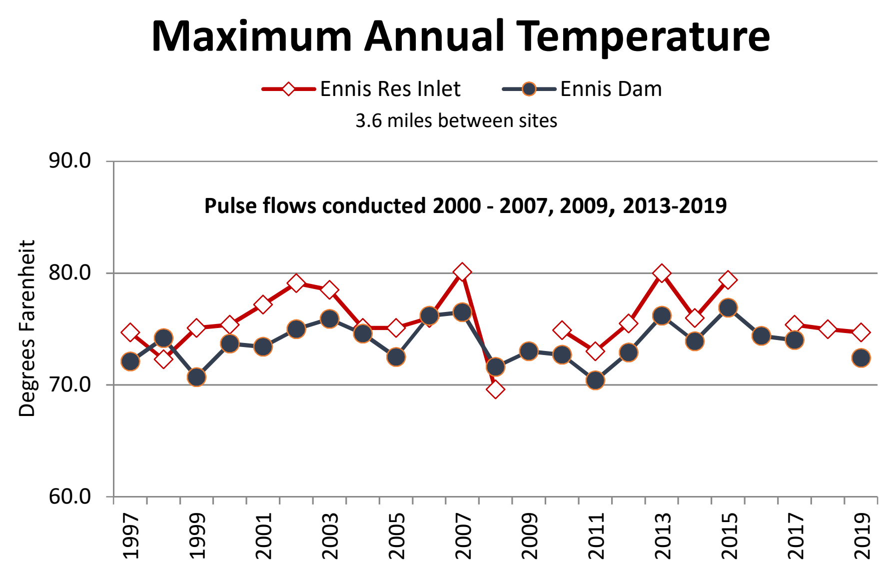

Maximum Annual Temperature
Quake Inlet
Quake outlet
5.6 miles between sites
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

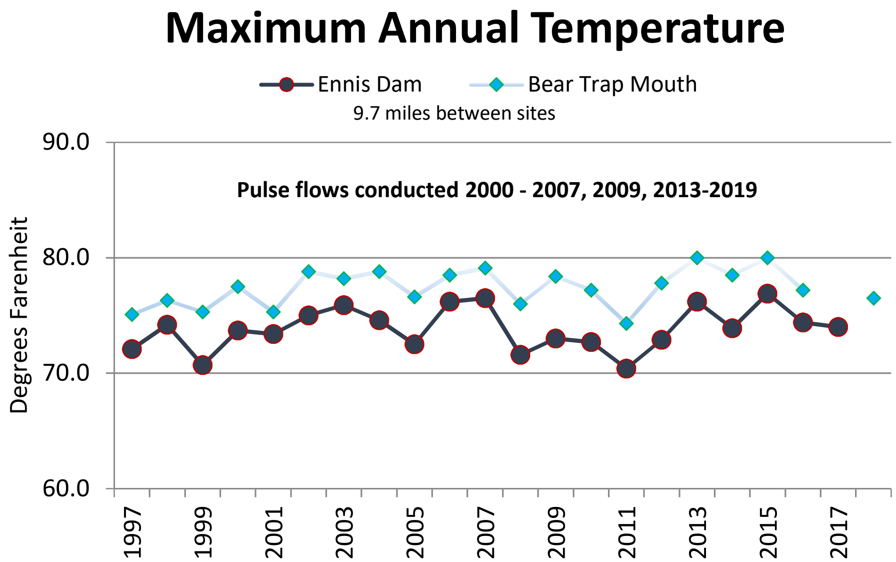

Maximum Annual Temperature
Quake outlet
Kirby
11.6 miles between sites
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

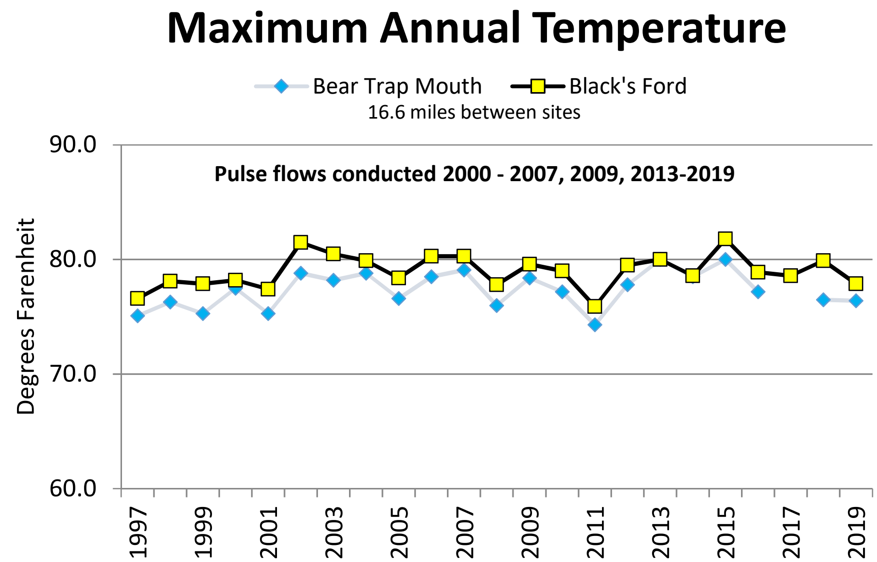

Maximum Annual Temperature
Kirby
McAtee
8.4 miles between sites
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

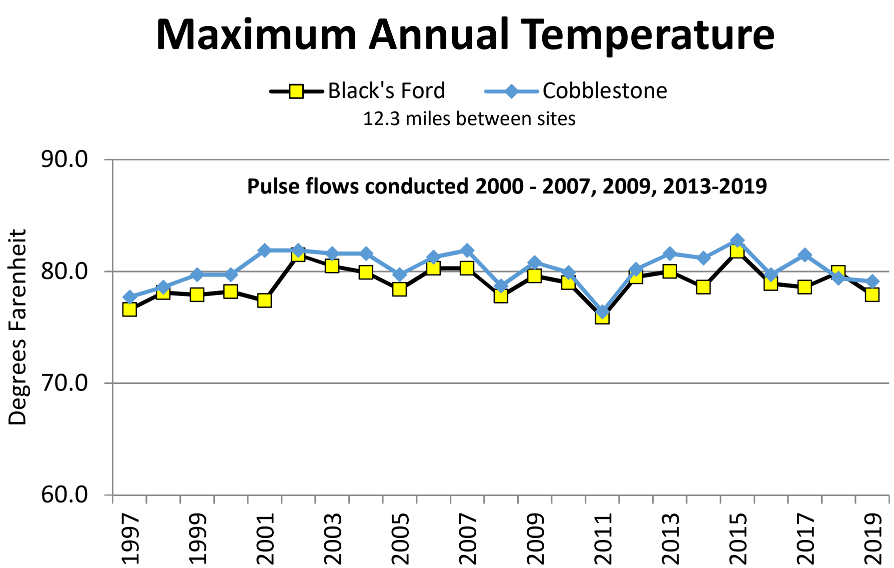

Maximum Annual Temperature
McAtee
Ennis Bridge
21.6 miles between sites
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

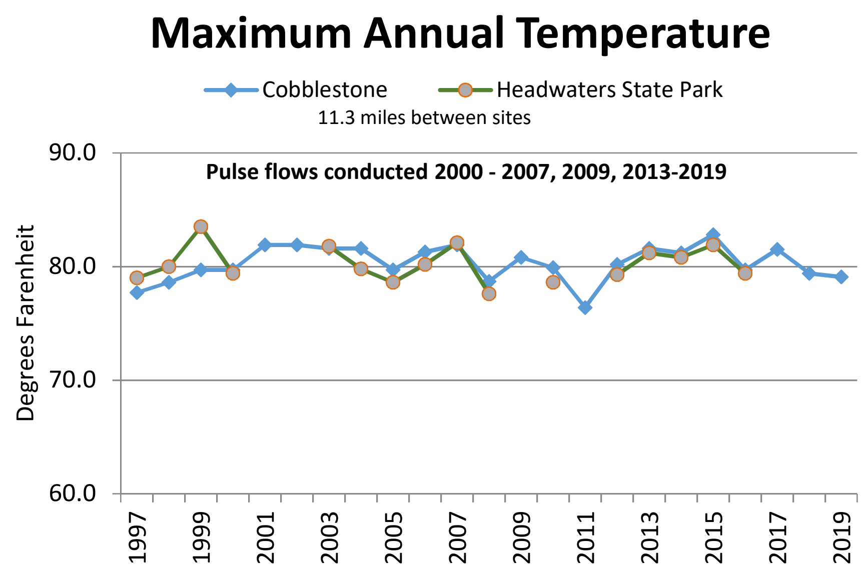

Maximum Annual Temperature
Ennis Bridge
Ennis Res Inlet
6.7 miles between sites
Degrees Farenheit
90.0
80.0
70.0
60.0
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

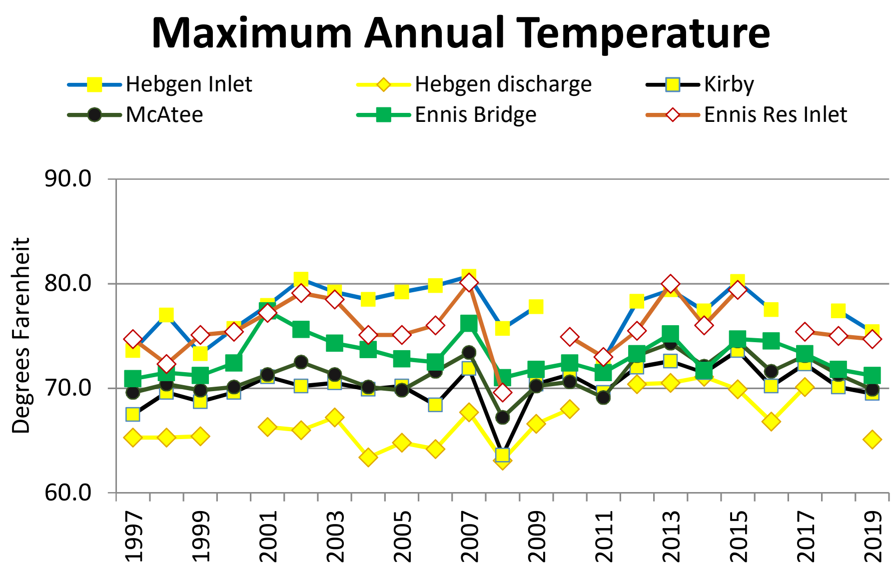

Maximum Annual Temperature
Ennis Res Inlet
Ennis Dam
3.6 miles between sites
Pulse flows conducted 2000 - 2007, 2009, 2013-2019
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

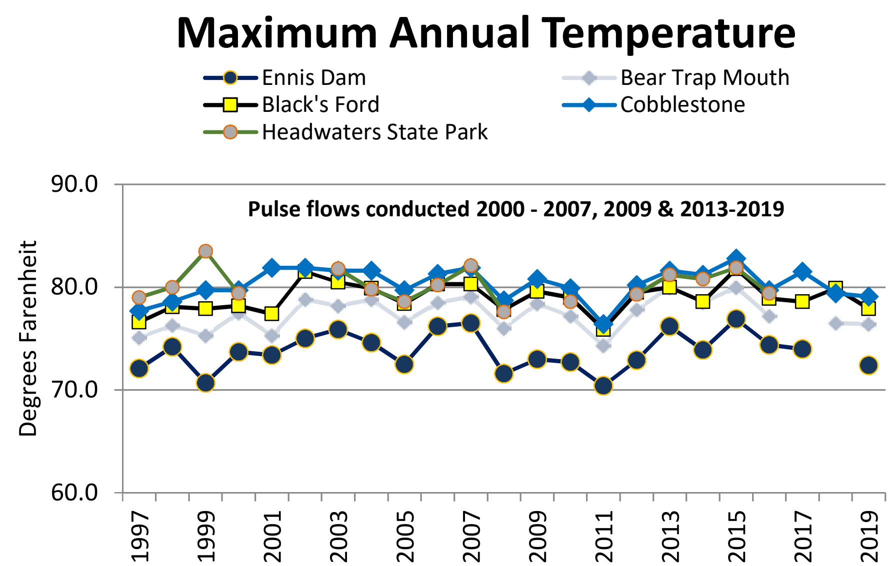

Maximum Annual Temperature
Ennis Dam
Bear Trap Mouth
9.7 miles between sites
Pulse flows conducted 2000 - 2007, 2009, 2013-2019
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017


Maximum Annual Temperature
Bear Trap Mouth
Black's Ford
16.6 miles between sites
Pulse flows conducted 2000 - 2007, 2009, 2013-2019
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019


Maximum Annual Temperature
Black's Ford
Cobblestone
12.3 miles between sites
Pulse flows conducted 2000 - 2007, 2009, 2013-2019
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019


Maximum Annual Temperature
Cobblestone
Headwaters State Park
11.3 miles between sites
Pulse flows conducted 2000 - 2007, 2009, 2013-2019
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019


Maximum Annual Temperature
Hebgen Inlet
Hebgen discharge
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019


Maximum Annual Temperature
Ennis Dam
Bear Trap Mouth
Black's Ford
Cobblestone
Headwaters State Park
Pulse flows conducted 2000 - 2007, 2009 & 2013-2019
Degrees Farenheit
90.0
80.0
70.0
60.0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

Appendix A3

Maximum annual water temperatures recorded at Madison River monitoring sites

1997 - 2019

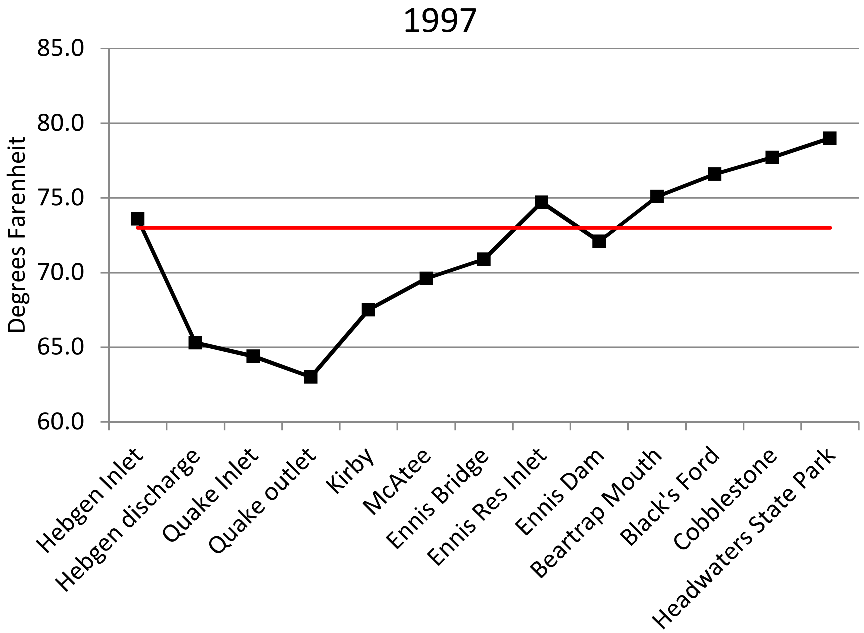
See Figure 11 for locations

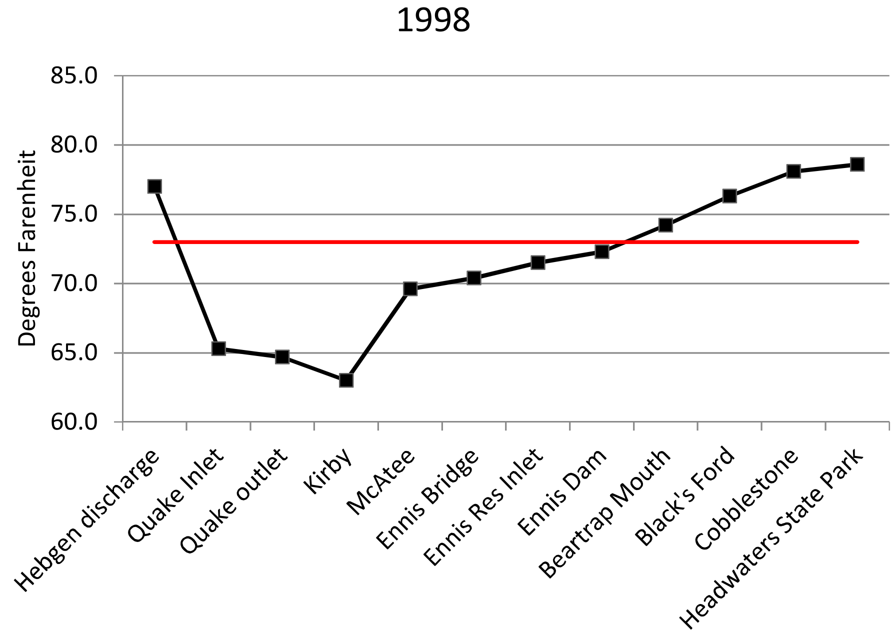
NOTES:

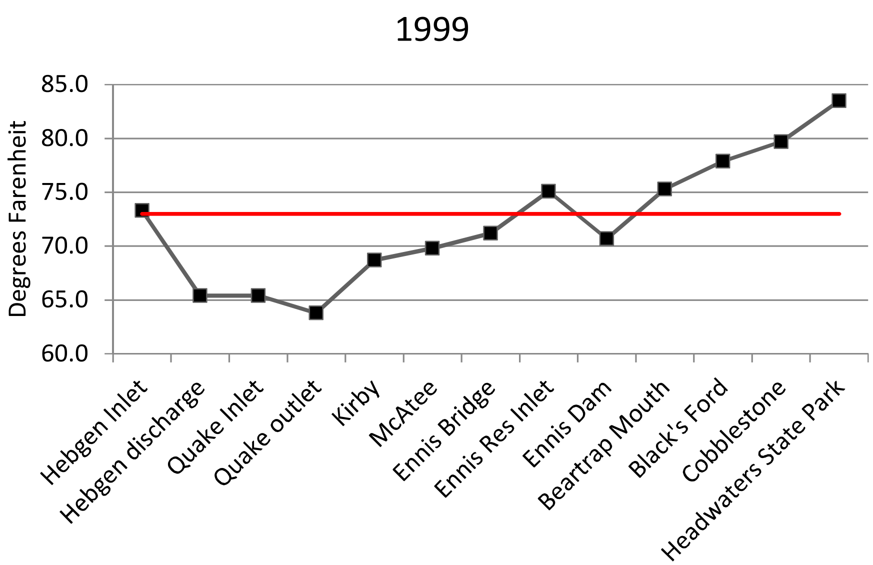
- Recorders at some locations were not recovered some years

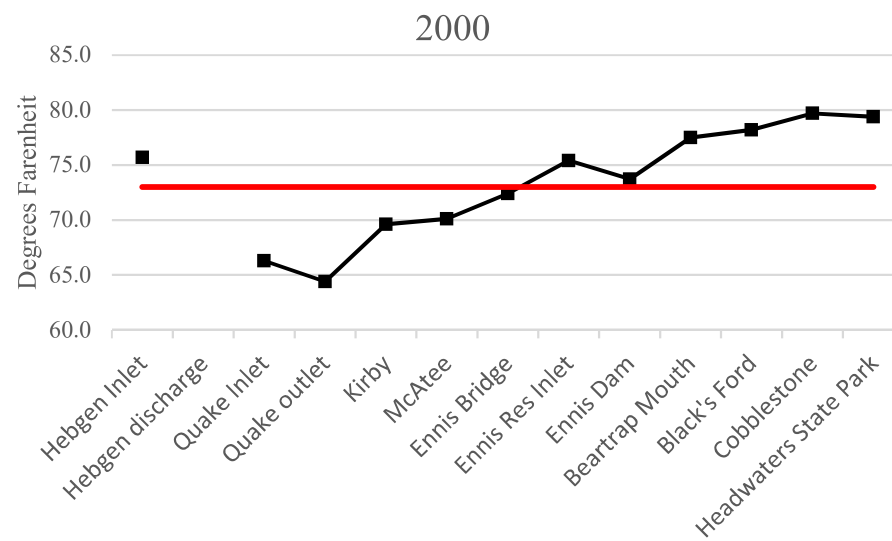
- It is important to note that the maximum temperatures at each site throughout the river did not all occur on the same day in any year, and that the maximum temperature at any given site may have been attained on more than just one day in a year.

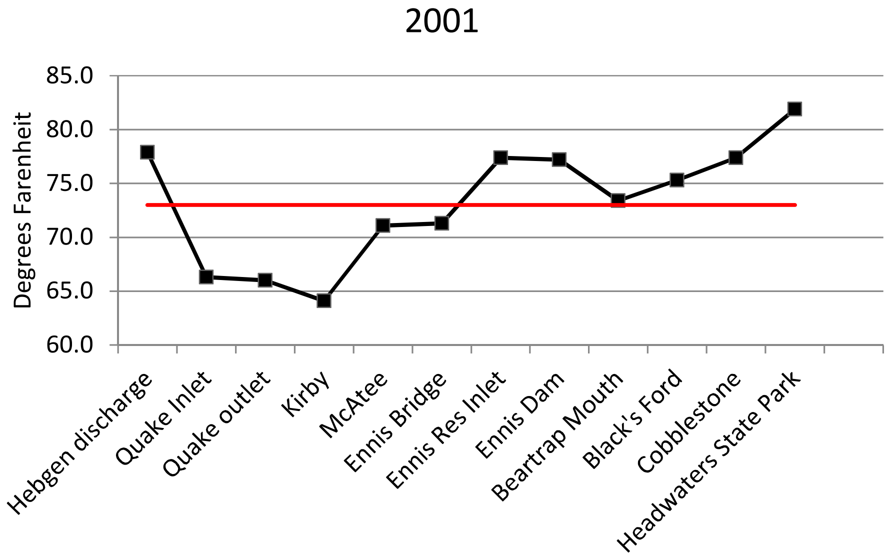
- Red lines show 73◦

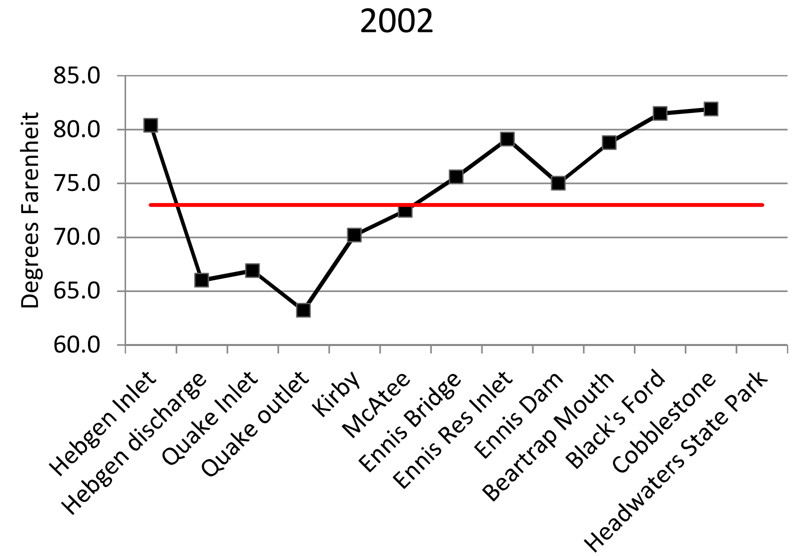

1997
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

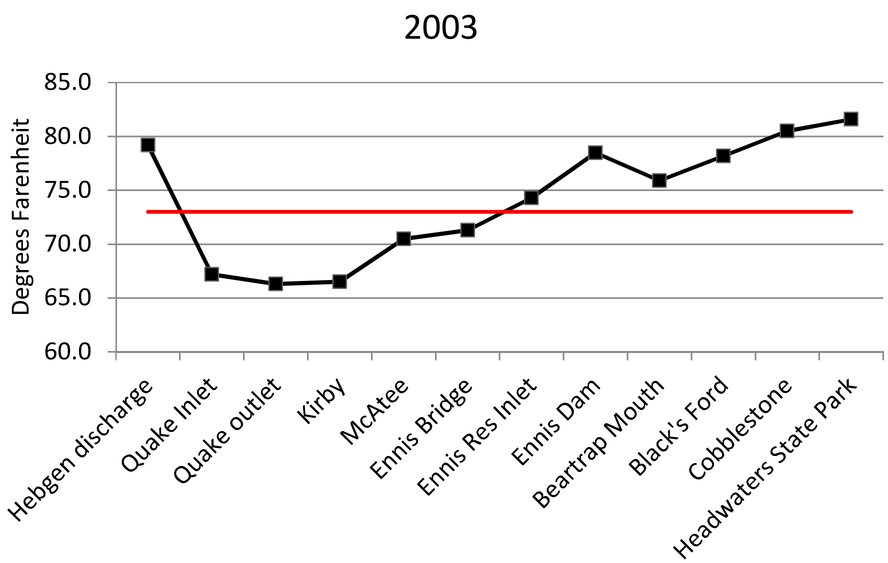

1998
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

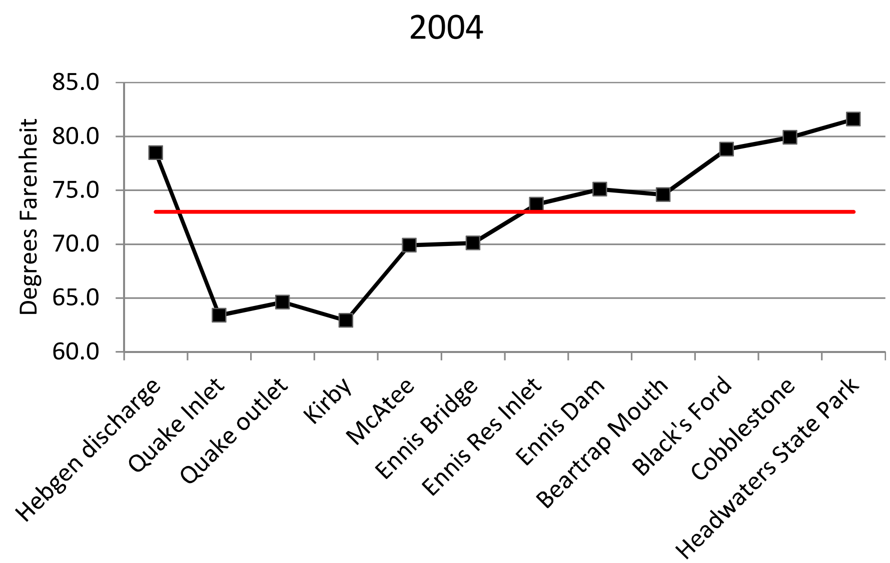

1999
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

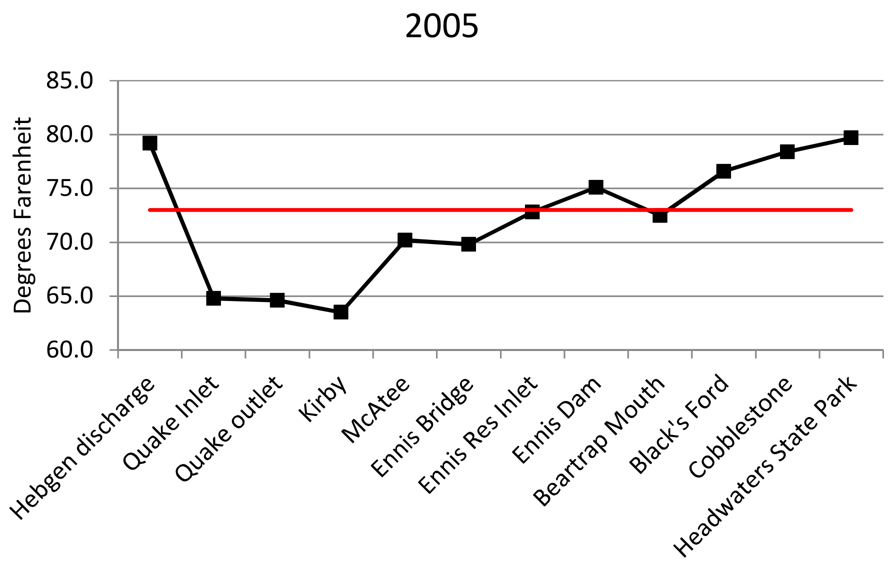

2000
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

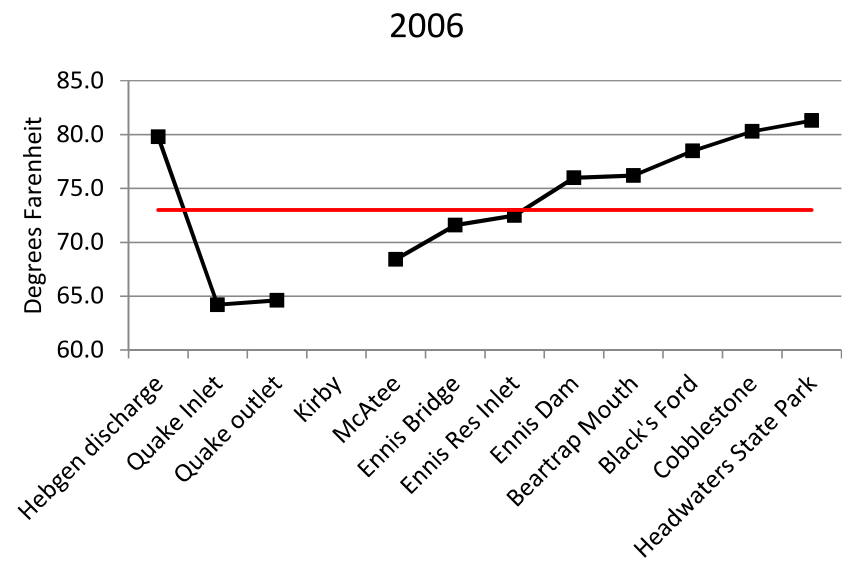

2001
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

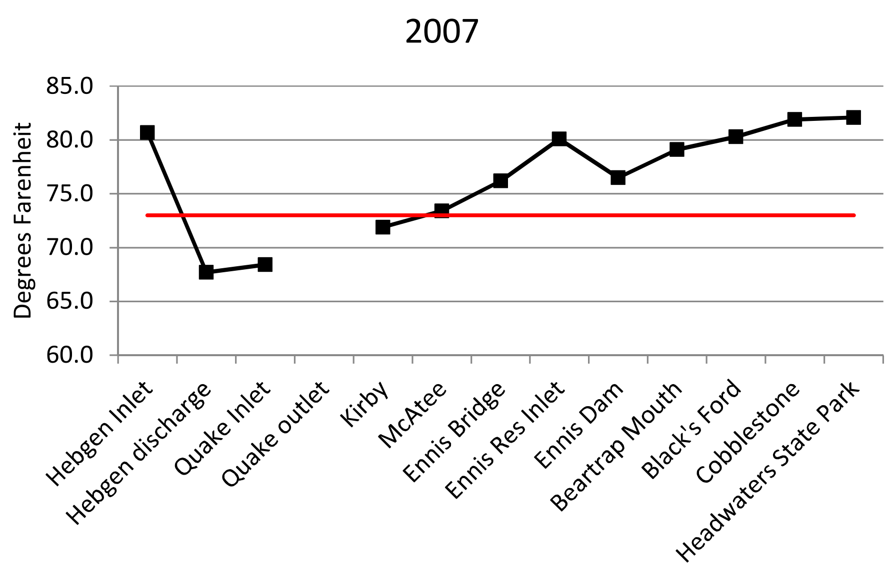

2002
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

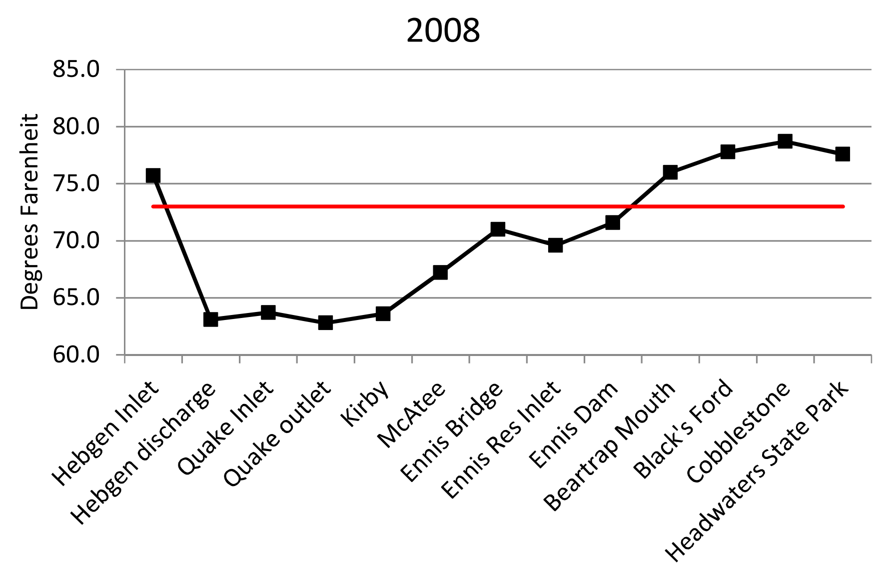

2003
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

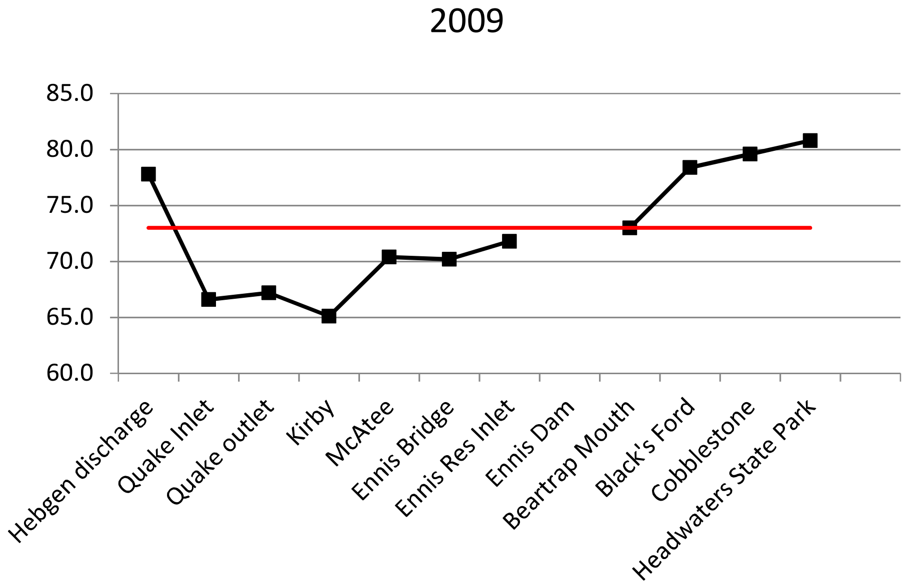

2004
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

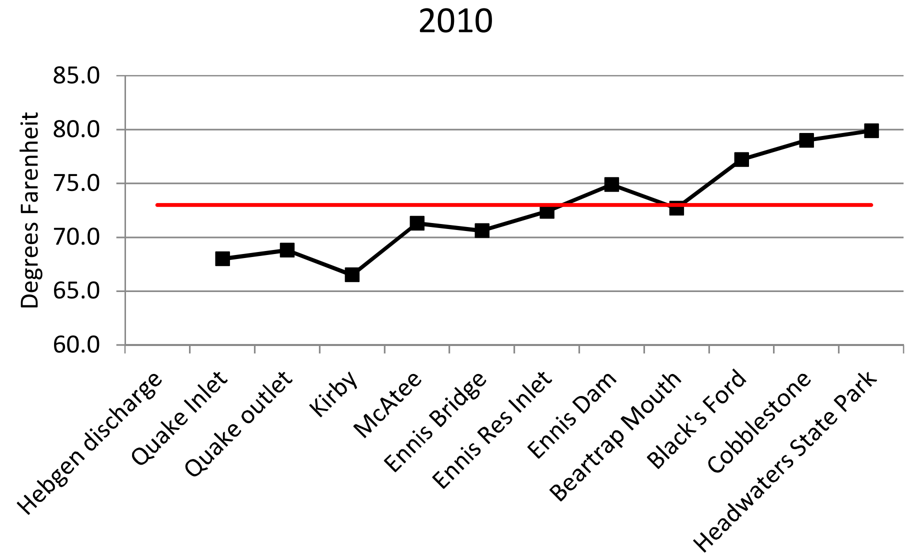

2005
85.0
80.0
75.0
70.0
65.0
60.0
Degrees Farenheit
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

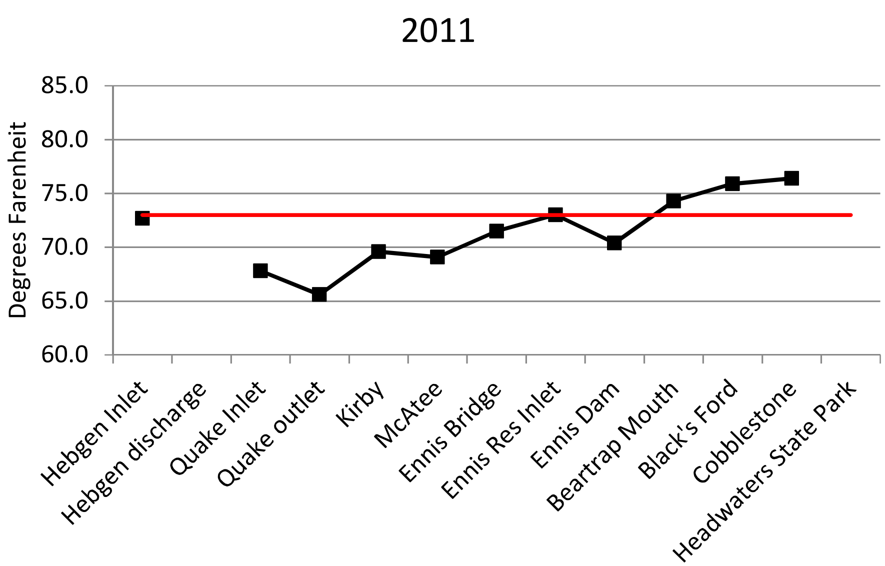

2006
85.0
80.0
75.0
70.0
65.0
60.0
Degrees Farenheit
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

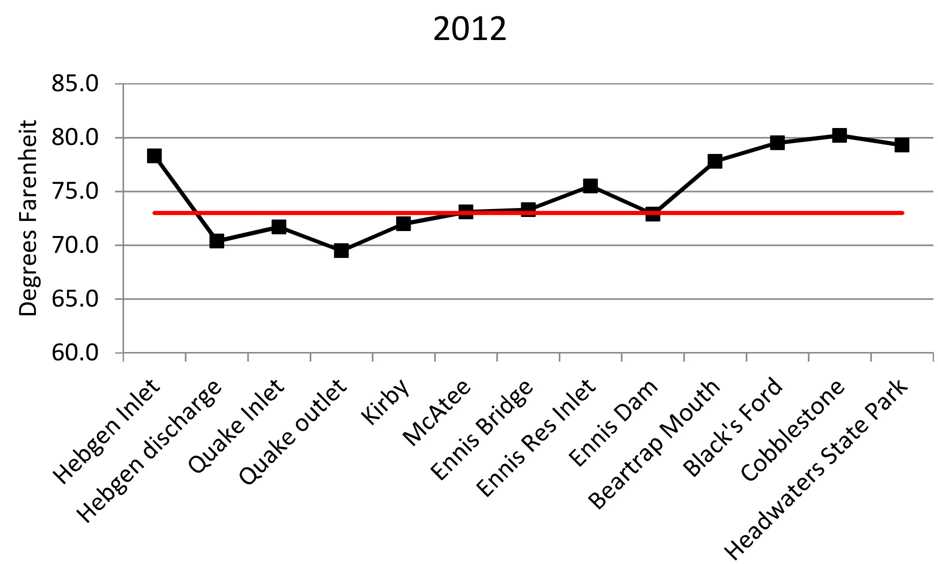

2007
85.0
80.0
75.0
70.0
65.0
60.0
Degrees Farenheit
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

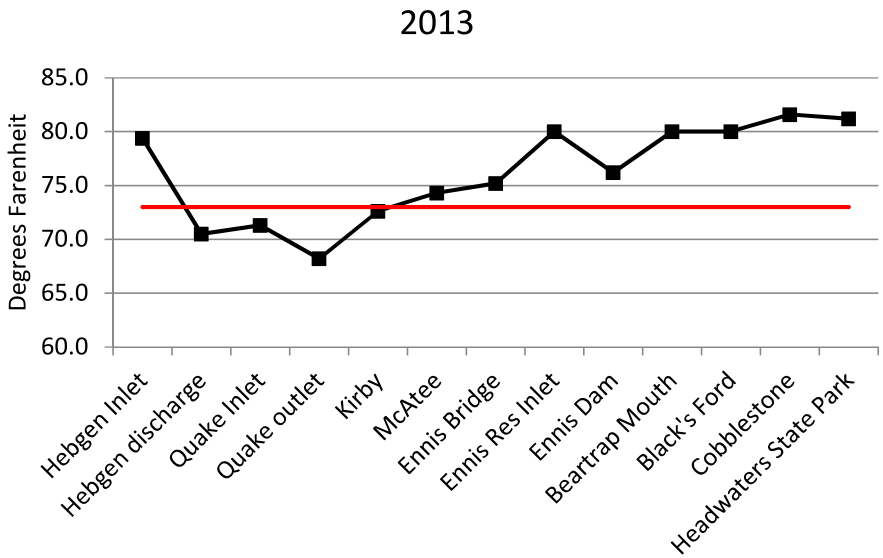

2008
85.0
80.0
75.0
70.0
65.0
60.0
Degrees Farenheit
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

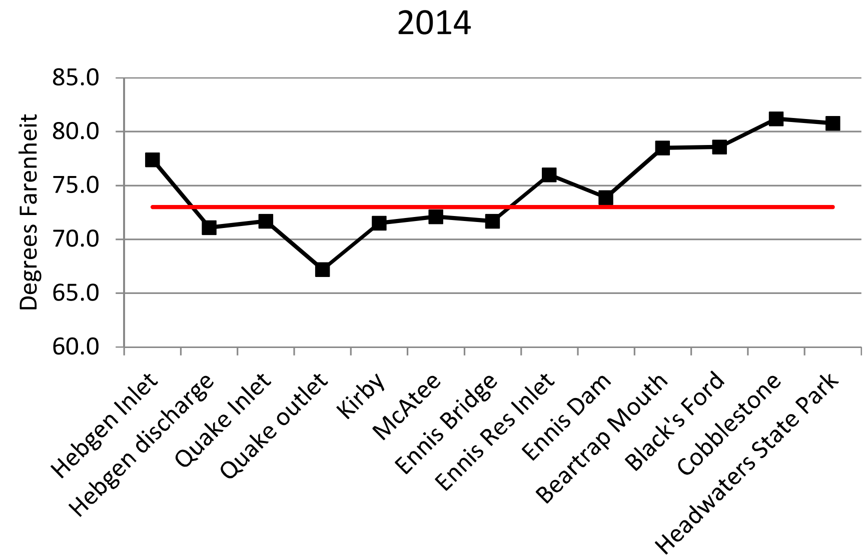

2009
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

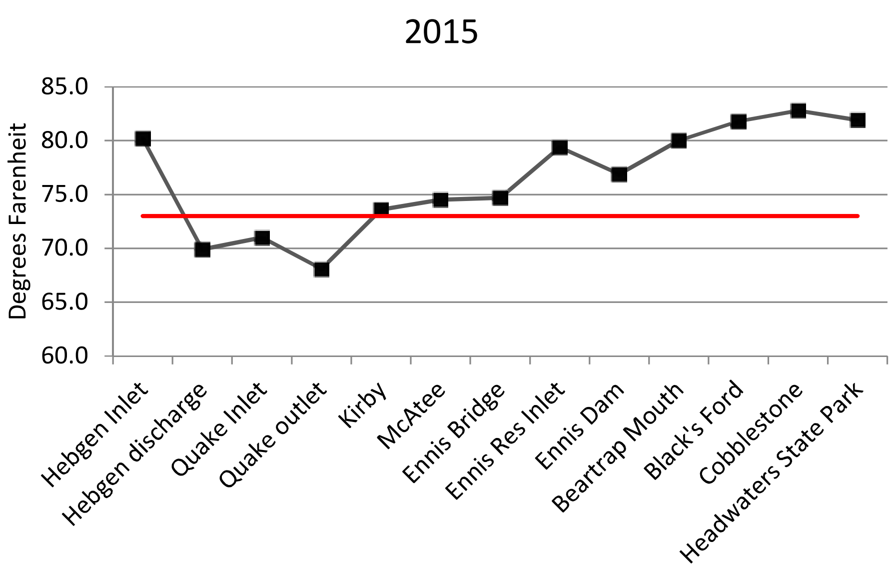

2010
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

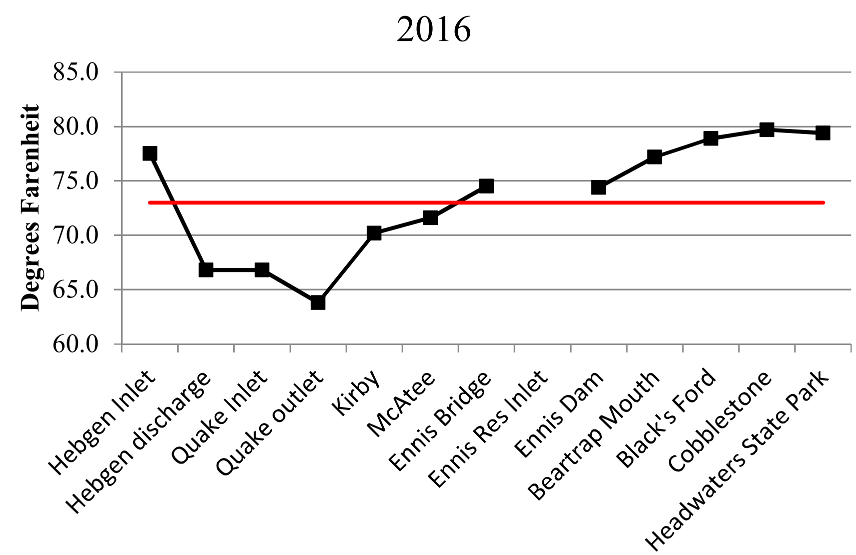

2011
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

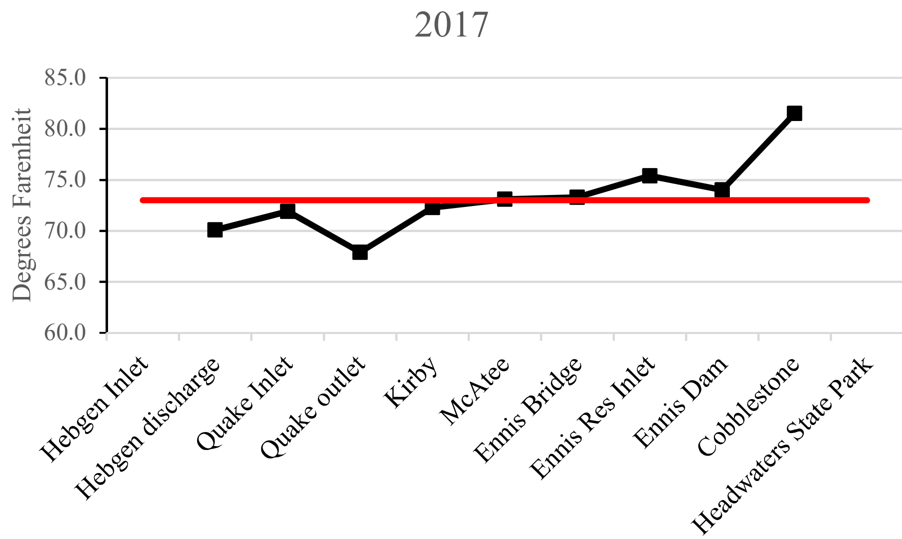

2012
Degrees Farenheit
85.0
80.0
75.0
70.0
65.0
60.0
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

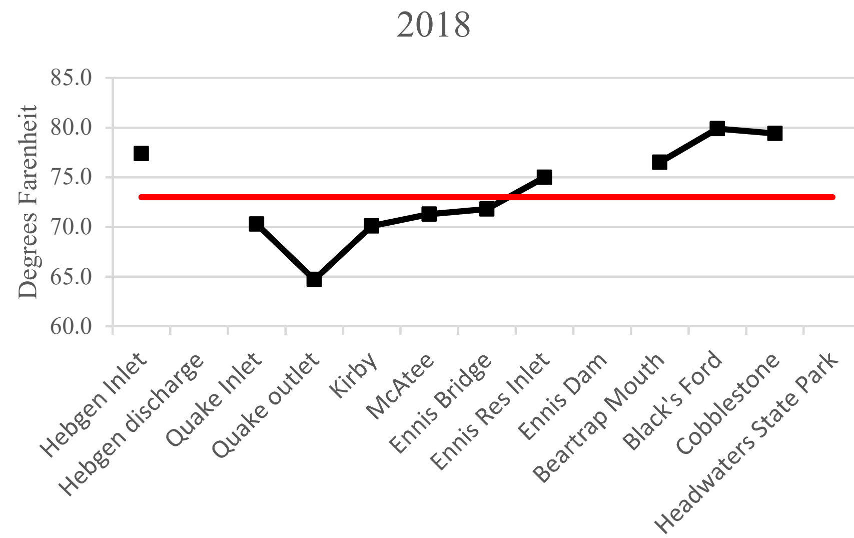

2013
85.0
80.0
75.0
70.0
65.0
60.0
Degrees Farenheit
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park

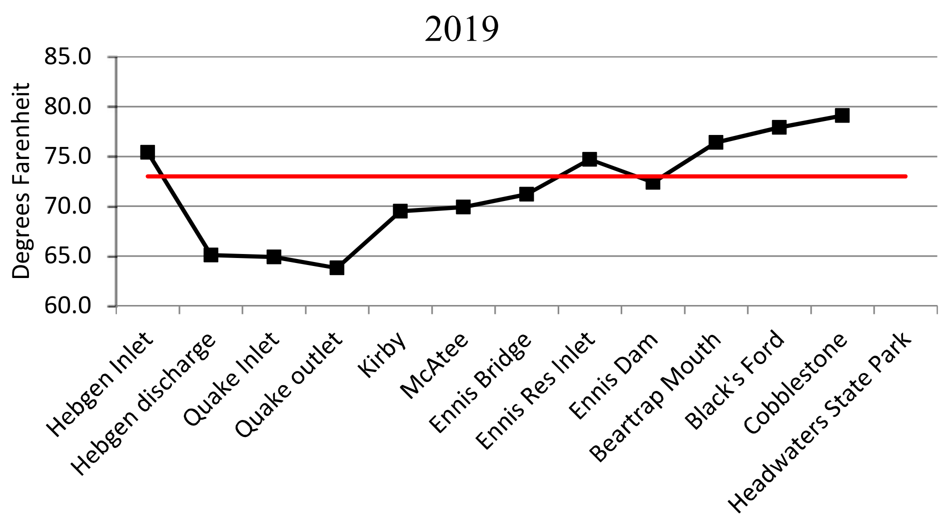

2014
85.0
80.0
75.0
70.0
65.0
60.0
Degrees Farenheit
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park


2015
85.0
80.0
75.0
70.0
65.0
60.0
Degrees Farenheit
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park


2016
85.0
80.0
75.0
70.0
65.0
60.0
Degrees Farenheit
Hebgen Inlet
Hebgen discharge
Quake Inlet
Quake outlet
Kirby
McAtee
Ennis Bridge
Ennis Res Inlet
Ennis Dam
Beartrap Mouth
Black's Ford
Cobblestone
Headwaters State Park







Appendix A3- Figures-Maximum water temperatures at Madison River monitoring sites 1997-2019.

Appendix A4

Project Title: **Beaverhead-Deerlodge National Forest, Madison Ranger District Seasonal Technicians and WF Madison Stream Restoration Project Report 2019**
Report by: **Darin Watschke**

The following work enhanced/supported PM&E measure(s) 408, 409, and 412 in the Project 2188 License.

Location of Projects: **Madison and Ruby River drainages**
The Madison River Fisheries Technical Advisory Committee provided $9,000 to the Madison Ranger District, Beaverhead-Deerlodge National Forest to help fund a fisheries technician during field season 2019. The technician worked a total of 128 days with 71 days funded by the USFS at a cost of about $10,000. Mad TAC dollars were used to fund 57 days ($7,800) of work on Madison River drainage projects and one Ruby River and one Gallatin River project (all listed below). Additionally, about $1,200 of Mad TAC funding was utilized to purchase supplies and field gear for the technicians. The following listed activities summarize the work performed by the technician in 2019.

- <u>Bear Creek Days: Education Outreach and Fish Dissection</u>: *2 days*
  Over 50 students were engaged with native species conservation, salmonid identification, and general fish biology and physiology.

- <u>Upper and Lower Sureshot Lakes</u>: *5 days*
  Conducted a thorough inventory of sensitive amphibians breeding sites at Upper and Lower Sureshot Lakes and connected ponds in the North Meadow Creek drainage over two days. The remaining 2 days were dedicated to brushing and clearing sections of the Sureshot Ditch (ditch repair was in 2016) and ongoing monitoring and headboard adjustments to maintain water levels in the lakes.

- <u>West Fork Madison Stream Habitat Restoration</u>: *16 days*
  Worked with biologist and Madison River foundation employees to plant over 200 willow slips in overburdened area in upper WF Madison River riparian enclosure on National Forest.

  Surveyed aquatic habitat and fish distribution in the headwaters of the WF Madison River drainage prior to large wood placement for pool habitat restoration. Part of this evaluation included a day of electrofishing in a one mile section downstream of the USFS Cabin, and a small section upstream to assess population size and distribution. The technician also identified pool construction locations and standing large wood that could later be incorporated into pool habitats. Over 10 pool habitats and other beneficial channel alterations were the successfully constructed with excavator and hand tools in ½ reach of the upper WF Madison River. (Please see restoration photos included on pages 3 – 6

- Crockett Lake/Doubtful Reservoir: 3 *days*
  On four separate occasions, surveys were conducted for Western Toad, Columbia Spotted Frog, and Tiger Salamander presence/absence, as well as in identified breeding sites. Habitat data was also collected on these visits to identify preferred breeding habitat and timing of breeding.

- Madison River: 3 days
  The technician assisted NW Energy, MT FWP and USFS to conduct annual sampling on the mainstem Madison River. Field work included sediment core, macroinvertebrate, and periphyton sampling. The technician also accompanied NW Energy staff to provide field assistance if needed during the Ennis Dam Leakage Test. In addition the technician participated in the Mad TAC biologist meeting.

- Hellroaring Creek: 2 day
  Conducted electrofishing presence/absence and population distribution surveys within the Hellroaring Creek drainage as part of the Strawberry-Cascade Sheep Allotment NEPA analysis data collection effort.

- Wigwam Creek BAER-Roads: 4 days
  Assisted with Burned Area Emergency Response activities in the Wigwam Creek drainage following the Wigwam Fire. Specific duties included riparian fence repair, culvert replacement and road repairs with the Madison County roads crew, and electrofishing presence/absence and population distribution surveys within the riparian enclosure area.

- Spanish Creek/Big Brother Lake Poisoning w/GNF: 3 days
  Assisted the Gallatin NF, MT FWP, and Turner Enterprise with a piscicide treatment in Spanish Creek and Big Brother Lake for Westslope cutthroat restoration.

- Wall Creek Barrier Grant Application Writing: 6 days
  Completed grant applications for SW RAC and the MT Trout Foundation to secure funding for the Wall Creek Fish Barrier and WCT Conservation project.

- Ramshorn Creek WCT Restoration Project: 6 days
  Assisted the Beaverhead-Deerlodge NF and MT FWP with a piscicide treatment in The Ramshorn Creek drainage for Westslope cutthroat restoration.

- Ruby Creek Drainage Assessment: 2 days
  Inventoried channel conditions and total number of landslides in the Ruby Creek drainage, from headwaters to mouth, to assess post Monument Fire effects.

Total Madison Days: 57 days

WF Madison River Stream Restoration Paired Before and After Photos

MADISON RIVER DRAINAGE 2188 PROJECT MONITORING REPORT 2020

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

By:
Travis Lohrenz, Mike Duncan, Nick Larson, and Matt Jaeger
Montana Fish, Wildlife & Parks
Region 3 Fisheries
1400 South 19th Avenue
Bozeman, MT 59718

27 May 2020

Contents

Introduction

Montana Fish, Wildlife & Parks (FWP) monitors the Madison River Fishery to establish population estimates and to detect any changes to the fishery over time. Results from these monitoring efforts are evaluated to determine the potential effects from the operations at Hebgen and Ennis dams on fisheries in the Madison River Drainage. 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. This includes Hebgen and Ennis dams (Figure 1), as well as seven dams on the Missouri River collectively referred to by FERC as the 2188 Project. The 2188 license details requirements NWE must follow for the operation of the dam and hydropower facilities on the Madison and Missouri Rivers.

NWE entered into a 10-year Memorandum of Understanding (MOU) with state and federal resource management agencies to provide annual funding to implement FERC license requirements for the protection, mitigation, and enhancement (PM&E) of fisheries, recreation, and wildlife resources. The MOU established Technical Advisory Committees (TACs) to collectively allocate annual funding to implement PM&E programs and the provisions of the 5-year fisheries and wildlife PM&E plans in a way that maintains flexibility to respond to emerging needs. 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 operations of the Hebgen and Madison Dams under the 2188 license.

This report summarizes work that is ongoing and completed by FWP in 2020 with funding provided by the MadTAC to address requirements of FERC 2188 license; specifically, Articles 403, 408, 409, 412, and 419 that pertain to the Madison river fishery. Work included 1) fish abundance assessments in the Madison River, 2) assessment of fish populations in Hebgen reservoir, 3) conservation and restoration of Arctic Grayling populations, 4) conservation and restoration of Westslope Cutthroat Trout populations, 5) enhancement and restoration of tributary streams, and 6) flushing flow evaluation.

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. 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 the town of Ennis. North of Ennis the river flows through a steep canyon for 11 miles before it transitions into a broad alluvial valley bottom and floodplain 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 the Madison Dam forms Ennis Lake (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 minimum flows of 1,100 cubic feet per second and mitigate thermal issues in the in the Madison river below Ennis Dam (Figure 1).

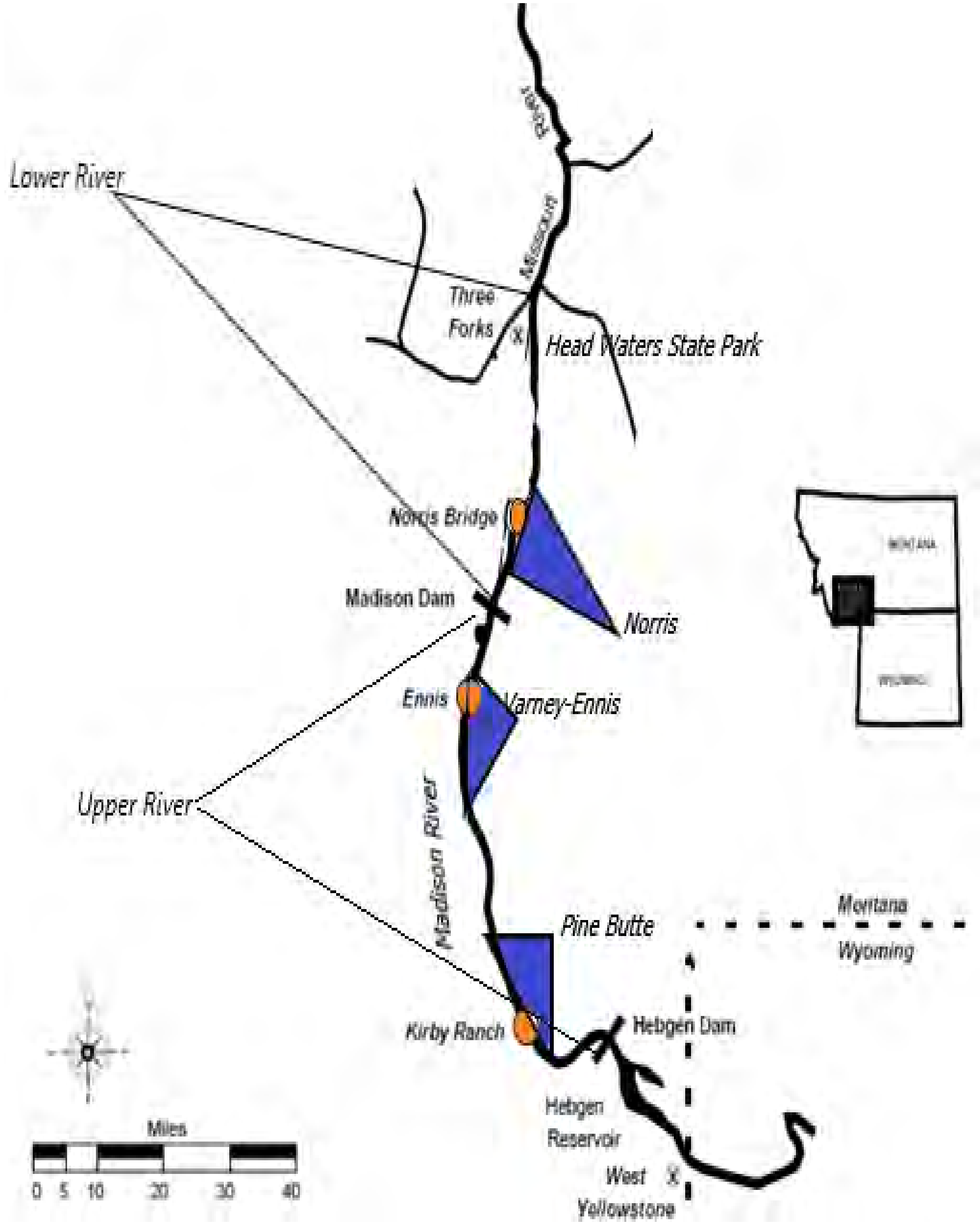


Figure 1. Locations of NWE dams on the Madison River (FERC Project 2188) and delineation of the upper and lower Madison River. FWP annual abundance estimate sections are shown in blue and NWE monitoring sites in orange.

Monitoring and Projects

Article 403-River Discharge

Minimum and maximum instream flows in various sections of the Madison River are described in Article 403 of the Project 2188 FERC license. Specifically, NWE is obligated to maintain a continuous minimum flow of at least 150 cfs in the Madison River below Hebgen Dam (gage no. 6-385), 600 cfs on the Madison River at Kirby Ranch (USGS gage no. 6-388), and 1,100 cfs on the Madison River at gage no. 6-410 below the Madison development. Flows at USGS gage no. 6-388 (Kirby Ranch) are limited to a maximum of 3,500 cfs under normal conditions excepting catastrophic conditions to minimize erosion of the Quake Lake outlet. License requirements also require the establishment of a permanent flow gauge on the Madison River at Kirby Ranch (USGS Gauge No. 6-388). FWP and NWE continue to jointly monitor river flows to avoid deviations from operational conditions. No deviation from the conditions for flow requirements in article 403 occurred in 2020.

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

FWP monitors trends in Hebgen Reservoir fish assemblages for the purpose of assessing the effects of project operations with annual gill netting surveys. Gross changes in fish assemblage or trends would warrant a review of and potential change to project operations to address identified issues.

The entire timeseries of Hebgen Reservoir gill net data was analyzed to optimize future monitoring design. Historically, 27 125-foot variable mesh experimental gillnets (13 sinking and 14 floating nets) have been used to characterize the Brown and Rainbow Trout fisheries of Hebgen Reservoir over three nights of sampling each spring. However, fewer gill nets reliably characterized trout populations of other lakes and reservoirs in the region (e.g., Clark Canyon and Ruby reservoirs). Three gill netting intensities were assessed to determine the effort needed to monitor the trout populations of Hebgen Reservoir most cost-effectively. Using historical sampling data, we evaluated the trends and sampling errors associated with 1) the full historical effort, 2) a combination of eight sinking and floating gill nets (i.e., Top 8) with the highest Brown and Rainbow Trout catch-per-unit effort (*C/f*), respectively, and 3) a combination of four sinking and floating gill nets (Top 4) with the highest Brown and Rainbow Trout *C/f*, respectively. We assessed the precision of the three sampling intensities described above by comparing the mean 95% confidence intervals (CI) of *C/f* and total length of Brown and Rainbow Trout among years.

All three sampling efforts yielded similar trends for mean Brown and Rainbow Trout *C/f* (Figure 2) and total length (Figure 3) in Hebgen Reservoir. In general, the mean 95% CI width of *C/f* and total length increased with decreased effort (Table 1); however, 95% CIs overlapped most years for both species so the ability to detect statistical differences among years was similar among sampling scenarios. Therefore, FWP recommends reducing sampling intensity for future monitoring as the Top 4 effort provided comparable precision and accuracy in characterizing the Hebgen Reservoir trout populations to the other sampling intensities analyzed. Although the Top 4 effort was statistically sufficient, that approach concentrated sinking gill nets along the west shoreline and floating gill nets in the main body leaving large areas of the reservoir unsampled. Therefore, we replaced a sinker that was historically set immediately next to 9S with 15S, which is another sinker with relatively high *C/f* of Brown Trout that is set across the Madison Arm on Horse Butte (Figure 4). We also added two floaters (14F and 21F), which provided improved distributions of nets in the Grayling and Madison arms. As a result, FWP recommends four sinkers and six floaters to annually monitor the trout populations in Hebgen Reservoir (Figure 4). The revised monitoring plan will improve efficiency by providing similar data while expending fewer FWP and NWE resources and minimizing the number of trout sacrificed during sampling.

Table 1. Mean 95% confidence interval width of catch-per-unit-effort (*C/f*; fish/net) and total length (TL; mm) of brown and Rainbow Trout captured in gill nets set in Hebgen Reservoir. Full effort represents the entire historical sampling effort of 27 nets (13 sinkers and 14 floaters) while the Top 8 and Top 4 efforts include a combination of the eight and four sinking and floating gill nets, respectively, with the highest *C/f* of Brown Trout in sinkers and Rainbow Trout in floaters over the last 20 years.

Species	Metric	Full Effort	Top 8	Top 4
Brown Trout	*C/f*	3.6	4.1	4.1
	TL	18.7	18.1	22.9
Rainbow Trout	*C/f*	2.4	3.0	4.0
	TL	25.7	28.0	34.8

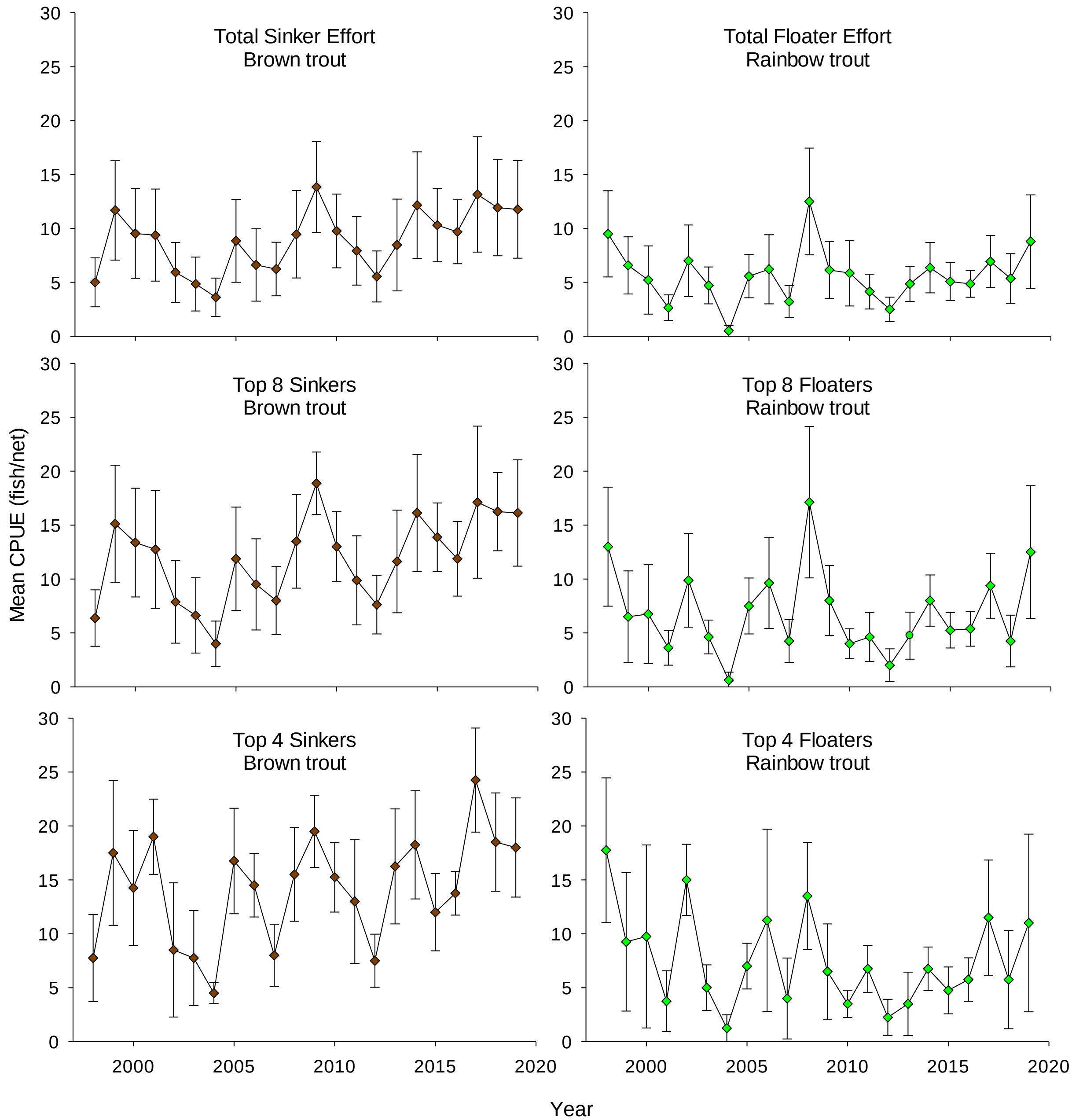


Figure 2. Mean catch-per-unit-effort (*C/f*) of sinking and floating gill nets set in Hebgen Lake for sampling Brown and Rainbow Trout, respectively, under three potential sampling intensities. Total effort illustrates the full historical sampling effort (13 sinkers and 14 floaters) followed by reduced efforts that rely on the either the top 8 or 4 sinkers and floaters to characterize the Hebgen Lake trout fishery. Error bars are 95% confidence intervals.

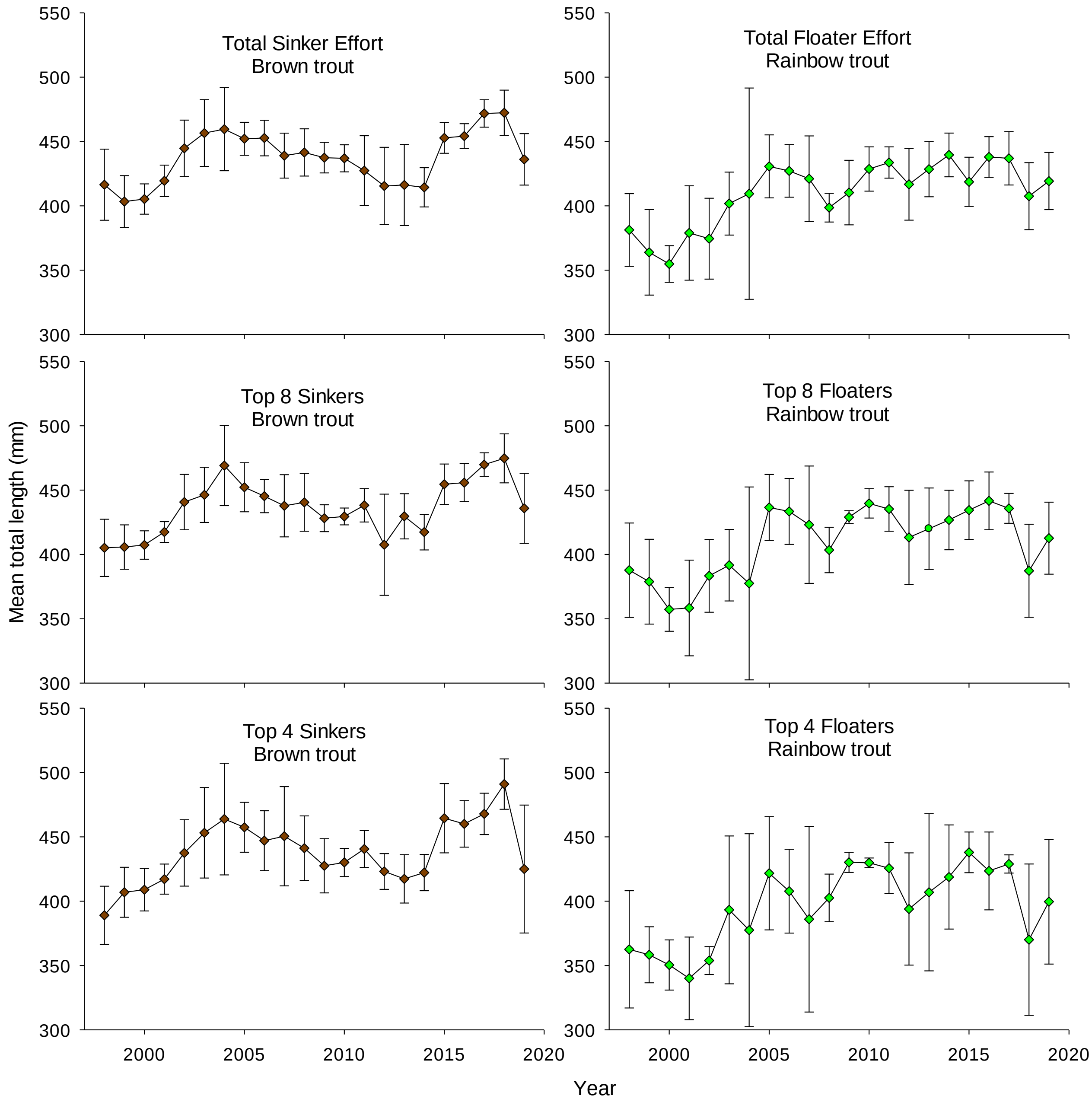


Figure 3. Mean total length (mm) of sinking and floating gill nets set in Hebgen Lake for sampling Brown and Rainbow Trout, respectively, under three potential sampling intensities. Total effort illustrates the full historical sampling effort (13 sinkers and 14 floaters) followed by reduced efforts that rely on the either the top 8 or 4 sinkers and floaters to characterize the Hebgen Lake trout fishery. Error bars are 95% confidence intervals.

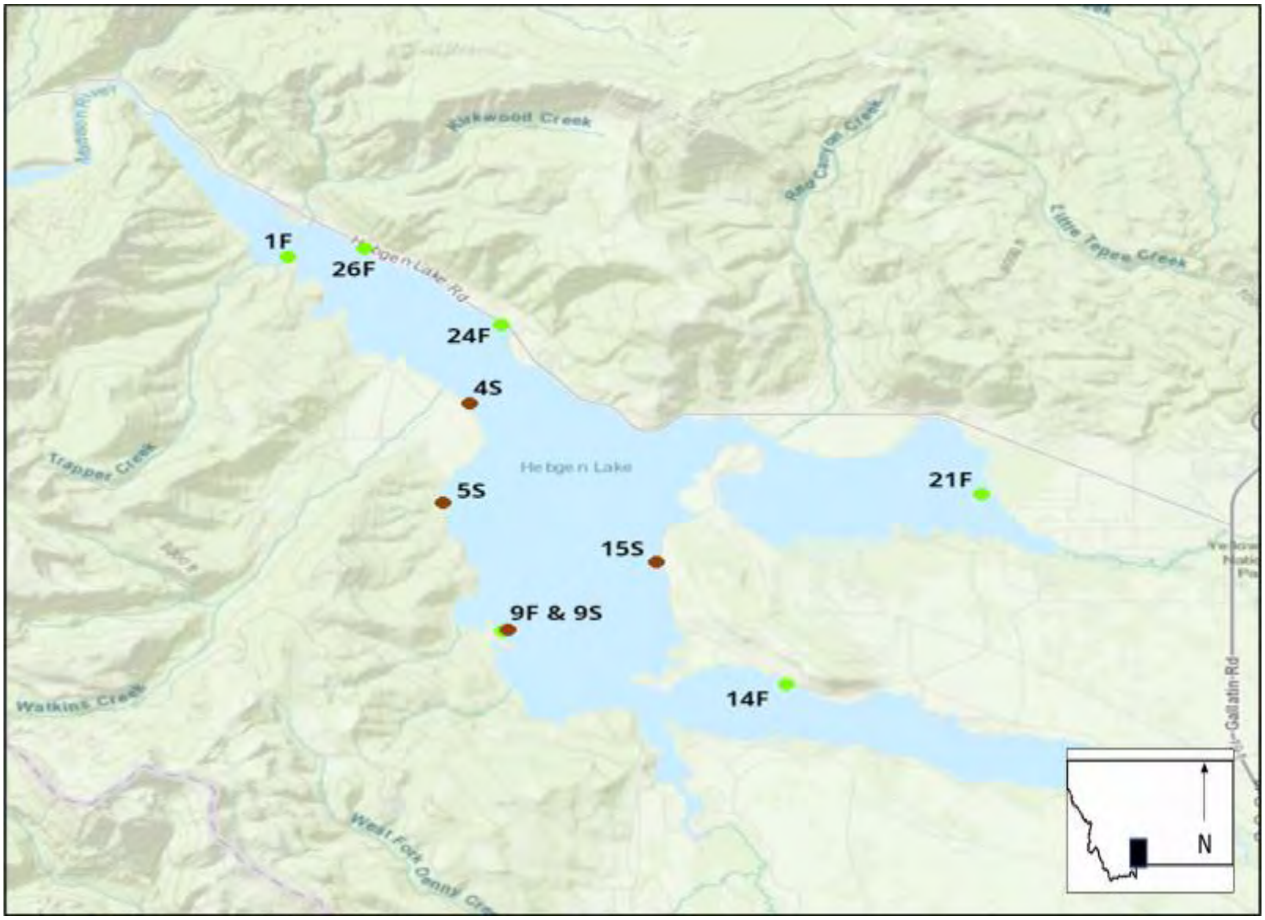


Figure 4**.** Updated Hebgen Reservoir gill net locations and names. Brown and green circles are sinking (N = 4) and floating (N = 6) gill nets, respectively.

FWP developed Hebgen Reservoir fishery management goals so that management actions can be implemented and evaluated to regularly and realistically maintain a fishery of above average condition. Hebgen Reservoir management goals for Rainbow Trout are 7.5 fish/net with 66% ≥ 406 mm (≈16”) while brown trout management goals are 15.5 fish/net with 75% being ≥ 406 mm (≈ 16”). Management goals for the Brown and Rainbow Trout fisheries in Hebgen Reservoir were established using the 66th percentiles of data collected over the past 20 years.

Brown and Rainbow Trout abundances were below management goals in 2020 (Figure 5). Brown Trout abundances decreased to 11.8 fish/net and Rainbow Trout to 6.3 fish/net (Figure 4), which are 29% and 25% lower than in 2019, respectively. However, both remain near the long-term averages (1998-2020) of 12.9 Brown Trout/net and 6.3 Rainbow Trout/net. Brown Trout have decreased by 56% since reaching a 20-year peak of 21.0 fish/net in 2017. Although this is concerning when considering recent declines in Brown Trout elsewhere in Montana including the Madison River, similar trends have been observed over the last 20 years. Rainbow Trout abundances have been trending upwards since a recent low of 3.2 fish/net in 2012, which is encouraging as the reservoir transitions to a wild trout fishery since FWP ceased stocking hatchery-reared Rainbow Trout in 2016. The size structure of the Rainbow Trout population rebounded above the management goal in 2020, but Brown Trout population size structure remained below the management goal (Figure 6). However, mean total lengths of Brown (435 mm; ≈ 17”) and Rainbow (412 mm; ≈ 16”) Trout remained near the long-term averages (Figure 5).

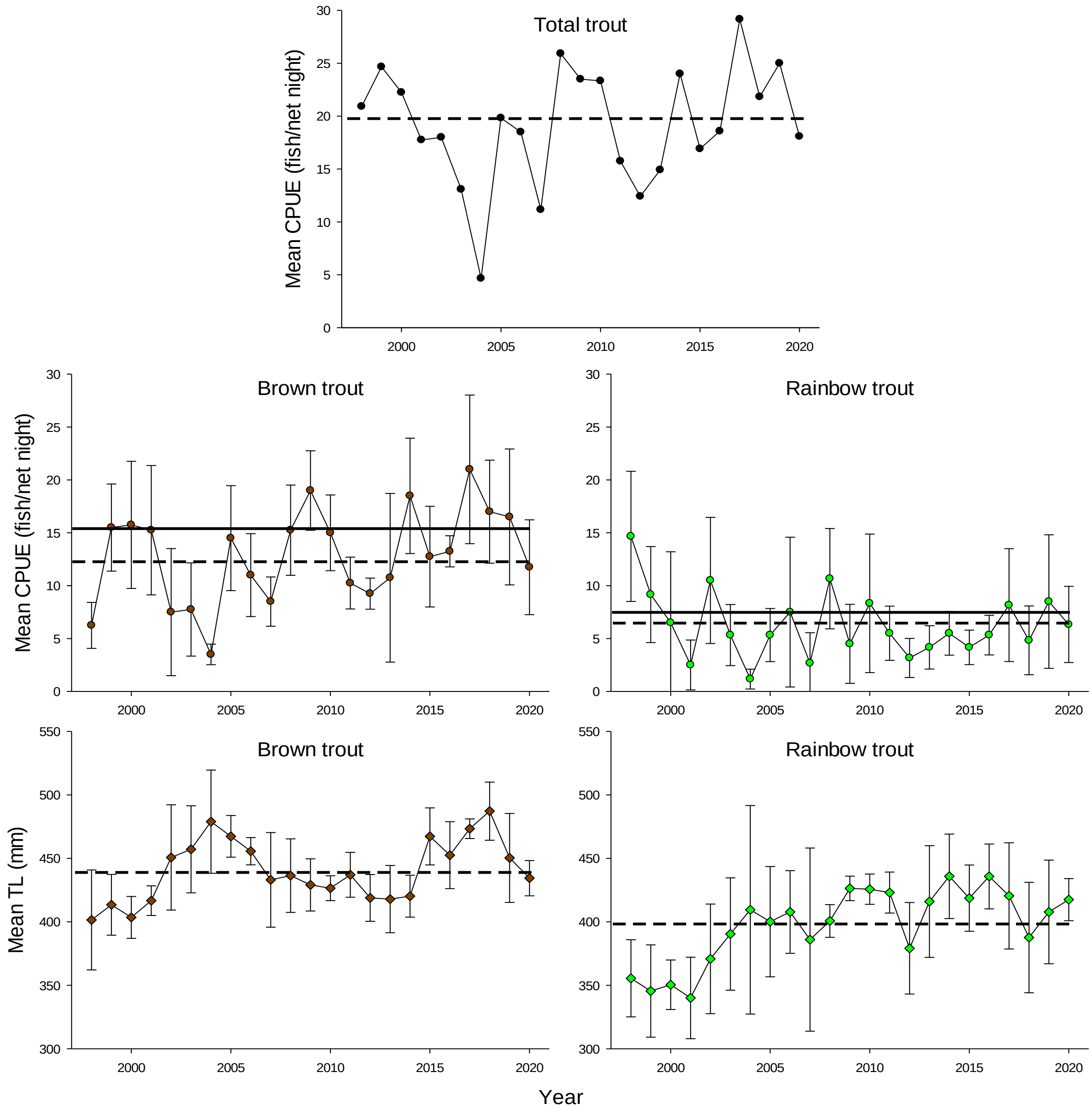


Figure 5**.** Mean *C/f* of total, Brown and Rainbow Trout captured in Hebgen Reservoir in 2020. Total trout abundances represent all trout captured in four sinking gill nets and six floating gill nets. Brown and Rainbow Trout *C/f* were limited to either sinking or floating gill nets, respectively. Mean total lengths were calculated using all Brown and Rainbow Trout captured each year. Dashed lines are the long-term averages (1998-2020). Solids lines are the management goals: Brown Trout = 15.5/net; Rainbow Trout = 7.5/net. Error bars are the 95% confidence intervals.

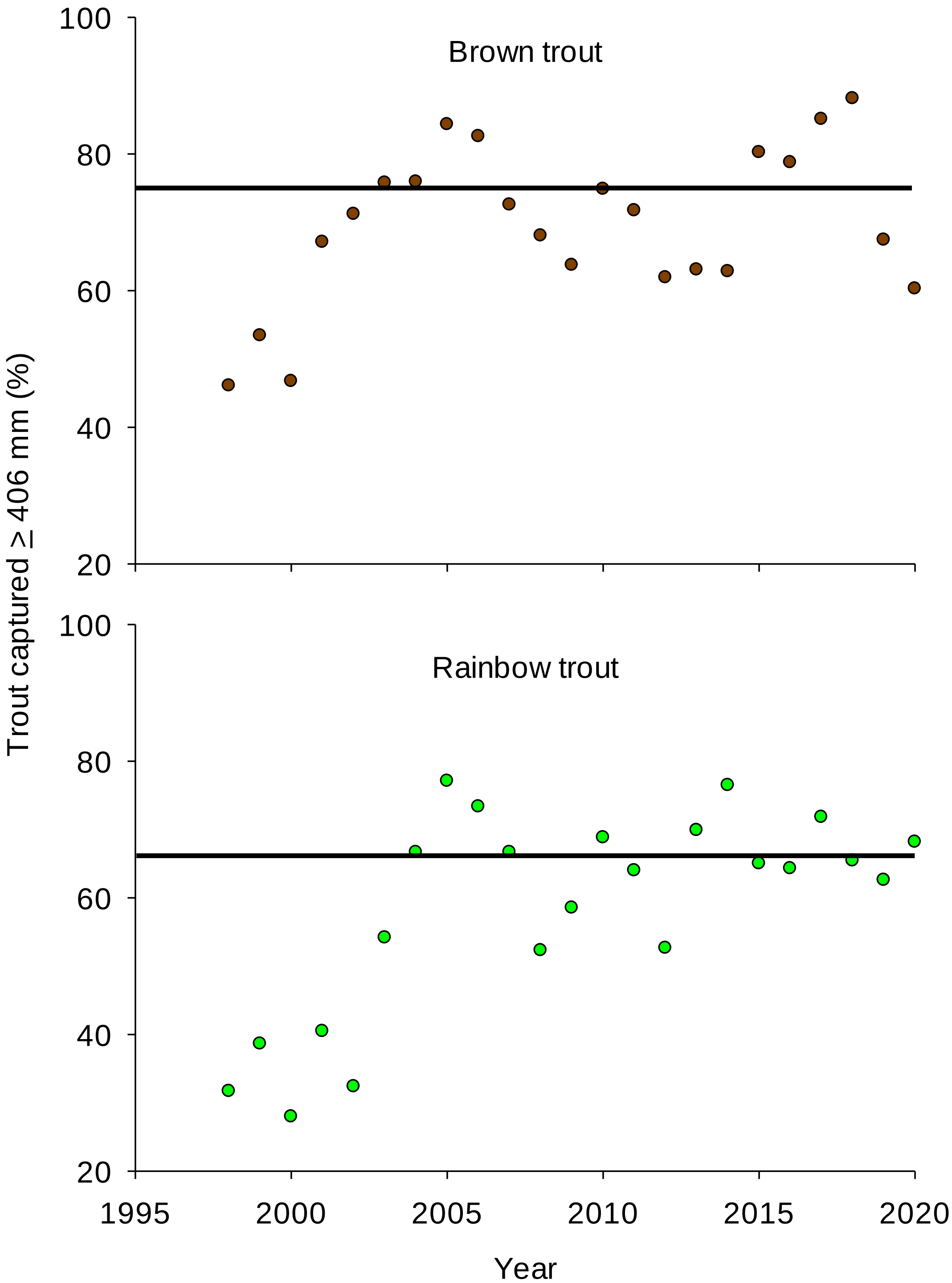


Figure 6. Percentages of trout captured in Hebgen Reservoir that were ≥ 406 mm (≈ 16”). Black lines are the management goals, which represent the 66th percentile of sampling data since 1998: Brown Trout = 75%; Rainbow Trout = 66%.

408-3) Reservoir Draw Down Effects on Fish

The interaction between Hebgen Reservoir elevation and operations, trophic status, and the trout population has been assessed annually by FWP since 2006. Reservoir elevation may influence juvenile trout success by increasing or reducing the amount of habitat along shorelines and the abundance of zooplankton. Large releases of water can impoverish the plankton community through the loss of nutrients and may result in deteriorated food conditions for juvenile trout, until they can switch to macroinvertebrates or piscivory (Axelson 1961; Haddix and Buddy 2005). Hebgen Reservoir has a full pool elevation of 6,534.87 feet (msl) and current operational standards require NWE to maintain reservoir elevations between 6530.26 and 6534.87 feet from June 20 through October 1 and reach full pool elevation by late June or early July.

Trophic status was assessed by taking Secchi disk measurements in conjunction with zooplankton tows to establish a Trophic State Index number (TSI; Carlson 1977). A Secchi disk was used to measure light penetration (in meters) into the water column and Secchi depths were recorded as the distance from the water surface to the point in the water column where the disk colors became indiscernible. Zooplankton samples were collected with a Wisconsin® plankton net with 153-micron mesh (1 micron = 1/1,000th millimeter) towed vertically through the entire water column at one meter per second. Tows were taken at locations with a minimum depth of 10 meters. Samples were rinsed and preserved in a 95% ethyl alcohol solution for enumeration. Zooplankton were identified to groups (i.e., cladocera or copepoda) and densities from each sample were calculated. Linear regression was used to determine whether mean zooplankton abundances and TSI were correlated with reservoir elevation. Months selected for analysis were June, July, and August because they correspond with the emigration of juvenile trout from natal tributaries to Hebgen Reservoir and their recruitment to the fishery could be influenced by the environmental conditions in the reservoir at the time of emigration (Watschke 2006; Clancey and Lohrenz 2007, 2008, 2009). Additionally, linear regression was used to assess whether reservoir elevation or zooplankton abundance were correlated with the relative abundance of trout ≤406 mm observed in annual gillnetting. Relative abundance of Brown and Rainbow Trout ≤406 mm at time t were compared to environmental covariates at time at t_{-1}, t_{-2} and t_{-3} to assess cohort-specific effects on juvenile trout.

Contemporary Hebgen Reservoir operations appear to have little influence on limnology and trout abundance. Mean zooplankton densities in June (23.72 individuals/L, ± 1.18; 95% *CI*) were the highest observed in 2020, with copepoda constituting 57% and cladocera 43% of the sample on average (Figure 7). Copepoda was the dominant group observed in May (84%), July (60%), August (58%), and September (54%; Figure 8). No statistically significant relationships ($P \geq 0.05$) were observed between reservoir elevation and zooplankton abundance, trophic status, or trout abundance or between zooplankton and trout abundances. However, trout cohorts emigrate to the reservoir at multiple ages and there was not adequate resolution to determine the exact year of emigration using fish length data from gillnets, which may have precluded inference. Moreover, the minimal mean fluctuation in reservoir elevation below full pool during the summer (June 0.70’, July 0.58’, August 1.91’) and the narrow operational range of between 6530.26’ and 6534.87’ from June 20 - October 1 reduces the likelihood of observing and describing interannual variability among these factors; no relationships exist or are expected under contemporary operations because conditions are similar each year. Therefore, it is expected that similar patterns will be observed within and among years and it is recommended that limnological sampling be suspended or reduced except in years where reservoir elevations fall outside of typical operational ranges.

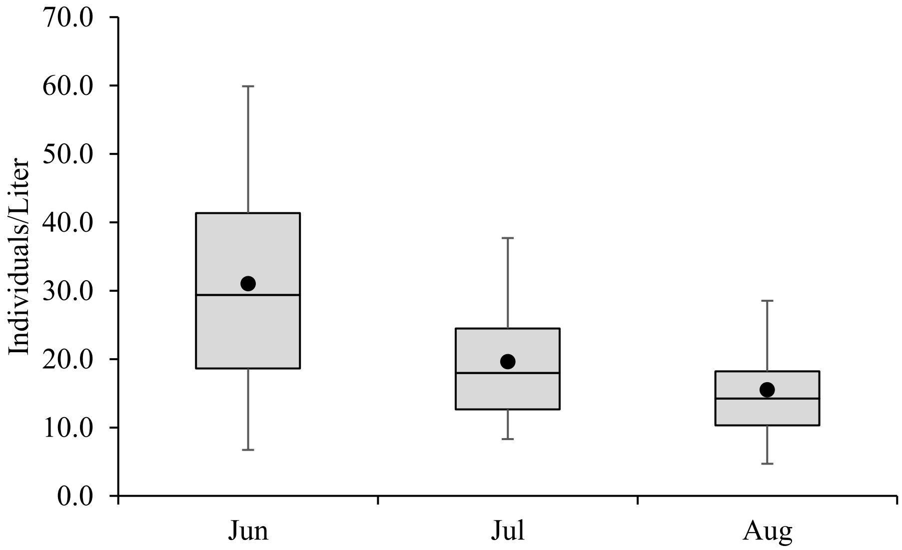


Figure 7. Total zooplankton abundance among months June, July, August 2006-2020. Within each box, ●’s denotes mean values, boxes extend from the 25th to the 75th percentile of each group's distribution of values, horizontal lines within each box are the median value, and whiskers are the 5th and 95th percentiles.

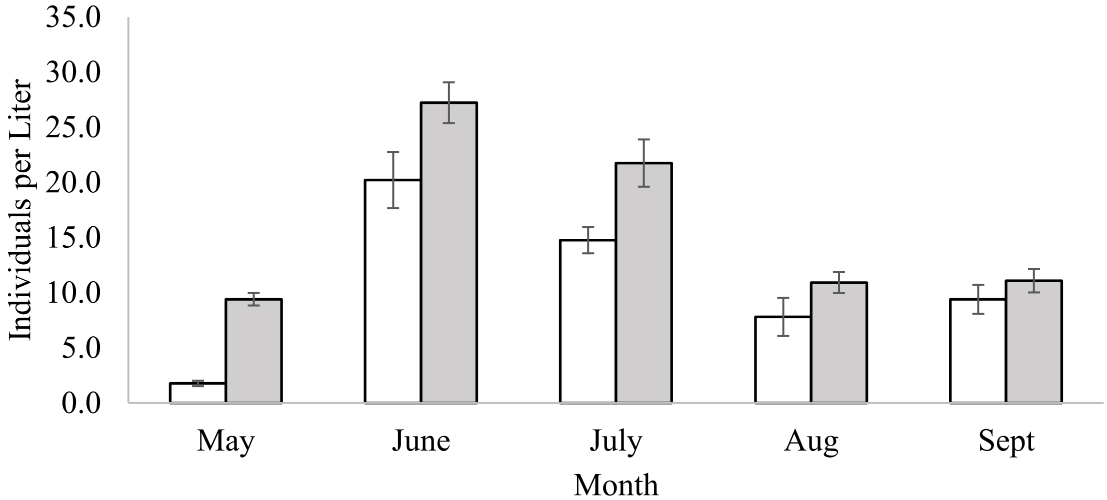


Figure 8. Calculated zooplankton abundances (individuals/liter) for the months of May-September 2020. White bars are cladocera and grey bars are copepoda. Error bars are 95% confidence intervals.

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

FWP estimated trout abundances using mark-recapture procedure in two long-term monitoring sections in the upper Madison River (Pine Butte and Varney; Figure 1) to evaluate the influence of modified project operations at Hebgen Dam on the fishery. Although only the influence of project operations are reported here, other potential population drivers (i.e., angling pressure, disease, etc.) are hypothesized to be influential and are being evaluated elsewhere. Trout were collected by electrofishing from a drift boat mounted mobile anode system (Figure 9). Fish captured in the initial trip (marking run) were weighed in grams and measured to the nearest millimeter, marked with a fin clip, observed for hooking scars, and released to redistribute. After ten days, FWP conducted a second trip (recapture run) where fish were examined for marks administered during the marking run, length recorded for marked fish, and length and weight recorded for unmarked fish. Length-specific mark-recapture log-likelihood closed population abundance estimates were generated and standardized to stream mile for Brown and Rainbow Trout using an R-based proprietary FWP fisheries database and analysis tool.

Figure 9. Mobile anode electrofishing (shocking) in the Norris section of the Madison River.

FWP developed management goals for total trout abundances (trout ≥ 252 mm [≈ 10”]; Figure 10) and size structure (percentages of trout ≥ 252 mm that are also ≥ 402 mm (≈ 16”]; Figure 11) for each of the long-term sampling sections using the 66th percentiles of data collected over the past 20 years. 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.

In 2020, abundances of trout ≥ 252 mm were below the management goals in the Pine Butte and Varney sections as well as the Norris section in 2021 (Figure 10). However, the size structure management goals for the percentages of trout ≥ 402 mm were exceeded in the most recent sampling efforts in all three sections (Figure 11). Except for Rainbow Trout in the Varney Section, estimated abundances of Brown and Rainbow Trout ≥ 152 mm (≈ 6) remained below the 20-year averages in the upper Madison River in 2020 (Figure 12). In the Pine Butte Section, 2020 sampling yielded an estimate of 2,152 Rainbow Trout/mile, which was similar to 2019 abundance. However, Brown Trout declined in Pine Butte to 1,367 Brown Trout/mile, which represents a decrease of about 15% from 2019 abundance. Primarily because of the highest abundance of age-1 fish observed in over 20 years (Figure 13), Rainbow Trout abundances (2,401 trout/mile) in the Varney Section nearly tripled from 2019 to 2020 (Figure 12). Estimated abundances of Brown Trout in the Varney Section remained relatively stable for the fourth consecutive year at 1,339 fish/mile, which is 82% of the 20-year average for that reach. In the Norris Section, Brown Trout abundance decreased to a 20-year low of 459 fish/mile in 2021 (Figure 12). Most concerning was the near lack of Brown Trout 152-277 mm captured in the Norris section in 2021 (Figure 13). Rainbow Trout abundance was 1,414 fish/mile, which was similar to 2018 but below the 20-year average for the Norris section. We will complete age and growth analyses using otoliths collected in 2020 to provide insight into factors limiting the growth and survival of Brown and Rainbow Trout and develop management actions to address these factors.

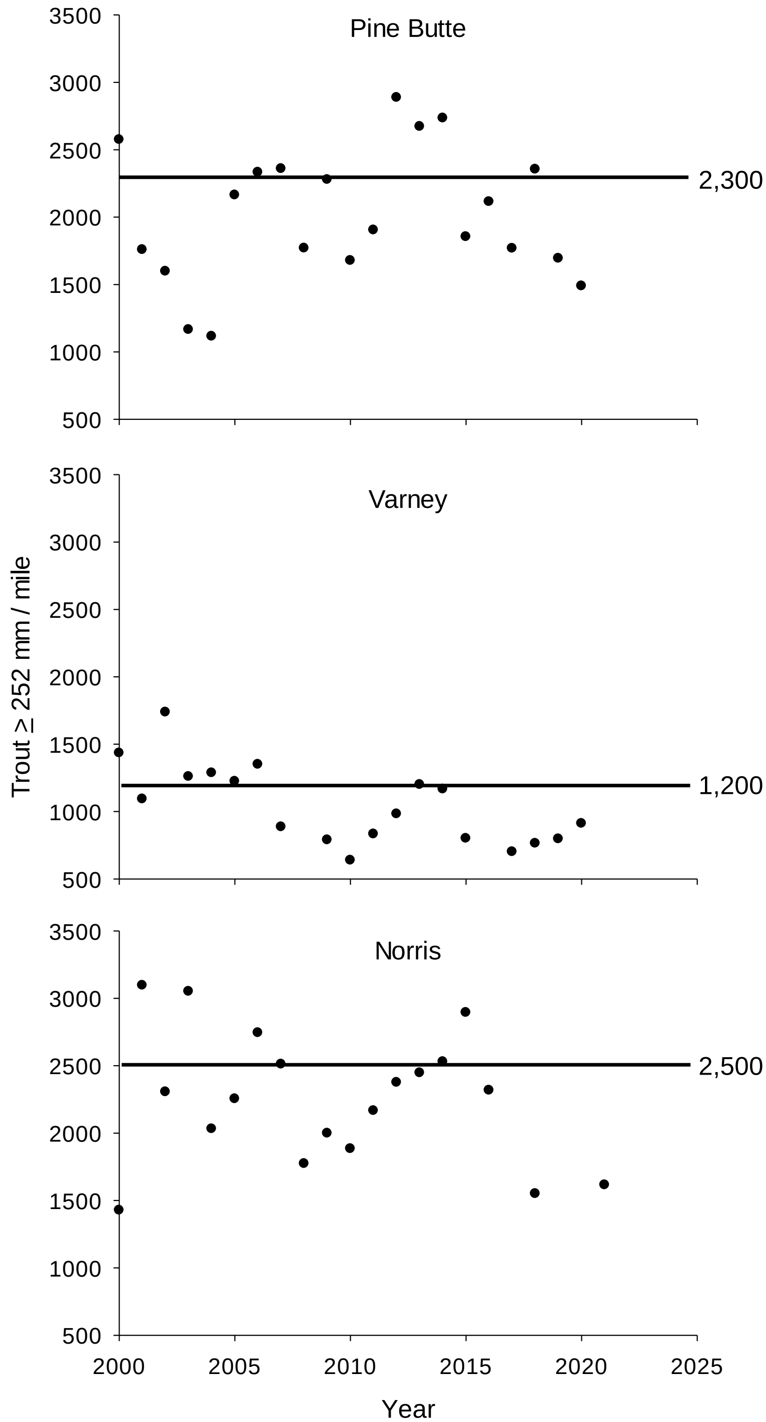


Figure 10. Estimated abundances of trout ≥ 252 mm (≈ 10”) in the Madison River. Black lines are the management goals for each section, which represent the 66th percentile of estimates over the last 20 years in each section. The Norris graph contains 2021 data.

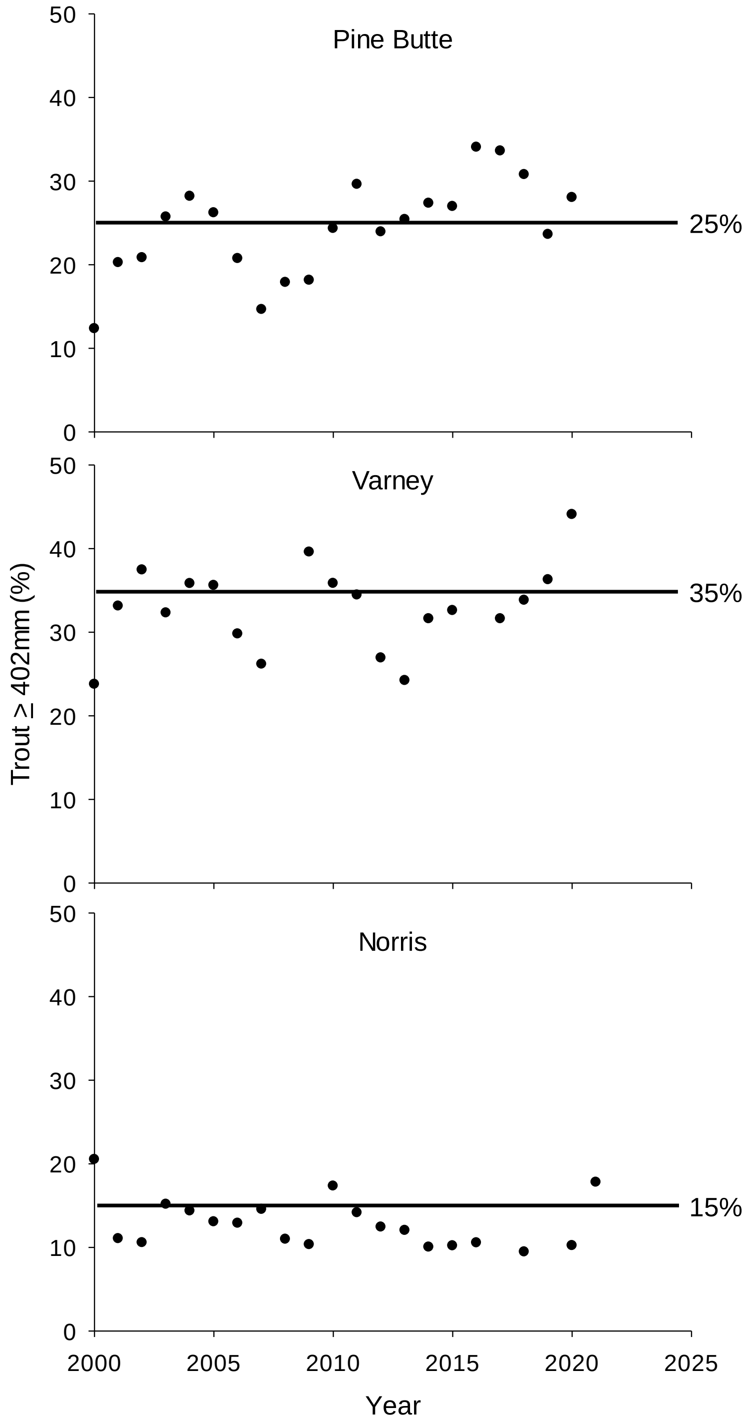


Figure 11. Percentages of ≥ 252 mm (≈ 10”) trout captured in the Madison River that were ≥ 402 mm (≈ 16”). Black lines are the management goals for each section, which represent the 66th percentile of sampling data over the last 20 years in each section. The Norris graph contains 2021 data.

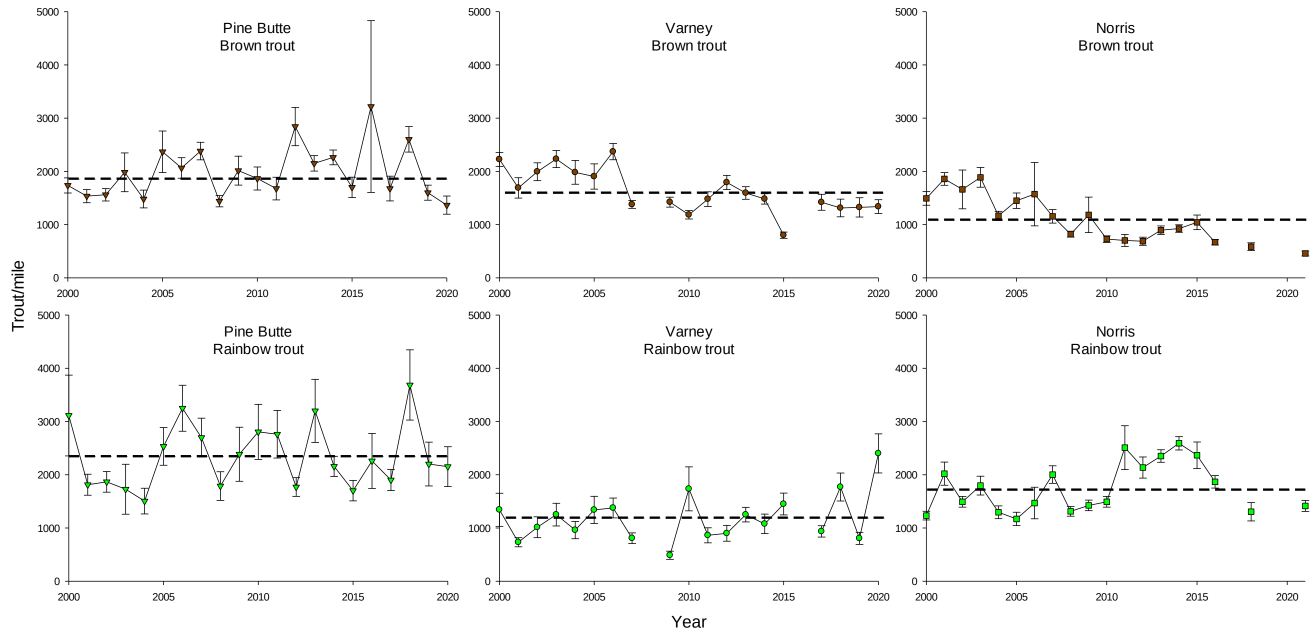


Figure 12. Estimated abundances of Brown (brown symbols) and Rainbow (green symbols) trout ≥ 152 mm (≈ 6”) captured in the three long-term sampling sections of the Madison River. Dashed lines are the 20-year averages of estimated abundances and error bars are the 95% confidence intervals for each sampling event. The Norris graphs include 2021 data.

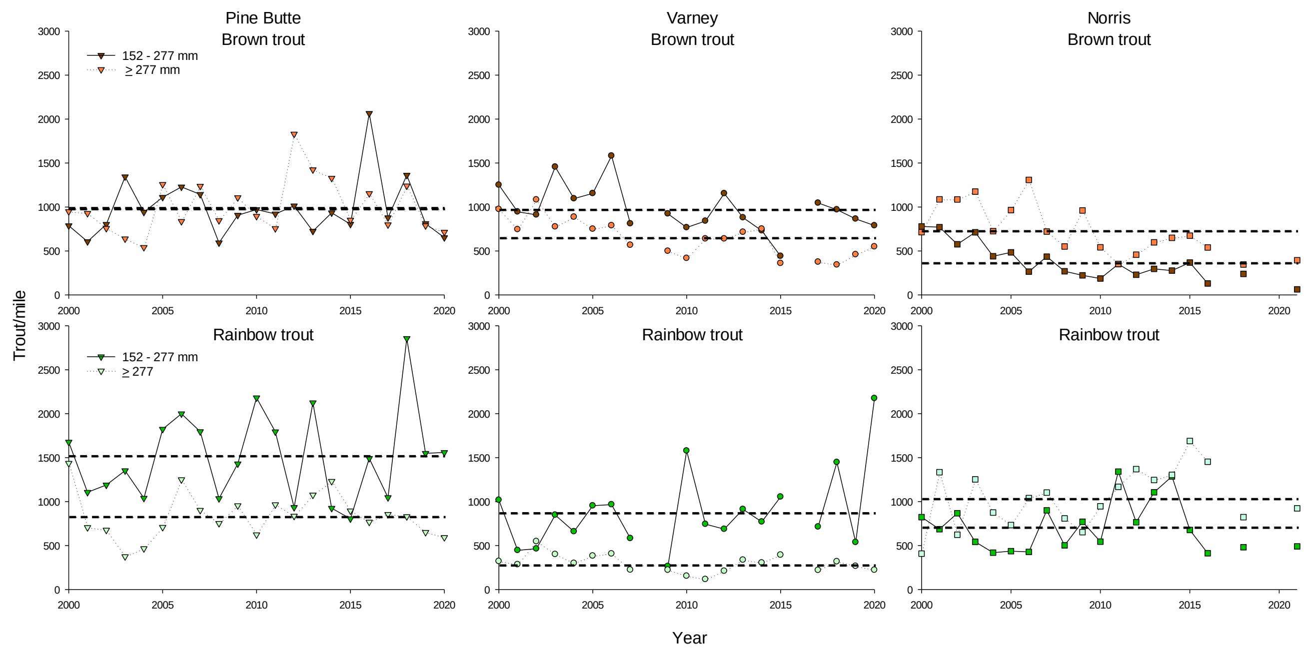


Figure 13. Estimated abundances of 152 – 277 mm (≈ 6 – 11”) and > 277 mm Brown and Rainbow Trout in the Pine Butte and Varney sections of the Madison River. Dashed lines are the 20-year averages of estimated abundances (nearly overlapping lines for Pine Butte Brown Trout). Norris graphs contain 2021 data.

408-4) Monitor the effects of modified operations on Upper Madison Fish Populations-Surface Release

During 2012-2015 and 2017 water was released from the surface of Hebgen Reservoir as repairs to the outlet structure used for mid-reservoir release was completed. The depth of water withdrawal from reservoirs can change the thermal characteristics of downstream waters. Surface release generally results in an increase of Spring-Summer water temperatures, whereas subsurface or hypolimnetic release can moderate or reduce Spring-Summer water temperatures, creating conditions that are optimal for cold water fish species such as trout. However, relative increases in water temperature can be beneficial; slight changes in temperature can move fish towards their ideal ranges for metabolic processes and influence fish growth and dispersion (Zoudd, 2018).

A general linear model and *t*-tests were used to evaluate whether water temperatures, trout abundances and trout condition in the Pine Butte, Varney, and Norris monitoring sections significantly differed between periods of mid-reservoir and surface release. We characterized mid-reservoir release as pre-surface (2000-2011) and post surface release 2016, 2018-2020. Surface releases occurred from 2012-2015 and in 2017. Mean daily water temperatures were calculated for the period July 1 through September 15 for the years 2000-2020. A one-way analysis of variance (ANOVA) was used to compare mean daily water temperatures between pre-surface, surface, and post surface release events. To evaluate if there was a response to surface release in age-1 trout abundances two sample t-tests were conducted at α=.05 confidence interval between estimated abundances of age-1 trout at time t and t_{-1} during years of mid-reservoir and surface release. Similarly, two sample t tests were also used to evaluate if surface release effected the proportion of trout ≥406 mm and trout condition (W*r*) at time t and t_{-1}.

On average, mean daily water temperatures were 2.0 °F higher in the Pine Butte monitoring sections during surface release than pre or post surface release (ANOVA F=129.9; df=2.0; P<0.05; Figures 14 and 15). No significant differences existed in mean daily water temperatures in the Varney or Norris sections among surface release and pre or post surface release periods.

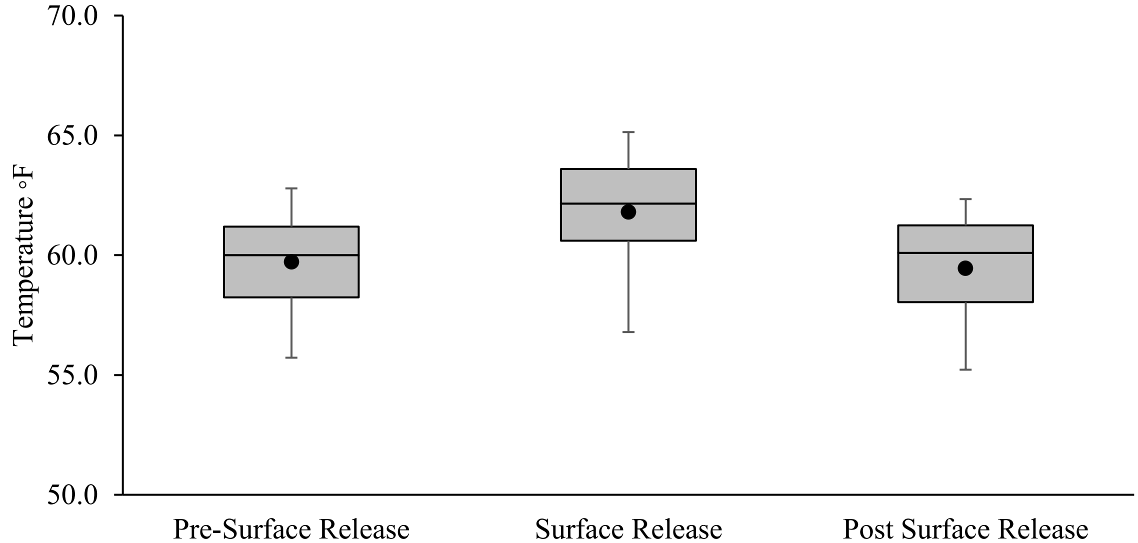


Figure 14. Boxplots of mean daily temperatures pre-surface release, during surface release, and post surface release for the Pine Butte monitoring section of the Madison River. Within each box, ●'s denotes mean values. Boxes extend from the 25th to the 75th percentile of each group's distribution of values and whiskers are the 5th and 95th percentiles.

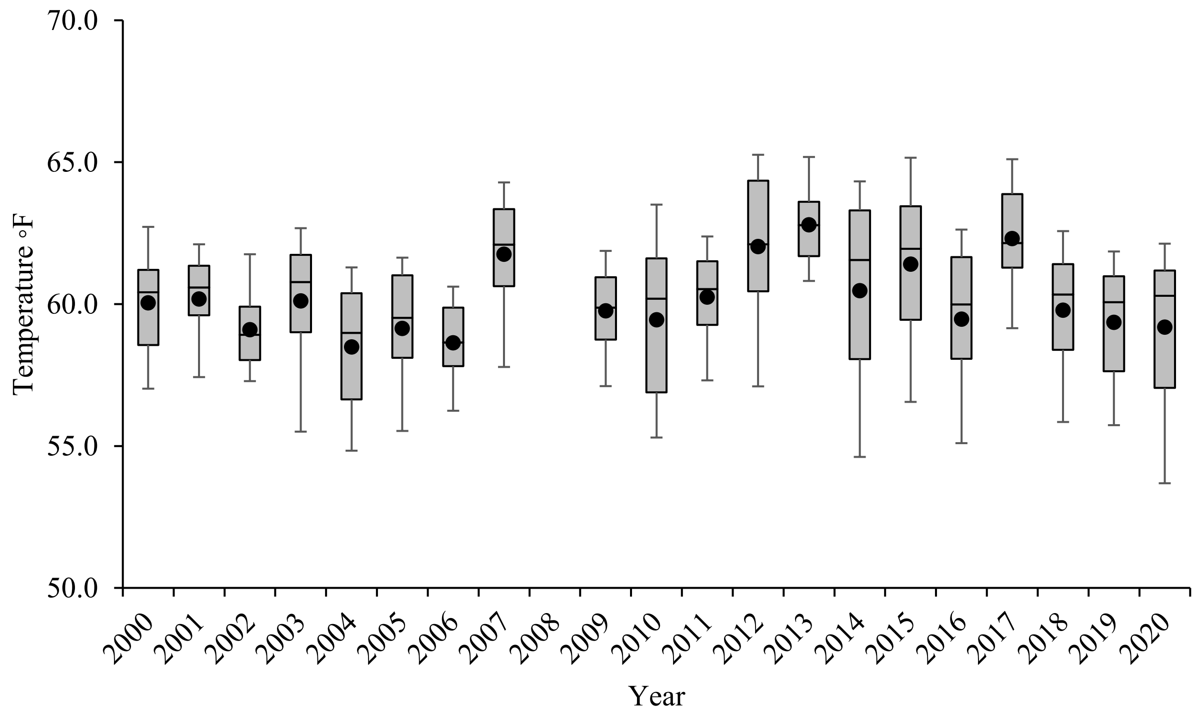


Figure 15. Mean daily water temperatures from July 1 - September 15, 2000-2020 at Pine Butte. 2008 data is missing. Years of surface-release are 2012-2015, 2017. Within each box, ●'s denotes mean values, boxes extend from the 25th to the 75th percentile of each group's distribution of values, horizontal lines within each box are the median value and whiskers are the 5th and 95th percentiles.

No significant difference was observed in the estimated abundance of age-1 Brown or Rainbow trout between mid-reservoir and surface release; however, there was an increase in the proportion of fish ≥406 mm that was marginally significant at time t (t-test, P=0.06) and statistically significant at time t_{-1} (t-test, P=0.03) during years of surface release in the Pine Butte monitoring section (Figure 16). This equated to roughly a 4% increase in the proportion of trout ≥406 mm at time t and a 5% increase at time t_{-1}. Surface release did not influence the proportion of trout ≥406 mm in the Varney or the Norris monitoring sections. A significant negative relationship between surface release and W*r* of age-1 trout in the Pine Butte monitoring section at time t and t_{-1} (t-test P<0.01; Figure 17) was observed; however, this relationship was not observed in the Varney or Norris monitoring sections, and there was no relationship between surface release and the W*r* of trout ≥ 406 mm in any of the monitoring sections.

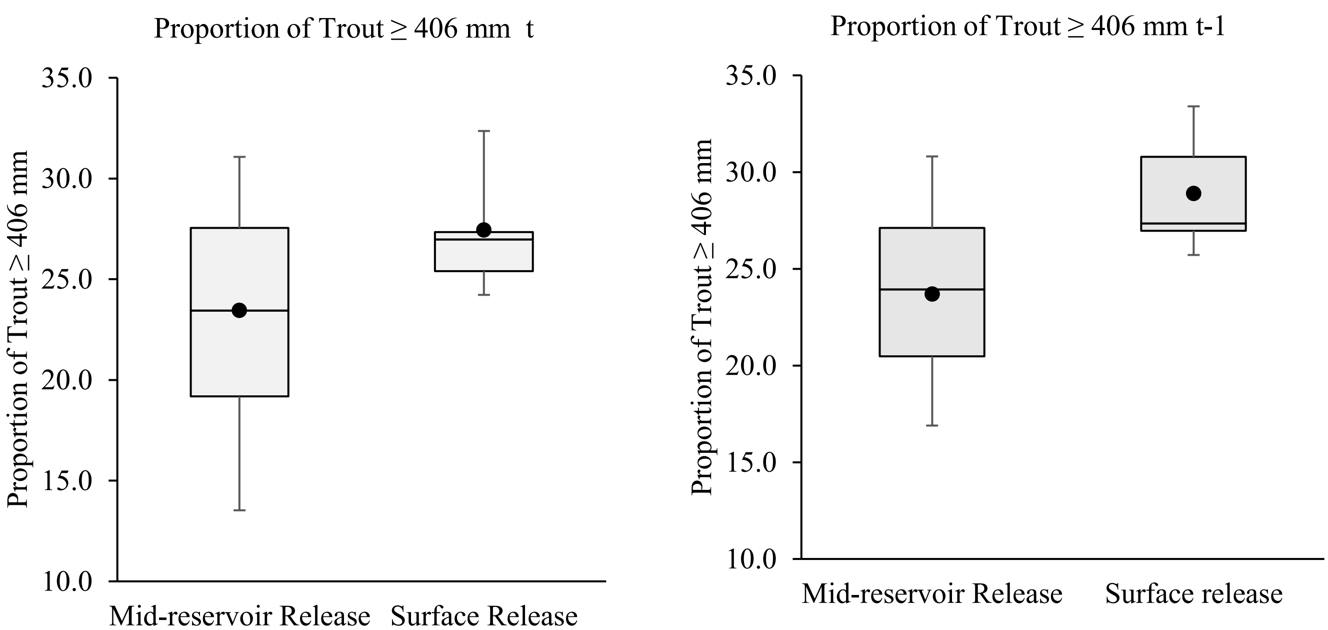


Figure 16. Boxplot of the proportion of fish ≥406 mm at t (t-test, P=.056) and t_{-1} (t-test, P=.028) during periods of mid-reservoir release and surface-release. Within each box, ●'s denotes mean values, boxes extend from the 25th to the 75th percentile of each group's distribution of values, horizontal lines within each box are the median value, and whiskers are the 5th and 95th percentiles.

The observed increase in the proportion of fish ≥406 mm during periods of surface release in the Pine Butte section suggest surface release may be a viable management action to regularly meet management goals for large trout, although the concurrent decline in juvenile W*r* is problematic. The decline in W*r* observed in age-1 Brown and Rainbow trout may be behaviorally related to the increase in the proportion of fish ≥406 mm during these events where juvenile trout evaded predation by a higher abundance of large trout in suboptimal habitat. The increase in the proportion of large trout was not driven by the low abundance of juvenile trout; there was no difference in age-1 abundance observed between mid-reservoir and surface release. Improved proportion of large trout and lower juvenile trout W*r* was not observed in the downstream Varney and Norris sections. It is recommended that discussions be initiated to evaluate surface release as a potential option for improving the proportion of large trout in the Pine Butte section.

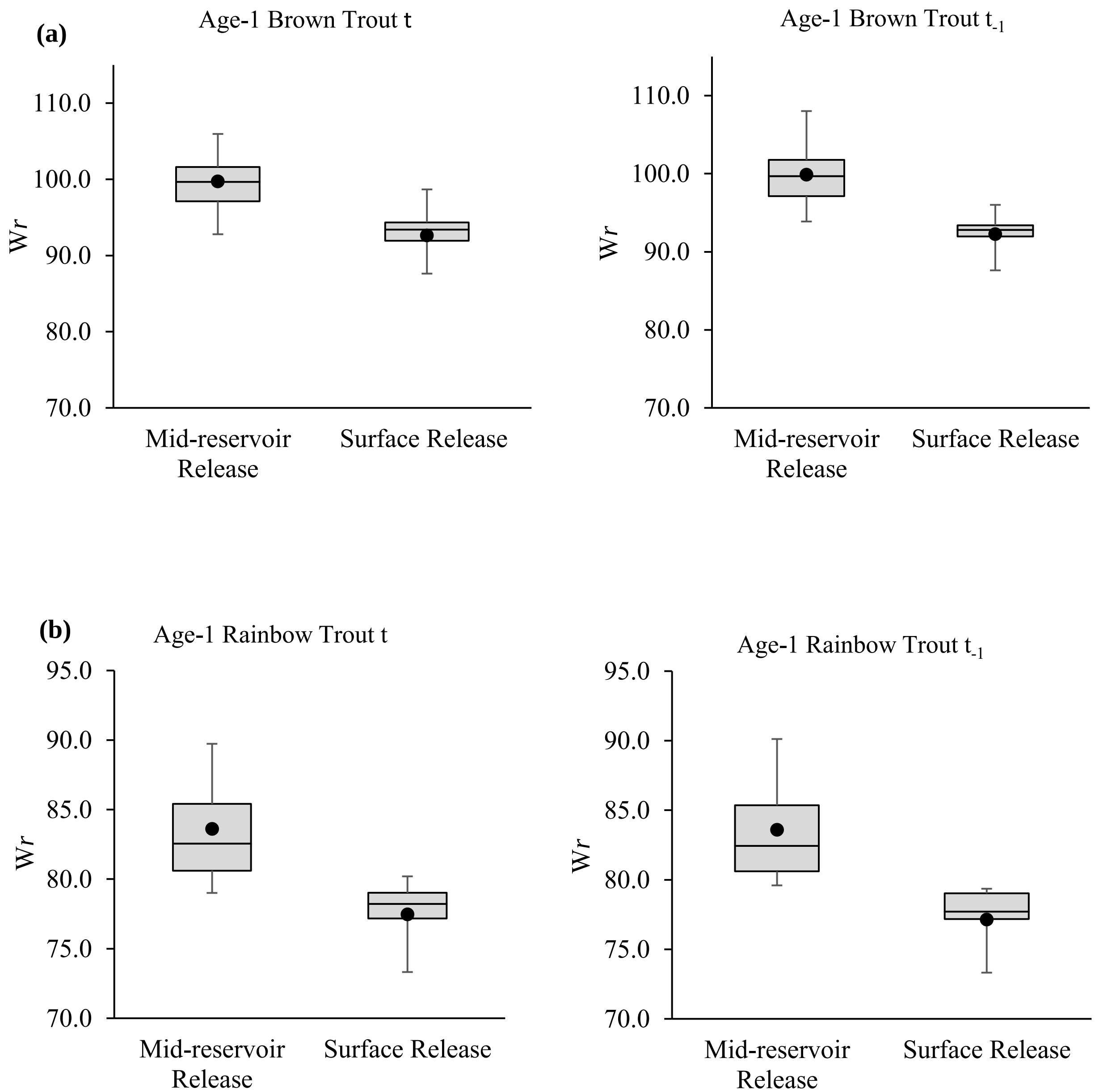


Figure 17**.** Boxplot of W*r* of age-1 **(a)** Brown Trout and **(b)** Rainbow Trout at t and t_{-1} during mid-release and surface release in the Pine Butte section. Within each box, ●'s denotes mean values, boxes extend from the 25th to the 75th percentile of each group's distribution of values, horizontal lines within each box are the median value, and whiskers are the 5th and 95th percentiles.

408-7) Monitor Species of Special Concern; Madison Artic 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, 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).

Arctic Grayling reintroduction occurred in several Madison River tributaries between 2014 and 2020. Introductions were carried out by placing eggs in remote site incubators (RSI; Figure 18) and allowing eggs to hatch and fry to enter the stream. To date there have been 689,200 eggs placed in Madison tributaries and hatching success of eggs and fry emigration out of RSI's in tributary streams has been good to fair every year introductions took place except for the 2017 Blaine Spring Creek introductions (Table 2). In 2020, 300,000 eggs from the Green Hollow and Axolotl Lake Big Hole Arctic Grayling genetic reserve brood ponds were evenly divided into Blaine Spring Creek and Moore Creek (Figure 19) to assess whether eggs stocked at higher densities resulted in higher abundances of juvenile Grayling. During autumn electrofishing surveys, six and zero young-of-the-year Grayling were observed in Moore and Blaine Spring creeks, respectively. The number of Grayling observed in Moore Creek was the most observed since introductions were initiated, suggesting simply stocking more fish may be a viable option for successful re-establishment. However, relative suitability of reintroduction streams may be influenced by density of juvenile Brown Trout; there are relatively few juvenile Brown Trout in Moore Creek whereas high densities of juvenile Brown Trout occur in Blaine Spring Creek and the other streams where Grayling were previously introduced. Future restoration efforts will use substantially more eggs (i.e., >100,000) at introduction sites and focus on waters with low juvenile Brown Trout densities.

Figure 18. Remote site incubators used to hatch Arctic Grayling eggs.

Table 2. Arctic Grayling introduction sites. Site, year, quantity of eggs introduced and egg survival and emigration success.

Site	Year	# eggs	Egg survival and emigration
West Fork Madison Upper	2014	1,200	Poor
West Fork Madison Middle Spring	2014	10,000	Good
	2015	30,000	Good
	2016	5,000	Good
Lake Creek	2014	13,000	Good
	2015	27,000	Good
	2016	5,000	Good
Upper O’Dell Creek Grainger Ranch	2015	36,000	Good
	2017	32,000	Good
	2018	60,000	Good
	2019	15,000	Good
O’Dell Creek Longhorn Ranch	2019	45,000	Good
Blaine Spring Creek	2015	15,000	Fair
	2016	5,000	Fair
	2017	1,000	Poor
	2018	42,000	Fair
	2019	10,000	Fair
	2020	150,000	Fair
Moore’s Creek	2015	5,000	Fair
	2016	5,000	Fair
	2017	20,000	Fair
	2020	150,000	Fair
Denny Creek	2017	5,000	Good
	2018	2,000	Good

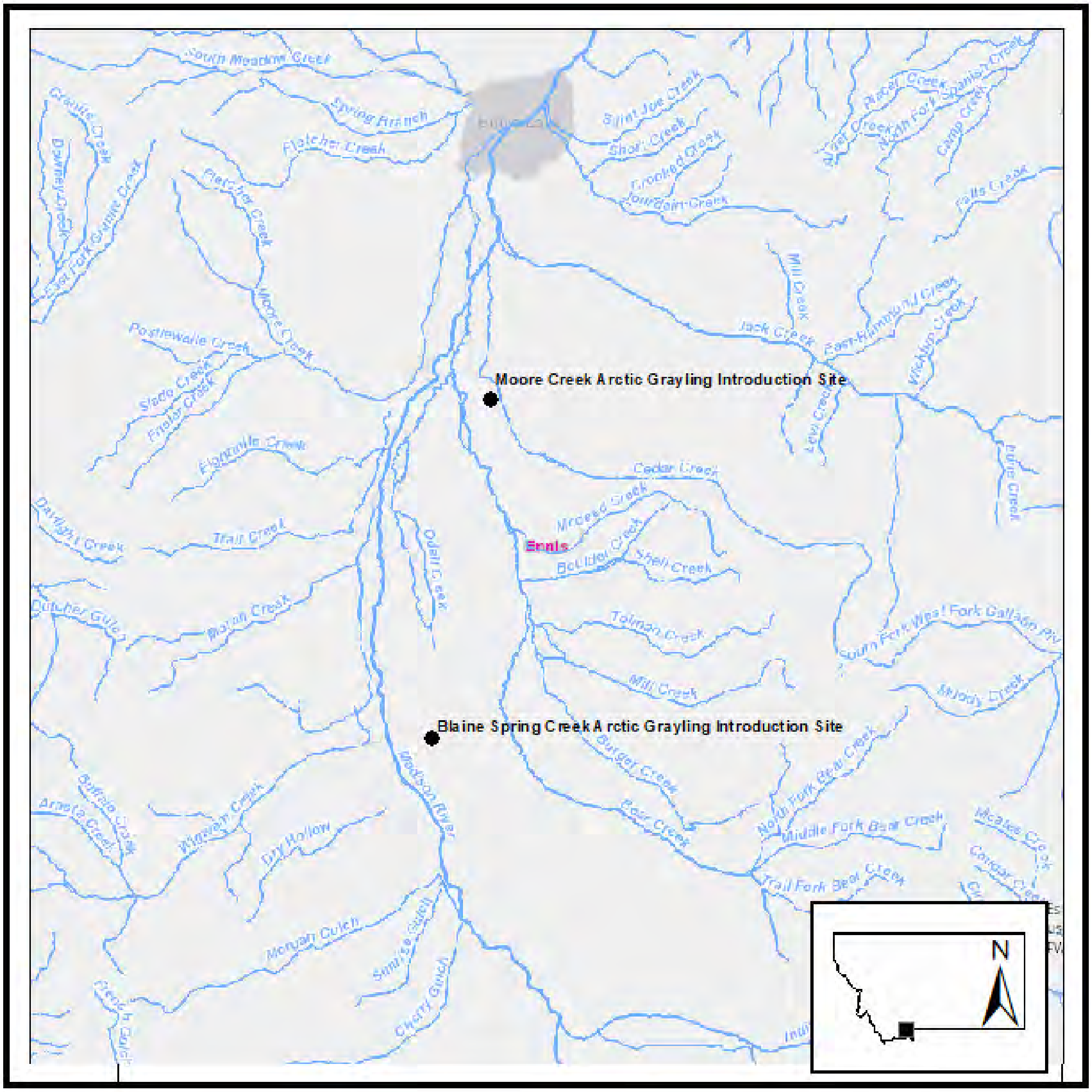


Figure 19. 2020 Arctic Grayling introduction sites Moore and Blaine Spring Creek.

FWP's Fisheries Management Plan calls for the protection and reintroduction of WCT with less than 10 hybridization by non-native fish (i.e., conservation populations) to 20% of historically occupied waters (Montana Statewide Fisheries Management Program and Guide 2018). The MadTAC has granted funding to FWP to pursue these conservation efforts under Articles 408, 409, and 412 of the 2188 project FERC license. WCT PM&E activities in 2020 included evaluation of the Tepee Creek fish barrier and the Ruby Creek WCT restoration project.

The Tepee Creek fish migration barrier is a natural waterfall that was improved to create a 12 ft vertical drop in 2019 by a Forest Service explosives crew. In the Summer of 2020 FWP initiated evaluation of the Tepee Creek fish migration barrier to 1) to examine whether the potential for fish passage exists during high flows, and 2) to directly assess whether fish passage occurs. FWP visited the barrier site during Spring runoff on June 10 and identified several potential issues that could compromise the effectiveness of the barrier. A pinch point occurs directly downstream of the barrier where debris could collect and cause the formation of a pool of sufficient depth for fish to jump over the barrier. Additionally, areas of reduced stream velocity and drop appear to be developing because of fractures in the rock on river left at the barrier site (Figure 20). FWP collected 90 fish above the barrier on July 15 and July 28 by electrofishing. Collected fish were marked with a left pelvic fin clip, moved below the barrier, and released. FWP will evaluate whether low-cost alterations can be made to address potential problems and will survey above the barrier for marked fish in 2021. If low-cost solutions cannot be identified or if upstream migration is still possible WCT recovery efforts in Tepee Creek will likely be abandoned or delayed.

Figure 20**.** Tepee Creek barrier and potential points of failure.

The Ruby Creek WCT restoration project initiated in 2012 with the removal of nonnative Rainbow Trout. Ruby Creek was confirmed to be fishless by sampling for environmental DNA (eDNA) in 2015. Since 2015, 81 genetically pure aboriginal Madison WCT from McClure and Last Chance Creek have been introduced into Ruby Creek. FWP surveyed 3.96 miles of Ruby Creek (Figure 21) on August 26 and 27 to evaluate post-restoration WCT distribution, reproductive status, and density. Surveys were conducted using a backpack electrofisher and all observed fish were netted, measured to the nearest millimeter, fin clipped to collect tissue for genetic testing, and released. A total of 120 WCT of different age classes, including young-of-the-year, were observed (Figure 22). Overall WCT abundance was about 1.6 fish per 100 meters (mean length=248 mm; 95% CI, ±13.0 mm). Fin clips were submitted to University of Montana genetics lab for genotyping to determine whether both donor populations are represented in the Ruby Creek population and which donor populations will be used for future introductions in Ruby Creek. Wild fish transfers from the Last Chance Creek population are scheduled for 2021 pending genetic results. Surveys of Ruby Creek WCT distribution and density will occur in every other year moving forward beginning in 2022.

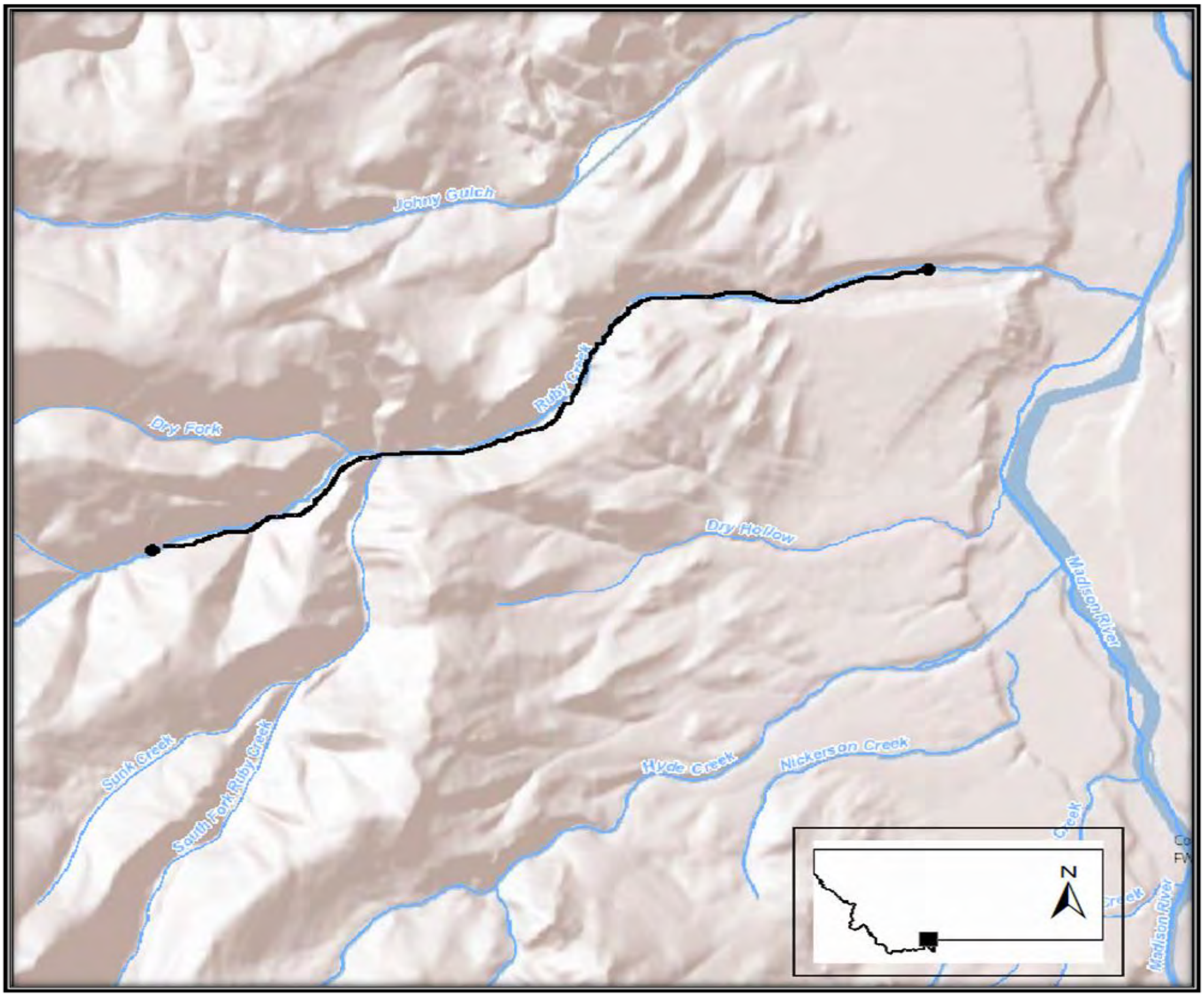


Figure 21. 2020 survey reach of Ruby Creek**.**

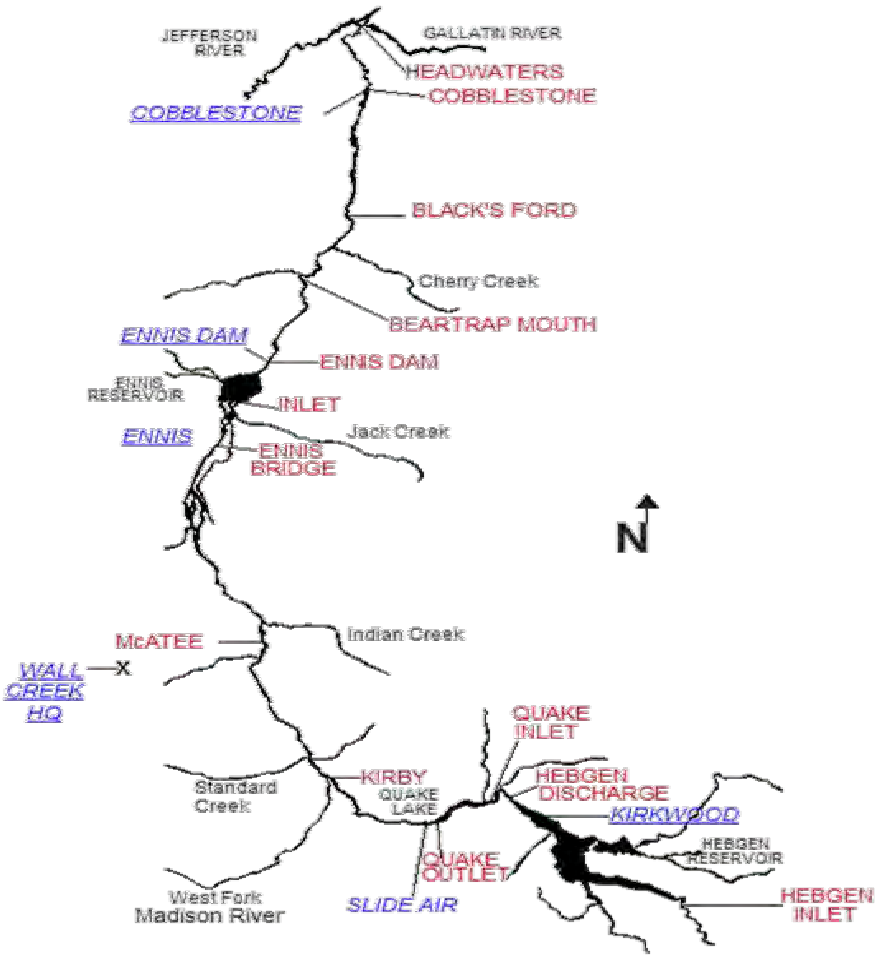
Figure 22. Age classes of WCT including young-of-the-year observed in Ruby Creek in 2020. The Ruby Creek reintroduction effort has been ongoing since 2015.

Article 409- 3) Fish habitat enhancement both in main stem and tributary streams

Previously conducted fisheries monitoring of O'Dell Creek was summarized in Appendix A.

Article 413-Pulse Flows

Temperature affects all living organisms and fish species have specific thermal ranges that are optimal for their persistence. However, 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 ^{o} F. Both 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 (Figure 23) since 1993. Temperature data has been used by FWP as criteria for implementing angling restrictions to reduce mortality of adult trout during periods of thermally induced stress. Angling restrictions are implemented when daily maximum water temperature $\geq 73^{o}$ 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 is comprised of two methods to determine a pulse volume to the delivered to the Lower Madison River: a thermo-dynamic physics model (physics model) and a manual protocol. Pulsed flows are triggered when 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 days forecasted maximum air temperature at



Three Forks (Table 3) to the manual protocol and the physics model to derive the volume of pulse needed for the following day. NWE determines the larger derived pulse of the two methods and directs the operations to release that volume the following day from 6:00 am to noon. Timing of the release is designed to allow for travel time of the water to arrive in the lower Madison River near Black's Ford and Sloan during the late afternoon when daily solar radiation is greatest.

Figure 23. FWP temperature monitoring sites. Air temperature monitoring sites are blue and underlined; water temperature monitoring sites are red.

Table 3. Madison DSS Manual Protocol (Northwestern Energy 2020)

Today's maximum power- house release temperature at the Madison DSS website or USGS McAllister gage on or after 8:30 p.m.	**Tomorrow's predicted maximum air temperature (◦F) and corresponding pulse flows (cfs). Look up predicted high air temperature for the next day at Sloan Station near Three Forks, MT.**		
	>=75 and < 85	>=85 and < 95	>=95 and < 105
Greater than or equal 68 to and less than 69	1150	1150	1400
Greater than or equal to 69 and less than 70	1150	1400	1600
Greater than or equal to 70 and less than 71	1150	1600	2000
Greater than or equal to 71 and less than 72	1400	1600	2100
Greater than or equal to 72 and less than 73	1450	1800	2400
Greater than or equal to 73 and less than 74	1600	2100	2800
Greater than or equal to 74 and less than 75	1800	2600	3000
Greater than 75	2600	3200	3200

Daily maximum water temperatures observed in the upper river were ≥ 73° F on two occasions at the Ennis Bridge and Ennis Reservoir inlet sites (Table 4); however, maximum daily temperatures at these sites did not occur in successive days and did not warrant implementation of angling restrictions. Daily maximum temperatures were ≥73° F at the lower river monitoring sites Bear Trap Mouth, Black's Ford, and Cobblestone, for 25, 30, and 29 days, respectively (Table 4). Since 2000, maximum daily water temperatures at the Black's Ford monitoring site have been ≥73° F an average of 43 times a year causing FWP to regularly implement restrictions that prohibited angling from 2 p.m. to 12 a.m. during Summer months. In 2020, FWP made permanent changes to Madison River angling regulations prohibiting angling between 2 p.m. and midnight from July 15th to Aug 15th from the Warm Springs Day Use Area to the confluence with the Jefferson River (Figure 23).

There were 26 days of pulse flows in 2020. Pulse flows kept maximum daily water temperatures from reaching 80° F at Sloan; however, maximum daily water temperature exceeded 80°F on one occasion at the Cobblestone monitoring site (Table 4). Pulse flows have been implemented an average of 20 days since 2000 and have been effective at moderating maximum daily water temperatures and preventing the occurrence of a thermally induced fish kill in the lower river (Table 5). FWP recommends continued monitoring of Madison River temperatures and that the pulse flow program continue as presently structured.

Table 4. Maximum and minimum temperatures (°F) recorded at monitoring sites in the Madison River Drainage, 2020. Mean temperature is mean daily temperate ± 95% confidence intervals (CI). Days ≥ 73.0 ° F the number of days daily maximum temperatures were at or exceeded 73.0° F, and days ≥ 80.0 ° F are the number of days daily maximum temperatures were at or exceeded 80.0 ° F. NA denotes temperature data was unable to be recovered.

Deployment	**Site**	**Max° F**	**Min° F**	**Mean daily temperature ± 95% CI**	**Days ≥73 ° F**	**Days ≥80 ° F**
Water	Hebgen inlet	NA	NA	NA	NA	NA
	Hebgen discharge	67.7 °	37.0 °	54.4±1.24	0	0
	Quake Lake inlet	NA	NA	NA	NA	NA
	Quake Lake outlet	NA	NA	NA	NA	NA
	Kirby Bridge	70.2°	36.0°	53.6±1.06	0	0
	McAtee Bridge	71.9°	35.7°	54.4±1.00	0	0
	Ennis Bridge	73.2°	39.8°	56.5±1.00	2	0
	Ennis Reservoir Inlet	74.1°	40.4°	56.3±0.91	2	0
	Ennis Dam	74.2°	41.6°	60.9±1.11	4	0
	Bear Trap Mouth	77.6°	40.5°	61.2 ±1.07	43	0
	Blacks Ford	79.1°	39.1°	60.5 ±1.09	50	0
	Cobblestone	80.1°	39.5°	61.7 ±1.05	54	1
	Headwaters S.P. (Madison mouth)	NA	NA	NA	NA	NA

Table 5. The number of days that maximum daily water temperatures at Black's Ford have been ≥73°F, ≥ 80.0° F, and the number of days pulse flows occurred 2000-2020.

Year	Days ≥73° F at Black's Ford	Days ≥ 80.0° F at Black's Ford	Number of days pulsing occurred
2000	44	0	29
2001	14	0	13
2002	39	2	18
2003	61	2	39
2004	37	0	12
2005	40	0	17
2006	49	4	15
2007	55	2	43
2008	28	0	0
2009	34	0	8
2010	29	0	3
2011	27	0	0
2012	50	0	0
2013	69	1	35
2014	42	0	42
2015	50	7	11
2016	51	0	26
2017	57	0	36
2018	38	0	36
2019	40	0	10
2020	50	0	26

Article 419-Coordinate and Monitor Flushing Flows

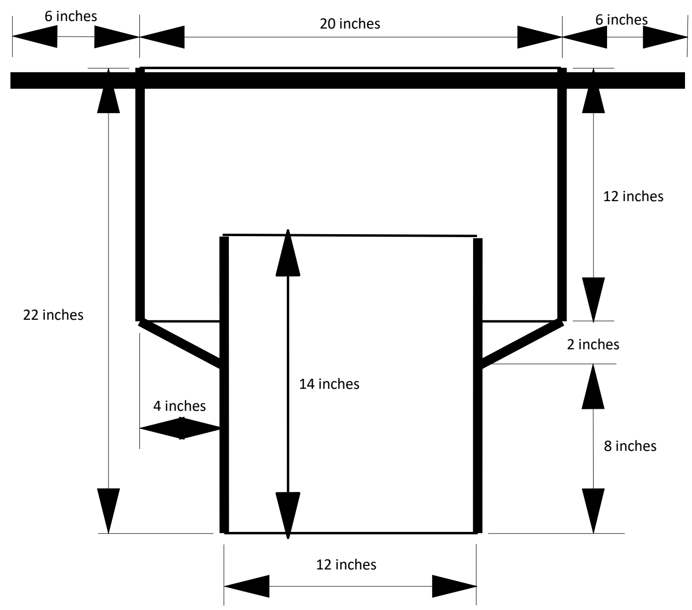
Article 419 of the 2188 FERC license requires that NWE develop and implement a plan to coordinate and monitor flushing flows in the Madison River downstream of Hebgen Dam. A flushing flow by design should be large enough to mobilize streambed materials and produce scour in some locations and deposition in other locations. This is a natural occurrence in unregulated streams and rivers that renews spawning, rearing, and food producing areas for fish as well as providing fresh mineral and organic soil for terrestrial vegetation and other wildlife needs. Impoundments such as dams interrupt the natural hydrograph of rivers and high flow events that are responsible for the replenishment and cleaning of 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 ≤0.84mm) in spawning gravels can adversely affect the survival of embryos and emergence of fry by inhibiting the delivery of oxygenated water and reducing the amount of interstitial space required for development (McNeil and Ahneil 1964, Kondolof 2000). Accordingly, the goal for the flushing flow program is to maintain ≤10% fines in the upper Madison River and a target of ≤15% in the lower Madison River with the understanding that release of 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 # 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 outflow from Hebgen Dam to no more than 10 percent 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 6,532.26 msl by June 20. Several approaches have been implemented to evaluate the efficacy of flushing flows to recruit and rejuvenate spawning gravels, and maintain % fine sediment thresholds under current operational constraints, including redd counts, core sampling, and scour chains.

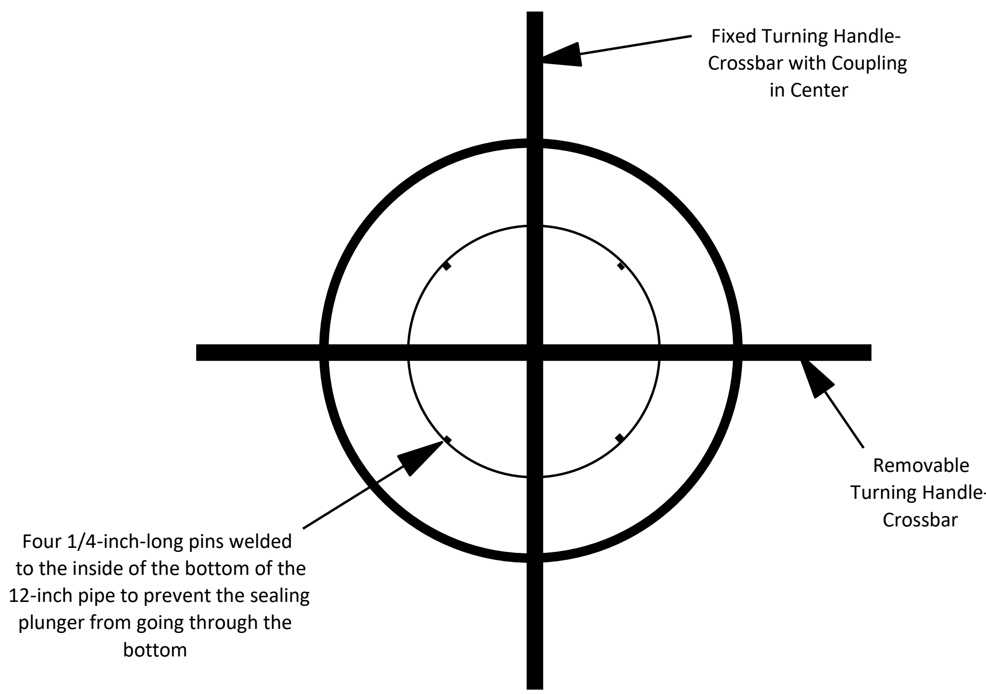
A redd is a nest constructed in the streambed by salmonids where fertilized eggs are deposited and develop until fry emerge from the gravel. Gravels selected for redd construction typically have a median diameter ≤10% of the female's body size, can be easily excavated, and contain minimal amounts of fine sediment and organic debris (Chambers et. al 1955, Kondolf and Wolman 1993). Sediment core sampling at the Kirby, Ennis, Norris, and Greycliff monitoring sections has occurred annually since 2002. These sites were selected to represent conditions in the upper (Kirby & Ennis) and lower (Norris & Greycliff) Madison River. Sediment core data provides an index of relative spawning habitat suitability during years with and without flushing flows. Redd counts were initiated in 2012 to ensure complementary substrate sampling (i.e., core samples, scour chains) occurs in actual spawning habitats.

Redd counts were done by walking in an upstream direction and visually identifying streambed disturbances consistent with redd morphology. 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 24). The number, physical dimensions, and location of individual redds within each monitoring section were recorded. Core samples were collected with a 12-inch McNeil core sampler (Figure 25) in substrate previously identified as spawning habitat during redd counts. The core sampler was manually drilled into the substrate to a depth of 8 inches. Substrate from within the 12"x 8" area was removed, dried, and sorted using a sieve method. The percent composition of the sample was then calculated according to particle size.

Figure 24. Redd (nest) at the Norris redd counting site. Pit is denoted with the X and black arrow shows the direction of stream flow over tail spill.



Cross-Section



Top View

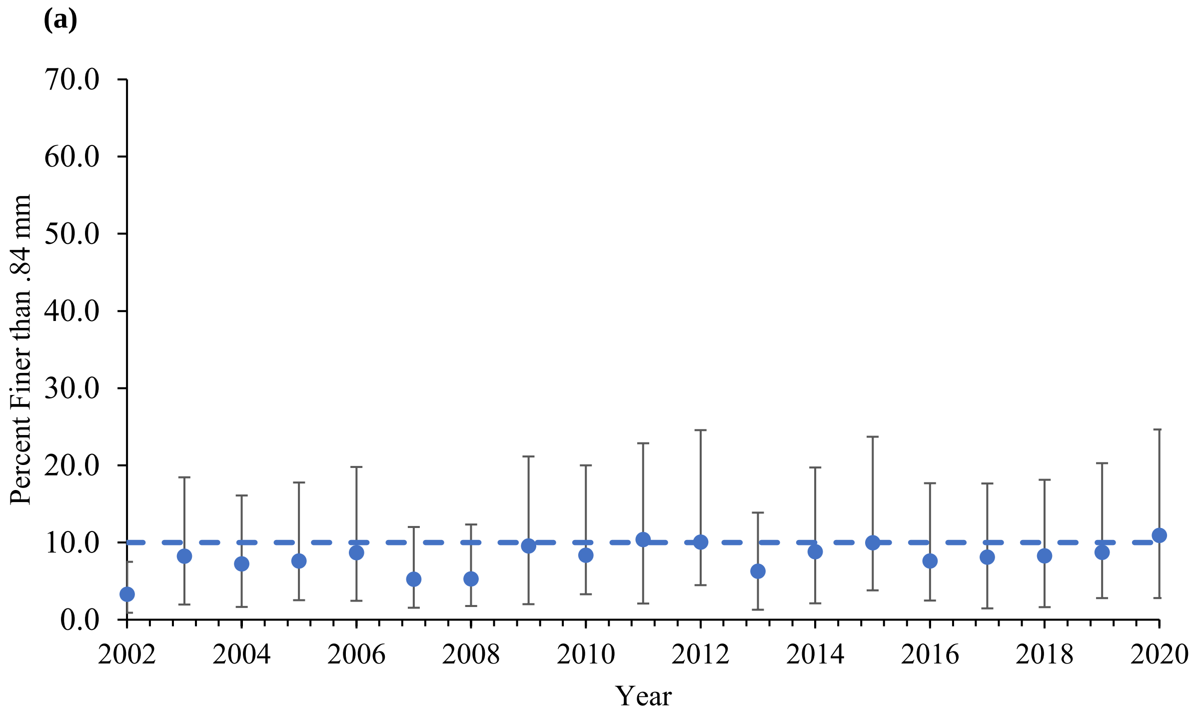
Figure 25. Schematic of 12-inch diameter substrate sampler, modeled after the original 6-inch diameter sampler developed by McNeil and Ahnell (1964).

Two sample *t*-tests were conducted at α =0.05 to test whether the mean number of redds differed in years with and without flushing flows and 95% CI's were calculated for the mean percent fines ≤ 0.84 mm in core samples from the upper river monitoring sites (Kirby, Ennis) and the lower river monitoring sites (Norris and Greycliff). There was no significant difference in the number of redds between years with and without flushing flows; however, sparse redd data and few flushing flows precluded meaningful statistical inference at any of the sites (Table 6). The last three years of Fall Brown Trout redd data for the Norris site are the lowest recorded since counts were initiated in 2013. It is unclear if this trend is because of flushing flow implementation or related to an observed downward trend in the number of Brown Trout in the lower river. Median values for percent fines ≤0.84 mm in the upper river ranged from 3.7% (2002) to 10.7% (2020) and from 8.5% (2007) to 22.9% (2014) in the lower river (Table 6). There were no statistical differences in the percent fines ≤0.84 mm observed between years with and without a flushing flow (Figure 26).

Inconsistencies in the timing and frequency of counts likely influenced the number of redds observed between years (Table 6). Additionally, flushing flows have had no significant effect on the percent fines present in spawning habitat. Therefore, it is recommended that goals be established for conducting redd counts that differs from the original intent under the flushing flow program with protocols for redd monitoring be refined to develop a more meaningful data set to meet the newly established goals and that core sampling be expanded to include spawning habitat associated with side channels and other geomorphic features to better evaluate the flushing flow program.

Table 6. Median % fines ≤0.84mm ± standard deviation (SD) and Brown (LL) and Rainbow (RB) Trout redds in the Upper and Lower Madison River, incidence of a NWE flushing flow event, and peak flow in cubic feet per second (CFS) at USGS gage 06041000.

	Upper Madison River			Lower Madison River				
Year	**% fines<.84 mm median ±SD**	**LL Redds**	**RB Redds**	**% fines<.84mm median ± SD**	**LL Redds**	**RB Redds**	**NWE flushing flow**	**Peak Flow CFS USGS gage 0604100**
1995	6.6 ±4.4			15.9 ±5.4				7360
1996	5.8 ±1.2			8.3 ±4.5				7980
1997	7.4 ±3.9			9.8 ±4.5				7910
1998								6820
1999								5500
2000								4450
2001								2460
2002	3.7 ±1.5			9.6 ±4.1			No	5180
2003	8.6 ±3.2			10.0 ±5.7			No	4670
2004	7.6 ±2.7			10.7 ±5.2			No	3440
2005	6.9 ±4.1			13.5 ±8.0			No	4470
2006	9.7 ±3.7			13.5 ±5.0			Yes	5390
2007	5.1 ±2.5			8.5 ±4.0			No	3400
2008	5.4 ±2.9			9.7 ±4.8			Yes	5390
2009	9.3 ±3.2			12.4 ±11.7			No	4050
2010	7.0 ±5.3			11.9 ±5.7			No	5540
2011	10.1±3.4			13.8 ±8.2			Yes	7100
2012	6.8 ±7.2			15.9 ±5.4			No	4810
2013	5.8 ±2.1	8	39	18.8 ±18.7	36	26	No	2850
2014	8.4 ±3.4	39		22.9 ±13.7	21		No	5560
2015	8.3 ±6.1	39	42	12.6 ±8.3	29	34	No	4490
2016	7.1 ±4.0	17	78	14.7 ±10.2	40	48	No	3180
2017	7.9 ±2.4	14	54	11.7 ±5.7	46	56	No	4520
2018	8.7±2.6	6		11.4±4.8	20		Yes	6510
2019	7.2±4.5	5	16	10.3±11.3	14	1	No	4670
2020	10.5±4.5	23	22	19.2±6.5	16	59	Yes	6180



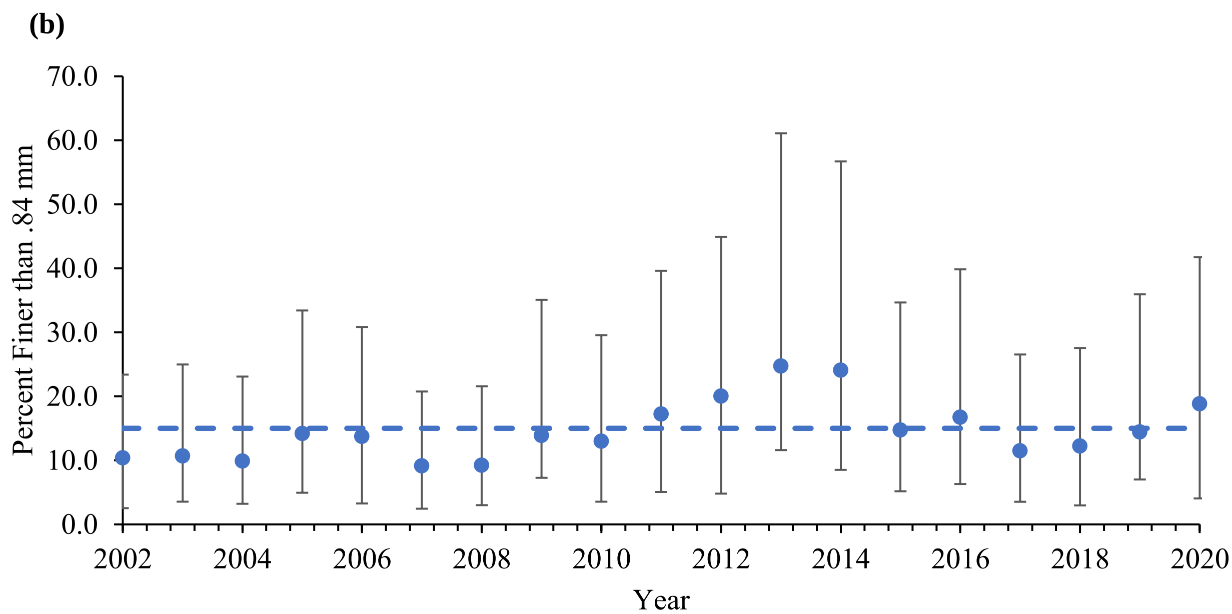


Figure 26. Mean percent fines and 95% CI's of <0.84 mm in core samples from the Madison River in the **(a)** Upper River where the blue dashed line is the 10% threshold for fines and **(b)** Lower River where the blue dashed line is the 15% threshold for fines.

Article 419-Flushing Flows Effect on Fish

We evaluated whether flushing flows under current operational constraints are beneficial or detrimental to fish recruitment and survival using FWP abundance estimates from three long-term monitoring sections (Pine Butte, Varney, and Norris) and USGS hydrograph data from 2000 to 2020. Abundance of age-1 fish was estimated in the Upper and Lower river based on Madison River length-at-age data (Table 7; Vincent 1971). We used linear regression models to determine whether abundances of age-1 Brown and Rainbow Trout in the Pine Butte and Varney sections were correlated with the occurrence of a flushing flow, peak discharge, or days discharge was ≥3,500 cfs at the USGS Kirby gage #0603880 at time periods t and t_{-1} and whether abundances of age-1 Brown and Rainbow trout in the Norris section were correlated with occurrence of a flushing flow or peak discharge at USGS gage #06041000 at t_{-1} and t_{-2}. The lag in time periods tested differed between Upper and Lower river sites because abundance estimation occurs in the fall in the Upper River and in the spring in the Lower River; post-flushing flow effects in the Lower River can be first assessed one year later than in the Upper River. A two-sample *t*-test was used to compare age-1 Brown and Rainbow Trout abundances between years when flushing flows did and did not occur at time t, t_{-1} and t_{-2} to determine whether flushing flows improved habitat conditions and produced strong cohorts. We used linear regression models to determine whether the proportion of trout ≥ 406mm in the Pine Butte and Varney section were correlated with flushing flows, peak discharge and days discharge was at or exceeded 3,500 cfs at the USGS Kirby gage #0603880 at time periods t and t_{+4} and whether the proportion of trout ≥406mm in the Norris section was correlated with occurrence of a flushing flow and peak discharge at USGS gage #06041000 at t_{-1} and t_{-4} to evaluate whether flushing flows improved habitat conditions for large trout. We considered time t and t_{-1} to assess the direct effects of a flushing flow on large trout and time t_{-4} to evaluate whether flushing flows produce strong cohorts that ultimately recruit into the adult population. A two-sample *t*-test was used to compare the proportion of trout ≥406mm at t_{-1} or t_{-4} between years with and without flushing flows.

Table 7. Madison length-at-age for Rainbow and Brown trout in the upper river (Varney and Pine Butte) and the lower river (Norris; Vincent 1973).

	Rainbow Trout			Brown Trout		
Location	**age-1**	**age-2**	**age-3+**	**age-1**	**age-2**	**age-3+**
Pine Butte and Varney	157<249 mm	249-348 mm	≥348 mm	157<-249 mm	249-361mm	≥360 mm
Norris	152<226 mm	226-305 mm	≥305 mm	152<-226 mm	226-328 mm	≥328 mm

Fish abundances were positively correlated with longer duration high flow events but not with flushing flow occurrence or peak flows. There were no significant differences between age-1 Brown or Rainbow Trout abundances and the occurrence of a flushing flow in any section. Similarly, there was no significant correlation between peak discharge and age-1 Brown or Rainbow Trout in any section, suggesting that peak discharge was not a population driver. However, there was a significant relationship between days ≥3500 cfs and age-1 Rainbow Trout abundances at time t (R^2=30.3%; *P*=0.01) in Pine Butte and age-1 rainbows at time t_{-2} and days ≥3500 cfs in the Varney section (R^2=47.5%; *P*<0.01). There were no significant correlations between abundances of age-1 Brown Trout and days ≥3500 cfs in the Pine Butte or Varney sections, no significant relationships between days ≥3500 cfs, or peak discharge and the proportion of fish ≥406mm at time t_{-1} or t_{-4} in any of the monitoring sections, and no statistical differences in the proportion of fish ≥406 mm at time t_{-1} or t_{-4} in any section related to the occurrence of a flushing flow. This suggests that duration of high flows is more important to relative survival of young Rainbow Trout than occurrence of flushing flow or peak flow under current operational constraints and that flushing flows do not affect large trout. Inference is limited by sparse data; planned flushing flows occurred in only four years and days ≥3500 cfs occurred in five of the twenty years used for analysis and had a relatively small range (1 to 6). There is also the potential that young fish were simply displaced from upstream habitat by high flows rather than experiencing higher survival. To better understand this dynamic, future flushing flows should emphasize extending the duration ≥3500 cfs to more than 6 days. This would require a new protocol for the flushing flow program and associated volume runoff calculations to accommodate the 3500 cfs volume for 6 days instead of the current 3 days.

Overall, considering flushing flows occurred in only 5 years, the narrow scope of monitoring to evaluate the effectiveness, and the present operational constraints for implementing a flushing flow it is difficult to make inference about their effectiveness at improving habitat conditions throughout the river.

2020 Flushing Flow Monitoring

Objectives and Methods

A flushing flow occurred in 2020 and monitoring was expanded to discern whether it was able to induce localized scour and pool maintenance at boulders, transport sediment and maintain pools and riffles in side channels, and recruit gravel from stream banks in the mainstem. Monitoring considered abundance goals for trout in FWP annual monitoring sections near Pine Butte, Varney, and Norris (Figure 1; Duncan et al. 2020) and Article 409 of the 2188 project. Duncan et al. hypothesize inadequate maintenance and development of habitats under current operational constraints in the Madison River may limit trout abundances. FERC article 409 of the 2188 License calls for *"Fish habitat enhancement both in mainstem and tributary streams, including enhancement for all life stages."* Fish abundances are often limited by quality and quantity of available habitat. Boulders tend to increase velocity and direct flow creating localized bed scour around the rock, producing a scour pool and a depositional area of sorted bed material downstream from the boulder. Scour pools provide in stream cover and reduced water velocities for fish and depositional areas associated with boulders can be utilized for spawning (Fischer and Klingeman 1984). Side channels provide spawning and rearing habitat in riverine systems and a source of gravel recruitment resulting from bank and stream bed scour as velocities increase. Scour of banks can provide recruitment of new gravels into a stream system and create undercut banks (Lawler 1993). This process could be important to the recruitment of new gravel for spawning in sections of the river where less static geomorphic conditions exist. Therefore, the specific objectives of 2020 monitoring were to evaluate 1) localized scour and pool maintenance at boulders, 2) the effects of flushing flow on sediment transport in side channels via pool and spawning gravel maintenance, and 3) gravel recruitment from stream banks in the mainstem.

Three monitoring sections, two in the upper river and one in the lower river, were selected. Monitoring sections integrated FWP annual abundance estimate sections with NWE flushing flow monitoring sections (Figure 1). Monitoring sites included areas where localized scour could potentially be induced by boulders and side channels where hydrogeomorphic processes may have a greater influence during high flows. Pre-flushing flow monitoring occurred from May 26-29 and post-flushing flow monitoring from June 29-July 2.

Boulders

Four boulders were selected in the Pine Butte-Kirby section and one in the Norris section to evaluate localized scour during the flushing flow. Monitoring consisted of installing scour chains on the upstream and downstream pool crests of each boulder (Figure 27; Lisle and Eads 1991). Stream bed elevation at each scour chain and the deepest part of the pool was measured using a self-leveling laser and stadia rod from an established benchmark. After the flushing flow elevations were resurveyed and the number of exposed links on the scour chains counted to corroborate elevation measurements.

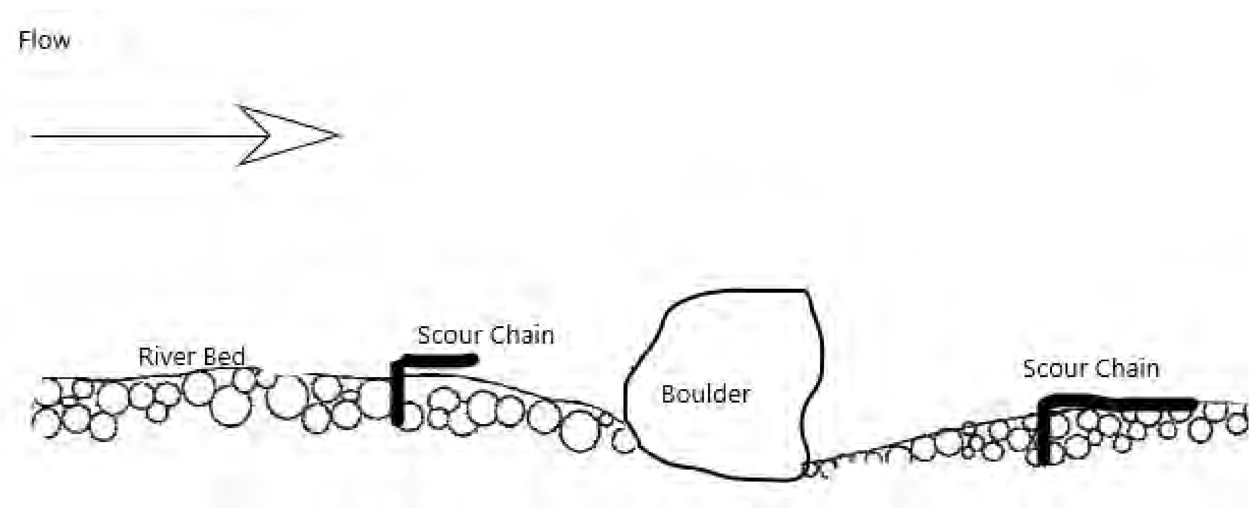


Figure 27. Scour chain placement

A substrate sample was collected at each site to evaluate sediment levels in the depositional area on the downstream side of boulders. Samples were collected with a shovel using methodology described by Grost and Hubert (1991). The shovel blade was oriented downstream and inserted vertically into the stream bed to a target depth of 20 cm, lifted until parallel with the stream bed, and allowed to drain for 2-3 seconds before being placed in a five-gallon bucket (Figure 28).

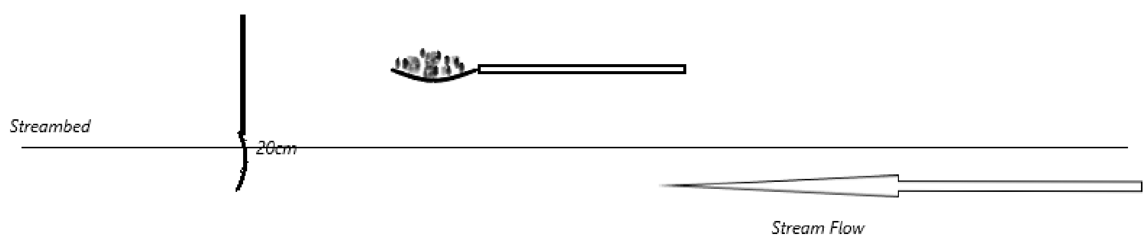


Figure 28. Substrate sampling method adopted from Grost and Hubert 1991.

Side Channels

To evaluate the effects of flushing flow on sediment transport in side channels, scour chains were installed at five locations in the Varney-Ennis section and two in the Norris section. Chains were deployed at the downstream crest of pools and elevations recorded as described above.

Additionally, a measurement of total channel width was recorded at the time of installation. Substrate samples were collected using the shovel method at each site to evaluate sediment levels in the depositional area downstream of pools. Additional samples were collected throughout the Varney-Ennis sections at sites visually estimated to have sediment levels of ≤10% and ≥15% to evaluate sediment transport.

Mainstem

To assess the extent of scour on and potential gravel recruitment from stream banks resulting from flushing flows, bank pins were installed in three randomly selected sites in the Varney-Ennis section (Figure 1). A 4-foot length of ½" rebar was inserted horizontally into the stream bank, leaving 3-4 inches protruding from the surface (Figure 29). Two pins were inserted at each site to account for the degree of bank scour at different heights from the water surface. The lowest pin was set at the wetted edge of the stream and the upper pin was set 12 inches above the lower pin. Scour was quantified by taking a measurement from the end of the rebar to the vertical surface of the bank before and after the flushing flow (Figure 29; Lawler 1993).

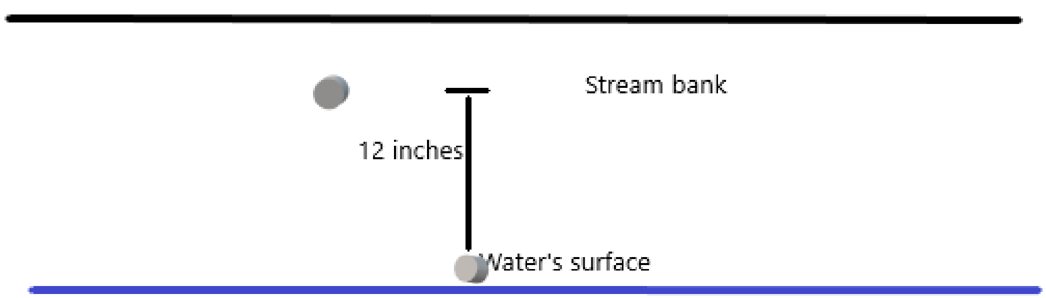


Figure 29. Bank Pin installation

Standard Monitoring

Scour chains were deployed at established NWE monitoring sites in the mainstem Madison at Ennis and Norris (Figure 1). Additionally, three substrate samples were taken at NWE monitoring sites as a control for particle distribution in areas of documented salmonid spawning in both the upper and lower river.

Results

NWE began increasing outflows from Hebgen Dam by 10% per day from May 27 to June 5. Discharges increased from May 27-29 as follows: Kirby gage (USGS 06038800) 1,380 cfs-2,180 cfs, Varney gage (USGS 0604000) 2,000-3,400 cfs, and McAllister gage (USGS 0604100) 2,300 cfs-3,780 cfs. Flows at Kirby peaked June 7 at 3,640 cfs and at Varney and McAllister on June 1 at 5,920 cfs and 6,110 cfs, respectively. On June 8 NWE began reducing flows out of Hebgen

Dam (Figure 30). The magnitude and duration of the 2020 flushing flow similar to those conducted in previous years (Table 8).

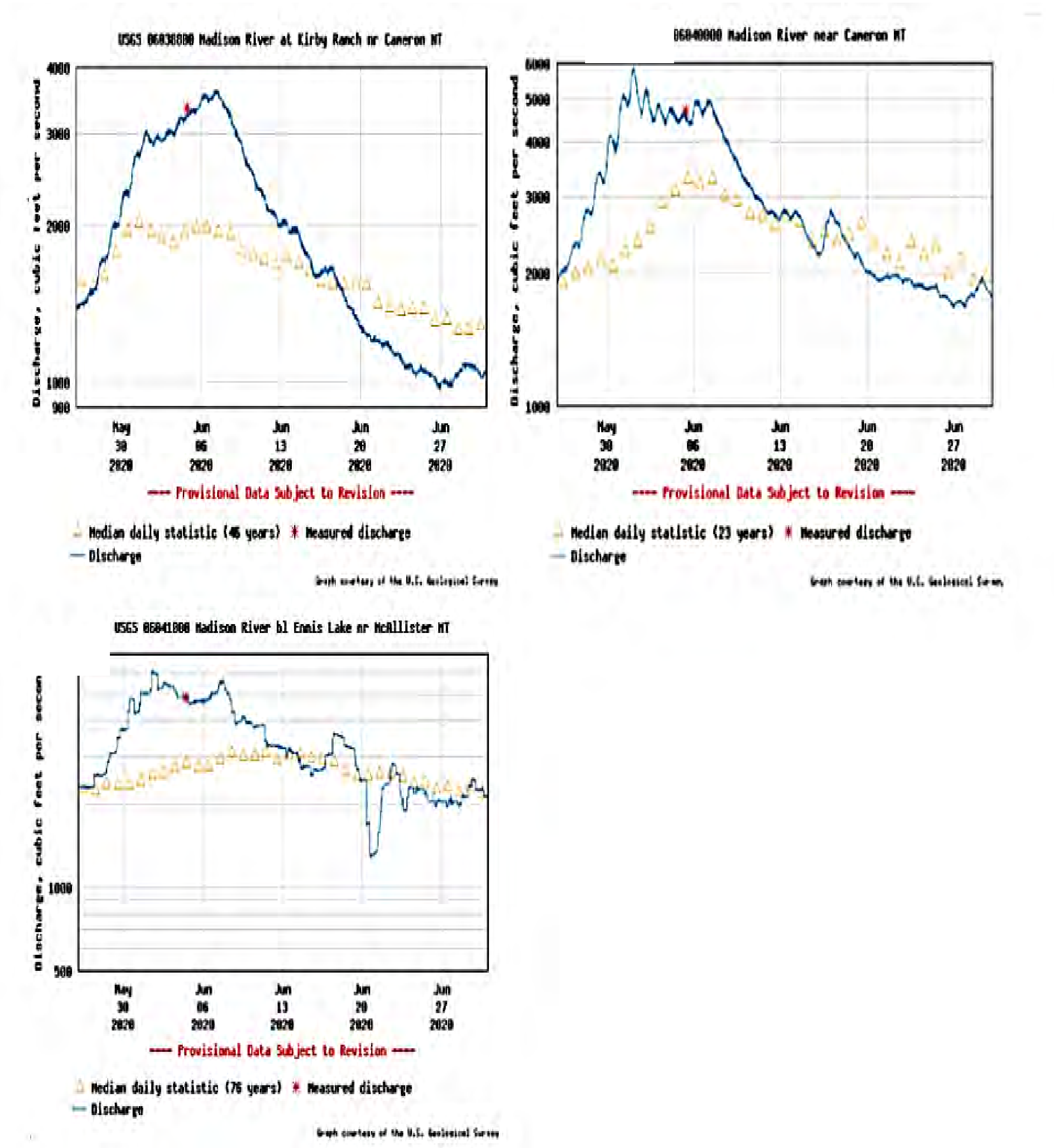


Figure 30. Discharge in cfs at the Kirby gage (USGS 06038800) gage May 26-June 29, the Varney gage (USGS 06040000) May 26-June 29 and, the McAllister gage (USGS 0604100) May 26-June 29.

Table 8. Peak discharge in cubic feet per second (cfs) measured at the McAllister gage (USGS 0604100) in years when a flushing flow was implemented on the Madison River.

Year	Discharge in cfs
2006	5,390
2008	5,390
2011	7,100
2018	6,510
2020	6,110

Substrate monitoring was hindered by developing and implementing the additional monitoring too close to the actual flushing flow when flows were already relatively high and turbid. At the time of deployment, spring runoff in Madison River tributaries was underway, which affected water clarity, river stage, and discharge (Figure 31). Substrate samples were going to be collected with a McNeal substrate sampler; however, depth and turbidity made site selection difficult and reduced the effectiveness of the McNeal sampler. Consequently, the potentially coarser shovel method was alternatively used to collect substrate samples. The shovel could be used as a probe to identify substrate type, was easy for one person to operate, and the approach lent itself to deeper water conditions (Pritchett and Pyron 2011).

Figure 31**.** Water conditions at Varney June 1, 2020.

Boulders

Localized scour and deposition occurred at all boulder sites and associated pools. All downstream crest locations showed a gain in elevation indicating deposition occurred during the flushing flow. The number of scour chain links exposed generally coincided with observed elevation changes; if scour occurred more links were exposed and if deposition occurred less links were exposed (Table 9). Analysis of substrate samples collected from depositional areas on the downstream side of boulders before and after the flushing flow has not been completed.

Table 9. Change in feet for chain/crest elevation and mid pool elevations adjusted for measurement error and scour chain links exposed pre and post flushing flow at boulder monitoring sites in Pine Butte-Kirby (PB) and Norris. NA is chain not recovered or unable to determine amount of deposition or scour.

	Chain/crest change in elevation		**Mid pool changes in stream bed elevation**		**Scour chain links exposed**			
Location	**Upstream**	**Downstream**	**Upstream**	**Downstream**	**Pre-Upstream**	**Pre-Downstream**	**Post Upstream**	**Post Downstream**
PB rock 8-1	-0.9	+0.23	-0.73	-0.21	25	23.5	NA	0
PB rock 13-2	-0.43	+0.51	+0.09	-0.31	19	22	27	0
PB rock 62-3	NA	+0.93	NA	+1.24	NA	22.5	NA	8
PB rock 72-4	+0.22	+0.31	+0.09	+0.21	20	NA	0	NA
Norris rock1	+0.52	+1.73	-0.07	+0.28	21	13	4	NA

Side Channels

The greatest scour and deposition in side channels occurred in the Varney-Ennis section at locations with a channel width of approximately 50 feet or less (Table 10). The number of scour chain links exposed generally coincided with observed elevation changes, except for the Norris 1 site. Measurements indicated a decrease in both pool depth and crest elevation, but the number of chain links exposed at recovery suggested pool crest deposition (Table 10). Evaluation of particle distribution in substrate samples has not been completed.

Table 10**.** Change in elevation (ft) at side channel and main channel for chain/crest and mid pool elevations adjusted for measurement error at Varney-Ennis and Norris monitoring sites. NA is chain not recovered or measurement not taken. MC is main channel where no channel width measurement was taken.

Location	**Channel width**	**Chain/crest change in elevation**	**Mid Pool changes in stream bed elevation**	**Scour chain length exposed**	
				Pre	**Post**
Varney-Ennis 29-1	87.3	NA	NA	NA	NA
Varney-Ennis 25-2	59.6	+0.08	+0.06	22.5	13
Varney-Ennis 21-3	22.2	+0.11	+0.24	22.5	6
Varney Ennis 23-4	31.7	-0.17	-0.24	18	NA
Varney -Ennis 6-5	50.9	+0.99	+1.59	22	0
Varney-Ennis NWE 1	MC	+0.02	+0.37	20	20
Norris 1	19.3	-0.12	-0.04	17	0
Norris 2	MC	+0.08	NA	15	15
Norris 4	MC	-0.05	NA	NA	NA

Mainstem

Scour chain sites at Varney-Ennis NWE 1 and Norris 2 showed little elevation change, which was corroborated by the scour chains. Norris 4 was not recovered but the elevation measurement suggests that minimal scour occurred here too. Bank pins indicated scour was induced during the 2020 flushing flow (Table 10). Though little scour was observed at the Varney-Ennis banks 1 and 2, 10 inches of bank scour occurred at Varney-Ennis 3 (Table 11).

Table 11. Bank pin change in inches pre and post flushing flow Varney-Ennis section.

Location	Pin change inches Water's surface	 12 inches above
Varney-Ennis Bank 1	+1.0	-0.1
Varney-Ennis Bank 2	-1.1	0.0
Varney-Ennis Bank 3	-10.0	-5.4

Standard Monitoring

No scour or elevation change at the mainstem NWE sites was observed.

Conclusions

Flushing flows may have benefits to mainstem and side channel habitats that are not captured by the historic monitoring program. Monitoring of stream bed mobilization with scour chains in the mainstem at NWE monitoring sites in the Ennis and Norris sections were consistent with NWE findings since 2014 that have shown no substantial scour or fill occurring at these sites during flushing flows. Results of the 2020 monitoring suggests that flushing flows may beneficially maintain and enhance habitats associated with geomorphic features such as boulders or those found in side channels where increased flows in conjunction with smaller channel dimensions can more efficiently mobilize stream bed materials. It is uncertain whether substrate samples collected pre and post flushing flow will show an increase or decrease in the percent fines ≤0.84mm. Analysis of these samples may be helpful to further characterize the effect of flushing flows. A broader more comprehensive assessment of flushing flow magnitude, substrate content and availability, and reach-specific geomorphic process is needed to understand the potential for flushing flows to improve fish habitats and the degree to which they can be used as a management tool.

High flows hampered the amount and scope of monitoring originally planned. Five sections on the Madison were originally selected for monitoring; however, efforts were limited to three because of changing stream conditions and water clarity. Monitoring efforts should continue; however, a more concise protocol and well-developed schedule for pre flushing flow measurements and installation of monitoring devices needs to be developed. Moreover, monitoring in more diverse habitats may better clarify the full benefit of flushing flows. At the very least, the monitoring conducted in 2020 should result in discussion and further investigation of how flushing flows may be used to enhance or maintain fish habitat features other than spawning gravels.

Literature Cited

Beck, S.M., M. Tiedemann., and A. Shelly. 2018. Flushing flow needs in the Madison River, Montana 2013 through 2017 stream bed and aquatic invertebrate monitoring results and comparison with results from 1994 through 2012 FERC project 2188 article 419 of project 2188 license. Northwestern Energy R2 Resource Consultants, Inc.

Behnke, R. 1992. Native Trout of Western North America. American Fisheries Society Monograph 6, American Fisheries Society, Bethesda, Maryland. 1992.

Brown, P. 2004. Predicting growth and mortality of Brown Trout *(Salmo trutta)* in the Goulburn River after mitigation of cold-water discharge from Lake Eildon, Australia, New Zealand Journal of Marine and Freshwater Research, 38-2, 279-287, DOI: 10.1080/00288330.2004.9517237

Bunte, K. and S. Abt. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel-and cobble-bed streams for analysis in sediment transport, hydraulics, and streambed monitoring. United Sates Department of Agriculture Rocky Mountain Research Station, General Technical Report RMRS-GTR-74, Rocky Mountain Research Station, 240 West Prospect Road, Fort Collins, CO 80526.

Byorth, P. and B. Shepard. 1990. Ennis Reservoir/Madison River Fisheries Investigations. Montana Fish, Wildlife, & Parks Final Report to Montana Power Company. 90 pages.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds, Transactions of the American Fisheries Society, 117:1-21. American Fisheries Society, Bethesda, Maryland. 1998.

Carlson, R.E. 1977. A Trophic State Index for Lakes. Limnology and Oceanography 22(2): 361-369.

Clancey, P. 1995. Madison River/Ennis Reservoir Fisheries. 1994 Annual Report to Montana Power Company, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. May 1995.

Clancey, P. 1996. Madison River/Ennis Reservoir Fisheries. 1995 Annual Report to Montana Power Company, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. February 1996.

Clancey, P. 1997. Madison River/Ennis Reservoir Fisheries. 1996 Annual Report to Montana Power Company, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. March 1997.

Clancey, P. 1998a. Madison River/Ennis Reservoir Fisheries. 1997 Annual Report to Montana Power Company, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. June 1998.

Clancey, P. 1999. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 1998 Annual Report to Montana Power Company, Environmental Division, Butte, and Turner Enterprises, Inc., Gallatin Gateway, from Montana Fish, Wildlife, & Parks, Ennis. April 1999.

Clancey, P. 2000. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 1999 Annual Report to PPL Montana (formerly Montana Power Company), Environmental Division, Butte, and Turner Enterprises, Inc., Gallatin Gateway, from Montana Fish, Wildlife, & Parks, Ennis. April 2000.

Clancey, P. 2002. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2001 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. June 2002.

Clancey, P. 2003. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2002 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. March 2003.

Clancey, P. 2004. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2003 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. May 2004.

Clancey, P. and T. Lohrenz. 2005. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2004 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. April 2005.

Clancey, P. 2006. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2005 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. June 2006.

Clancey, P. 2007. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2006 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. June 2007.

Clancey, P. 2008. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2007 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. July 2008.

Clancey, P. 2012. Environmental Assessment for the Reintroduction of Native Westslope Cutthroat Trout in Ruby Creek by Removal of Non-native Rainbow Trout with

Electrofishing and Rotenone, 43 pages. Montana Fish, Wildlife, & Parks, Ennis. May 2012.

Clancey, P. 2014. Southwest Montana Arctic Grayling Reintroductions Environmental Assessment. 25 pages. Montana Fish, Wildlife & Parks, Ennis. January 2014.

Clancey, P. and D. Downing. 2001. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2000 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. April 2001.

Clancey, P. and T. Lohrenz. 2009. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2008 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. August 2009.

Clancey, P. and T. Lohrenz. 2010. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2009 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. June 2010.

Clancey, P. and T. Lohrenz. 2011. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2010 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. May 2011.

Clancey, P. and T. Lohrenz. 2012. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2011 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis. May 2012.

Clancey, P. and T. Lohrenz. 2013. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2012 Annual Report to PPL Montana, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. May 2013.

Clancey, P. and T. Lohrenz. 2014. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2013 Annual Report to PPL Montana, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. May 2014.

Clancey, P. and T. Lohrenz. 2015. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2014 Annual Report to PPL Montana/Northwestern Energy, Environmental Division, Butte, from Montana Fish, Wildlife, & Parks, Ennis. February 2015.

Duncan, M. et al. 2000. Madison management goals. Montana Fish, Wildlife and Parks, Region 3 Fisheries Division, Bozeman, MT. 59717

Federal Energy Regulatory Commission. 2000. Order Issuing New License, Project No. 2188-030. Issued September 27, 2000.

Fisher, A., & Klingeman, P.C. (1984). Local Scour at Fish Rocks. Water for resource development, conference proceedings, ASCE, Coeurd'Alene, Idaho.

Gillespie, B.R. et. al .2015. A critical analysis of regulated river ecosystem responses to managed environmental flows from reservoirs. Freshwater Biology, 60: 410-425. 2015. Fisheries Society of the British Isles. Liverpool, England.

Graham, R.J. 1955. Biology of the Utah chub in Hebgen Lake, Montana. Master's thesis. Montana State University.

Grost, R. T., W. A. Hubert, and T. A. Wesche. 1991. Field comparison of three devices used to sample substrate in small streams. North American Journal of Fisheries Management 11:347-351.

Jobling, M. 1981. Temperature tolerance and the final preferendum-rapid methods for the assessment of optimum growth temperatures. Journal of Fish Biology. 19: 439-455. 1981. Fisheries Society of the British Isles. Liverpool, England.

Johnson, B. and P. Martinez. 2000. Trophic economics of lake trout management in reservoirs of differing productivity. North American Journal of Fisheries Management. 20: 127-143.

Johnson, J. 1988. Environmental assessment of plans to restore Strawberry Reservoir fishery. Utah Division of Wildlife Resources No 87-14. Salt Lake City, Utah.

Kondolf, G.M and M. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research. 29: 2275-2285.

Kondolf, G.M. et. al. 1991. Distribution and stability of potential salmonid spawning gravels in steep boulder-bed streams of the Eastern Sierra Nevada. Transactions of the American Fisheries Society 120: 177-186. 1991.

Lawler, D.M. 1993. The measurement of river bank erosion and lateral channel change. Earth Surface Processes and Landforms 18(9):777-821.

Lisle, T.E., R.E. Eads. 1991. Methods to measure sedimentation of spawning gravels. Res. Note PSW-411. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 7 p.

Lisle, T.E. 1989. Sediment transport and resulting deposition in spawning gravels, North Coastal California. Water Resources Research 25: 1303-1319. 1989.

Mitro, M., Wherley, K. and W. Lizhu. 2007. Field-based estimates of thermal tolerance limits for trout: incorporating exposure time and temperature fluctuation. Transactions of the American Fisheries Society 136: 365-374. 2007.

Myrick, C.A. and J. Cech. 2000. Temperature influence on California Rainbow Trout physiological performance. Fish Physiology and Biochemistry 22: 245-254. 2000.

Montana Fish, Wildlife, & Parks. 1999. Memorandum of Understanding and Conservation Agreement for Westslope Cutthroat Trout in Montana. May 1999.

Montana Fish, Wildlife, & Parks. 2004. FA+. Montana Fish, Wildlife, & Parks, Information Services Unit, Bozeman.

Montana Fish, Wildlife, & Parks. 2007. Memorandum of Understanding and Conservation Agreement for Westslope Cutthroat Trout and Yellowstone Cutthroat Trout in Montana. July 2007.

Montana Fish, Wildlife, & Parks. 2019. 2019-2027 Statewide Fisheries Management Plan. 446-447.

NorthwesternEnergy.2020.MadisonDSSDashboard.www.madisondss.com/page/dashboard.php

Olden, J.D. and R. Naiman. 2010. Icorporating thermal regimes into environment flows assessments: modifying dam operations tor restore freshwater ecosystem integrity. Freshwater Biology 55: 86-107. 2010.

O'Gorman, E.J et.al. 2016. Temperature effects of fish production across a natural thermal gradient. Global Change Biology 22: 3206-3220. 2016.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-species in the United States. Ecological Economics, 2005 (Vol. 52) (No. 3) 273-288.

Pritchett, J., and M. Pyron. 2011. Predicting fish assemblages from substrate variation in a turbid river: Grab samples compared with pole probing. Habitat structure and stream fish communities. North American Journal of Fisheries Management 31:574-579.

R2 Resource Consultants, Inc. Flushing flow needs in the Madison River 2013 through 2017 streambed and aquatic invertebrate monitoring results and comparison with results from 1994 through 2012. 4-7 and 4-8.

Schuett-Hames, D and A. Plues. 1996. Literature review and monitoring recommendations for salmonid spawning habitat availability. Northwest Indian Fisheries Commission. 1996.

Sloat, M.R., B.B. Shepard, and P. Clancey. 2000. Survey of tributaries to the Madison River from Hebgen Dam to Ennis, Montana with an emphasis on distribution and status of Westslope Cutthroat Trout. Report to Montana Fish, Wildlife, & Parks, Helena, Montana. 165 pages.

Teuscher D. and C. Luecke. 1996. Competition between kokanees and Utah chub in Flaming Gorge Reservoir, Utah-Wyoming. Transactions of the American Fisheries Society. 125:505-511.

Tollefson, J. Update on Madison river flushing flow program. Flushing Flow Meeting 2020.
United States Geological Survey. 2020. USGS current water conditions for Montana. https://waterdata.usgs.gov/mt/nwis/uv?

Tonello, M.A. and A.J. Nuhfer. 2004. Manistee River Hodenpyl Dam to Red Bridge. Michigan Department of Natural Resources. Status of the Fishery Resource Report. 2004-2, 2004.

Valentine, B.E. 1995. Stream substrate quality for salmonids: Guidelines for sampling, processing, and analysis. Perpetual Draft. California Department of Forestry and Fire Protection Coast Cascade Regional Office. Santa Clara, CA. 1995.

Viljanen M. et. al. 2009. Temporal and spatial heterogeneity of the pelagic plankton in Lake Pyhäselkä, Finland. Boreal Environment Research 14: 903-913. 2009.

Vincent, R. 1978. Fisheries assessment report for the Madison River. Montana Fish, Wildlife and Parks. Bozeman, MT. 59717.

Watschke, D. 2006. Assessment of tributary potential for wild Rainbow Trout recruitment in Hebgen Reservoir, MT. Master's Thesis. Montana State University, Bozeman, MT. 59717

Young, M.K., W.A. Hubert., and T.A. Wesche. 2011. Biases associated with four stream substrate samplers. Canadian Journal of Fisheries and Aquatic Sciences: 48(10):1882-1886.

Appendix A

8 December 2020

O'Dell Creek Report 2005-2012

By:

Travis Lohrenz, Nick Larson and Matt Jaeger

Region 3 Fisheries

1400 South 19th Avenue

Bozeman, MT 59718

Introduction

The purpose of this report is to describe fish populations using O'Dell Creek before and after channel restoration and flow improvement in the headwaters of O'Dell Creek. From 2005 to 2009 stream restoration activities on O'Dell Creek resulted in channel narrowing, increased stream sinuosity, lowering of streambank elevation, and an increase in water surface elevations. Montana Fish, Wildlife & Parks (FWP) monitored responses in Brown Trout abundance and size structure, as Brown Trout are the predominant gamefish species inhabiting O'Dell Creek in the restoration area. Additional restoration work has occurred downstream of the monitoring area annually.

Study Area

O'Dell Creek is a spring fed tributary of the Madison River. It originates from its headwaters 13 miles Southeast of Ennis Montana and flows North for approximately 13 miles to its confluence with the mainstem Madison 1.5 miles below the town of Ennis and roughly 5 miles above Ennis Reservoir (Figure 1). Monitoring occurred in the headwater reaches of O'Dell Creek (Figure 2).

Figure 1. Study area in the headwaters of O'Dell Creek.

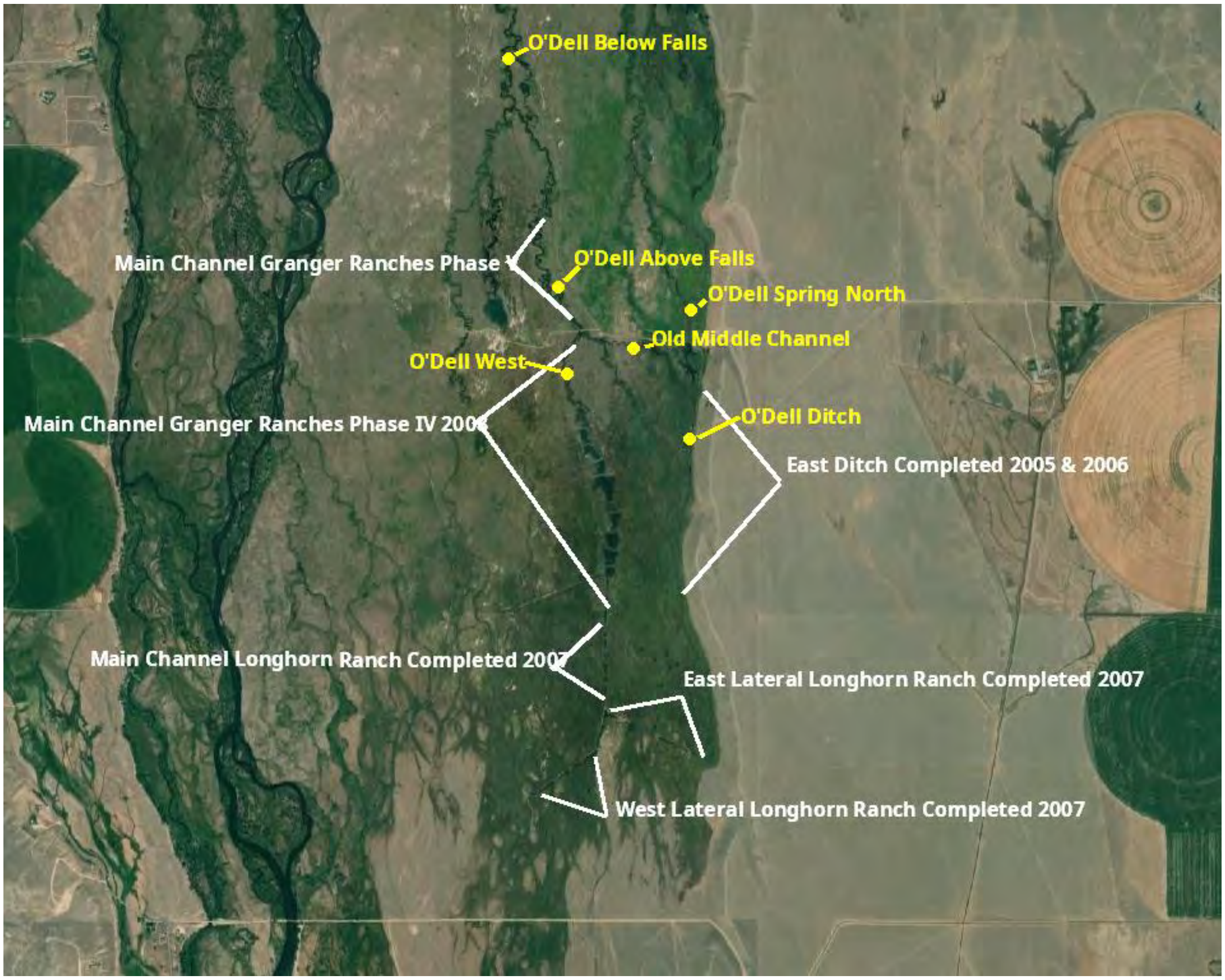


Figure 2. Restoration activities denoted in white and O'Dell Creek monitoring sections in yellow.

Methods

Six monitoring sections were established throughout the restoration area. The restoration schedule and actions in O'Dell monitoring sections are summarized in Figure 2 and Table 1. Fish were collected by a crew of three to four individuals using a mobile anode crawdad electrofisher in all sections except the O'Dell Spring North section where a backpack electrofisher was used. Catch-per-unit-effort (C/f; number of fish sampled per section length) was used in all sampling sections to determine relative abundance and was calculated as the number of fish per mile by dividing the number of fish captured during a sampling event by the section length converted to miles. Sampling efficiency was assessed by completing three mark-recapture abundance estimates between sections and years and ranged from 47%-98%. Accordingly, comparisons of relative abundance among sections and years should be made cautiously. All captured Brown Trout were measured to the nearest tenth of an inch and weighed to the nearest hundredth of a pound, which were converted to millimeters and grams. Not all fish handled were weighed during every sampling event or in every section, specifically in the Old

Middle Channel prior to restoration and the O'Dell Spring North sampling sections. Biomass per mile was calculated by multiplying the mean weight observed by the calculated C/f for each individual section where weights were taken. Age was assigned as 0: 0-150 mm, 1: 151-277 mm, 2: 278-404 mm, >2: >404 mm in total length as was done in previous monitoring (Inter-Fluve, Inc. 1989).

Table 1. Summary of stream restoration actions and fish monitoring sections at O'Dell Creek, 2005 - 2012.

Monitoring site	Result of stream channel modification	Monitoring section length (ft)	Years sampling occurred
O'Dell Ditch	Backfilled	500	2005
O'Dell Spring North	Increase in stream discharge, no physical modifications	500	2005-2010
Old Middle	Historic channel reconnected and reconstructed	500	2005-2012
O'Dell West	Channel narrowed & deepened, increase in stream discharge	500	2005
Above Falls	Increase in stream discharge, stream channel restoration	1000	2005-2010
Below Falls	Increase in stream discharge, no physical modifications	1000	2005-2008

Results

Median lengths and weights were significantly different among years in all sections, although some differences may not be biologically significant. In general, the Above (Table 2) and Below Falls (Table 3) sections had larger fish in 2008 and fish size in the Old Middle (Table 4) and North Spring (Table 5) sections increased through time. Variation in capture efficiency (47%-98%) precluded assessment of differences in abundance among years and sections. For example, a C/f of 1000 fish per mile could describe a point estimate of abundance between 1020 and 2127 fish per mile. Unless there was an at least two-fold difference in C/f among years inference is somewhat speculative. In the Above Falls section, fish abundance decreased immediately following restoration then returned to pre-restoration levels within 5 years. In the Below Falls section, fish abundance did not change following increased flows and was lower in 2008 than other years. It is unclear whether abundance changed following restoration in the Old Middle and North Spring sections; similar relative abundances were observed before and after restoration. The population was comprised of primarily juvenile fish in all sections and years; however, North Spring was skewed towards younger ages than in other sections.

Sampling of the O'Dell Ditch has not occurred since the completion of phase one of the project in the summer of 2005 when the ditch was backfilled. In 2005 sampling yielded and 137 Brown Trout in 500 ft (C/*f* = 1,522 trout/mile). Brown Trout ranged in TL from 51 to 254 millimeters, mean total length of 157mm±0.8 SE.

Table 2**.** Median length and weight (interquartile range), biomass, and overall and by age group relative abundance for Above Falls section 2005, 2006, 2007, 2008, 2010. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α = 0.05).

				C/*f* (fish/mile) by age group				
Year	Median length (mm)	Median weight (grams)	C/f (fish/mile)	0+	1+	2+	>2+	Biomass (kilograms/mile)
2005*	180^{a} (109)	73^{a} (170)	1063	374	389	274	26	180.71
2006*	174^{a} (71)	77^{a} (130)	1916	316	1258	300	42	291.23
2007	178^{a} (79)	54^{a} (100)	543	137	374	32	0	54.30
2008	264^{b} (157)	213^{b} (290)	837	174	316	321	26	201.72
2010	173^{a} (110)	59^{a} (33)	1137	268	658	200	11	133.03
	178 (99)	68 (168)	1099 ±229	253 ±44	599 ±175	225 ±53	21 ±7	172.20 ±34.96

Table 3. Median length and weight (interquartile range), biomass, and overall and by age group relative abundance for Below Falls section 1989, 2005, 2006, 2007, 2008. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α = 0.05).

Year	Median length (mm)	Median weight (grams)	C/f (fish/mile)	C/*f* (fish/mile) by age group 0+	1+	2+	>2+	Biomass (kilograms/mile)
1989*	161	145	1121	705	195	121	100	162.55
2005*	206[a] (145)	91[a] (227)	721	90	389	168	74	167.42
2006*	221[a] (150)	127[a] (254)	763	121	411	163	68	183.12
2007	188[a] (121)	82a (204)	537	53	358	105	21	99.35
2008	319[b] (97)	358[b] (324)	221	21	32	142	26	89.28
	221 (142)	118 (272)	672 ±132	198 ±114	277 ±64	140 ±11	57.8 ±13	139.94 ±16.94

Table 4. Median length and weight (interquartile range), biomass, and overall and by age group relative abundance for Old Middle Channel section 2007, 2008, 2009, 2010, 2012. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α = 0.05).

Year	Median length (mm)	Median weight (grams)	C/*f* mile (fish/mile)	C/f (fish/mile) by age group				Biomass (kilograms/mile)
				0+	1+	2+	>2+	
2005*	123^{a} (25)	-	2211	1989	222	0	0	-
2006*	147^{b} (62)	-	1289	712	522	33	22	-
2007	163^{bc} (53)	54^{a} (64)	1056	279	733	44	0.0	81.31
2008	168^{c} (102)	41^{a} (109)	2422	900	1366	156	0.0	203.45
2010	221^{d} (138)	154^{b} (218)	1922	511	878	522	11	332.51
2012	216^{d} (127)	127^{b} (213)	1367	289	700	367	11	233.76
	154 (97)	73 (150)	1711 ±206	780±238	737 ±142	224 ±86	7 ±3	212.76 ±44..80

Table 5. Median length (interquartile range), and overall and by age group relative abundance for O'Dell Spring North section 2005, 2006, 2007, 2008, 2009, 2010, 2012. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α = 0.05).

Year	Median length (mm)	C/*f* (fish/mile)	C/*f* (fish/mile) by age group			
			0+	1+	2+	>2+
2005*	156^{a} (81)	1367	289	700	0	0
2006	117^{ab} (25)	2044	1789	256	0	0
2007	114^{abc} (25)	1033	956	78	0	0
2008	124^{abcd} (28)	1144	1011	133	0	0
2010	132^{ad} (33)	811	622	189	0	0
2012	144^{a} (26)	867	500	356	11	0
	127 (41)	861 ±197	867 ±197	285 ±84	11 ±0	0

O'Dell Brown Trout Trapping

A rigid style weir was installed 23 September 2010 and operated until 5 November 2010 on O'Dell Creek above the Highway 287 bridge outside of the town of Ennis to evaluate use by Madison River Brown Trout during the fall spawning period. The weir was installed in a shallow glide approximately 1.5-2.0 ft in depth with two trap boxes positioned at the right and left bank. The right bank trap box was oriented downstream to capture fish ascending O'Dell Creek and the left bank trap box oriented upstream to capture downstream migrants. Fish captured were identified to species, measured, weighed, tagged with a uniquely numbered floy-tag and given a fin clip as a secondary mark for identification in the event the tag was not retained. Additionally, water temperature, staff gauge height, and weather conditions were recorded daily during trap operation.

Little use of O'Dell Creek by spawning Madison River Brown Trout was observed. Trapping yielded one adult male Brown Trout (444.5 mm in TL) in the upstream trap and 11 juvenile fish (6 Brown Trout, 2 Rainbow Trout, and 3 Mountain whitefish) from 76-101.6 mm TL in the downstream trap. The adult Brown Trout was tagged, and the adipose fin was removed. No increase in upstream migration was observed on the ascending or descending limbs of the hydrograph during seasonal weather events. Increased movement has been observed during increasing flows on other streams where trapping has occurred. Additionally, fluctuations in water temperature and daily weather conditions appeared to have little to no effect on fish movement. It appeared there was not significant use of O'Dell Creek for spawning by Madison River Brown Trout.

O'Dell Creek Fish Movement

Movements of adult trout in O'Dell Creek were assessed by opportunistically implanting radio transmitters during 2010 fisheries monitoring. Two Brown Trout and three Rainbow Trout were telemetered on 4 May 2010. Radio tags were surgically implanted into the body cavity of fish after they were anesthetized. The incision was closed using stainless steel surgical staples and the fish was held in a live car until the anesthesia wore off and fish demonstrated the ability to stay upright and swim on their own. Fish relocations were conducted on foot on four separate occasions in the restoration area, and once by aerial survey of the Madison River and O'Dell Creek. Transmitter batteries expired around the end of August 2010.

Brown Trout exhibited only localized movements; fish remained in the reach they were initially captured in throughout the summer. Rainbow Trout movements are ambiguous; two fish were never relocated, and one shed its transmitter or died downstream of where it was captured (Table 6). Failure to relocate fish may be attributed to their predation and removal from the study area, movement out of the study area, or tag failure. Migration into the Madison River was not observed, although inference is severely limited by small sample size and infrequent detections.

Table 6. Species Rainbow Trout (RB) and Brown Trout (LL), length in inches and relocation and date of radio transmitter fish in O'Dell Creek 2010.

Species	Length (mm)	Date, survey type and area relocated				
		14-May Foot	17-May Foot	26-May Foot	15-Jul Aerial	23-Aug Foot
RB	419	X	X	X	X	X
RB	445	X	X	X	X	X
RB	422	O'Dell Middle	O'Dell Middle	X	Longhorn Granger Boundary	Tag Recovered @ Longhorn Granger Boundary
LL	356	O'Dell Middle	O'Dell Middle	O'Dell Middle	X	O'Dell Middle
LL	424	O'Dell Middle	O'Dell Middle	O'Dell Middle	O'Dell Middle	O'Dell Middle

O'Dell Creek Temperature

One of the objectives of the restoration on O'Dell Creek was to reduce water temperatures. Temperature monitoring at the Below Falls site was conducted by DJP Consulting from 2006-2009. Restoration activities above this site appeared to have minimal if any effect on stream temperature at the Below Falls site during this time (Figure 3a, 3b, 3c, 3d; Peters 2010); however, temperatures in upper (mile 0.9) and lower (mile 5.0) were similar, indicating minimal gain in temperature through the system (Figure 4).

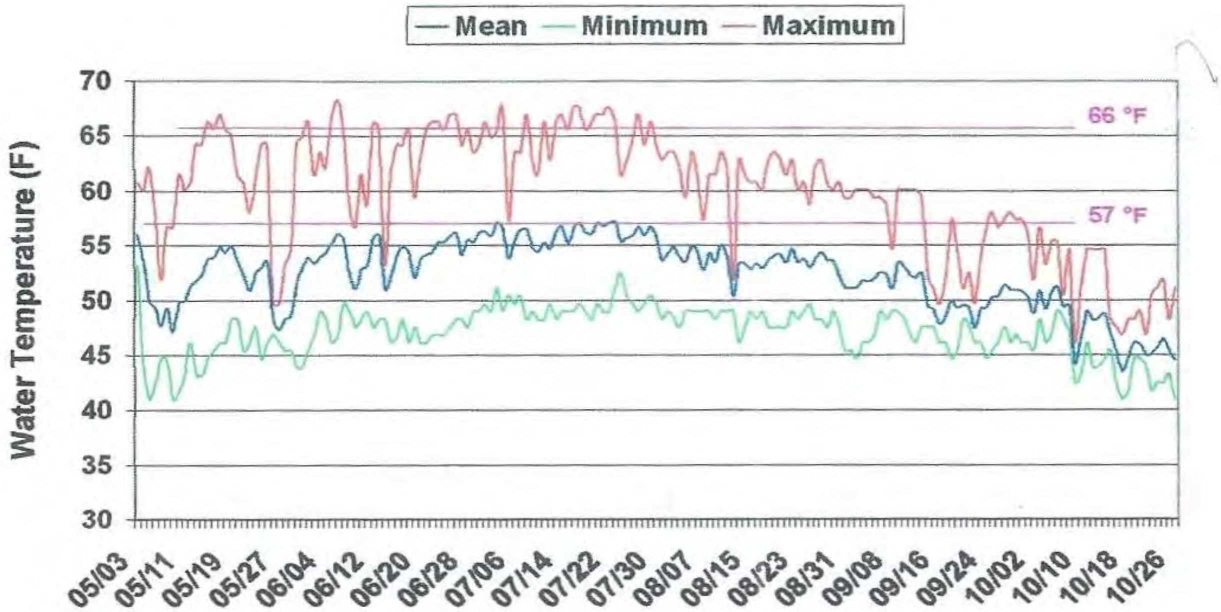


Figure 3a. Mean, minimum, and maximum daily temperatures for the Below Falls monitoring site 2006 (Peters 2010).

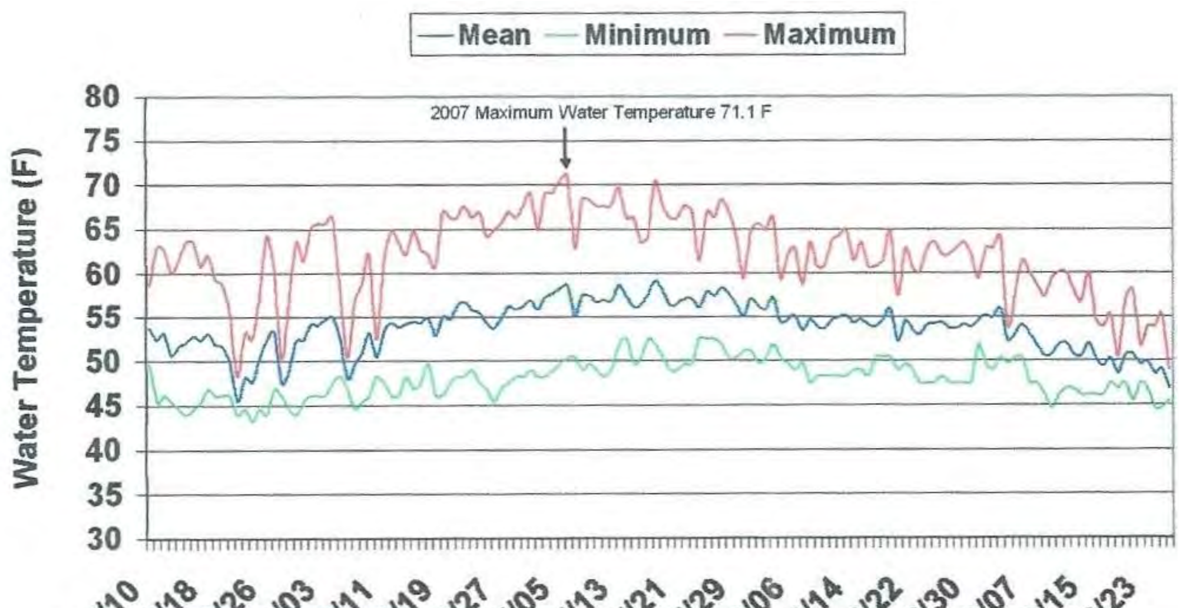
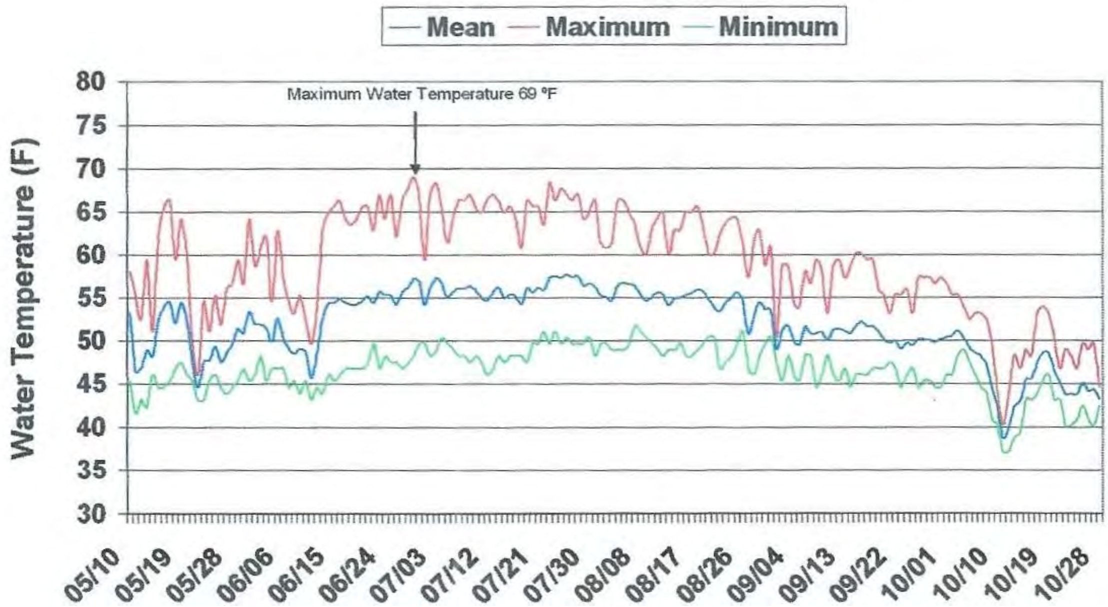


Figure 3b. Mean, minimum, and maximum daily temperatures for the Below Falls monitoring site 2007 (Peters 2010).



Figue 3c**.** Mean, minimum, and maximum daily temperatures for the Below Falls monitoring site 2008 (Peters 2010).

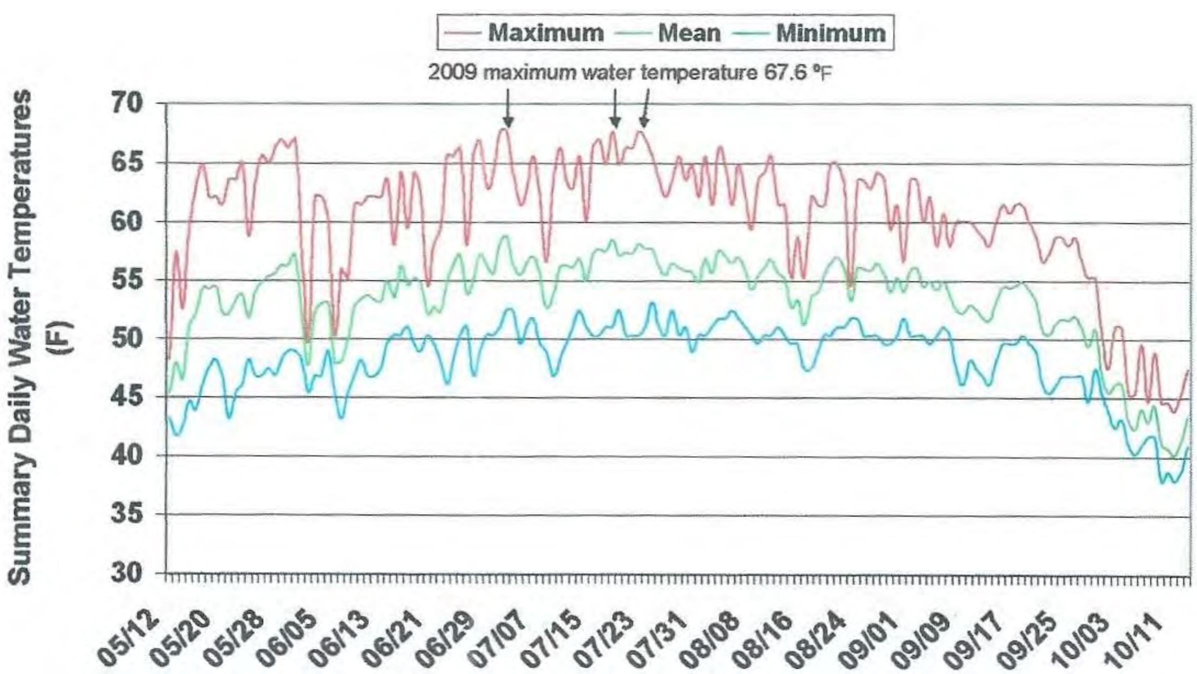


Figure 3d. Mean, minimum, and maximum daily temperatures for the Below Falls monitoring site 2009 (Peters 2010).

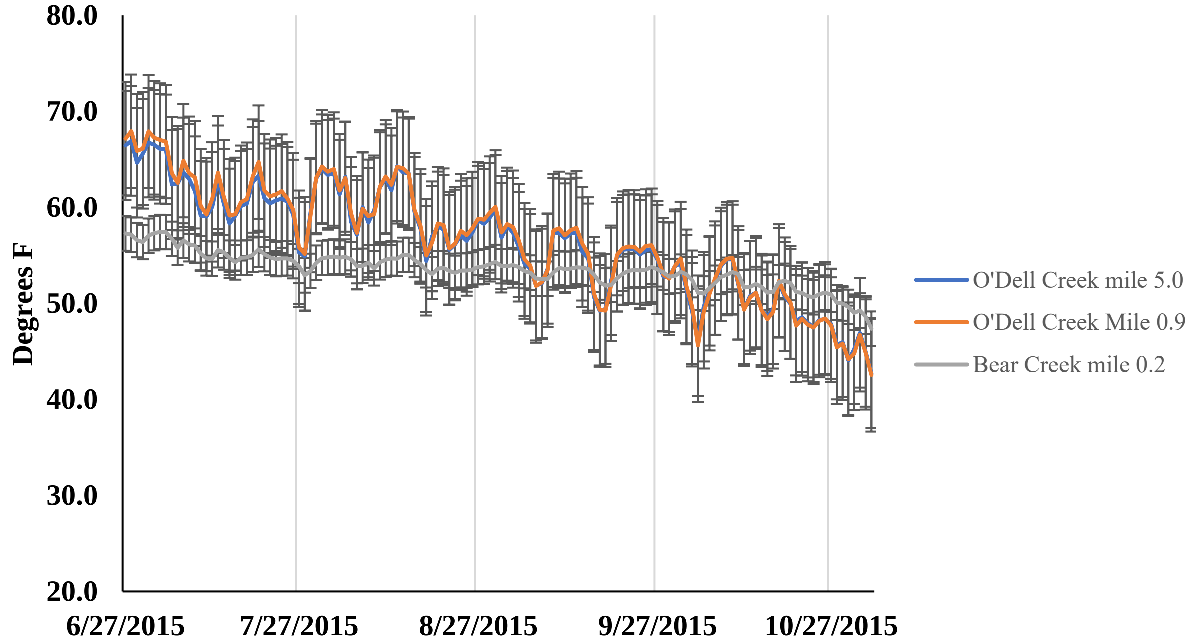


Figure 4. Daily mean water temperatures for O'Dell Creek stream mile 5, 0.9 and 0.2. Error bars are standard deviations.

Literature Cited

Clancey, P. 2006. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2005 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Gallatin Gateway, from Montana Fish, Wildlife, & Parks, Ennis. June 2006.

Clancey, P. 2007. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2006 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Gallatin Gateway, from Montana Fish, Wildlife, & Parks, Ennis. June 2007.

Clancey, P. 2008. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2007 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Gallatin Gateway, from Montana Fish, Wildlife, & Parks, Ennis. July 2008.

Clancey, P. and T. Lohrenz. 2009. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2008 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Gallatin Gateway, from Montana Fish, Wildlife, & Parks, Ennis. August 2009.

Clancey, P. and T. Lohrenz. 2010. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout Conservation and Restoration Program. 2008 Annual

Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Gallatin Gateway, from Montana Fish, Wildlife, & Parks, Ennis. June 2010.

Inter-Fluve Inc. Fisheries Report for O'Dell Creek, Madison County Montana. November 1, 1989.

Pearsons, Todd N., Fritts, Anthony L., & Temple, Gabriel M. Yakima River Species Interactions Study; Yakima/Klickitat Fisheries Project Monitoring and Evaluation Report 7 of 7, 2003-2004 Annual Report. United States. doi:10.2172/887228.

Peters, Don. Restoration Monitoring O'Dell Creek -2009. January 13, 2010.

MADISON RIVER DRAINAGE 2188 PROJECT MONITORING REPORT 2021

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

By:
Travis Lohrenz, Mike Duncan, Jenna Dukovcic, Terrill Paterson, and Matt Jaeger
Montana Fish, Wildlife & Parks
Region 3 Fisheries
1400 South 19th Avenue
Bozeman, MT 59718

August 2022

Contents

Introduction

Montana Fish, Wildlife & Parks (FWP) monitors the Madison River fishery to determine the potential effects from the operations at Hebgen and Madison dams on fisheries in the Madison River Drainage. 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 includes Hebgen and Madison dams (Figure 1), as well as seven dams on the Missouri River collectively referred to by FERC as the 2188 Project. The 2188 license details requirements NWE must follow for the operation of 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 FERC license requirements for the protection, mitigation, and enhancement (PM&E) of fisheries, recreation, and wildlife resources. The MOU established Technical Advisory Committees (TACs) 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 2021 with funding provided by the MadTAC to address requirements of the FERC 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 the three mainstem impoundments: Hebgen Reservoir, Quake Lake, and Ennis Reservoir, 3) conservation and restoration of Arctic Grayling populations, 4) conservation and restoration of Westslope Cutthroat Trout populations, 5) enhancement and restoration of tributaries, 6) participation in a flushing flow evaluation, 7) statistical evaluation of habitat types on fish abundances, 8) assistance with a microchemistry study to evaluate tributary and mainstem spawning contributions to the Madison River fisheries.

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. 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 the 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 the required minimum flow of 1100 cubic feet per second (cfs) and mitigate thermal issues in the Madison River below Madison Dam (Figure 1).

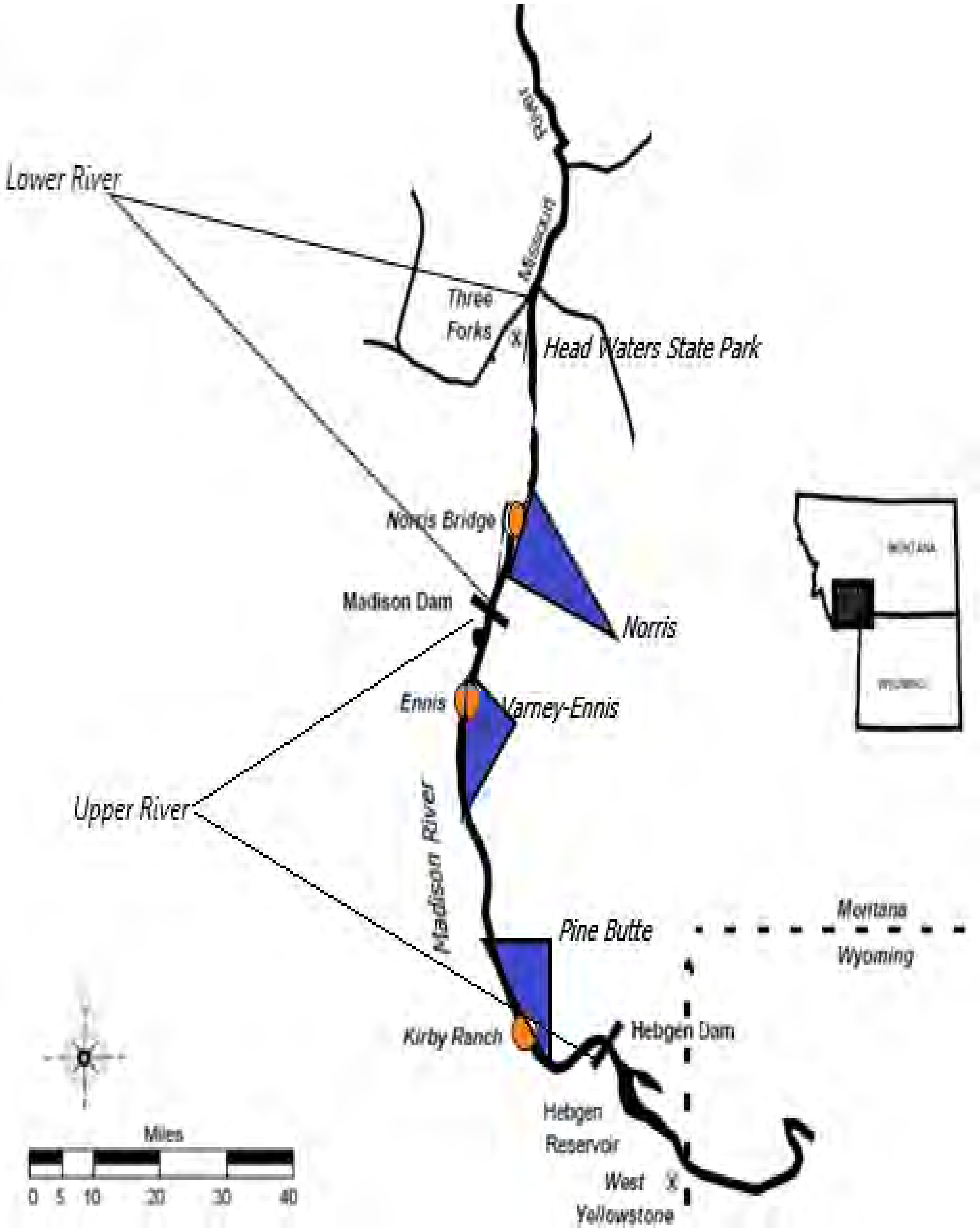


Figure 1. Locations of NWE dams on the Madison River (FERC Project 2188) and delineation of the upper and lower Madison River. FWP annual abundance estimate sections are shown in blue and NWE monitoring sites in orange.

Monitoring and Projects

Article 403-River Discharge: Article 403 of the Project 2188 FERC license specifies operational conditions, including minimum and maximum instream flows in various sections of the Madison River. Specifically, 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 outflow from Hebgen to no more than 10% per day. Additionally, a minimum flow of 600 cfs on the Madison River at Kirby Ranch (USGS gage no. 6-388) and 1100 cfs on the Madison River at 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. License requirements also require the establishment of the permanent flow gauge at Kirby Ranch. FWP and NWE monitor river flows to avoid deviations from operational conditions.

Deviations from Article 403 operational conditions occurred below Hebgen Dam and at Kirby Ranch on November 30, 2021. The deviations were the result of a broken component on the Hebgen Dam gate, which caused the gate to fall and reduce flows from 648 cfs to 228 cfs in 45 minutes. NWE staff increased outflows to 248 cfs 12 hours later where they remained for about 31 hours until the gate could be raised. The abrupt change in discharge resulted in a deviation from the condition that limits changes in the outflow from Hebgen Dam to no more than 10% per day. Additionally, because flows out of Hebgen were 248 cfs or less for about 31 hours, flows at the downstream Kirby Gage decreased below the minimum 600 cfs flow requirement to 395 cfs for about 48 hours.

The rapid reduction of river stage in the Madison River between Hebgen Dam and Quake Lake stranded and killed adult and juvenile fish as well as exposed Brown Trout and Mountain Whitefish redds. FWP, NWE, and volunteers from the public completed a fish salvage operation on December 1st in the affected reaches. Stranding occurred downstream of Quake Lake but was primarily limited to juvenile fish in overwintering habitats (e.g., side channels) upstream of Kirby Bridge that became disconnected from the river as stage dropped. Although no stranded adult fish were observed in this stretch of river, the change in river stage dewatered numerous Brown Trout redds in important spawning areas (Byorth 1999; Downing 2002; Figures 4 and 5). Between Hebgen Dam and the Quake Lake inlet, an estimated 3.4 acres of nearshore spawning habitat may have been exposed (Figure 2). Although that reach of the Madison River is predominantly a single thread channel, the gate failure demonstrated the potential effect of reduced river stage on redds in near-shore habitats (Figure 3). Exposed near-shore habitat was not quantified for the reach between the Raynolds FAS and Kirby Bridge.

NWE and FWP will monitor fish populations to assess the effects of gate failure over the next five years. NWE additionally proposed, in consultation with MadTAC, immediate mitigation options to address the impacts to the fishery caused by the gate failure.

Feet=204+.0329(cfs)

648 cfs=225.31ft

216 cfs=211.10ft

Difference=14.22ft

Acres=(10560ft*14.22ft)/43560ft^2

3.44 acres of exposed near shore habitat

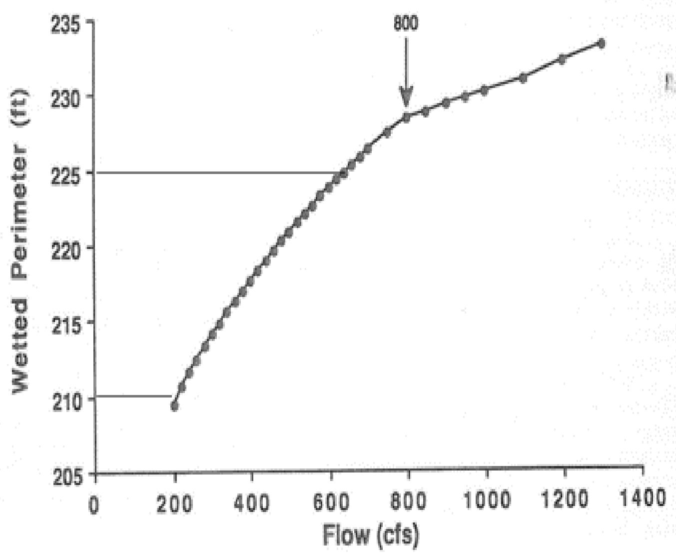


Figure 2. Wetted perimeter of the Madison River between Hebgen Dam and Quake Lake. The area of exposed near shore habitat is estimated from the following equation: Feet = 204 + 0.0329 (cfs).

Figure 3. A dewatered Brown Trout redd near the bank in the Madison River between Hebgen Dam and Quake Lake.

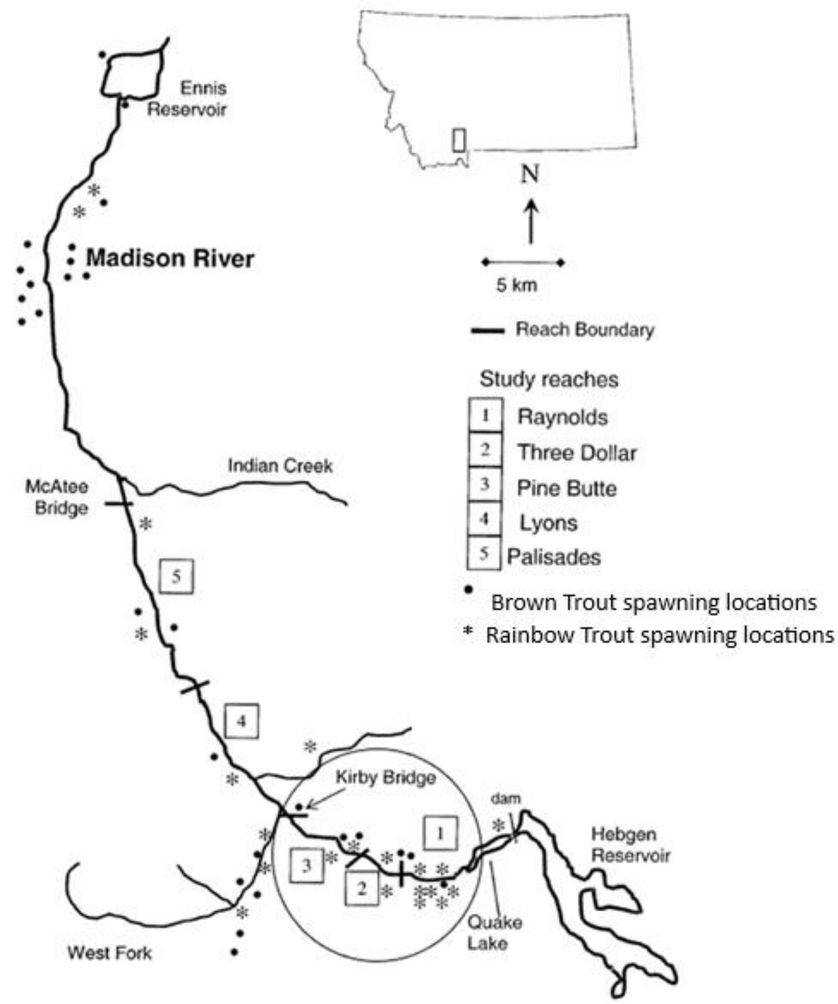


Figure 4. Spawning areas of Brown and Rainbow Trout (Byorth 1999; Downing 2002). The area of concern is in the circle. Brown Trout spawning locations are represented by black dots and Rainbow Trout spawning locations are represented by asterisks. Numbered squares identify reaches delineated by Downing (2002).

Figure 5. Partially dewatered Brown Trout Redd in a side channel near the Kirby Bridge.

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 for the purpose of assessing the effects of project operations (Figure 6). Significant changes in the fish assemblage would warrant a review of and potential change to project operations to address identified issues.

The mean catch-per-unit-effort (C/f) of total trout in Hebgen Reservoir was about 20 trout/net in 2021, which was slightly above the long-term average (Figure 7). The C/f of Brown Trout decreased about 21% to 14.8 trout/net while Rainbow Trout decreased 12% to 5.2 trout/net, which were below the management goals for each species (Brown Trout management goal = 15.5 fish/net; Rainbow Trout = 7.5 fish/net). However, the mean lengths of Brown and Rainbow Trout increased to 459 mm (≈ 18”) and 433 mm (≈ 17”), respectively, which were above the long-term averages. Eighty-five percent of the Brown Trout captured in gill nets were ≥ 406 mm [≈ 16”], which exceeded the management goal of 75%. Sixty-six percent of the Rainbow Trout captured were ≥ 406 mm, which met the management goal.

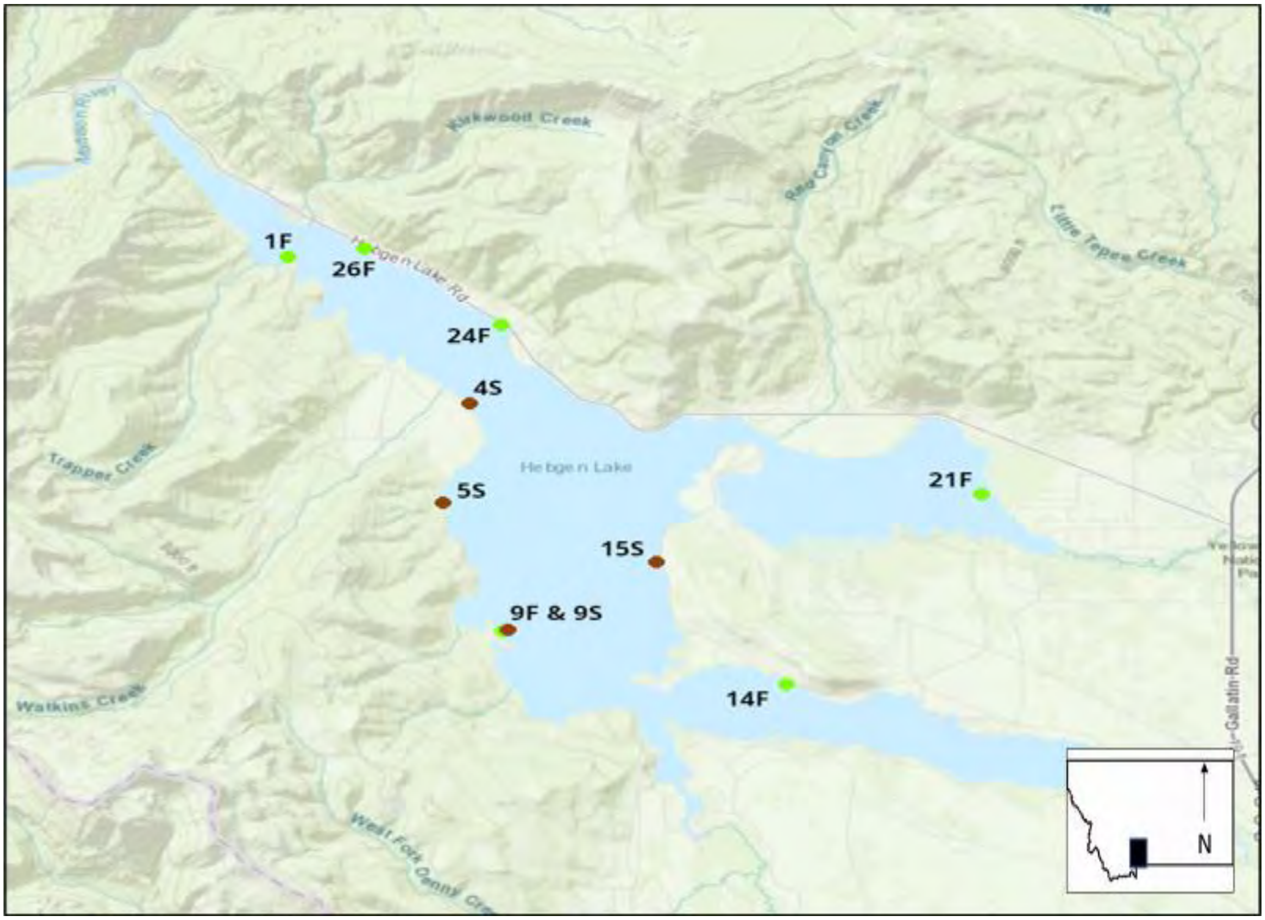


Figure 6. Hebgen Reservoir gill net locations and names. Brown and green circles are sinking (N = 4) and floating (N = 6) gill nets, respectively.

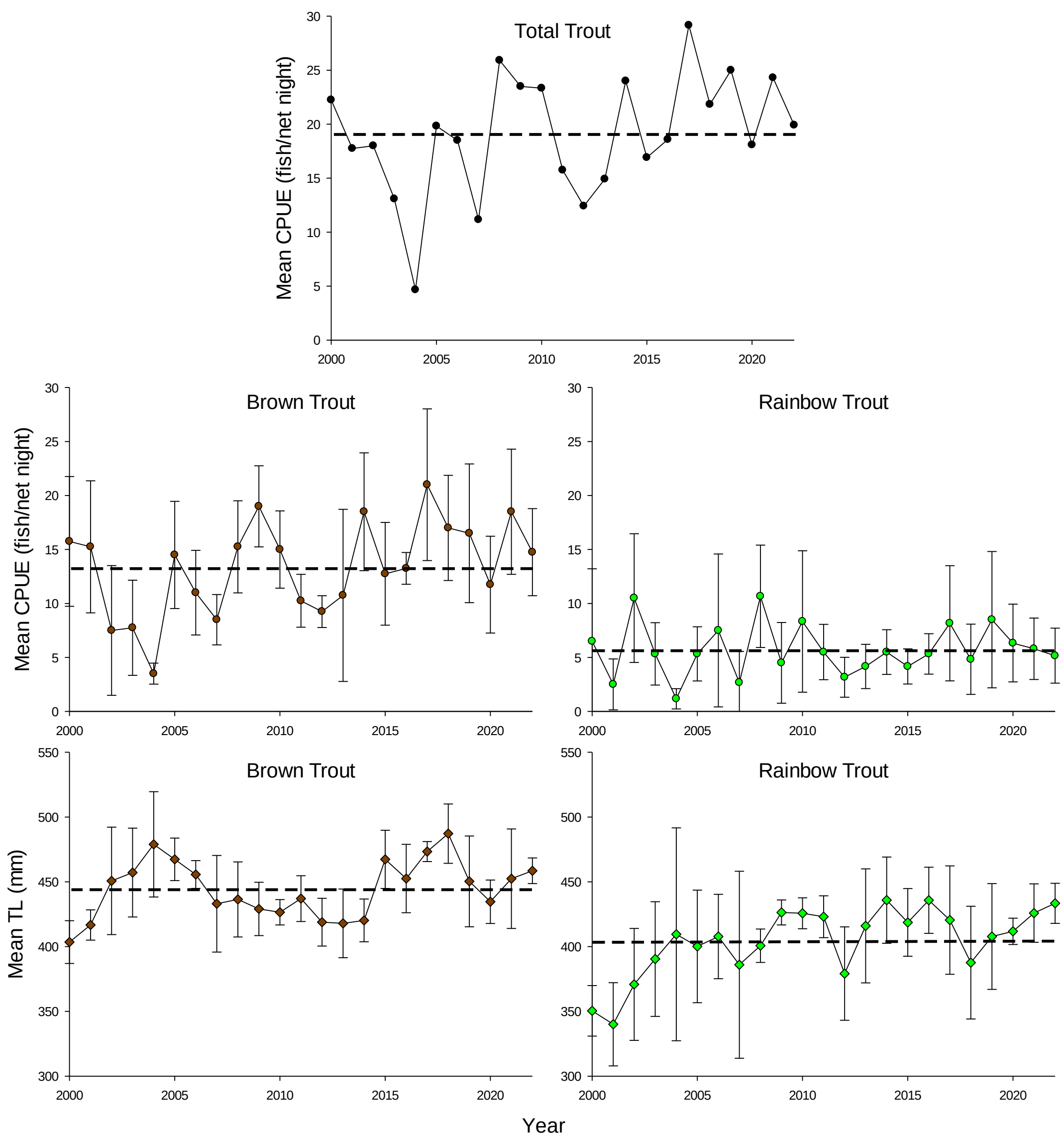


Figure 7. Mean catch-per-unit-effort (CPUE) of total, Brown, and Rainbow Trout captured in Hebgen Reservoir from 2000 to 2022. Total trout abundances represent all trout captured in four sinking gill nets and six floating gill nets. Brown and Rainbow Trout CPUE were limited to either sinking or floating gill nets, respectively. Mean total lengths were calculated using all Brown and Rainbow Trout captured each year. Dashed lines are the long-term averages (2000-2022) and error bars are the 95% confidence intervals.

Article 412–1) Effects of Project Operations on Ennis Reservoir Fish Populations: FWP has 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 provide better coverage of the reservoir while eliminating gill net sets in shallow habitats that reduced capture efficiencies. Sampling will occur annually for at least five consecutive years to provide data that can be used to establish management goals for the Rainbow and Brown 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 C/f of total trout, Brown Trout, and Rainbow Trout, remain below the long-term averages (Figure 8). However, the mean lengths of Brown Trout (398 mm [≈ 15.5”]) and Rainbow Trout (387 mm [≈ 15.0”]) increased above the long-term averages for both species.

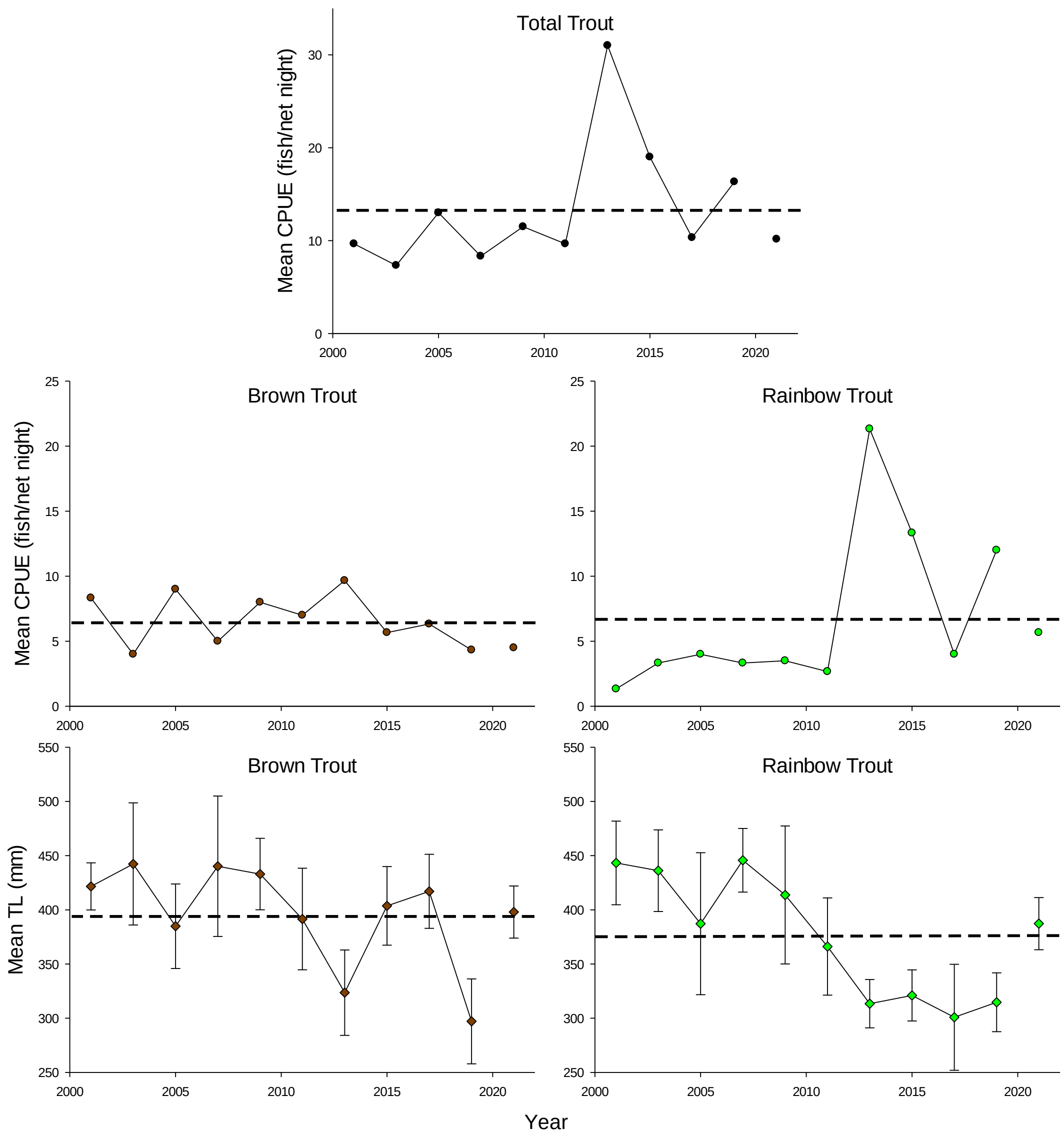


Figure 8. Mean catch-per-unit-effort (CPUE) of total, Brown, and Rainbow Trout captured in gill nets set in Ennis Reservoir from 2001 to 2021. Brown and Rainbow mean CPUE and were calculated using all nets set each year. Mean total lengths were calculated using all Brown and Rainbow Trout captured each year. Dashed lines are long-term averages (2001-2021) and error bars are 95% confidence intervals for mean lengths.

408-3) Reservoir Draw Down Effects on Fish: The interactions between Hebgen Reservoir elevation and operations, trophic status, and the trout populations have been 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 conditions in the reservoir 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 habitat along shoreline 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 operational standards require 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, reservoir conditions are similar among years. As a result, no relationships have been detected between trophic status, zooplankton abundance, or trout and zooplankton abundances. Therefore, limnological sampling, based upon FWP recommendations and input from NWE, will occur every other year or when reservoir elevations fall outside of normal operational ranges.

FWP did not conduct limnological sampling in 2021. However, developing extreme drought conditions resulted in Hebgen pool elevations dropping below normal operational ranges. On 51 occasions, during the summer of 2021, operational changes were made to provide for thermal mitigation in the lower river. Consequently, Hebgen pool elevation dropped below the 6530.26 feet elevation minimum by July 28,2021 and resulted in a 7.0-ft decrease in elevation from June 20 to October 1, 2021.

408-4) Monitor the Effects of Modified Project Operations on Upper Madison River Fish Populations- Madison River Fisheries Assessment: FWP estimated Rainbow and Brown Trout abundances using mark-recapture sampling in three long-term monitoring sections in the Madison River (Pine Butte, Varney, and Norris) to evaluate the influence of modified project operations at Hebgen and Madison dams on the trout fisheries. Although only the influence of project operations are reported here, other potential population drivers (i.e., angling pressure, disease, etc.) are hypothesized to be influential and are being evaluated elsewhere. Trout were collected by electrofishing from a drift boat mounted mobile anode system (Figure 9). Fish captured in the initial trip (marking run) were weighed in grams and measured to the nearest millimeter, marked with a fin clip, observed for hooking scars, and released to redistribute. FWP conducted a second trip (recapture run) about a week later to examine trout for marks administered during the marking run, record lengths of marked fish, as well as document lengths and weights of unmarked fish. Length-specific mark-recapture log-likelihood closed population abundance estimates were generated and standardized to stream mile for Brown and Rainbow Trout using an R-based proprietary FWP fisheries database and analysis tool.

Figure 9. Mobile anode electrofishing (shocking) in the Norris section of the Madison River.

FWP developed management goals for total trout abundances (trout ≥ 252 mm [≈ 10”]) and size structure (percentages of trout ≥ 252 mm that are also ≥ 402 mm (≈ 16”]) for each of the long-term sampling sections using the 66th percentiles of data collected over the past 20 years. The abundance goals for the Pine Butte, Varney, and Norris sections are 2300, 1200, and 2500 trout/mile, respectively. The following are the size structure goals for proportion of fish ≥ 402 mm in each section: Pine Butte – 25%, Varney – 35%, and Norris – 15%. 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. However, difficult sampling conditions in the fall led to unreliable estimates of Brown Trout in the Pine Butte and Varney sections (note the large confidence intervals associated with each estimate in Figure 10). These issues may preclude inference about abundance of Brown Trout in the upper Madison River, which also confounds our ability to determine whether management goals were achieved in those sections. Therefore, the discussion of management goals will be limited to the Norris Section.

Upper Madison River Rainbow Trout abundances were below average in Pine Butte and above average in Varney. In 2021, estimated abundance of Rainbow Trout ≥ 152 mm (≈ 6”) decreased about 22% in the Pine Butte Section to 1,685 trout/mile, which was below the long-term average (Figure 10). The decreased abundance of Rainbow Trout in Pine Butte appeared to be a result of poor recruitment of small fish, which is evidenced in length-frequency histograms by the relatively low number of Rainbow Trout < 252 mm (≈ 10”; Figure 11). Estimated abundances of Rainbow Trout decreased about 17% to 1,995 trout/mile in the Varney Section. However, abundances of Rainbow Trout in Varney remain well-above the long-term average as 2021 provided the second highest abundance estimate in that section in over 20 years. Similar to 2020, many small Rainbow Trout (< 252 mm) were captured in the Varney Section (Figure 12), which may lead to relatively high abundances of large Rainbow Trout the next several years.

Below average abundances of Brown and Rainbow Trout occurred in the lower Madison River. The total estimated abundance of trout in the Norris Section during the spring of 2022 was 1907 trout/mile, which was 24% below the management goal. The estimated abundance of Rainbow Trout in the Norris Section decreased 8% to 1301 trout/mile while Brown Trout increased 14% to 523 trout/mile, which are below the long-term averages for both species (Figure 13). The estimated abundance of Westslope Cutthroat Trout decreased by 16% to 82 trout/mile. Fifteen percent of trout ≥ 252 mm captured in the Norris Section were also ≥ 402 mm, which achieved the management goal for that section. However, the truncated length-frequency histograms of both populations the last two years (Figure 13) indicate survival of juvenile and adult Rainbow and Brown Trout have decreased in the lower Madison River relative to the size structures that supported both populations in the 2000s and 2010s.

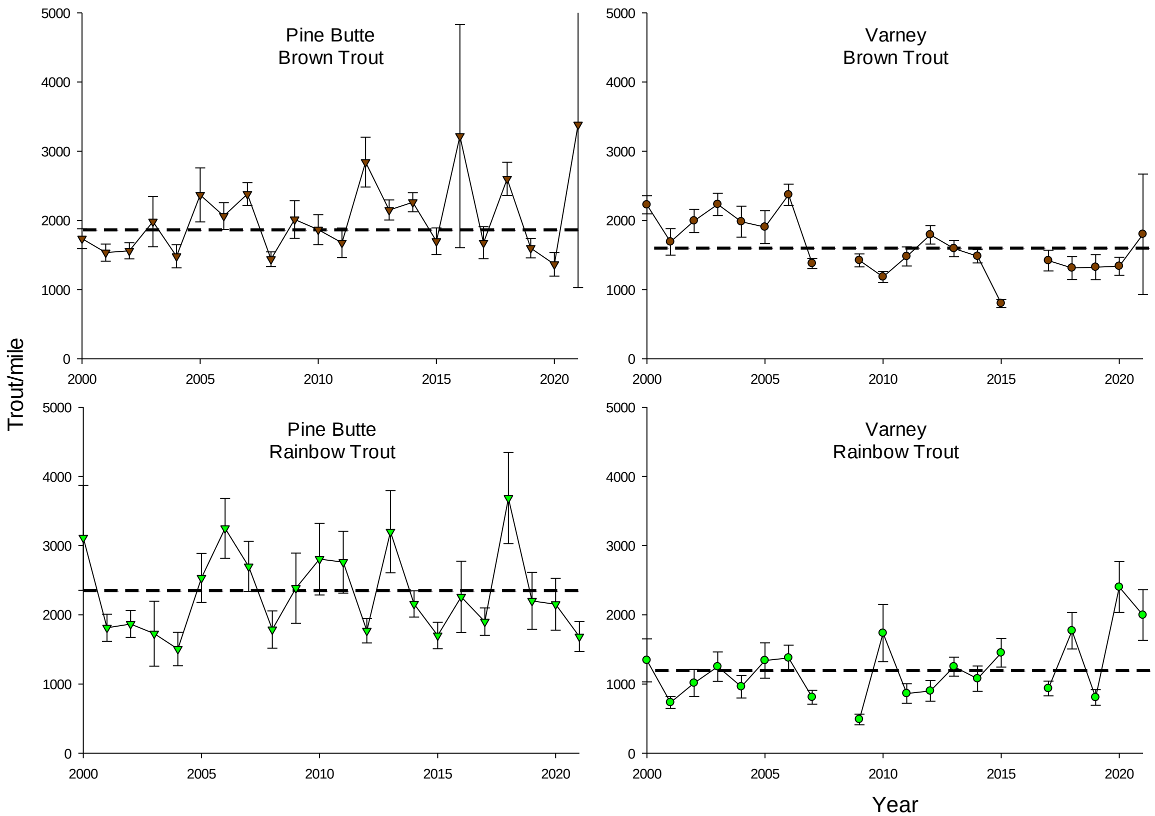


Figure 10. Estimated abundances of Brown and Rainbow Trout ≥ 152 mm (≈ 6") captured in the three long-term sampling sections of the Madison River. Dashed lines are the long-term averages (2000-2022) and error bars are the 95% confidence intervals.

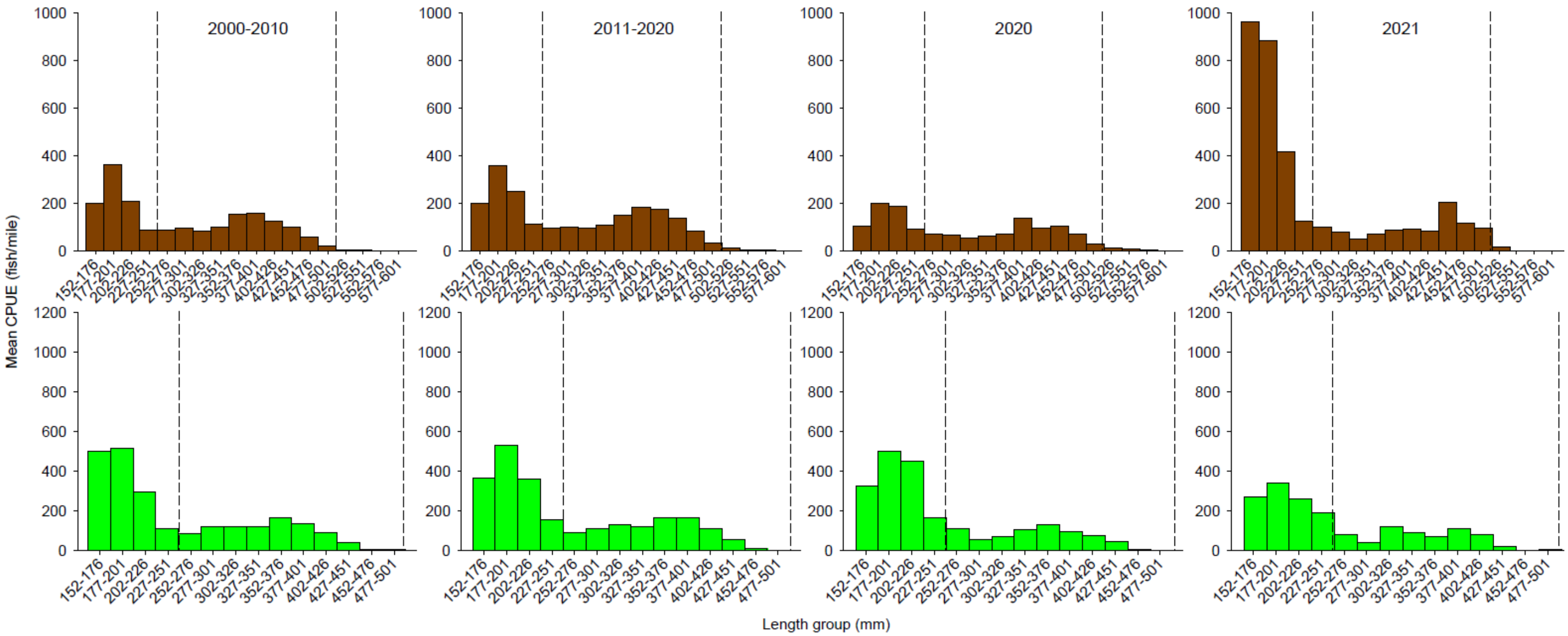


Figure 11. Length frequency histograms of Brown (brown bars) and Rainbow Trout (green bars) ≥ 152 mm (≈ 6”) captured in the Pine Butte Section of the Madison River. Dashed lines delineate 10” and 20”.

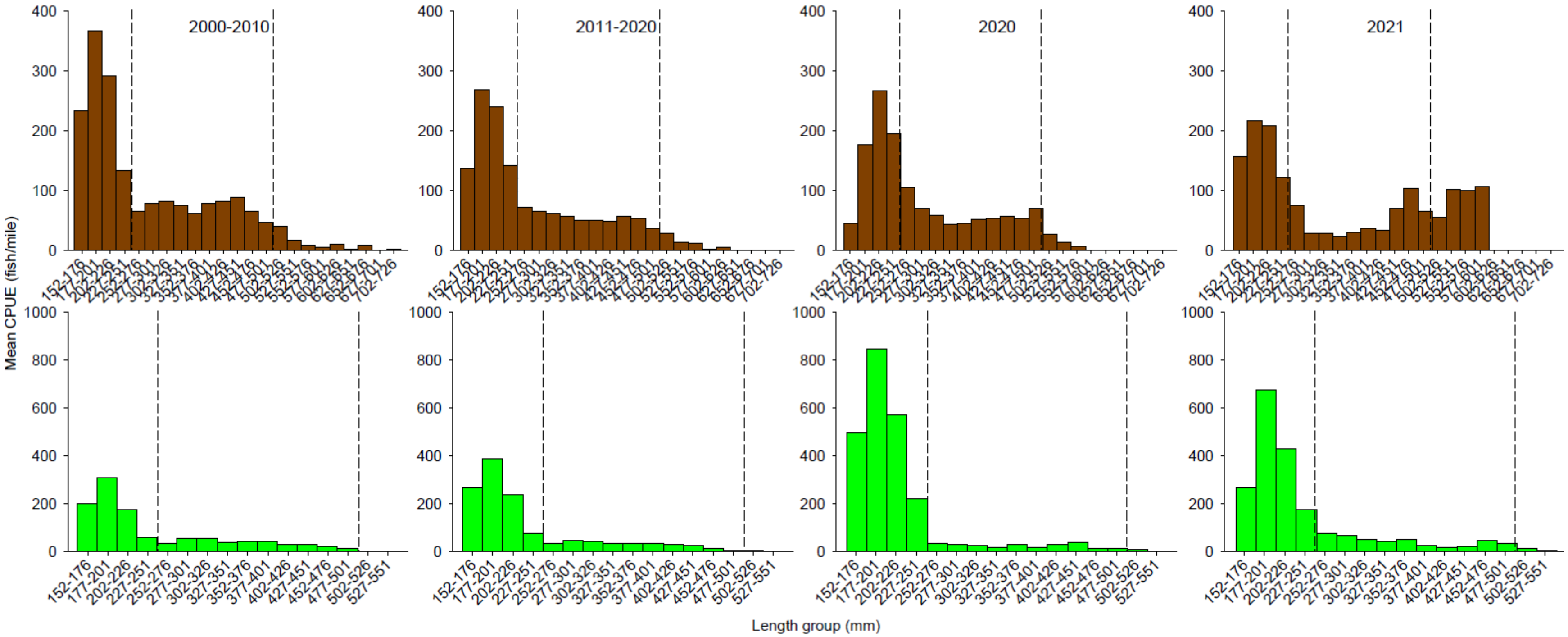


Figure 12. Length frequency histograms of Brown (brown bars) and Rainbow Trout (green bars) ≥ 152 mm (≈ 6”) captured in the Varney Section of the Madison River. Dashed lines delineate 10” and 20”.

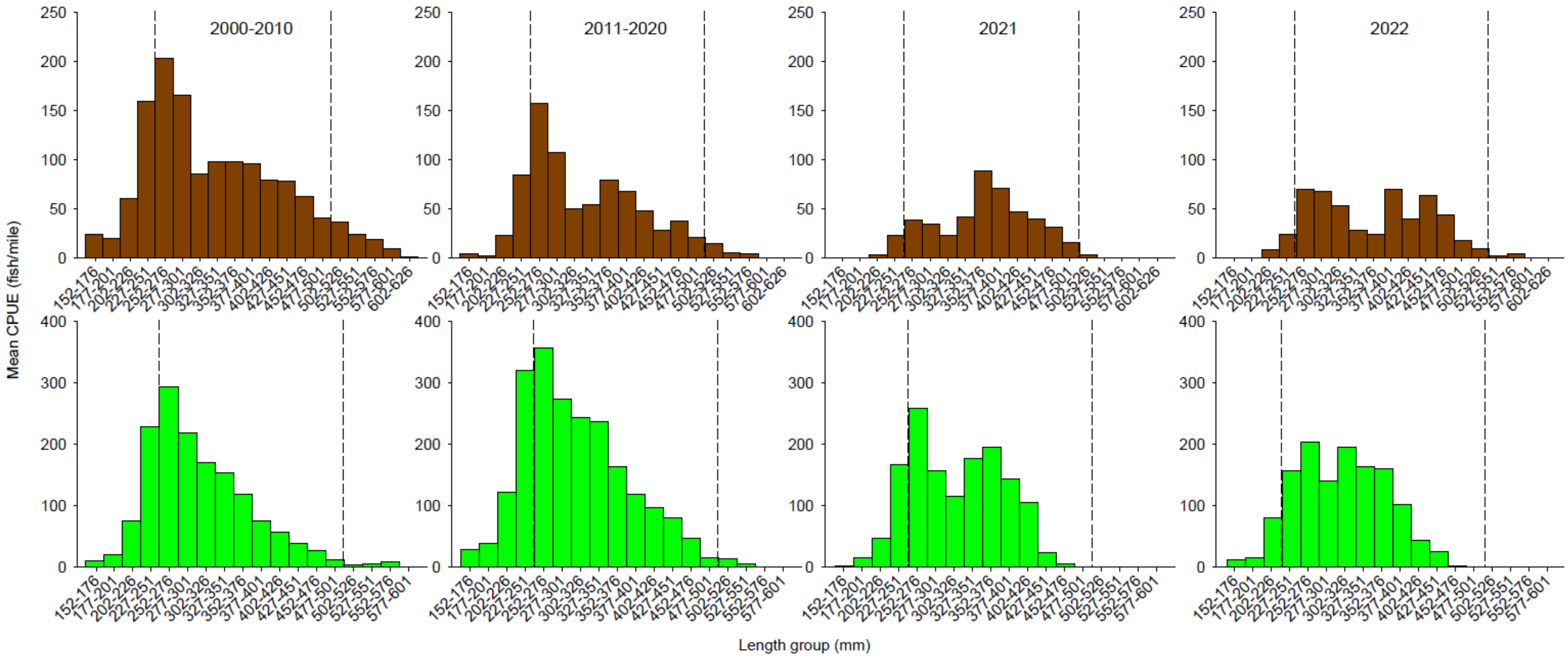


Figure 13. Length frequency histograms of Brown (brown bars) and Rainbow Trout (green bars) ≥ 152 mm (≈ 6”) captured in the Norris Section of the Madison River. Dashed lines delineate 10” and 20”.

408-7) Monitor Species of Special Concern; Madison Artic 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, 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).

Arctic Grayling: Arctic Grayling reintroduction occurred in several Madison River tributaries between 2014 and 2020. Introductions were carried out by placing embryos in remote site incubators (RSI; Figure 14) and allowing them to hatch and fry to enter the stream. To date, 939,200 eggs have been placed in Madison River tributaries. Hatching success of embryos and fry emigration out of RSIs in tributary streams has been good to fair every year introductions took place except for the 2017 in Blaine Spring Creek, although poor recruitment was observed (Table 1). In 2021, 250,000 eggs from the Green Hollow and Axolotl Lake Big Hole Arctic Grayling genetic reserve brood ponds were divided into Black Sands Spring Creek (150,000) and Moore Creek (100,000) to determine whether higher stocking rates resulted in improved recruitment (Figure 15). During autumn electrofishing surveys, no young-of-year Arctic Grayling were observed in Black Sands Springs or Moore creeks. However, the quality of eggs used for introductions in 2021 was inferior to past years. Eye-up at the Big Timber Hatchery was estimated to be as low as 70% (FWP personal communication, 2021). Introductions will be discontinued in Moore Creek. While there has been limited success in recovering young-of-year grayling in Moore Creek following emigration from RSIs, they have failed to recruit to older age classes. Additionally, access to Moore Creek has been restricted due to a change in land ownership. Arctic Grayling introduction efforts for the next 3-5 consecutive years will focus on Hebgen Reservoir and its tributaries where FWP plans to introduce 1,000,000 eggs and fry from populations of primarily Madison ancestry.

Figure 14. Remote site incubators used to hatch Arctic Grayling eggs in Black Sands Springs in 2021.

Table 1. Arctic Grayling introduction sites. Site, year, quantity of eggs introduced and egg survival and emigration success.

Site	Year	# eggs	Egg survival and emigration
West Fork Madison Upper	2014	1200	Poor
West Fork Madison Middle Spring	2014	10,000	Good
	2015	30,000	Good
	2016	5000	Good
Lake Creek	2014	13,000	Good
	2015	27,000	Good
	2016	5000	Good
Upper O'Dell Creek Grainger Ranch	2015	36,000	Good
	2017	32,000	Good
	2018	60,000	Good
	2019	15,000	Good
O'Dell Creek Longhorn Ranch	2019	45,000	Good
Blaine Spring Creek	2015	15,000	Fair
	2016	5000	Fair
	2017	1000	Poor
	2018	42,000	Fair
	2019	10,000	Fair
	2020	150,000	Fair
Moore's Creek	2015	5000	Fair
	2016	5000	Fair
	2017	20,000	Fair
	2020	150,000	Fair
	2021	100,000	Fair
Denny Creek	2017	5000	Good
	2018	2000	Good
Black Sands Spring	2021	150,000	Fair

Figure 15. 2021 Arctic Grayling introduction sites Moore and Blaine Springs creeks.

North Fork Spanish Creek-Chiquita Lake: Funding was granted for the construction of a fish barrier on the North Fork Spanish Creek in the Gallatin Drainage by the MadTAC in 2018. The intent of the North Fork Spanish Creek project was to remove non-native trout from 17 miles of stream habitat and two alpine lakes with the intent to reestablish WCT and Arctic Grayling. Typically, funds are restricted to projects in the Madison Drainage; however, an exception to the allocation of funding was made because of limited opportunities and the difficulties of establishing Arctic Grayling populations within the Madison River Basin.

In 2019, Chiquita Lake was treated with the fish toxicant CFT Legumine to remove non-native fishes. The toxicant was applied to the waters of Chiquita Lake from a raft by a two-person crew. The raft was rowed in a grid pattern across the lake while chemical was dispersed from a plastic pesticide tank equipped with a small electric pump. The pump moved the chemical through an array of perforated hoses that were suspended below the water surface. Complete removal was confirmed through the use of gillnets and environmental DNA (eDNA) sampling in 2021. FWP restocked Chiquita Lake with 3666 Arctic Grayling fry of primarily Madison ancestry in 2021. This population will be monitored and managed to ensure it meets long-term conservation goals.

Westslope Cutthroat Trout: FWP's Statewide Fisheries Management Plan calls for the protection and reintroduction of WCT with less than 10% hybridization by non-native fish (i.e., conservation populations) to 20% of historically occupied waters (Montana Statewide Fisheries Management Program and Guide 2018). The MadTAC has granted funding to FWP to pursue these conservation efforts under Articles 408, 409, and 412 of the 2188 project FERC license. WCT PM&E activities in 2021 included completion of the Wall Creek fish migration barrier, assessment of the Tepee Creek barrier, wild fish transfer of WCT from Last Chance Creek into Ruby Creek, and feasibility assessments of Madison River tributaries for fish migration barrier construction to protect WCT conservation populations.

The Wall Creek barrier was constructed over a three-month period in fall 2021. A pre-construction meeting between FWP staff, project engineers, and contractors was held at the construction site on June 9, 2021 to discuss and agree upon material specifications and a construction schedule. Initially, barrier construction was to begin the third week of July, 2021. However, construction was delayed until August 23, 2021 to mitigate the risk of fire caused by construction activities during the extremely hot and dry conditions that predominated July and much of August. Construction site preparation, which consisted of primitive road improvements, clearing and grubbing, and rerouting of the stream to dewater the construction area was completed September 30 (Figure 16). Excavation of the barrier footprint was completed September 22 and the barrier footers were formed and poured the first week of October (Figure 17). Inclement weather during October prohibited concrete trucks from accessing the site because of deteriorating road conditions. Consequently, the final pour for the barrier structure did not occur until November 16 when the ground had frozen. Wall Creek was diverted back to its channel and over the completed barrier on November 22 (Figure 18). The Wall Creek barrier secures 7.5 miles of stream occupied by WCT of 95% genetic purity from invasion by non-native fishes. FWP will continue to monitor and report on the WCT population and performance of the barrier.

Figure 16. Road improvements and barrier site excavation on Wall Creek.

Figure 17. Wall Creek concrete barrier forms.

Figure 18. Completed Wall Creek barrier in November 2021.

Evaluation of the Tepee Creek fish barrier was equivocal and further analysis is needed to develop direction for this project. The Tepee Creek fish migration barrier is a natural waterfall that was improved to create a 12-ft vertical drop in 2019 by a Forest Service explosives crew. In 2020, FWP initiated evaluation of the Tepee Creek barrier to determine the potential for upstream fish passage. On July 15 and July 28, 2020, FWP collected 90 trout above the Tepee Creek barrier by electrofishing. Trout were marked with fin clip and released below the barrier. On July 21, 2021, FWP and CGNF personnel surveyed above the Tepee Creek barrier for the presence of marked fish that were released below the barrier in 2020. The survey was conducted by two crews using backpack electro-fishers in tandem. No marked fish were captured or observed; however, low water conductivity greatly reduced the electrofishing effectiveness and results of the survey do not definitively evaluate the effectiveness of the barrier to prevent upstream fish migration. FWP and CGNF have identified several issues that would likely compromise the effectiveness of the barrier. A pinch point occurs directly downstream of the barrier where debris could collect and cause the formation of a pool of sufficient depth for fish to jump over the barrier. Additionally, areas of reduced stream velocity and drop appear to be developing because of fractures in the rock on river left at the barrier site. WCT recovery efforts in Tepee Creek have been suspended pending a decision among partner agencies on the value of pursuing modifications to the barrier.

Creation of the Ruby Creek WCT population continued with translocation of fish from Last Chance Creek to improve genetic diversity. The Ruby Creek WCT restoration project was initiated in 2012 with the removal of nonnative Rainbow Trout. Ruby Creek was confirmed to be fishless by eDNA sampling in 2015. Since 2015, 94 genetically pure, aboriginal Madison WCT from McClure and Last Chance creeks have been introduced into Ruby Creek with 71 of those fish coming from McClure Creek. FWP and Yellowstone National Park personnel transferred 13 pure, aboriginal Madison WCT from Last Chance Creek to Ruby Creek on July 8, 2021. Fish from Last Chance Creek were collected with a backpack electro-fisher, measured to the nearest millimeter, and a fin clip for genetic analysis was taken from each fish. Fish were placed in an aerated cooler for transport after processing. Fish were placed in a net and allowed to acclimate to the temperature of the Ruby Creek for about 10 minutes. Although few Last Chance Creek trout have been introduced, their genetic contribution to the Ruby Creek population is greater than expected (Fuerstein 2021; Figure 19). FWP anticipates the 2021 introduction of Last Chance trout will continue to improve genetic diversity and increase the fitness of the population. FWP plans to evaluate Ruby Creek WCT distribution, reproductive status, and density in the summer of 2022.

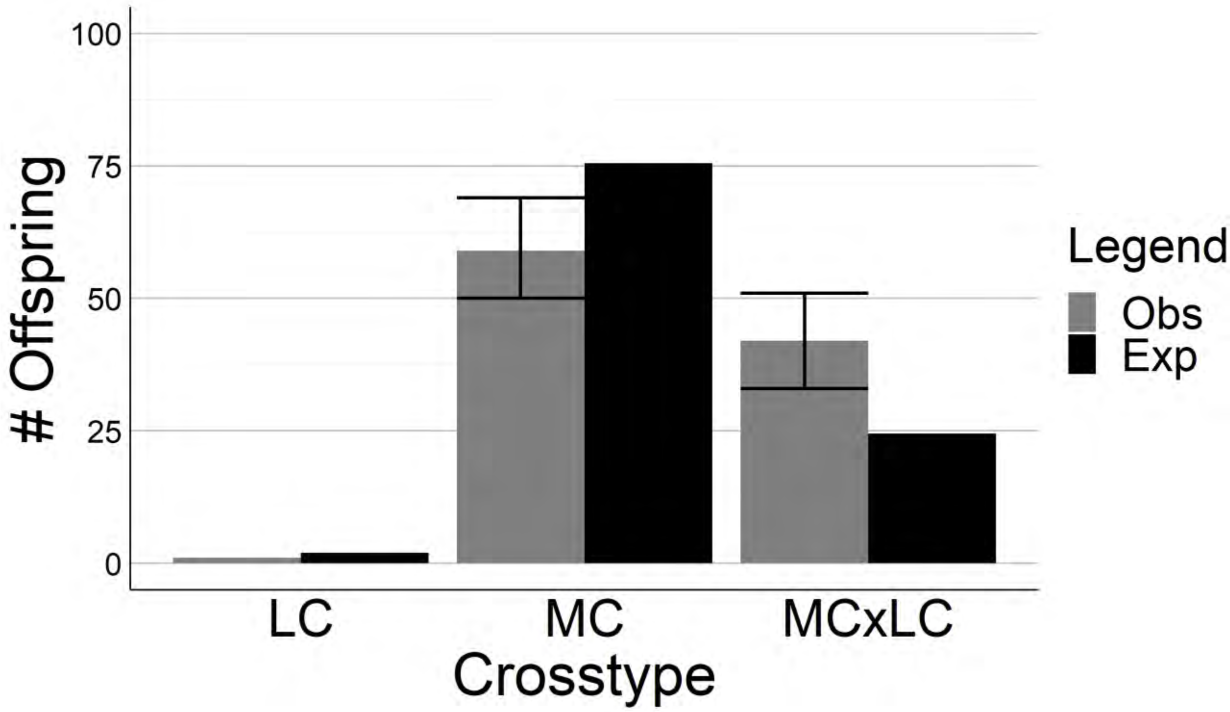


Figure 19. Ruby Creek Westslope Cutthroat Trout introduced into Ruby Creek and the genetic contribution of donors. Gray bars are the observed frequencies of offspring by crosstype. Black bars are the expected frequencies. Error bars are 95% confidence intervals (Feurstein 2021).

Article 409- 3) Fish habitat enhancement both in mainstem and tributary streams: Previous and potential future habitat enhancement activities in the mainstem Madison River and its tributaries were evaluated in 2022. The influence of habitat features (boulders, islands, side channels) in the mainstem Madison River on fish abundances were evaluated using arial imagery and historic electrofishing data. We found no evidence that addition of boulder and side channels will influence overall abundances of Madison River trout > 10"; however, increasing side channel or island density may increase abundances of large trout > 16". Riparian enhancement on South Meadow Creek shows continued willow recruitment. Habitat restoration in the upper reaches of O'dell Creek between 2005 and 2009 narrowed stream channels, increased stream sinuosity, lowered streambank elevation, and increased stream channel water surface elevations. It appears these restoration activities ultimately enhanced conditions for and increased abundance of large adult fish after initially improving abundances of younger fish. These assessments are described in more detail below.

Associations between Madison River habitat types and fish abundances: The influence of habitat features (boulders, islands, side channels) in the mainstem Madison River on fish abundances was evaluated using arial imagery and historic electrofishing data. Addition of boulders or other mainstem habitat features have been routinely suggested to improve Madison River trout abundances. Habitat or cover (e.g., boulders, large woody debris, undercut banks) have been correlated to trout abundance (Binns and Eiserman 1979; Varley and Gresswell 1988; Molony 2001). Cover provides refuge from predators as well as thermal and velocity heterogeneity. To determine the potential benefits of addition of mainstem habitat features to the Madison River, FWP examined the effects of three habitat covariates (boulders, islands, and side channels) on trout abundances for fish ≥ 10" and ≥ 16" in the Pine Butte, Varney, and Norris sections. Twenty years of data (2000-2020) for each of the monitoring reaches was sorted by sub-stops. Sub-stops were pooled for analysis if sub-stops were combined in some years. For example, if sub-stop A was consistently stopped at but B was often passed by, then A and B were pooled and considered one sub-stop each year. Abundance estimates for fish ≥ 10" and ≥ 16" within each sub-stop were calculated using Chapman's estimator to initially assess variation among years and sub-stops. Covariates within sub-stops were enumerated using satellite imagery provided by Google Earth (Figure 20). We counted boulders and measured side channel length and main channel length using the measurement tools provided in the Google Earth program. Total channel length (*TCL*) was calculated by adding the main channel length (MCL) of each sub-stop section to side channel length (*SCL*) of each sub-stop section $TCL = MCL + SCL$. Densities (habitat feature/mile) for each covariate were calculated by dividing the number of observed features by *TCL*, $habitat\ feature/mile = \#\ of habitat\ features\ with\ in\ a\ sub\ stop/TCL$. These metrics were sorted and compiled for use in a statistical model to determine covariate effects on abundances (Table 2).

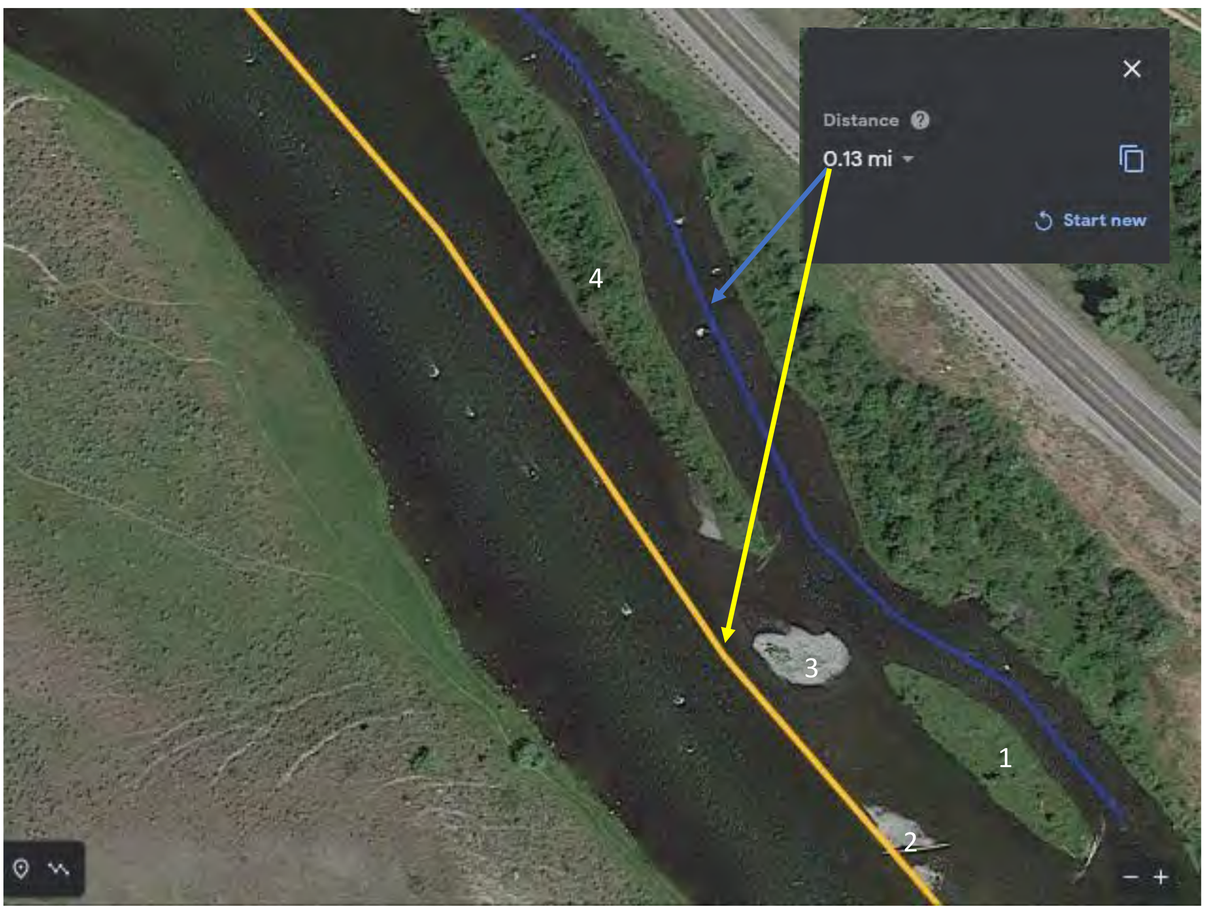


Figure 20. Satellite imagery from Google Earth used to determine channel lengths and covariate densities within sub sections of long-term Madison monitoring reaches. The blue line represents a side channel

length measurement, the yellow line a main channel measurement, and the numbers are identified islands within the reach.

Our modeling approach was focused on assessing the influence of stream characteristics (boulder, side-channel, and island density) on fish abundance while allowing for extra variation from random year effects and a robust negative binomial model for fish abundance. The complex model structure we used (a count-based model estimated from mark-recapture data for multiple sections within stream reaches) had variation at multiple levels, and we would like to highlight the inference available from our model as a series of questions:

1) How much do trout abundances vary through time within sections and within reaches?
2) What is the relationship between stream characteristics and fish abundance, and how does this relationship change between stream reaches?
3) After accounting for variation in abundance due to variation in stream characteristics, how much do fish abundances vary among years within reaches, and among years between reaches (i.e., otherwise unexplained variation)?

Moreover, we ran separate models for two length groups (> 10 inches and > 16 inches), which allowed us to add an additional question:

4) How do the above relationships change between length groups?

The model had two key components: a model to estimate fish abundances using the mark-recapture data, and a model for the estimated fish abundance as a function of stream characteristics (boulder density, islands, and side channels). The mark-recapture data were based on single-pass electrofishing sampling: data were collected by making marking and recapture runs on the right bank, left bank, and center of the channel, respectively and analyzed by treating them as single mark and recapture runs. We treated the marking and recapture runs as two independent sampling events with an identical probability of detection, which we estimated using a binomial model for the number of marked fish captured during the second sampling event (i.e., recapture run). We then estimated fish abundance by modeling it as a binomial random variable assuming the number of fish on the marking run and total fish on the recapture run as replicated observations, i.e., we inflated the number of fish caught on the marking and recapture runs by the estimated detection probability. We used a simple structure for the probabilities of detection: each reach (i.e., Varney, Pine Butte, and Norris) had an independent overall mean probability of detection, and yearly variation in detection probabilities was incorporated using random-effects unique to each reach (i.e., year random effects were not shared between reaches).

We used a negative binomial model for the model for fish abundance as a function of environmental covariates, a flexible count-based model that was able to accommodate more variation in abundance than a simple Poisson model. Using a log-link, we modeled the expected number of fish in each section within each reach using a section-specific overall intercept (corresponding to the estimated number of fish with all covariates held to their mean value), a random year effect specific to each reach (i.e., a random year effect applied to all sections within each reach), reach-specific regression coefficients (i.e., all sections within a reach responded similarly to variation in the covariate), and an offset for the length of the section within the reach.

Initial data exploration and model results indicated that the correlation between side channel and island density was substantial enough to affect inference on regression coefficients. Therefore, we constructed two separate models: a model of fish abundance as a function of boulder density and island density, and a model of fish abundance as a function of boulder density and side-channel density.

Notably, our model had several substantial limitations due to the relationship between the available data and the inference required. First, the relationship(s) between stream covariates and fish abundance (accounting for differences in section length) was assumed to be the same for every section within a reach, i.e., the proportional impact of variation in stream covariates was the same for each section, a simplification required because stream covariates did not vary through time. Second, the random effects of year on fish abundance were shared across sections within reaches (i.e., different sections did not have unique yearly random effects), which assumed that year effects applied equally to all sections within reaches. Finally, the probability of detection for the mark-recapture component of the model was assumed to be constant within reaches and years (i.e., no among-section variation in detection probability, only variation among years and reaches), which we justified after initial modeling efforts suggested very little among-section variation in detection within years.

The complex hierarchical structure of our model, combined with our intent to readily produce figures of the predicted relationships among stream covariates, fish abundance, reaches and sections using derived covariates, necessitated a Bayesian approach to estimation. We used the runjags package as an interface to the JAGS probabilistic programming language in the R environment. Each model was run for 250,000 iterations with 4 chains, with the first 50,000 samples discarded as the adaptation and burn-in phase, and the resulting chain thinned by a factor of 40 (due to memory constraints and autocorrelation issues), resulting in 20,000 iterations for inference. We used the medians and 95% highest posterior density intervals (a credible interval, or Bayesian version of a confidence interval) to summarize the posterior distributions of estimated parameters. All covariates were centered and scaled.

Boulder density was highest in Pine Butte (400 boulders/mile) followed by Norris (248 boulders/mile) and Varney (16 boulders/mile). Overall, the Varney Section had the greatest densities of islands and side channels with 10 islands/mile and 4 side channels/mile. Norris had the lowest island density among all sections with 4 islands/mile and similar side channel density to Pine Butte (Table 2).

Between sub-stops within the Pine Butte section, sub-stop C had the highest density of boulders (715 boulders/mile), sub-stop A had the highest density of islands (10 islands/mile), and sub-stop F had the highest density of side-channels (3 side channels/mile). In the Varney section, sub-stop

A-D had the greatest density of boulders (18 boulders/mile), and sub-stop G-I had the greatest density of islands and side channels at 19 islands/mile and 4 side channels/mile. Boulder densities were greatest among Norris sub-stops in sub-stop D (813 boulders/mile). Island densities were the highest in sub-stop E (8 islands/mile) and side channel densities greatest in sub-stop G (4 side channels/mile; Table 2).

Table 2. Stream habitat covariate densities in the Pine Butte, Varney, and Norris sections.

Section	Sub-stop	Stream length (miles)	#Boulders	Boulder density (#/mile)	#Islands	Island density (#/mile)	#Side channels	Side channel density (#/mile)
Pine Butte	A	1.2	281	244	12	10	2	2.0
Pine Butte	B	0.6	394	657	1	2.0	0	0.0
Pine Butte	C	0.4	293	715	2	5.0	0	0.0
Pine Butte	D	1.2	647	530	5	4.0	3	3.0
Pine Butte	E	0.5	123	256	1	2.0	1	2.0
Pine Butte	F	0.8	120	154	3	4.0	2	3.0
Totals		**4.6**	**1858**	**400**	**24**	**5.0**	**8**	**2.0**
Varney	A-D	4.8	85	18	30	6.0	18	4.0
Varney	E-F	2.7	36	13	16	6.0	7	3.0
Varney	G-I	3.1	50	16	58	19.0	12	4.0
Totals		**10.5**	**171**	**16**	**104**	**10.0**	**37**	**4.0**
Norris	A	0.6	40	67	3	5.0	1	2.0
Norris	B	0.6	148	269	1	2.0	0	0.0
Norris	C	0.4	153	373	1	2.0	0	0.0
Norris	D	0.5	374	813	0	0.0	0	0.0
Norris	E	0.7	184	252	6	8.0	1	1.0
Norris	F	0.4	102	237	0	0.0	0	0.0
Norris	G	0.5	118	227	4	8.0	2	4.0
Norris	H	0.7	97	139	4	6.0	2	3.0
Norris	I	0.9	96	108	4	5.0	3	3.0
Totals		**5.3**	**1312**	**248**	**23**	**4.0**	**9**	**2.0**

The abundance of trout showed considerable variation among length groups, among section sub-stops, within sub-stops, and among years (Table 3; Figures 21 and 22). Within section variation in abundance of > 10” and > 16” trout across sub-stops and years were lowest in Pine Butte and highest in the Varney section; however, sub-stop abundances differed among years in each section. For the Pine Butte section, across all section sub-stops and years the abundance of trout > 10” varied from a minimum of 501 [414, 651] in 2004 to 1526 [1193, 1904] in 2009. Among section sub-stops, the standardized ranges (the difference between the maximum estimated abundance and the minimum estimated abundance divided by the mean estimated abundance across years; higher values indicate more substantial swings in abundance around the long-term average) across years had a minimum of 0.66 and a maximum of 0.81. For trout > 16” the abundances across all section sub-stops and years varied from a minimum of 104 [69, 160] in 2010 to a maximum of 495 [353, 649] in 2013, and standardized ranges had a minimum of 0.63 and a maximum of 1.04. For the Varney section, across all section sub-stops and years the abundance of trout > 10” varied from a minimum of 623 [524, 765] in 2017 to 3440 [2999, 3908] in 2007, and the standardized ranges had a minimum of 0.97 and a maximum of 1.00. For trout > 16” the abundances across all section sub-stops and years varied from a minimum of 256 [185, 312] in 2017 to a maximum of 871 [716, 1089] in 2002, and standardized ranges had a minimum of 0.61 and a maximum of 0.77. It is noteworthy that the Varney Section required considerably more consolidation of sub-stops than other sections to make comparisons among years. For the Norris Section, abundance of trout > 10” varied from a minimum of 498 (95% credible interval = [391, 623]) in 2000 to 2177 [1826, 2557] in 2001, and standardized ranges had a minimum of 0.47 and a maximum of 1.01. For trout > 16”, the abundances across all section sub-stops and years varied from a minimum of 74 [47, 137] in 2002 to a maximum of 359 [264, 495] in 2003, and standardized ranges had a minimum of 0.49 and a maximum of 0.89.

Table 3. Estimated trout abundances by length group, year, section, and sub-stop.

Length group (inches)	Year	Section	Sub-stop	Estimated abundance	2.5%	97.5%
> 10	2000	Norris	A	759	612	927
> 10	2000	Norris	B	618	497	766
> 10	2000	Norris	C	552	434	678
> 10	2000	Norris	D	498	391	623
> 10	2000	Norris	E	638	515	796
> 10	2000	Norris	F	834	671	1014
> 10	2000	Norris	G	545	436	679
> 10	2000	Norris	H	1000	821	1225
> 10	2000	Norris	I	871	724	1087
> 10	2001	Norris	A	1026	829	1213
> 10	2001	Norris	B	1011	847	1238
> 10	2001	Norris	C	1094	931	1354
> 10	2001	Norris	D	1250	1057	1521
> 10	2001	Norris	E	1209	1046	1511
> 10	2001	Norris	F	2177	1826	2557
> 10	2001	Norris	G	1119	919	1331
> 10	2001	Norris	H	2150	1837	2574
> 10	2001	Norris	I	1686	1421	2012
> 10	2002	Norris	A	763	628	968
> 10	2002	Norris	B	1017	823	1245

> 10	2002	Norris	C	766	626	960
> 10	2002	Norris	D	1091	903	1356
> 10	2002	Norris	E	1217	989	1481
> 10	2002	Norris	F	1193	946	1427
> 10	2002	Norris	G	659	531	826
> 10	2002	Norris	H	1316	1109	1653
> 10	2002	Norris	I	842	662	1021
> 10	2003	Norris	A	1123	940	1326
>10	2003	Norris	B	1080	906	1278
> 10	2003	Norris	C	827	692	992
> 10	2003	Norris	D	1002	822	1162
> 10	2003	Norris	E	1250	1052	1473
> 10	2003	Norris	F	1123	959	1351
> 10	2003	Norris	G	803	682	978
> 10	2003	Norris	H	1880	1581	2172
> 10	2003	Norris	I	1203	986	1387
> 10	2004	Norris	A	860	708	1028
> 10	2004	Norris	B	682	551	818
> 10	2004	Norris	C	645	512	762
> 10	2004	Norris	D	841	653	955
> 10	2004	Norris	E	848	676	982
> 10	2004	Norris	F	962	798	1154
> 10	2004	Norris	G	793	645	938
> 10	2004	Norris	H	1427	1175	1662
> 10	2004	Norris	I	740	612	905
> 10	2007	Norris	A	919	762	1076
> 10	2007	Norris	B	1001	826	1163
> 10	2007	Norris	C	696	593	856
> 10	2007	Norris	D	1069	915	1280
> 10	2007	Norris	E	1146	976	1359
> 10	2007	Norris	F	1545	1336	1828
> 10	2007	Norris	G	709	603	866
> 10	2007	Norris	H	1432	1197	1656
> 10	2007	Norris	I	1076	889	1251
> 10	2008	Norris	A	710	621	863
> 10	2008	Norris	B	712	595	832
> 10	2008	Norris	C	664	564	790
> 10	2008	Norris	D	850	700	966
> 10	2008	Norris	E	946	772	1062
> 10	2008	Norris	F	1272	1103	1490
> 10	2008	Norris	G	741	635	881
> 10	2008	Norris	H	986	845	1157
> 10	2008	Norris	I	1025	895	1220
> 10	2010	Norris	A	903	762	1069
> 10	2010	Norris	B	858	707	1001

> 10	2010	Norris	C	699	587	839
> 10	2010	Norris	D	830	711	1004
> 10	2010	Norris	E	1022	863	1203
> 10	2010	Norris	F	1499	1295	1762
> 10	2010	Norris	G	673	567	813
> 10	2010	Norris	H	1216	1039	1431
> 10	2010	Norris	I	1414	1177	1612
> 10	2000	Pine Butte	A	846	668	1062
> 10	2000	Pine Butte	B	949	737	1161
> 10	2000	Pine Butte	C	1038	810	1272
> 10	2000	Pine Butte	D	1058	855	1343
> 10	2000	Pine Butte	E	919	722	1142
> 10	2000	Pine Butte	F	737	570	918
> 10	2001	Pine Butte	A	1064	818	1344
> 10	2001	Pine Butte	B	847	681	1140
> 10	2001	Pine Butte	C	1033	799	1323
> 10	2001	Pine Butte	D	1257	975	1594
> 10	2001	Pine Butte	E	838	658	1101
> 10	2001	Pine Butte	F	762	594	1001
> 10	2002	Pine Butte	A	948	759	1185
> 10	2002	Pine Butte	B	758	637	1003
> 10	2002	Pine Butte	C	761	594	939
> 10	2002	Pine Butte	D	1106	890	1377
> 10	2002	Pine Butte	E	672	534	850
> 10	2002	Pine Butte	F	759	621	981
> 10	2003	Pine Butte	A	557	436	734
> 10	2003	Pine Butte	B	682	524	873
> 10	2003	Pine Butte	C	579	427	726
> 10	2003	Pine Butte	D	784	604	1008
> 10	2003	Pine Butte	E	570	445	748
> 10	2003	Pine Butte	F	534	411	701
> 10	2004	Pine Butte	A	645	506	786
> 10	2004	Pine Butte	B	781	635	973
> 10	2004	Pine Butte	C	563	454	713
> 10	2004	Pine Butte	D	657	550	850
> 10	2004	Pine Butte	E	650	513	797
> 10	2004	Pine Butte	F	501	414	651
> 10	2005	Pine Butte	A	901	645	1208
> 10	2005	Pine Butte	B	841	610	1143
> 10	2005	Pine Butte	C	805	620	1163
> 10	2005	Pine Butte	D	1012	780	1449
> 10	2005	Pine Butte	E	808	572	1079
> 10	2005	Pine Butte	F	861	584	1087
> 10	2006	Pine Butte	A	906	741	1117
> 10	2006	Pine Butte	B	926	780	1170

> 10	2006	Pine Butte	C	924	727	1095
> 10	2006	Pine Butte	D	1183	972	1441
> 10	2006	Pine Butte	E	912	764	1144
> 10	2006	Pine Butte	F	735	604	924
> 10	2007	Pine Butte	A	1042	851	1260
> 10	2007	Pine Butte	B	1056	868	1280
> 10	2007	Pine Butte	C	1093	914	1343
> 10	2007	Pine Butte	D	1399	1155	1682
> 10	2007	Pine Butte	E	1075	891	1314
> 10	2007	Pine Butte	F	903	752	1109
> 10	2008	Pine Butte	A	908	738	1058
> 10	2008	Pine Butte	B	904	743	1060
> 10	2008	Pine Butte	C	691	554	811
> 10	2008	Pine Butte	D	1184	1023	1434
> 10	2008	Pine Butte	E	1134	935	1315
> 10	2008	Pine Butte	F	868	713	1023
> 10	2009	Pine Butte	A	860	675	1107
> 10	2009	Pine Butte	B	901	714	1165
> 10	2009	Pine Butte	C	877	677	1115
> 10	2009	Pine Butte	D	1526	1193	1904
> 10	2009	Pine Butte	E	871	676	1108
> 10	2009	Pine Butte	F	906	705	1147
> 10	2010	Pine Butte	A	998	831	1221
> 10	2010	Pine Butte	B	980	805	1181
> 10	2010	Pine Butte	C	1139	934	1358
> 10	2010	Pine Butte	D	946	781	1157
> 10	2010	Pine Butte	E	713	588	883
> 10	2010	Pine Butte	F	770	619	922
> 10	2011	Pine Butte	A	1006	800	1298
> 10	2011	Pine Butte	B	795	627	1039
> 10	2011	Pine Butte	C	886	699	1142
> 10	2011	Pine Butte	D	936	757	1240
> 10	2011	Pine Butte	E	674	535	901
> 10	2011	Pine Butte	F	754	609	1004
> 10	2012	Pine Butte	A	1116	888	1375
> 10	2012	Pine Butte	B	1050	829	1289
> 10	2012	Pine Butte	C	1346	1031	1590
> 10	2012	Pine Butte	D	1259	987	1521
> 10	2012	Pine Butte	E	1091	851	1327
> 10	2012	Pine Butte	F	1179	953	1468
> 10	2013	Pine Butte	A	1314	1097	1589
> 10	2013	Pine Butte	B	1167	977	1422
> 10	2013	Pine Butte	C	1278	1046	1514
> 10	2013	Pine Butte	D	1315	1107	1592
> 10	2013	Pine Butte	E	1172	983	1420

> 10	2013	Pine Butte	F	1176	929	1349
> 10	2014	Pine Butte	A	1225	1029	1502
> 10	2014	Pine Butte	B	1303	1095	1587
> 10	2014	Pine Butte	C	1246	1017	1476
> 10	2014	Pine Butte	D	1409	1188	1717
> 10	2014	Pine Butte	E	1066	891	1308
> 10	2014	Pine Butte	F	1153	934	1360
> 10	2015	Pine Butte	A	1127	918	1334
> 10	2015	Pine Butte	B	1211	1014	1468
> 10	2015	Pine Butte	C	1271	1064	1525
> 10	2015	Pine Butte	D	1116	912	1328
> 10	2015	Pine Butte	E	1302	1131	1619
> 10	2015	Pine Butte	F	890	742	1088
> 10	2017	Pine Butte	A	792	634	975
> 10	2017	Pine Butte	B	760	630	966
> 10	2017	Pine Butte	C	867	715	1087
> 10	2017	Pine Butte	D	1065	869	1313
> 10	2017	Pine Butte	E	1160	918	1372
> 10	2017	Pine Butte	F	888	731	1107
> 10	2000	Varney	A-D	2711	2370	3178
> 10	2000	Varney	E-F	1157	982	1357
> 10	2000	Varney	G-I	1736	1477	2001
> 10	2001	Varney	A-D	2500	2186	2950
> 10	2001	Varney	E-F	978	819	1148
> 10	2001	Varney	G-I	1276	1079	1494
> 10	2002	Varney	A-D	2519	2157	2977
> 10	2002	Varney	E-F	1160	980	1386
> 10	2002	Varney	G-I	1735	1490	2067
> 10	2003	Varney	A-D	2633	2295	3120
> 10	2003	Varney	E-F	1070	922	1292
> 10	2003	Varney	G-I	1466	1261	1745
> 10	2004	Varney	A-D	2460	2092	2990
> 10	2004	Varney	E-F	1042	853	1260
> 10	2004	Varney	G-I	1390	1193	1729
> 10	2005	Varney	A-D	2242	1878	2671
> 10	2005	Varney	E-F	803	650	970
> 10	2005	Varney	G-I	1230	1047	1526
> 10	2006	Varney	A-D	3309	2852	3823
> 10	2006	Varney	E-F	1589	1383	1889
> 10	2006	Varney	G-I	1964	1702	2312
> 10	2007	Varney	A-D	3440	2999	3908
> 10	2007	Varney	E-F	1579	1363	1814
> 10	2007	Varney	G-I	2068	1814	2397
> 10	2009	Varney	A-D	1451	1272	1753
> 10	2009	Varney	E-F	755	619	869

> 10	2009	Varney	G-I	1118	948	1309
> 10	2010	Varney	A-D	1461	1221	1704
> 10	2010	Varney	E-F	651	529	765
> 10	2010	Varney	G-I	943	826	1160
> 10	2011	Varney	A-D	1814	1470	2169
> 10	2011	Varney	E-F	681	559	858
> 10	2011	Varney	G-I	779	620	961
> 10	2012	Varney	A-D	2589	2208	3162
> 10	2012	Varney	E-F	1182	963	1413
> 10	2012	Varney	G-I	1517	1265	1845
> 10	2013	Varney	A-D	2357	1991	2835
> 10	2013	Varney	E-F	995	848	1240
> 10	2013	Varney	G-I	1515	1287	1850
> 10	2014	Varney	A-D	2868	2531	3411
> 10	2014	Varney	E-F	1081	920	1285
> 10	2014	Varney	G-I	1585	1344	1844
> 10	2015	Varney	A-D	1624	1418	1935
> 10	2015	Varney	E-F	781	664	931
> 10	2015	Varney	G-I	1217	1033	1420
> 10	2017	Varney	A-D	1209	988	1423
> 10	2017	Varney	E-F	623	524	765
> 10	2017	Varney	G-I	884	753	1087
> 10	2018	Varney	A-D	1815	1535	2130
> 10	2018	Varney	E-F	737	608	876
> 10	2018	Varney	G-I	1058	913	1292
> 10	2019	Varney	A-D	1597	1292	1845
> 10	2019	Varney	E-F	694	586	861
> 10	2019	Varney	G-I	993	828	1204
> 10	2020	Varney	A-D	1747	1474	2072
> 10	2020	Varney	E-F	835	709	1018
> 10	2020	Varney	G-I	910	749	1086
> 16	2000	Norris	A	151	105	215
> 16	2000	Norris	B	84	49	125
> 16	2000	Norris	C	106	67	153
> 16	2000	Norris	D	122	75	172
> 16	2000	Norris	E	191	125	258
> 16	2000	Norris	F	223	156	309
> 16	2000	Norris	G	227	164	325
> 16	2000	Norris	H	298	214	412
> 16	2000	Norris	I	204	146	293
> 16	2001	Norris	A	106	69	160
> 16	2001	Norris	B	81	52	129
> 16	2001	Norris	C	108	70	159
> 16	2001	Norris	D	131	92	201
> 16	2001	Norris	E	134	84	197

> 16	2001	Norris	F	230	159	320
> 16	2001	Norris	G	192	125	262
> 16	2001	Norris	H	327	239	466
> 16	2001	Norris	I	198	133	278
> 16	2002	Norris	A	80	46	140
> 16	2002	Norris	B	74	47	137
> 16	2002	Norris	C	85	59	159
> 16	2002	Norris	D	132	82	220
> 16	2002	Norris	E	154	99	256
> 16	2002	Norris	F	122	75	214
> 16	2002	Norris	G	134	89	232
> 16	2002	Norris	H	179	114	298
> 16	2002	Norris	I	131	79	222
> 16	2003	Norris	A	163	109	224
> 16	2003	Norris	B	139	89	191
> 16	2003	Norris	C	104	71	163
> 16	2003	Norris	D	181	127	257
> 16	2003	Norris	E	232	169	329
> 16	2003	Norris	F	189	131	273
> 16	2003	Norris	G	198	139	282
> 16	2003	Norris	H	359	264	495
> 16	2003	Norris	I	240	161	322
> 16	2004	Norris	A	149	97	207
> 16	2004	Norris	B	102	67	152
> 16	2004	Norris	C	113	75	169
> 16	2004	Norris	D	116	77	172
> 16	2004	Norris	E	134	91	205
> 16	2004	Norris	F	169	108	234
> 16	2004	Norris	G	209	145	294
> 16	2004	Norris	H	280	207	403
> 16	2004	Norris	I	154	100	221
> 16	2007	Norris	A	133	88	199
> 16	2007	Norris	B	168	110	235
> 16	2007	Norris	C	123	81	187
> 16	2007	Norris	D	195	132	278
> 16	2007	Norris	E	212	156	323
> 16	2007	Norris	F	272	187	376
> 16	2007	Norris	G	183	129	280
> 16	2007	Norris	H	244	172	362
> 16	2007	Norris	I	246	166	342
> 16	2008	Norris	A	85	54	134
> 16	2008	Norris	B	82	52	127
> 16	2008	Norris	C	106	71	158
> 16	2008	Norris	D	149	94	203
> 16	2008	Norris	E	194	127	263

> 16	2008	Norris	F	189	131	270
> 16	2008	Norris	G	193	143	288
> 16	2008	Norris	H	183	124	263
> 16	2008	Norris	I	193	131	272
> 16	2010	Norris	A	127	94	198
> 16	2010	Norris	B	111	78	170
> 16	2010	Norris	C	142	98	205
> 16	2010	Norris	D	220	147	292
> 16	2010	Norris	E	270	184	353
> 16	2010	Norris	F	277	202	385
> 16	2010	Norris	G	175	122	251
> 16	2010	Norris	H	245	165	331
> 16	2010	Norris	I	264	180	347
> 16	2000	Pine Butte	A	162	102	296
> 16	2000	Pine Butte	B	196	121	328
> 16	2000	Pine Butte	C	139	89	246
> 16	2000	Pine Butte	D	228	149	386
> 16	2000	Pine Butte	E	161	104	272
> 16	2000	Pine Butte	F	110	74	208
> 16	2001	Pine Butte	A	273	166	401
> 16	2001	Pine Butte	B	236	154	375
> 16	2001	Pine Butte	C	191	114	284
> 16	2001	Pine Butte	D	261	162	388
> 16	2001	Pine Butte	E	152	100	252
> 16	2001	Pine Butte	F	160	103	261
> 16	2002	Pine Butte	A	298	215	464
> 16	2002	Pine Butte	B	248	156	350
> 16	2002	Pine Butte	C	146	86	213
> 16	2002	Pine Butte	D	223	161	358
> 16	2002	Pine Butte	E	178	107	250
> 16	2002	Pine Butte	F	138	85	204
> 16	2003	Pine Butte	A	189	126	300
> 16	2003	Pine Butte	B	263	173	387
> 16	2003	Pine Butte	C	159	103	247
> 16	2003	Pine Butte	D	229	142	326
> 16	2003	Pine Butte	E	142	93	222
> 16	2003	Pine Butte	F	131	82	203
> 16	2004	Pine Butte	A	291	204	403
> 16	2004	Pine Butte	B	374	255	490
> 16	2004	Pine Butte	C	134	94	208
> 16	2004	Pine Butte	D	228	156	322
> 16	2004	Pine Butte	E	160	116	245
> 16	2004	Pine Butte	F	184	115	242
> 16	2005	Pine Butte	A	309	203	477
> 16	2005	Pine Butte	B	220	137	341

> 16	2005	Pine Butte	C	146	94	247
> 16	2005	Pine Butte	D	241	154	371
> 16	2005	Pine Butte	E	143	89	231
> 16	2005	Pine Butte	F	177	116	278
> 16	2006	Pine Butte	A	303	198	418
> 16	2006	Pine Butte	B	213	152	328
> 16	2006	Pine Butte	C	142	100	228
> 16	2006	Pine Butte	D	252	187	392
> 16	2006	Pine Butte	E	207	141	296
> 16	2006	Pine Butte	F	159	97	220
> 16	2007	Pine Butte	A	287	198	422
> 16	2007	Pine Butte	B	196	137	309
> 16	2007	Pine Butte	C	159	106	247
> 16	2007	Pine Butte	D	229	154	341
> 16	2007	Pine Butte	E	148	98	226
> 16	2007	Pine Butte	F	157	99	225
> 16	2008	Pine Butte	A	346	241	459
> 16	2008	Pine Butte	B	249	178	351
> 16	2008	Pine Butte	C	179	118	246
> 16	2008	Pine Butte	D	234	165	331
> 16	2008	Pine Butte	E	180	123	253
> 16	2008	Pine Butte	F	136	91	197
> 16	2009	Pine Butte	A	254	156	387
> 16	2009	Pine Butte	B	241	159	389
> 16	2009	Pine Butte	C	185	121	297
> 16	2009	Pine Butte	D	257	181	432
> 16	2009	Pine Butte	E	122	73	202
> 16	2009	Pine Butte	F	140	83	220
> 16	2010	Pine Butte	A	321	240	449
> 16	2010	Pine Butte	B	277	205	388
> 16	2010	Pine Butte	C	258	185	350
> 16	2010	Pine Butte	D	227	169	326
> 16	2010	Pine Butte	E	104	69	160
> 16	2010	Pine Butte	F	159	105	214
> 16	2011	Pine Butte	A	365	265	502
> 16	2011	Pine Butte	B	266	193	377
> 16	2011	Pine Butte	C	192	137	278
> 16	2011	Pine Butte	D	222	155	309
> 16	2011	Pine Butte	E	139	93	199
> 16	2011	Pine Butte	F	146	97	208
> 16	2012	Pine Butte	A	351	266	559
> 16	2012	Pine Butte	B	328	226	482
> 16	2012	Pine Butte	C	278	197	422
> 16	2012	Pine Butte	D	293	203	442
> 16	2012	Pine Butte	E	259	168	368

> 16	2012	Pine Butte	F	235	159	346
> 16	2013	Pine Butte	A	495	353	649
> 16	2013	Pine Butte	B	359	268	504
> 16	2013	Pine Butte	C	318	227	429
> 16	2013	Pine Butte	D	297	210	405
> 16	2013	Pine Butte	E	240	167	327
> 16	2013	Pine Butte	F	229	159	313
> 16	2014	Pine Butte	A	467	359	647
> 16	2014	Pine Butte	B	363	287	524
> 16	2014	Pine Butte	C	292	213	400
> 16	2014	Pine Butte	D	386	290	532
> 16	2014	Pine Butte	E	246	169	327
> 16	2014	Pine Butte	F	177	128	260
> 16	2015	Pine Butte	A	412	296	553
> 16	2015	Pine Butte	B	381	276	513
> 16	2015	Pine Butte	C	329	232	438
> 16	2015	Pine Butte	D	262	187	369
> 16	2015	Pine Butte	E	292	214	405
> 16	2015	Pine Butte	F	228	158	311
> 16	2017	Pine Butte	A	330	237	444
> 16	2017	Pine Butte	B	257	171	335
> 16	2017	Pine Butte	C	238	180	339
> 16	2017	Pine Butte	D	344	262	481
> 16	2017	Pine Butte	E	242	178	338
> 16	2017	Pine Butte	F	217	163	313
> 16	2000	Varney	A-D	713	576	856
> 16	2000	Varney	E-F	343	262	411
> 16	2000	Varney	G-I	546	443	661
> 16	2001	Varney	A-D	737	579	858
> 16	2001	Varney	E-F	360	296	456
> 16	2001	Varney	G-I	541	428	647
> 16	2002	Varney	A-D	871	716	1089
> 16	2002	Varney	E-F	486	406	632
> 16	2002	Varney	G-I	712	600	912
> 16	2003	Varney	A-D	708	593	879
> 16	2003	Varney	E-F	422	335	512
> 16	2003	Varney	G-I	577	472	708
> 16	2004	Varney	A-D	824	670	1012
> 16	2004	Varney	E-F	406	319	502
> 16	2004	Varney	G-I	488	414	643
> 16	2005	Varney	A-D	730	585	898
> 16	2005	Varney	E-F	340	271	435
> 16	2005	Varney	G-I	519	407	639
> 16	2006	Varney	A-D	857	702	1019
> 16	2006	Varney	E-F	447	365	547

> 16	2006	Varney	G-I	598	489	721
> 16	2007	Varney	A-D	792	652	960
> 16	2007	Varney	E-F	440	363	547
> 16	2007	Varney	G-I	616	500	743
> 16	2009	Varney	A-D	740	604	892
> 16	2009	Varney	E-F	399	307	473
> 16	2009	Varney	G-I	547	446	669
> 16	2010	Varney	A-D	661	529	789
> 16	2010	Varney	E-F	345	277	431
> 16	2010	Varney	G-I	636	520	770
> 16	2011	Varney	A-D	506	403	732
> 16	2011	Varney	E-F	284	208	394
> 16	2011	Varney	G-I	321	241	459
> 16	2012	Varney	A-D	652	536	886
> 16	2012	Varney	E-F	358	266	459
> 16	2012	Varney	G-I	471	367	626
> 16	2013	Varney	A-D	494	395	655
> 16	2013	Varney	E-F	290	224	381
> 16	2013	Varney	G-I	426	330	551
> 16	2014	Varney	A-D	810	659	973
> 16	2014	Varney	E-F	366	298	462
> 16	2014	Varney	G-I	562	460	689
> 16	2015	Varney	A-D	633	486	752
> 16	2015	Varney	E-F	328	242	390
> 16	2015	Varney	G-I	456	364	569
> 16	2017	Varney	A-D	447	347	561
> 16	2017	Varney	E-F	256	185	312
> 16	2017	Varney	G-I	329	245	406
> 16	2018	Varney	A-D	650	518	788
> 16	2018	Varney	E-F	299	234	375
> 16	2018	Varney	G-I	443	360	558
> 16	2019	Varney	A-D	570	449	692
> 16	2019	Varney	E-F	288	230	369
> 16	2019	Varney	G-I	429	351	545
> 16	2020	Varney	A-D	777	644	953
> 16	2020	Varney	E-F	439	343	522
> 16	2020	Varney	G-I	455	362	563

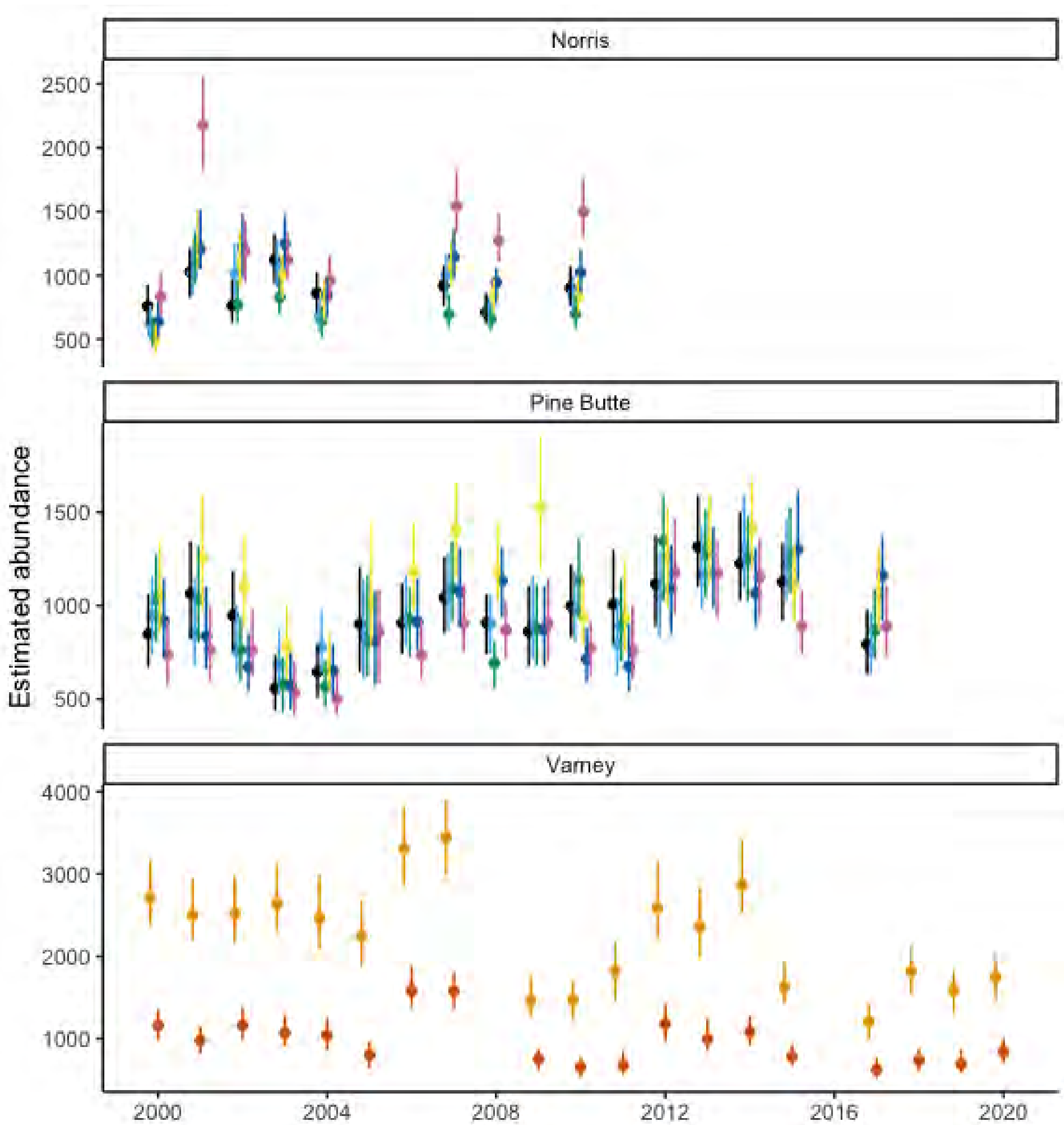


Figure 21. Estimated abundances of trout > 10” (brown trout and rainbow trout) in the Norris, Pine Butte, and Varney sections. Circles indicate the medians and lines indicate 95% credible intervals. Colors represent the different sub-stops in each section. Note the different scales on the y-axes in each panel.

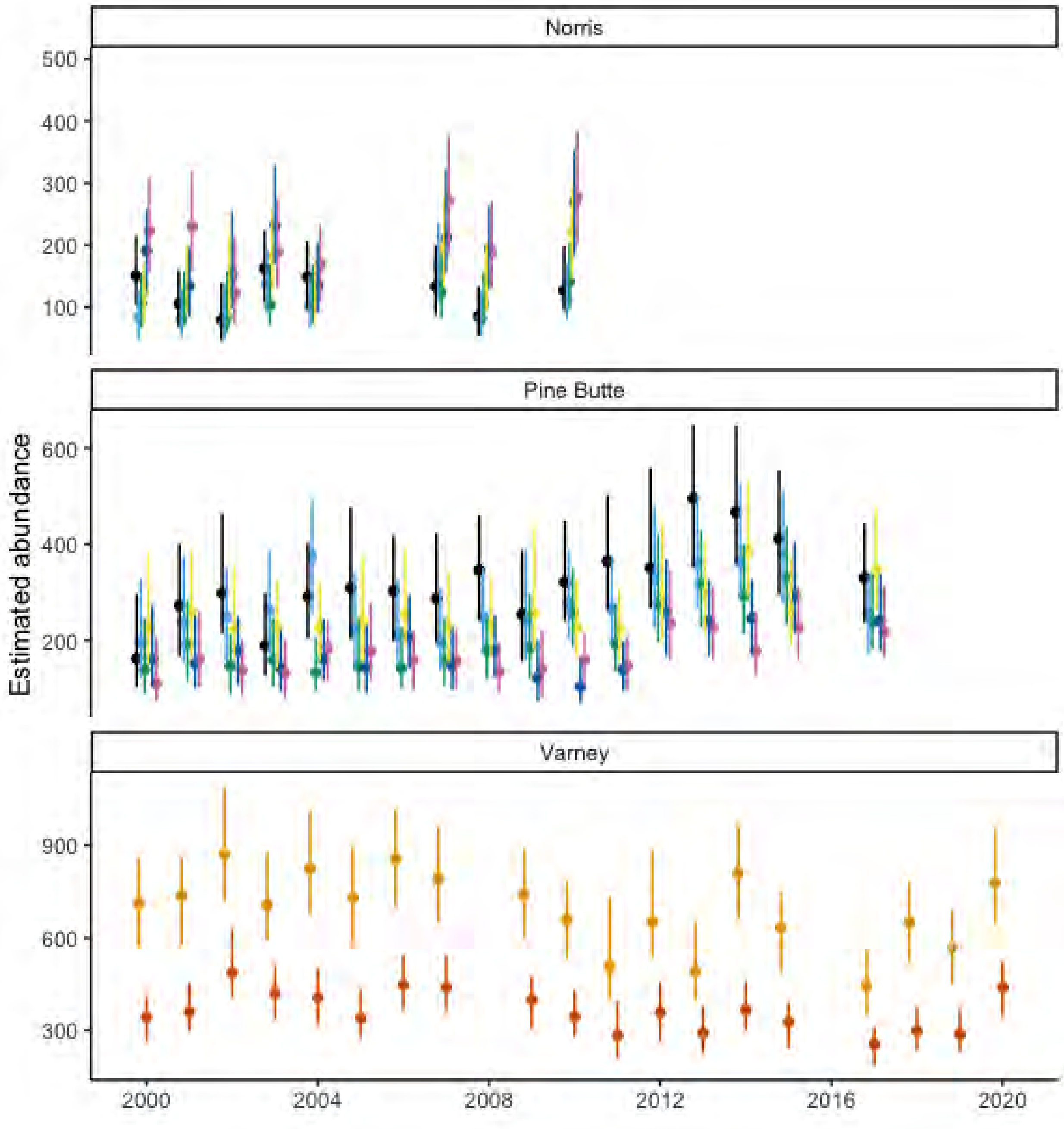


Figure 22. Estimated abundances of trout > 16” (Brown Trout and Rainbow Trout) in the Norris, Pine Butte, and Varney sections. Circles indicate the medians and lines indicate 95% credible intervals. The colors represent the different sub-stops in each section. Note the different scales on the y-axes in each panel.

Variation in trout abundances were not related to boulder densities; however, a suggestive positive relationship existed between abundance of trout > 16” and island and side channel densities. No evidence for an association between the abundance of trout > 10” and stream characteristics existed (Figure 23 and Figure 24). However, the credible intervals for the estimated coefficients for island density (-1.16 [-0.07, 0.04]) and side channel density (-0.004 [-

0.18, 0.18]) overlapped zero and prevented strong inference. We wanted to provide an easily-interpreted explanation for the effect of these covariates (log-scale estimates are hard to interpret), so we used the approximate posterior distributions to create predictions of how much trout abundance would vary in response to variation in stream characteristics, assuming average conditions. The lack of an estimated relationship translated into weak predictions of how much trout abundance would vary over the ranges of stream characteristics (Figure 23). In contrast, we found suggestive but inconclusive evidence (i.e., point estimates different than zero, but with credible intervals whose tails overlapped zero) that the abundance of trout > 16” was positively related to island density (0.02 [-0.02, 0.06]) and side channel density (0.11 [-0.07, 0.24]; Figure 23). These estimated relationships translated into predictions that suggested for the average sub-stop in the average year, predicted abundances could vary from 252 [121, 471] to 412 [180, 717] over the range of side channel density, and from 300 [134, 508] to 402 [153, 718] over the range of island density (Figure 25). However, the uncertainty in the point estimates translated into considerable uncertainty in these projections, and strong inference was not possible.

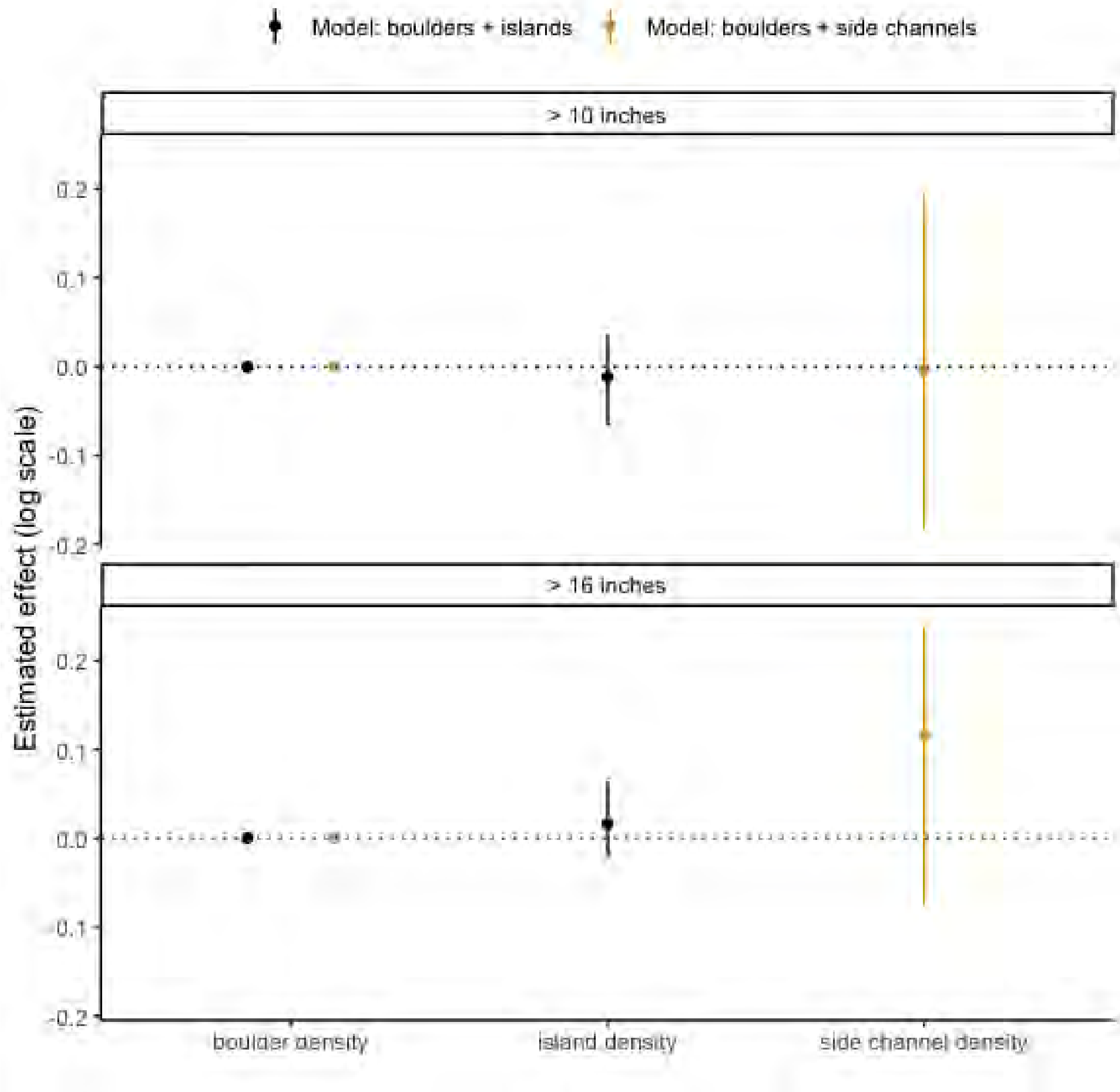


Figure 23. Estimated effects of physical characteristics of the waterbody on trout abundance (on the log scale) for the two length groups (> 10" and > 16"). Circles indicate medians and lines indicate the 95% credible intervals. Estimates greater than zero suggest abundances increase as the physical characteristics increase, estimates less than zero indicate abundances decreased as the physical covariates increase. Credible intervals that overlap zero indicate we cannot confidently claim relationships exist.

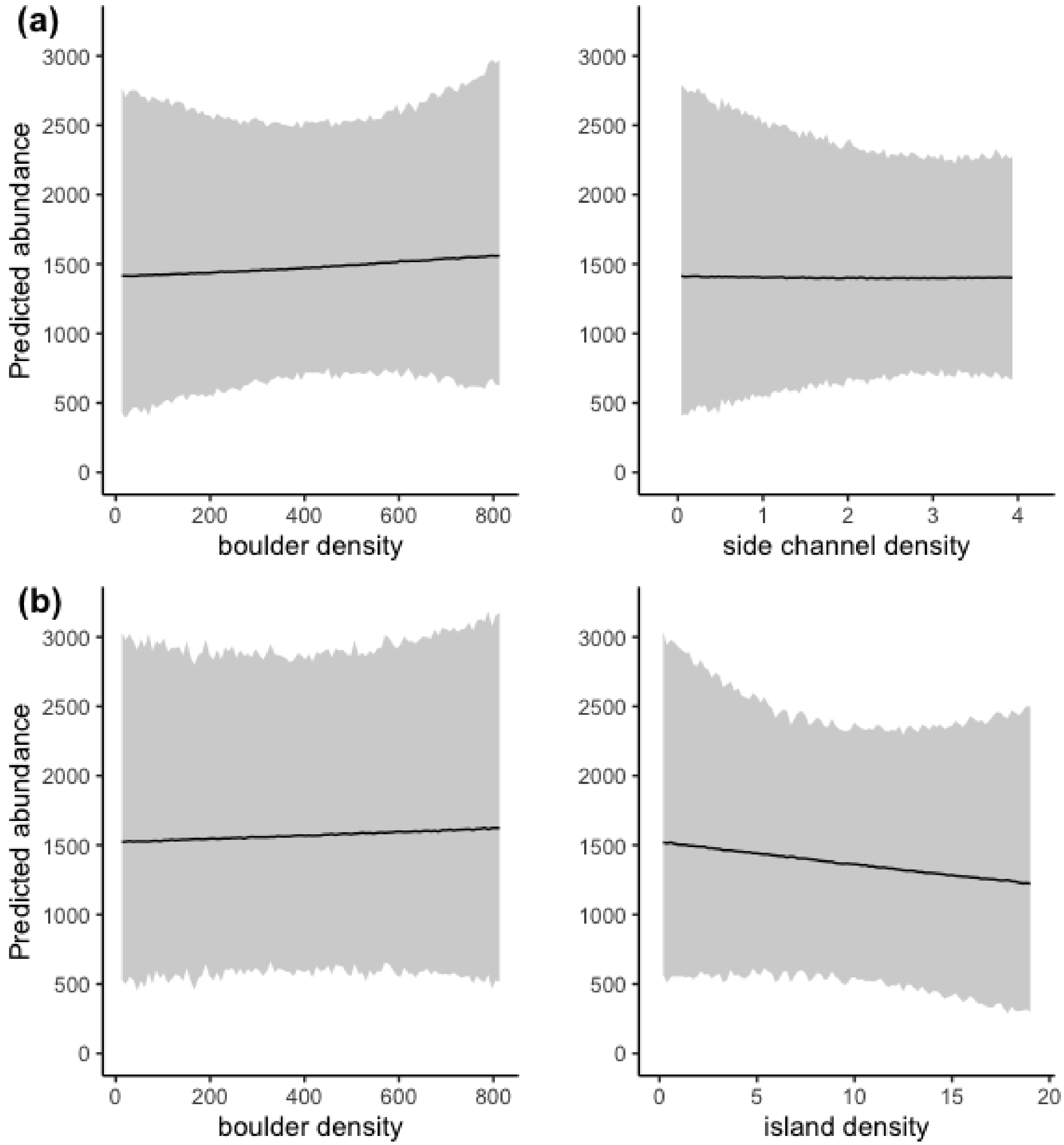


Figure 24. Estimated relationships between physical characteristics of the waterbody and abundances of trout > 10”. Lines indicate medians and ribbons indicate 95% credible intervals. Note the different scales on the y-axes in each panel. These predictions were made for an average year and represent an average across all sections and sub-stops.

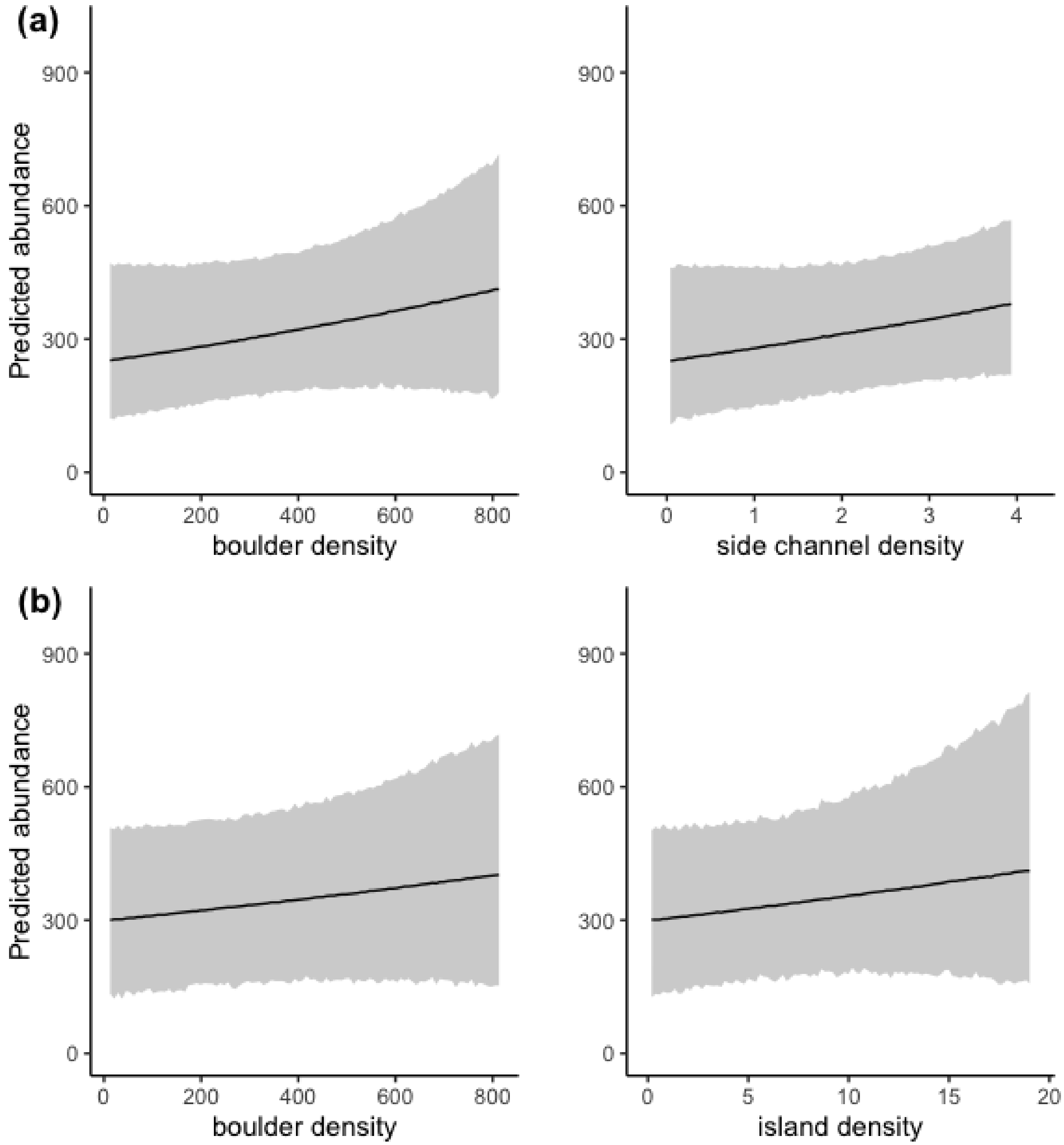


Figure 25. Estimated relationships between the physical characteristics of the waterbody and the abundances of trout > 16”. Lines indicate medians and ribbons indicate 95% credible intervals. Note the different scales on the y-axes in each panel. These predictions were made for an average year and represent an average across all sections and sub-stops.

Overall abundances of trout > 10” are influenced by unexplained among year variation; however, annual variation in factors other than physical features had a similar level of effect on abundance of trout > 16” as physical features. We incorporated a random effect of year on trout abundance for each section to estimate the significance of unmodeled variation in trout abundance (e.g., stream discharge and hydrograph, temperature, population structure, crew efficiency). We then took our approximate posterior distributions and created predictions of how those random effects translated into variation in abundance by assuming the average within-section among-sub-stop abundance. Although substantial uncertainty existed in the estimates (note the wide credible intervals; Figures 26 and 27), the results indicate that otherwise-unexplained variation captured as a yearly random effect is influencing trout abundances significantly for both length groups. For trout > 10”, predicted abundances among years varied from 1482 [876, 2220] to 2867 [1694, 4194] for the Norris Section, 551 [0, 1680] to 1348 [0, 4057] for the Pine Butte Section, and 902 [0, 2745] to 2243 [1382, 3355] for the Varney Section. For trout > 16”, predicted abundances among years varied from 285 [126, 495] to 413 [206, 683] for the Norris Section, 210 [86, 330] to 414 [196, 664] for the Pine Butte Section, and 313 [148, 492] to 576 [293, 934] for the Varney Section. Finally, we wanted to compare the variation in predicted abundances in response to stream characteristics for trout > 16” (recall we found no evidence for a relationship for trout > 10”) and otherwise-unexplained yearly variation to get a rough feel for the relative importance of the two model results (Figure 28). Results indicate nearly commensurate variation (i.e., yearly variation and stream characteristic variation are about several hundred fish across sections).

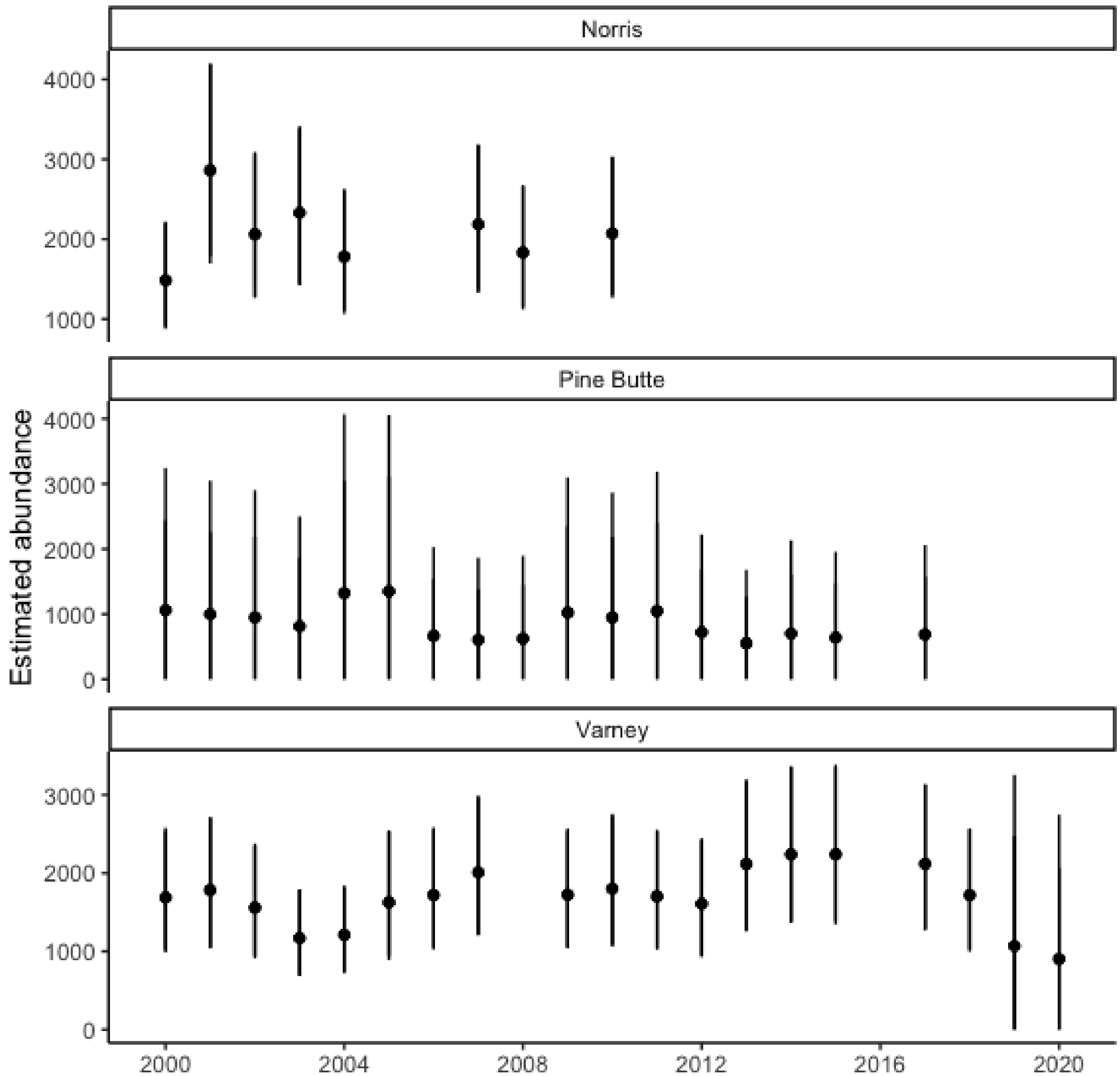


Figure 26. Predicted among-year variation in the abundance of trout > 10” for each section (predictions were made for the mean covariate values in each section). Circles are medians and lines are 95% credible intervals.

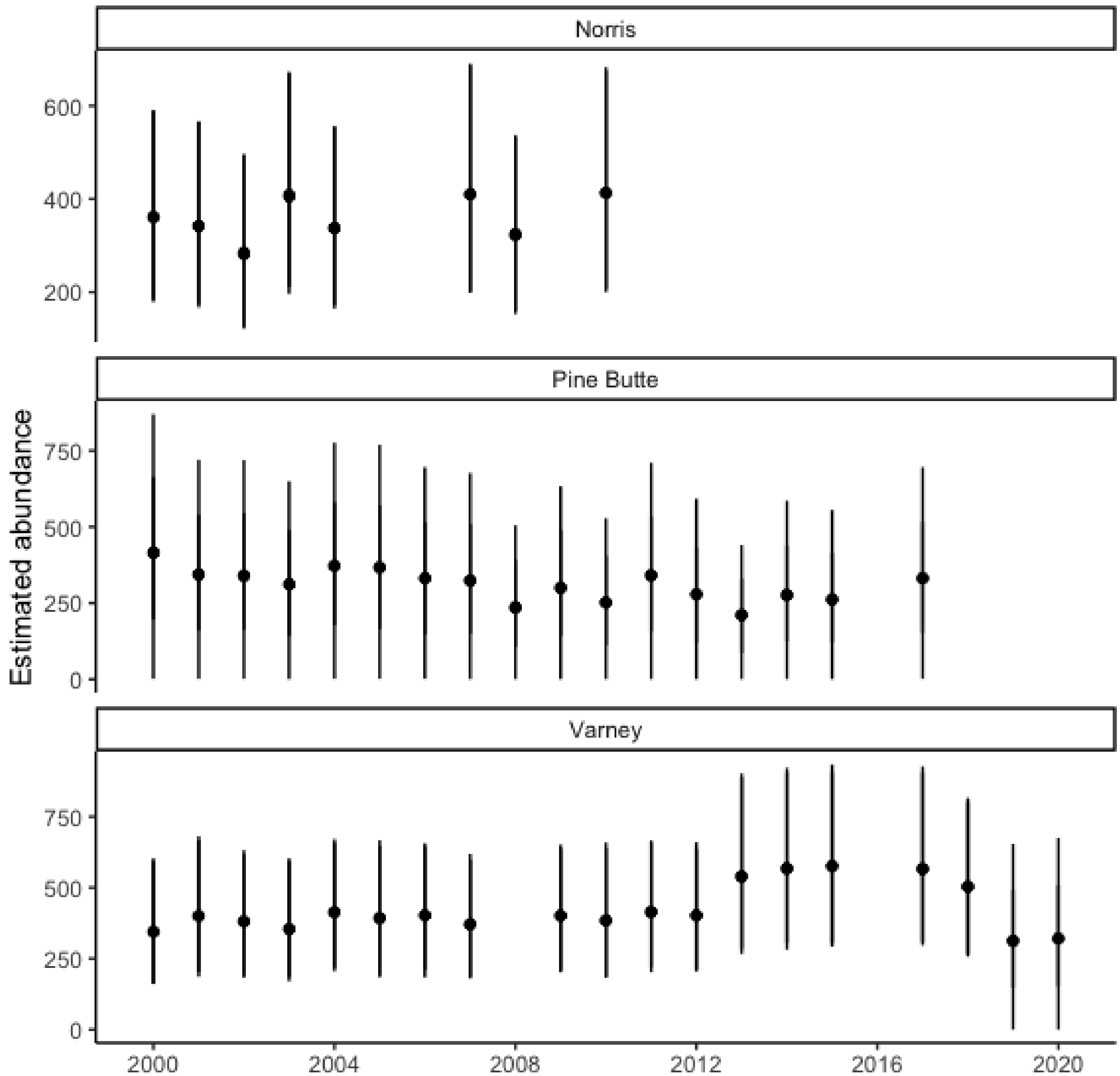


Figure 27. Predicted among-year variation in the abundance of trout > 16” for each section (predictions were made for the mean covariate values in each section). Circles are medians and lines are 95% credible intervals.

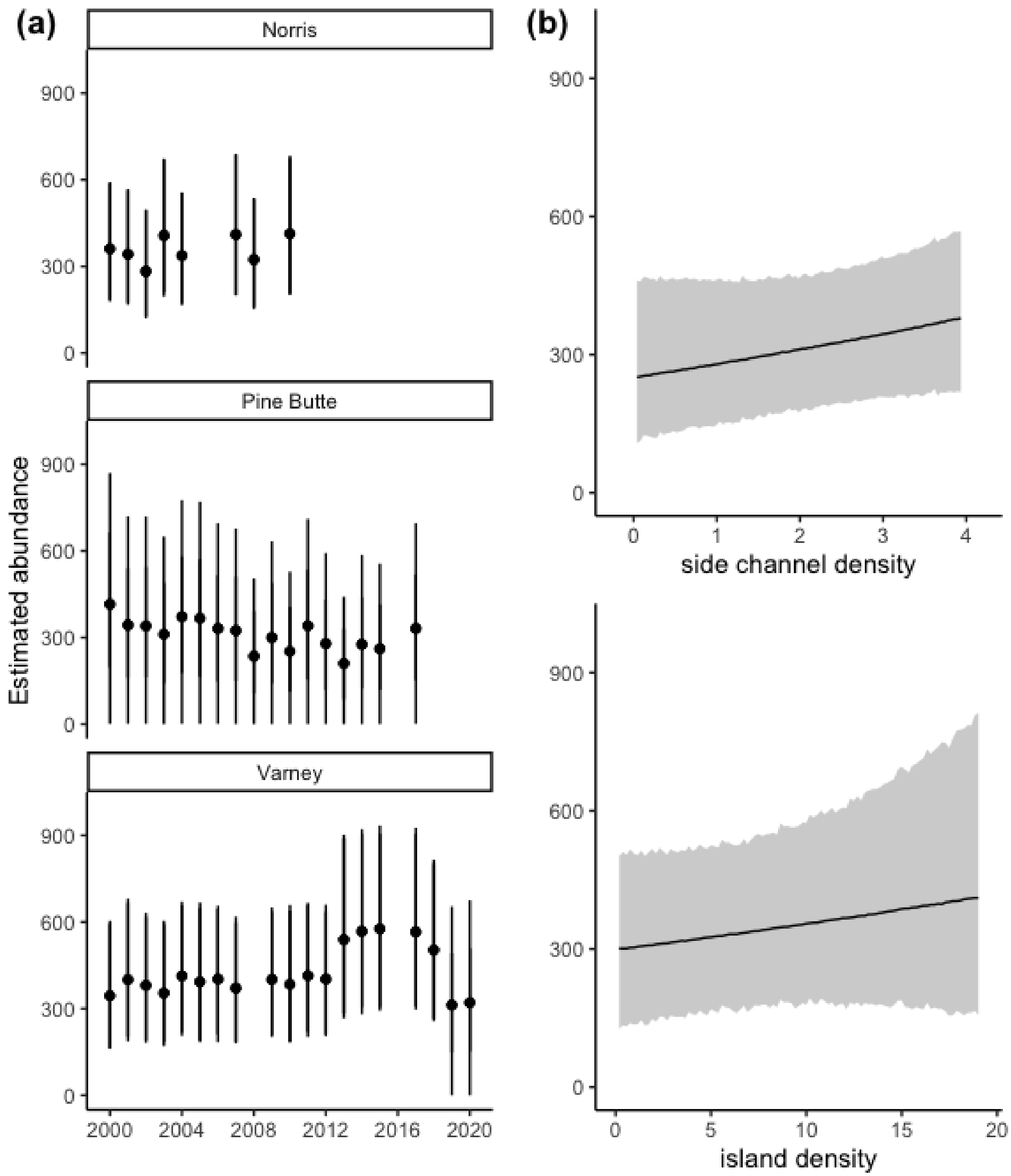


Figure 28. Observed (a) trout abundances in each Madison River sampling section and expected (b) trout abundances based on habitat characteristics combined across sections.

We found no evidence that addition of boulder and side channels will influence overall abundances of Madison River trout > 10”; however, increasing side channel or island density may increase abundances of large trout > 16”. Consistent within section variation among sub-stops across years suggests that factors other than year affects influence abundances; if abundances were related solely to year-specific effects standardized abundances would be similar within sections. However, the physical features we investigated had either no or an unclear effect on trout abundances. Boulder density, which has been suggested as a possible mitigative action to improve the fishery, had no effect on overall trout abundances or the abundance of large trout. Island and side channel density also had no effect on overall trout abundance, but there was a suggestive positive relationship with the abundance of large trout > 16”. Although islands and side channels most influenced large trout abundances, it is important to note that we did not investigate the effect of these features on trout < 10”; relative abundances of young-of-year and age-1 trout are commonly linked to complex habitats like side channels and high island density.

Inference about the effect of physical features on trout abundances was limited by the resolution of historic electrofishing data and the scale and observational nature of this assessment, limitations that precluded clear inference regarding the effect of these features. Abundances derived from electrofishing data are assumed to be homogeneous within a sub-stop and cannot account for the spatial distribution (and re-distribution among years) of fish within sub-stop and sections in response to physical drivers such as stream characteristics. Moreover, abundances estimated from small sample sizes are notoriously imprecise: this has the practical effect of conflating sampling variation (variation originating from the sampling process) with process variation (actual variation in the abundances of fish among sub-stops, sections and years) into a “noisy” representation of population dynamics. This problem of “noisy” abundance is amplified due to population size being the result of a complex interplay of biological mechanisms (i.e., the process variation component of variation in abundance results from variation in both reproduction and survival). These vital rates do not necessarily respond to environmental and intrinsic drivers of population demography in the same way; the classic example of which is the negative relationship between survival and reproduction when populations near carrying capacity in a density-dependent model. We suggest a clearer picture of the influence of extrinsic drivers on fish populations requires a better understanding of the vital rates that underly population dynamics, rather than the aggregated result of vital rates that is abundance. Our work indicates a multi-year monitoring program designed to estimate key reproduction and survival rates is required to improve our understanding. Moreover, we could improve our inference by incorporating experimental manipulations into the monitoring program; the inference available from the current observational study hinders our better understanding by conflating a wide series of unmodeled parameters into a very simple model structure to account for among-sub-stop variation. Experimental manipulation of stream characteristics would dramatically improve our inference by creating variation in stream characteristics within sub-stops, a notable characteristic lacking in the current study. Specifically, if the goal is to better understand the relative costs and benefits of island or side channel construction to the Madison River trout population we recommend side channel and/or island creation in a relatively simple reach (or set of reaches) and monitoring of vital rates of all age classes relative to one or more control sections for multiple years.

South Meadow Creek riparian enhancement: In 2011, FWP cosponsored a riparian fencing and off channel water development project with the Madison Conservation District to address water quality and degraded riparian and in-stream habitat conditions on South Meadow Creek, a tributary to Ennis Reservoir. Past grazing practices had largely eliminated the presence of riparian vegetation leaving streambanks unstable and in a highly erosive condition. Riparian vegetation has started to become re-established, and streambanks stabilized within much of the treatment area. However, 1500 ft of channel within the 2011 treatment reach was not exhibiting the rate of recovery observed in the downstream portion of the treatment reach. The 1500 ft section had previously been straightened for water delivery purposes. The straightening of the channel resulted in abandonment of the historic floodplain, channel widening, and loss of instream habitat. In 2019, FWP implemented restoration activities that re-established floodplain connectivity, appropriate channel dimensions, and in-stream habitat (Figure 29 and Figure 30). New willow and riparian vegetation within the project reach colonized the reach. FWP anticipates this will provide shade and moderate summer water temperatures during reduced flows associated with irrigation withdrawals. FWP did not sample the South Meadow Creek fish assemblage through the project reach in 2021.

Figure 29. South Meadow Creek Fall 2021. Circles and ellipses are new willow growth.

Figure 30. New Willow growth along South Meadow Creek restoration in July 2021.

O'Dell Creek habitat enhancement: O'Dell Creek is a spring-fed tributary of the Madison River that originates southeast of Ennis. The stream flows north for about 13 miles to its confluence with the mainstem Madison about 1.5 miles downstream of Ennis and 5.0 miles above Ennis Reservoir (Figure 31). From 2005 to 2009, stream restoration efforts on O'Dell Creek narrowed stream channels, increased stream sinuosity, lowered streambank elevation, and increased stream channel water surface elevations. FWP monitored responses in Brown Trout abundance and size structure, as Brown Trout are the predominant game fish species in the restoration area. Additional restoration work has occurred downstream of the monitoring area annually. Monitoring occurred in the headwater reaches of O'Dell Creek in April 2021.

Six monitoring sections were established throughout the restoration area (Figure 31; Table 4). In 2021, fish were collected by a crew of three to four individuals using a mobile anode electro-fisher in all sections except the O'Dell Spring North section where a backpack electro-fisher was used. C/f was used in all sampling sections to determine relative abundance and was calculated as the number of fish per mile. In 2021, FWP completed three mark-recapture abundance estimates among sections to assess catchability and determine whether comparisons of C/f among years and reaches were valid. Most fish were weighed (g) and measured (mm). However, some fish in the Old Middle Channel and O'Dell Spring North sections were released after recording species. Biomass per mile was calculated by multiplying the mean weight observed by the calculated C/f for each individual section where weights were taken. Age was assigned as age-0: 0-150 mm, age-1: 151-277 mm, age-2: 278-404 mm, age-3 or older: ≥ 404 mm based on Inter-Fluve Inc (1989).

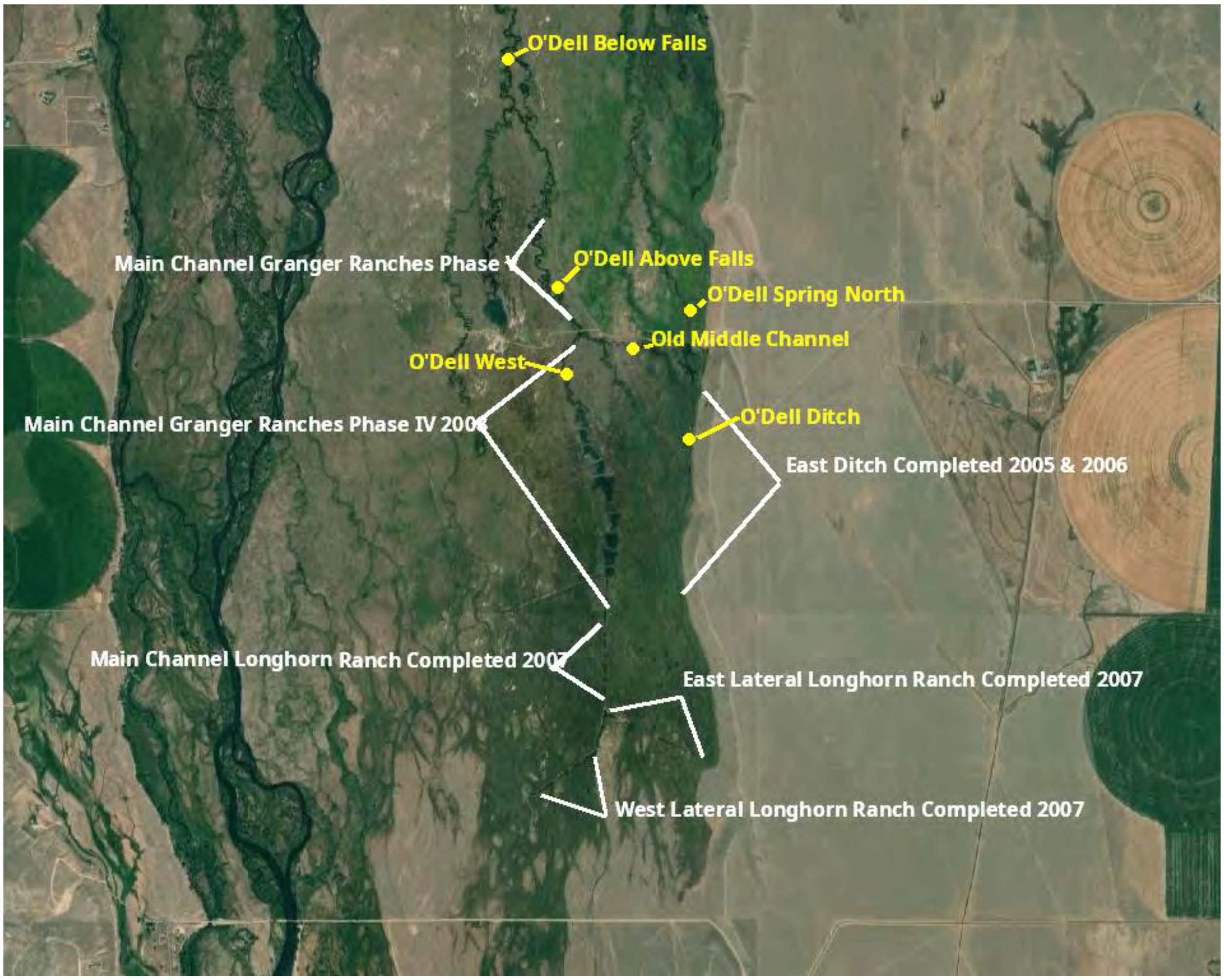


Figure 31. Aerial view of O'Dell Spring Creek Restoration sites (white) and FWP sampling sites (yellow).

Table 4. Stream restoration actions on fish monitoring sites at O'Dell Creek, 2005 - 2012.

Site	Stream channel modification	Section length/ft	Years
O'Dell Ditch	Backfilled	500	2005
O'Dell Spring North	Increase in stream discharge, no physical modifications	500	2005-2010
Old Middle	Historic channel reconnected and reconstructed	500	2005-2012
O'Dell West	Channel narrowed & deepened, increase in stream discharge	500	2005
Above Falls	Increase in stream discharge, stream channel restoration	1000	2005-2010
Below Falls	Increase in stream discharge, no physical modifications	1000	2005-2008

Fewer and larger fish were captured in 2021 but limited inferences can be made about relative abundance. Catchability ranged 33% to 68%, so comparisons of relative abundance among sections and years should be made cautiously. For example, a C/f of 1000 fish/mile could describe a point estimate of abundance between 1470 and 3030 fish/mile. Unless there was at least a two-fold difference in C/f among years, inference is speculative. However, relative abundances (Tables 5, 6, 7, and 8) in 2021 were lower than those in previous years. Overall, the reduction can largely be attributed to a decline in juvenile trout (Figures 32, 33, and 34). Relative abundance of age-2 and older fish was greater than that observed in all previous sampling events in the Above Falls and Old Middle Channel sections and was similar to abundances observed prior to restoration in the Below Falls section (Tables 5, 6, and 7).

Median lengths and weights were statistically significantly different among years in all sections, although some differences may not be biologically significant. In general, the Above Falls and Below Falls sections (Tables 5 and 6; Figures 35 and 36) had larger fish by length (mm) and weight (g) in 2021, and a reduction in median fish length was observed in the Old Middle (Table 7; Figure 36) section, while fish size in O'Dell Spring North (Table 8) section showed no significant change.

In summary, it appears that restoration activities, such as deepening and narrowing the channel as well as increasing discharge, have ultimately enhanced conditions for and increased abundance of large adult fish after initially improving abundances of younger fish.

Table 5. Median lengths and weights (interquartile range), biomass, and relative abundances for Above Falls Section. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α =0.05).

Year	Median length (mm)	Median weight (g)	C/f (fish/mile)	C/*f* (fish/mile) by age group 0+	1+	2+	> 2+	Biomass (kg/mile)
2005*	180[a] (109)	73[a] (170)	1063	374	389	274	26	181
2006*	174[a] (71)	77[a] (130)	1916	316	1258	300	42	291
2007	178[a] (79)	54[a] (100)	543	137	374	32	0	54
2008	264[b] (157)	213[b] (290)	837	174	316	321	26	202
2010	173[a] (110)	59[a] (33)	1137	268	658	200	11	133
2021	266[b] (210)	215[b] (470)	316	63	111	68	74	110
	178 (104)	82(186)	969 ± 228	222 ± 48	517 ± 164	199 ± 50	30 ± 11	162 ± 34

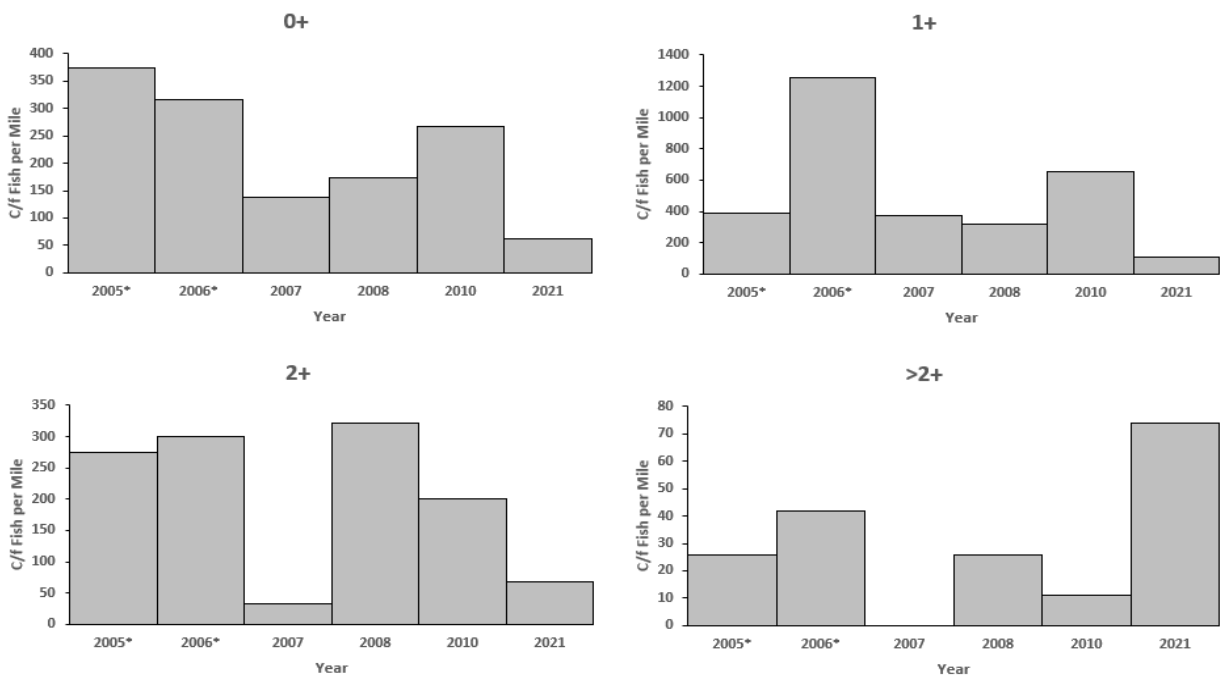


Figure 32. Relative abundance histograms of age groups for the Above Falls Section. Pre-restoration years are denoted with asterisks. Note that the y-axes are not the same scale.

Table 6. Median lengths and weights (interquartile range), biomass, and relative abundances for Below Falls Section. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α =0.05).

Year	Median length (mm)	Median weight (g)	C/f (fish/mile)	C/*f* (fish/mile) by age group 0+	1+	2+	> 2+	Biomass (kg/mile)
1989*	161	145	1121	705	195	121	100	163
2005*	206[a] (145)	91[a] (227)	721	90	389	168	74	167
2006*	221[a] (150)	127[a] (254)	763	121	411	163	68	183
2007	188[a] (121)	82[a] (204)	537	53	358	105	21	99
2008	319[b] (97)	358[b] (324)	221	21	32	142	26	89
2021	283[b] (223)	240[b] (520)	326	63	89	100	74	122
	243 (148)	150 (290)	614 ± 133	176 ± 107	246 ± 67	133 ± 12	61 ± 13	137 ± 16

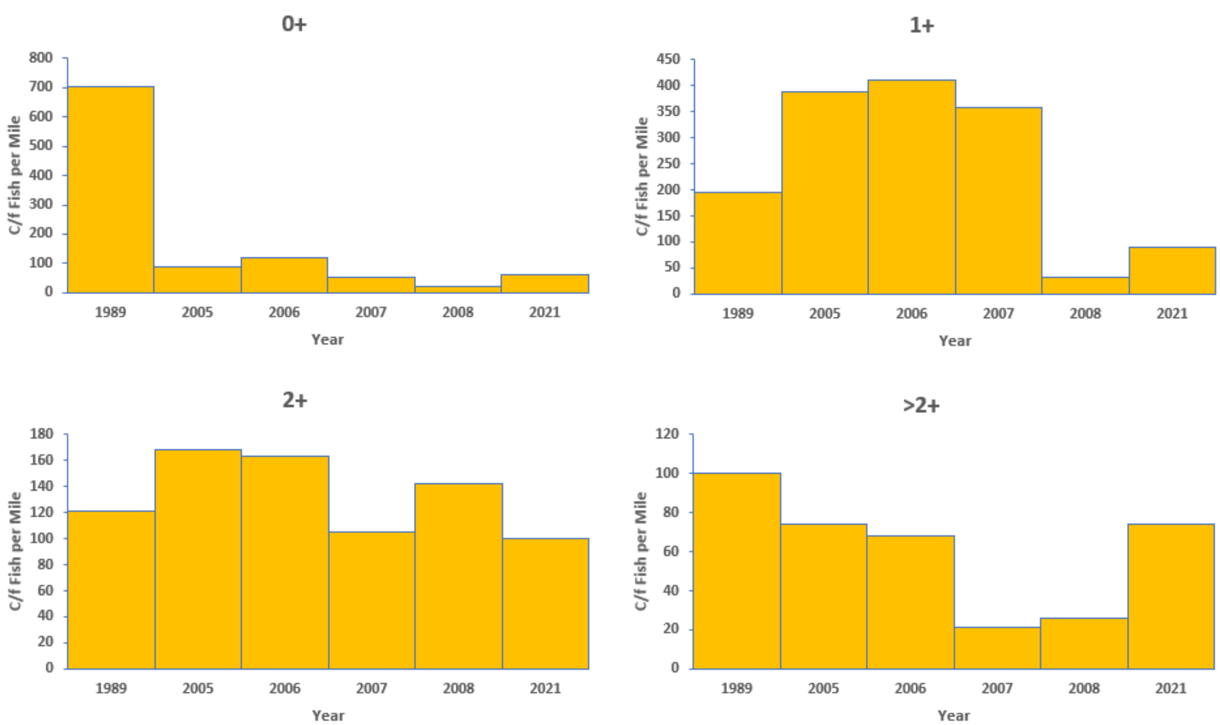


Figure 33. Relative abundance histograms of age groups for the Below Falls Section. Pre-restoration years are denoted with asterisks. Note that the y-axes are not the same scale.

Table 7. Median lengths and weights (interquartile range), biomass, and relative abundances for Old Middle Channel Section. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years ($\alpha = 0.05$).

Year	Median length (mm)	Median weight (g)	C/*f* mile (fish/mile)	C/f (fish/mile) by age group				Biomass (kg/mile)
				0+	1+	2+	> 2+	
2005*	123^{a} (25)	-	2211	1989	222	0	0	-
2006*	147^{b} (62)	-	1289	712	522	33	22	-
2007	163^{bc} (53)	54^{a} (64)	1056	279	733	44	0.0	81
2008	168^{c} (102)	41^{a} (109)	2422	900	1366	156	0.0	203
2010	221^{d} (138)	154^{b} (218)	1922	511	878	522	11	332
2012	216^{d} (127)	127^{b} (213)	1367	289	700	367	11	234
2021	176^{bcd} (121)	52^{a} (172)	667	211	300	122	33	102
	157 (104)	91 (166)	1,557 ± 226	695 ± 219	675 ± 135	175 ± 69	11 ± 4	189 ± 42

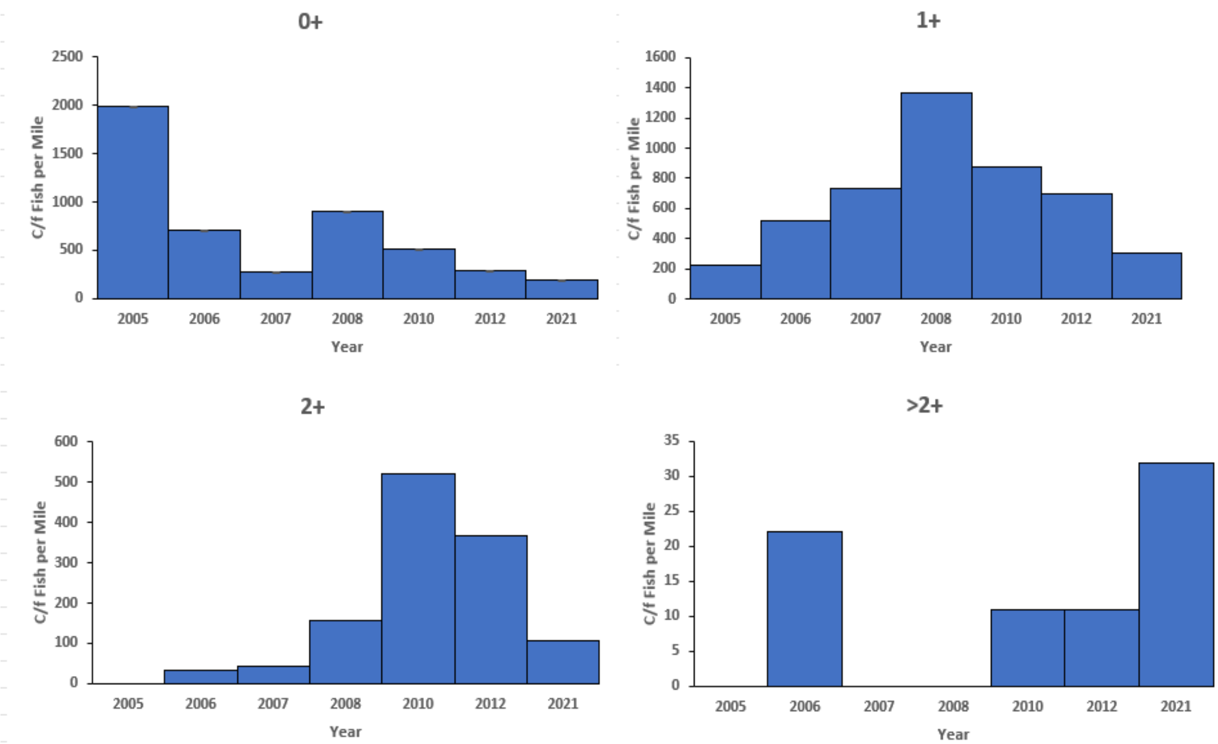


Figure 34. Relative abundance histograms of age groups for the Old Middle Section. Pre-restoration years are denoted with asterisks. Note that the y-axes are not the same scale.

Table 8. Median lengths (interquartile range) and relative abundances for O'Dell Spring North Section. Asterisks denote pre-restoration monitoring. Median lengths and weights with different superscripts are significantly different among years (α = 0.05).

Year	Median length (mm)	C/*f* (fish/mile)	C/*f* (fish/mile) by age group 0+	1+	2+	> 2+
2005*	156[a] (81)	1,367	289	700	0	0
2006	117[ab] (25)	2,044	1,789	256	0	0
2007	114[abc] (25)	1,033	956	78	0	0
2008	124[abcd] (28)	1,144	1,011	133	0	0
2010	132[ad] (33)	811	622	189	0	0
2012	144[a] (26)	867	500	356	11	0
2021	130[ad] (32)	466	322	144	0	0
	127 (41)	1,104 ± 189	784 ± 198	265 ± 80	11 ± 0	0

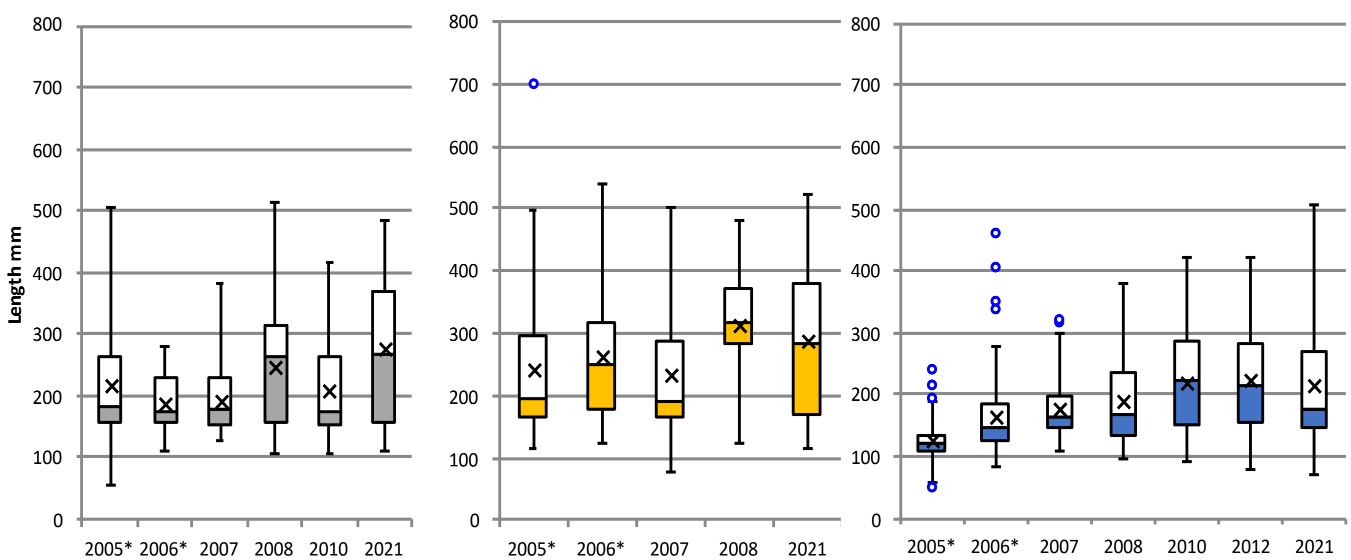


Figure 35. Median and mean lengths for Above Falls (gray), Below Falls (yellow), and O'Dell Old Middle (blue) sections. Asterisks denote pre-restoration monitoring years. Xs denote mean values, horizontal lines are medians, bars are the 5th and 95th percentiles, and circles are outliers.

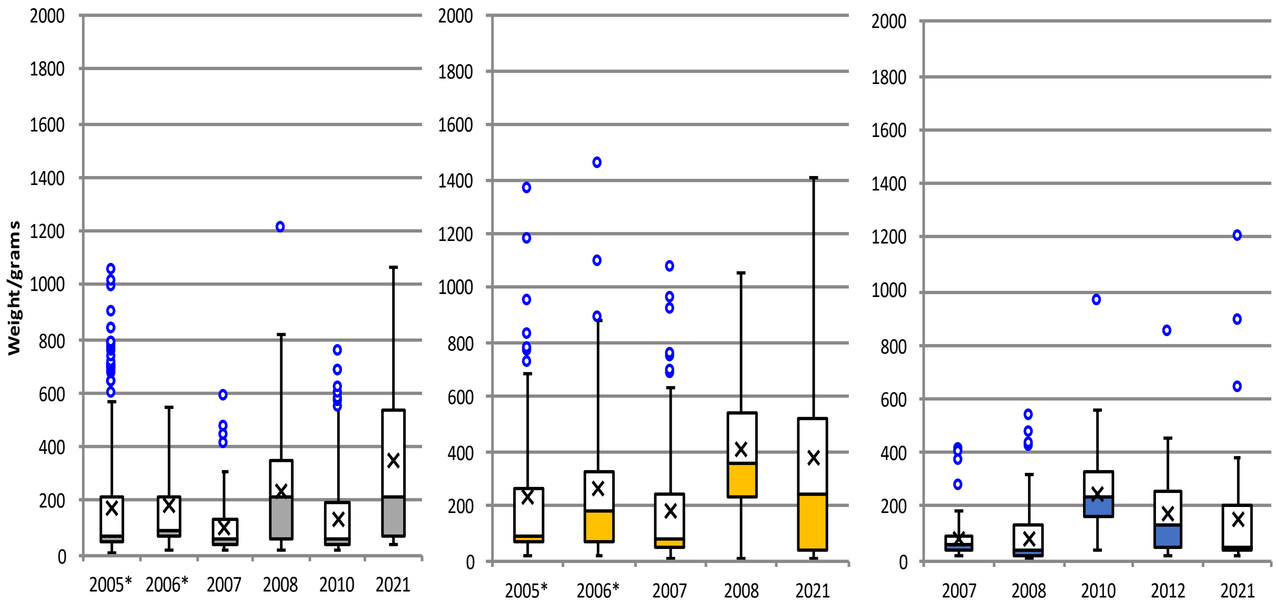


Figure 36. Median and mean weights for Above Falls (gray), Below Falls (yellow), and O'Dell Old Middle (blue) sections. Asterisks denote pre-restoration monitoring years. Xs denote mean values, horizontal lines are medians, bars are the 5th and 95th percentiles, and circles are outliers.

Article 413-Pulsed Flows: Temperature affects all living 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 82.5ºF. 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 37). Temperature data has been used by FWP as criteria for implementing angling restrictions to reduce mortality of adult trout during periods of thermally induced stress. Angling restrictions are implemented when daily maximum water temperature ≥ 73ºF 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 ≤ 80ºF at Sloan and avoid the 82.5ºF lethal thermal limit of resident fish in the Lower Madison River. The Madison DSS is comprised of two methods to determine a pulse volume to the delivered to the Lower Madison River: a thermo-dynamic physics model (physics model) and a manual protocol. Pulsed flows are triggered when water temperature at the Madison (Ennis) Powerhouse is 68ºF or higher and the predicted air temperature at the Sloan Station (River Mile 17) near Three Forks, MT for the following day is 80º F or higher. NWE enters the maximum water temperature recorded at the McAllister USGS gage and the next days forecasted maximum air temperature at Three Forks to the manual protocol and the physics model to derive the volume of pulse needed for the following day (Table 9). NWE determines the larger derived pulse of the two methods and directs the operations to release that volume the following day from 6:00 am to noon. Timing of the release is designed to allow for travel time of the water to arrive in the lower Madison River near Sloan during the late afternoon when daily solar radiation is greatest.

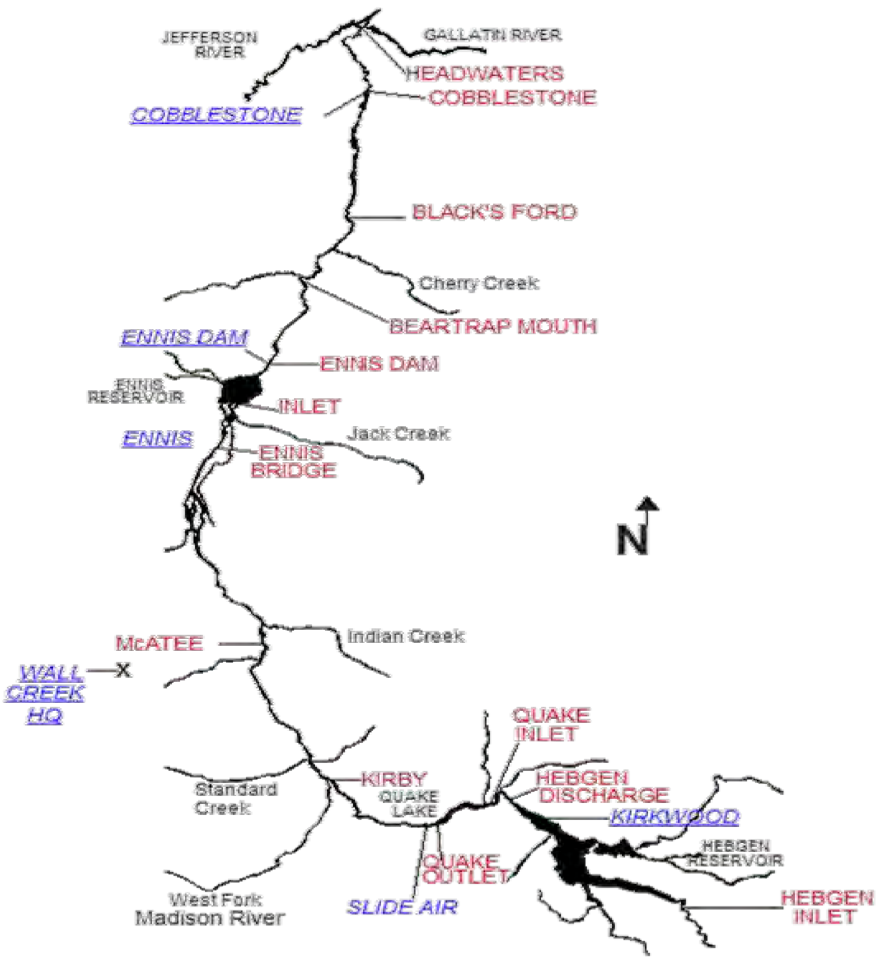


Figure 37. FWP temperature monitoring sites. Air temperature monitoring sites are blue and underlined; water temperature monitoring sites are red.

Table 9. 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 water temperatures recorded in the upper river were ≥ 73°F on 29 occasions, (once at the Ennis Bridge and 28 times at Ennis Reservoir inlet; Table 10); maximum daily temperatures at the Ennis Reservoir inlet met or exceeded the ≥ 73°F on June 28 -July 4, July 28-July 30, and again Aug 11-Aug 14, for periods of 7, 3, and 5 successive days, respectively. Daily maximum temperatures were ≥ 73°F at the lower river monitoring sites, Bear Trap Mouth and Black's Ford for 58 and 63 days, respectively (Table 10). Since 2000, maximum daily water temperatures at the Black's Ford monitoring site have been ≥ 73°F an average of 45 times a year causing FWP to regularly implement restrictions that prohibited angling from 2 p.m. to 12 a.m. during summer months.

In 2021, there were 64 calls for a pulse flow, but only 51 of those resulted operational changes to accommodate a pulse flow. This was the highest number of days where pulsing occurred since the program's inception. Pulse flows kept maximum daily water temperatures from reaching 80° F at Sloan; however, we were not able to ascertain if values for maximum daily water temperatures reached or exceed 80° F below the Sloan site, because the temperature loggers at the Cobblestone and Headwaters sites were not recovered (Table 10). Pulse flows have been implemented an average of 21 days since 2000 and have been effective at moderating maximum daily water temperatures and preventing the occurrence of a thermally induced fish kill in the lower river (Table 11). FWP recommends continued monitoring of Madison River temperatures and that NWE continue to adjust the pulse flow program as needed.

Table 10. Maximum and minimum temperatures (oF) recorded at monitoring sites in the Madison River Drainage, 2021. Mean temperature is mean daily temperate ± 95% confidence intervals (CI). Days ≥ 73oF the number of days daily maximum temperatures were at or excee ded 73^{o}F, and days ≥ 80^{o}F are the number of days daily maximum temperatures were at or exceeded 80^{o}F. NA denotes temperature data was unable to be recovered.

Site	Max^{o}F	Min^{o}F	Mean daily temperature ± 95% CI	Days ≥ 73^{o}F	Days ≥ 80^{o}F
Hebgen inlet	NA	NA	NA	NA	NA
Hebgen discharge	56.8	38.4	56.8 ± 0.1	0	0
Quake Lake inlet	65.7	35.7	56.5 ± 1.2	0	0
Quake Lake outlet	67.2	38.9	55.5 ± 1.2	0	0
Kirby Bridge	68.7	36.4	55.9 ± 1.0	0	0
McAtee Bridge	70.9	34.3	56.9 ± 1.0	0	0
Ennis Bridge	73.1	34.2	59.0 ± 1.0	1	0
Ennis Reservoir Inlet	76.5	34.2	59.7 ± 1.0	28	0
Madison Dam	74.6	41.2	63.6 ± 1.2	15	0
Bear Trap Mouth	78.1	41.2	63.7 ± 1.1	58	0
Blacks Ford	79.2	40.7	63.1 ± 1.1	63	0
Cobblestone	NA	NA	NA	NA	NA
Headwaters S.P. (Madison mouth)	NA	NA	NA	NA	NA

Table 11. The number of days that maximum daily water temperatures at Sloan ≥ 73°F and ≥ 80°F.

Year	≥ 73°F	≥ 80.0°F	Number of days pulsing occurred
2009	34	0	2
2010	29	0	1
2011	27	0	0
2012	50	0	0
2013	69	1	22
2014	42	0	7
2015	50	7	15
2016	51	0	21
2017	57	0	34
2018	38	0	25
2019	40	0	10
2020	50	0	26
2021	59	0	51

Article 419-Coordinate and Monitor Flushing Flows: Article 419 of the 2188 FERC license requires that NWE 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. Impoundments such as dams interrupt the natural hydrograph of rivers and high flow events that are responsible for the replenishment and cleaning of 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 ≤ 0.8 mm) in spawning gravels can adversely affect the survival of embryos and emergence of fry by inhibiting the delivery of oxygenated water and reducing the amount of interstitial space required for development (McNeil and Ahneil 1964; Kondolof 2000). Accordingly, a goal to maintain ≤ 10% fines in the upper Madison River and ≤ 15% in the lower Madison River were established with the understanding that release of 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 # 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 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 6,532.26 msl by June 20. Several approaches have been implemented to evaluate the efficacy of flushing flows to recruit and rejuvenate spawning gravels and maintain fine sediment thresholds under current operational constraints, including redd counts, core sampling, and scour chains.

A redd is a nest constructed in the streambed by salmonids where fertilized eggs are deposited and develop until fry emerge from the gravel. Gravels selected for redd construction typically have a median diameter ≤ 10% of the female's body size, can be easily excavated, and contain minimal amounts of fine sediment and organic debris (Chambers et. al 1955; Kondolf and Wolman 1993). Sediment core sampling at the Kirby, Ennis, Norris, and Greycliff sections has occurred annually since 2002. These sites were selected to represent conditions in the upper (Kirby & Ennis) and lower (Norris & Greycliff) Madison River sediment core data provides an index of relative spawning habitat suitability during years with and without flushing flows. Redd counts were initiated in 2012 to ensure complementary substrate sampling (e.g., core samples, scour chains) occurs in actual spawning habitats.

Redd counts are completed by walking upstream and identifying streambed disturbances consistent with redd morphology. A typical redd consists of a pit where gravel was excavated with a mound of gravel (tail spill) immediately downstream of the pit (Figure 38). The number, physical dimensions, and location of individual redds within each monitoring section were recorded. Core samples were collected with a 12-inch McNeil core sampler in substrate previously identified as spawning habitat during redd counts. The core sampler was 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 percent composition of the sample was calculated according to particle size.

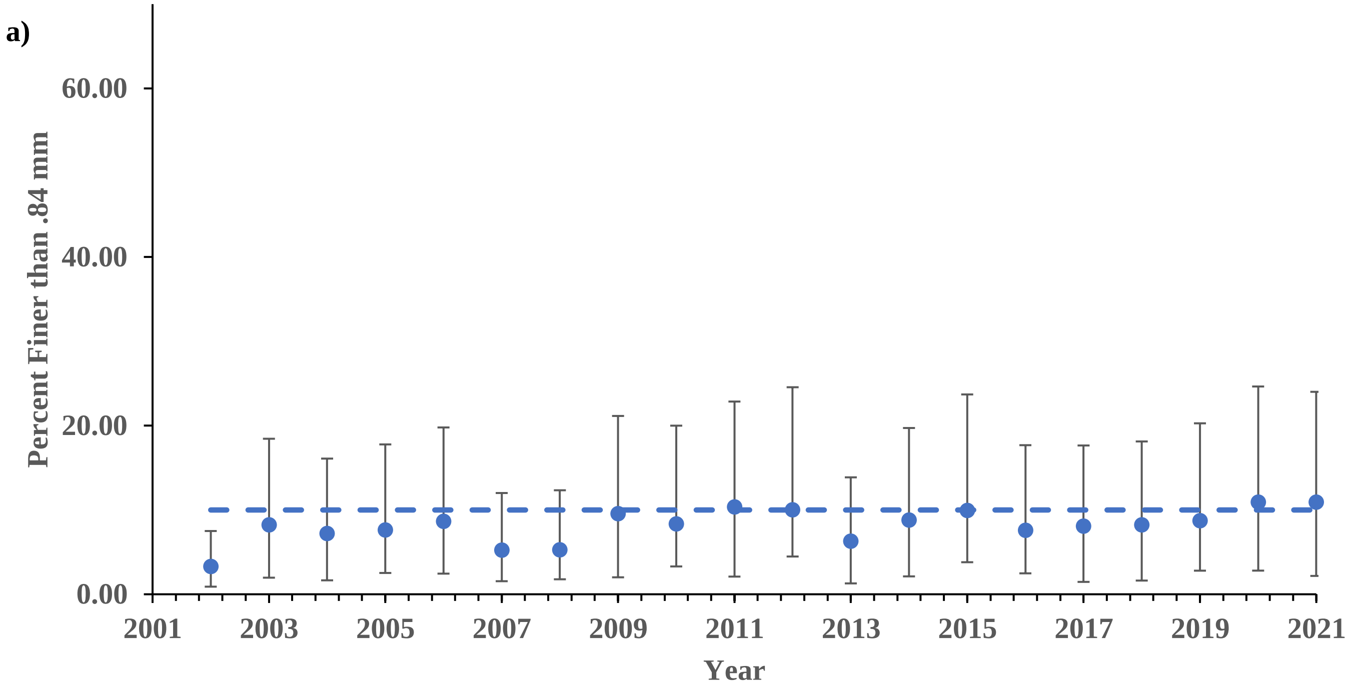
Figure 38. Redd (nest) at the Norris redd counting site. Pit is denoted with the X and black arrow shows the direction of stream flow over tail spill.

Two sample *t*-tests were conducted at $\alpha = 0.05$ to test whether the mean number of redds differed in years with and without flushing flows and 95% CIs were calculated for the mean percent fines ≤ 0.84 mm in core samples from the upper river monitoring sites (Kirby, Ennis) and the lower river monitoring sites (Norris and Greycliff). No significant difference between the number of redds for years with and without flushing flows existed; however, sparse redd data and few flushing flows precluded meaningful statistical inference at any of the sites (Table 12). Inconsistencies in the timing and frequency of counts likely influenced the number of redds observed between years (Table 12). Additionally, flushing flows have had no observed effect on the percent fines present in spawning habitat. Median values for percent fines ≤ 0.8 mm in the upper river ranged from 3.7% (2002) to 10.7% (2020) and from 8.5% (2007) to 22.9% (2014) in the lower river (Table 12). There have been no statistical differences in the percent fines ≤ 0.8 mm observed between years with and without a flushing flow (Figure 39). The flushing flow program and its utility is being evaluated. Discussions about continuing the flushing flow program between NWE and FWP will continue.

In 2021 the number of Fall Brown Trout redds recorded in the lower river were the highest observed since redd counts were implemented. Simple linear regression was used to test if the mean discharge for the month of October affected the ability of observers to identify redds. A negative relationship existed between river discharge in the month of October and the number of Brown Trout redds with 45% of the variation in the number of redds observed explained by the magnitude of the October discharge ($P = 0.05$; $R^2 = 0.45$). The high number of Brown Trout redds observed in 2021 could be due in part to increased visibility of redds at lower flows and or spawning fish being concentrated into limited habitats of suitable depth. The number of Brown Trout redds in the lower Madison River were lowest from 2018-2020. However, mean discharge in October during those years was on average 258 cfs greater than that observed in 2021. Because redd count data is not focused river wide, no inference can be made as to the number of adult spawning fish or their success in a given year. Additionally, observations are potentially skewed by river conditions and other factors. Therefore, FWP recommends discontinuing redd counts as a primary tool to evaluate flushing flow performance.

Table 12. Median % fines ≤ 0.84mm ± standard deviation (SD) and Brown (LL) and Rainbow (RB) Trout redds in the Upper and Lower Madison River, incidence of a NWE flushing flow event, and peak flow in cubic feet per second (CFS) at USGS gage 06041000.

	Upper Madison River			Lower Madison River				
Year	% fines < 0.84 mm median ± SD	LL Redds	RB Redds	% fines < 0.84 mm median ± SD	LL Redds	RB Redds	NWE flushing flow	Peak Flow CFS USGS gage 0604100
1995	6.6 ± 4.4			15.9 ± 5.4				7360
1996	5.8 ± 1.2			8.3 ± 4.5				7980
1997	7.4 ± 3.9			9.8 ± 4.5				7910
1998								6820
1999								5500
2000								4450
2001								2460
2002	3.7 ± 1.5			9.6 ± 4.1			No	5180
2003	8.6 ± 3.2			10.0 ± 5.7			No	4670
2004	7.6 ± 2.7			10.7 ± 5.2			No	3440
2005	6.9 ± 4.1			13.5 ± 8.0			No	4470
2006	9.7 ± 3.7			13.5 ± 5.0			Yes	5390
2007	5.1 ± 2.5			8.5 ± 4.0			No	3400
2008	5.4 ± 2.9			9.7 ± 4.8			Yes	5390
2009	9.3 ± 3.2			12.4 ± 11.7			No	4050
2010	7.0 ± 5.3			11.9 ± 5.7			No	5540
2011	10.1 ± 3.4			13.8 ± 8.2			Yes	7100
2012	6.8 ± 7.2			15.9 ± 5.4			No	4810
2013	5.8 ± 2.1	8	39	18.8 ± 18.7	36	26	No	2850
2014	8.4 ± 3.4	39		22.9 ± 13.7	21		No	5560
2015	8.3 ± 6.1	39	42	12.6 ± 8.3	29	34	No	4490
2016	7.1 ± 4.0	17	78	14.7 ± 10.2	40	48	No	3180
2017	7.9 ± 2.4	14	54	11.7 ± 5.7	46	56	No	4520
2018	8.7 ± 2.6	6		11.4 ± 4.8	20		Yes	6510
2019	7.2 ± 4.5	5	16	10.3 ± 11.3	14	1	No	4670
2020	10.5 ± 4.5	23	22	19.2 ± 6.5	16	59	Yes	6180
2021	9.9 ± 3.5	52	28	14.7 ± 11.5	64	16	No	3260



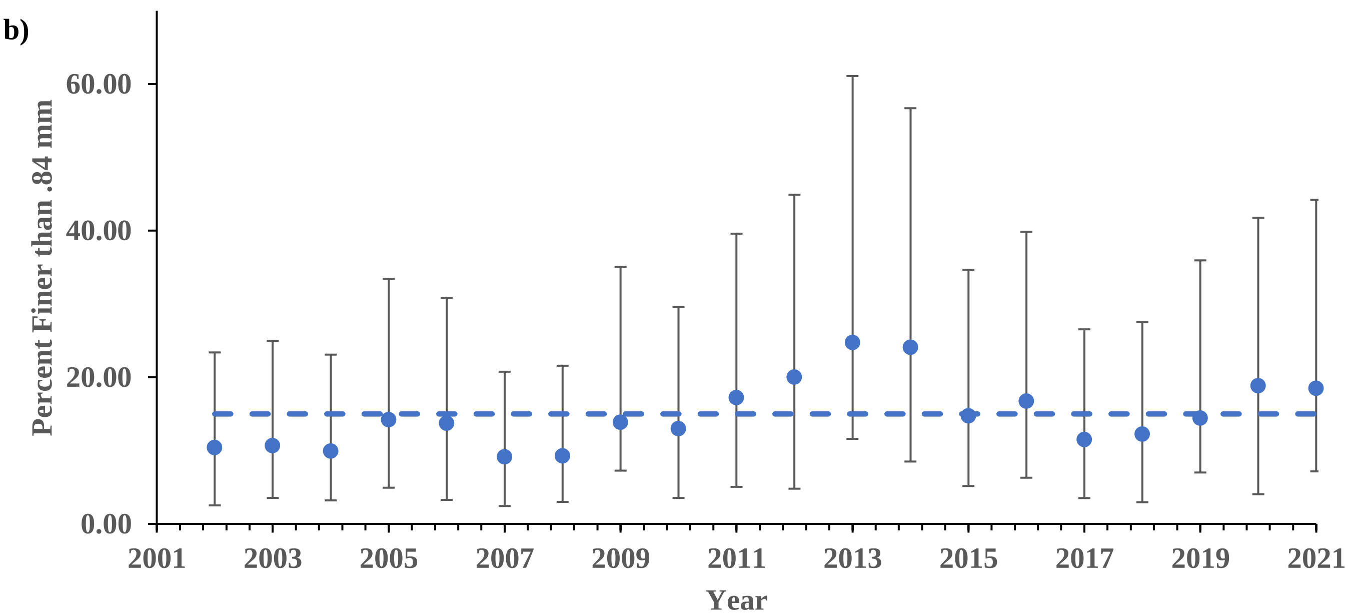


Figure 39 Mean percent fines and 95% CI's of < 0.84 mm in core samples from the Madison River in the (a) Upper River where the blue dashed line is the 10% threshold for fines and (b) Lower River where the blue dashed line is the 15% threshold for fines.

Literature Cited

Axelson, J. 1961. Zooplankton and impoundment of two lakes in Northern Sweden (Ransaren and Kultsjoen). Rep. Inst. Freshwater Res. Drottningholm 42: 84-168.

Binns, N. A., and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108:215-228.

Brown, P. 2004. Predicting growth and mortality of Brown Trout *(Salmo trutta)* in the Goulburn River after mitigation of cold-water discharge from Lake Eildon, Australia, New Zealand Journal of Marine and Freshwater Research 38-2, 279-287

Byorth, P.A., 2000. Madison River trout population surveys: July 1994-June 1999 project 3302. Montana Fish, Wildlife, and Parks. Bozeman, Montana.

Clancey, P., and T. Lohrenz. 2007. Madison River/Ennis Reservoir fisheries and Madison River Drainage Westslope Cutthroat Trout conservation and restoration program. 2006 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis.

Clancey, P., and T. Lohrenz. 2008. Madison River/Ennis Reservoir fisheries and Madison River Drainage Westslope Cutthroat Trout conservation and restoration program. 2007 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis.

Clancey, P., and T. Lohrenz. 2009. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout conservation and restoration program. 2008 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis.

Chambers. J. S., G. H. Alien, and R. T. Pressey. 1955.Research relating to the study of spawning grounds in natural areas. Annual report to U.S. Army Corps of Engineers, Contract DA-35026-Eng-20572. Washington State Department of Fisheries, Olympia.

Downing, D.C., T.E. McMahon, and B.L. Kerans. 2002. Relation of spawning and rearing life history of Rainbow Trout and susceptibility to *Myxobolus cerebralis* infection in the Madison River, Montana. Journal of Aquatic Animal Health 14:191-203.

FERC. 2000. Order Issuing New License, Project No. 2188-030. Issued September 27, 2000.

Fuerstein, C., University of Montana, personal communication, 2022.

Kondolf, G.M. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129: 262-281.

Kondolf, G.M. and M. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research. 29: 2275-2285.

Kondolf, G.M. et. al. 1991. Distribution and stability of potential salmonid spawning gravels in steep boulder-bed streams of the Eastern Sierra Nevada. Transactions of the American Fisheries Society 120: 177-186. 1991.

Haddix, T. and P. Budy. 2005. Factors that limit growth and abundance of Rainbow Trout across ecologically distinct areas of Flaming Gorge Reservoir, Utah-Wyoming. North American Journal of Fisheries Management 25:1082-1094.

Inter-Fluve Inc. Fisheries report for O'Dell Creek, Madison County Montana. November 1, 1989.

Molony, Brett. (2001). Environmental requirements and tolerances of Rainbow trout (Oncorhynchus mykiss) and Brown trout (Salmo trutta) with special reference to Western Australia: A review. Fish Res Rep West Aust. 130.

Montana Fish, Wildlife, & Parks. 2019. 2019-2027 Montana statewide fisheries management program and guide. 446-447. Helena, Montana.

Varley, J. D., and R. E. Gresswell. 1988. Status and management of interior stocks of cutthroat trout. American Fisheries Society, Symposium 4, Bethesda, Maryland.

Watschke, D. 2006. Assessment of tributary potential for wild Rainbow Trout recruitment in Hebgen Reservoir, MT. Master’s Thesis. Montana State University, Bozeman.

March 2023

Madison River Drainage 2188 Project Monitoring Report 2022

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

By:
Travis Lohrenz, Mike Duncan, Jenna Dukovcic, 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 for the operation of 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 2022 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) evaluation of the effects of the 2021 Hebgen gate failure to upper Madison River fisheries 3) conservation and restoration of Arctic Grayling populations, 4) conservation and restoration of Westslope Cutthroat Trout populations, 5) evaluation of opportunities for the enhancement of mainstem and tributary habitats, and 6) evaluation of the effects of high-water on riparian regeneration.

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. 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 the 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 Project 2188 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 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 gauge at Kirby Ranch. FWP and NWE monitor river flow to avoid deviations from operational conditions.

Deviations from Article 403 occurred below Hebgen Dam and at Kirby Ranch on November 30, 2021. The deviations were the result of a broken component on the Hebgen Dam gate which 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 2022 is summarized in Appendix A and FWP's review of literature relevant to the gate failure is described in Appendix B of this report.

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 (Figure 1). Significant changes in the fish assemblage would warrant a review of project operations to address identified issues.

The mean catch-per-unit-effort (CPUE) of total trout in Hebgen Reservoir was about 20 trout/net in 2022, which was slightly above the long-term average (Figure 2). The CPUE of Brown Trout decreased by about 21% to 14.8 trout/net while Rainbow Trout decreased by 12% to 5.2 trout/net, which are below the management goals for each species (Brown Trout management goal = 15.5 fish/net; Rainbow Trout = 7.5 fish/net). However, the mean lengths of Brown and Rainbow Trout increased to 459 mm (≈ 18") and 433 mm (≈ 17"), respectively, which were above the long-term averages. Eighty-five percent of the Brown Trout captured in gill nets were ≥ 406 mm [≈ 16"], which exceeded the management goal of 75%. Sixty-six percent of the Rainbow Trout captured were ≥ 406 mm, which met the management goal.

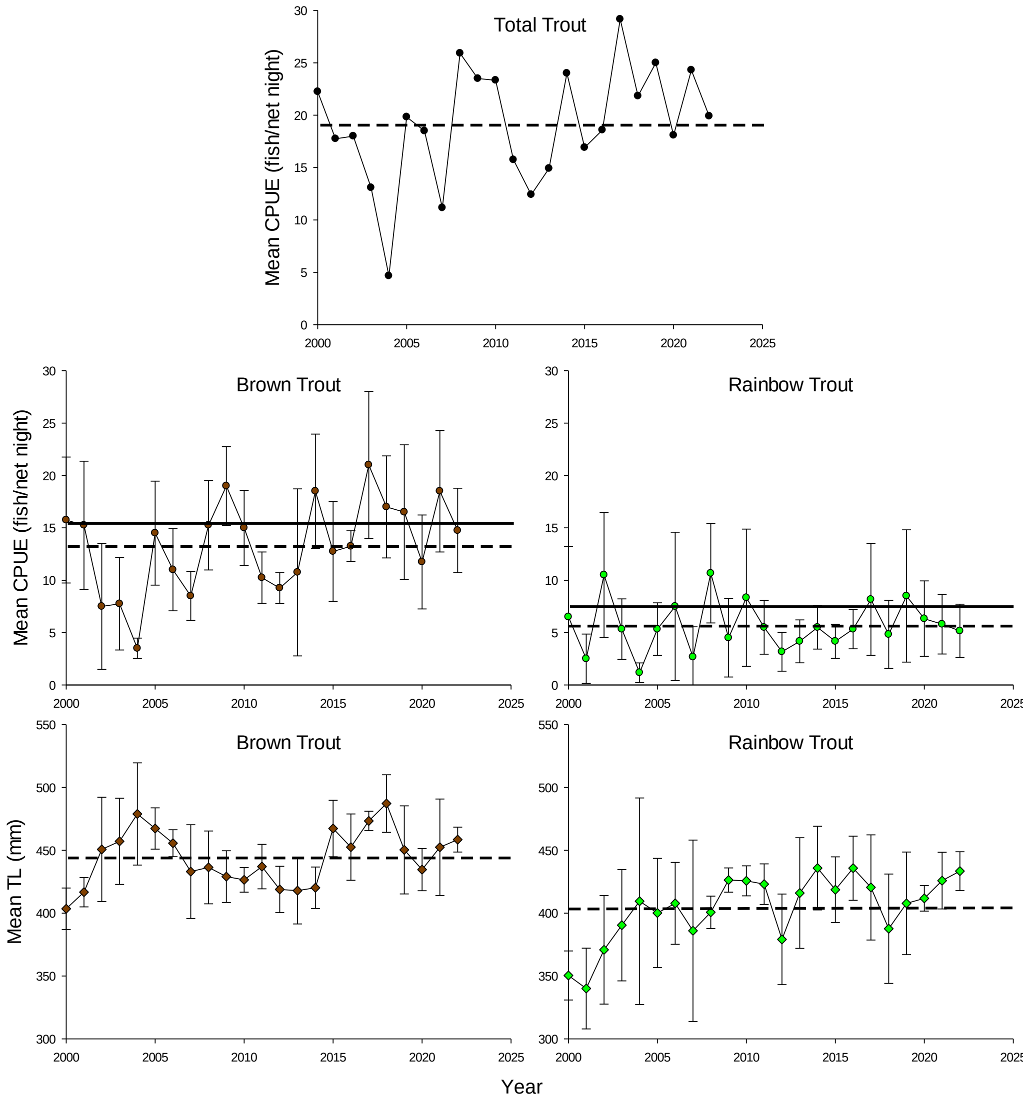


Figure 2. Mean catch-per-unit-effort (CPUE) of total, Brown, and Rainbow Trout captured in Hebgen Reservoir from 2000 to 2022. Total trout abundances represent all trout captured in four sinking and six floating gill nets. Brown and Rainbow Trout CPUE were limited to either sinking or floating gill nets, respectively. Mean total lengths were calculated using all Brown and Rainbow Trout captured each year. Dashed lines are the long-term averages (2000-2022), solid lines are management goals, and error bars are the 95% confidence intervals.

FWP completed a creel survey on Hebgen Reservoir in 2020-2021 (hereafter referred to as the "2020 survey) to characterize angler success and satisfaction following the transition to a wild Rainbow Trout fishery in the reservoir. Creel clerks used similar methodology to a creel survey completed in 2000-2001 (hereafter referred to as the "2000 survey"; Byorth 2004) to assess changes in angler use. However, travel restrictions following the onset of COVID-19 influenced angler use in the recent creel survey, which likely decreased nonresident angler-days and influenced other metrics used to characterize anglers and their use of the fishery as well.

Montana residents composed 56% of the anglers interviewed during the 2020 survey compared to only 39% in 2000. The 2020 creel survey represents nonresident anglers from 38 states and the District of Columbia with nonresidents from Idaho (13%), California (6%), and Utah (6%) composing about 25% of the total anglers interviewed. Anglers were generally pleased with their overall experience with 85% being satisfied or very satisfied (1 being "very unsatisfied" to 5 being "very satisfied; mean = 4.5; Figure 3). Catch rates of Rainbow and Brown Trout nearly doubled between the 2000 and 2020 surveys while harvest rates of Rainbow and Brown Trout were similar between the creel surveys (Figure 4). The mean lengths of Rainbow and Brown Trout harvested by interviewed anglers increased 24 mm and 27 mm (≈ 1"), respectively (Figure 4). Anglers indicated they were slightly more satisfied with the size of fish caught (mean = 3.6) than the number of fish caught (3.2; Figure 3). A thorough analysis and summary of the 2020 creel survey will be provided in a separate report in 2023.

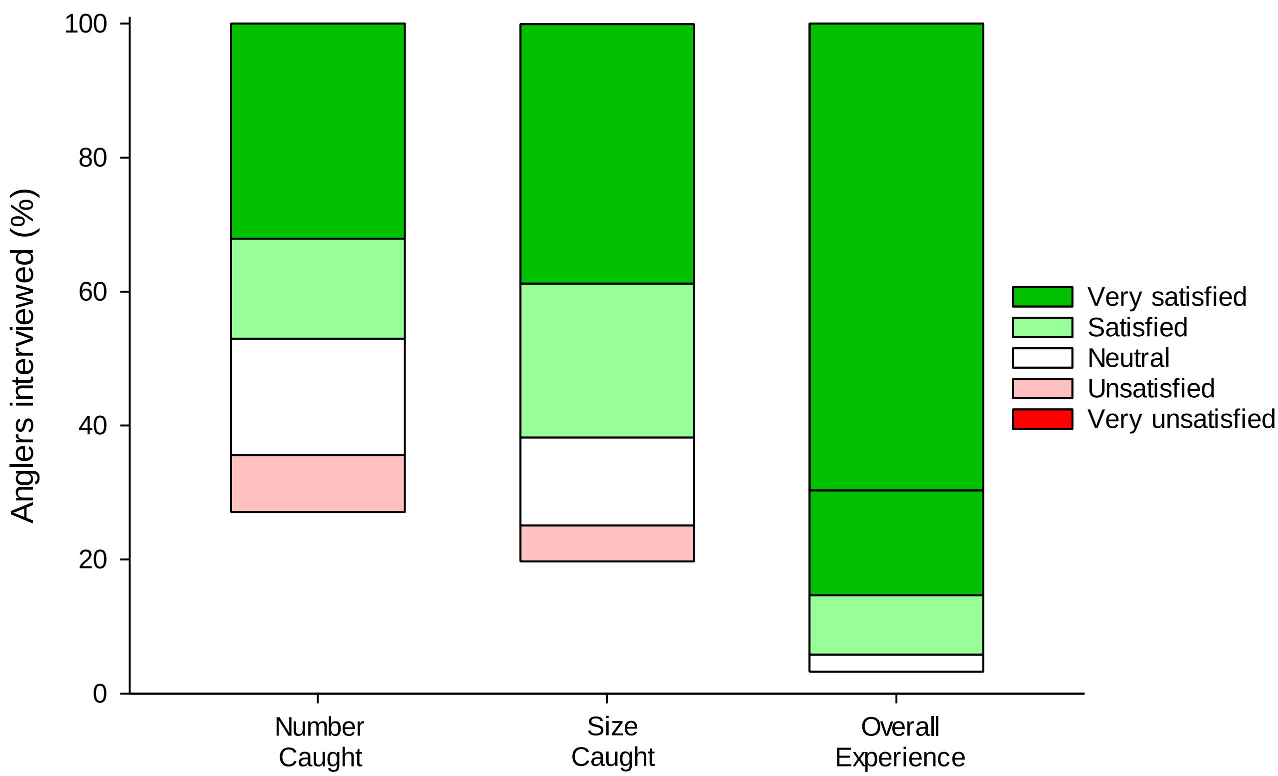


FIGURE 3. Angler satisfaction about the number and size of fish caught as well as the overall experience during the 2020 Hebgen Reservoir creel survey (*N* = 1287).

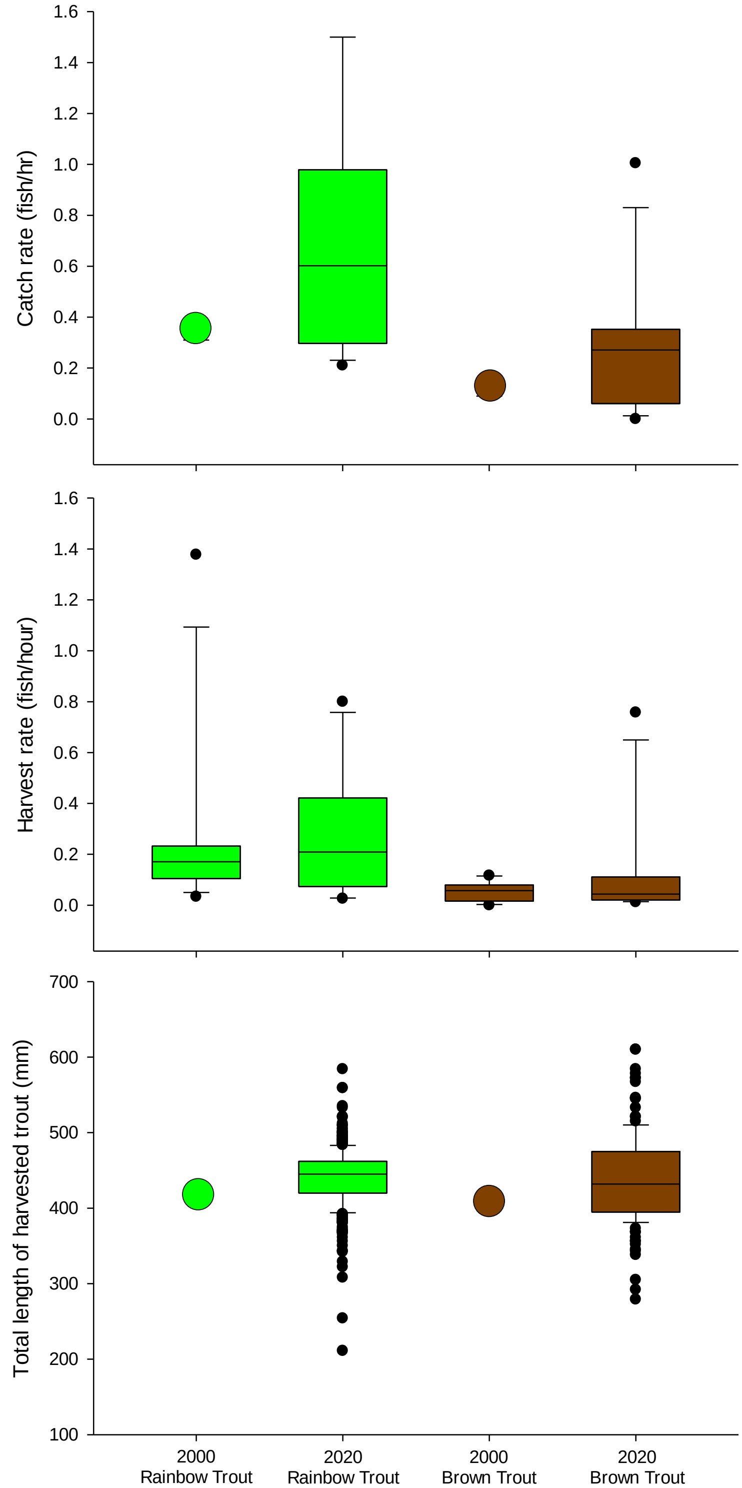


FIGURE 4. Catch rates, harvest rates, and total lengths of Rainbow (green) and Brown Trout (brown) from 2000 and 2020 Hebgen Reservoir creel surveys. Green and brown circles are means from 2000 creel report (Byorth 2004). Within each boxplot, horizontal black lines are medians; boxes extend from the 25th to 75th percentiles, vertical lines denote the 5th and 95th percentiles, and black circles are observations beyond those percentiles.

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 provide better coverage of the reservoir while eliminating gill net sets in shallow habitats that had poor capture efficiencies. Sampling will occur annually for at least three consecutive years to provide data that can be used to establish management goals for the Rainbow and Brown 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 catch-per-unit-effort (CPUE) of total trout, Brown Trout, and Rainbow Trout were near the long-term averages as were the mean lengths of Brown Trout (402 mm [≈ 16”]) and Rainbow Trout (356 mm [≈ 14.0”]; Figure 5).

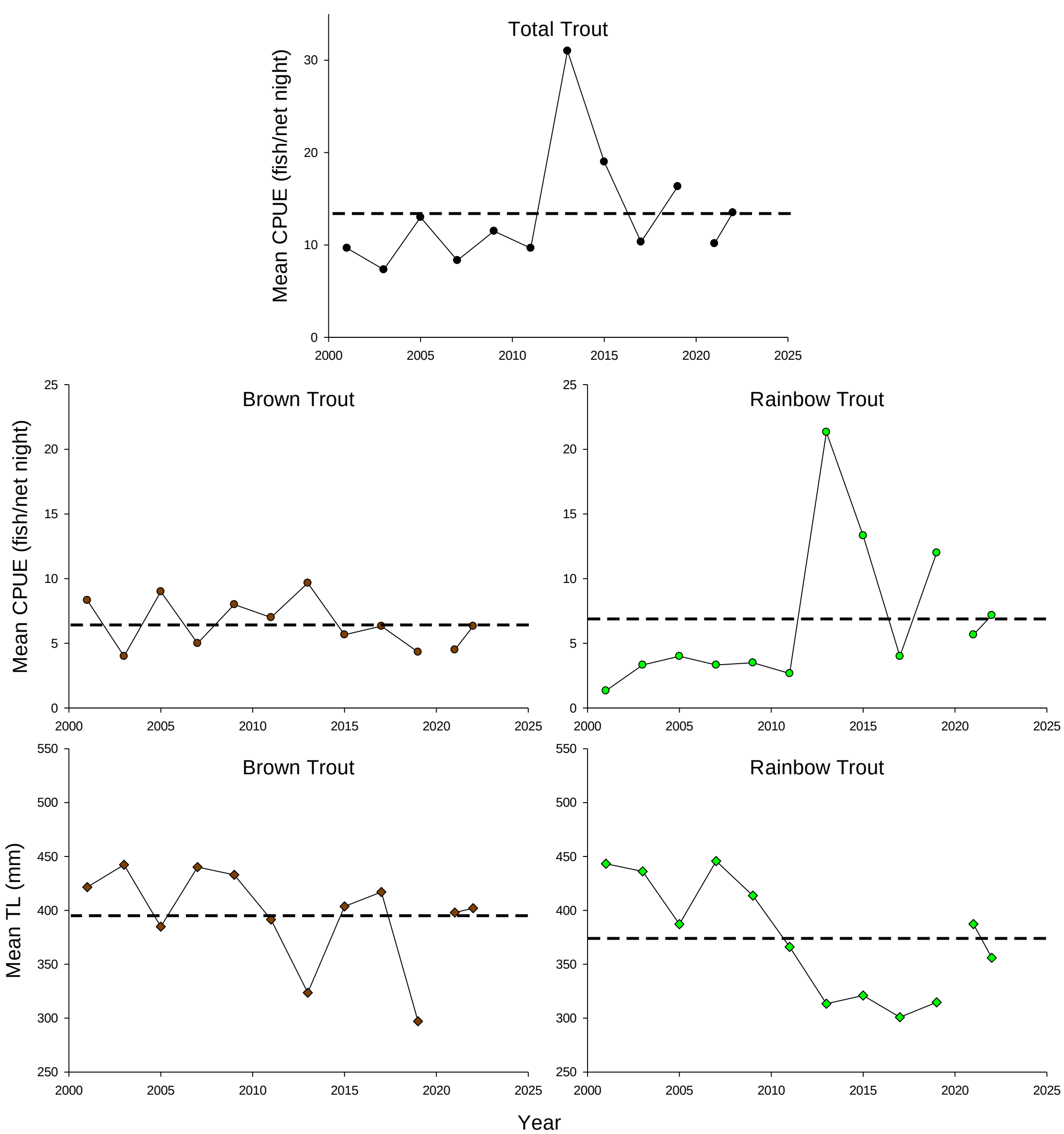


Figure 5. Mean catch-per-unit-effort (CPUE) of total, Brown and Rainbow Trout captured in gill nets set in Ennis Reservoir from 2001 to 2021. Brown and Rainbow mean CPUE and were calculated using all nets set

each year. Mean total lengths were calculated using all Brown and Rainbow Trout captured each year. Dashed lines are long-term averages (2001-2022) and error bars are 95% confidence intervals for mean lengths.

408-3) Reservoir Draw Down Effects on Fish:

The interactions between Hebgen Reservoir elevation and operations, trophic status, and the trout populations had been 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 2022. 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 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 a rate of 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 was calculated.

There was no statistical difference in zooplankton densities between the months of June and July or between July and August (ANOVA, $p>0.05$). However, there was a difference in densities between June and August (Figure 6; ANOVA, $p=0.037$). Copepoda comprised 76% of the sample in June, 70% in July, and 79% in August. Cladocera comprised 24%, 30%, and 21% 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 occur every other year and in years when departures from normal operations occur.

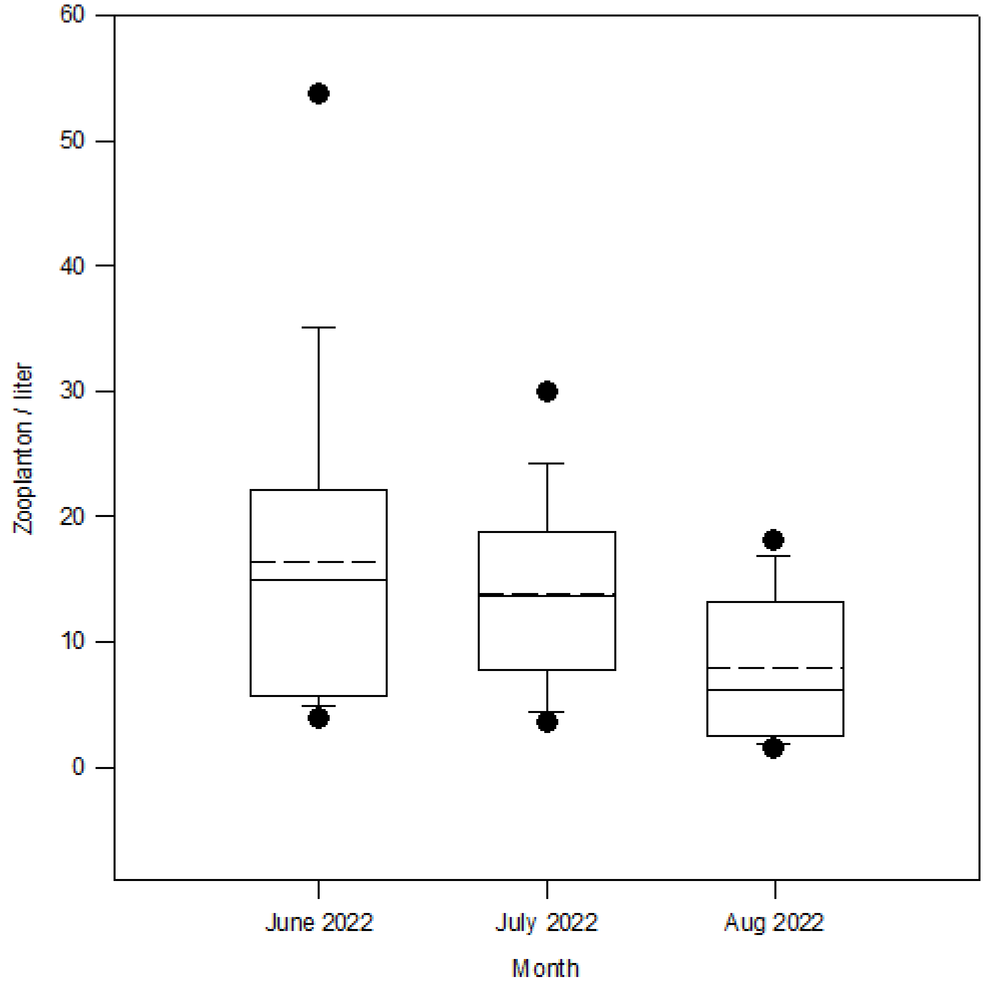


Figure 6. Total zooplankton abundance in June, July, and August 2022. Within each box, horizontal black lines denote median values and dashed lines represent mean values; boxes extend from the 25th to the 75th percentile of each group's distribution of values, vertical lines denote the 5th and 95th percentile of each group's distribution of values, black dots are observations beyond those percentiles.

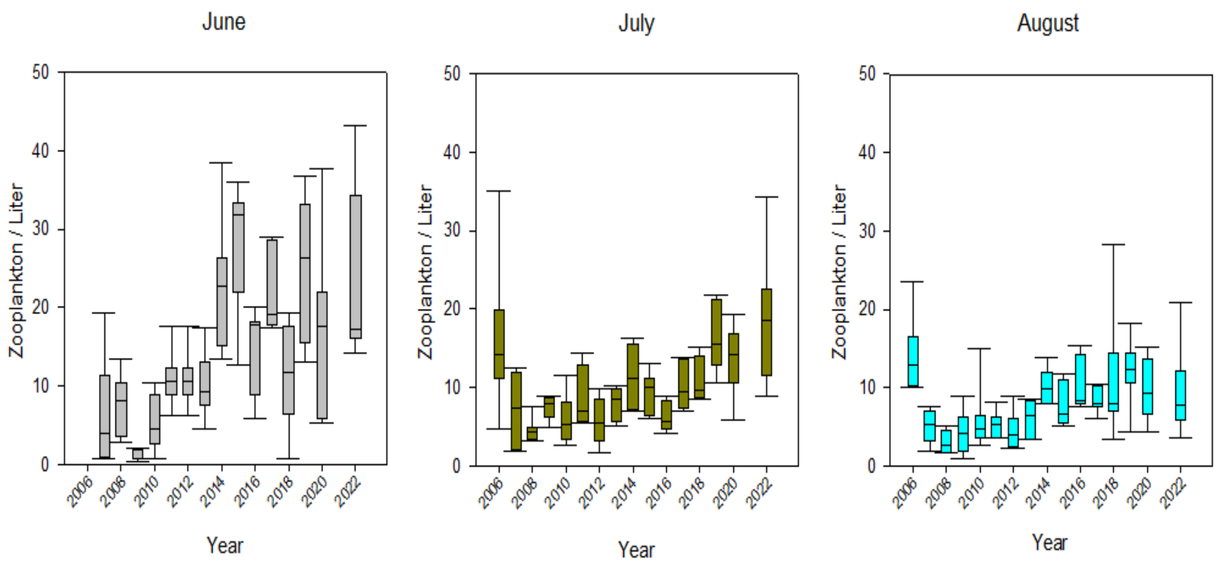


Figure 7. Total zooplankton abundance among months June, July, and August 2006-2022. Within each box, horizontal black lines denote median values; boxes extend from the 25th to the 75th percentile of each group's distribution of values, and vertical lines denote the 5th and 95th percentile of each group's distribution of values.

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

FWP estimated Rainbow and Brown Trout abundances using mark-recapture surveys in three long-term monitoring sections for the Madison River (Pine Butte, Varney, and Norris) to evaluate the influence of modified project operations at Hebgen and Madison dams on the trout fisheries. Although this report is limited to a discussion of potential influences of project operations, other potential population drivers (e.g., angling pressure, disease) are hypothesized to be influential and evaluated elsewhere. Trout were collected by electrofishing from a drift boat mounted mobile anode system. Fish captured in the initial trip (marking run) were weighed (g) and measured (mm), marked with a fin clip, and released. FWP conducted a second trip (recapture run) about a week later to examine trout for fin clips administered during the marking run, record lengths of marked fish, and record lengths and weights of unmarked fish. Length-specific mark-recapture log-likelihood closed population abundance estimates were generated and standardized to stream mile for Brown and Rainbow Trout using an R-based proprietary FWP fisheries database and analysis tool.

FWP developed management goals for total trout abundances (trout ≥ 252 mm [≈ 10”]) and size structure (percentages of trout ≥ 252 mm that are also ≥ 402 mm (≈ 16”]) for each of the long-term sampling sections using the approximate 66th percentiles of data collected over the past 20 years (Figures 8 and 9). The abundance goals for the Pine Butte, Varney, and Norris sections are 2,200, 1,100, and 2,500 trout/mile, respectively. The proportional size structure goals for each section are Pine Butte – 25%, Varney – 35%, and Norris – 15% (Figures 8 and 9). 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.

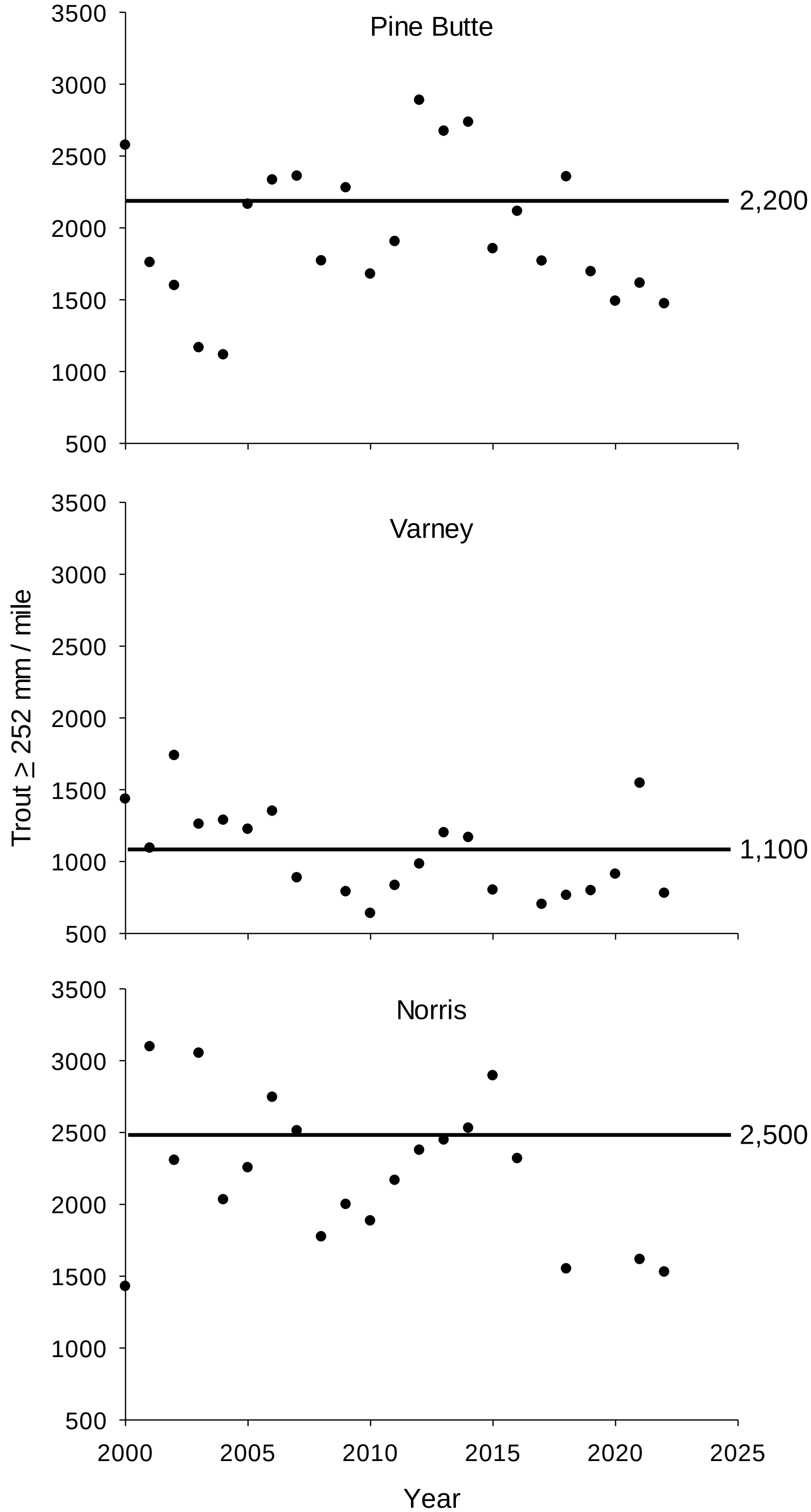


Figure 8. Estimated abundances of trout ≥ 252 mm (≈ 10") in the Madison River. Black lines are the management goals for each section.

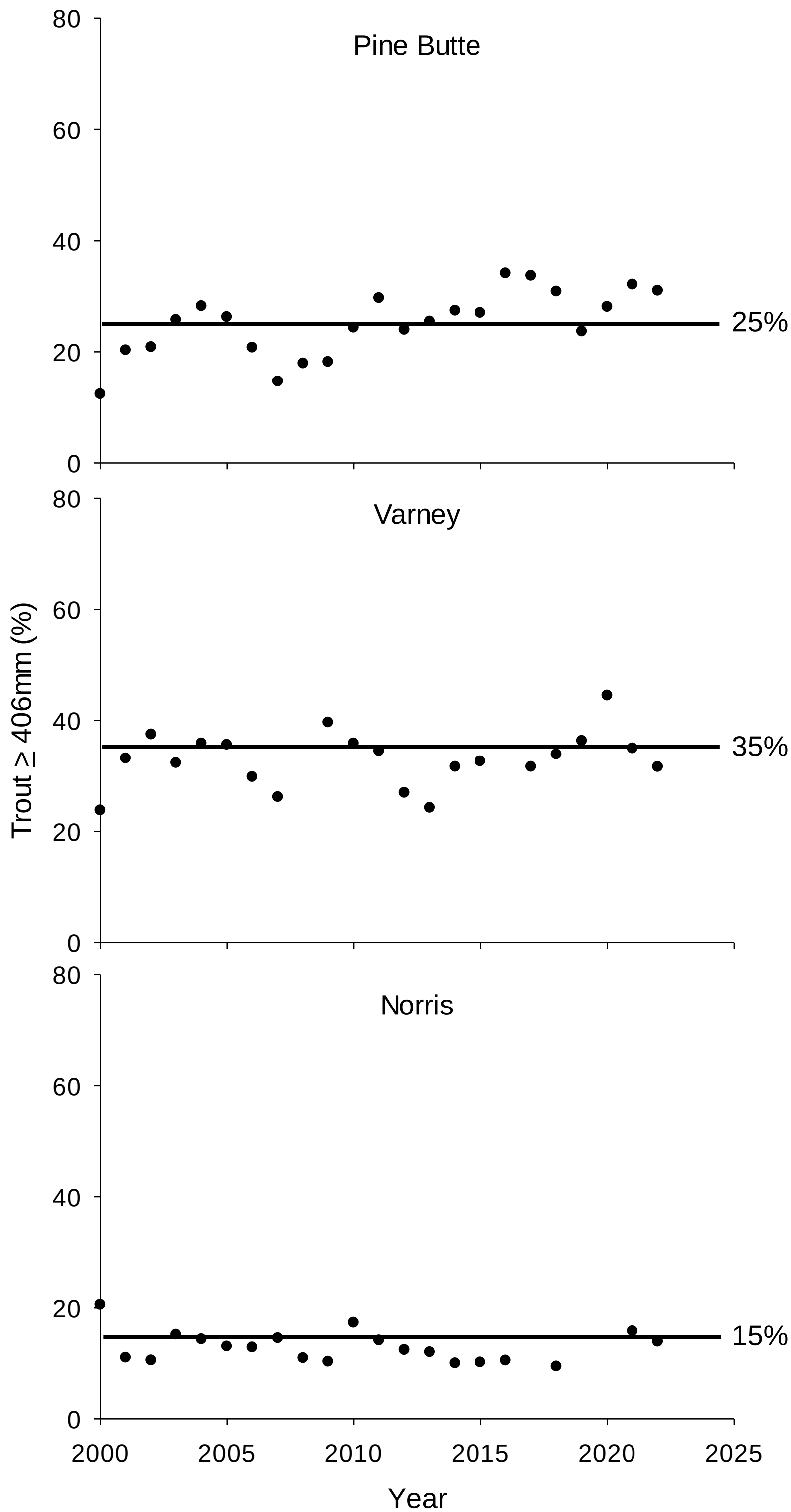


Figure 9. Percentages of ≥ 252 mm (≈ 10”) trout captured in the Madison River that were ≥ 406 mm (≈ 16”). Black lines are management goals for each section.

In 2022, each sampling section failed to achieve abundance management goals and Pine Butte was the only section where the size structure goal was achieved (Figures 8 and 9). The estimated abundance of Rainbow Trout ≥ 152 mm (≈ 6”) nearly doubled in the Pine Butte Section to 2,937 trout/mile in 2022 (Figure 10), which was primarily a result of the high abundance of fish < 252 mm (≈ 10”; Figure 11). Brown Trout in Pine Butte continued to decline to a 20-year low in 2022. It should be noted that water was released from the surface of Hebgen for a portion of the year as repairs to the failed gate component were being made. While no difference in trout abundance has been attributed to this kind of operational change, an increase in the proportion of fish ≥406mm in the Pine Butte section has been attributed to surface release (Lohrenz et al. 2020).

Abundances of trout ≥ 254 mm have been relatively low in Varney since 2015 with great variability in the size structure over the past several years. However, estimated abundances of Rainbow Trout ≥ 152 mm remain well above the long-term average at 1,946 trout/mile in the Varney Section (Figure 10) primarily because of a high abundance of relatively small Rainbow Trout < 252 mm (Figure 12), which will hopefully contribute to relatively high abundances of large Rainbow Trout in the upper Madison River and potentially Ennis Reservoir in the coming years.

Abundances of trout ≥ 252 mm remain at historical lows in Norris with that section of the river also failing to meet the size structure goal since 2015 (Figure 8). The estimated abundances of trout ≥ 152 mm remained below the long-term averages in the Norris Section with 1,301 Rainbow Trout/mile in 2022 and Brown Trout at a near historical low of 523 trout/mile (Figure 10). The truncated length-frequency histograms of both populations in recent years (Figure 13) indicate the survival of juvenile and adult Rainbow and Brown Trout have decreased in the lower Madison River relative to the populations observed in the 2000s and 2010s. The estimated abundance of Westslope Cutthroat Trout was 82 trout/mile, which is similar to 2021.

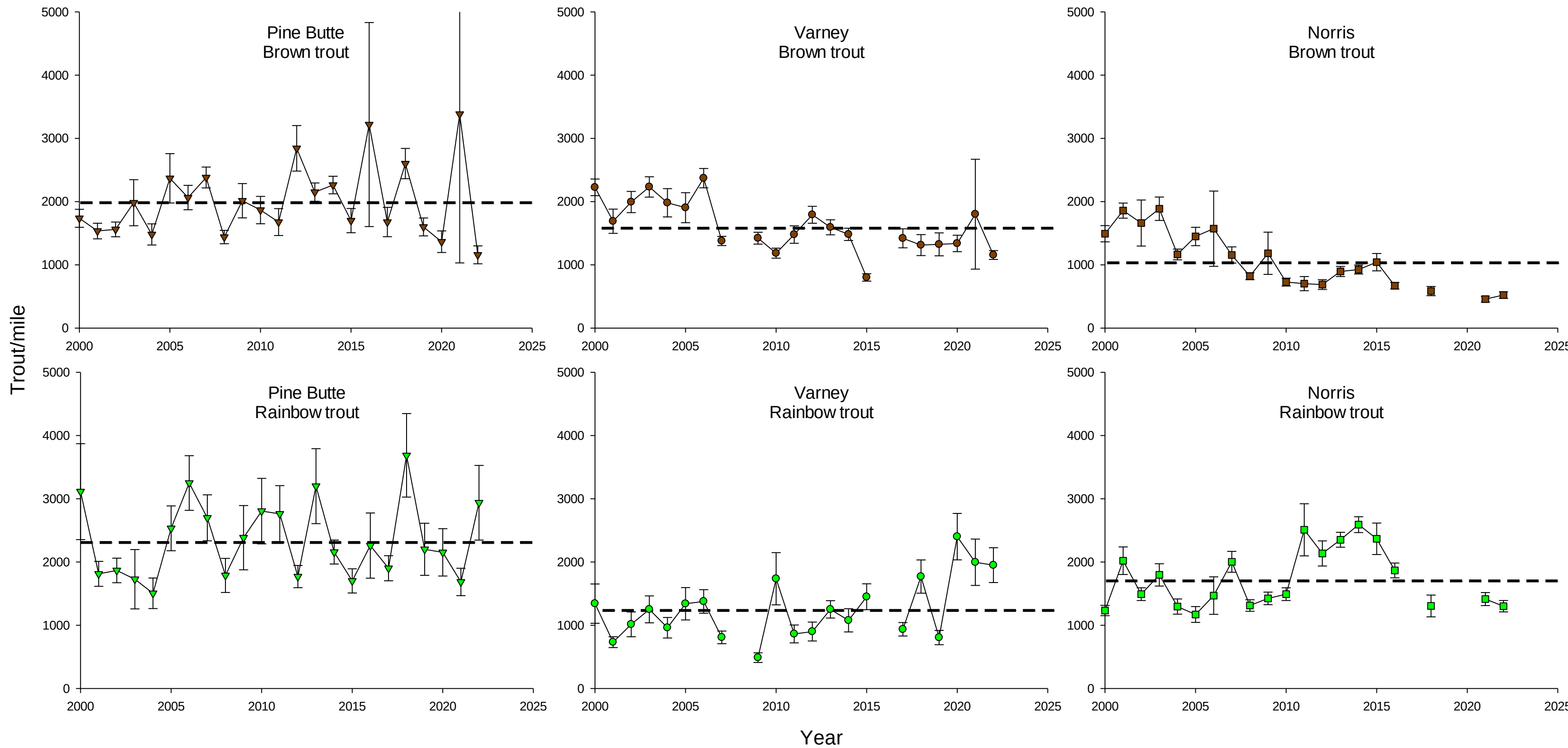


Figure 10. Estimated abundances of Brown and Rainbow Trout ≥ 152 mm (≈ 6") captured in the three long-term sampling sections of the Madison River. Dashed lines are the long-term averages (2000-2022) and error bars are the 95% confidence intervals.

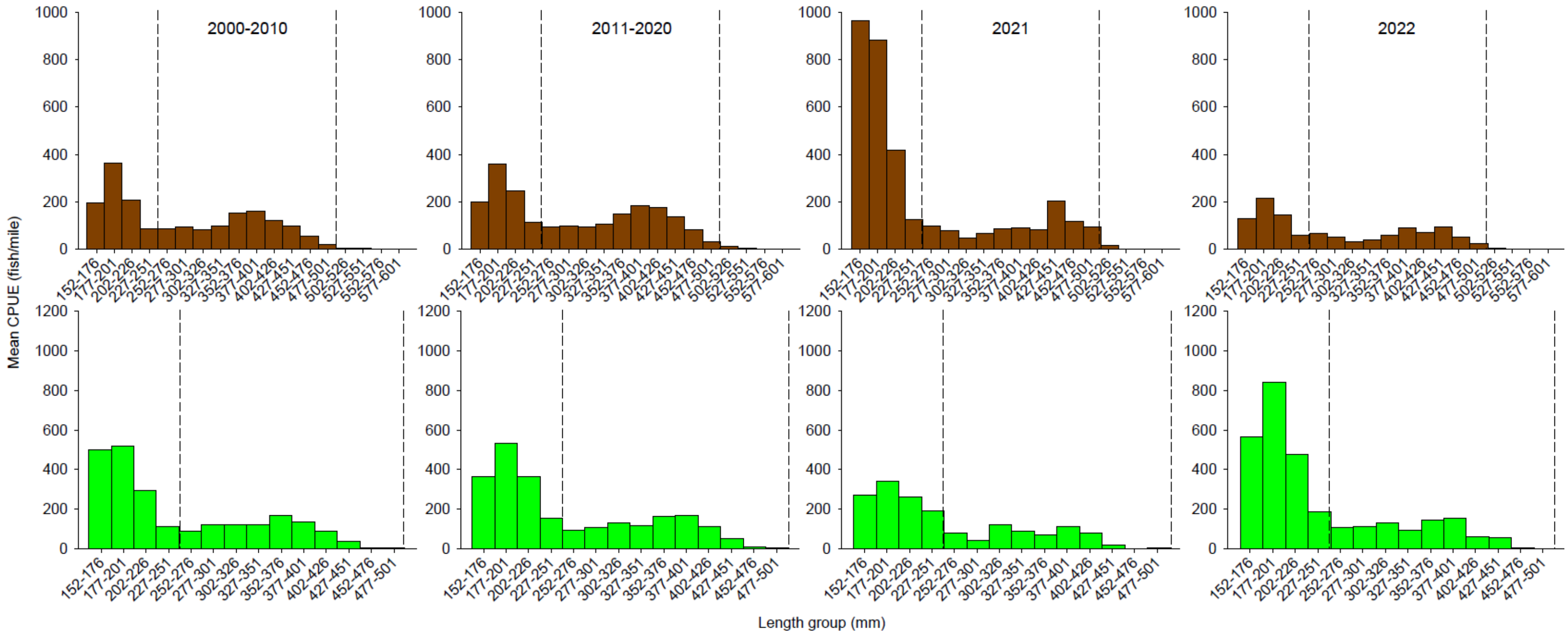


Figure 11. Length frequency histograms of Brown (brown bars) and Rainbow Trout (green bars) ≥ 152 mm (≈ 6") captured in the Pine Butte Section of the Madison River. Dashed lines delineate 10" and 20."

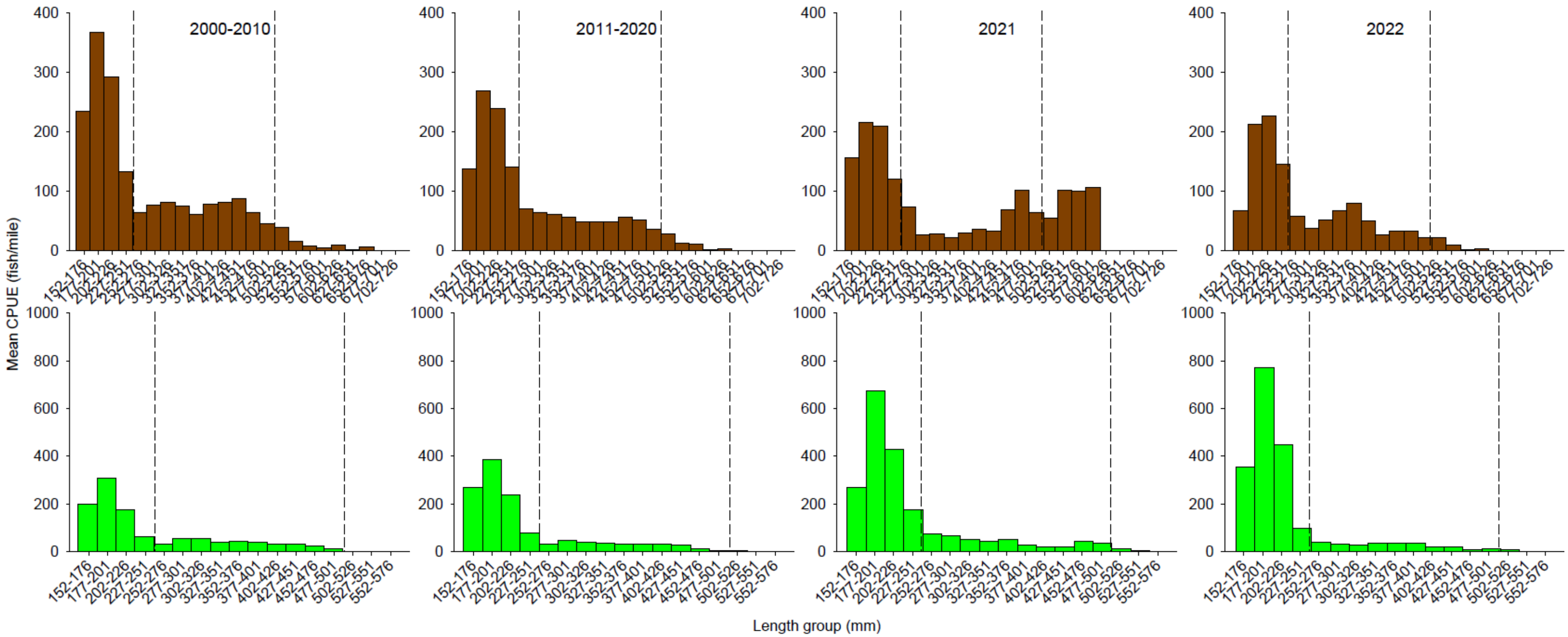


Figure 12. Length frequency histograms of Brown (brown bars) and Rainbow Trout (green bars) ≥ 152 mm (≈ 6”) captured in the Varney Section of the Madison River. Dashed lines delineate 10” and 20.”

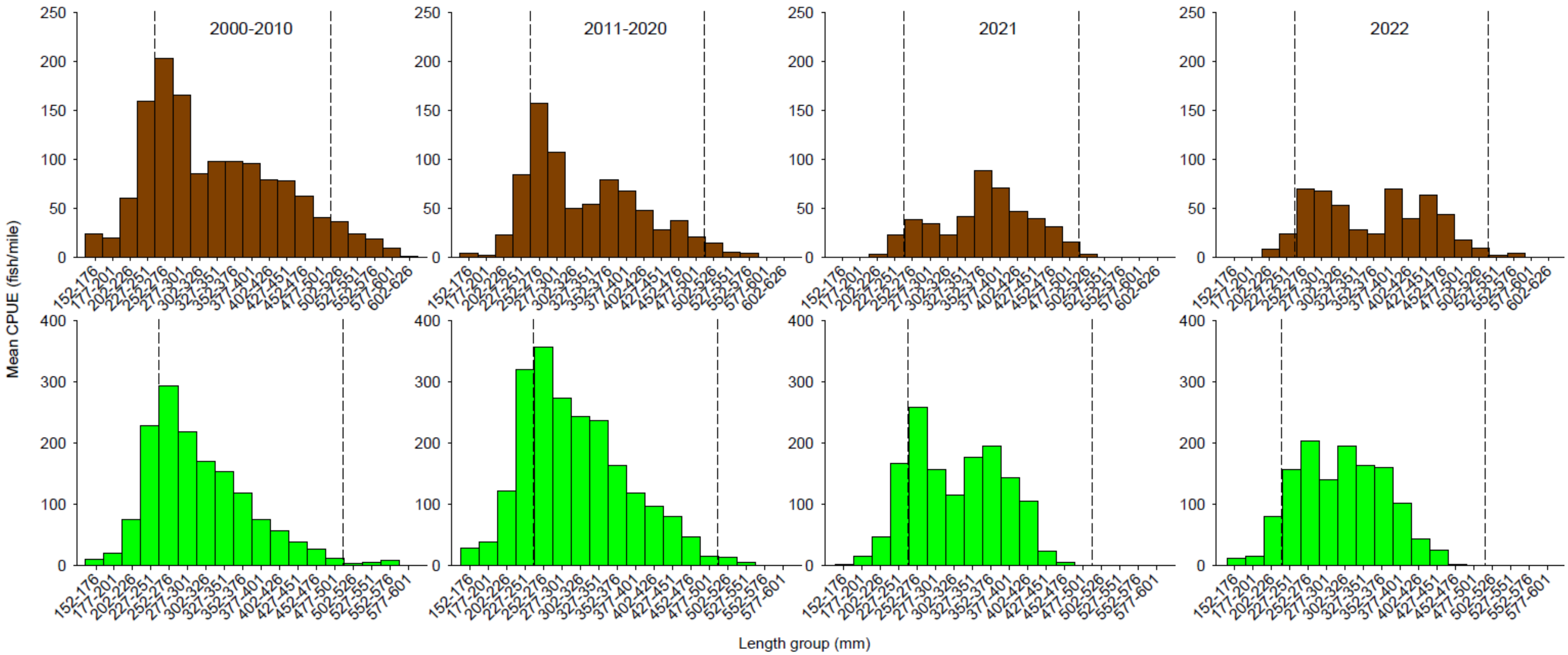


Figure 13. Length frequency histograms of Brown (brown bars) and Rainbow Trout (green bars) ≥ 152 mm (≈ 6”) captured in the Norris Section of the Madison River. Dashed lines delineate 10” and 20”.

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 due to the high density of Brown Trout in mainstem and tributary waters. However, the removal of nonnative fish from Grayling Creek and the Gibbon River and low densities of resident Brown Trout in the 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 the use of a minimum of 500,000 grayling eggs/year from fish of primarily Madison genetic ancestry for 3-5 consecutive years.

In 2022, FWP stocked 500,000 Arctic Grayling embryos in the South Fork Madison and 78,570 fry into the southwest arm of Hebgen Reservoir (Figure 1). Embryos were placed in remote site incubators (RSI; Figure 14) and entered the stream as fry (Figure 15). Additionally, fry reared at FWP hatcheries were introduced in the fall of 2022. To date, FWP has introduced 650,000 embryos and 94,709 fry into the Hebgen Basin.

Introductions of Arctic Grayling into the North Fork of Spanish Creek continued in 2022. Although the North Fork of Spanish Creek is outside of the Madison drainage, NWE committed funds in 2016 to native fish recovery there due to limited opportunities in the Madison drainage at that time. About 12,000 Arctic Grayling fry (6,000 per year) were introduced into Chiquita Lake in 2021 and 2022 and observed migrating into the North Fork of Spanish Creek. Arctic Grayling introductions will continue in 2023 and will be expanded in the drainage to include Willow Swamp Creek.

Figure 14. Remote site incubators used to hatch Arctic Grayling eggs in Black Sands Springs, a tributary to the South Fork Madison, in 2022.

Figure 15. Arctic Grayling Fry in the South Fork Madison hatched from RSI's.

FWP's Statewide Fisheries Management Plan calls for the protection and reintroduction of WCT conservation populations (i.e., populations with less than 10% hybridization by non-native 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.

WCT conservation populations in the Madison River subbasin inhabit 15.9% of historically occupied tributaries; however, only 30% of the identified populations are considered secure (isolated from nonnative fishes, typically by a physical barrier, and have a population >2,500 fish >75mm and occupy enough habitat to ensure long-term persistence). The MadTAC granted funding to pursue WCT conservation efforts in the Madison subbasin. WCT PM&E activities in 2022 included completion of the Pine Butte and Deadman creeks fish migration barriers, wild fish transfers of WCT from Last Chance and McClure creeks into Ruby Creek, genetic and population assessments of Ruby Creek and other Madison River tributaries.

The re-establishment of an unaltered WCT population in Ruby Creek has been ongoing since 2015, with translocations of genetically unaltered, aboriginal Madison WCT from McClure and Last Chance creeks. In the summer of 2022, FWP translocated 10 WCT from McClure and 13 from Last Chance creeks, respectively. Fish from McClure and Last Chance Creek were collected with a backpack electro-fisher, measured (mm), and had a fin clip taken for genetic analysis. Fish were transported to Ruby Creek in an aerated cooler. Before being released, fish were placed in a net and allowed to acclimate to the temperature of Ruby Creek for approximately 10 minutes. Since 2015, 130 individuals from McClure (81) and Last Chance Creek (49) have been translocated to Ruby Creek. Although fewer Last Chance Creek fish have been introduced, their genetic contribution to the Ruby Creek population has been greater than expected (Feuerstein 2021). FWP anticipates the 2022 introduction of McClure and Last Chance trout will continue to improve genetic diversity and increase the fitness of the population. FWP does not intend to translocate fish from either donor stream in 2023.

In addition to the translocations, FWP evaluated WCT population abundance and distribution throughout the Ruby Creek drainage. Abundances were estimated 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.

The average WCT abundance in Ruby Creek was 19 fish/100 m (± 11.0; 95% *CI*) or roughly 306 fish/mile (± 176; 95% *CI*). WCT abundances increased from 8 fish/100 m at the lowest site to 29 fish/100 m at the top of the drainage (Figure 16). The average length was 222 mm (± 10.0mm) and ranged from 353 mm to 104 mm. Given the current abundance of the Ruby Creek WCT population, roughly 2295 over 7.5 miles, FWP may consider using Ruby Creek as a donor source to re-establish WCT populations in streams targeted for reintroduction in the Madison or nearby drainages.

FWP updated the abundance, demographic, and genetic status of populations identified in the Missouri Headwaters WCT conservation strategy.

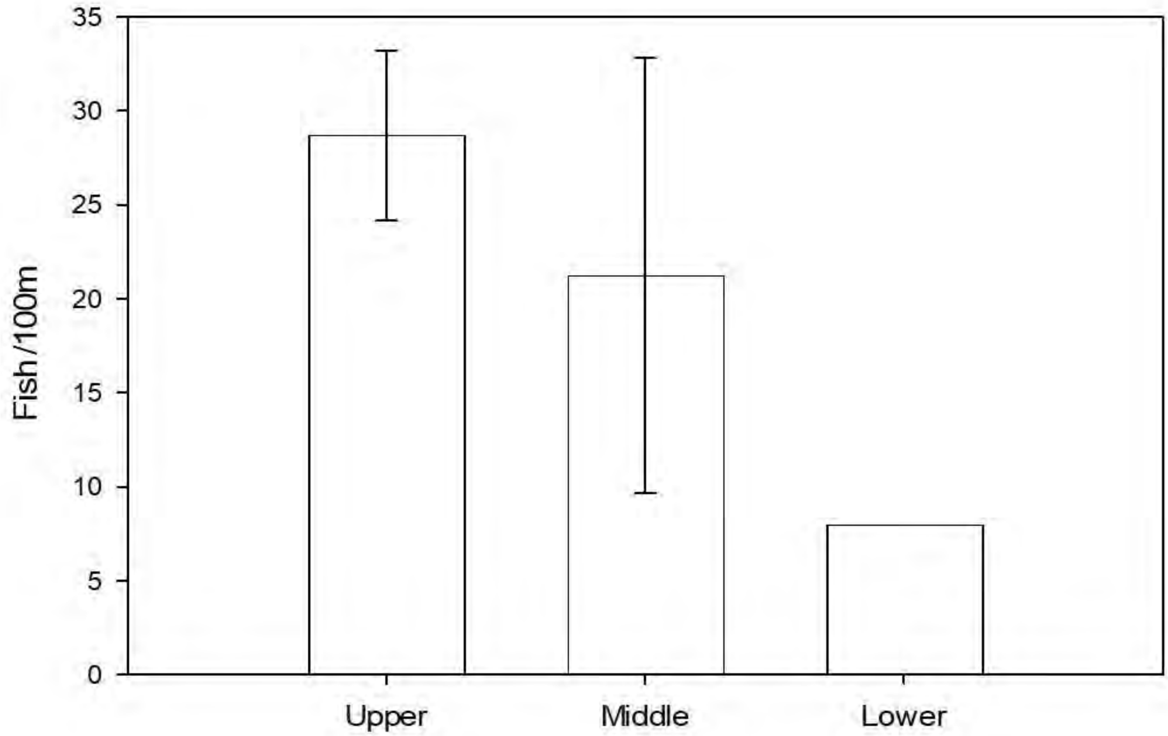


Figure 16. WCT abundances per 100 meters in Ruby Creek by sampling reach. Error Bars are 95% confidence intervals.

Fish barriers were constructed with MadTAC funding on Pine Butte and Deadman creeks in 2022 as prescribed by the Missouri Headwaters WCT conservation strategy (Figure 16). The installation of these barriers protects roughly 7 miles of stream occupied by WCT conservation populations (98.4% and 97.8% WCT, respectively) from further hybridization with or displacement by nonnative fish species.

Figure 17. Wooden migration barriers installed on Pine Butte (top photo) and Deadman (bottom photo) creeks in 2022.

In 2016 NWE committed funding to aid in the North Fork of Spanish Creek native fish restoration project, which is nearing completion. FWP continued their participation in the project in 2022. Results from environmental DNA testing (eDNA) showed Brook Trout had not been eradicated from the system during prior removal efforts. Consequently, another removal with piscicide was initiated in August 2022. Two of the three Brook Trout identified by eDNA were accounted for during the removal effort and it is expected this removal effort was successful in eliminating Brook Trout from the project area. eDNA will be conducted in the early summer of 2023 to confirm the success of the 2022 removal effort.

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 to flows under normal operations. The scarcity of gravel sources to replenish spawning habitats is further exacerbated by the loss of existing gravel to Ennis Lake due to the frequent capacity of the river to mobilize the D_{50} 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). Consequently, in 2022 FWP and NWE initiated efforts to develop projects to mitigate the loss of spawning habitat and improve general habitat conditions for fish production and recruitment to the mainstem fishery. Projects that restore spawning habitat in side channels, tributaries, and associated with constructed islands are under consideration.

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 18). Temperature data has been used by FWP as criteria for implementing angling restrictions to reduce the mortality of adult trout 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 is comprised 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 1). 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.

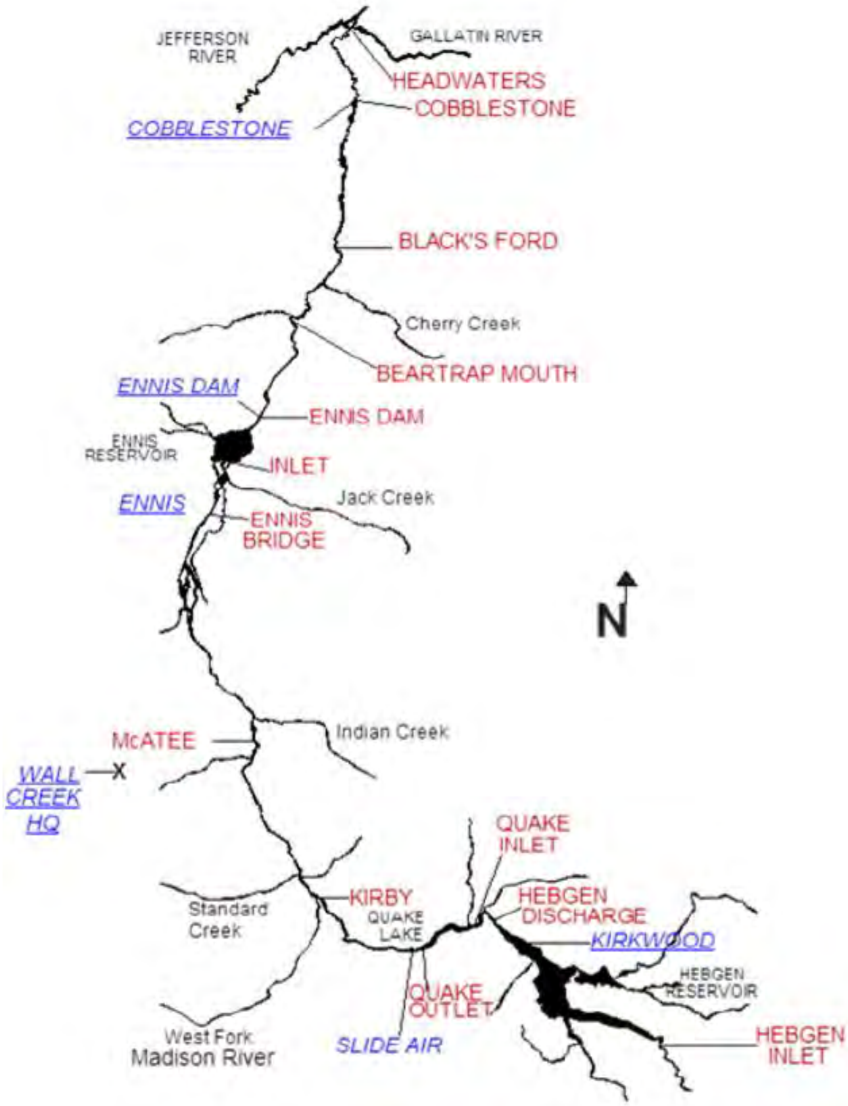


Figure 18. FWP temperature monitoring sites. Air temperature monitoring sites are blue and underlined; water temperature monitoring sites are red.

Table 1. 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, Bear Trap Mouth and Black's Ford and Cobblestone for 46, 55, and 59 days, respectively (Table 2). Since 2000, maximum daily water temperatures at the Black's 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 2022, there were 64 calls for a pulse flow, but only 45 of those resulted in operational changes to accommodate a pulse flow. Maximum daily water temperatures reached 80° F at Sloan Station for a total of 15 minutes on August 12. Downstream of Sloan Station at the Cobble Stone FAS water temperatures reached or exceeded 80°F on August 11 and 12. (Table 2; Figure 19). Pulse flows have been implemented an average of 19 days since 2009 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 20).

Table 2. Maximum and minimum temperatures (˚F) recorded at monitoring sites in the Madison River Drainage, 2022. 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	NA	NA	NA	NA	NA
Hebgen discharge	69.7°	49.2°	58.0.° ± 0.8°	0	0
Quake Lake inlet	70.2°	43.0°	58.5° ± 1.0°	0	0
Quake Lake outlet	66.6°	40.8°	58.1° ± 1.0°	0	0
Kirby Bridge	68.7	36.4°	58.6° ±0.9°	0	0
McAtee Bridge	72.9°	40.8°	58.5° ± 0.9°	0	0
Ennis Bridge	74.9°	41.7°	59.5° ± 1.2°	5	0
Ennis Reservoir Inlet	77.5°	48.4°	60.8° ± 1.0°	19	0
Madison Dam	75.1°	50.0°	65.1° ± 1.1°	11	0
Bear Trap Mouth	78.1°	50.4°	65.1° ± 1.0°	46	0
Blacks Ford	79.7°	49.3°	63.9° ± 1.2°	55	0
Cobblestone	80.4°	51.1°	65.5° ±1.0°	59	2
Headwaters S.P. (Madison mouth)	NA	NA	NA	NA	NA

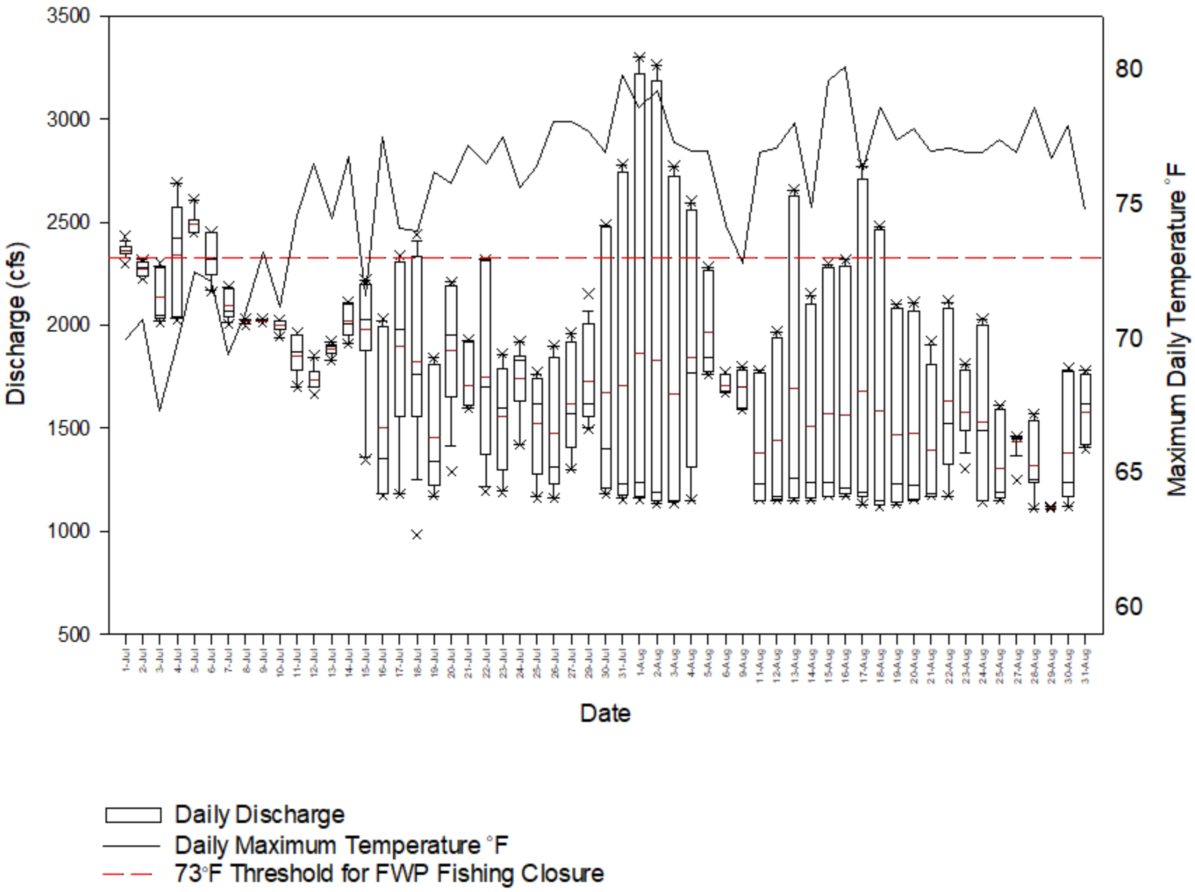


Figure 19. Daily distribution of discharges (left axis) collected every 15 minutes from July 1-Aug 31 2022 (pulse flow season) at USGS gage # 6041000 and daily maximum water temperature at Sloan (right axis). Boxes extend from the 25th to the 75th percentile and whiskers are the 5th and 95th percentile. 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 threshold used by FWP to implement angling closures.

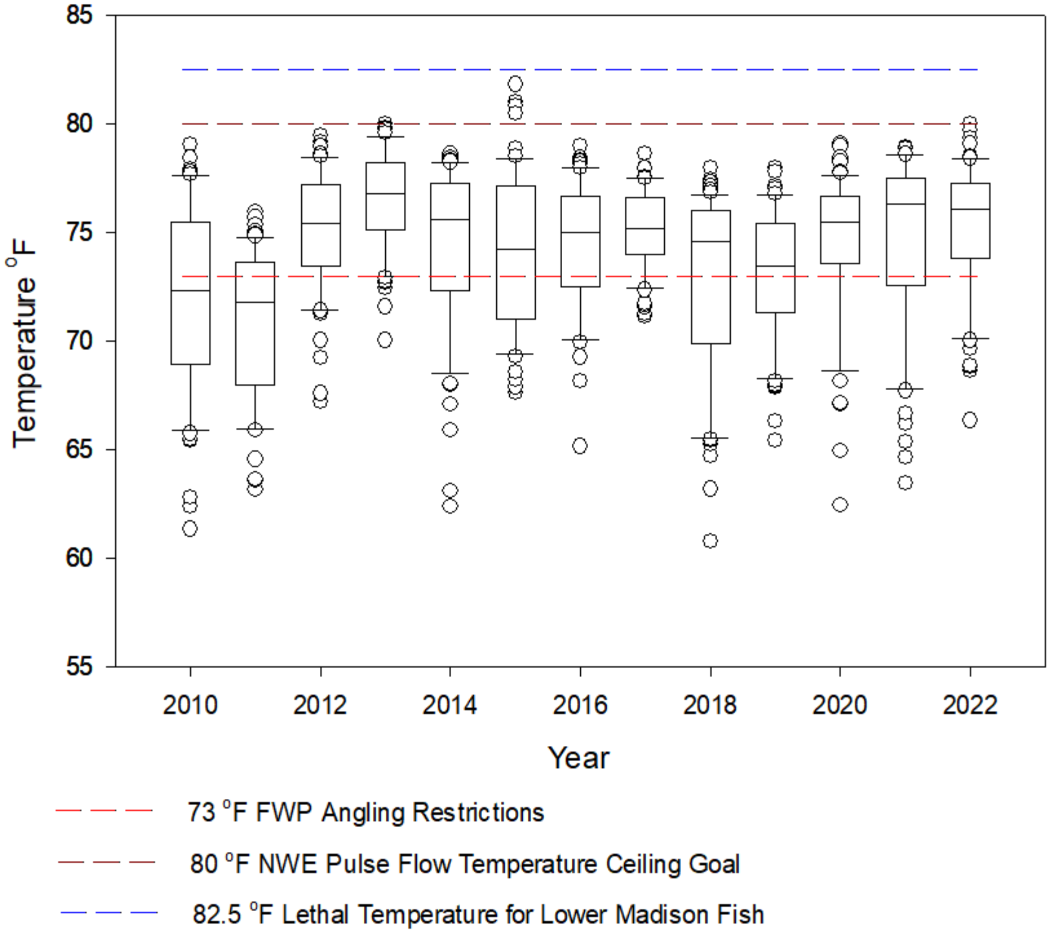


Figure 20. Distribution of daily maximum water temperatures at Sloan from July 1-August 31 from 2010-2022. Boxes extend from the 25th to the 75th (interquartile range) percentile, whiskers are the 5th and 95th percentile and circles are values beyond the 5th and 25th percentiles. The red dashed line denotes the 73°F threshold used by FWP to implement angling restrictions, the green 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.

General linear models (linear regression) were used to determine whether negative correlations existed between abundances of age-3+ Rainbow and Brown Trout and the number of days water temperatures were ≥ 73°F, age-1, age-2, and age 3+ Rainbow and Brown Trout and average pulse change, and between age-1, age-2 Rainbow and Brown Trout and the number of days a pulse flow occurred in the Norris section. Age-specific abundances were generated using length-age relationships described by Vincent (1978; Table 3). Because the Norris section is sampled in the spring prior to the pulsed flow season within year comparisons (i.e., at time t) were not relevant. Therefore, we assessed whether covariates at time t_{-1}, t_{-2}, predicted abundances of age-1, age-2, or age-3+ Rainbow or Brown Trout at time t. For example, an age-1 trout in 2022 would have been affected as an age-0 fish by conditions during the pulsed flow season in 2021 (t_{-1}) and the quality of the spawning habitat that produced it would have potentially been affected by the pulsed flow season in 2020 (t_{-2}).

Table 3. Madison River length at age for Rainbow and Brown Trout in the Norris Section (Vincent 1978).

	Rainbow trout			**Brown trout**		
Location	**Age 1**	**Age 2**	**Age 3+**	**Age 1**	**Age 2**	**Age 3+**
Norris	0-226mm	227-305mm	≥305mm	0-226mm	226-328mm	≥328mm

There was no correlation between the abundances of age-1 or age-2 Rainbow or Brown Trout at t_{-1} or t_{-2}, or age-3+ Rainbow or Brown Trout at t_{-2} and average pulse flow change. Additionally, no correlation was found between the number of days water temperatures were ≥ 73°F and the abundance of age-3+ Rainbow or Brown Trout at t_{-1}. The abundances of age-1 or age-2 Brown Trout and the number of days a pulse flow occurred at t_{-1}, t_{-2} were not correlated (Table 4); however, there were significant negative correlations between age-1 Rainbow Trout and the number of pulse flows at a t_{-1} ($R^2 = 0.22$; $P = 0.04$) and age 2 Rainbow Trout at t_{-2} ($R^2 = 0.54$; $P = 0.05$) (Table 4).

Table 4. Summary of hypothesis tested for negative correlations.

Hypothesis	*P*	R^2
Age 3+ RB negatively correlated with # days >73°F max temp (t-1)	>0.05	na
Age 3+ LL negatively correlated with # days >73°F max temp (t-1)	>0.05	na
Age 1 RB negatively correlated with # pulses (t-1)	0.04	21.9%
Age 2 RB negatively correlated with # pulses (t-2)	0.05	21.3%
Age 1 LL negatively correlated with # pulses (t-1)	>0.05	na
Age 2 LL negatively correlated with # pulses (t-2)	>0.05	na
Age 1 RB negatively correlated with average pulse flow change (t-1)	>0.05	na
Age 2 RB negatively correlated with average pulse flow change (t-2)	>0.05	na
Age 1 LL negatively correlated with average pulse flow change (t-1)	>0.05	na
Age 2 LL negatively correlated with average pulse flow change (t-2)	>0.05	na

Statistical results suggest that FWP's implementation of angling restrictions and the pulse flow program are effective in limiting thermally induced mortality in the lower river. No correlation between the average pulse flow change and Rainbow and Brown Trout age-1, age-2, and age-3+ abundances were found and is likely because pulse flow changes are proportionally small. However, negative correlations between age-1 and age-2 Rainbow Trout and the number of pulses might suggest that YOY Rainbow Trout displacement is a cumulative effect. For example, if one pulse flow equates to 100 YOY Rainbow Trout being displaced then 5 pulse flows would equate to 500 YOY Rainbow Trout being displaced. The Norris section has very little habitat complexity in the form of features such as side channels and islands that may provide velocity refugia. Limited complexity could prohibit juvenile fish from finding areas of reduced velocity during pulse events. An examination of the relationships between habitat features and total trout abundance showed a suggestive positive relationship between island and side channel density and large fish ≥ 16" (Lohrenz et al. 2021). While the effect of these features was not evaluated on young-of-the-year and age-1 fish, the relative abundances of young-of-the-year fish are commonly linked to complex habitats like side channels and high island density (Lohrenz et al. 2021). Pioneer Technical (2022) suggested that island construction could improve hydraulic diversity and habitat conditions for trout in the river. Pulse flows have been very effective at keeping water temperatures in the lower river below lethal thermal limits for trout and FWP recommends NWE continue the pulse flow program. FWP also recommends pursuing mainstem projects in this reach to improve habitat complexity and diversity to improve conditions for all life stages of fish.

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 et al. 1990). Impoundments such as dams interrupt the natural hydrograph of rivers and high flow events responsible for the replenishment and cleaning of 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 ≤ 0.8 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; Kondolof 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 the release of 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.

While 2022 was not considered a flushing flow year operationally by NWE, the rain-on-snow event in the Spring of 2022 resulted in river discharges that were greater in magnitude and longer in duration than with scheduled flushing flows. River discharges were at or exceeded 3500 cfs at the Kirby gage for five days and resulted in a peak discharge of 6340 cfs at Varney. 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 # 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 6,532.26^{ft} msl by June 20. Since 2002, evaluation of the efficacy of flushing flows to recruit spawning gravels and maintain fine sediment thresholds under current operational constraints has primarily been achieved 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 2022 with a 12-inch McNeil core sampler that was 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 percent composition of the sample was calculated according to particle size. The results from annual core sampling are reported elsewhere and provide an index of relative spawning habitat suitability (Kleinshmidt 2022). There is no statistical difference in the % fines ≤ 0.8 between years when a flushing flow was implemented or years when a flushing flow 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 have the capacity to 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).

Riparian plant communities are largely influenced by fluvial processes. These processes are often disrupted on regulated streams through the timing and magnitude of high-water events. In unregulated river systems, high flows typically occur in early summer and coincide 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 and are critical to the establishment of riparian species, such as cottonwood and willows. Due to its lack of hydrologic complexity as a predominately single-thread channel and operational constraints that limit flows, the formation of depositional features, such as point bars and islands, which provide moist barren surfaces for cottonwood and willow regeneration and expansion is largely limited throughout much of the Madison River. However, suitable conditions for riparian regeneration and expansion do occur in some reaches of the river, such as Varney and Greycliff, that are characterized by multi-thread channels of high complexity that dissipate stream energy and create zones of deposition during high flows.

FWP conducted a cursory evaluation of riparian vegetation recruitment at three islands in the Varney reach following the high flow event. Sites selected for evaluation were in close proximity to an island where new growth cottonwood and or willow was observable. At each site, the high-water mark was delineated by identifying a depositional band of debris on the river banks created as high water began to recede. Elevation measurements from the top of the bank, the high-water mark, the water's surface, and the top of the adjacent island were made using a stadia rod and laser level. Elevation measurements were used to calculate the level to which islands were inundated during high flows and the difference in elevation between the observed high-water mark and bank full elevation. Additionally, photos of areas with new vegetation growth were taken to document the environmental conditions in which new growth occurred. New cottonwood growth was observed on perched banks as well as on island surfaces and bank margins. Cottonwood growth observed on the perched banks were likely suckers from mature trees, that developed as a result of the banks becoming saturated during high flows (Payne and Parker pers. com. 2022). New cottonwood and willow growth observed on the islands was likely from seeds dispersed through the air and water that were deposited as water levels receded (Figure 21). Achieving bank full discharges under normal operations is uncommon; however, the river stage achieved during the implementation of a flushing flow is likely sufficient to create conditions conducive to promoting cottonwood and willow regeneration on depositional features, such as islands and point bars. Established stands of cottonwood and willows stabilize and increase the capacity of islands and point bars to store gravels that can slowly be recruited back into the system to replenish spawning gravels, which could become important as upstream sources of gravel are depleted. FWP recommends pursuing more in-depth evaluations of the relationship between flushing flows and the establishment and maintenance of cottonwood and willow communities along the Madison River.

Figure 21. Depositional features in the Varney reach where new riparian vegetation (cottonwoods) were observed growing after high water in 2022.

Literature Cited

Byorth, P. A. 2004. Hebgen Reservoir creel survey and contribution of stocked rainbow trout to the recreational fishery: June 2000 to June 2001. Montana Department of Fish, Wildlife & Parks, Helena.

Clancey, P., and T. Lohrenz. 2007. Madison River/Ennis Reservoir fisheries and Madison River Drainage Westslope Cutthroat Trout conservation and restoration program. 2006 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis.

Clancey, P., and T. Lohrenz. 2008. Madison River/Ennis Reservoir fisheries and Madison River Drainage Westslope Cutthroat Trout conservation and restoration program. 2007 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis.

Clancey, P., and T. Lohrenz. 2009. Madison River/Ennis Reservoir Fisheries and Madison River Drainage Westslope Cutthroat Trout conservation and restoration program. 2008 Annual Report to PPL Montana, Environmental Division, Butte, and Turner Enterprises, Inc., Bozeman, from Montana Fish, Wildlife, & Parks, Ennis.

Lohrenz, T. et al. 2021. Madison River 2188 project monitoring report 2021. Annual Report to NorthWestern Energy Environmental Division. Butte, Montana. From Montana Fish Wildlife and Parks. Ennis, Montana.

Downing, D.C., T.E. McMahon, and B.L. Kerans. 2002. Relation of spawning and rearing life history of Rainbow Trout and susceptibility to *Myxobolus cerebralis* infection in the Madison River, Montana. Journal of Aquatic Animal Health 14:191-203.

FERC. 2000. Order Issuing New License, Project No. 2188-030. Issued September 27, 2000.

Fuerstein, C., University of Montana, personal communication, 2022.

Jaeger, M. et al. 2002.Westslope cutthroat trout conservation strategy for the Missouri River headwaters of southwest Montana. Bozeman, Montana.

Kleinschmidt Associates. 2023. Flushing flow needs in the Madison River, Montana 2018 through 2022. Northwestern Energy, Butte, Montana.

Kondolf, G.M. 2000. Assessing salmonid spawning gravel quality. Transactions of the American Fisheries Society 129: 262-281.

Kondolf, G.M., and M. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research. 29: 2275-2285.

Kondolf, G.M. et. al. 1991. Distribution and stability of potential salmonid spawning gravels in steep boulder-bed streams of the Eastern Sierra Nevada. Transactions of the American Fisheries Society 120: 177-186. 1991.

McBain and Trush, 2003, Coarse sediment management plan Lewiston Dam to Grass Valley Creek Trinity River. 8-19. CA.U.S. Bureau of Reclamation. Northern California Area Office. Shasta Lake, California.

Montana Arctic Grayling Workgroup. 2002. Upper Missouri river Arctic Grayling conservation strategy.28. Bozeman, Montana.

Montana Fish, Wildlife, & Parks. 2019. 2019-2027 Montana statewide fisheries management program and guide. 446-447. Helena, Montana.

Parker, T. Geum Consultants, personal communication, 2002.

Payne, J. Fish Wildlife and Parks,.personal communication, 2002.

Pioneer Technical Services, Inc. 2002. Madison River Sediment Mobility Assessment.2002. Bozeman, Montana.

Poff, N.L. et. al. 1997. The natural flow regime a paradigm for river conservation and restoration. BioScience 47:769-784.

Reiser, D.W., M. Ramey, and T.Wesche. 1990. Alternatives in regulated river management. Chapter 4. Gore, P., and G. Petts. Boca Raton, Florida.

Vincent, R.E. 1978. Fisheries assessment report for the Madison River. Montana Fish, Wildlife and Parks. Bozeman, MT. 59717.

Watschke, D. 2006. Assessment of tributary potential for wild Rainbow Trout recruitment in Hebgen Reservoir, MT. Master’s Thesis. Montana State University, Bozeman.

Appendix A

Madison River Fishery Monitoring related to the Hebgen Dam Gate Failure

Compliance Report 2022

Prepared by

Travis Lohrenz, Jenna Dukovcic, Mike Duncan, 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. Within 15 minutes of the failure, Madison River flows between Hebgen Dam and Quake Lake declined 370 cfs, from 648 cfs to 278 cfs (Figure 1). From Quake Lake to Lyons Bridge (a 13-mile reach; Figure 1), the decline was more protracted with flows decreasing 381 cfs, from 780 cfs to 399 cfs in roughly a 48-hour period. The rate and volume of water reduction resulted in deviations from NorthWestern Energy's (NWE) Project 2188 Article 403 requirements: (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 1. Areas of the Madison River affected by the Hebgen Dam gate failure on November 30, 2021. Orange segments indicate the areas of greatest concern and the focal area of 2022 monitoring.

Impacts to the fishery immediately following gate failure were greatest between Hebgen Dam and Quake Lake where Brown Trout redds were dewatered along channel margins and within side channels. Adult and juvenile salmonids and sculpins were stranded in disconnected side channels and pools (Figure 2). From 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 Lyon's Bridge and no dewatered Brown Trout redds or stranded fish were observed in this reach during initial surveys (Figure 1).

Figure 2. The left panel shows a Brown Trout redd that was dewatered, and the right panel shows stranded juvenile salmonids in the Madison River between Hebgen Dam and the Quake Lake inlet following the rapid reduction in flow and stage during the Hebgen gate failure.

Figure 3. A partially dewatered Brown Trout redd in a side channel of the Madison River near Lyon's Bridge.

Assessment of impacts:
To assess the potential 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, which was approved by the Federal Energy Regulatory Commission (FERC) on August 18, 2022.

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;

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;

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,

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.

Additionally, a literature review to evaluate whether impacts from the low flows could have resulted in a total loss of the population or an individual age class will be prepared and 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, alternative analysis to evaluate improvements to spawning habitat, gravel recruitment, and embryo survival), will be developed.

This report summarizes the monitoring completed in 2022 related to the Hebgen Gate failure.

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 during the marking run were weighed (g) and measured (mm), marked with a fin clip, observed for hooking scars, and released. 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).

The ratio of Brown to Rainbow Trout was lower than average and age-1 Rainbow Trout comprised the largest proportion of the total combined trout population in 2022. Brown and Rainbow Trout are typically found in similar abundances in the Pine Butte Section; however, 73% of the trout captured in 2022 were Rainbow Trout (Table 1). Age-1 Rainbow Trout made up 53% of the total trout captured, age-2 9%, and age-3+ 10%. Age-1 Brown Trout comprised 14%, age-2 5%, and age-3+ 9% (Table 1). The proportion of Age-1 Rainbow was 18% higher and the proportion of age-1 Brown Trout 10% lower than the 20-year average. Similarly, the proportion of age-2 Brown and Rainbow Trout and age-3+ Brown Trout were 1%, 5%, and 4% lower than the 20-year average, respectively, while age-3+ Rainbow Trout was 3% higher than the 20-year average (Table 1).

Future monitoring will improve inference about potential effects of the Hebgen gate failure on the trout population. Brown Trout abundances were below the 20-year averages for all ages (Figure 4). The high abundance of age-1 Brown Trout in 2021 did not translate into a strong age-2 cohort in 2022; however, difficult sampling conditions (high water temperatures and crew inexperience) in the fall of 2021 led to unreliable abundance estimates and inferences should be cautious. It is presently unclear whether the apparent decrease in abundance of that cohort is attributable to the 2021 Hebgen gate failure, given the uncertainty in the 2021 estimate and the observed relative decline in age 2 Brown Trout in previous years. Age 2 Brown Trout have been below the 20-year average since 2018, indicating other factors may also affect brown trout abundance in the upper Madison River. Continued monitoring in 2023 will provide more insight into the effects of the gate failure on YOY Brown Trout as fish from the 2022 cohort that were eggs in the gravels of spawning redds during the dam failure will have recruited to electrofishing surveys. The estimated above average abundance of age 1 Rainbow Trout suggests the gate failure did not have a major negative effect on that cohort (Figure 4). The 2020 cohort declined on a relative basis from average abundances of 2021 age-1 fish to below average abundances of 2022 age-2 fish. However, the previous cohort of rainbow trout followed a similar pattern without being subjected to gate failure (Figure 4). To ascertain the effects of the 2021 gate failure on the trout population, tracking of cohorts and species ratios in the Pine Butte reach will be continued for the next four years and new length-at-age data from otoliths will improve aging precision.

Table 1. Percent composition of Brown Trout (LL) and Rainbow Trout (RB) for the 2022 total combined trout estimate and the total combined trout estimated 20-year average by age group in the Pine Butte section.

	Age Group			
Species	1	2	3+	Total
LL 2022	14%	5%	9%	28%
RB 2022	53%	9%	10%	72%
LL 20-year average	24%	10%	13%	47%
RB 20-year average	35%	11%	7%	53%

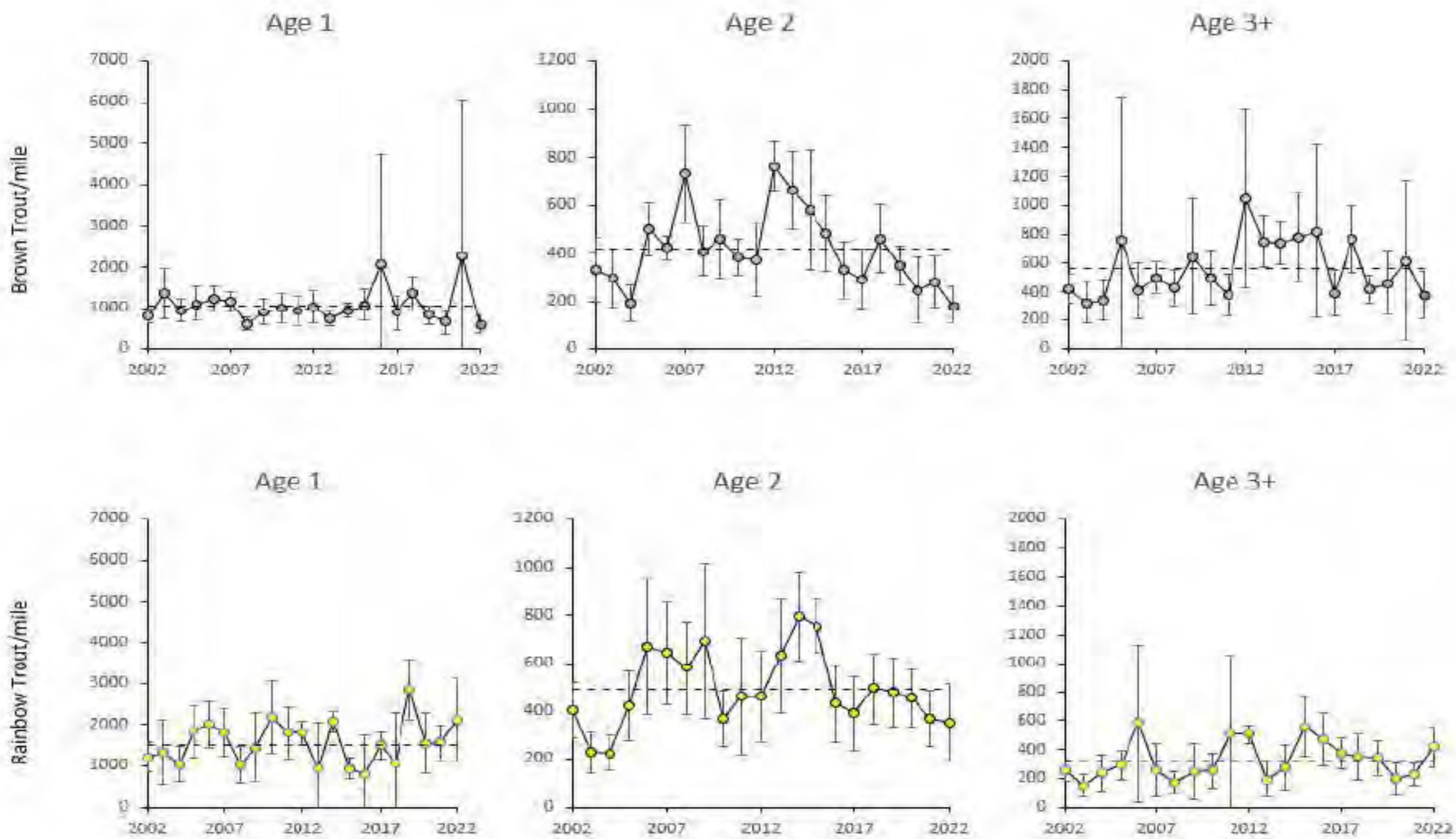


Figure 4. Estimated abundances of Brown and Rainbow Trout by age group in the Pine Butte monitoring section. Dashed lines are the 20-year averages (2002-2022), and error bars are the 95% confidence intervals. Note that the y-axis is not on the same scale.

2) Juvenile Salmonid Presence-Absence Survey

FWP conducted backpack electrofishing surveys in the side channels and margins of the mainstem Madison River between Hebgen Dam and Lyons Bridge to determine the presence or absence of YOY, age-1, and age-2 salmonids during the summer of 2022 (Figure 5). Four monitoring reaches were selected using satellite imagery: Between the Lakes (BTL)was from Hebgen Dam to the Quake Lake inlet (Figure 6), Upper (U) was from the Slide Inn to below Raynolds Bridge (Figure 7), Middle (M) was from below Raynolds Bridge to the Pine Butte primitive boat launch (Figure 8), Lower (L) was from the Pine Butte primitive boat launch to Lyons Bridge (Figure 9). Side channels that had a minimum of 300 feet of island shoreline and did not have a wetted width greater than one-third of the total wetted width of the mainstem river were identified within each reach. Those criteria were based on previous observations of spawning gravel recruitment and juvenile salmonid habitat use. Twenty-five side channels were identified among the four sampling reaches (9 BTL, 8 U, 9 M, and 8 L; Table 2). Four side channels were randomly selected from each reach with the exception of BTL. All but one of the side channels in BTL were sampled (side channel 5 was dry) because the effects of the gate failure were likely greatest in this reach due to the rapid decline in discharge. Sampling occurred on June 7-8 and July 25-26 following emergence of YOY Brown and Rainbow Trout, respectively (Downing 2001). Side channels were sampled in an upstream direction with a backpack electrofisher focusing on shorelines and habitat features used by juvenile salmonids such as woody debris, pools, and backwaters. The ages of captured fish were assigned in the field based on length; YOY (< 152mm), age-1 (152.0mm-276.9mm), and age-2 salmonids (277.0mm-376.9mm; Vincent 1973). Sampling continued until one of each species and age class was observed or the entire side channel was sampled. Additionally, about 100 YOY salmonids were collected from each side channel, preserved in ethanol, and identified in the laboratory (Weisel 1966; Figure 10).

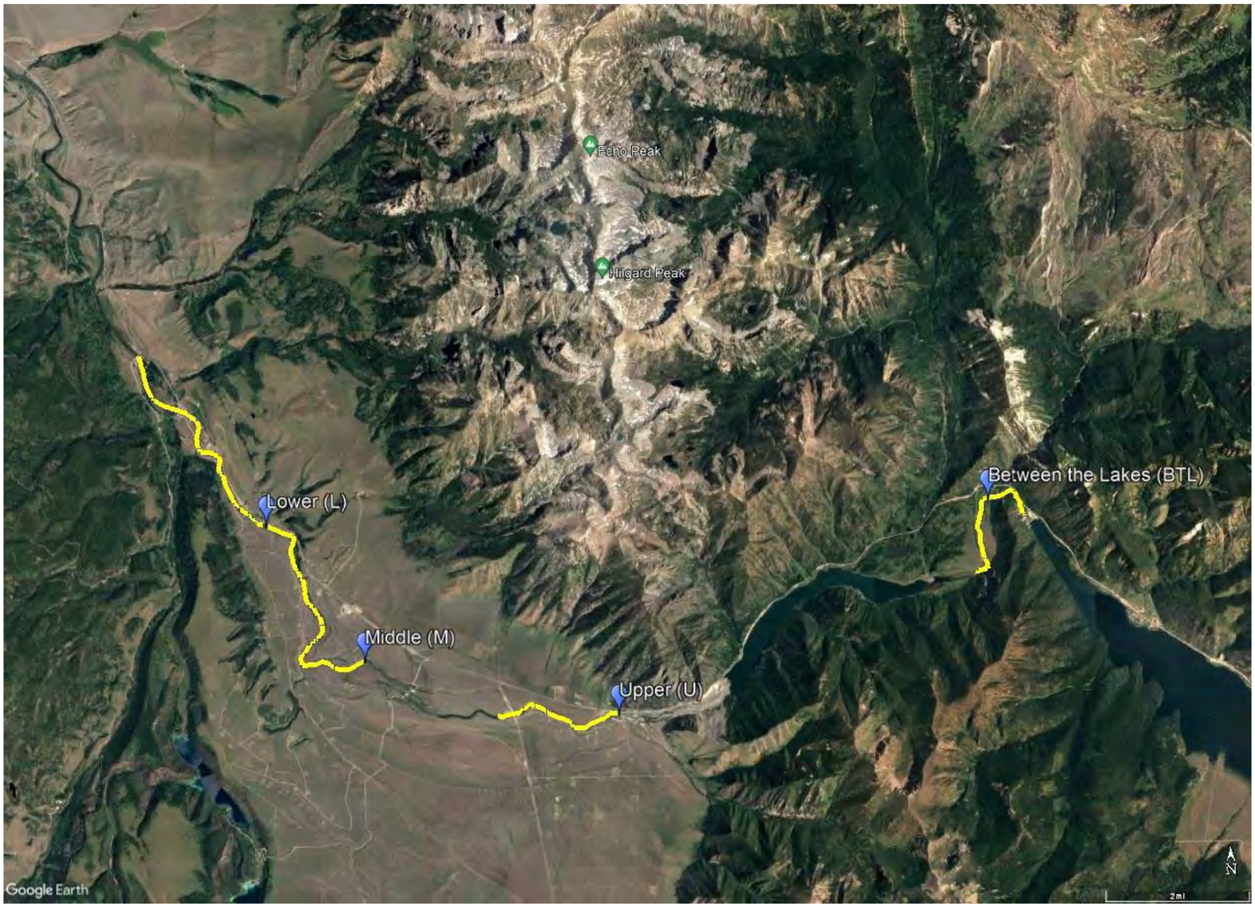


Figure 5. Madison River sections selected for juvenile presence/absence surveys.

Figure 6. Selected side channels for juvenile salmonid sampling in the Between The Lakes (BTL) reach. All side channels were sampled except side channel 5.

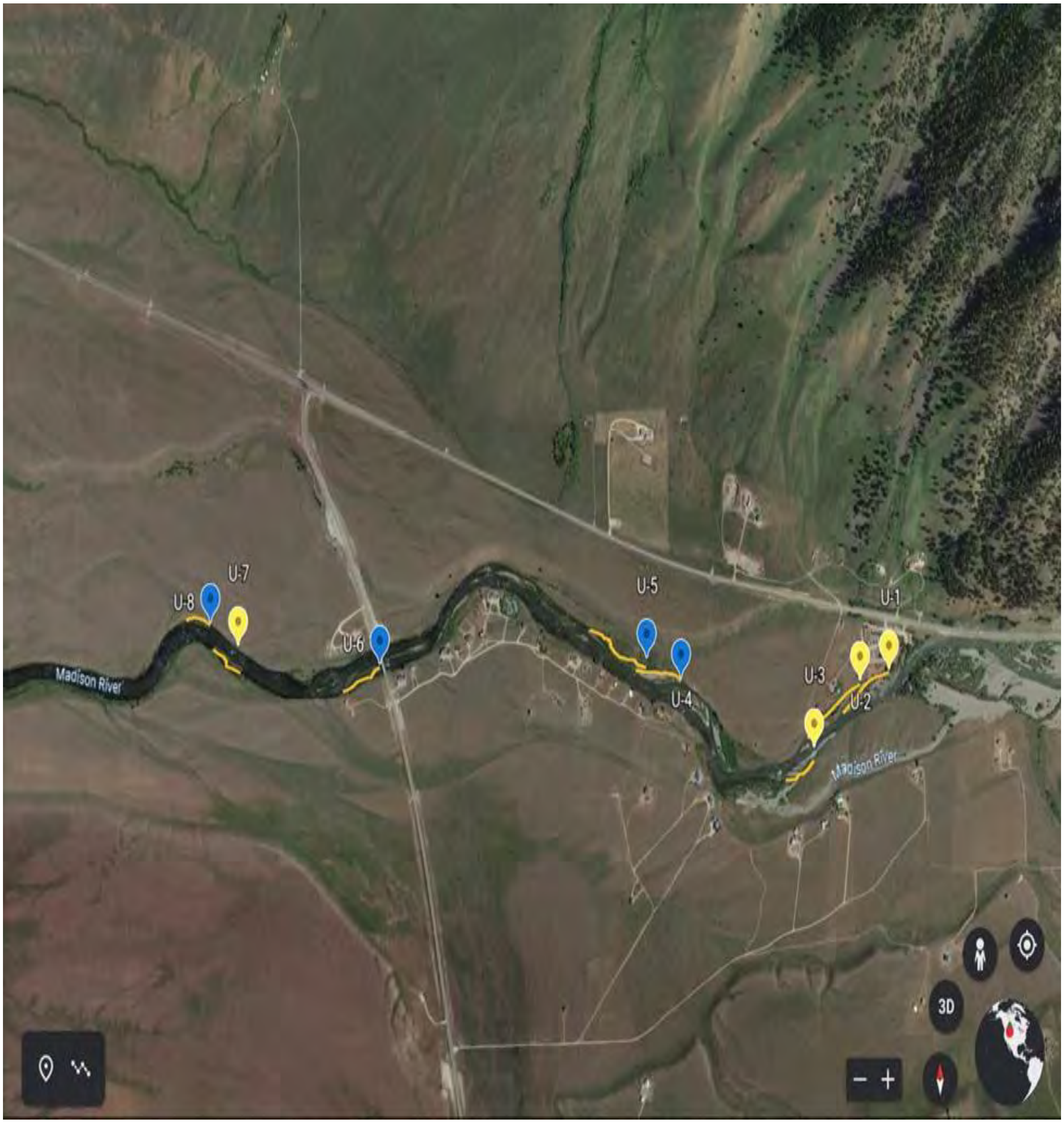


Figure 7. Side channels in the Upper reach (U). Blue markers represent side channels not sampled and yellow markers represent side channels that were randomly selected for sampling.

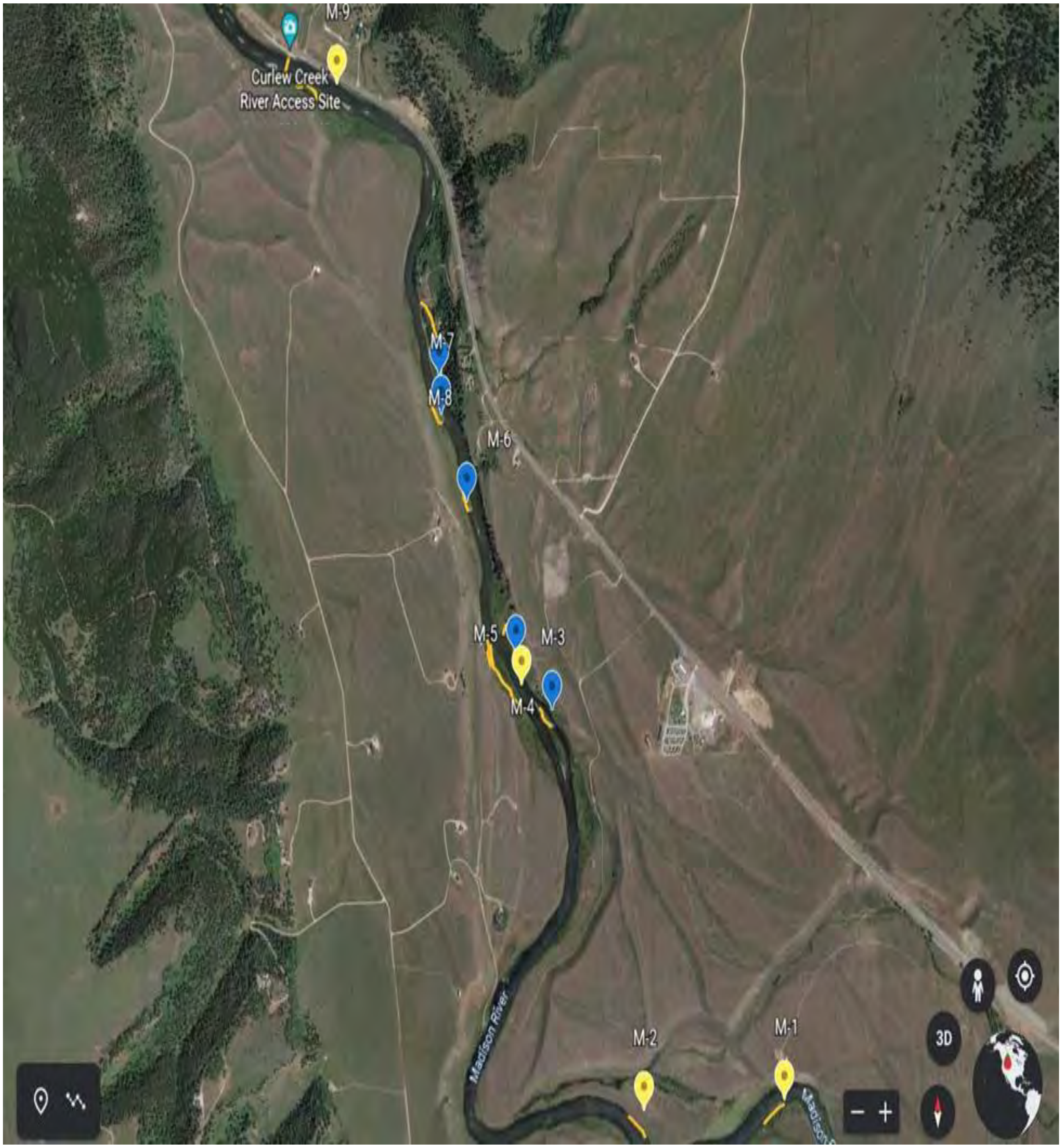


Figure 8. Side channels in the middle reach (M). Blue markers represent side channels not sampled and yellow markers represent side channels that were randomly selected for sampling.

Figure 9. Side channels in the Lower reach (L). Blue markers represent side channels not sampled and yellow markers represent side channels that were randomly selected for sampling.

Table 2. Side channels selected for sampling by reach Between the Lakes (BTL), Upper (U), Middle (M),and Lower (L).

Reach	Side Channel Number	Latitude	Longitude
BTL	1	44.869701	-111.342301
BTL	2	44.869113	-111.348333
BTL	3	44.868643	-111.348551
BTL	4	44.865800	-111.348256
BTL	5	44.863263	-111.349883
BTL	6	44.863063	-111.350606
BTL	7	44.861304	-111.349335
BTL	8	44.858382	-111.348953
BTL	9	44.855846	-111.347920
U	1	44.825465	-111.459008
U	2	44.824053	-111.462250
U	3	44.825060	-111.467977
U	8	44.827633	-111.493859
M	1	44.838111	-111.529385
M	2	44.837105	-111.535760
M	6	44.853858	-111.544382
M	7	44.856010	-111.545619
L	1	44.867208	-111.558981
L	3	44.868999	-111.563532
L	6	44.888190	-111.579357
L	7	44.889932	-111.584686

Figure 10. Young-of-year salmonids collected for identification.

Presence-absence surveys confirmed that YOY and juvenile salmonids occupied 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. Young-of-year Rainbow Trout were present in 90% of the side channels sampled in July (Table 3). Rainbow Trout YOY absence from the June sample is attributable to relatively late emergence compared to brown trout (Downing 2001), which resulted in clear size differences between YOY Brown and Rainbow Trout; Brown Trout YOY were on average 20mm longer than Rainbow Trout YOY during July sampling. Age-1 Brown (70% and 75%) and Rainbow Trout (80% and 40%) were present in most side channels during both sampling periods (Table 3). Age-2 Brown (15% and 35%) and Rainbow trout (10% and 35%) were present in some 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 (Table 3). Larval drift of Mountain Whitefish may have distributed juveniles to areas of slower velocities than sampled for this report (Boyer 2016). However, YOY Mountain Whitefish are common throughout the mainstem Madison River and are frequently observed by FWP personnel during annual electrofishing surveys.

Table 3. June and July 2022 presence-absence survey of Madison River side channels Between the Lakes (BTL), Upper (U), Middle (M), and Lower (L) for young-of-the-year (YOY), age-1, and age-2, Brown Trout (LL), Rainbow Trout (RB), and Mountain Whitefish (MWF), X denotes presence. X? was a suspect Rainbow Trout later identified as a Cutthroat Trout.

Side Channel	YOY LL		Age-1 LL		Age-2 LL		YOY RB		Age-1 RB		Age-2 RB		YOY MWF		Age-1 MWF		Age-2 MWF	
	June	July	June	July	June	July	June	July	June	July	June	July	June	July	June	July	June	July
BTL1	x	x		x				x										
BTL2	x	x				x		x	x			x			x			
BTL3	x	x	x					x	x									
BTL4	x	x		x				x	x		x?	x						
BTL6	x		x	x				x	x									
BTL7	x			x				x								x		
BTL8	x	x		x				x		x						x		
BTL9	x	x	x	x				x	x							x		
U1	x	x	x	x	x	x		x	x	x	x	x						
U2		x	x			x		x	x		x	x						
U3		x	x	x					x									
U8	x	x	x	x				x	x	x								
M1	x	x	x		x	x		x	x									
M2	x	x		x		x		x		x		x					x	x
M6	x	x	x	x				x	x							x		
M7	x	x	x	x	x	x		x	x	x		x						
L1	x	x	x	x				x	x	x								
L3	x	x	x	x				x	x	x								
L6	x	x	x	x				x	x	x								
L7	x	x	x	x		x		x	x	x		x						

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

FWP performed a catch-per-unit effort (C/*f*) survey to assess population structure and relative abundances of salmonids in the Madison River between Hebgen Dam and the Quake Lake inlet on September 6, 2022. Fish were collected by electrofishing from a drift boat-mounted mobile anode system, weighed (g) and measured (mm). Age-specific C/*f* estimates 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.

Sampling between Hebgen Dam and Quake Lake showed lower C/*f* for all fish species and age classes than anticipated, which may be a result of the swift and deep river conditions throughout the section. Rainbow Trout and Mountain Whitefish comprised the majority of the fish sampled, and Brown Trout were at relatively low abundances (Table 5). The paucity of Brown Trout observed in the section may be attributable to the lack of habitat complexity (e.g.,undercut banks, large woody debris) throughout the sampling reach. As discussed 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.

Table 4. 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.

	0	1	2	3+
Species	< 152	152-276	277-376	> 377
LL	1.0	1.0	0	4.7
RB	8.2	28.2	11.8	15.3
MWF	10.7	3.6	5.0	67.9

Data collected in 2022 will be compared to subsequent surveys to assess the potential effects of the Hebgen gate failure. In general, sampling conditions, normal fluctuations in abundances, and the lack of baseline data could confound our ability to attribute future changes in the trout populations to the gate 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. Assuming the trout populations immediately downstream of Hebgen Dam possess comparable vital rates to those in the Pine Butte Section, similar fluctuations, including declines, in electrofishing C/*f* could be expected in the monitoring section between Hebgen Dam and Quake Lake regardless of potential effects caused by the dam failure. Moreover, electrofishing efforts in large rivers inherently produce abundance estimates with notable uncertainty (i.e., relatively large confidence intervals for abundance estimates), which further inhibits our ability to statistically detect and attribute population changes to the dam failure. 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 conducted Brown Trout redd counts on the Madison River between Hebgen Dam and Quake Lake on November 15, 2022 to identify and document key spawning areas used by Brown Trout. Discharge at the time redd counts was 689 cfs (measured at the USGS 06038500 Grayling gage below Hebgen Lake). Redd counts were completed by walking upstream and identifying streambed disturbances consistent with redd morphology (Gallagher et al. 2007). A typical redd consists of a defined pit where gravels were excavated with a mound of gravels (tail spill) immediately downstream of the pit (Figure 11). GPS coordinates were recorded and redd locations were mapped using Google Earth (Table 6; Figure 12).

Figure 11. Brown Trout redds in a side channel of the Madison River between Hebgen Dam and the Quake Lake inlet, November 2022.

Table 5. Redd locations and the number of redds observed during surveys conducted November 15, 2022, in the Madison River between Hebgen Dam and Quake Lake.

Latitude	Longitude	Redds observed
44.85481	-111.34861	1
44.85497	-111.34633	7
44.85498	-111.34822	11
44.85529	-111.34819	19
44.85530	-111.34820	5
44.85564	-111.34840	17
44.85576	-111.34819	2
44.85575	-111.34833	2
44.85576	-111.34830	3
44.85564	-111.34840	17
44.85590	-111.34849	2
44.85616	-111.34870	1
44.85758	-111.34891	5
44.85626	-111.34940	4
44.86198	-111.35023	4
44.86239	-111.35029	6
44.86276	-111.35040	6
44.86266	-111.35058	2
44.86314	-111.35061	6
44.86953	-111.34012	5
44.86942	-111.34005	1
44.86949	-111.33990	1
44.86958	-111.33988	1
44.86957	-111.34014	1
44.86973	-111.34006	1
44.86959	-111.34045	1
44.86970	-111.34046	1
44.86979	-111.34027	1
44.86993	-111.34041	1
44.86997	-111.34054	1
44.87000	-111.34060	1
44.87002	-111.34055	1
44.87026	-111.34104	1
44.87029	-111.34102	1
44.87029	-111.34101	1
44.87035	-111.34096	1
44.87037	-111.34095	1
44.87038	-111.34104	1
44.87038	-111.34103	1
44.87043	-111.34113	1
44.87039	-111.34118	1
44.87033	-111.34119	1
44.87033	-111.34120	1
44.87042	-111.34133	1
44.87043	-111.34135	1
44.87044	-111.34142	1
44.87031	-111.34158	1
44.87039	-111.34171	1
44.87037	-111.34171	1
44.87033	-111.34171	1
44.86658	-111.35117	1
44.86577	-111.35114	1

Most Brown Trout redds between Hebgen Dam and Quake Lake occurred in side channels, which were the habitat most impacted by gate failure. Of the 165 redds identified, 151 were located in side channels and 14 were located within the main river channel (Figure 12). 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). Based upon the wetted perimeter and discharge relationship curve for the Madison River below Hebgen Dam, the reduction in discharge during the gate failure dewatered an estimated 3.4 acres of nearshore mainstem habitat (FWP 1989; Figure 13). Although the graph represents a single thread channel, it demonstrates the potential effect of reduced river stage on redds in shallow or nearshore habitats and the potential for side channels within the reach to become disconnected. Future investigations into the relationship between stage and discharge in this section of the river would provide insight into the flows required to maintain adequate spawning conditions.

Figure 12. Locations of redds identified in the Madison River between Hebgen Dam and the Quake Lake inlet. The size of the diamond is a general representation of redd density (i.e., the larger the diamond the greater the number of redds at that location).

Feet=204+.0329(cfs)

648 cfs=225.31ft

216 cfs=211.10ft

Difference=14.22ft

Acres=(10560ft*14.22ft)/43560ft^2

3.44 acres of exposed near shore habitat

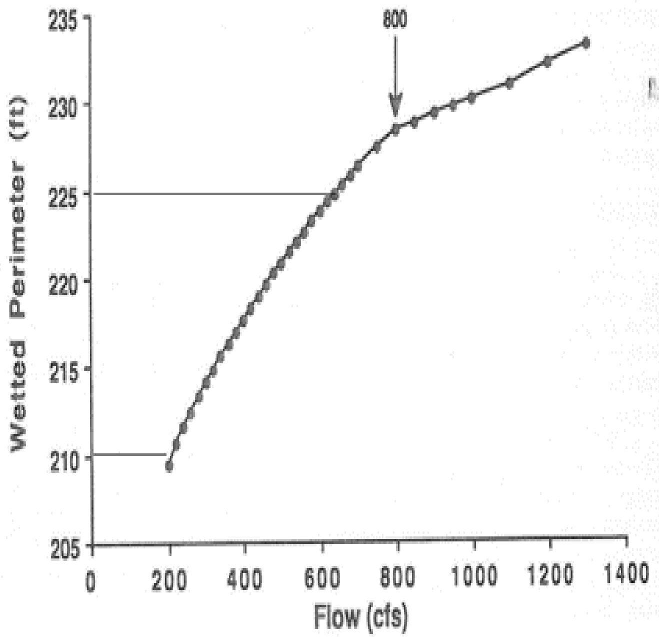


Figure 13. The wetted perimeter of the Madison River between Hebgen Dam and the Quake Lake inlet (FWP, 1989). The area of exposed nearshore habitat is estimated from the following equation: Feet=204+0.0329(cfs).

Literature Cited

Boyer. J.K. 2017. Spawning and early life history of Mountain Whitefish in the Madison River, Montana. Transactions of the American Fisheries Society 146: 939-954.

Chambers. J. S., G. H. Alien, and R. T. Pressey. 1955.Research relating to the study of spawning grounds in natural areas. Annual report to U.S. Army Corps of Engineers, Contract DA-35026-Eng-20572. Washington State Department of Fisheries, Olympia.

Downing, D.C., T.E. McMahon, and B.L. Kerans. 2002. Relation of spawning and rearing life history of Rainbow Trout and susceptibility to *Myxobolus cerebralis* infection in the Madison River, Montana. Journal of Aquatic Animal Health 14: 191-203.

FWP. 1989. Reservation requests for waters above Canyon Ferry Dam. 2: 396-398. Montana Department of Fish, Wildlife and Parks, Helena.

Gallagher, S.P., Hahn P.K.J., and Johnson D.H. 2007. Redd Counts. Pages 197-233 in D.H. Johnson, B.M. Shrier, J.S. O'Neil, J.A. Knutzen, X. Augerot, T.A. O'Neil, and T.N. Pearsons. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Kondolf, G.M., and M. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29: 2275-2285.

Vincent, E.R. 1973. Evaluation of river fish populations. Job Completion Report, Federal Aid in Fish and Wildlife Restoration Acts. Montana Project No. F-9-R-20, Job No. III-a.

Weisel, G.F. 1966. Young salmonid fishes of western Montana. Proceedings of the Montana Academy of Sciences 26: 1-21.

Appendix B

Hebgen Dam Gate Failure Literature Review: Effects of Dewatering on Salmonid Species

Madison River, Montana

By Jenna Dukovcic, Travis Lohrenz, and Matt Jaeger

Montana Fish, Wildlife & Parks

Bozeman, Montana FWP

Introduction

A well-known tailwater trout fishery, the Madison River runs for approximately 180 miles from its headwaters in Yellowstone National Park through Southwest Montana before joining with the Jefferson and Gallatin rivers to form the Missouri River. The Madison River is one of the most heavily used water bodies in the state, logging over 300,000 angler days in 2020 (FWP 2020). The high angler and commercial guide and outfitter use it receives combine to make it regionally economically important. The Upper Madison averages approximately 1,500 trout per mile near Pine Butte (Lohrenz et al. 2023). Brown Trout (*Salmo trutta*), Rainbow Trout (*Oncorhynchus mykiss*), and Mountain Whitefish (*Prosopium williamsoni*) are the most prevalent and commonly targeted fish species in the Upper Madison River from Hebgen Dam to Ennis Lake (Lohrenz et al. 2022a). Other fish species within the Upper Madison River include native Westslope Cutthroat (*Oncorhynchus clarkii lewisi*), Arctic Grayling (*Thymallus arcticus*), Rocky Mountain Sculpin (*Cottus bondi*), Mountain Sucker (*Catostomus platyrhynchus*), and Longnose Sucker (*Catostomus Catostomus*).

Flows on the Madison are regulated by two dams, Hebgen Dam and Madison Dam, owned and operated by NorthWestern Energy (NWE) under the 2188 license granted by the Federal Energy Regulatory Commission (FERC) for hydropower operations on the Madison and Missouri rivers. Minimum flows within the 2188 project license (Article 403) are set at no lower than 150 cfs at Hebgen outflow (USGS gage # 6-3850), 600 cfs at Kirby (gage # 6-388), and 1100 cfs at Madison Dam (gage # 6-410) with no more than a 10% change in daily outflows from Hebgen Dam. To minimize erosion of Quake Lake, maximum flow at Kirby is 3500 cfs. The average annual flow of the Upper Madison River from Hebgen to Ennis Dam is 1444 cfs (USGS gauge #6040000; 1951-2023).

On November 30, 2021, a gate failure at Hebgen Dam decreased the flow on the Madison River between Hebgen and Quake Lake from 648 cfs to 228 cfs in 45 minutes. The flow remained at 248 cfs for 40 hours with an estimated of 3.4 acres of near shore habitat and several side channels dewatered (Lohrenz et al. 2022b). The rapid decrease in flow left numerous Brown Trout redds exposed to potentially lethal air temperatures and many juvenile and adult Brown Trout, Rainbow Trout, Mountain Whitefish, and Rocky Mountain Sculpin stranded and disconnected from flow. This event caused a 65% change of flow in 45 minutes and a deviation from the 10% per day change allowed at Hebgen Dam by Article 403 of the 2188 license. Flow also decreased below the Article 403 minimum of 600 cfs at the Kirby gage to 395 cfs for approximately 48 hours. Flows were restored to 648 cfs and all side channels and near shore habitat was re-inundated on December 2, roughly 48 hours after initial loss of flow.

NWE submitted a proposal for protection, mitigation, and enhancement measures in response to the gate failure on March 23, 2022 that was confirmed by FERC on August 18, 2022 that included conducting 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. Investigation of literature that describes the effects of hydropower-related flow fluctuations on fish life stage and assemblage provides insight into the potential effects the sudden flow reduction may have had on the Madison River fishery. To provide framework for evaluating the extent of impacts on the Madison River fishery, the goals of this literature review are to 1) describe life histories of affected fish species (Brown Trout, Rainbow Trout, Mountain Whitefish, and Rocky Mountain Sculpin), 2) synthesize effects of similar stranding and dewatering events on all fish life stages, and 3) identify knowledge gaps relevant to the gate failure and stranding and dewatering events for the Madison River.

Life History

Brown Trout, Rainbow Trout, and Mountain Whitefish

Brown Trout, Rainbow Trout, and Mountain Whitefish belong to the Salmonidae Family and have overlapping ranges (Moyle and Cech 2004b). Salmonids inhabit cold-water streams in North America and are highly regarded for their economic, social, and recreational value (Moyle and Cech 2004b). Brown Trout are native to Europe, North Africa, and Western Asia, but were first introduced to the United States in 1883 (Gilbert and Williams 2002; Klemetsen et al. 2003). Rainbow Trout native range includes much of Western North America in the Pacific Coast drainages from Mexico to Alaska (Raleigh et al. 1984). Similarly, Mountain Whitefish are indigenous to Western North American rivers (Brown 1972; Meyer et al. 2009). In Montana, both Brown Trout and Rainbow Trout were introduced to the headwaters of the Madison River in 1889 (Alvord 1991).

Although from the same family, Brown Trout, Rainbow Trout, and Mountain Whitefish exhibit different life history strategies (Table 1). Brown Trout and Mountain Whitefish spawn in the fall while Rainbow Trout spawn during spring months (Table 1; Brown 1972; Raleigh et al. 1984; Klemetsen et al. 2003). Female Brown Trout and Rainbow Trout construct and deposit eggs into a redd, a mound of gravel designed to increase the flow of water and dissolved oxygen to the egg pocket for proper development (Tonina and Buffington 2009). Mountain Whitefish are dispersal spawners and their eggs are released directly into the water column without construction of a nest and displace downstream into low velocities areas (Boyer 2016). Variation in duration and timing of incubation and emergence of salmonid fry is largely a function of water temperature, but emergence of fry typically occurs in early spring for Brown Trout and Mountain Whitefish with Rainbow Trout fry emerging later in the spring to early summer months (Table 1; Bjorn and Reiser 1991; Gilbert and Williams 2002; Klemetsen et al. 2003; Boyer 2016).

Differences in habitat selection occur between juvenile and adult salmonids, but habitat needs between species are relatively similar. Juvenile and young-of-year (YOY) trout prefer shallower habitat and lower velocity areas with stream cover such as log jams, woody debris, overhanging banks, inundated bank margins and interstices of cobbles (Lewis 1967; Raleigh et al. 1984; Klemetsen et al. 2003). Mountain Whitefish rearing areas include slow silty backwaters, eddies, and beaver ponds (Brown 1972; Boyer 2016). In addition, Mountain Whitefish are characterized as being benthically oriented and would typically inhabit lower parts of the water column than Brown Trout and Rainbow Trout (Brown 1972; DosSantos 1985). As body size increases, larger salmonids prefer deeper habitats with cover and can occupy higher velocity areas than juveniles (Raleigh et al. 1984; Bjornn and Resier 1991; Klemetsen et al. 2003). However, habitat use varies seasonally and salmonids tend to seek out areas with deep pools and low velocity to maximize energy savings and survival for overwintering (Lewis 1967; Brown 1972; Cunjak 1996; Klemetsen et al. 2003).

Diet and feeding behavior of salmonids are highly variable by season, time of day, age, and body size within and between populations (Bradford and Higgins 2001; Railsback et al. 2005). Brown Trout, Rainbow Trout, and Mountain Whitefish are visual hunters and feed mainly on drifting aquatic invertebrates or actively forage for insects (Brown 1972; Klemestsen et al. 2003; Syrjänen et al. 2011; Vinson and Budy 2011). Larger salmonids tend to have a wider range of prey items available and larger trout are known to switch to a more piscivorous diet (DosSantos 1985; Klemestsen et al. 2003; Syrjänen et al. 2011; Vinson and Budy 2011). Additionally, larger salmonids outcompete smaller individuals for better feeding positions and habitat (Raleigh et al. 1984; Klemetset et al. 2003). Increased foraging usually occurs during warmer spring and summer months and decreases during the winter (Cunjak 1996; Klemetsen et al. 2003).

Rocky Mountain Sculpin

Sculpin are characterized as a small-bodied, bottom dwelling fish, known for their lack of swim bladder, large pectoral fins, and propensity to feed on salmon and trout eggs (Moyle and Cech 2004a). The Rocky Mountain Sculpin, *Cottus bondii*, is one of six species of sculpin located within Montana. Their range extends from Western to Central Montana although they are also found in two river basins in Canada (Rudolfsen et al. 2018). A non-game species, sculpin have recently gained more attention as a bioindicator of stream health and ecology for fisheries management (Adams and Schmetterling 2007). While many aspects of sculpin ecology and life history remain unknown, fisheries managers and researchers are investigating interactions between salmonids and sculpin with more intensity because of similar diet, behavior, and habitat (Adams and Schmetterling 2007; Adams et al. 2015).

Freshwater sculpins occupy cold-water streams and prefer swift to moderate riffle-run habitats with cobbles and boulders (Moyle and Cech 2004a). Rocky Mountain Sculpin sexually mature at age 2 and spawn in the spring from April to June (Bailey 1951). Male adults construct nests on the undersides of rocks, submerged wood, and/or aquatic vegetation where females will deposit egg clusters (Bailey 1951). The male sculpin remain near the nests while eggs are incubating to guard and clean the eggs of slit and debris. Eggs incubate in roughly 20-30 days and hatchlings average 7.1 mm in length (Bailey 1951). Adult Rocky Mountain sculpin can range in length from 45-70 mm (Bailey 1951). Juvenile sculpin occupy near shore habitats within rocks and larger adults will occupy slightly deeper waters but remain relatively close to the shoreline (Bailey 1951). An analysis of stomach contents shows sculpin mostly feed on benthic macroinvertebrates with a smaller portion of their diet consisting of small trout and trout eggs (Bailey 1951).

Table 4. General life history summaries for Brown Trout (LL), Rainbow Trout (RB), Mountain Whitefish (MWF), and Rocky Mountain Sculpin (RMS). Spawning is the time period from beginning to end of spawning, spawn method refers to embryo disposition (redd, dispersal, nest), incubation is the time in days for embryos to develop and hatch (FWP unpublished data 2023). Emergence period defines the window when young-of-year fish hatch, habitat describes preferences for juvenile (J) and adult (A) salmonids and sculpin, and food highlights fish diets.

Species	Spawning	Method	Incubation	Emergence	Habitat	Food
LL RB MWF	Oct-Dec Mar-Jun Oct-Nov	redd redd dispersal	157-257 78-136	Mar-Jun Jun-Jul Spring	(J) Cobble interstices, woody debris, channel margins, (A) undercut banks, riffles, pools	Aquatic and terrestrial invertebrates, fish
RMS	Apr-Jun	nest	20-30	Jun-Jul	(J)(A) Cobble interstices, channel margins	Aquatic invertebrates, fish eggs, juvenile fish

Fish Stranding and Dewatering Effects on Life Stage

The most obvious and direct impact observed by fisheries personnel and volunteers following the Hebgen Dam gate failure and from literature review of hydropower operations was fish stranding. Fish stranding occurs when fish become disconnected from suitable habitat without means of escaping. Stranding due to both natural and anthropogenic events has been documented worldwide (Nagrodski et al. 2012). The most frequent causes of fish stranding are on regulated river systems during dam operations such as hydropeaking and plant shutdowns (Nagrodski et al. 2012). Hydropeaking is a method of meeting high energy demands on regulated river systems by rapidly ramping up flow and down ramping when energy usage is lower. Several studies investigated the relationship between down ramping rate and fish stranding using rates of 6-60 cm/hr to simulate hydropeaking dewatering scenarios (Bradford et al. 1995; Saltveit et al. 2001; Halleraker et al. 2003; Irvine et al. 2009; Sauterleaute et al. 2016). Saltveit et al. (2001) found 60% of wild, young-of-year Atlantic Salmon stranded during a flow reduction from 110 m^3/s to 30 m^3/s in 42 minutes, a proportional change in flow of 73%. The magnitude of flow reductions were set at 12.5% or 20% to emulate fish stranding for a study on the Columbia River and ramping rates used ranged from 3.9 – 35.3 cm/hr (Irvine et al. 2009). The gate failure at Hebgen dam resulted in a proportional change in flow of approximately 65% and a change in stage of 22 cm in 45 minutes (29 cm/hr), which is within the range of down ramping rates that caused or was used to assess the effects of fish stranding in other studies. Effects of fish stranding on life stage is outlined below and summarized in Table 2.

Eggs, embryos, alevins: Salmonid eggs are more tolerant to periods of dewatering than later stages of development (Becker et al. 1982; Reiser and White 1983; Neitzel and Becker 1985; McMichael et al. 2005). High relative humidity within the gravel of the redd allows eggs to survive periods of dewatering because eggs can absorb oxygen through the air (Bjornn and Reiser 1991). Reiser and White (1983) found salmonid eggs could survive 1-5 weeks of complete dewatering with no negative effect on development or growth if eggs were close (10 cm below egg pocket) to groundwater. McMichael et al. (2005) concluded that many redds were not truly dewatered because Chinook Salmon egg pocket depths can range from 18 to 43 centimeters, therefore redds may have remained moist or near groundwater during stranding. Similar findings from Neizel and Becker (1985) showed no mortality of Chinook Salmon eggs that were dewatered for 24 hours in 100% humidity. Additionally, a lab experiment testing the tolerance of Robust Redhorse eggs to dewatering found eggs survived longer periods of dewatering than emerging larvae (Fisk II et al. 2013). Higher mortality rates seen at later developmental phases of fish eggs in dewatered redds is partly due to the lack of available dissolved oxygen to support gill respiration (Becker et al. 1982; McMichael et al. 2005, Fisk II et al. 2013).

Temperature also plays a key role in egg and embryo survival. Freezing and extreme heat conditions within the gravel can be lethal to eggs and later developmental stages (Neizel and Becker 1985; Bjornn and Reiser 1991). Redds that are dewatered lose thermal insulation which may subject them to greater fluctuations in intragravel temperatures from exposure to the ambient air (Becker et al. 1982; Bjornn and Reiser 1991). Eggs and embryos exposed to higher temperatures resulted in altered timing of hatch, development, and growth (Becker et al. 1982; Reiser and White 1983; Bjornn and Reiser 1991). Low air and water temperatures can increase the risk of egg and developing embryo mortality by freezing and slowing growth (Becker et al. 1982; Bjornn and Reiser 1991). Becker et al. (1982) observed lack of advancement in cell division phases in development of Chinook Salmon eggs and higher mortality when eggs had been dewatered for 16 hours, during which mean intragravel temperatures were higher than in shorter treatments. Resier and White (1983) found that dewatered Steelhead eggs hatched earlier than watered eggs due to exposure to higher temperatures within egg pocket which resulted in larger alevins from the earlier hatched group. Garrett et al. (1998) observed faster development and earlier hatching of Kokanee Salmon in a stream in Idaho that was influenced by groundwater; upwelling sites were 2°C warmer than redd areas without upwellings.

Juvenile Fish: Juvenile fish are more vulnerable to stranding and mortality because they tend to occupy high risk habitats and have a weaker swimming ability than adult fish (Hayes et al. 2019). However, juvenile fish respond differently to rapid flow decreases depending on season and time of day (Bradford et al. 1995; Saltveit et al. 2001; Halleraker et al. 2003; Nagrodski et al. 2012; Irvine et al. 2015). Higher stranding and mortalities in juvenile salmonids are associated with high ramp rates, low gradients, coarse substrate (i.e., more cover), and cold-water temperatures (Bradford et al. 1995; Halleraker et al. 2003; Sauterleute et al. 2016). Bradford et al. (1995) found juvenile Rainbow Trout stranding in the winter significantly decreased during experiments that simulated down ramping at night compared to day-time experiments in an artificial stream channel. In the winter during the day, juvenile salmonids typically seek shelter within the interstices of streambed cobbles and are less active than at night (Bradford et al. 1995; Irvine et al. 2015). Therefore, rapid changes in flow during the day in the winter put juvenile fish at greater risk to stranding because they are not active in the water column (Bradford et al. 1995). Stream areas with low cover (i.e., smaller substrate, no large wood debris) are expected to have lower stranding potential because juvenile fish do not occupy areas where stranding is likely (Halleraker et al. 2003). These studies support that the proportion of stranded juvenile salmonids decreased significantly when down ramping occurred at a slow rate at night due to diurnal and seasonal behavior changes (Bradford et al. 1995; Saltveit et al. 2001; Halleraker et al. 2003; Nagrodski et al. 2012; Irvine et al. 2015).

Rapid flow decreases can have negative effects on juvenile fish even when stranding and direct mortality do not occur. Sub-lethal effects on juvenile trout include increased stress levels, higher energy use, and reduced growth (Flodmark et al. 2002; Halleraker et al. 2003). A lab experiment on age 1 juvenile Brown Trout measured cortisol levels in a control (constant flow) and experimental group (rapid reduction in flow) and found stress levels to be significantly higher in the experimental group (61.3 ng/ml +/- 26.8 ng/ml) than the control group (4.9 +/- 3.7 ng/ml) after one day of the trial (Flodmark et al. 2002). However, after 4 days of treatment cortisol levels returned to "pre-stress" values in the experimental group. Flodmark et al. (2002) showed juvenile salmonids acclimated to their environment but that over time constant exposure to stressful stimuli may still be detrimental and have population level effects (i.e., decreased growth rate, poor recruitment).

Adult Fish: In general, adult fish are expected to be less vulnerable to mortality due to stranding because they are more adaptive to sudden changes in discharge on regulated river systems than juvenile fish. Pander et al. (2022) observed smaller, weaker swimming fish had higher rates of stranding than larger fish that preferred open water habitat. Using habitat preference curves, Jelovcia et al. (2022) showed adult Arctic Grayling had higher average suitability indices during 5 different hydropeaking scenarios than juvenile Brown Trout, suggesting that adult fish had a wider range of suitable habitats during different flows. Adult fish are more mobile, have better swimming ability, and occupy deeper habitats that have lower risk of dewatering compared to juvenile fish that occupy near shore habitats (Irvine et al. 2015; Vollset et al. 2016; Hayes et al. 2019; Jelovica et al. 2022).

Other factors affecting adult fish during rapid fluctuations in flow, are access to spawning areas, abandoning nest sites, altered migration, displacement of food, increased predation, and increased stress (Quinn et al. 2001; Grabowksi and Isley 2007; Young et al. 2011, Vollset at al. 2016). Grabowski and Isely (2007) suggest the possibility of increased mortality of Robust Redhorse due to redd superimposition because of decreased flows on the Savannah River that limit access to critical spawning habitat. Chaotic swimming behavior and frequent abandoning of nest sites was observed by Vollset et al. (2016) when Atlantic Salmon and Brown Trout were subject to rapid fluctuations in flow during spawning, indicating increased stress. Conversely, rapid increases in flow on two hydropeaking rivers in Finland triggered spawning migrations in Atlantic Salmon (Vehanen et al. 2020).

The effects of dewatering can vary among salmonid life stages from direct mortality to non-lethal effects such as altered emergence, development, and increased stress (Becker et al. 1982; Reiser and White 1983; Flodmark et al. 2002; Vollset et al. 2016). Impacts of dewatering can also depend on season, time of day, and river channel morphology (Bradford et al. 1995; Saltveit et al. 2001; Halleraker et al. 2003; Nagrodski et al. 2012; Irvine et al. 2015). Table 2 summarizes dewatering impacts.

Table 5. Summary of dewatering effects on fish life stage (eggs, juveniles, and adults). Level of impact ranges from low (L), medium (M), and high (H) based on findings in this literature review.

		Impact		
Life Stage	Range	L	M	H
Eggs	L-H	Diffuse 0_2 through air with high humidity, Groundwater buffer	Altered timing of development and emergence	Increased risk of lethal intragravel temperatures, Increased reliance on gill respiration as eggs develop
Juveniles	M-H		Increased stress, Lower growth rates, Diurnal and seasonal behavior changes	Occupy shallow near shore habitats, Weaker swimming ability
Adults	L-M	Occupy deeper habitats Better swimming ability	Increased stress, Limited access to spawning areas, Altered migration, Increased predation, Food displacement	

Population Level Effects and Vital Rates

Survival rates vary greatly depending on the timing of dewatering. If dewatering occurred during the early stages of egg incubation, survival rates of eggs could be higher than if the dewatering occurred just prior to hatching when alevins have formed. For example, researchers on the Columbia River compiled over 30 years of data to describe average survival rates of Chinook Salmon presmolts (age 1-2) in relation to new dam operations. This study observed high mortality and low survival rates during a dewatering event occurring in March and April just prior to hatching (0.15; Table 3; Harnish et al. 2014). A similar dewatering event occurred in mid-November and presmolt average survival was much higher, supporting higher tolerances to dewatering at early egg stages (0.54; Table 3; Harnish et al. 2014). These two dewatering examples highlight the importance of timing of dewatering and the range of effects on survival rates at differing life stages.

Managing flow during critical juvenile life stages may influence population dynamics to a greater extent than other age classes because of density dependence. Two studies using vital rates looked at fry (0+) and juvenile (1+) age classes to determine the effects of stranding on Atlantic Salmon and Coho Salmon populations due to hydropeaking (Sauterleaute et al. 2016; Gibeau and Palen 2021). Both models incorporated density dependence that illustrated how some mortalities due to flow fluctuations may be offset if there is high density dependent compensation. Gibeau and Palen (2021) found high density dependence was able to compensate for mortalities in low impact scenarios (1-5 dewatering events per year), but density dependence did little to offset mortalities when dewatering events were frequent (16-20 events per year) for Coho Salmon. In addition, Sauterleaute et al. (2016) suggested that stranding of older Atlantic Salmon juveniles plays a larger role in population dynamics because of reduced density compensation at later life stages. Whereas fry to smolt survival and ocean survival for Coho Salmon appeared to have the largest impact on population growth (Gibeau and Palen 2021), these studies point towards dam mitigation strategies that prioritize juvenile age classes when considering flow alterations for these systems.

Population dynamics and vital rates can vary widely between systems and species (Table 3). Brown Trout, Chinook Salmon, and Atlantic Salmon are fall spawners with similar life history characteristics; therefore, it may be appropriate to use vital rates for these species to understand potential effects of dewatering in the Madison River. For instance, average Brown Trout age 0+ survival, in a system that was not regulated (no dewatering), was 0.26 and maximum survival was 0.47 (Table 3; Dieterman and Hoxmeier 2011). Average Chinook Salmon age 0+ survival during dewatering was 0.29 with a maximum of 0.67 (Table 3; McMichael et al. 2005). In contrast, average age 0+ survival for Atlantic Salmon during a dewatering experiment was 0.89 with a maximum of 1.00 (Table 3; Casas-Mulet et al. 2014). While comparisons of survival rates among salmonids with and without dewatering are limited by few studies and parochial factors, it is important to note that 100% cohort mortality did not occur in any study.

Table 6. Summary of dewatering (D) average survival rates and no-dewatering (ND) average survival rates from published sources by age class (0, 1, 2+) for Brown Trout, Chinook Salmon, Atlantic Salmon, Bull Trout, Bonneville Cutthroat, and Mountain Whitefish. Survival rates in () are maximum survival rates observed.

	0+		1+		2+	
Species	D	ND	D	ND	D	ND
Brown Trout[a]		**0.26** (0.47); 9 months		**0.43** (0.50); 1 year		
Chinook Salmon[bc]	**0.29** (0.67); 5 months		**0.15** (0.54); 1 year			
Atlantic Salmon[d]	**0.89** (1.00); 4 months	**1.00** (1.00); 4 months				
Bull Trout[e]				**0.09** (0.60); 1 year		
Bonneville Cutthroat[f]				**0.41** (0.52); 1 year		**0.45** (0.55); 1 year
Mountain Whitefish[g]						**0.82** (0.91); 1 year

[a] Dieterman and Hoxmeier 2011; [b] McMichael et al.2005; [c] Harnish et al. 2014; [d] Casas-Mulet et al.2014; [e]Al-Chokhachy and Budy 2008; [f] Budy et al. 2007; [g] Meyer et al. 2009

Discussion

Several papers discuss water management approaches to reduce the stranding of fish due to rapid changes in flow on hydropeaking rivers. Duration, timing, and magnitude of flow fluctuations appear to have the largest influence on stranding rate. As discussed earlier, juvenile salmonids were found to strand less frequently if flow reductions occurred at night and were conducted more slowly during the winter (Salveit et al. 2001; Halleraker et al. 2003; Nagrodski et al. 2012; Irvine et al. 2015; Sauteleute et al. 2016). Conditioning flows have been used to train fish to avoid areas of stranding by rapidly reducing flow and increasing flow again before a significant reduction; however, this type of manipulation produced mixed results (Irvine et al. 2015). Avoiding large reductions in flow during spawning and intragravel development is considered critical to survival of several fish species on the Columbia and Kootenay Rivers (Irvine et al. 2015). Hayes et al. (2019) emphasizes the importance of establishing the “emergence window” on a river system for salmonid species and to stabilize flow during this time period. Overall, knowledge of specific habitat use of different life stages of fish species is crucial when considering flow fluctuations in a regulated river system.

Brown Trout and Mountain Whitefish egg mortality was likely low during the Hebgen gate failure that caused Brown Trout redds to be dewatered for approximately 48 hours. Salmonid eggs can tolerate several weeks of dewatering depending on temperature and humidity (Resier and White 1983). Neitzel and Becker (1985) observed 0% mortality of salmonid eggs that were dewatered for 24 hours in 100% humidity. Average air temperature near Hebgen Dam during the dewatering period was 36.5°F and the minimum temperature was 25°F (Montana SNOTEL Site West Yellowstone (924)). Although near lethal temperatures, this SNOTEL site is roughly 300 feet higher in elevation than where the dewatered redds were located; therefore, it is possible temperatures were not as low at the dewatered area or within the gravels. In addition, relative humidity within the dewatered redds may have been maintained at or near 100% because of trapped water and groundwater influence. Lastly, the gate failure on the Madison River occurred at the end of November, during the end of Brown Trout spawning. In this respect, the timing of the gate failure on the Madison that resulted in dewatering of redds, may not have had detrimental effects on Brown Trout eggs because eggs were early in development and can diffuse oxygen through the air rather than relying on gill respiration.

Juvenile Brown Trout, Rainbow Trout, Mountain Whitefish, and Rocky Mountain Sculpin likely experienced the highest mortalities from the gate failure because of swimming ability, habitat use, and behavior (Bradford et al. 1995; Halleraker et al. 2003; Pander et al. 2022). Juvenile fish typically occupy shallow near shore habitats with overhead cover or burrow in the interstices of cobble to hide from larger predators. An estimated 3.4 acres of juvenile habitat was dewatered between the lakes during the Hebgen gate failure (Lohrenz et al. 2022b). Although some juveniles escaped or were rescued, many mortalities were observed in these areas on the Madison River. However, it remains possible that demographic effects of the gate failure are negligible if compensatory density dependence occurs. Future monitoring will directly assess cohort-specific abundance of Brown and Rainbow Trout to determine whether high morality of juvenile fish occurred.

Adult Brown Trout, Rainbow Trout, and Mountain Whitefish were likely the least affected by dewatering below Hebgen Dam. Reviewed literature suggests that adult fish suffered fewer direct mortalities from dewatering because of their larger body size, greater mobility, and diverse habitat use (Irvine et al. 2015; Vollset et al. 2016; Jelovica et al. 2022). However, indirect effects such as increased stress, limited access to spawning areas, and disrupted spawning during the dewatering period, could have population level effects such as reduced growth rate and produce a weak cohort (Grabowski and Isely 2007; Vollset et al. 2016).

Given the variation in vital rates and the wide range of anthropogenic flow fluctuations among systems, it is somewhat difficult to make conclusive inferences about potential impacts to fish populations on the Madison River from other studies. Vital rates are a valuable tool for fisheries managers to assess management alternatives and, in the case of regulated systems, operational impacts, but developing precise estimates of these parameters is often costly and labor intensive. Few studies have quantified population level effects and survival rates of fish during a dewatering event or comparatively assessed differences between dewatering and non-dewatering demographic rates (Gibeau and Palen 2021). This summary of estimated survival rates based on published literature for salmonid species provides a coarse indication of potential population level effects and should be viewed conservatively.

Reviewed literature suggests the gate failure at Hebgen dam is unlikely to have caused catastrophic damage to the Madison River fishery or total loss of fish populations or individual age classes. Juvenile Brown Trout, Rainbow Trout, Mountain Whitefish, and Rocky Mountain Sculpin likely had the highest mortalities, followed by adults and salmonid eggs. In addition, it is possible that demographic effects could be reduced if density dependent compensation occurs. Gibeau and Palen (2021) showed greater negative impacts on fish populations when there are frequent hydropeaking events. The dewatering event on the

Madison River was not the result of a scheduled decrease in flow. Most reviewed studies described scheduled and repeating hydropeaking events. Furthermore, Hebgen Dam is not a power producing facility and therefore would not be subject to hydropeaking. The incident on the Madison River was a unique situation; however, research on rivers that experience regular rapid increases or decreases in flow and experiments highlighting the effects of dewatering on fish provide valuable insight about potential effects of the Hebgen gate failure.

Future research on the Madison should consider available habitat, depth and water stage for critical life stages of trout, especially juveniles, when evaluating changes in flow. Specifically, loss of shoreline and other complex habitats to dewatering at different discharges should be quantified. This information, in conjunction with ongoing monitoring, would provide a better understanding of how typical or unplanned hydropower operations may affect Madison River fish populations. If a higher resolution understanding of effects of hydropower operations in general or the Hebgen gate failure in particular is desired, then precise estimation of vital rates may be necessary. However, this is a costly and labor-intensive approach, and this resolution of data may not be necessary to inform management decisions or make inference about effects. Continuing to pursue novel information specific to the Madison River will aid in refinement of hydropower operations and prioritization of protection, mitigation, and enhancement measures.

Literature Cited

Adams, S.B. and Schmetterling, D.A. 2007. Freshwater sculpins: phylogenetics to ecology. Transactions of the American Fisheries Society. 136: 1736-1741.

Adams, S.B., Schmetterling, D.A., and Neely, D.A. 2015. Summer stream temperatures influence sculpin distributions and spatial partitioning in the Upper Clark Fork River basin, Montana. Copeia. 103:416-428.

Al-Chokhachy, R. and Budy, P. 2008. Demographic Characteristics, Population Structure, and Vital Rates of a Fluvial Population of Bull Trout in Oregon. Transactions of the American Fisheries Society. 137: 1709-1722.

Alvord, B. 1991. A History of Montana's Fisheries Division from 1890 to 1958. Montana Fish, Wildlife and Parks. Helena, Montana.

Bailey, J.E. 1951. Life history and ecology of the freshwater sculpin *cottus baridii punctualtus* in southwestern Montana. Master's Thesis. Montana State University, Bozeman Montana.

Becker, C.D., Neitzel, D.A., and Fickeisen, D.H. 1982. Effects of Dewatering on Chinook Salmon Redds: Tolerance of Four Developmental Phases to Daily Dewaterings. Transactions of the American Fisheries Society. 111: 624-637.

Bjornn, T.C. and Reiser, D.W. 1991. Habitat Requirements of Salmonids in Streams. In: Influence of Forest and Rangeland Management on Salmonids Fishes and Habitats (Ed. W.R. Meehan), American Fisheries Society, Special Publication, 19, 83–138.

Boyer, J.K. 2016. Spawning and early life history of Mountain Whitefish in the Madison River, Montana. Master's Thesis. Montana State University, Bozeman, Montana.

Bradford, M.J. and Higgins, P.S. 2001. Habitat-, season-, and size-specific variation in diel activity patterns of juvenile chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Oncorhynchus mykiss). Can.J.Aquat. Sci. 58: 365-374.

Bradford, M.J., Taylor, G.C., and Allan, J.A. 1995. An experimental study of the stranding of juvenile coho salmon and rainbow trout during rapid flow decreases under winter conditions. North American Journal of Fisheries Management. 15:473-479.

Brown, L.G. 1972. Early Life History of the Mountain Whitefish Prosopium williamsoni (Girard) in the Logan River, Utah. Master's Thesis. Utah State University, Logan, Utah.

Budy, P., Thiede, G.P., and McHugh, P. 2007. Quantification of Vital Rates, Abundance, and Status of a Critical, Endemic Population of Bonneville Cutthroat Trout. North American Journal of Fisheries Management. 27: 593-604.

Casas-Mulet, R., Saltveit, S.J., and Alfredsen, K. 2014. The Survival of Atlantic Salmon (Salmo Salar) eggs during dewatering in a river subjected to hydropeaking. River Research and Applications. DOI: 10.1002/rra.2827.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Can. J. Aquat. Sci. 53:267-282.

Dieterman, D.J. and Hoxmeier, R.J.H. 2011. Demography of Juvenile and Adult Brown Trout in Streams of Southeastern Minnesota. Transactions of the American Fisheries Society. 140: 1642-1656.

DosSantos, J.M. 1985. Comparative Food Habits and Habitat Selection of Mountain Whitefish and Rainbow Trout in the Kootenai River, Montana. Master's Thesis. Montana State University, Bozeman, Montana.

Fisk II, J.M., Kwak, T.J., Heise, R.J., and Sessions, F.W. 2013. Redd Dewatering Effects on Hatching and Larval Survival of the Robust Redhorse. River Res. Applic. 29: 574-581.

Flodmark, L.E.W., Urke, H.A., Hallerraker, J.H., Arnekleiv, J.V., Vøllestad, L.A, and Poléo, A.B.S. 2002. Coritsol and glucose responses in juvenile brown trout subjected to a fluctuating flow regime in an artificial stream. Journal of Fish Biology. 60:238-248.

FWP. 2020. Montana Statewide Angling Pressure 2020. Helena, MT

Garrett, J.W., Bennett, D.H., and Frost, F.O. 1998. Enhanced Incubation Success for Kokanee Spawning in Groundwater Upwelling Sites in a Small Idaho Stream. North American Journal of Fisheries Management. 18:925-930.

Gibeau, P. and Palen, W.J. 2021. Impacts of run-of-river hydropower on coho salmon (Oncorhynchus kisutch): the role of density-dependent survival. Ecosphere. 12(8):e03684. 10.1002/ecs2.3684

Gilbert, C.R. and Williams, J.D. Trouts and Salmons. 2002. Pages 200-204 *in.* National Audubon Society Field Guide to Fishes North America. Alfred A. Knopf, New York.

Grabowkski T.B. and Isely J.J. 2007.Effects of Flow Fluctuations on the spawning habitat of a Riverine Fish. Southeastern Naturalist. 6(3):471-478.

Halleraker, J.H., Saltveit, S.J., Harby, A., Arnekleiv, J.V., Fjeldstand, H.P., and Kohler, B. 2003. Factors influencing stranding of wild juvenile brown trout (salmo trutta) during rapid and frequent flow decreases in an artificial stream. River.Res.Applic. 19:589-603

Harnish, R.A., Sharma, R., McMichael, G.A., Langshaw, R.B., and Pearsons, T.N. 2014. Effect of hydroelectric dam operations on the freshwater productivity of a Columbia River fall Chinook Salmon population. Can.J.Fish.Aquat.Sci. 71:602-615.

Hayes, D.S., Moreira, M., Boavida, I., Haslauer, M., Unfer, G., Zeiringer, B., Greimel, F., Auer, S., Ferreria, T., and Schmutz S. 2019. Life Stage-Specific Hydropeaking Flow Rules. Sustainability. 11, 1547

Irvine, R.L., Oussoren, T., Baxter, J.S., and Schmidt, D.C. 2009. The Effects of Flow Reduction Rates on fish in British Columbia, Canada. River Research and Applications. 25: 405-415.

Irvine, R.L., Thorley, J.L., Westcott, R., Schmidt, D., and Derosa, D. 2015. Why do fish strand? An analysis on ten years of flow reduction monitoring data from the Columbia and Kootenay Rivers, Canada. River Res. Applic. 31:1242-1250.

Jelovica, B., Marttila, H., Ashraf, F.B., Kløve, B., and Haghighi, A.T. 2022. A probability-based model to quantify the impact of hydropeaking on habitat suitability in rivers. River Res Applic. 1-11.

Klemetsen, A., Amundsen, P-A., Dempson, JB., Jonsson, B., Jonsson, N., O'Connell, MF., and Mortenson, E. 2003. Atlantic salmon Salmo salar L., brown trout Salmo trutta L. and Arctic charr Salvelinus aplinus (L.): a review of aspects of their life histories. Ecology of Freshwater Fish. 12: 1-59.

Lewis, S.L. 1967. Physical Factors Influencing Fish Populations in Pools of a Trout Stream. Master's Thesis. Montana State University, Bozeman, Montana.

Lohrenz, T., Duncan, M., Dukovcic, J., and Jaeger, M. 2022a. Madison River drainage 2188 project monitoring report 2021. Montana Fish, Wildlife and Parks. Bozeman, Montana.

Lohrenz, T., Dukovcic, J., Duncan, M., McCormack, M., and Jaeger, M. 2022b. Madison River Fishery Monitoring related to the Hebgen Dam Gate Failure. Montana Fish, Wildlife and Parks. Bozeman, Montana.

Lohrenz, T., Duncan, M., Dukovcic, J., McCormack, M., and Jaeger,M. 2023. Madison River Drainage 2188 project monitoring report 2022. Montana Fish, Wildlife and Parks. Bozeman, Montana.

McMichael, G.A., Rakowski, C.L., James, B.B., and Lukas, J.A. 2005. Estimated Fall Chinook Salmon Survival to Emergence in Dewatered Redds in a Shallow Side Channel of the Columbia River. North American Journal of Fisheries Management. 25:876-884.

Meyer, K.A., Elle, F.S., and Lamansky, J.A. Jr. 2009. Environmental Factors Related to the Distribution, Abundance, and Life History Charactertistics of Mountain Whitefish in Idaho. North American Journal of Fisheries Management. 29:753-767.

Moyle, P.B. and Cech, J.J.Jr. 2004a. Opahs, squirrelfish, dories, pipefish, and sculpins. Pages 374 *in* T.Chung, editor. Fishes an introduction to ichthyology fifth edition. Pearson Benjamin Cummings, San Francisco.

Moyle, P.B. and Cech, J.J.Jr. 2004b. Smelt, salmon, and pike. Pages 324-328 *in* T.Chung, editor. Fishes an introduction to ichthyology fifth edition. Pearson Benjamin Cummings, San Francisco.

Nagrodski, A., Raby, G.D., Hasler, C.T., Taylor, M.K., and Cooke, S.J. 2012. Fish stranding in freshwater systems: Sources, consequences, and mitigation. Journal of Environmental Management. 103:133-141.

Neitzel, D.A., and Becker, C.D. 1985. Tolerance of eggs, embryos, and alevins of Chinook salmon to temperature changes and reduced humidity in dewatered redds. Transactions of the American Fisheries Society.114:267-273.

Pander, J., Nagel, C., and Geist, J. 2022. Effects of a hydropower-related temporary stream dewatering on fish community composition and development: From ecology to policy. Frontiers in Environmental Science. 10:929746. doi:10.3389/fenvs.2022.929746

Piper, R.G., McElwain, I.B., Orme, L.E., McCraren, J.P., Fowler, L.G., and Leonard, J.R. 1983. Pages 189-190. Fish hatchery management. Department of the Interior U.S. Fish and Wildlife Service.

Quinn, T.P., Hendry, A.P., and Buck, G.B. 2001. Balancing natural and sexual selection in sockeye salmon: interactions between body size, reproductive opportunity and vulnerability to predation by bears. Evolutionary Ecology Research. 3:917-937.

Railsback, S.F., Harvey, B.C., Hayse, J.W., and LaGory, K.E. 2005. Tests of Theory for Diel Variation in Salmonid Feeding Activity and Habitat Use. Ecology. 86 (4). 947-959.

Raleigh, R.F., Hickman, T., Solomon, R.C., and Nelson, P.C. 1984. Habitat Suitability Information: Rainbow Trout. Western Energy and Land Use Team, Division of Biological Services, Research and Development, Fish and Wildlife Service. U.S. Department of the Interior, Washington, DC 20240

Reiser, D.W. and White, R.G. 1983. Effects of Complete Redd Dewatering on Salmonid Egg-Hatching Success and Development of Juveniles. Transactions of the American Fisheries Society. 112:532-540.

Rudulfsen, T., Ruppert, J.L., Taylor, E.B., Davis, C.S., Wakinson, D.A., and Poesch, M.S. 2018. Habitat use and hybridization between Rocky Mountain sculpin (Cottus sp.) and slimy sculpin (Cottus cognatus). Freshwater Biology. 1-14.

Saltveit, S.J., Halleraker, J.H., Arnekleiv, J.V., and Harby, A. 2001. Field experiments on stranding in juvenile Atlantic salmon (salmo salar) and brown trout (salmo trutta) during rapid flow decreases caused by hydropeaking. Regul. Rivers: Res. Mgmt. 17:609-622.

Sauterleute, J.F., Hedger, R.D., Hauer, C., Pulg, U., Skoglund, H., Sundt-Hansen, L.E., Bakken, T.H., and Ugedal, O. 2016. Modelling the effects of stranding on the Atlantic salmon population in the Dale River, Norway. Science of Total Environment.573:574-584.

Syrjänen, J., Korsu, K., Louhi, P., Paavola, R., and Muotka, T. 2011. Stream salmonids as opportunistic foragers: the importance of terrestrial invertebrates along a stream-size gradient. Can. J. Fish. Aquat. Sci. 68: 2146-2156.

Tonina, D. and Buffington, J.M. 2009. A three-dimensional model for analyzing the effects of salmon redds on hyporheic exchange and egg pocket habitat. Can.J. Fish. Aquat. Sci. 66: 2157-2173.

Vehanen, T., Louhi, P., Huusko, A., Mäki-Petäys, A., Meer, O., Orell, P., Huusko, R., Jaukkuri, M., and Sutela, T. 2020. Behavior of upstream migrating adult salmon (Salmo salar L.) in the tailrace channels of hydropeaking hydropower plants. Fish Manag Ecol. 27:41-51.

Vinson, M.R. and Budy, P. 2011. Sources of variability and comparability between salmonid stomach contents and isotopic analyses: study design lessons and recommendations. Can. J. Fish. Aquat. Sci. 68: 137-151.

Vollset, K.W., Skoglund, H., Wiers, T., and Barlaup, B.T. 2016. Effects of hydropeaking on the spawning behaviour of Atlantic salmon Salmo salar and brown trout Salmo trutta. Journal of Fish Biology. doi:10.1111./jfb.12985,

Young, P.S., Cech Jr, J.J., and Thompson, L.C. 2011. Hydropower-related pulsed-flow impacts on stream fishes: a brief review, conceptual model, knowledge gaps, and research needs. Rev Fish Biol Fisheries. 21:713-731.

2023 Madison River Fisheries Monitoring

Final results from 2023 monitoring activities are being developed and will be available in early 2024, and shared with the Technical Advisory Committee. This summary describes all activities that were accomplished during 2023 season.

Article 403: Madison River discharge

- Deviations from Article 403 occurred below Hebgen Dam and at Kirby Ranch on November 30, 2021, as a result of a broken component on the Hebgen Dam gate, which 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. The literature review suggested the gate failure at Hebgen dam is unlikely to have caused catastrophic damage to the Madison River fishery or total loss of fish populations or individual age classes and that juvenile Brown Trout, Rainbow Trout, Mountain Whitefish, and Rocky Mountain Sculpin likely had the highest mortalities, followed by adults and salmonid eggs. Initial monitoring confirmed that there was no catastrophic damage to the Madison River fishery or total loss of fish populations or individual age classes. FWP continued monitoring to assess cohort-specific effects on young-of-the-year fish and embryos in the Pine Butte and the Between the Lakes monitoring sections in 2023. Monitoring completed by FWP and NWE will be summarized.

Article 408-1: Effects of project operations on Hebgen Reservoir fish populations

- Gill netting efforts in Hebgen Reservoir were completed by FWP in the Spring of 2023 to evaluate the effects of project operations on Hebgen Reservoir fish populations. Monitoring completed by FWP will be summarized

Article 408-3: Reservoir Draw Down Effects on Fisheries

- Limnological sampling was not conducted in Hebgen Reservoir in 2023. Contemporary Hebgen Reservoir operations appear to have little influence on limnology and trout abundance. As such limnological sampling is conducted on a biennial basis or in years when there is a departure from normal operations.

Article 408-4: Monitor the effects of modified operations on Upper Madison Fish Populations

- Annual abundance estimates were conducted in the Pine Butte and Varney monitoring sections in 2023. Monitoring completed by FWP will be summarized in the 2023 annual report to NorthWestern Energy.

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

- Arctic Grayling**:** Arctic Grayling reintroduction efforts continued in Hebgen Reservoir tributaries in 2023. This work will be summarized in the 2023 annual report to NorthWestern Energy.

- Funding for a migration barrier was secured in 2023 to protect extant Westslope cutthroat trout populations from non-native fish in the West Fork Madison. Construction will occur in 2024.

- Surveys of Madison River tributaries were conducted by FWP to identify potential WCT recovery efforts and identify new WCT populations of aboriginal Madison Drainage origin for introduction into Ruby Creek. Westslope Cutthroat were introduced into the North Fork of Spanish Creek. This work will be summarized in the 2023 annual report to NorthWestern Energy.

Article 409- 3: Fish habitat enhancement both in the main stem and tributary streams

- FWP participated in on-the-ground evaluations of mainstem habitat projects to be implemented in 2024.

- In 2023 FWP initiated pre-project monitoring on Oliffe Creek a tributary of the Madison River. Monitoring included depletion estimates, a riparian assessment, and the installation of two passive integrated tag readers (PIT tag). Monitoring completed by FWP will be summarized in the 2023 annual report to NorthWestern Energy.

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

- New gill net locations were established on Ennis Reservoir in 2021 to provide better coverage of the reservoir while eliminating gill net sets that often had poor capture efficiencies in shallow habitats. FWP conducted sampling in 2023. Monitoring completed by FWP will be summarized in the 2023 annual report to NorthWestern Energy.

Article 413-Pulse Flows

- FWP evaluated the effect pulsed flows delivered by the Madison Decision Support System (DSS) program had on the fishery. General linear models (linear regression) were used to determine whether negative correlations existed between abundances of age-3+ Rainbow and Brown Trout and the number of days water temperatures were ≥ 73oF, age-1, age-2, and age 3+ Rainbow and Brown Trout and average pulse change, and between age-1, age-2 Rainbow and Brown Trout and the number of days a pulse flow occurred in the Norris section. There was no correlation between the abundances of age-1 or age-2 Rainbow or Brown Trout at t-1 or t-2, or age-3+

Rainbow or Brown Trout at t-2 and average pulse flow change. Additionally, no correlation was found between the number of days water temperatures were ≥ 73oF and the abundance of age-3+ Rainbow or Brown Trout at t-1. The abundances of age-1 or age-2 Brown Trout and the number of days a pulse flow occurred at t-1, and t-2 were not correlated (Table 4); however, there were significant negative correlations between age-1 Rainbow Trout and the number of pulse flows at a t-1 ($R2 = 0.22$; $P = 0.04$) and age 2 Rainbow Trout at t-2 ($R2 = 0.54$; $P = 0.05$). Statistical results suggest that FWP's implementation of angling restrictions and the pulse flow program are effective in limiting thermally induced mortality in the lower river. This analysis was summarized in the 2022 annual report and will be continued in the 2023 annual report to NorthWestern Energy.

Article 419-Coordinate and Monitor Flushing Flows

- FWP evaluated whether flushing flows under current operational constraints are beneficial to Madison River riparian vegetation recruitment and side channel spawning and rearing habitat maintenance. Monitoring completed by FWP will be summarized in the 2023 annual report to NorthWestern Energy.