Yale SCHOOL OF FORESTRY &
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Methods for Non-Native Trout Removal in Rocky Mountain Streams

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Ucross High Plains
Stewardship

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Introduction

The reintroduction of native trout in the Mountain West is a valuable conservation tool for fisheries managers with an interest in maintaining healthy populations of threatened trout species. At the same time, the choice to reintroduce native trout involves a complex decision-making process with numerous biological, ecological, and social considerations. This process is complex, namely, because the reintroduction of native trout necessitates the removal of non-native trout from the same stream. The eradication aspect of these kinds of reintroduction project creates a slew of difficult questions - about ensuring the continued ecological health of the stream, the biodiversity of macroinvertebrates and other species, and the fully effective eradication of the non-native trout.

The decision to pursue a trout conservation project requires research, planning, and the consideration of many interconnected steps - especially regarding the mechanism of non-native eradication. By the time a fisheries manager begins the serious consideration of a native reintroduction project, they should also be taking into consideration the complex system of the surrounding watershed, the stream characteristics on their particular project site, and a suite of other concerns that will ensure the viability of native trout into the future. Williams et al. (2006) outlined many of these considerations in their *A Guide to Native Trout Restoration*.

In light of the myriad concerns a fisheries manager may have in considering a native trout reintroduction project, our purpose in producing this management handbook is to synthesize these considerations into a practically applicable tool for fisheries managers. This handbook explores the significance of native trout conservation, the importance of non-native trout eradication, and the range of methods available to execute a successful eradication project. This handbook focuses specifically on piscicides and electrofishing as tools for eradication, and provides a framework for deciding which methods best suit a particular stream environment. Rather than an instructional guide for non-native trout eradication, this handbook is a decision-making tool intended for use in the planning stages of the process.

The focus of this project arose specifically from the interest of The Nature Conservancy's Tensleep Preserve in northeastern Wyoming in exploring the reintroduction of native trout in Canyon Creek. For that reason, the Nature Conservancy's project and its specifics bounded the research and data collected and have guided some of the considerations related to our proposed management suggestions. The Nature Conservancy at Tensleep, just as any fisheries manager with similar considerations on their specific project site, is interested in native trout reintroduction in an exploratory way. This particular stretch of Canyon Creek on the Tensleep Preserve is a complex riparian ecosystem, and presents its own unique challenges. However, we intend for the content presented here to find wide applicability to other native trout reintroduction projects across the Mountain West and beyond.

Tensleep Preserve and Canyon Creek

Tensleep Preserve is a property in northeastern Wyoming owned by The Nature Conservancy (TNC). Canyon Creek runs through the property, originating in Bighorn National Forest and flowing through the property before joining with Tensleep Creek. It continues on to the Nowood River, and eventually connects with Bighorn River—a major tributary of the Yellowstone River drainage system.

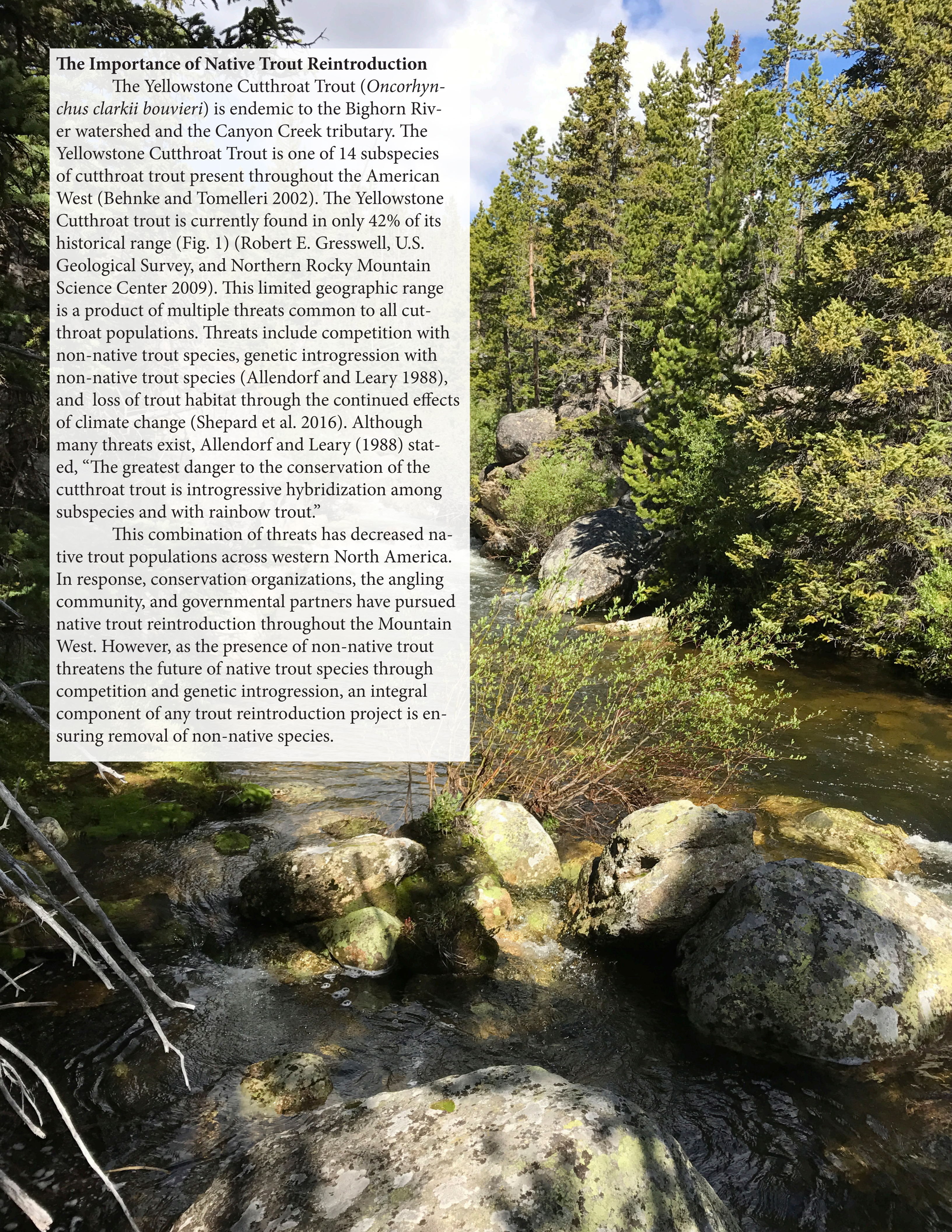
A defining characteristic of Canyon Creek on the Tensleep Preserve is the presence of multiple sinks. A sink is an area of a stream where water flows underground with no visible outlet. While the exact geology and hydrology of the creek's sinks are poorly understood, water flows underground and only returns to the surface further downstream. Canyon Creek travels from its headwaters on the Bighorn National Forest, through private property and onto the TNC property, thus the land adjacent to the stream is comprised of different owners with a variety of interests. Furthermore, Canyon Creek is an important local natural resource used for fishing and irrigation by the residents of Washakie County. Broadly, these themes became central considerations to our research on the project: the unique hydrology and ecology of Canyon Creek, and the public perception associated with trout removal.

Currently, Canyon Creek provides habitat for rainbow and brown trout, two non-native species introduced to the western United States, to enhance sport fisheries (Halverson 2010). There are currently no native trout populations in Canyon Creek. Initial research led us to an important question: why reintroduce native trout where none currently exist?

The Importance of Native Trout Reintroduction

The Yellowstone Cutthroat Trout (*Oncorhynchus clarkii bouvieri*) is endemic to the Bighorn River watershed and the Canyon Creek tributary. The Yellowstone Cutthroat Trout is one of 14 subspecies of cutthroat trout present throughout the American West (Behnke and Tomelleri 2002). The Yellowstone Cutthroat trout is currently found in only 42% of its historical range (Fig. 1) (Robert E. Gresswell, U.S. Geological Survey, and Northern Rocky Mountain Science Center 2009). This limited geographic range is a product of multiple threats common to all cutthroat populations. Threats include competition with non-native trout species, genetic introgression with non-native trout species (Allendorf and Leary 1988), and loss of trout habitat through the continued effects of climate change (Shepard et al. 2016). Although many threats exist, Allendorf and Leary (1988) stated, "The greatest danger to the conservation of the cutthroat trout is introgressive hybridization among subspecies and with rainbow trout."

This combination of threats has decreased native trout populations across western North America. In response, conservation organizations, the angling community, and governmental partners have pursued native trout reintroduction throughout the Mountain West. However, as the presence of non-native trout threatens the future of native trout species through competition and genetic introgression, an integral component of any trout reintroduction project is ensuring removal of non-native species.



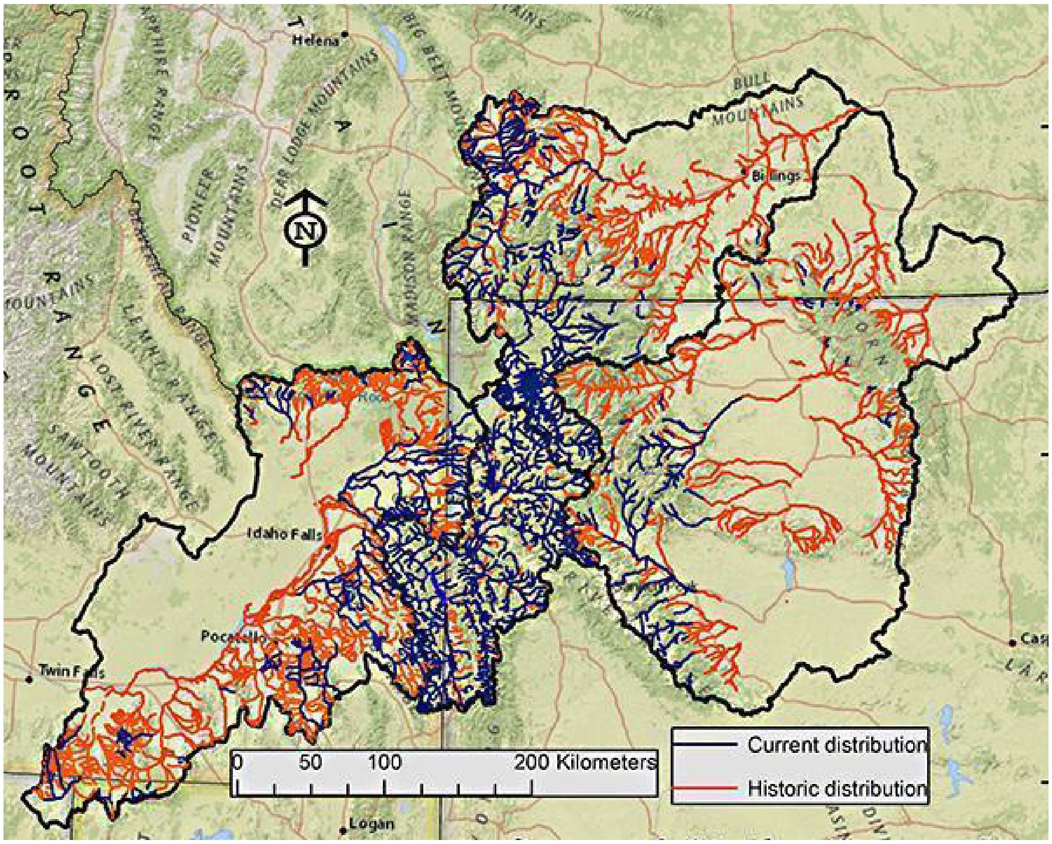


Figure 1: The current and historic range of Yellowstone Cutthroat Trout in the United States of America, 2017

Source: Al-Chokhachy, Robert, Bradley Shepard, Jason Burkhardt, Scott Opitz, Dan Garren, Todd Koel, and Lee M. Nelson. "Status & Conservation of Yellowstone Cutthroat Trout in the GYE (U.S. National Park Service)." *Yellowstone Science* 25, no. 1 (2017). https://www.nps.gov/articles/status-and-conservation-of-yellowstone-cutthroat-trout-in-the-gye.htm.

Trout Removal Methods

Fish removal practices are diverse and plenty. They range from adjustment of angling regulations to the use of explosives (Finlayson et al. 2000). Meronek et al. (1996) provided a literary review of all fish control projects found in scholarly literature at the time of publication. Bounded by our project environment at the Tensleep Preserve, and seeking the most effective of these various methods, we narrowed our scope and considered the use of two different piscicides, rotenone and antimycin A, and a physical method of removal through electrofishing.

Piscicides

The only fish management technique to entirely remove an unwanted fish population, other than complete dewatering, is the use a piscicide—a fish pesticide (Finlayson et al. 2000). Currently, two piscicides have been approved for use in the US, rotenone and antimycin A.

However, as of early 2018, antimycin A is no longer available, as the sole firm producing the piscicide is no longer in business. Some government agencies still have remaining antimycin stores, but generally it is not available on the commercial market for land managers (Finlayson, personal communication, Fish Control Solutions).

Rotenone

Background

Rotenone is a piscicide which has been used to manage fish populations in North America since the 1930s. Rotenone, derived from bean plants, was used by indigenous people for fishing. Today, plant roots are either dried and made into a powder for use in standing waters or prepared as a liquid for use in flowing waters (City of Seattle, 2017). Rotenone was first used in lakes and ponds, and then managers began to use rotenone in streams during the early 1960s (Finlayson et al., 2000). During 1988, the Environmental Protection Agency (EPA) approved rotenone for fish management. Regulations for the use of rotenone vary by state, and approval of projects is required at the state level (American Fisheries Society).

Rotenone affects gill-breathing organisms when it is absorbed through gills, stopping cellular oxygen transfer once in the bloodstream (Montana Fish, Wildlife & Parks 2012). Organisms with the highest effects of rotenone exposure are fish, followed by aquatic invertebrates, and gill-breathing amphibians (City of Seattle 2017). Relatively low concentrations of rotenone can be used successfully because the thin layer of cells in gills allow rotenone to quickly enter the bloodstream (Montana Fish, Wildlife & Parks 2012).

Rotenone is a very effective piscicide for non-native fish eradication. For example, the Utah Division of Wildlife Resources completed 26 native trout restoration projects using rotenone; all but one were successful. The West Fork Deer Creek project was ineffective due to the complexity of the stream, which decreased the likelihood of successful eradication. Once managers realized this, the treatment was halted. (Golden 2011).

Application

The application of rotenone requires certified technicians, a clear understanding of the stream system, and detailed plan implementation. The details below about rotenone application are meant to aid in manager decision-making and should not be used as a comprehensive guide. For detailed information about how to plan a rotenone application project, refer to "Rotenone Use in Fisheries Management: Administrative and Technical Guidelines Manual" (Finlayson et al. 2000).

Rotenone can only be applied by certified pesticide applicators from state, federal and provincial government natural resource agencies. Individuals can also attain permits after consultation and licensing through the agencies (Finlayson et al. 2000)

Rotenone can be bought in the powder (Prentox) or liquid (CFT Legumine) forms. Rotenone treatments should have a concentration of 1 ppm. The amount of rotenone required for treatment in streams is dependent on flow and the distance that rotenone needs to remain active downstream (Montana Fish, Wildlife & Parks 2012). Liquid rotenone can be added to the treatment site via drip stations with bucket dispensers calibrated to discharge specific amounts of liquid rotenone. Manual applications via backpack sprayers can help ensure backwaters, spring areas, and small tributaries as well as any standing water are treated (Golden 2011, City of Seattle 2017).

Managers should consider the proper training and equipment to mitigate potential human exposure during rotenone application, especially for technicians and handlers. Rotenone via oral and inhalation exposures has high acute toxicity while dermal exposure causes low toxicity. As a chemical pesticide, rotenone exposes occupational handlers to some short and intermediate-term exposures (EPA 2007). Applicators should protect themselves by wearing protective clothing such as gloves, coveralls, eye protection, and air purifying respirators. Rotenone training, specific to the formulation used, is required for all personnel involved in the application process (Finlayson et al. 2000).

At the downstream end of a removal project, managers use potassium permanganate to neutralize rotenone via oxidation. Potassium permanganate should be applied at concentrations between 3 and 5 ppm, depending on the on-site testing done prior to treatment (Montana Fish, Wildlife & Parks 2012). From the site of potassium permanganate addition, the neutralization process takes about 0.25-0.5 miles (Golden 2011). Alternatively, to fully oxidize rotenone with permanganate, the CFT Legumine label recommends at least 20-30 minutes of contact between the rotenone treated waters and the permanganate (Montana Fish, Wildlife & Parks 2012). To ensure the effectiveness of the detoxification of rotenone, caged fish can be placed in the stream and monitored for signs of stress.

Rotenone Degradation

Managers should consider physical and chemical water qualities when considering rotenone application. Rotenone efficacy decreases as it degrades. The rate of rotenone degradation increases with high temperatures, alkalinity, and pH of the water as well as high sunlight penetration (Finlayson et al. 2000). Water temperatures above 10°C are acceptable, but in water temperatures below 5°C can have two-fold negative repercussions: fish might not react and the rotenone might not completely deactivate (Finlayson, personal communication). Waters with an alkalinity above 170 ppm $CaCO_3$ or a pH above 9 degrade rotenone at faster rates than below those values. High temperatures as well as greater light exposure in the summer quickens rotenone degradation (Finlayson et al. 2000). Projects conducted in the summer or during warmer temperatures can therefore increase the likelihood of a successful project.

Secondary Treatments

Depending on the site characteristics, a second rotenone treatment might be needed for complete eradication of non-native fish. Following the first treatment, the site can be sampled via electrofishing in spring or summer to estimate success of the initial treatment (Montana Fish, Wildlife & Parks 2012). The Utah Division of Wildlife Resources has found that usually two full treatments are required to eradicate a species (Golden 2011).

Barriers

Barriers are required for defining the application site to prevent the migration of target fish from outside the treatment area from entering the treatment site. Barriers can be constructed with large rocks to create a drop in the channel. Below the drop, large flat boulders should be placed to prevent the formation of a plunge pool (Crooshanks 2001). Fish barriers can also be created by blasting an already existing water fall into a vertical waterfall of greater height into the bedrock (Montana Fish, Wildlife & Parks 2012). Detoxification is usually administered following the downstream barrier (Crooshanks 2001). If barriers, such as beaver dams or diversion structures, are within the treatment area, they should be removed prior to treatment to ensure appropriate concentrations of rotenone are held consistently throughout the site (Finlayson et al. 2000).

There are many options for constructed barriers including use of gabions, boulders, concrete, sheet pilings, and ecology blocks (Toye and Alves, personal communications). In past piscicide treatments, failed barriers have caused unsuccessful projects, so steps must be taken to ensure proper barrier placement and construction. Components to aid in the success of the barrier include backfilling upstream and using a filter fabric to ensure that fish cannot squeeze through any holes in the barrier. Additionally, barriers must be higher than the high-water line (Alves, personal communication).

Sinks

Sinks, areas where water flow drops underground, within rotenone-treated areas are not uncommon and are actually especially common in the arid western lands. Sinks can sometimes be used as a barrier to upstream migration for fish, and in most instances, rotenone does not carry suitably through a sink due to adsorption into the soil. However, the sink must first be checked for any signs of a stream channel from high flows during which fish could migrate (Finlayson, personal communication).

If a sink is within the treatment area, a dye test should be conducted to determine the timing of the water resurfacing. Rotenone might need to be reapplied after the sink to ensure proper concentrations. For example, during a rotenone treatment involving a sink,permanganate was administered 36 hours after treatment, but the piscicide resurfaced 48 hours after the permanganate treatment stopped , which caused fish kills outside the application site (Shepard, personal communication). This highlights the importance of a dye test to understand the hydrology of the area prior to treatment to ensure rotenone containment.

Within sinks, macroinvertebrates (e.g., unique stoneflies) might inhabit the groundwater zones. However, the recolonization of these macroinvertebrates in groundwater zones has not been studied (Shepard, personal communication).

Environmental Effects of Rotenone

Impacts on Non-Target Species

Rotenone, when used at proper concentrations for fish extermination, does not seem to have a direct impact on terrestrial plants and animals and has limited impacts on non-target aquatic organisms. At low concentrations, rotenone can be quickly absorbed through the gills and enter the bloodstream. So, non-gilled organisms such as birds and mammals are of limited concern for direct exposure to rotenone. The most common exposure for these organisms is through ingestion; however, rotenone easily breaks down during digestive processes and therefore, is not absorbed through the digestive tract (Montana Fish, Wildlife & Parks 2012).

Effects on Invertebrates

It is generally believed that rotenone has temporary or minimal effects on invertebrates. In the immediate and short term, *Ephemeroptera*, *Plecoptera*, and *Trichoptera* insect groups exhibit more sensitivity than *Coleoptera* and *Diptera* (Vinson et al. 2010). One study found that after rotenone treatment, all invertebrate taxa declined but after a year, there was a full recovery of most taxa. Invertebrates abundance rose compared to before treatment (Montana Fish, Wildlife & Parks 2012). Generally, a year after treatment, most invertebrate assemblage abundances return to pre-application levels (Vinson et al. 2010).

However, there is limited long term data on the effects of rotenone on aquatic invertebrates (Vinson et al. 2010). In one of the few longer-term impact studies, Engstrom-Heg et al. (1978) found that impacts of rotenone on invertebrates are limited because the most sensitive insects also having a high recolonization rate.

To reduce negative impacts on invertebrates while still effectively eradicating unwanted fish species using rotenone, Finlayson et al. (2010) recommends eight measures:

- Apply rotenone between 25 and 50 mg/L.
- Use drip stations for 4-8 hours per treatment.
- Use un-synergized (CFT Legumine) formulations of rotenone because synergized forms are more toxic to aquatic insects and less toxic to fish.
- Allow time between rotenone treatments to limit cumulative effects of multiple treatments in large drainage basins so invertebrates can recolonize and disperse.
- Leave areas beyond the treatment sites, such as headwaters, untreated so they can be recolonization sources.
- Neutralize rotenone.
- Do not conduct aquatic invertebrate rescues in un-isolated basins as this can be unrealistic.
- Use caged fish and sample the water or monitoring the effectiveness of the treatment.

Effects on Amphibians

The effects of rotenone on amphibians depends on their life stage. Billman et al. (2012) found rotenone can lead to the mortality of tadpoles, but not metamorphosed juveniles nor adult frogs. In the breeding season after rotenone treatment, tadpole populations recovered to previous levels before treatment. However, the loss of an entire generation of tadpoles can have a large ecological effect due to the important role tadpoles play in food webs. Additionally, because amphibian recruitment can be highly variable year to year, administering the treatment during a large tadpole cohort year could largely impact the population for years to come. To limit the effects of rotenone treatment on amphibians, managers can:

- Time treatments to occur when amphibians are not in the tadpole stage or when they are at older tadpole stage.
- Collect tadpoles prior to treatment. However, if multiple rotenone applications are needed, managers can treat within the same year to limit consecutive tadpole cohort losses.
- Consider conservation status of amphibians in the area, distance to potentially colonizing amphibian populations, and the specific life histories of the amphibians.

Case Study: Rotenone and Unintended Effects

While rotenone is traditionally thought to be the most effective fish eradication treatment for the largest variety of stream environments, there is a growing effort to identify and mitigate harmful effects of piscicides on “non-target” organisms, especially macroinvertebrates. On Silver King Creek in Alpine County, California, Brian Finlayson (a piscicide treatment expert) led a study to evaluate the effects of two varieties of rotenone, CFT Legumine and Nusyn Noxfish, on non-target aquatic insects. These insect species included caddisflies, mayflies, and stoneflies. The target species was the Rainbow trout (*Oncorhynchus mykiss*) with the intent to reintroduce the Paiute Cutthroat trout (*Oncorhynchus clarkii seleniris*) to the stream.

In a follow-up conversation with Finlayson, he noted that the sensitivity of trout to rotenone ranges on a tenfold scale, while the sensitivity of invertebrates to rotenone ranges on a thousandfold scale. The rotenone level at which the trout eradication is most successful is fairly straightforward, given a multiple pass approach and adequate barriers to reentry. Much more challenging to land managers is the prospect of balancing those concentrations with concentrations that have the least significant effect on existing invertebrates. Critical, too, to Finlayson’s work was that the study focused on the concentration of the active ingredient in rotenone, rather than the commercial formulation concentration.

The results were promising. Rates of rotenone introduction of 25-50 micrograms per liter over 4-8 hours produced the most significant effects on trout eradication, while limiting the effect of rotenone on macroinvertebrates. Although most invertebrate species survived, adequate rainbow trout mortality required twice as much Nusyn Noxfish than CFT Legumine, resulting in higher mortality (still less than 50%) in two particular species of invertebrates, *B. tricaudatus* and *R. morrisoni*.

Most importantly, treatment must be conducted in the right way to avoid unintended consequences on non-target organisms. Synergized formulations, such as Nusyn Noxfish, add a pesticide synergist such as Piperonyl butoxide (PBO). These formulations accelerate mortality for macroinvertebrates. Time allowed for recolonization in between treatments keeps rotenone from overwhelming macroinvertebrate populations. And lastly, consistent monitoring, both for efficacy and prevention of unintentional downstream effects, is essential.

- Consider the elevation of the treatment site, which impacts amphibian breeding. Higher elevation restoration sites can potentially have a greater amphibian impacts due to longer times needed for breeding (Billman et al. 2012). (In the Billman et al (2012) study, high elevation was a lake at 2638 m and mid to low elevation wetlands were at 1463 to 1830 m.)

Effects on Birds

Rotenone use is unlikely to have a direct effect on birds. Birds most likely to be exposed are piscivorous birds that may eat the dead fish. The EPA recommends the collection and burial of dead fish after rotenone treatment to limit chances of treated fish consumption. Additionally, sunken dead fish will not be able to be consumed by birds. Even if a bird consumes a rotenone-treated fish, it is highly unlikely that the bird would eat enough to lead to a lethal dose. For example, a 1 kg bird would have to consume 274,000 perch based on the avian subacute dietary LC50, the lethal dose at which 50% of the birds die (EPA 2007).

Trophic Effects

Birds and mammals that consume fish and invertebrates can also be indirectly affected by the loss in their food supply post-treatment , leading to a trophic cascade. Until fish populations are restored, there will be a reduction in food supply for these species. The literature is sparse on the impacts of piscicide application to local bird populations. Donnelly (2018) found that the overall body mass of dippers, aquatic insectivores, in a rotenone treatment area in Montana was reduced by 3.0-3.7%. Heron rookeries can crash or move quickly if they can't reasonably commute to other feeding grounds (Donnelly, personal communication). Rosendal (1996) observed a decrease in otter presence after fish removal from rotenone application. Alternatively, some species may not be significantly impacted depending on the potential use of other water bodies and food sources (Finlayson et al. 2000). This will vary species by species based on their ability to disperse and food availability in the area.

The species' life stage can impact its sensitivity to the loss of a food source, such as during mating season or while rearing young. To mitigate impacts, a California-based project removed bald eagle eggs during mating and placed them in a recovery program. Alternatively, Michigan postponed treatment until the loon chicks fledged (Finlayson et al. 2000). Best methods for mitigating food supply reductions are likely to be site specific and therefore dependent on species present in the area and their associated sensitivities.

Contamination Effects on Riparian Environments

Rotenone quickly breaks down with a half-life (time to decrease by half of its original amount) ranging from a few days to several weeks (EPA 2007). For this reason, rotenone treatments are often applied during warmer temperatures to maximize the shorter half-life and the effects on fish (City of Seattle 2017) (See Rotenone Degradation Section). Binding easily to sediments, rotenone usually only moves one inch into most soil types, except in sand, rotenone seeps in about three inches (Montana Fish, Wildlife & Parks 2012) so there is little concern for groundwater contamination.

Ecological Impacts Post-Treatment

After rotenone treatment, the presence of dead fish leads to an increase in phosphorus, which can cause an algae bloom. Bradbury (1986) found 9 of 11 treated sites experienced algae blooms shortly after treatment, but these effects were short term. Fish killed from treatment can be left onsite; decomposition of fish can lead to plankton growth, helping invertebrate recovery (Montana Fish, Wildlife & Parks 2012).

Hence, there are many considerations to the environmental effects of rotenone treatment. The mitigation management actions in this section are recommendations based on specific taxa. However, some of these recommendations may conflict such as removal of dead fish to limit bird ingestion of rotenone and leaving the fish on site to encourage plankton growth for invertebrate recovery. Therefore, the site managers must make decisions about their conservation priorities specific to the ecology and species at the site.

Antimycin A

Background

Antimycin A, discovered in 1945, is an antibiotic derived from a soil mold and kills fish by disrupting mitochondrial pathways. As a piscicide, Antimycin A can be used for both selective and complete kills depending on the concentration used. Antimycin A concentrations of 0.5-1.0 mg/L kill only small scaled fish and these levels are often used to manage fish populations by to reducing competition for food and resources for larger fish (Moore et al. 2008). However, Antimycin A is not currently an option for most people as it is no longer being sold.

Deactivation

About eight hours after Antimycin A has been mixed with water, it becomes inactive; however, this is dependent on water temperature and alkalinity. In water warmer than 12°C and more basic than pH of 8.0, Antimycin A breaks down more quickly. Water aeration and agitation also alters the degradation and effectiveness of Antimycin A as a piscicide. Elevation drops can therefore deactivate Antimycin A, but there is wide variability in the amount of drop required for deactivation. Deactivation has occurred after 15m drop but also not until a 200m drop. Similar to rotenone, potassium permanganate can be used to deactivate Antimycin A (Moore et al. 2008).

Without actions to deactivate, Antimycin A can remain active less than 500 m or up to 1.75 km downstream of treatment areas. Antimycin A absorbs into the soil, (depths have not been studied) limiting its spread outside the treatment area as well as limiting its effectiveness (Moore et al. 2008).

Other Effects

If Antimycin A is administered as directed for fish management, it is not toxic to salamanders, crayfish, or terrestrial organisms. Laboratory studies have found that fish eggs are impacted by Antimycin A, but instream observations found that Antimycin A-treated water does not mix with the water flowing near the eggs. For example, a restoration project in Rocky Mountain National Park failed to eliminate non-native fish because Antimycin A was applied while non-native trout eggs were in the gravel, thus these eggs were not destroyed, allowing the population to persist. (Moore et al. 2008)

Piscicide Conclusion

Deciding Between Fish Removal Treatments

If piscicide use is determined to be the preferred fish removal method, managers must choose between rotenone and Antimycin A. One deciding factor can be the differing effects of these treatments on invertebrates. A study comparing the invertebrate effects of Antimycin A and rotenone found that although both were effective in eradicating fish, they had differing effects on invertebrates. In areas where rotenone was used, macroinvertebrate richness and density were significantly reduced, affecting species composition. In Antimycin A treated sites, no taxa were lost as compared to rotenone-treated reaches where four taxa were lost one year after treatment. Three years after treatment, two taxa were still lost compared to initial assessments in the rotenone site (Hamilton et al. 2009). Alternatively, Brian Finlayson, an expert on rotenone, stated rotenone is often over-treated leading to more macroinvertebrate kills than necessary (Finlayson, personal communication).

More generally, macroinvertebrates can recover when treated by either piscicide. Hamilton et al. (2009) recommends use of Antimycin A in areas where short term effects (less than 1 year) are of concern for macroinvertebrates. Antimycin A should also be used in areas where managers want a quick replacement of fish or amphibians. In areas where short term effects are not of concern, rotenone can be used (Hamilton et al. 2009). However, when deciding between piscicides, the major deciding factor between rotenone and Antimycin A is the current availability of Antimycin A since it is off the market.

Political and Social Implications

Managers must consider social and political implications of applying a piscicide to a water source. Most rotenone treatments have not lead to problems, but a few have instigated public protests (Finlayson et al. 2000). For example, residents have concerns about potential impacts of piscicide on human health, including Parkinson's disease and drinking water contamination, and animal welfare, and therefore, people have urged for other solutions to be considered (Bosworth and Bosworth 2010). Environmental and animal rights groups voiced similar concerns about the use of rotenone, which led to state restrictions on rotenone use in California and Michigan (Finlayson et al. 2000). Recently, two projects in Wyoming, Porcupine Creek and Eagle Creek, were also halted due to major public pushback. However, in these cases the primary public concern was the loss of the opportunity to fish recreationally, not the use of rotenone itself. When the conservation goal of the project was explained, many individuals agreed with the overall intent of native trout conservation, but did not want the project implemented in their "backyard" (Sam Hochhalter, personal communication).

Public opposition can be minimized by engaging with the public at the beginning of the project. (Finlayson, personal communication). Similarly, Brad

Shepard, an expert in fisheries management, recommends managers assign someone onsite to work with the public to ensure they understand the effects of the treatment (Shepard, personal communication). To reduce incidents, the *Rotenone Use in Fisheries Management Manual* also suggests gathering public input and support before treatment. Additionally, managers should ensure proper treatment through appropriate procedures and trained personnel (Finlayson et al. 2000).

In conclusion, piscicide treatment is the most effective method for complete non-native fish eradication. However, there are a wide array of potential ecological impacts, both direct (killing invertebrate communities) and indirect (through trophic cascades) as well as social implications. For these reasons, the decision to apply a piscicide must be thorough and a comprehensive management plan, including educating the public and building public support, must be implemented.

Opportunities and More Information

For further guidance on piscicide use for management, the American Fisheries Society hosts as 4.5-day training on "Planning & Executing Successful Rotenone & Antimycin Projects." More information on the course is available at: http://rotenone.fisheries.org, where the American Fisheries Society provides a wide array of information about rotenone use.

Electrofishing

Alternative methods to eradicate non-native species to facilitate reintroduction of native fish have been investigated. However, the use of these methods has been limited because piscicides are more effective. An alternative method that has received mixed results is electrofishing. Electrofishing as a management tool for full eradication of non-native trout has been successful in a number of case studies (Shepard et al. 2014 (see case study below); Shepard et. al 2002; Kulp and Moore 2000). However, electrofishing efforts have failed to achieve full removal of non-native species in other projects (Ward 2015; Meyer, Lamansky, and Schill 2006). Electrofishing has proven to be a useful tool for controlling non-native trout population by selectively decreasing populations through physical removal while still not completely eradicating non-native species (Carmona-Catot et al. 2010; Peterson et. al 2008; Thompson and Rahel 1996; Moore, Ridley, and Larson 1983).

How Does Electrofishing Work?

Electrofishing has traditionally been used to survey fish populations in a body of water. Fish are temporarily stunned by an electrical current that is delivered from a backpack-mounted battery-powered or generator-powered unit, or from a similar unit mounted on a boat. While one person is utilizing the backpack-mounted unit in the water, one or multiple other people must catch the stunned fish with dip-nets. When using electrofishing for removal, all fish are initially netted. Where native trout coexist with non-native trout without threat of genetic introgression, native trout can be selectively returned to the stream. If a stream does not contain native trout, all netted non-native species are removed. Removal of the non-native species must also include plans for disposal of fish once captured. In one proposed electrofishing project, the non-native fish, once removed from the stream, were to be buried on site (US Fish and Wildlife Service 2010).

Source: NPS/Jay Fleming

Benefits of Electrofishing

The major benefit to electrofishing for a trout removal project is the option to be selective in species removed. In a stream where native trout are present among non-native trout, electrofishing allows for native fish to be selectively released, thus maintaining the native stock in that body of water. This suppression of non-native trout stocks reduces predation on native trout and increases prey availability for native trout. Where genetic introgression is not a threat, this practice has shown promise for promoting populations of native trout. (Carmona-Catot et al. 2010; Peterson et. al 2009; Thompson and Rahel 1996; Moore, Ridley, and Larson 1983)

Additionally, the public often views electrofishing more positively than the use of piscicides. With public opinion often making or breaking such projects, the increased public acceptance achieved through use of electrofishing can speed up project approval. However, project length can be substantially longer for electrofishing than piscicide treatments, as electrofishing often requires treatments over many years.

Electrofishing is perceived as having less ecological effects than piscicide applications. Electrofishing allows for more selection and localized application, as compared to piscicides, however negative effects to macroinvertebrates have been documented. Taylor et. al (2001) documented a 90% removal rate for macroinvertebrates when using electricity as a sampling method. Mesick and Tash (1980) highlighted a similar amount of removal (80% of macroinvertebrates in shocked areas). However, given that this removal is in the form of "drift," rather than mortality they comment: "We found no long-lasting or fatal effects on any of the nine species of benthic stream insects at voltages currently used for electrofishing." Drift refers to the downstream transport of macroinvertebrates in stream currents. (Waters 1972)

In the case of Tensleep Preserve, the structure of Canyon Creek may provide habitat for unique aquatic species. Therefore, the effects of fish removal on the food web must be considered. While electrofishing results in less mortality of macroinvertebrates, and greater opportunity for recolonization by these

Case Study: Successful Electrofishing Non-native Trout Removal

In the small trout streams of Southern Appalachia, Rainbow trout (*Oncorhynchus mykiss*) have nearly entirely overtaken native brook trout for control of the fishery range. Recreational fishing as a feature of the national park experience has been an essential arm of the National Park Service framework since its inception in 1872, facilitating significant anthropogenic impacts on the health and diversity of stream ecologies. The establishment of Great Smoky Mountain National Park in 1934 followed thirty years of large-scale recreational stocking of rainbow trout in the stream, which would continue for another thirty years until the practice was discontinued. Already by the park's inception rainbow trout were "the most frequently encountered species," displacing the native brook trout from their geographic niche in nearly the entirety of the river (Kulp and Moore 2005).

For that reason, Great Smoky Mountain National Park has provided a unique opportunity to experiment with intentional invasive trout eradication and the eventual reintroduction of native trout (Kulp and Moore 2000). Relatively simple stream habitat (little woody debris, few undercut banks or sinks) enables electrofishing as a potential treatment method. In simple habitat conditions, a manager can actually wade through a stream ecosystem with a team, AC voltage backpacks, and nets to artificially select for the native fish, attempting to backtrack the trajectory of anthropogenic influence.

Accurately estimating the proportion of fish killed relative to fish remaining is a painstaking procedure. While larger rainbow trout are fairly straightforward to tally, electrofishing is a human procedure just as much as traditional recreational fishing and undoubtedly involves human error. Electrofishers will undoubtedly miss smaller trout, allowing small adult and age-0 trout to remain and failing to provide a truly clean slate for eventual native reintroduction (Habera et al. 2010).

Brad Shepard, with the Montana Department of Fish, Wildlife and Parks, found similar electrofishing success in four Rocky Mountain streams in Montana (Shepard et al. 2014), but cautioned against the viability of electrofishing in a complex stream environment. After noting that he had initially sought to prove the impossibility of electrofishing as an effective eradication method, Shepard concluded: "If you put enough effort in, and concentrate that effort over 2-3 years, you can be successful in that length of time" (Shepard, personal interview).

species, Mesick and Tash (1980) warn "endangered invertebrate species, especially those of low productivity, could be eliminated from heavily shocked areas."

The impacts of electrofishing on other aquatic species requires additional research. In general, while the treatment poses less ecological harm to stream environments, impacts to other species do occur and should be incorporated into treatment decisions.

Electrofishing Shortcomings

Electrofishing does show some promise in removing non-native fish from smaller streams where native fish also exist, however, it requires extensive labor, and is highly dependent on the nature of the stream. Ultimately, electrofishing has only shown rare success at total removal of non-native trout.

Electrofishing is a labor-intensive process, the efficiency of which can be easily affected by the structure of the stream and the riparian environment. In his study detailing successful eradication of non-native brook trout from Montana streams, Shepard (2014) found a substantial cost increase in streams where clearing of woody debris was necessary. The projects incurred a cost range of $3,500-$5,500 per kilometer without clearing compared to $8,000-$9,000 per kilometer when clearing was necessary. Such physical constraints affect the efficacy of electroshocking due to the need to be close enough to fish for them to be both effectively shocked and caught once temporarily stunned. Once non-native fish have been caught these must also be removed from the area. In a stream like Canyon Creek, with a low tight canopy, such physical limitations from the riparian can limit the efficacy of electrofishing. The combination of stream complexity and overall efficacy of removal via electrofishing requires multiple treatments over long periods of time.

Even in simple streams with ideal conditions for electrofishing, success is still variable. Ward et. al (2015) investigated the effectiveness of single-pass and three-pass treatments in a small warm-water stream in southern Arizona. After initial electrofishing treatments, rotenone was applied to the stream to judge overall effectiveness. The single-pass treatment was found to catch 23% of fish present, while the three-pass treatment, conducted over consecutive days removed 55% of fish present.

Electrofishing is more effective on larger fish, both due to an improved efficacy of stunning on larger fish and the difficulty of netting smaller fish (Sharber and Carothers 1988). In some attempts to eradicate brook trout using electrofishing, a compensatory population response, resulting in an increase of young fish, countered yearly removal of older individuals of the species (Meyer, Lamansky, and Schill 2006; Thompson and Rahel 1996). The removal of older fish more susceptible to the electrofishing both removed the predatory control on smaller fish and provided additional forage/resources.

Many issues make full eradication with electrofishing difficult, however the threat of genetic introgression from remaining non-native species to reintroduced native trout is likely the greatest threat to any trout reintroduction project utilizing electrofishing. If a core population of trout, with genetic purity is the ultimate desired outcome, anything but full eradication of non-native species could pose a threat through hybridization.

Electrofishing Conclusion

Electrofishing has been explored as an option for non-native trout removal due to the benefits of public perception and for the minimized ecological impact on treated ecosystems. However, mechanical removal of trout using electrofishing treatments presents a number of challenges. Stream complexity, notably depth and riparian vegetation can impede access, reduce efficacy of current, and make removal via nets difficult. These conditions require multiple treatments over a period of years, resulting in growing costs of labor and time. Where full eradication of non-native species is sought, the greatest shortcoming of this treatment is the risk of genetic introgression between reintroduced native species and uncaught non-natives. In the Environmental Impact Statement to restore Silver King Creek Paiute Cutthroat Trout, electrofishing was considered as an alternative to rotenone treatment, but the threat of failure of complete removal was highlighted as a major issue:

> "If complete removal of non-native trout species is not achieved, the potential for re-establishment of a hybridized population remains and no net benefit to Paiute cutthroat trout viability (recovery) may be achieved."(US Fish and Wildlife Service 2010)

In the case of Canyon Creek at the Tensleep Preserve, the current dominant fish species are rainbow and brown trout. It is important to note that rainbow trout can hybridize with cutthroat trout and brown trout cannot. The threat of hybridization between reintroduced Yellowstone Cutthroat trout and

Case Study: Failed Electrofishing Removal

In our findings, it was common to hear about failed attempts of electrofishing at removing non-native fish. Because fisheries are sites of such cultural memory and significance, land managers have held out that electrofishing, while less effective than rotenone in fully eradicating invasive fish from an ecosystem, is worth the larger investment in time and resources. A paper by Meyer et al. (2006) dives more deeply in the "mechanisms of failure" for electrofishing efforts, to more thoroughly evaluate the use of electrofishing as an alternative to piscicide use.

Meyer et al. (2006) studied a selective eradication operation out of Pike's Fork in southwest Idaho, a second-order tributary of the Boise River, itself a tributary of the Snake River. Land managers in the area were particularly concerned with the loss of native Redband and Bull trout due to the introduction of the non-native brook trout (*Salvelinus fontinalis*). This is the case across large swaths of the continental US, and especially in the Snake River, home to an estimated 1.2 million brook trout. Because the bull trout population in the area was too small to reliably study, the reintroduction efforts focused more significantly around the native Redband, named so for the crimson stripe that runs along their side.

The particular "mechanism of failure" for the Pike's Fork project, as Meyer et al. identified, was the ability of brook trout population as a whole to compensate for the electrofishing disturbance. A well-known concern in electrofishing attempts has been the uncertain nature of estimating age-0 fish, often too small to shock or reliably count. The possibility of a compensatory response exacerbates this issue, implying that, not only do electrofishing efforts not capture all non-native species, they may instead accelerate the proliferation of non-natives throughout the system. Over the two years following the end of removal efforts, the population of age-0 fish increased nearly 8-fold. Natural mortality dramatically decreased, and rates of reproduction increased significantly. Compounded with the fact the eradication of age-0 fish is commonly overestimated, what may have begun as an ethical approach to stream management soon accelerated the issue it sought to solve.

The project that Meyer et al. studied resulted in no significant increase in native Redband counts. However, without a control group it may have been difficult to evaluate how specific environmental conditions may have confounded study variables, as the authors acknowledge. But most importantly: electrofishing has only found success under a specific set of stream conditions, namely, uniformity and limited size. Future native reintroduction projects will have to balance the ethical ramifications of electrofishing with its inherent mechanisms of failure, choosing either to mitigate them or to pursue a traditional piscicide method instead.

rainbow trout makes electrofishing unattractive.

In streams where non-native fish and native fish coexist without threat of genetic introgression, as is the case with brook trout and cutthroat trout, the use of electrofishing can greatly reduce the number of non-native trout, and full eradication is possible, but difficult (Thompson and Rahel 1996; Caudron and Champigneulle 2011; Shepard, Spoon, and Nelson 2002). In such situations, electrofishing should be considered due to the opportunity for preserving native fish stocks, but the time and cost required in both the short-term and long-term for limiting non-native populations should be considered.

Overall Conclusion on Trout Removal Methods

For non-native trout removal, rotenone application is the most effective option for complete eradication, while electrofishing can be useful for a reduction of non-native populations if a native population already exists and is not at threat of genetic introgression. Both of these treatment methods come with many advantages and disadvantages (Table 1). The choice between electrofishing and rotenone treatments must include an analysis of other species of concern in the area, the potential effectiveness of the treatment due to the structure of the stream itself, and the public perception and support for a project. For these reasons, a management decision of no action should also be considered. Managers are strongly encouraged to balance the benefits of native trout reintroduction with potential detrimental effects related to any required fish removal treatments.

Table 1: Advantages and Disadvantages for Trout Removal Practices

Practice	Advantages	Disadvantages
Rotenone (piscicide)	• Complete removal of fish populations • Application can be spatially selective • Can be used in large river systems • Rapid results • Controls all post-embryonic stages of life	• Temporary loss of potable water and recreation • Temporary effects on non-target species and aquatic habitat • Potentially repellent • Does not kill fish eggs
Antimycin A (piscicide)	• Complete removal of fish populations • Controls all post-embryonic stages of life • Selective by species • Non-repellent • Rapid results	• Not registered in every state • Limited history and availability • Not effective at high pH (>8.5) • Does not kill fish eggs • Temporary loss of potable water and recreation • Temporary effects on non target species and aquatic habitat
Electrofishing (physical removal)	• Publicly acceptable	• Need high exploitation rates • Juveniles and other game fish fill void • Expensive and labor intensive • Potential escapement • Benefits are of short duration

Source: Finlayson et al. 2000

Tensleep Recommendation

Rotenone is the only viable option for Tensleep Preserve, due to stream complexity, stream length, and the threat of genetic introgression between reintroduced Yellowstone cutthroat trout and the non-native rainbow trout. However, given the reserve's larger mission of biological diversity and preservation, the ecological effects to the reserve are a major concern. Additionally, given conversations with other Wyoming natural resource managers, the current climate of trout reintroduction in the region has been marked by public opposition. Given all of these difficulties with piscicides, a decision of no immediate action would be prudent. As the local public debate over native trout reintroduction evolves, public perception may be more amenable to non-native trout removal projects. The Wyoming Game and Fish Department, as lead on native trout reintroduction projects, is the primary agency through which projects are developed and will be an important partner for considering action in the future.

Additional Research

Our recommendation is based on the information available through a literature review and interviews with experts in the field. However, in order for land managers to make sound management decisions in the future, further information on the impacts of rotenone on site-specific species will be needed. Areas of future research could focus on the ecological consequences of rotenone application to birds, amphibians, and invertebrates. During the summer of 2018, the Tensleep Preserve will be conducting research related to the invertebrate assemblage in Canyon Creek's sinks to determine which species could be affected by a rotenone application. Additionally, the use of Antimycin A, while not currently in production, could be further investigated to see if there are opportunities for future application of this piscicide.

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