IMPROVING RESTORATION OF BREEDING SITES TO INCREASE RECRUITMENT OF *ANAXYRUS BOREAS* IN WESTERN MONTANA

by

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ABSTRACT

The Montana native western toads (*Anaxyrus boreas*) have, like most amphibians, been declining in recent years. Although it is endangered and at high risk of extirpation in many states, there are still several healthy breeding populations in Montana. Montana can increase recruitment of this increasingly rare anuran species through habitat restoration. However, using habitat restoration to addressing the decline of this species is not well researched. Here, I evaluate potential restoration methods that could increase recruitment. I provide an overview of the habitat requirements and preferences of *A. boreas* as well as effective restoration methods for this and other anuran species. To increase recruitment, restoration efforts should include construction of permanent ponds with low turbidity and extensive shallows that gradually increase to a maximum depth of 40 cm. Trees should be removed along the pond perimeter if they shade the water. Active management measures such as sediment removal in ponds, strict regulation of livestock grazing, periodically prescribed burns, and removal of invasive species such as the American bullfrog (*Lithobates catesbeianus*) should also be implemented. Farther from the breeding site, native deciduous shrubs should be planted, if they are not otherwise present. For existing breeding sites, the area within a 3-km radius should be protected from development and clearcuts. Introduction of beaver (*Castor canadensis*) to their historical range will also have a significant beneficial impact on the restoration of *A. boreas*. The locations of these efforts should also be carefully chosen to take into account the continuing effects of climate change. Taking these actions now, based on the data that are available, will help increase recruitment and improve the chances of this species recovering.

I. INTRODUCTION

Amphibians have existed on earth for approximately 363 million years (Carroll, 1988), yet they are currently facing unprecedented extinction rates (Roelants et al., 2007). Of all amphibian species around the world, 32% are at risk of extinction in the near future, and 43% are declining (Stuart et al., 2004). Amphibians are an indicator species for the overall state of ecosystems due to their heightened sensitivity to detrimental environmental changes (Blaustein & Kiesecker, 2002), and their recent dramatic population declines worldwide are a strong indication of stressed ecosystems. Stressors driving these declines include climate change, environmental pollutants, invasive species, pathogens, and anthropogenic habitat modification (Hayes et al., 2010). Factors such as climate change and pathogens are very difficult for local agencies to address; however, habitat degradation can be mitigated locally and is an effective tool to address amphibian decline (Pechmann et al., 2001).

Anaxyrus boreas is one of the many species of amphibian that is at risk. In Montana, it is listed as a Species of Concern by Montana Fish, Wildlife, and Parks (MT FWP, 2005b). According to FWP, "Species of Concern are native taxa that are at-risk due to declining population trends, threats to their habitats, restricted distribution, and/or other factors (MT FWP, 2007)." These declines are seen in most states within *A. boreas*'s range. Corn et al. (1989) conducted a survey between 1986 and 1988 and found that out of the 59 known *A. boreas* habitats in Colorado and Wyoming, only 17% still contained individuals. Today, locations that still contain healthy populations are even less common.

Anaxyrus boreas is a medium-sized toad that is 80-100 mm in length (Figure 1) and is found in western North America, from Alaska to Baja California, Mexico in montane areas close to breeding ponds (MT FWP, 2005b). In Montana, it is only found in the western part of the state

(Figure 2), and up to 2,810 m in elevation (MT FWP, 2005b). Breeding occurs in the spring and early summer, when temperatures are above 10 ℃ (Thompson & Chase, 2001), and *A. boreas* usually return to the same breeding sites each year (Bull & Carey, 2008). Egg clutches consist of an average of 6,000 eggs and are deposited in long strings in warm, shallow littoral zones that receive significant amounts of sunlight (Lannoo, 2005). When these eggs hatch, the larvae have a diverse diet, which includes algae, detritus, and fish carcasses (Leonard, 1993).

Figure 1. *Anaxyrus boreas* adult

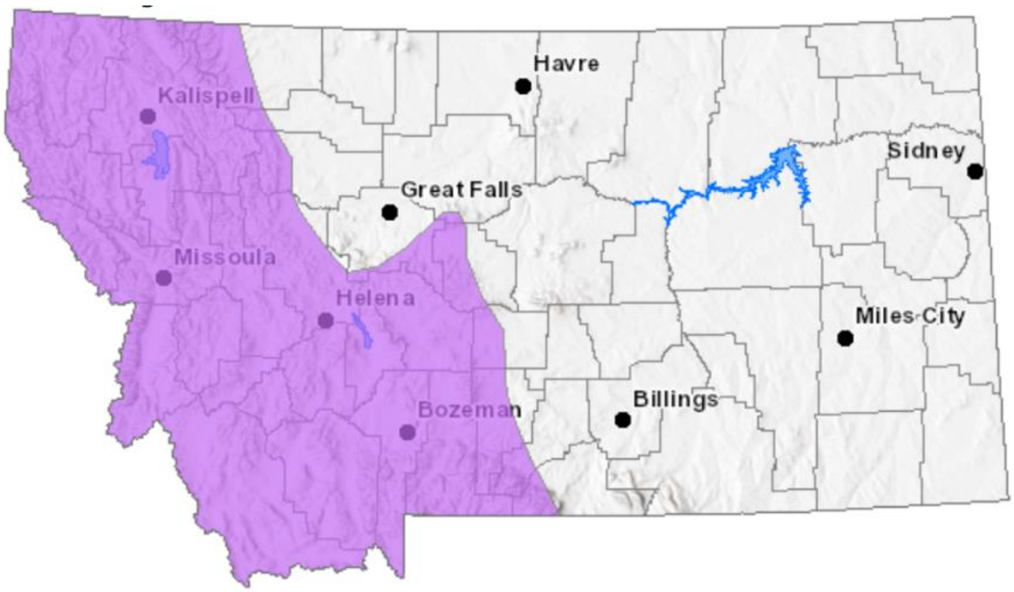

Figure 2. Range of *Anaxyrus boreas* in Montana. Retrieved from MT FWP (2005b)

Although a clutch size of 6,000 per female may seem large, it is smaller than that of most common toad species, which can lay up to 20,000 eggs per season. Although other species of toads can breed several times per season, 95% of female *A. boreas* only breed once in their lifetime (COSEWIC, 2012). Also, because of the very short growing season, the species slowly grows to sexual maturity. When successful reproduction does occur, an estimated one to five percent of toad larvae actually survive to adulthood (Samollow, 1980). These factors exacerbate its declines in times when populations are compromised (Lannoo, 2005; COSEWIC, 2012).

There have been many attempts to restore amphibians to their historical populations. Captive breeding programs and translocation have been employed with a variety of species, such as the Wyoming toad (*Anaxyrus baxteri*) (Browne et al., 2006). However, habitat restoration has a lower cost-benefit ratio than captive breeding, especially in cases where stable breeding populations still exist (Dodd Jr. & Seigel, 1991; Lannoo, 2005; Muths et al., 2003). Areas where habitat restoration was implemented often have an even higher recruitment (the addition of new individuals to the population) rate than unrestored areas (Dixon et al., 2011; Pearl & Bowerman, 2006; Klimaszewski et al., 2016). Beas and Smith (2014) found that amphibian species richness in restored areas was twice that of unrestored areas. Likewise, Arntzen et al. (2016) found that amphibian richness in constructed ponds was comparable to reference sites, and Klimaszewski et al. (2016) observed almost all native amphibian species present in restored areas.

Efforts to increase recruitment of *A. boreas* in Montana should, therefore, be focused on habitat restoration, especially in the vicinity of breeding locations. These methods should incorporate previous research regarding known habitat preferences as well as relevant restoration efforts in other states and with other species of anurans, as there is little information related to restoration efforts of *A. boreas*, especially in Montana, and many restoration efforts related to this species elsewhere are still underway (P. Thompson, personal correspondence). These management strategies should be closely monitored each year to document the results and should be adjusted as new research comes out. Implementing this now, using the information that is currently available, will be more cost effective and more likely to succeed than waiting until the species is in such critical status that more drastic and costly measures need to be carried out. When a species has declined to such extremes that there is little genetic diversity among the population, the chances of a successful recovery are low, especially now with deadly, highly infectious diseases wiping out entire populations (Allentoft & O'Brien, 2010). This toad species is the only toad native to western Montana and is vital to the health of the overall ecosystem, as it is a food source for other animals and reduces insect pest species. Restoring populations to their previous levels will not only benefit this species, but others as well that share similar habitats.

Here I examine habitat requirements that are necessary for each life stage of *A. boreas*. This will hopefully guide managers in restoration efforts that ensure that these requirements are met. I then provide an overview of the relevant research to date—what has shown to be effective and what has not, what habitat restoration efforts provide the lowest cost:benefit ratio, etc. Based on this, I provide management restoration recommendations to be implemented in Montana.

II. HABITAT REQUIREMENTS OF *A. BOREAS*

Anaxyrus boreas is limited in terms of where it can survive and thrive. To increase recruitment, habitat requirements must be taken into account. Amphibians are ectothermic and are therefore usually found in warmer climates, but *A. boreas* is one of the few species that is found in very cold regions that have minimum temperatures well below freezing (MT FWP, 2005b). These harsh environments create a tradeoff: on the one hand, the growing season is significantly shorter, leading to a reduction in weight and slower growth rates (Holenweg & Reyer, 2000), but on the other hand there is less competition with other amphibian species.

Warm water temperatures are essential in determining whether the larvae can metamorphose before winter, as higher water temperatures lead to faster development (Klaus & Noss, 2016; Rannap et al., 2012; Muths et al., 2001). In many amphibian species, UV-B light has been shown to be detrimental to larvae and hatching success, but this has not been shown to be the case with *A. boreas* (Corn, 1998). Direct sunlight is therefore an important component to establish water temperature necessary for the species' successful development. There is a risk that in high elevation areas, larvae may not metamorphose before freezing temperatures set in, leading to premature mortality (Fetkavich & Livo, 1998). Shallow water is another habitat requirement for larvae, not only for warmer temperatures, but also for higher oxygen concentrations (Fridell et al., 2000; Klaus & Noss, 2016). Larvae also require areas of deeper water to avoid predation, although these areas are only used temporarily (Hossack, 2016; Olson, 1989).

When the toads metamorphose (Figure 3), adults tend to spend most of their time near breeding ponds, but females can travel about 2.4 km from ponds outside of the breeding season, staying mostly within shrub cover and woody debris (Bartelt, 2000). They tend to be found in areas that are neither excessively sunny nor shady, as they need to maintain ideal body temperature to support activity, but avoid desiccation (Bartlet, 2000). Toads are also found within 25 m of a forest edge but rarely in the middle of a clearcut (Bartlet, 2000).

Figure 3. *Anaxyrus boreas* metamorph

In the winter, the toad hibernates underground, often in rodent burrows (COSEWIC, 2012). Snowpack is especially important in regions where temperatures can stay well below freezing for several months, as it insulates the toad from freezing. Once temperatures are above freezing in the spring, breeding occurs.

Breeding locations for this species are diverse; however, they are often characterized by areas of minimal water current that receive plenty of sunlight, shallow edges, and low gradient banks (Fridell et al., 2000). These breeding locations may even occur in human-made water bodies, such as ditches, road ruts, and flooded gravel pits; however, these are not ideal, as they are highly prone to evaporation later in the summer, are often continually disturbed by human activities, and have high turbidity (COSEWIC, 2012; Klimaszewski et al., 2016). Figures 4-6 are examples of ideal breeding habitat that provide permanent, low-turbidity sources of water close to adult habitat and away from urban development.

Figure 4. Example of typical breeding habitat (Emerald Lake, Montana)

Figure 5. Example of typical breeding habitat (Axolotl Lake, Montana)

Figure 6. Example of typical breeding habitat (Mystic Lake, Montana)

These unique habitat requirements are necessary for the continued health of this species. However, each is currently compromised due to anthropogenic factors such as climate change, habitat modification, and livestock grazing.

III. FACTORS AFFECTING *A. BOREAS* IN MONTANA

Introduction

Although Montana has more than 10.9 million hectares of public land, it has not been immune from the ecological effects of anthropogenic activities. The environment of Montana is very different today than it was historically, and this has had a negative effect on *A. boreas* and has significantly reduced both its population numbers and its distribution in the state.

Climate Change

Climate change is a universal factor impacting global amphibian populations. Montana is no exception to this. During the past 100 years, the state has experienced an increase of about one ^{o}C (U.S. EPA, 2016). Increased temperatures increase evaporation, leading to shorter hydroperiods necessary for toad larvae to metamorphose. This shorter time can lead to premature mortality via desiccation (Lannoo, 2005).

As this temperature trend continues, it is expected to increase the risk of wildfire (U.S. EPA, 2016). Severe fires are detrimental to *A. boreas* via direct mortality, but also through destruction of habitat and degradation of water quality due to ash and sedimentation (Hogrefe et al., 2005).

Decreased snowpack has also been observed in the state, with some areas experiencing as much as an 80% decrease during the last 60 years (U.S. EPA, 2016). This poses a danger to *A. boreas*, which requires deep snowpack to act as an insulator during hibernation. Increased temperatures are cited as being largely a result of increased anthropogenic industrial activities that release greenhouse gas emissions into the atmosphere. This growth in urbanization and industrialization has also been witnessed in Montana.

Anthropogenic Habitat Modification and Human Population Growth

Historically, Montana has had a low human population, but, with technological advancements allowing people to work remotely, Montana's human population has changed drastically over the past couple decades. This increased higher-income population has led to a growth in urban development. High-income households often have a corresponding increased environmental impact, with a carbon footprint 76% higher than low-income households (Freeman, 2009). Increased development affects *A. boreas* both through direct mortality in the construction process and destruction of habitat. High-elevation development is a contributing factor to *A. boreas* declines in Utah (Hogrefe et al. 2005). In Montana, many high-elevation locations, such as Big Sky, are desirable to people moving in from out-of-state. Big Sky is located within the range of *A. boreas* and between 2012 and 2017, the population grew by more than 20%—three times more than that of Aspen, Colorado (Big Sky Chamber, 2019). The number of businesses also increased by 17%, and the number of annual new commercial building permits more than tripled during this same time (Big Sky Chamber, 2019).

This trend is unlikely to change and puts tremendous pressure on *A. boreas* populations. Although urbanization is a relatively recent phenomenon in Montana, other detrimental anthropogenic activities have existed for much longer, one of which is agriculture, specifically ranching.

Cattle Grazing

Cattle grazing is an additional factor negatively affecting *A. boreas*. About 62% of all land in Montana is used for agricultural purposes, and about 66% of this is reserved for grazing (NASS, 2020). Beef cattle make up most of the livestock, with an average of 2.5 million heads of cattle raised each year (NASS, 2020), which is more than twice the human population of the state. Nationwide, cattle production has more than doubled during the past 100 years (Trimble & Mendel, 1995). There are often few limitations to cattle grazing, with 91% of federal lands in the West open to grazing (Armour et al., 1994).

Raising cattle on such a large scale has negative environmental impacts. Most at risk are riparian areas, 80% of which have been degraded as a result of cattle grazing (Hirsch & Segelquist, 1978; Bureau of Land Management, 1994). The most obvious impact is a decrease in plant biomass. Biomass and cover of woody species in riparian areas has been shown to decline with grazing (Kauffman & Krueger, 1984). Studies that used exclosures in riparian ecosystems demonstrated that when cattle were removed from the location, woody species such as willows increased significantly (Schulz & Leininger, 1990; Ammon & Stacy, 1997). *Anaxyrus boreas* uses these riparian areas for breeding sites and adult habitat and prefer woody vegetation as a source of cover to avoid predation and high temperatures during the day.

The decrease in vegetation has a subsequent effect on soils. Decreased vegetation leads to decreased litter, decreased water infiltration, and increased bare ground (Belsky, 1999; Clary & Medin, 1990). Cattle also have direct physical effects on soil properties, such as compaction, which can further reduce water infiltration (Belsky, 1999). Although some of these effects may even be beneficial to *A. boreas* (such as the decreased litter), it alters the hydroperiod and leads to more pronounced spikes in runoff. Decreased riparian vegetation also increases erosion of sediment into water bodies (Bureau of Land Management, 1994), which decreases larval health and fitness.

Another more visible impact is direct mortality. Trampling by livestock may cause direct mortality of all life stages of *A. boreas* (Hogrefe et al., 2005). This is especially a concern in cases where there are large herds of cattle gathering near a water source.

Invasive Species

In the U.S., invasive species are cited as a contributing factor to the declines of 400 endangered species (USFWS, 2012). Larger, invasive anurans are well documented as having a negative effect on smaller species, whether or not there is direct predation (Peacor & Werner, 1997). This is partly because of the transmission of foreign diseases as well as competition for resources (COSEWIC, 2012). A common invasive predator of native amphibians is the American bullfrog (*Lithobates catesbeianus*). Bullfrogs have invaded most of the continental U.S., including western Montana, and have contributed to declines of many native amphibian species, including *A. boreas* (MT FWP, 2005a*;* COSEWIC, 2012). They are highly adaptable to a wide range of environmental conditions, but tend to be most common in areas of large, open bodies of water with dense emergent vegetation (MT FWP, 2005a). They are also more tolerant to the presence of fish than other anuran species (MT FWP, 2005a).

These factors are likely to intensify in the future. Development and resource use in Montana are not slowing, and climate change models predict drastic ecological effects to continue without immediate action. It is important, then, to take steps to mitigate these issues, incorporating research conducted to date on habitat restoration.

IV. HABITAT RESTORATION OF ANURAN SPECIES

Relatively little research related to restoration efforts of *A. boreas* has been conducted, especially in Montana. However, other states have implemented strategies that have been shown to be effective. Restoration efforts related to other anuran species have also been extensively studied. Most restoration efforts are focused on recreating the historical vegetation community dynamics and constructing suitable breeding ponds.

Vegetation

Vegetation composition is important for amphibian populations to avoid predation and high temperatures. For instance, the planting of native macrophytes in the littoral zone of flooded gravel pits in Poland had a positive impact on all native amphibian species (Klimaszewski et al. 2016). Yet, too much vegetation is detrimental to this and other anuran species (Klaus & Noss, 2016; Rittenhouse, 2011; Vincent & Abbott, 2015). The issue, then, is to find the balance of providing native vegetation cover while ensuring it is not too dense to hinder toad movement, decrease water temperatures and pH, and influence turbidity.

One ecological process that has historically regulated vegetation is wildfire. Severe fires may be harmful to *A. boreas* due to the initial destruction of vegetation, habitat fragmentation, decrease in water quality, and direct mortality. However, low-intensity burns have been shown to be beneficial in many instances. In Florida, restoration efforts that included prescribed fire in longleaf pine stands led to increased amphibian species richness (Klaus & Noss, 2016). These restoration practices created an open forest canopy and reduced leaf litter, which allowed increased sunlight access to the water surface. This led to a corresponding increase in water temperature, causing more rapid growth of amphibian larvae (Klaus & Noss, 2016), and increased periphyton population (Klaus & Noss, 2016), which is an important food source to *A. boreas.* As leaf litter decays, it decreases water pH and dissolved oxygen (Stoler & Relyea, 2011; Earl & Semlitsch, 2013). Low intensity fires remove leaf litter from the forest floor. These ecological changes benefit amphibian larvae, which require high levels of dissolved oxygen, a neutral pH, and habitats with high primary production (Klaus & Noss, 2016).

Rittenhouse (2011) found, contrary to expectations, that dense vegetation had detrimental effects on amphibian populations, as the decomposition of high amounts of dead plant matter in the water outweighed the positive effects of the cover riparian vegetation provided. This decomposing plant matter is especially detrimental in the spring and early summer when larvae are developing, as it can create anoxic conditions that quickly lead to larval mortality.

Controlling vegetation benefits the critically endangered Wyoming toad (*Anaxyrus baxteri*). Overgrowth of emergent vegetation leads to a reduction in water temperature and hinders the toads from migrating to the ponds to breed (Vincent & Abbott, 2015). Vegetation in this area has historically been regulated by bison populations. However, their extirpation from most of the U.S. has led to the need to develop alternative vegetation control methods in Wyoming toad habitat, such as allowing occasional cattle grazing and implementing prescribed burns (Vincent & Abbott, 2015). American toad (*Bufo americanus*) metamorphs have also been found to more frequently use constructed wetland areas with sparse vegetation than areas with dense vegetation, likely for similar reasons (Shulse et al., 2012).

Similarly, Pacific tree frogs (*Pseudacris regilla*), Columbia spotted frogs (*Rana luteiventris*), and northern red-legged frogs (*Rana aurora*) had lower population levels in wetlands that had an elevated density of the invasive plant species reed canarygrass (Hossack, 2016; Rowe & Garcia, 2013). This was also due to the reduced access to open bodies of water as well as the elevated levels of dissolved organic carbon (Hossack, 2016; Rowe & Garcia, 2013). Reed canarygrass is especially harmful to amphibians, as it contains alkaloids which are toxic to anuran larvae (Rowe & Garcia, 2013).

Another strategy for reducing vegetation density is selective logging. While clearcutting is detrimental to most aspects of forest ecosystem functioning, more selective logging practices often have negligible or even beneficial effects on toad populations (deMaynadier & Hunter, 1995). Bartelt (2000) recommends against clearcutting and instead proposes thinning the tree canopy to 40% cover with 40-50% shrub, 30% debris, and 50-60% herbaceous cover. He also recommends that coarse woody debris not be removed after timber harvest, but left on the forest floor, and that livestock be excluded from breeding sites.

Hydroperiod and Water Depth

Hydroperiod and water depth have also been found to be crucial environmental factors to the health of amphibian populations. Amphibians have been documented as benefiting from water bodies that have both a shallow slope as well as areas of increased water depth (Shulse et al., 2012; Hossack, 2016). Constructed wetlands with shallow littoral zones have been found to be correlated with increased numbers of leopard frog (*Lithobates pipiens*), boreal chorus frog (*Pseudacris triseriata*), and American toad metamorphs (*Anaxyrus americanus*) (Shulse et al., 2012). These shallow zones allow for elevated temperatures and sunlight as well as emergent vegetation (Shulse et al., 2012). Klimaszewski et al. (2016) had similar results, showing that ponds with increased shallows and low gradient slopes had the highest amphibian recruitment. These shallows are especially important to species that live at higher latitudes, as it allows for warmer water temperatures and higher oxygen concentrations than deeper waters (Rannap et al., 2012; Noland & Ultsch, 1981). Rannap et al. (2012) found that natterjack toads (*Epidalea* *calamita*) in Estonia bred in ponds that were shallower than breeding ponds in Denmark, and that this led to an increased rate of larval development. They concluded that these results confirm the view that amphibian restoration efforts need to be tailored not only to the target species but also to the specific location (Klaus & Noss, 2016; Rannap et al., 2012).

Wetlands that have zones of increased depth can also have a positive effect on amphibian survival. Hossack (2016) found that deeper ponds were positively correlated with Columbia spotted frog (*Rana luteiventris*) populations. This is assumed to be a result of the extended hydroperiod, which gives more time for larvae to metamorphose as well as the ability to avoid predation (Hossack, 2016). Likewise, Pacific tree frogs were found to colonize larger ponds more rapidly (*Pseudacris regilla*), and their population was less likely to experience extirpation (Hossack, 2016). Deeper waters have also been documented as being important to the survival of *A. boreas.* Olson (1989) observed that toads that had access to deeper water were less likely to be preyed upon by ravens.

High inputs of sediment and nutrients in breeding ponds have been shown to decrease *A. boreas* larval growth and survival (Wood & Richardson, 2009). Beas and Smith (2014) observed that sediment removal in breeding ponds in Nebraska had a beneficial effect on amphibian populations, especially during years of reduced precipitation, as it increased the hydroperiod. This increased hydroperiod means that larvae have a longer time to metamorphose (Gray & Smith, 2005). Accounting for evaporation is especially important considering the continual effects of climate change (Kiesecker et al., 2001). While sediment removal of water bodies involves an invasive process, Beas and Smith (2014) found that the benefits of removing sediment and altering the morphology of breeding habitats outweighed the detrimental effects of the excavation process.

Other researchers have also emphasized the importance of maintaining the integrity of historical hydroperiods. Bateman et al. (2008) found that flooding significantly increased the abundance of the toads *Anaxyrus cognatus* and *Anaxyrus woodhousii*, as it created pools necessary for breeding and brought the groundwater closer to the soil surface, which reduced the risk of desiccation. However, severe modifications of rivers and streams have disconnected streams from the floodplain. Because of this, they recommend the incorporation of managed flooding to toad habitat (Bateman et al., 2008).

Restoring the historical hydroperiod and ensuring that a permanent water source exists for breeding will, therefore, be an important component to increasing recruitment of *A. boreas.* This can be accomplished through abiotic methods such as bank and channel construction, but other methods exist as well, such as the reintroduction of native species that affect hydrology.

Reintroduction of Beaver

One method that has been proposed to create these needed hydroperiods and channel morphology for toad reproduction is the reintroduction of beaver (*Castor canadensis*) to its historical native habitat. The westward expansion of European migrants during the nineteenth century led to a severe reduction in beaver populations, as their fur was a highly sought-after commodity (Schullery & Whittlesey, 1992). Their populations experienced a brief increase in the early 1900s, then declined again until the 1990s (Smith & Tyers, 2012). While populations have been increasing in recent decades (largely due to increased density of willow), it is unknown if their populations are as widespread as they were before westward expansion (Smith & Tyers, 2012). In a survey, Stevens et al. (2005) found that *A. boreas* abundance was highly correlated with the presence of beaver, to the extent that no individuals were found on unobstructed streams, and others have had similar findings (e.g., Russell et al., 1998). This is assumed to be because beaver ponds create the necessary shallow water and low flow necessary for toad reproduction. These habitats are also permanent rather than ephemeral and provide a continuous source of water that is well-oxygenated.

Fish Removal

One factor that often seems to be correlated with amphibian recruitment following restoration is the presence of fish (Petranka & Holbrook, 2006; Shulse et al., 2012; Rowe & Garcia, 2013). Many fish species prey on amphibian eggs and larvae, which leads to direct mortality and predator avoidance behavior by adults (Petranka & Holbrook, 2006). Fish introductions also contribute to indirect mortality by reducing the number of aquatic macroinvertebrates, a food source for predaceous amphibian larvae species (USFS, 2011). Because of this, fish removal has often been cited as a necessary component of restoration efforts.

Interestingly, this correlation has not been seen with *A. boreas*. Hirner and Cox (2007) found that *A. boreas* larvae abundance was higher in lakes that contained rainbow trout. However, they acknowledge that there may be a difference between toads that evolved with native fish and those that did not (such as alpine lakes that contained introduced fish). The lakes in the study were also highly productive, which may increase the resiliency to trout predation (Hirner & Cox, 2007). *Anaxyrus boreas* does not feed on macroinvertebrates, but on algae and detritus, which means that there is little competition for resources. The larvae are also unpalatable to fish and are therefore less likely to experience predation (Welsh et al., 2006).

Constructed Ponds

Constructed ponds are often a component of habitat restoration, especially in wetlands. Wetlands in the U.S. have been severely reduced due to dredging for urban development and agriculture. The U.S. historically had over 89 million hectares of wetlands, which has been reduced by 50% due to anthropogenic activities (EPA, 2013). Relatively little research has been conducted related to how *A. boreas* specifically respond to constructed ponds. However, one study found that *A. boreas* individuals were observed breeding in all newly constructed ponds the year after construction; however, the number of larvae observed at each location varied greatly (Pearl and Bowerman, 2006). Each pond had varying characteristics, but all had areas of shallow water and lacked macrophytic vegetation. They emphasize that further research is needed to determine exactly what characteristics lead to such differences in recruitment, but it shows that *A. boreas* is able to locate newly constructed ponds that are as far as 4 km from the nearest known breeding pond.

These findings are useful, as they can potentially be put into practice in Montana. Although there are certainly gaps in the research, there is enough to at least begin restoration efforts.

V. MANAGEMENT RECOMMENDATIONS

In cases such as amphibians, determining which actions should be taken can be overwhelming. Amphibians are declining at a rapid rate. This is especially troublesome considering global factors such as climate change. In states such as Montana, anthropogenic development and habitat modification are rapidly accelerating. This economic growth is often prioritized over ecological functioning. Additionally, local agencies often have a limited set of resources available to them. Considering this, it is important to take actions that are both effective and an efficient use of resources, and habitat restoration is the best initial step to take. Based on the species' habitat preferences and the documented benefits of specific restoration techniques, I have developed the following list of restoration and management approaches.

Site Selection: The site location is an essential component of finding the lowest cost:benefit ratio. Sites should be mid-high elevation that receive high snowfall, are within 4 km of known breeding sites, and at least 3 km from urban development and roads that experience high levels of traffic. Choosing sites that also receive low sediment inputs will lead to increased water clarity, increased temperatures, and improved larval survival rates.

Hydrology: Although *A. boreas* uses ephemeral water bodies for reproduction, these are not ideal as they have the potential to evaporate prematurely. Therefore, it is important to construct breeding ponds that have a continual source of water, either from a spring or stream. These ponds should have extensive shallows that gradually increase in depth.

Vegetation Composition and Control: Farther from the breeding locations, native deciduous shrubs should be planted, if they are not otherwise present. These shrubs provide vital habitat refugia, protection from high temperatures during the summer, and habitat for insects.

Reduction of vegetation in the immediate vicinity of breeding ponds has other benefits as well. Removal of trees that shade the water body will allow increased sunlight access as well as reduce organic matter inputs. This will raise water temperatures and decrease turbidity, which will lead to increased larval survival as well as contribute to higher adult toad recruitment to employ these areas as breeding locations.

Timber harvesting is a double-edged sword that can be incorporated into restoration efforts but should also be carefully regulated. Timber harvesting can certainly be conducted in a way that is not only sustainable but may even have beneficial effects. Coordinated efforts with the U.S. Forest Service to incorporate practices that enhance *A. boreas* habitat, such as leaving woody debris on site and favoring selective timber harvesting over clearcuts, will have a positive impact on *A. boreas* recruitment.

Another component to vegetation regulation is prescribed burns. Wildfires are an integral aspect to the ecology of Montana, but have been suppressed in the past several decades, which has led to an overgrowth of vegetation (Ecological Society of America, 2002). This restricts toad movement patterns, but also increases the frequency of high-intensity fires. Low intensity fires on a regular interval are beneficial to many species of toads, but high-intensity fires lead to more pronounced habitat destruction as well as direct mortality. Forest managers have only relatively recently recognized the importance of incorporating fire to the ecosystem (Ecological Society of America, 2002). Reintroducing this into the ecosystem will not only benefit *A. boreas,* but also other plant and animal species that have evolved with periodical wildfires.

<u>Predator Control:</u> Eradicating bullfrogs in western Montana should also be carried out. However, fish eradication is not an important aspect to *A. boreas*. That does not mean eradication of fish should not be considered in the cases of other amphibian species though,

especially salamander species. Ensuring that the toads have habitat refugia to escape predation should also be an aspect to habitat restoration. This can be accomplished through the creation of pools that have deeper areas, leaving debris on the forest floor after logging, and planting native shrubs.

Livestock Control: Livestock grazing is quite common in Montana, but it is important to regulate this as a component to *A. boreas* management. Occasional grazing can even be beneficial, but this should be strictly monitored, with complete exclusion from riparian areas in the spring and early summer.

Facilitate Beaver Habitat: The reintroduction of beaver (*Castor canadensis*) into their historical habitats will be an important component to the recovery of this and other species. Beaver are often seen as a nuisance species and are often removed by private landowners, but their role in ecosystem functioning cannot be overstated. The habitat modifications they create allow for ideal breeding locations for *A. boreas.* Their reintroduction is a low-cost method of creating these habitats.

Other Considerations: Unfortunately, there are gaps in the research related to this species. One of these is a lack of data regarding long-term trends (COSEWIC, 2012). More research is also needed as to the specifics of toad preferences of one breeding site over another (Pearl and Bowerman, 2006). Toads may use a variety of breeding ponds, but they do not use all of them at the same rate. More in-depth research into the reasons behind this will improve restoration efforts.

Restoration is not a one-time event. It is an ongoing process that requires continual monitoring, and this is no exception. As more data are recorded as to the success of these restoration practices, efforts can be adjusted accordingly.

VI. CONCLUSION

Anaxyrus boreas is an unfortunate example of the effects anthropogenic activities are having on ecosystems. Amphibians have existed on earth much longer than humans and have survived countless environmental changes. However, the Anthropocene is a period that may be their undoing if drastic efforts are not taken immediately. Unless immediate action is taken, most of the global amphibian species may become extinct in the near future.

Implementing efforts now, while healthy populations still exist, will be more effective than waiting until populations diminish to the point where they are at the brink of extinction, as it gives managers time to adjust their efforts as new data come out. Additionally, waiting until populations are so low that there is a lack of genetic diversity makes the potential of a full recovery unlikely. Amphibians are especially susceptible to the negative effects of low genetic diversity—decreased fitness and adaptability, and increased sensitivity to pathogens and pollutants (Allentoft & O'brien, 2010). Small populations are also more vulnerable to detrimental stochastic events (Begone et al., 1990). These events can wipe out an entire population that otherwise would have historically survived such events.

Climate change will drive amphibian declines regardless of which strategies are implemented. A targeted approach can potentially increase the survival of this cold-dwelling species. Some areas may become uninhabitable in the future regardless of habitat modifications, but others may still have the ability to maintain breeding populations, especially if restoration efforts are conducted ahead of time and populations are large enough to contain the necessary genetic diversity to be more resilient to these changes.

The restoration recommendations laid out will not only benefit this species, but others as well. Western ecosystems have generally become disconnected from historical processes, such as wildfire cycles, grazing by bison and other native ungulates, and habitat modification by beaver. These processes helped to regulate the ecosystem in a way that prevented high vegetation density, and severe, catastrophic wildfires. Beaver historically created habitat for many species besides just *Anaxyrus boreas*. Each of these essential processes are largely considered to be a nuisance to modern human activities; however, their suppression has created many problems, even to humans (e.g. decades of wildfire suppression leading to more severe wildfire events). Wetland banking has become a common practice in light of increasing urbanization, and taking these factors into account will contribute to a more properly functioning paradigm going forward.

Even though there are gaps in the research, there is enough to build on to at least start on these restoration efforts. It is important to be in close communication with others working on this and other species. This needs to be an interagency effort.

Humans have largely contributed to the decline of *A. boreas*, and it is therefore fitting that we should also invest the necessary resources in its recovery. The Anthropocene has generally been viewed as detrimental, but the ability of humans to so drastically alter their environment shows just how much of an impact we can have, and this can potentially be used to implement practices that contribute to a more healthy functioning of local ecosystems. Improving habitat restoration efforts should be a very small undertaking for a species that has the capacity to alter the entire global climate.

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