The feasibility of a brucellosis vaccination program for bison in Yellowstone National Park

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ANIMAL ETHICS

Abstract

Wild bison in the Greater Yellowstone Area have been the targets of culling due to political pressure from the animal exploitation industry who fears that bison will spread brucellosis to cattle. Vaccinating bison and other wild animals against brucellosis could be a way of not only preventing the killings, but also protecting them from the natural harms related to the disease. Currently, there is mandatory vaccination of cattle and domesticated bison in areas surrounding the park. However, problems with the vaccine impede the success of a possible mass vaccination program against brucellosis for bison inside the park. First, elk, rather than bison, appear to be the main transmitters of the disease. Second, the currently available vaccine does not appear to prevent the disease in elk. Third, the ability to develop a more effective vaccine is very limited. This report considers what could be done to improve this situation and suggests and explores ways in which both bison and elk might be helped rather than harmed in the future, including, in addition to the development of new vaccines, contraception.

Introduction

Animals in the wild often suffer from infectious diseases for which there are no cures or effective preventative vaccines. In some cases, wild animals are killed when they are stricken with diseases that potentially affect other animals under human control. Justification for killing animals in this situation relies on a framework that disregards the interests of individual animals and sees them only as reservoirs of disease or as possible threats to the income generated by exploiting other animals. Bison (*Bison bison*) in Yellowstone National Park have been regularly killed on the premise that it will help control the spread of the infectious bacterial disease known as brucellosis. Hundreds of them have been killed each year. Although numerous lawsuits have been brought by bison advocates around the US and residents in the vicinity of the park, many in the ranching and farming communities have supported the yearly slaughter. The economic reliance on dairy farming and ranching within the three states comprising the Greater Yellowstone Area has been a source of ongoing conflict since the early 20th century when brucellosis was discovered inside Yellowstone Park. Ranchers in the area have claimed that wild bison have infected the cattle on their property, leading to economic losses for the animal farming industry through abortions, infertility, lowered milk production, and killing sick animals. The vaccines developed and deployed to protect animals used for food from being infected with brucellosis have also been used on wild bison for over thirty years to attempt to prevent disease transmission to herds of domesticated animals.

This is, therefore, a case of a conflict between policies harming animals living in the wild and policies that could prevent both anthropogenic and natural harms (Animal Ethics 2020a). Vaccination can be used not just to prevent animals like bison from being killed because they can transmit a certain disease, but also to save them from a disease that may otherwise affect them. In fact, vaccination has been typically advocated as a promising way of reducing wild animal suffering that also exemplifies how work in natural science can be applied in ways that could make a significant difference for animals (Koenig et al. 2007; Gormley et al. 2017; Animal Ethics 2020b; Faria & Horta 2019).

In this report, we will examine the prospects for this measure for bison and other animals in the Greater Yellowstone Area. We will first examine the past and current situations of bison in the Greater Yellowstone Area. We will then show how brucellosis has spread in Yellowstone. Next, we will consider how the animal farming industry heavily controls policies concerning the management of bison in ways that are negative for them because they are potential transmitters of brucellosis. We will see the present jurisdictional and regulatory complexities confounding the situation of bison in Yellowstone. We will then see why vaccinating elk could be more effective than vaccinating bison and we look at the obstacles currently impeding its success. Finally, we consider options like contraception and spreading awareness and concern for animals in the wild.

History of bison in Yellowstone

Yellowstone National Park, established in 1872 as the world's first national park, is in the northwestern United States. It covers parts of three states, and much of its almost 3,500 square miles (8,991 km2) sits inside a volcanic caldera (Yellowstone National Park). Most of the park is in Wyoming. A small section to the north and northwest of the park lies in Montana, and a sliver on the far west in Idaho. Visitors to the park average over 4 million every year (NPS 2022c). In addition to approximately 5,000 bison and 125,000 elk, animals from 67 species of mammals, 285 species of birds, 16 species of fishes, and various species of amphibians and reptiles live in Yellowstone (Geremia 2020; NPS 2021b).

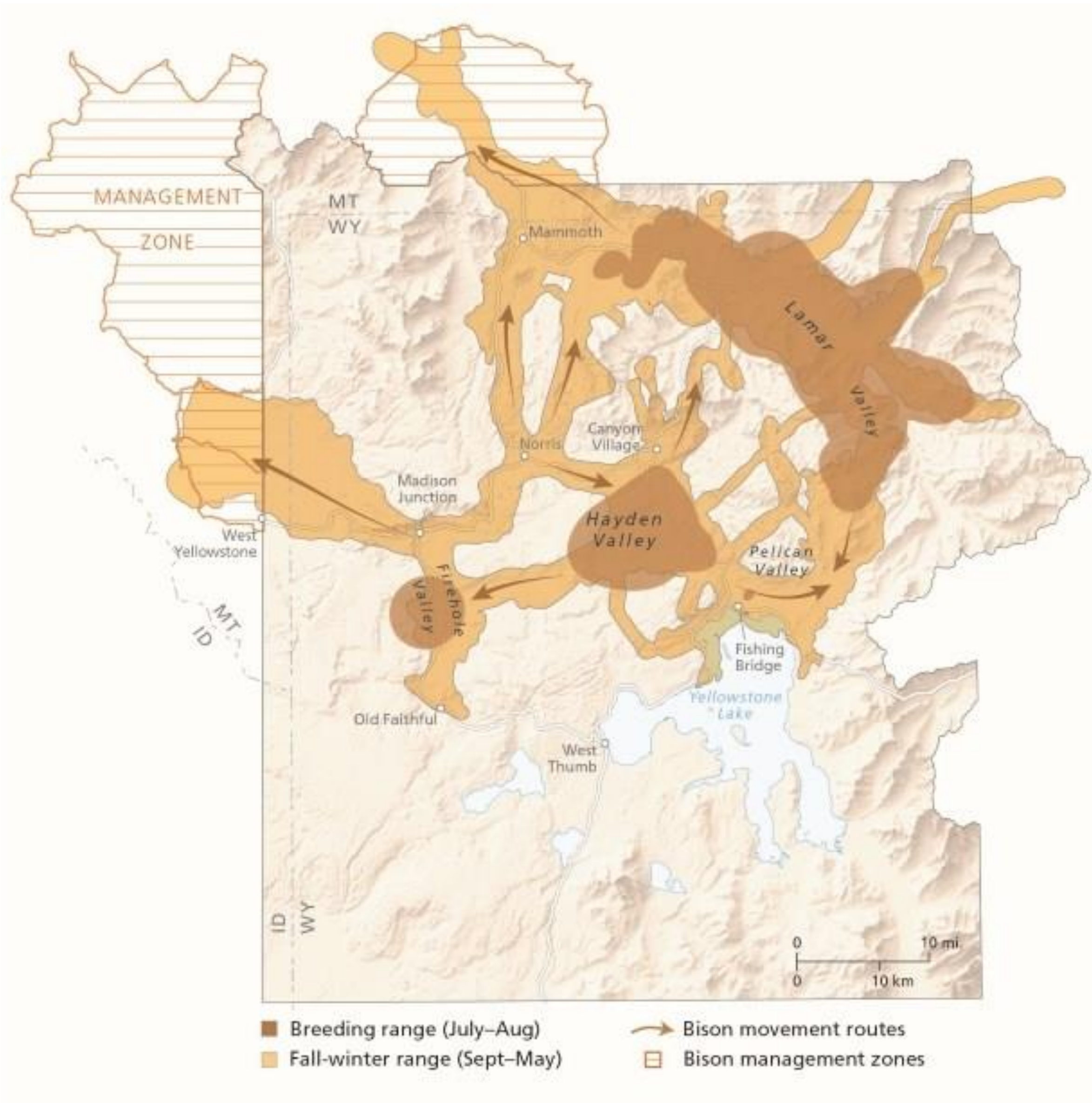
Bison, referred to by some as buffalo, have lived in the Greater Yellowstone Area (GYA) continuously since prehistoric times. According to the National Park Service (2021b), only about two dozen bison survived in the Pelican Valley following the mass extermination of hundreds of thousands during the late 19th century. A few more found protection on private ranches. Today about 500,000 bison live in North America, the majority of which are in privately owned herds (Yong 2019; Greater Yellowstone Coalition 2021). Around 20,000 live on public lands, and only about 8,000 are free to move without barriers. At the time of the 2021 count, approximately 5,450 of those unfenced bison lived in Yellowstone (Geremia 2021). Spatial modeling of the Yellowstone system has found that the park has a "food-limited" carrying capacity of at least 6,200 bison (Plumb et al. 2009; IBMP 2009).

The annual population growth of bison is 10-17% due to high survival rates and reproduction. The bison population numbers are managed by the National Park Service (NPS) using an integrated population model which considers the current number of bison, their age, and sex. The NPS currently recommends killing or removing animals from the herd each year to maintain a population of under 5,000. The bison are removed through tribal hunting, quarantine, or by being sent to slaughter (NPS 2021a; Geremia 2021).

Today there are two primary herds, northern and central, defined by their breeding grounds.[1] The central herd is currently less than half the size of the northern herd. During the breeding season (summer) the northern herd can be found in the Lamar Valley and nearby areas. The central herd occupies the central plateau of the park, from the Pelican and Hayden valleys in the east to the lower-elevation and Madison headwaters area in the west. They congregate in the Hayden Valley for breeding and move throughout the valleys to the east and west during the remainder of the year. Recently, bison from the central herd have begun assimilating into the northern herd (NPS 2022a).

Bison in the GYA travel up to 70 miles between their summer and winter ranges within the park and adjacent landscapes. Most cover about 1,000 miles over the course of a year back and forth between their preferred areas (NPS 2022a).

1 Although it is beyond the scope of this report, there is disagreement about differences in the genetic lineages of the northern and central herds. For further discussion, see Halbert et al. (2012); White & Wallen (2012); and Forgacs et al. (2016).



Seasonal distribution of Yellowstone bison

Adapted from Marcus, W. A. (2022)

Brucellosis

History of brucellosis in Yellowstone

The Bison National Legacy Act 2016 named the Yellowstone bison as the national mammal of the US (Bison National Legacy Act 2016; Simon 2016). They are the most iconic and arguably most vilified animals living in the park (NPS 2022a; White et al. 2015). Although nearly all signage of the National Park Service and Yellowstone National Park (YNP) prominently features images of bison, hundreds are killed every year as they leave the park during their annual winter migration. Despite their long history in the Yellowstone area, what bison represent for many is brucellosis, a highly infectious disease carried by up to 60% of all Yellowstone bison (NPS 2021a).

Brucellosis, colloquially known as contagious abortion or Bang's disease, is a disease caused by a group of bacteria of the genus *Brucella*. The type of brucellosis that primarily infects animals in Yellowstone is known as *Brucella abortus* (*B. abortus*), one of the six types of the *Brucella* bacteria. *B. abortus* was discovered inside YNP in 1917 (Treanor et al. 2010). It was most likely introduced to North America when infected cattle were imported from Europe in the early 1860s, although some trace-back studies suggest that some bison brought to the park in 1902 might have been already infected (Mosley & Mundinger 2018; Meagher & Meyer 1994). The question of the bacteria's origin in North American cannot be answered definitively but persists due to arguments about removing the wild bison for the protection of animals used for food (Meagher & Meyer 1994).

Effects of brucellosis in animals and humans

Brucellosis primarily infects hoofed mammals like cattle, bison, and elk, but can also be spread to other animals including humans. In humans, the disease can be recurrent and debilitating, and lifelong infection is possible (NAS 1998). There is no available vaccine for humans, but they can be treated with antibiotics (CDC 2021). In the US there are only about 100 cases of the disease reported each year, and most of these infections occur when travelers from the United States consume unpasteurized milk while abroad (Glynn & Lynn 2008).

In ungulates the disease doesn't cause death in adult animals. It primarily affects the reproductive system and mammary glands, associated lymph nodes, and lymph nodes of the head and neck. It often causes infertility, retained placenta, spontaneous abortions, and weakened newborn calves (NAS 1998; Nishi 2010). Some studies suggest that bison might be more susceptible to brucellosis than cattle. Davis et al. (1991) found that 2% of cattle aborted when they contracted the 2038 strain of brucellosis after being vaccinated with the S19[2] vaccine compared to 58% of bison. Additionally, in unvaccinated cattle and bison exposed to the virus, higher rates of both infection and abortion occurred in bison compared to cattle (Olsen 2012; Olsen & Johnson 2012).

In bison the *B. abortus* bacteria can be primarily confined to the lymph nodes, spleen, and other lymphoid organs, which harbor fewer bacteria than when the disease affects the reproductive organs (NAS 1998). Bison affected in this way do not shed bacteria in saliva, urine, or other bodily secretions. Bison with non-reproductive tract infections pose little risk of disease transmission to other animals (NAS 1998). Brucellosis may also cause suffering to bison through general malaise, abscesses, chronic septic arthritis, lameness, weight loss, bursitis, and swelling of the testes in males (Rhyan et al. 2013b).

Brucellosis is one of the most regulated diseases of domesticated animals exploited for food in the United States. Under United States Department of Agriculture (USDA) regulations, states are classified according to the success of their brucellosis control and eradication programs (Federal Register 2010). Other diseases lead to more morbidity and mortality, but today all cattle transported interstate are routinely tested only for

2 Strain 19 is a live attenuated vaccine and the first *B. abortus* vaccine to be used extensively for bovine brucellosis control. In the US, this vaccine was used for more than five decades from 1941 and is still being used in several other countries (Dorneles et al. 2015).

tuberculosis and brucellosis (NAS 1998). Fears about the negative impacts of the disease led to the formation of the Cooperative State-Federal Brucellosis Eradication Program in 1934. The program was a direct response to demands from the animal industry based on their views about both human public health and economic consequences resulting from infected herds. National practices for testing, quarantine, and culling implemented through that program have changed very little over the last century (NAS 1998) despite the virtual eradication of brucellosis in cattle in the early 2000s. Only the GYA remains a reservoir for the disease (USDA APHIS 2020a).

Transmission of brucellosis

The primary route of transmission of brucellosis is through direct contact with birthing materials. Animals may sniff or lick the aborted fetus or contaminated substances (USDA APHIS 2020a; Nishi 2010). The numbers of bacteria in infected milk are high enough to be considered a serious risk of transmission from cow to calf (Treanor et al. 2010). It can also be passed through contact during breeding but that isn't considered significant in the transmission of the disease (Nishi 2010).

Most bison are infected with the *B. abo*rtus bacteria at 8-12 months[3], but females will typically not begin shedding the bacteria until about three years old as they reach reproductive age (Roffe et al. 1999; Rhyan et al. 2009; Treanor et al. 2011; White et al. 2015). Following the initial infection of the female, the bacteria remain inactive in the lymph tissues until the latter part of gestation when they multiply and spread throughout the reproductive tract (White et al. 2015). The rapid increase of bacteria can induce abortions, still-births, and premature live births in some animals (Rhyan et al. 1994; Grovel & Moreno 2002). It's possible for females to clear the bacteria and completely recover after the first infective phase. Some will retain the bacteria and potentially shed it during subsequent pregnancies, while others could become

3 For a more detailed explanation of the cycle of transmission in bison see White et al. (2015).

reinfected in the future by contact with birthing materials from other animals. In these cases, the risk of abortion and further spread would be reduced by a healthy immune system (Treanor et al. 2011).

The spread of brucellosis

Vulnerability to infection and spread of brucellosis are increased during the winter months when both bison and elk experience compromised immune systems due to chronic undernourishment (Treanor 2013). However, increased transmission depends on infected animals being near others and giving birth or aborting the bacteria into the environment
(Cross et al. 2007; Kilpatrick et al. 2009; Schumaker et al. 2010; Kauffman et al. 2013). The risk of transmission from bison and elk to cattle depends largely on the extent bison are forced into lower elevations outside of the park in search of food in late winter and early spring and how often interactions occur (Kilpatrick et al. 2009; Schumaker et al. 2010; Schumaker 2013; Hobbs et al. 2014). The persistence of *B. abortus* in the environment presents an additional complexity. Research carried out by Aune et al. (2011) showed that the *Brucella* bacteria can live in birthing materials and soil or vegetation for 21-81 days. In colder, darker winter months like February, they found that the bacteria can last much longer than in warmer sunnier months. In the Aune et al. study, no bacteria survived beyond early June. This type of research is the basis for the current spatial and temporal separation of bison and cattle to lower risks of transmission.

Ranchers in the GYA claim that the spread of brucellosis from wild bison to domesticated animals leads to economic losses through abortions, infertility, lowered milk production, and killing of infected animals (USDA APHIS 2007; Goodman 2016). In addition, infected herds cannot enter interstate markets (Keiter 2020). Since the early 20th century, the federal government, the states, and the ranching industry have spent billions of dollars attempting to eliminate the disease in the US. The perception that bison alone are responsible persists in much of the GYA ranching industry. The animals are also held responsible for causing property damage, damage to rangelands, and consuming the forage claimed by ranchers for their herds (Goodman 2016). One trend for protecting the ranching industry has been to manage wild bison by not allowing a population above 3,000, frustrating their yearly migration patterns, and keeping them separate from domesticated animals year-round within the boundaries of the park or within herds on either tribal or private land. (CBS Sacramento; GYC 2021; Keiter 2020; French 2020). There are some calls for hunting inside the park to further reduce the number of bison leaving during migration. However, hunting inside Yellowstone is illegal, and park managers strongly oppose this idea (NPS 2018; 2021b).[4]

The animal industry influence in the GYA

The economies of the three GYA states — Montana, Wyoming, and Idaho — rely heavily on the animal farming industry, and the attitude of many ranchers is that if any wild bison appear to pose a risk of disease transmission to their herds, then bison should be the focus of disease control. Bison have been subject to slaughter as they leave Yellowstone Park but elk are allowed to roam relatively unfettered although multiple elk to cattle transmissions in Wyoming and Idaho have been detected through DNA testing (Bienen & Tabor 2006).

Most of the park lies in Wyoming, but the Montana ranching community wields enormous power in the area. With 58.1 million acres of land devoted to farming and ranching, Montana ranks second in the nation. Cattle raised for food are the state’s most important agricultural product (Montana Agricultural Facts 2020). In the most recent census, the value of all cattle sold in the state was approximately $1.3 billion (Sommer 2021).

4 For an overview of the Lacey Act, see Wisch (2003).

In 1995, under pressure from its constituency, the Montana legislature assigned management of bison "that are from herds exposed to or infected with brucellosis," i.e., those migrating into Montana from Yellowstone, to the Montana Department of Livestock. As a result, considerable control of the fate of bison was handed to the Montana government's animal agriculture arm (NPS 1995; Montana Code Annotated 2021).

Brucellosis management — the Interagency Bison Management Plan

With the establishment of the park, the bison gained protection from hunting, and by 1954 the population had grown to about 1,300 despite near yearly culling since the early 1920s. This practice was halted due to a moratorium in 1969, and the herd increased from a low of 500 in 1970 to 3,000 in 1990 (NPS 2021b).

The concurrent increase in the elk population created competition for food and bison began crossing the northern and western park boundaries in increasing numbers during the winter. Between 1985 and 2000, about 3,100 bison were killed as they migrated outside the park in search of food. Some were captured and sent to slaughter while others were shot by hunters or state agents.

The National Park Service was sued by the state of Montana in 1995 for allowing potentially brucellosis-infected bison to leave the park and enter private property. After five years of litigation, consultation, study, and temporary plans, Montana and the US federal government established the Interagency Bison Management Plan (IBMP).

In 2000, the Final Environmental Impact Statement and Bison Management Plan for the State of Montana and Yellowstone National Park (also referred to as a Record of Decision) was signed as a joint management plan, subsequently becoming the IBMP (Keiter 2020). The signatories included the Director of the National Park service, a representative from US Department of Agriculture Animal and Plant Health Inspection Service, the Chief of the US Forest Service, and the US Secretaries of both the Interior and Agriculture. The plan professed a long-term commitment towards eradicating brucellosis in YNP, but its primary mission was to minimize brucellosis transmission in the GYA through population control and keeping bison away from cattle (IBMP 2000). The IBMP was explicitly established as a direct consequence of bison leaving Yellowstone Park and entering Montana during the winter migration.

IBMP 2000-2010

The first IBMP established a bison herd target of 3,000 to be achieved through lethal means such as serotesting (blood tests) for brucellosis and subsequent slaughter of those testing positive and killing, primarily by Montana state agents (Keiter 1997; Keiter 2020). It is important to note that serologic testing is only indirect evidence of infection, and many seropositive animals are killed who would likely be incapable of infecting others. This includes many males, who can't transmit the disease through birthing materials, and fully recovered females. In addition, bison with non-reproductive tract infections pose virtually no risk of transmission to other animals. Simultaneous testing by serology and bacterial culture conducted on slaughtered animals suggests that seroprevalence, the number of animals who test positive for exposure, will appear two to four times higher than the prevalence of infection established through bacterial culture (Kilpatrick et al. 2009). Using current diagnostic technology, a positive blood test does not necessarily indicate infection; only culturing performed after death can determine that.

A complicated zoning plan was designed for the separation of bison and cattle. It included the hazing of bison back into the park in the spring, from grazing areas in Montana, as soon as they could return based on snow and weather conditions. Hazing could mean that the animals were driven by riders on horseback, helicopters, or land vehicles like trucks and other all-terrain vehicles. If hazing was unsuccessful in moving the bison back into the park, they would be captured or shot (IBMP 2000).

Capture, test, and slaughter of brucellosis seropositive bison at two park locations was an integral element of the plan. Some seronegative pregnant bison were to be monitored with radiotelemetry collars and vaginal radiotelemetry implants in case of a birthing or abortion event. Although elk are acknowledged in the plan as reservoirs of brucellosis along with bison, the belief at this time was that the risk of elk to cattle transmission was much lower than that of bison to cattle transmission (IBMP 2000).

The 2000 plan suggested hunting for population control outside of the park as a future option (IBMP 2000). Montana Fish, Wildlife & Parks (MFWP) subsequently completed its Final Bison Hunting Environmental Assessment in September 2004, and hunting was reinstated in the Western Yellowstone Basin in September 2005 as part of the IBMP's 5-year status review (MFWP 2004; Clarke et al. 2005).

IBMP 2000 contained an experimental bison vaccination program and followed adaptive management principles (Keiter 2020) allowing alterations to the plan as needed based on ongoing research as well as the situation on the ground. The planned vaccination program relied on the approval of a safe and effective vaccine and, crucially, a safe and effective remote delivery system. During the commentary period prior to adoption of the final 2000 plan more than 1,700 of 4,000 commenters expressed support for mandatory vaccination of cattle alone, while 1,800 supported or strongly supported a vaccination program for bison provided a safe and effective vaccine was found . Many also expressed concern for the physical and psychological welfare of bison calf vaccinates, while others worried that the plan contained no provisions for cessation of the experimental program should bison suffer negative impacts from the vaccine (IBMP 2000).

In response, mandatory cattle vaccination became a possibility with adoption of the plan should voluntary vaccination not reach 100% compliance. Although awaiting pending biosafety studies for the RB51/SRB51[5] vaccine, the plan preemptively

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5 RB51, also known as strain RB51 (SRB51), is a live attenuated vaccine that has been licensed in the US for use in cattle against brucellosis since 1996 (USDA APHIS 2018).

included a stepwise program to vaccinate vaccine-eligible bison, i.e., those who tested seronegative and were not slaughtered, as well as any calves captured trying to exit the park. As of the signing of the plan, no vaccine and no remote delivery system had been analyzed and proven safe and effective according to the included vaccination protocol (Montana Department of Livestock 2004). Those commenters concerned about the welfare of bison vaccinates were given little assurance, only that in the event of negative impacts to bison, the IBMP agencies "might modify, adjust or begin a new, safe program" (IBMP 2000).

In 2004, a Bison Vaccination Environmental Assessment (BVEA) was undertaken because the vaccination program was still on hold. Prior studies concluded that the RB51 vaccine was safe for use in both free-ranging bison and non-target species. The vaccine also had the advantages of inducing an immune response similar to that in cattle and not interfering with subsequent pregnancies and the delivery of normal calves. RB51 is also a Distinguish Infected from Vaccinated Animals (DIVA) vaccine, so it does not induce antibodies that would be confused with the presence of disease in serotesting, thereby preventing some animals from being killed (Olsen et al. 1997; 1998). The purpose of the 2004 BVEA was to document these conclusions and evaluate the best ways of moving ahead with the vaccination program delineated in the 2000 IBMP (Montana Department of Livestock 2004).

In 2009, IBMP began producing and publishing an annual report on its new website for purposes of public transparency. According to the 2009 report, intermittent hand vaccination had been practiced on captured bison at the Stephens Creek facility at the northern edge of the park, although the report states that no bison had been captured and vaccinated during that reporting year. The management recommendation was to proceed with the development of a consistent and coordinated vaccination program covering both the north and west boundaries of the park which would include both central and northern breeding herds. The National Park Service had prepared a Draft EIS for remote vaccination with the final Record of Decision on whether to proceed expected in summer 2011 (IBMP 2009). The 2010 report extends the tentative date of the final EIS and ROD to winter 2012, but it was not completed and signed until early 2014 (IBMP 2014). Remote vaccination still seemed feasible in 2010 although the report concedes that RB51 offers little protection from infection but does reduce shedding of the *B. abortus* bacteria and therefore should reduce seroprevalence of brucellosis in bison over time (IBMP 2010).

IBMP 2013-2014

Despite its prior positive outlook on vaccination, during 2013 and 2014 two sets of research findings changed the course of the IBMP and might have signaled its obsolescence (IBMP 2013; 2014). Schumaker et al. (2010), veterinarians from the University of California, Davis working with the NPS concluded that mass vaccination of bison against brucellosis would be ineffective in reducing transmission to cattle. Seroprevalence in bison was not declining (IBMP 2013). The killing of bison due to seropositivity and hunting (Keiter 2020) continued without making any impact on transmission rates. However, the risk of bison contact with cattle had been significantly minimized due to temporal and spatial separation. The Schumaker et al. study found that the transmission risk from bison to cattle was insignificant (0-0.3%) compared to elk (99.7-100% of total risk).

Although inconsistent syringe vaccination of calves would continue, the new knowledge regarding elk transmission along with a review of remote vaccination research questioned the feasibility, efficacy, and welfare and psychological effects of remote delivery on bison. A panel of eight wildlife scientists concluded that the available data didn’t support remote vaccination of bison with current vaccines (IBMP 2013; MFWP 2013). The NPS issued a Record of Decision in March 2014 against a remote vaccination program, citing lack of vaccine effectiveness, potential unintended adverse consequences to bison, and high cost (IBMP 2014).

Why vaccinating elk, rather than bison, should be the solution

Eradication appears unattainable for now and is not a current objective of the IBMP (2021a). Since the signing of the first IBMP in 2000, brucellosis has been increasing in the GYA and the risk of it spreading beyond the GYA is growing. In 2000, vaccination using available vaccines seemed a certainty for controlling brucellosis in bison and preventing both their slaughter due to positive serotesting and further spread of the disease. However, studies on the RB51 and S19 vaccines and delivery systems have shown unsatisfactory results, and development of new ones is unlikely in the near term due to funding and regulatory complications (IBMP 2014; NAS 2020). In addition, the management of brucellosis transmission to cattle has shifted radically away from bison forcing the IBMP to alter some of its practices.

Elk are the main transmitters of the disease

Evidence suggesting that elk (*Cervus canadensis*) are a much greater source of transmission to cattle than bison are to cattle has been called the most important update to understanding brucellosis in Yellowstone since 1998 (Bienen & Tabor 2006). Bison were previously thought to be sources of the infection because rates of brucellosis are higher among them. However, due to IBMP spatial and temporal grazing separations (White et al. 2015), hazing and hunting, bison rarely interact with cattle in ways that facilitate transmission of the infection. In contrast, there have been documented cases of transmission from elk to cattle. Genetic analysis also strongly indicates that elk are a greater source of transmission. The strain of brucellosis that is most common in cattle is virtually identical to the strain most common in elk, differing only in one or two mutational steps. In contrast, the strain that is most common in bison differs by 12 to 20 mutational steps (Beja-Pereira et al. 2009; Kamath et al. 2016). All cases of brucellosis in cattle herds from 1998 - 2017 could be genetically and epidemiologically traced to elk, and evidence suggests this trend continues today (NAS 2020).

Unlike bison, elk frequently do commingle with cattle, and it is very common for elk to migrate throughout the GYA from any of the 22 elk feeding grounds around Yellowstone (Cross et al. 2013). In addition, elk in and around feedground areas have significantly higher rates of brucellosis (20-30%) than those not frequenting them (Beja-Pereira et al. 2009). Unfortunately, rates of infection among elk have been increasing in recent years and evidence strongly suggests that elk herds maintain brucellosis infections without contact with other animals, meaning that they can function as a reservoir for infecting others (Kamath et al. 2016; NAS 2020).

There have been no known cases of GYA bison to cattle transmission of brucellosis despite the high seroprevalence of brucellosis in bison. Even with the lack of evidence that they are a driver of transmission to cattle, bison primarily have been targeted by attempts to control the disease through proposed vaccination programs, hazing, and culling. To date, there have been no studies on contact between elk and cattle in the GYA (NAS 2020). Elk as a source of transmission may not be the focus because there are economic interests in maintaining a large population in the area. Although the practice of feeding wild ungulates has decreased sharply in other areas, Wyoming continues to cater to its powerful hunting and ranching communities by feeding about 13,000 elk each year on the 22 feedgrounds it oversees (Keiter 2020). The feedgrounds are intended to prevent elk from dying of starvation and give hunters more animals to shoot. The feedgrounds also help keep elk away from cattle and stored feed for them and other domesticated animals (Tara Kuipers Consulting 2021). The lack of an economic interest in the Yellowstone bison might make scapegoating them easier than focusing on elk. Bison may also be targeted on the pretense that they compete with the ranching industry for grass, may pose a danger to humans, and damage property (NPS 2022a). These additional factors could be the real reason that some ranchers support confining the Yellowstone bison within the park or even killing them. Elk would be a less convenient target given economic interests, so the abundant evidence that elk play a larger role in transmission may be ignored. It could also be argued that with 125,000 elk and only about 5,000 bison in the GYA, the smaller target might seem more manageable.

Problems with existing vaccines

Vaccination is a widely accepted and proven method of protecting animals and controlling infectious diseases on a large scale. The best-known vaccination programs have been vaccination against rabies which has been carried out in various countries (OIE 2021). The brucellosis vaccine RB51 was developed in 1982 (Dorneles et al. 2015) and licensed for use in cattle in 1996 (USDA APHIS 2018). Since then, it has been a valuable tool in eradicating the disease in cattle in the US and across the world (Animal Ethics 2020b; Yang et al. 2021). An improved vaccine for elk, bison, and cattle would help suppress and could eventually eliminate brucellosis in the GYA. For wild bison and elk, safe and cost-effective vaccine delivery systems would be critical (NAS 2020).

Unfortunately, the current vaccines for brucellosis are suboptimal in many ways. First, the approved ones, S19 and RB51 are both effective for cattle but offer virtually no protection for elk. Elk on feedgrounds in Wyoming were vaccinated ballistically with S19, using biobullets shot from a type of air rifle, beginning in 1985 without lowering seroprevalence, and with little effect on abortion numbers (Cross et al. 2013). The program was halted due to ineffectiveness.[6] The differences between the immune responses in cattle and elk aren't well understood, and a safe and reliable vaccine will require significantly more research. The most promising vaccine for bison, RB51, seems safe for them, including males, pregnant females, and calves (Elzer et al. 1998) but effectiveness in the field varies widely. Results for protection against abortion using RB51 ranged from 0% to 100% over studies conducted from 1999 to 2015 (NAS 2020).

6 In addition, the manufacturer of biobullets halted its production. For additional information on remote vaccination of feedground elk, see National Academies of Sciences, Engineering, and Medicine (2020).

A more effective vaccine will be necessary to eradicate the disease in the area if that is a goal for the future. Second, RB51 is only available commercially as an injection, which first requires taking the animals into captivity. This is far more stressful for animals than technologies that are available for other vaccines, such as oral baits. Studies on remote vaccines using biobullets have yielded conflicting results (Olsen et al. 2002; 2006; 2007).

Third, regular booster doses are required to maintain effectiveness (Olsen & Johnson 2012; Olsen et al. 2015), and the methods of delivering the boosters are similarly invasive, requiring capture and manual injection. Finally, according to the *Brucellosis science review workshop* (MFWP 2013), remote vaccination with RB51 would not be sufficiently effective at reducing brucellosis in wild bison to satisfy the ranching community and compel a change in IBMP strategies. The best available data at the time of the 2013 report suggested that remote vaccination would not be cost-effective for preventing brucellosis spillover into cattle even were a vaccine of 100% efficacy employed. The cost was estimated to be $300,000-$500,000 annually to optimistically achieve a 30% drop in prevalence over 30 years. However, given contemporaneous data and management processes, the drop in prevalence was estimated to be closer to 3% than 30% (MFWP 2013). This assessment could change with new technologies, but the IBMP's 2009 statement that lack of market incentives and research funding had hampered the development of new or improved vaccines, delivery technologies, or diagnostic tests for *B. abortus* over the previous 15 years is still relevant (IBMP 2009). No new vaccines, remote delivery systems, or diagnostic tests have been developed for use.

As evidenced by an analysis of the history of the IBMP, an additional challenge to a successful vaccination program in the GYA is the slow-acting multi-jurisdictional bureaucracy. Multiple mandates across states and agencies are likely to hinder coordination of a vaccination campaign. Vaccination of targeted wild populations might be successful for brucellosis reduction in the short term, but barring complete eradication, an expensive program might need to be maintained in perpetuity to avoid a resurgence (Cross et al. 2013). This would require a challenging approval process across a large stakeholder constituency which includes the National Park Service, the US Forest Service, US Fish and Wildlife Service, Bureau of Land Management, US Department of Agriculture Animal and Plant Health Inspection Services, as well as individual state agencies in Montana, Wyoming, and Idaho whose jurisdiction often overlaps with federal agencies (Keiter 2020).

Designation of *B. abortus* as a bioweapon

Likely the most serious obstacle to vaccine research is the inclusion of three species of *Brucella* — (*B. abortus*, *B. melitensis*, and *B. suis* — on the biological select agent and toxins (BSAT) list since its inception.[7] This is a list of substances "determined to have the potential to pose a severe threat to both human and animal health, to plant health, or to animal and plant products" (CDC 2021). The list has been overseen jointly, depending on the specific agent, by the US Department of Health and Human Services and USDA since 1996.[8] It was codified as part of the USA PATRIOT Act in 2001 and the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 and the Agricultural Bioterrorism Protection Act of 2002. All three were eventually designated overlap agents because they appear on the lists of both agencies due to their zoonotic capabilities (Olsen et al. 2018). The BSAT designation for *B. abortus* requires

7 Other serious impediments to the development of new more effective vaccines and delivery systems include the classification of the *B. abortus* bacteria as a biosafety level 3(BSL-3) of 4 levels. A BSL-3 agent is one with potential for aerosol transmission causing a disease which may have serious or lethal consequences. Research on *B. abortus* requires enhanced containment facilities, BSL-3/ABSL-3/BSL-3-Ag or higher. The "A" in this designation refers to animal, and BSL-3-Ag is a special biosafety level referring to foreign animal disease agents defined as "high consequence" by the USDA, meaning their dispersal could have a potentially significant impact on the nation's economy (NAS 2020; CDC 2013).

8 For more information on the history of the select agent program see CDC (2020).

that researchers have facilities, follow complex protocols and reporting requirements, and possess security clearances that are beyond the requirements for a BSL-3 pathogen. Many institutions find compliance out of their reach (NAS 2020). Some important research has been halted due to compliance interpretation issues. Studies on land use in previously infected areas, remote vaccination of wild animals, and the ability of male bison to transmit brucellosis were decommissioned in 2017 along with a study examining the transmission of bison treated with contraceptives (Eatherton 2017).

There can be significant costs associated with research on BSAT listed materials beyond the direct costs of the research itself. Select agent regulation costs related to security, personnel screening, and compliance compound project costs and likely reduce the number of funded projects overall. Because of these associated hardships, many studies on brucellosis must be done using the S19 strain of the disease, but not being able to study the disease directly may introduce inaccuracies (NAS 2020).

A better future for Yellowstone bison

New vaccine technologies

According to the National Academies of Sciences, Engineering, and Medicine, 22 cattle herds in the GYA were infected with brucellosis following their 1998 report. The animals in all 22 herds had at minimum been vaccinated as calves, and some had been vaccinated as both calves and adults. Given the lack of contact between bison and cattle, this suggests at least some herds mingled with infected elk. We shouldn't assume from this that vaccination, per se, is ineffective but improved vaccines might be more beneficial. An improved vaccine for use in cattle may appear more logistically feasible (Cross et al. 2013), but better vaccines for each of the three affected species in addition to remote vaccine delivery systems for bison and elk could help both suppress and eventually eliminate brucellosis in the GYA (NAS 2020).

Dorneles et al. (2015), in a review of brucellosis vaccines, list only a few vaccines as having been used in cattle immunization against *B. abortus* on a mass scale — S19, RB51, 45/20, and SR82 — and highlight S19 and RB51 as the most widely used. They review additional *B. abortus* vaccine candidates that have been more recently developed, including DNA, subunit, and recombinant *B. abortus* vaccines. The majority have not been tested in cattle (or bison and elk) and some have shown no protection in cattle.

DNA vaccines contain only a portion of a pathogen's genome. Several DNA vaccines have been found to provide various levels of protection. These vaccines have the advantage of being inexpensive to produce and large quantities of vaccine can be manufactured easily and quickly. A DNA-derived vaccine has been successfully adapted and licensed for horses against West Nile virus, and bison calves appear to be responsive to these types of vaccines (Davis et al. 2001). Despite some of *B. abortus* DNA vaccine candidates showing encouraging results, several boosters may be needed to maintain protection, and this could be impractical in bison and elk and increase overall costs (Dorneles et al. 2015).

A subunit vaccine contains the purified parts of a pathogen, such as *B. abortus*, necessary to elicit a protective immune response. Subunit vaccines don't contain the whole pathogen, unlike the live attenuated RB51 and S19 vaccines or inactivated vaccines. The potential use of *B. abortus* subunit vaccines under field conditions appears limited. The requirement of multiple boosters would likely render it economically unsuitable for use in large wild animals (Dorneles et al. 2015).

Vaccines produced by using recombinant DNA technology, the mixing and purification of DNA from two different sources are called recombinant vaccines. There are several broad categories of recombinant vaccines including subunit, attenuated, and vector (Shahzad et al. 2019). These types of vaccines are sometimes referred to as recombinant mutants due to the use of DNA from different sources in one vaccine. Dorneles et al. (2015) suggest that the most promising research indicates the future of *B. abortus* vaccination lies in the use of recombinant mutant vaccines. They appear to exclude some of the drawbacks of current vaccines while increasing immune responses. However, a 2009 study from Olsen et al. found that the parental vaccine RB51 was more effective in bison calves than the mutant RB51+*sodC*.

Immunotherapeutic vaccines are vaccines that can stimulate immune responses to components of an infectious organism not usually recognized by the immune system because their concentration is too low or sequestered in specific tissues. Therapeutic vaccines may also redirect a protective immune response. Although these types of vaccines are unlikely to be developed soon, they should be part of future research (NAS 2020).

Some pessimistic researchers fail to see real solutions for diseases such as brucellosis in wild animals for at least another decade due in part to prohibitively high costs of vaccination. The *B. abortus* reservoir in the GYA consists of wide-ranging groups of herbivores and oral baits appear to be the most cost-effective and least invasive method of vaccine delivery. However, most past successes with oral bait delivery have involved carnivores or omnivores who may be easier to attract with baits (Cross et al. 2013).

Fortunately, some important advances have already been made in this direction. One trial of the RB51 vaccine mixed into feed for cattle showed promising results (NAS 2020; Elzer et al. 1998). Two trials of vaccinating red deer (who are closely related to elk) using oral baits containing RB51 also had promising results, with the deer showing elevated cellular immune responses to brucellosis. No mortality or adverse health effects have been seen from oral vaccination against brucellosis. To further reduce the need for stress inducing contact with the animals, an extended-release vaccine has also been developed and tested on red deer. This vaccine delivery method contains polymers that slowly degrade after consumption releasing the vaccine over a long period of time. This mimics the effect of a booster dose of the vaccine (Arenas-Gamboa et al. 2009).

Importantly, it seems likely that because of the method of delivery, an orally administered vaccine would also be more effective at preventing infection. Orally administered vaccines work on the mucosa of the animal, which is also the area most exposed to brucellosis when animals lick birthing materials. Studies on mucosal delivery have thus far been disappointing, but the research in nasal delivery of a vaccine is likely to continue (Suraud et al. 2008). Oral bait vaccine technologies could potentially revolutionize efforts to eradicate brucellosis if they can be made attractive to bison and elk and dispersed effectively.

Some method of remote vaccination is key to a successful vaccination program. A dry dart method of vaccine delivery is now being tested and shows promise. Olsen et al. (2021) showed that using this method, RB51 in a compressed powder pellet form, reduced abortion in bison but not infection when compared to non-vaccinated bison. The results of this study reaffirmed that vaccination with RB51 requires at least two inoculations to be effective but that a remote delivery method requiring only one dose of a more effective vaccine is possible in the future (Olsen et al. 2021).

Removing of *B. abortus* from select agent list

The range of brucellosis continues to spread towards the outskirts of the GYA. To prevent it from spreading back into more states, to eventually eradicate it from the GYA, and to end the slaughter of bison, effective vaccines must be developed for bison, elk, and cattle. Maintaining the status quo and killing bison while ignoring the disease in the elk population is unsatisfactory. Even ranchers, who are not concerned about the wellbeing of animals, support improved vaccines and delivery methods (CWG 2011).

Scientific research in understanding brucellosis and progress in brucellosis diagnostics and vaccines have been hampered by select agent regulations and restrictions. For example, an animal's immune responses may differ according to how virulent the strain is. Conducting research on immune responses to existing or new vaccines or immunotherapeutics (Saxena & Raj 2018) requires working directly with the *B. abortus* bacteria in currently very limited laboratory space. In addition, the higher cost of research as well as limitations of facilities capable of conducting brucellosis research could discourage young scientists from pursuing research on brucellosis (NAS 2020).

The inclusion of *B. abortus* on the BSAT list makes little sense if the concern is use on humans as a bioweapon. Although older studies claim that an infectious dose for *Brucella* would be 10 to 100 bacteria, newer research in closed environments shows that a much higher concentration in aerosol form would be required to cause an infection. Consequently, exposure under natural conditions is unlikely to result in infections in either humans or animals at that dose (USAHA 2019). However, were it the aim to cause *Brucella* infections in humans, collecting the bacteria from natural hosts from birthing materials in the wild could be done easily and with little risk of detection. In addition, significantly more harmful pathogens now exist that could be deployed as bioweapons and are much harder to treat in humans (Olsen et al. 2018).

Few in the affected communities around the GYA would support continuing to list *Brucella* among the BSAT. In 2017 most Montana state legislators approved a resolution to remove *B. abortus* from the BSAT list. The US Animal Health Association, Montana Audubon, and others including the Montana Stock Growers Association and All-Creatures.org, approved and lobbied for its removal in 2019-2020. Public commentary was taken through mid-2020. The Federal Select Agent Program (FSAP) issued a draft policy related to large animal *B. abortus* studies in late 2020, but the bacteria remain on the BSAT list as of late 2021. If adopted, the new policies relating to large animal studies would ease but not eliminate restrictions for that type of research (USDA APHIS 2020b; CDC 2020). Agents on the list are reviewed every two years by the Intra-agency Select Agents and Toxins Technical Advisory Committee (Olsen et al. 2018).

Contraception

Supporters of the Yellowstone bison abhor the brucellosis test and slaughter policies (Buffalo Field Campaign 2016). However, ending this alone would not solve the problem. The resulting population increase would likely lead to hunters killing more bison outside of the park (IBMP 2009). Recent analyses indicate that brucellosis reduces overall population growth due to abortions. A large population increase could also decrease bison welfare within the park. A reduction in the prevalence of brucellosis through vaccination would most likely lead to faster growing populations (Kilpatrick et al. 2009). In any of these scenarios, contraceptives could be used to keep the population at a better equilibrium. This is an available alternative that does not harm the animals and may be required as another tool to control or eliminate brucellosis in Yellowstone and to support the animals there.

The use of porcine zona pellucida (PZP) as a nonlethal contraceptive for animals has shown promise since the mid-1990s. However, using it in ungulates has possible negative welfare effects. A study in white-tailed deer vaccinated with PZP showed that, although they could not conceive, the deer continued to have estrus cycles. The use of PZP appears to artificially extend the breeding season into the winter when energy conservation could be critical. In bison, the energy depletion from increased breeding activity during their migration season could affect their chances for surviving the harsh winters in the GYA, so PZP is not a satisfactory option for them.

The contraceptive GonaCon™ has shown good results in inhibiting the reproduction of other animals in the wild, and a pilot study conducted on bison in Yellowstone found that none of the six female bison tested became pregnant the year after treatment (Yager 2011; USDA APHIS 2012). Some studies of GonaCon™ on bison in other areas have also been shown to be effective (NAS 2020). An experimental trial in Rocky Mountain elk (*Cervus elaphus nelsoni*) was recently undertaken, and GonaCon™ was shown to be 90% effective after 1 year and 50% effective 3 years post-vaccination (Powers et al. 2014).

There is another benefit of using contraceptives for population control. Because contraceptives inhibit pregnancies, they reduce the frequency of abortions in animals infected with brucellosis. Since abortions are one of the primary ways that brucellosis spreads, contraception should also help control the spread by preventing the pregnancies that lead to transmission events (NAS 2020; Rhyan 2013b).

Most importantly, contraception could potentially supplant the practice of test and slaughter because it might be more effective in slowing brucellosis transmission. Ebinger et al. (2011) suggest that in social species who form groups, like bison, sterilized individuals essentially initiate herd immunity similar to a successful vaccination program. But when seropositive individuals are killed through test and slaughter, this may be removing mostly recovered animals (Treanor et al. 2011), so new susceptible individuals may be brought into contact with the remaining infectious members of the group. Herd immunity will be reduced and the potential for a strong resurgence of disease increased. Test and slaughter practices have never, on their own, been successful in eradicating brucellosis (Nishi 2010; NAS 2020). This suggests ceasing those practices in favor of further research into contraception and remote delivery systems for it.

Growing tolerance for bison

According to Rick Wallen, retired lead wildlife biologist (2002-2018) for the bison program at Yellowstone National Park, tolerance for wild bison in Montana outside of park boundaries has improved significantly over the last twenty years. Prior to 1995, there is reputed to have been zero tolerance and any bison crossing park boundaries could be shot by state officials (Keiter 2020). Now, there are additional areas for bison to move outside the park during migration and a couple of year-round areas where bison are accepted. They can now roam over more than 75,000 acres adjacent to the park in the state of Montana (NPS 2021a). Over the last two decades, park officials determined that a population of 2,500-4,500 park bison can co-exist with humans with no extra stress, e.g., risk of disease transmission to domesticated animals or human conflicts such as injuries or bison entering privately held land (NPS 2022a).[9]

9 In early 2022, the NPS published a Notice of Intent to prepare a new environmental impact statement for the management of wild bison inside YNP. The Notice of Intent states that updates are required because some assumptions regarding disease transmission informing the initial

If a Yellowstone bison population of 4,500 could be maintained through contraception or other non-lethal means, this might be an improvement over the current situation. But the 2021 bison count was 5,450 up from 4,800 in June 2020, and the NPS recommended to the IBMP that 600-900 bison be removed over the winter 2021-2022. The plan was to intercept the bison as they entered Montana near the northern boundary of the park, where the northern and central herds mix. Bison could be “harvested” (that is, killed and used) by state and tribal hunters outside the park or rounded up near the northern park boundary. Some were to be captured and enter brucellosis quarantine, and a few would be released. The remainder would be routed to Native American tribes for slaughter. The NPS recommended that 200 additional animals be killed or captured at the end of the winter season to further reduce the population to fewer than 5,000 after calving in spring 2022. The additional 200 bison would be removed from the herd by state or tribal hunters (Geremia 2021).

For the second consecutive year, many fewer bison than predicted left the park for the lower elevations over the winter 2021-2022, and all but 39 of the potential 1,100 lives were spared. State hunters and Native American tribes killed 12 bison, 27 were sent to slaughter, and 10 more were captured and entered brucellosis quarantine (Dore 2022; IBMP 2022a) to be considered for the Bison Conservation and Transfer Program.

For those stakeholders more interested in defending the bison as sentient individuals and rejecting all future lethal management policies, gaining a larger winter range where bison are not affected by YNP policies has been and continues to be a primary objective. As more land has been acquired from ranchers through the purchase

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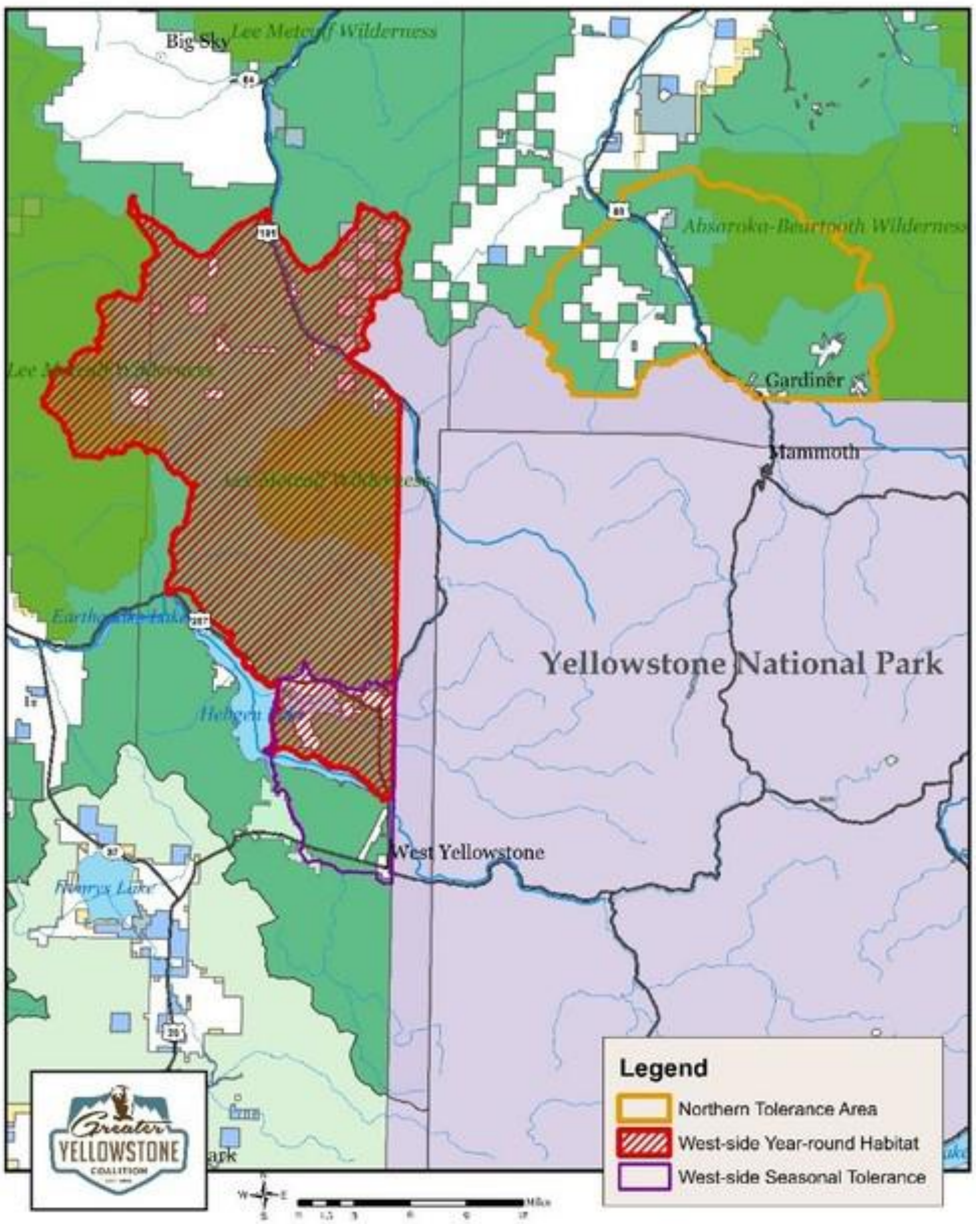
IBMP of 2000 were incorrect or have changed over the ensuing decades. Of the three preliminary alternatives being considered, two acknowledge an increase in the food-carrying capacity of YNP, up to 8,000 bison (Alternative 3). Generally, in Alternatives 2 and 3 the focus of population control would shift from shipments to slaughter to tribal hunting, and reliance on the Bison Conservation and Transfer Program would increase. Alternative 1 would maintain current management practices. A draft EIS is expected in late 2022 with the Final EIS being made available to the public in late 2023 (Yellowstone Forever 2021; NPS 2022a, 2022b).

or retirement of grazing allotments, easements, or property bison have gained more seasonal habitat with less potential contact with domesticated animals (NAS 2020). The following are a few examples.

In 2008, Montana Fish, Wildlife and Parks agreed to prohibit grazing on the Royal Teton Ranch for thirty years. The agreement also established a transit zone which allowed bison access to habitat north of the ranch (MFWP 2008). Also in 2008, male bison were allowed access to lands north and west of the park due to the recognition that disease transmission through male bison is virtually impossible (IBMP 2009). Both male and female bison were allowed to migrate as far north as Yankee Jim Canyon in 2011 (IBMP 2011), and in 2015 as cattle grazing ceased beyond the western border of the park, a Citizen Working Group proposal was endorsed by the governor of Montana which opened about 300,000 acres to bison year-round. (IBMP 2016; Montana. Office of the Governor 2016; Keiter 2020).



Western park boundary and year-round bison habitat (Greater Yellowstone Coalition n.d.)

The future of human-animal interactions

The public's interest in the plight of Yellowstone's wild animals is reflected regularly across the US popular media by dozens of outlets, large and small. In addition to members of the public who support bison, in particular, there are several groups working for the conservation of the Greater Yellowstone Ecosystem, the conservation of the specific species of Yellowstone's bison, or are working to increase the wellbeing of those bison. The conservation objectives are complicating factors common to several groups across the GYA including the National Park Service and the IBMP. Those objectives are beyond the scope of this report, but several groups warrant mention for influencing overall improvements in the situation of bison from the viewpoint of their wellbeing.

The Citizen's Working Group began as a concept in 2009 and was active through 2012, although many of their recommendations are influential a decade later. The diverse group consisted of ranchers, environmentalists, bison advocates, and interested members of the public. The Citizen's Working Group exemplified the potential of diverse individuals to successfully collaborate to improve the lives of wild animals. The group significantly influenced positive changes for bison through the IBMP, the NPS, and the Montana governor's office. Their recommendations included focusing on mandatory vaccination of domesticated animals using current vaccines while supporting research on improved vaccines for all the affected animals; lobbying for the removal *B. abortus* from the BSAT list; and strongly encouraging funding and research for tests to reliably determine between seropositive and infectious animals. Two of their overarching goals were that bison be granted increased habitat inside and outside of the GYA and that landowners and residents learn how to live comfortably with nearby bison (CWG 2011). Those goals have been realized to some extent, and other groups are continuing that work.

The Greater Yellowstone Coexistence Program works to increase acceptance for bison by helping landowners technically and financially to install fencing to keep wandering bison from entering private property. This ten-year-old program is a collaborative effort between several groups including the Greater Yellowstone Coalition. The Greater Yellowstone Coalition works to reduce culling and end the hazing and slaughter of bison who migrate beyond the boundaries of Yellowstone.

The Buffalo Field Campaign (formerly Cold Mountain, Cold Rivers) was created in 1997 in reaction to the Montana Department of Livestock's slaughter of nearly 1,100 bison during that year's winter migration. Since that time, they have been active in the field monitoring and recording state actions against bison and engaging in political and legislative activities to protect them.

Conclusion

Because current evidence suggests that elk rather than bison play the principal role in transmission to some domesticated animals, refocusing on elk is necessary, though continued focus on bison is also needed both for their health and because they could potentially spread brucellosis back to elk (and very rarely to cattle) (NAS 2020).

The current vaccines for brucellosis, S19 and RB51, have been in use since 1941 and 1996 respectively. Both have significant downsides associated with their use. For example, S19 interferes with serological testing, and RB51 is not consistently effective, especially in bison and elk. There are promising new vaccine technologies, and research in the use of recombinant mutant vaccines may lead to a breakthrough soon. This group of vaccines appears to increase immune responses while eliminating some of the drawbacks of current vaccines. Development and approval of this or any type of new vaccine is virtually dependent on the removal of the *B. abortus* bacteria from the biological and select agent and toxins list. Broad stakeholder support for its removal might eventually be the key to the development of new and more effective vaccines.

For bison and elk, oral baits or other remote vaccination technologies will be required. Some advances have already taken place in the development of an oral bait version of a vaccine for cattle and at least one species of deer. The addition of a remote version of a new vaccine with a program for distribution could greatly accelerate the fight against the disease and would reduce the stress and hardship associated with the vaccination process for all bison, cattle, and elk.

Little effort seems to have been directed towards a cure for brucellosis in the affected animals. Some research in the mid and late twentieth century found that combinations of antibiotics, but not single antibiotics, could reduce the shedding of *B. abortus* in cow's milk. The infection was not eliminated even in combination with the S19 vaccine (NAS 2020; Jiménez de Bagués et al. 1991). This type of research could be further developed for post-infection treatments for both bison and elk.

If we consider the interests of animals, we will realize that the practice of killing bison is unacceptable and that contraception should be used instead when population management is in the animals' interests. Using contraceptives would also reduce risk of transmission by reducing pregnancy, the primary way that the disease spreads, and could accelerate the growth of herd immunity and help reduce wild animal suffering (Dorado 2015; Faria 2016; Animal Ethics 2020a, 2020b; Faria & Horta 2019; Johannsen 2020).

Lessons learned from a successful vaccine development program and careful use of contraception in concert with continuing victories over political gridlock could inform future efforts to help animals in the wild. This could potentially be done over even larger geographical areas and include more species. If we are successful in reforming management of brucellosis in Yellowstone, it could serve as a blueprint for managing diseases of wild animals in other areas.

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