Brucellosis Transmission Pathways and Management

P. J. White, John J. Treanor, and Rick L. Wallen

The increasing emergence or resurgence of infectious diseases that move between livestock, wildlife, and humans has raised interest in disease ecology and wildlife health. Wildlife and their parasites do not recognize political or jurisdictional boundaries and, as a result, can affect the natural ecosystems of national parks and human health in nearby communities. Brucellosis is a contagious bacterial disease caused by various species of the genus *Brucella* that infects domestic animals, wildlife, and humans worldwide. *Brucella abortus* is the only species of *Brucella* that has been identified in cattle, bison (*Bison bison*), elk (*Cervus elaphus*), and sometimes other wildlife species of the greater Yellowstone ecosystem (Cheville et al. 1998, Thorne et al. 1997, Kreeger 2002). Brucellosis was likely introduced to the United States via European livestock and was detected in bison and elk in Yellowstone National Park (YNP) by 1930 (Meagher and Meyer 1994). Studies in captivity have demonstrated the transmission of *B. abortus* among bison, cattle, and elk is feasible and tangible (Flagg 1983, Davis et al. 1990, Cheville et al. 1998).

In ungulates, transmission of *B. abortus* typically occurs through ingestion of live bacteria. The incubation period (or time between exposure and onset of infection) varies widely depending on exposure dose, previous vaccination, species, age, sex, stage of gestation, and susceptibility (Nicoletti and Gilsdorf 1997). Following a brief system-wide infection, the *Brucella* bacteria typically localize in the udder or lymphatic system and, depending on the stage of gestation, in reproductive tissues. Abortion is the characteristic sign of acute brucellosis, and *Brucella* bacteria can be shed in aborted tissues, reproductive tissues, and discharges; especially just prior to, during, or soon after abortion or live birth (Rhyan et al. 1994, 2009). The bacteria may also be shed in milk by lactating adult females (Rhyan and Drew 2002). After pregnancy, the *Brucella* bacteria may become dormant, persisting only within cells of the lymphatic system (Cheville et al. 1998, Galey et al. 2005). Following a dormant period, acute infection may recur during subsequent pregnancy (U.S. Department of the Interior and U.S. Department of Agriculture 2000, Galey et al. 2005). There appears to be no feasible treatment (e.g., antibiotics) or cure for wild bison and elk infected with *Brucella* (Young and Corbel 1989). However, some animals may completely clear the bacterium and recover (John and Samuel 2000, Ficht 2003), while other animals appear have a natural resistance to the disease (Templeton et al. 1988, Derr et al. 2002).

In humans, brucellosis is known as undulant fever. Though insidious with a slow and subtle onset, undulant fever is rarely fatal. Transmission to humans is through ingestion, contact with mucous membranes such as the eyes, through an open wound, or by direct contact with skin (Young and Corbel 1989). Infected bison and elk are a very minor health risk for people that improperly handle animal carcasses or are exposed to birth tissues. With progress toward eradication of brucellosis in livestock and pasteurization of milk, the national occurrence of undulant fever in humans from all *Brucella* spp. has decreased from 6,500 reported cases in 1940 to 70 cases in 1994. There were five confirmed cases reported to the Wyoming Department of Health during 1995-2005, and 17 confirmed cases reported to the Idaho Department of Health and Welfare from 1980-2003—none of which were attributed to wildlife (Snow 2005). However, there have been two confirmed cases of hunters contracting undulant fever from elk in Montana (Greater Yellowstone Interagency Brucellosis Committee 1997, Zanto 2005).

Most livestock and natural resources personnel view elk associated with feeding programs in Wyoming and Yellowstone bison as the primary sources for brucellosis transmission to other elk and cattle (Bienen and Tabor 2006). Thus, brucellosis management focuses on elk in the southern greater Yellowstone area and bison in the northern portion. Elk often mingle with cattle and every recent brucellosis transmission to cattle where the species could be reasonably assigned has been attributed to elk (Cheville et al. 1998, Beja-Pereira et al. 2009). Conversely, bison seldom mingle with cattle because management agencies actively prevent bison dispersal and range expansion outside established conservation areas in and near YNP via hazing, hunting, and culling (U.S. Department of the Interior and U.S. Department of Agriculture 2000). Brucellosis control strategies for bison and elk have changed little in the past 2 to 3 decades, despite evidence that the prevalence of the disease is not being reduced (Bienen and Tabor 2006). We review the state of the knowledge regarding brucellosis transmission pathways, and discuss options for brucellosis control in wildlife.

Brucellosis transmission pathways

The risk of brucellosis transmission within or between bison and elk should increase as the proportion of infectious animals increases, and the degree of mingling increases between infectious and susceptible animals (Greater Yellowstone Interagency Brucellosis Committee 1997, Hobbs et al. 2009). Transmission risk is also affected by environmental factors such as snow pack and predation that congregate or disperse bison and/or elk during their potential abortion and calving seasons, and varies by age, species, and sex (Cross et al. 2007). Brucellosis exposure in bison increased from approximately 20-30% when numbers were relatively low (<1,000) to 40-60% as numbers increased to approximately 5,000 during the past several decades

(Hobbs et al. 2009, Kilpatrick et al. 2009). *Brucella*-induced abortions can produce abundant infectious material (Rhyan et al. 2009) and occur primarily from January through April (Jones et al. 2009). Some potentially large exposure events have been observed where many bison interacted with fetuses or birth tissues. These “mobbing” events may be an important transmission source of brucellosis among bison (Jones et al. 2009). The birthing period for Yellowstone bison is synchronous, with the peak birthing period from April 25 to May 26 (Jones et al. 2010). Females clean birth sites and typically leave the site within two hours; thereby lowering the risk of brucellosis transmission to other bison. However, contact of at least one bison with potentially infectious material was observed during 30% of parturition events (Jones et al. 2009). Thus, infectious live births could be an important transmission event for brucellosis among Yellowstone bison (Rhyan et al. 2009).

Yellowstone elk also exhibit a high degree of birth synchrony, with the majority birthing during May 21 to June 12 (Barber-Meyer et al. 2008). Brucellosis transmission between elk is likely low during calving because mothers segregate themselves while giving birth and clean the site (Johnson 1951). Thus, birth sites are dispersed and the likelihood of other elk encountering infected birth tissues is low. However, transmission risk may be higher during the potential abortion period from February through April when many elk aggregate in larger groups on lower-elevation winter ranges. Spontaneous abortions by elk that are not segregated from the herd could expose many susceptible elk to infected fetuses and birth tissues.

Historically, 1-3% of elk in the northern portion of the greater Yellowstone area tested positive for brucellosis exposure. These low seropositive (i.e., test-positive) rates may have been sustained by immigration of infected elk from feed grounds in Idaho and Wyoming, where brucellosis exposure was consistently higher (8-60%; Hamlin and Cunningham 2008). In fact, there was general agreement until recently that brucellosis would not be maintained in elk at levels that are a risk to cattle or other wildlife without the feed grounds (Thorne and Linfield 2004, Bienen and Tabor 2006). However, elk abundance increased substantially in some areas during the past decade, with a concurrent increase in large groups and occupation of winter ranges that likely facilitates disease dynamics similar to the artificial feed grounds (Cross et al. 2009). Coincident with these changes in elk population and group sizes, brucellosis seroprevalence apparently increased to between 7-20% in some non-feed ground areas (Cody and Buffalo Valley, Wyoming; Barbknecht et al. 2007, Wyoming Game and Fish Department 2009). Model simulations based on historic indices of migration suggest that these changes were not likely due only to dispersal of elk from the feed grounds (Cross et al. 2009). Thus, elk populations far from both bison and feed grounds may be becoming viable reservoirs perpetuating higher levels of brucellosis due to increased densities and group sizes of elk on their winter ranges (Cross et al. 2009).

Bison-to-elk transmission of brucellosis is feasible, but likely rare, because the peak bison calving period occurs approximately one month earlier than for elk and, overall, there is little overlap in distribution during the potential abortion or calving periods for both species. Even in areas where elk often mingle with bison during winter and spring, such as the Madison headwaters area in YNP, elk have much lower seroprevalence rates for brucellosis (3%) than sympatric bison (40-60%) or elk associated with feeding programs (7-60%; Ferrari and Garrott 2002). Proffitt et al. (2010) found that brucellosis transmission risk from bison to elk was quite low in this area, despite a high degree of spatial overlap during the period of late-pregnancy abortions and bison parturition. Predation risk associated with wolves increased elk and bison spatial overlap temporarily, but these risk-driven behavioral responses by elk did not have important disease implications. DNA genotyping also indicates a relatively high genetic divergence between elk and bison *B. abortus* isolates, which suggests that *B. abortus* is not exchanged extensively between elk and bison (Beja-Pereira et al. 2009).

Brucellosis control in elk

The best available scientific information suggests that elk-to-elk transmission, including dispersal of elk from populations with relatively high levels of infection, is primarily responsible for the observed levels of *B. abortus* exposure within elk populations and, in turn, their concomitant risk of brucellosis transmission to cattle. Eradication of brucellosis from these populations is likely not possible or practical with current technology without resorting to ethically and politically unacceptable techniques such as depopulation (Cheville et al. 1998, U.S. Animal Health Association 2006, Cleveland et al. 2008). Thus, management of brucellosis in elk populations should focus on reducing elk-to-elk transmission risk by curtailing practices that unnaturally increase elk densities and group sizes during the potential abortion period, including elk aggregation on feed grounds, elk use of cattle feed lines, and elk use of refuge areas where human harvests and/or natural predation are reduced.

Wyoming has 22 state feed grounds and one federal feed ground (National Elk Refuge, U. S. Fish and Wildlife Service) where feeding is conducted to keep brucellosis-infected elk from foraging on cattle ranches and maintain higher numbers of elk than remaining winter habitat can otherwise support (Cross et al. 2007). Supplemental feeding creates elk aggregations that facilitate disease transmission and keep disease levels high (Bienen and Tabor 2006, Cross et al. 2007). Thus, there is general agreement that feeding should be phased out as sustainable alternatives for maintaining elk numbers are developed because it may lead to decreased brucellosis seroprevalence over time (Bienen and Tabor 2006). Idaho eliminated most elk feeding over the last decade by implementing conservation easements and habitat enhancements to increase elk forage, and re-locating elk that habitually returned to feeding areas (Drew 2002). However, these actions are unlikely to compensate the much higher numbers of currently fed elk in Wyoming and, as a result, the cessation of feeding would almost certainly result in a substantial decrease (perhaps 80%) in elk numbers (Talbott et al. 2010). Also, wildlife and livestock managers remain concerned that reduced feeding would lead to increased mingling of elk and cattle and increased brucellosis transmission (Cross et al. 2007). In the interim, strategies that reduce the length of the feeding season and the duration of elk aggregation during the peak transmission periods (February through May) may decrease the seroprevalence of brucellosis in elk associated with feed grounds in the southern greater Yellowstone area (Cross et al. 2007).

Test and slaughter of seropositive elk has been applied on a small scale in some Idaho and Wyoming feed grounds because herd depopulation is not realistic given the large numbers (25,000-50,000) of potentially exposed elk (Bienen and Tabor 2006). Management plans that remove small to moderate numbers of elk (10-25%) are unlikely to control brucellosis and could possibly even facilitate disease transmission by removing recovered or resistant animals (Gross et al. 2002). However, preliminary results from a 5-year pilot test and slaughter project on three feed grounds (Muddy, Fall, and Scab creeks) in the Pinedale elk herd unit in Wyoming suggests that consistent captures of a large portion of the total female elk in the population, with the culling of test-positive elk and the vaccination of calves, may produce a significant reduction in seroprevalence (Scurlock 2010). For example, brucellosis seroprevalence decreased from 37-7% at the Muddy Creek feed ground during 2006 through 2009. However, 7 elk were exposed to brucellosis (seropositive) during 2007 and 2008, indicating that brucellosis transmission events continued to occur (Scurlock 2010). Also, even after brucellosis prevalence has been reduced to low levels in a population through test and slaughter, model simulations suggest that rapid increases in seroprevalence in a short period of time may occur because exposed animals are culled, which reduces population immunity and creates a large pool of susceptible animals that can be infected by contact with aborted fetuses and result in large exposure or "super-spreader" events (Ebinger et al. 2010). Keeping animals in the population that have been exposed to the disease but become resistant or recovered reduces disease transmission similar to vaccination (Donnelly et al. 2003). In addition, the test and slaughter pilot project in the Pinedale elk herd unit has been extremely expensive to implement in terms of time, effort, and money, with more than $281,000 spent in fiscal year 2009 to capture 816 elk and cull 50 of these elk testing positive for brucellosis exposure (Scurlock 2010). Thus, test and slaughter is likely not a landscape-level solution for reducing brucellosis prevalence.

Elk calves using feed grounds in Wyoming (except Dell Creek) have been vaccinated annually with Strain 19 biobullets since 1985 (Cross et al. 2007). This vaccine decreased abortion events in captive elk from 93-71% during the first pregnancy, which could reduce brucellosis transmission and lower infection rates in wild populations (Roffe et al. 2004). Historically, brucellosis seroprevalence was lower on vaccinated feed grounds than at Dell Creek (unvaccinated), suggested a positive effect of vaccination. However, Cross et al. (2007) reported that the average seroprevalence on Dell Creek was not higher than expected based on the length of the feeding season. Thus, the protective effect of Strain 19 vaccination at a feed ground level may not be strong, though more research is needed (Cross et al. 2007).

Ranching and development of rural homes in the greater Yellowstone ecosystem has fragmented valley bottom and flood plain habitats with higher plant productivity and more moderate conditions that are crucial for the migration and use during winter by elk in this temperate mountain environment (Gude et al. 2007, Hansen and DeFries 2007). This human influence has also contributed to elk use of cattle feed lines and refuges from predation or human harvest that result in elk aggregating in large groups (Haggerty and Travis 2006, Coughenour 2008, Cross et al. 2009). Studies of bison and elk have found only weak or no relationships between brucellosis seroprevalence and population sizes or densities (Dobson and Meagher 1996, Joly and Messier 2004, Cross et al. 2007). However, the density of elk aggregating on feed grounds, natural winter ranges, or in human-induced refuge areas may still affect animal contact rates with potentially infected aborted fetuses during late winter and early spring just prior to and during calving (Altizer et al. 2006, Hamlin and Cunningham 2008). Thus, wildlife agencies need to explore strategies for dispersing large aggregations of elk in late winter and spring such as gaining enhanced cooperation from private landowners to increase access for hunters, providing increased tolerance and protection of large predators such as wolves that may disperse elk, and assisting landowners with infrastructure to isolate cattle and their feed from wildlife. By providence, if the 50-year warming trend continues, with earlier snow melt and vegetation green-up, then aggregations of elk on feed grounds or natural winter ranges may disperse earlier in the late-season abortion period, which could lower brucellosis prevalence over the long term (Wilmers and Getz 2005, Cross et al. 2007).

Brucellosis control in bison

Numerous strategies to mitigate transmission risk and reduce brucellosis prevalence have been implemented or suggested for Yellowstone bison. The federal government and the state of Montana agreed to a court-negotiated Interagency Bison Management Plan (IBMP) in 2000 that established guidelines for cooperatively managing the risk of brucellosis transmission from bison to cattle. The IBMP is designed to adaptively progress through a series of management steps that initially tolerate only bison testing negative for brucellosis exposure on winter ranges outside YNP, but will eventually tolerate limited numbers of untested bison on key winter ranges adjacent to the park when cattle are not present (U.S. Department of the Interior and U.S. Department of Agriculture 2000, 2008). The IBMP uses intensive management (e.g., hazing, hunting, and culls) of bison migrating outside the park to maintain spatial and temporal separation between bison and cattle. With the exception of a few male bison that provide no significant risk of brucellosis transmission, the agencies have successfully maintained spatial and temporal separation between bison and cattle with no transmission of brucellosis (Lyon et al. 1995, White et al. 2010). However, this intensive management is expensive, logistically taxing, and controversial due to sporadic, large-scale culls of >1,000 bison. It has also been criticized as unnecessary due to low risk of transmission and dwindling presence of cattle near designated bison conservation areas on public lands adjacent to the park in Montana (Bienen and Tabor 2006, Kirkpatrick et al. 2009). However, the risk of brucellosis transmission from bison to cattle is tangible and, without intensive management intervention, there is little doubt that bison would continue to expand their range and disperse to suitable habitat areas outside the park where cattle could come into contact with *Brucella* bacteria shed on birth tissues (Flagg 1983, Davis et al. 1990, Cheville et al. 1998, Plumb et al. 2009).

The shipment of bison to slaughter, either with or without testing for brucellosis exposure, has been implemented to mitigate the risk of brucellosis transmission from bison once hazing has become ineffective at keeping them within established conservation areas. Since the late 1980s, recurrent, small (<100) to large (~1,700) numbers of bison have been removed near the park boundary (Geremia et al. 2010, White et al. 2010). Only about one-half of female bison testing positive for exposure to brucellosis are actually infectious (Roffe et al. 1999). However, there are no available tests that conclusively or reliably detect active infection of *B. abortus* in live bison (Roberto and Newby 2007). The killing of seropositive animals that have passed through the infectious phase and may be somewhat resistant or recovered could actually exacerbate brucellosis transmission efficiency by increasing the proportion of susceptible animals (Gross et al. 2002, Donnelly et al. 2007, Bienen and Tabor 2006). Indeed, the seroprevalence of brucellosis in Yellowstone bison has not decreased under this strategy (Kilpatrick et al. 2009) and may actually be increasing (Hobbs et al. 2009). Thus, the current non-random culling strategy serves more as a population reduction program than to reduce brucellosis (Bienen and Tabor 2006). Intensifying this strategy to a level that would be effective at reducing brucellosis transmission would be extremely expensive, unacceptable to the public, and questionable as a management practice given the National Park Service policy to maintain ecosystem integrity (Bienen and Tabor 2006, National Park Service 2006).

The probability of active infection increases rapidly in young bison and peaks during the age (3 years old) of first pregnancy, suggesting that young reproductively active and infected females are likely to drive brucellosis dynamics (Rhyan et al. 2009). Thus, selective management actions that target pre-reproductive females (e.g., vaccination) and young, reproductively active, seropositive females (e.g., culling), while retaining test-positive bison that are likely recovered and may provide protection to the population through the effect of herd immunity, may be effective at reducing disease transmission (Ebinger et al. 2010). Consistent vaccination of 40-50% of female bison each year could reduce brucellosis prevalence, especially if vaccine technology and methods for remote vaccine delivery to free-ranging wildlife are improved

(Gross et al. 2002, Treanor et al. 2007, 2010). Vaccines available for brucellosis in wildlife have changed little in 60 years, despite significant progress in the field of vaccine technology (Bienen and Tabor 2006). In 2005, the Greater Yellowstone Interagency Brucellosis Committee, in collaboration with the U.S. Animal Health Association, developed a strategic roadmap for new technologies in vaccine development, delivery systems for wildlife, and diagnostics of brucellosis in elk and bison (U.S. Animal Health Association 2006). However, there has been little progress to date due to the lack of market incentives and funding. A vaccine with low or medium efficacy is unlikely to succeed in controlling brucellosis in the long-term without the eventual inclusion of test and slaughter or fertility control (Treanor et al. 2010, Ebinger et al. 2010). Thus, the development of more effective vaccines, delivery methods, and diagnostic techniques (e.g., biomarkers to identify infectious animals) is urgently needed. Until substantial improvement is made in these areas, vaccination efforts will, at best, only result in relatively slow decreases in seroprevalence and infection over decades of effort (Treanor et al. 2007, 2010, Ebinger et al. 2010).

Contraception has also been suggested as a method to reduce brucellosis transmission in wildlife. National Park Service policy allows for the use of reproductive intervention in wildlife if these techniques are appropriate for achieving management goals (National Park Service 2006). Thus, if an effective, reliable, and safe contraceptive was developed, contraception of seropositive bison or elk might be considered for decreasing brucellosis transmission and dampening population growth; especially when combined with the vaccination of seronegative animals against brucellosis (Ebinger et al. 2010). At this time, the most likely products to be considered for use in park units include gonadotropin releasing hormone vaccine (GnRH), porcine zona pellucida vaccine (PZP), and the GnRH agonist leuprolide, which are generally designed to be short-term, reversible treatments (Fagerstone et al. 2010). A single dose of GnRH vaccine was effective at preventing pregnancy in captive female bison and elk for at least 1 year, which could reduce brucellosis transmission in a population, though this supposition has not been tested (Miller et al. 2004, Powers et al. 2007). However, fertility control products may also cause effects such as localized or systemic inflammatory reactions, long-term or permanent sterility, altered reproductive or social behaviors such as decreased group fidelity, extended breeding seasons, increased or decreased life spans, and changes in the age and sex structure of a population (McShea et al. 1997, Heilmann et al. 1998, Powers et al. 2007, Killian et al. 2008, Kirkpatrick and Turner 2008, Baker et al. 2009, Gionfriddo et al. 2009, Nuñez et al. 2009, Ransom et al. 2010). Thus, it is uncertain whether available fertility control products can effectively decrease brucellosis infection in free-ranging bison and elk over a reasonable time frame without unacceptable side effects (Gray and Cameron 2010; see Rutberg and Naugle 2008 for a different perspective). Furthermore, fertility control is unlikely to be a viable means for reducing brucellosis infection when there is imprecise control over the delivery and efficacy of contraceptives to eligible animals (Merrill et al. 2006). Given the substantial uncertainties about the severity, duration, and timing of direct and indirect impacts from fertility control products, there are serious concerns that contraception could harm the integrity of iconic and keystone populations of bison and elk, especially if these populations were infected with a debilitating disease (e.g., tuberculosis or chronic wasting disease) while a substantial portion of prime-aged animals were inhibited from producing calves by a contraceptive or sterilant (National Park Service 2006). Thus, application of these techniques should still be considered experimental and discussions regarding the contraception of free-ranging bison or elk in the greater Yellowstone area to reduce numbers or brucellosis infection are not appropriate at this time. There are also strong opponents to contraception and addressing the social conflicts and values associated with fertility control may be more difficult in the long term than managing the biological components of wildlife management decision making (Fagerstone et al. 2002).

To maintain the spatial and temporal separation of bison and cattle, management agencies should continue to allow bison migration to essential winter range areas in and adjacent to YNP, but actively prevent dispersal and range expansion to outlying private lands until there is tolerance for bison in these areas (Plumb et al. 2009). Bison abundance and distribution on lands adjacent to Yellowstone can be adjusted based on evaluations of available habitat, new conservation easements or land management strategies, reduced brucellosis prevalence in bison, and new information or technology that reduces the risk of disease transmission (U.S. Department of the Interior et al. 2008). However, the Comprehensive Wildlife Conservation Strategies of Idaho, Montana, and Wyoming express little support for resident, free-ranging wild bison (Plumb et al. 2009). Since the evolution of a substantially larger bison conservation area outside Yellowstone is the prerogative of these states, the social carrying capacity of Yellowstone bison is perhaps most limiting. To increase tolerance for bison, Kilpatrick et al. (2009) recommended establishing a local brucellosis infection status zone for cattle in the greater Yellowstone area and testing all cattle within this area for brucellosis (with a "split status" for the remaining portions of Idaho, Montana, and Wyoming). The Animal and Plant Health Inspection Service proposed such a strategy in October 2008 and has disseminated a concept paper for public review and comment that describes a new direction for the bovine brucellosis program (U.S. Department of Agriculture 2008b, 2009). The concept paper provides an action plan that (1) demonstrates the brucellosis-free status of cattle in the United States, (2) enhances efforts to mitigate brucellosis transmission from bison and elk, (3) enhances disease response and control measures, (4) modernizes the regulatory framework, and (5) implements a risk-based disease management area concept. Kilpatrick et al. (2009) also recommended the cessation of cattle grazing in areas where bison leave the park in winter and compensating ranchers for lost earnings and wages. Conservation groups and government agencies have successfully used, and are still pursuing, this strategy with willing landowners (U.S. Department of the Interior et al. 2008). However, further efforts are needed to identify additional habitat and conservation areas for bison in Montana, develop fencing strategies in collaboration with private landowners that raise susceptible cattle, and identify opportunities for the enhancement or creation of bison habitat in Montana to sustain bison during April and May and discourage bison movements onto private lands with cattle (U.S. Department of the Interior et al. 2008).

Conservation Implications

Over time, the strategies discussed in previous sections could reduce the costs and need for brucellosis risk management activities, while maintaining low risk for the cattle industry. The best available scientific information suggests that elk-to-elk transmission, including dispersal of elk from populations with relatively high levels of infection, is primarily responsible for the observed levels of *B. abortus* exposure within elk populations and, in turn, elk risk of brucellosis transmission to cattle. Thus, management of brucellosis in elk populations should focus on reducing elk-to-elk transmission risk by curtailing practices that unnaturally increase elk densities and group sizes during the potential abortion period, including elk aggregation on feed grounds, elk use of cattle feed lines, and elk use of areas where harvests and/or predation are reduced by land ownership or management practices. Approximately 50,000 elk live in the greater Yellowstone area, with brucellosis in elk populations throughout the area. Less than

20,000 of these elk summer in YNP, with brucellosis seroprevalences of 1-3%. Thus, YNP is not the primary source for brucellosis transmission to cattle. In fact, ecological process management in YNP, including grizzly bear recovery and wolf restoration already has resulted in changes that reduced risk factors for disease transmission by contributing to a greater than 70-80% decrease in densities of elk wintering inside the park since 1995. Wolves and other predators could continue to reduce disease transmission in bison and elk by increasing mortality rates, removing animals with the disease, redistributing elk from areas of high concentration, and removing infected fetuses from the environment (Barber-Meyer et al. 2007). Similarly, the protection of predators and scavengers near feed grounds in Wyoming has been suggested as a means to reduce brucellosis transmissions in elk (Maichak et al. 2009).

Bison management and vaccination conducted only at boundary capture facilities is unlikely to yield significant long-term reductions in brucellosis infection (Treanor et al. 2010). Thus, efforts to reduce the prevalence of brucellosis in bison through vaccination or a combination of methods would be most effective through a sustained, park-wide effort that can consistently and reliably deliver vaccine to a large portion of eligible bison each year over decades. Such a program will be controversial, logistically challenging, expensive, and intrusive, with no guarantee of successfully reducing brucellosis prevalence to near zero. Chronic brucellosis infection does not adversely affect the long-term viability of Yellowstone bison (Fuller et al. 2007, Geremia et al. 2009), though it has prevented the use of their unique wild state and adaptive capabilities to synergize the restoration of the species in the greater Yellowstone area and elsewhere (Freese et al. 2007, Sanderson et al. 2008, Gates et al. 2010). Thus, an essential first step for the National Park Service is to decide if a comprehensive vaccination effort for Yellowstone bison is desirable, feasible, and sustainable.

Regardless of the disease issue, the Yellowstone bison population will likely continue to grow and attempt to expand their range in the future unless hunting, culling, and/or re-locations are used to remove several hundred bison per year from population (Hobbs et al. 2009). Hunting in YNP is not authorized by Congress and longstanding policy prohibits hunting in units of the National Park Service system unless specifically authorized by Congress (Organic Act of 1916, 16 USC I, V § 26). However, the Montana Department of Fish, Wildlife, and Parks and the Wyoming Game and Fish Department administer hunts of bison that migrate outside the park during winter on available habitat adjacent to the eastern and western boundaries of the park. Also, some American Indian tribes (Confederated Salish-Kootenai Tribes of the Flathead Nation, Nez Perce, and Shoshone-Bannock) have recognized treaty rights for bison harvest on unclaimed federal lands adjacent to the park. When there are 2,500 to 4,500 bison park-wide, approximately 200 to 300 bison would need to be culled during most winters to limit large-scale migration to the park boundary and stabilize population growth (Hobbs et al. 2009, Geremia et al. 2010). Some of these culls could be conducted by state and treaty hunters, but a successful hunting paradigm would necessitate increased tolerance for bison in available habitat areas of Montana, better access for hunters, integration of fair chase ethics, and creative harvest strategies with non-traditional seasons because most bison migrate outside the park during late winter and spring, during their third trimester of pregnancy. These constraints limit the likelihood that hunting alone can be used to limit bison numbers and distribution.

Thus far, Yellowstone bison have only been transported to domestic slaughter or research facilities due to the potential for infection with brucellosis. These removals are contentious, unpopular, and have not contributed to a reduction in seroprevalence (Hobbs et al. 2009, Kirkpatrick et al. 2009). Thus, IBMP managers intend to increase the use of, and allocation of resources to, management actions that reduce the number of bison sent to slaughter (U.S. Department of the Interior et al. 2008). In 2005 and 2006, the Montana Department of Fish, Wildlife, and Parks and the United States Department of Agriculture's Animal and Plant Health Inspection Service (2006) initiated a limited scope quarantine feasibility study with 100 bison calves from YNP to provide a source of live, disease-free bison for tribal governments and other requesting organizations. Eighty-seven of these bison were translocated to the Green Ranch near Bozeman, Montana in 2010 to complete the quarantine study, after which Turner Enterprises, Inc. will send the original quarantine bison plus about 25% of their offspring to American Indian tribes or public lands as directed by the Montana Department of Fish, Wildlife, and Parks (Montana Fish, Wildlife, and Parks 2010). The rest of the bison will be retained by Turner Enterprises, Inc. and could be used to increase the genetic diversity of the Castle Rock bison herd in New Mexico.

The Secretary of the Interior is authorized to "dispose of the surplus buffalo of the Yellowstone National Park herd," including giving them to "Federal, State, county, and municipal authorities for preserves, zoos, zoological gardens, and parks" (16 USC 1V § 36). Thus, the existing protocols and agreements developed during the successful quarantine feasibility study could be modified and expanded to operationally move brucellosis test-negative, bison each year from YNP to quarantine facilities for further surveillance and eventual release onto suitable restoration sites. Similarly, test-positive or untested bison could potentially be transported to terminal destinations on tribal or other lands that are separated from cattle and periodically harvested for food or ceremonial purposes. The shipment of "surplus" Yellowstone bison directly to terminal pastures or suitable restoration sites operated by American Indian tribes or other interested organizations would reduce the number of bison sent to domestic slaughter facilities and be a transformational moment in the conservation of plains bison because it would support the nutrition and culture of American Indians, enhance the conservation of the bison genome, and establish or augment new wild populations from a gene source that has not been contaminated by interbreeding with cattle and has been continuously exposed to natural selection through predation, competition, diseases, and other ecological processes.

Literature Cited

Altizer, S., A. Dobson, P. Hosseini, P. Hudson, M. Pascual, and P. Rohani. 2006. Seasonality and the dynamics of infectious diseases. Ecology Letters 9:467-484.

Baker, D. B, J. G. Powers, M. A. Wild, and T. M. Nett. 2009. Evaluation of methods for managing elk population health and abundance in Rocky Mountain National Park. Investigators Annual Report (OMB # 1024-0236) <https://science.nature.nps.gov/research/ac/search/iars/pdf/IAR.pdf?reportId=53080>. Accessed April 3, 2010.

Barber-Meyer, S. M., L. D. Mech, and P. J. White. 2008. Survival and cause-specific elk calf mortality following wolf restoration to Yellowstone National Park. Wildlife Monographs 169.

Barber-Meyer, S. M., P. J. White, and L. D. Mech. 2007. Survey of selected pathogens and blood parameters of northern Yellowstone elk: wolf sanitation effect implications. American Midland Naturalist 158:369-381.

Barbknecht, A., J. Rogerson, E. Maichak, L. Linn, W. S. Fairbanks, B. Scurlock, K. Belinda, H. Edwards, and T. Cornish. 2007. Ecology of elk abortion and parturition in the brucellosis endemic area of Wyoming. <http://gf.state.wy.us/wildlife/Brucellosis/index.asp>. Accessed March 16, 2009.

Beja-Pereira, A., B. Bricker, S. Chen, C. Almendra, P. J. White, and G. Luikart. 2009. DNA genotyping suggests recent brucellosis outbreaks in the greater Yellowstone area originated from elk. Journal of Wildlife Diseases 45:1174-1177.

Bienen, L., and G. Tabor. 2006. Applying an ecosystem approach to brucellosis control: can an old conflict between wildlife and agriculture be successfully managed? Frontiers in Ecology and the Environment 4:319-327.

Cheville, N. F., D. R. McCullough, and L. R. Paulson. 1998. Brucellosis in the greater Yellowstone area. National Academy Press, Washington, D.C.

Cleveland, T., W. Cook, and F. Galey. 2008. Letter dated January 18, 2008 from the Wyoming Game and Fish Department and Wyoming Livestock Board to James Leafstedt, President, U.S. Animal Health Association, St. Joseph, Missouri.

Coughenour, M. B. 2008. Causes and consequences of herbivore movement in landscape ecosystems. Chapter 3 in K. A. Galvin, R. S. Reid, R. H. Behnke, Jr., and N. T. Hobbs, editors. Fragmentation in semi-arid and arid landscapes: Consequences for human and natural systems. Springer, The Netherlands.

Cross, P. C., E.K. Cole, A. P. Dobson, W. H. Edwards, K. L. Hamlin, G. Luikart, A. D. Middleton, B. M. Scurlock, and P. J. White. 2009. Probable causes of increasing brucellosis in free-ranging elk of the greater Yellowstone ecosystem. Ecological Applications 20:278-288.

Cross, P. C., W. H. Edwards, B. M. Scurlock, E. J. Maichak, and J. D. Rogerson. 2007. Effects of management and climate on elk brucellosis in the greater Yellowstone ecosystem. Ecological Applications 17:957-964.

Davis, D. S., J. Templeton, T. Ficht, T. Williams, J. Kopec, and G. Adams. 1990. *Brucella abortus* in captive bison. Serology, bacteriology, pathogenesis, and transmission to cattle. Journal of Wildlife Diseases 26:360-371.

Derr, J., C. Seabury, C. Schutta, and J. W. Templeton. 2002. Pages 24-37 in T. J. Kreeger, editor. Brucellosis in elk and bison in the greater Yellowstone area. Wyoming Game and Fish, Cheyenne, Wyoming.

Dobson, A., and M. Meagher. 1996. The population dynamics of brucellosis in the Yellowstone National Park. Ecology 77:1026-1036.

Donnelly, C. A., R. Woodroffe, D. R. Cox, J. Bourne, G. Gettinby, A. M. Le Fevre, J. P. McInerney, and W. I. Morrison. 2003. Impact of localized badger culling on tuberculosis incidence in British cattle. Nature 426:834-837.

Donnelly, C., G. Wei, W. Johnston, D. Cox, R. Woodroffe, F. Bourne, C. Cheeseman, R. Clifton-Hadley, G. Gettinby, and P. Gilks. 2007. Impacts of widespread badger culling on cattle tuberculosis: concluding analyses from a large-scale field trial. International Journal of Infectious Diseases 11:300-308.

Drew, M. 2002. State of Idaho brucellosis management program report of progress to the Governor of Idaho. 10 October 2002. Idaho Department of Fish and Game, Boise, Idaho.

Ebinger, M. R., P. Cross, R. Wallen, P. J. White, and J. Treanor. 2010. Modeling brucellosis management in bison: a heuristic model of management actions on disease dynamics. Yellowstone Center for Resources, Mammoth, Wyoming.

Fagerstone, K. A., M. A. Coffey, P. D. Curtis, R. A. Dolbeer, G. J. Killian, L. A. Miller, and L. M. Wilmot. 2002. Wildlife fertility control. The Wildlife Society, Bethesda, Maryland.

Fagerstone, K. A., L. A. Miller, G. Killian, and C. A. Yoder. 2010. Review of issues concerning the use of reproductive inhibitors, with particular emphasis on resolving human-wildlife conflicts in North America. Integrative Zoology 1:15-30.

Ferrari, M. J., and R. A. Garrott. 2002. Bison and elk: brucellosis seroprevalence on a shared winter range. Journal of Wildlife Management 66:1246-1254.

Ficht, T. A. 2003. Intracellular survival of *Brucella*: defining the link with persistence. Veterinary Microbiology 92:213-223.

Flagg, D. E. 1983. A case history of a brucellosis outbreak in a brucellosis free state which originated in bison. U.S. Animal Health Association 87:171-172.

Freese, C. H., K. E. Aune, D. P. Boyd, J. N. Derr, S. C. Forrest, C. C. Gates, P. J. P. Gogan, S. M. Grassel, N. D. Halbert, K. Kunkel, and K. H. Redford. 2007. Second chance for the plains bison. Biological Conservation 136:175-184.

Fuller, J. A., R. A. Garrott, P. J. White, K. E. Aune, T. J. Roffe, and J. C. Rhyan. 2007. Reproduction and survival in Yellowstone bison. Journal of Wildlife Management 71:2365-2372.

Galey, F., J. Bousman, T. Cleveland, J. Etchpare, R. Hendry, J. Hines, B. Lambert, J. Logan, S. Madden, B. Mead, K. Mills, K. Musgrave, D. Oldham, M. Olsen, T. Pollard, C. Purves, J. Snow, A. Sommers, T. Thorne, B. Wharff, and B. Williams. 2005. Wyoming brucellosis coordination team report and recommendations. University of Wyoming, Laramie, Wyoming.

Gates, C. C., C. H. Freese, P. J. P. Gogan, and M. Kotzman, editors. 2010. American bison: status survey and conservation guidelines 2010. IUCN, Gland, Switzerland.

Geremia, C., P. J. White, J. Borkowski, R. L. Wallen, J. J. Treanor, F. G. R. Watson, C. S. Potter, and R. L. Crabtree. 2010. Drivers of migration in Yellowstone bison – Implications for conservation of migratory wildlife outside protected areas. Yellowstone National Park, Mammoth, Wyoming.

Geremia, C., P. J. White, R. A. Garrott, R. Wallen, K. E. Aune, J. Treanor, and J. A. Fuller. 2009. Demography of central Yellowstone bison: effects of climate, density and disease. Pages 255-279 in R. A. Garrott, P. J. White, and F. G. R. Watson, editors. The ecology of large mammals in central Yellowstone: sixteen years of integrated field studies. Elsevier, San Diego, California.

Gionfriddo, J. P., J. D. Eisemann, K. J. Sullivan, R. S. Healey, L. A. Miller, K. A. Fagerstone, R. M. Engeman, and C. A. Yoder. 2009. Field test of a single-injection gonadotrophin-releasing hormone immunocontraceptive vaccine in female white-tailed deer. Wildlife Research 36:177-184.

Gower, C. N., R. A. Garrott, P. J. White, F. G. Watson, S. Cornish, and M. S. Becker. 2009. Spatial responses of elk to winter wolf predation risk: using the landscape to balance multiple demands. Pages 373-399 in R. A. Garrott, P. J. White, and F. G. R. Watson, editors. The ecology of large mammals in central Yellowstone: sixteen years of integrated field studies. Elsevier, San Diego, California.

Gray, M. E. and E. Z. Cameron. 2010. Does contraceptive treatment in wildlife result in side effects? A review of quantitative and anecdotal evidence. Reproduction 139:45-55.

Greater Yellowstone Interagency Brucellosis Committee. 1997. Greater Yellowstone Interagency Brucellosis Committee “White Paper.” <http://www.nps.gov/gyibc/whitepap. htm>. Accessed March 31, 2010.

Gross, J. E., B. C. Lubow, and M. W. Miller. 2002. Modeling the epidemiology of brucellosis in the Greater Yellowstone Area. Pages 24-37 in T. Kreeger, editor. Brucellosis in elk and bison in the greater Yellowstone area. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Gude, P. H., A. J. Hansen, D. A. Jones. 2007. Biodiversity consequences of alternative future land use scenarios in greater Yellowstone. Ecological Applications 17:1004-1018.

Haggerty, J. H., and W. R. Travis. 2006. Out of administrative control: absentee owners, resident elk and the shifting nature of wildlife management in southwestern Montana. Geoforum 37:816-830.

Hamlin, K. L., and J. A. Cunningham. 2008. Montana elk movements, distribution, and numbers relative to brucellosis transmission risk. Montana Department of Fish, Wildlife, and Parks, Bozeman, Montana.

Hansen, A. J., and R. DeFries. 2007. Ecological mechanisms linking protected areas to surrounding lands. Ecological Applications 17:974-988.

Heilmann, T. J., R. A. Garrott, L. L. Cadwell, and B. L. Tiller. 1998. Behavioral response of free-ranging elk treated with an immunocontraceptive vaccine. Journal of Wildlife Management 62:243-250.

Hobbs, N.T., R. Wallen, J. Treanor, C. Geremia, and P. J. White. 2009. A stochastic population model of the Yellowstone bison population. Colorado State University, Fort Collins, Colorado.

John, T. J., and R. Samuel. 2000. Herd immunity and herd effect: new insights and definitions. European Journal of Epidemiology 16:601-606.

Joly, D. O., and F. Messier. 2004. Factors affecting apparent prevalence of tuberculosis and brucellosis in wood bison. Journal of Animal Ecology 73:623-631.

Johnson, D. E. 1951. Biology of the elk calf, *Cervus canadensis nelsoni*. Journal of Wildlife Management 15:396-410.

Jones, J. D., J. J. Treanor, and R. L. Wallen. 2009. Parturition in Yellowstone bison. Report YCR-2009-01. National Park Service, Mammoth Hot Springs, Wyoming.

Jones, J. D., J. J. Treanor, R. L. Wallen, and P. J. White. 2010. Timing of parturition events in Yellowstone bison—Implications for bison conservation and brucellosis transmission risk to cattle. Wildlife Biology 16:1-7.

Killian, G., D. Wagner, K. Fagerstone, and L. Miller. 2008. Long-term efficacy and reproductive behavior associated with GonaCon use in white-tailed deer (*Odocoileus virginianus*). Proceedings Vertebrate Pest Conference 23:240-243.

Kilpatrick, A. M., C. M. Gillin, and P. Daszak. 2009. Wildlife-livestock conflict: the risk of pathogen transmission from bison to cattle outside Yellowstone National Park. Journal of Applied Ecology 46:476-485.

Kirkpatrick, J. F., and A. Turner. 2008. Achieving population goals in a long-lived wildlife species (*Equus caballus*) with contraception. Wildlife Research 35:513-519.

Kreeger, T. J., editor. 2002. Brucellosis in elk and bison in the greater Yellowstone area. Wyoming Game and Fish, Cheyenne, Wyoming.

Lemke, T. 2008. Gardiner late elk hunt annual report. Montana Department of Fish, Wildlife, and Parks, Bozeman, Montana.

Lyon, L. J., S. Cain, N. F. Cheville, D. Davis, P. Nicoletti, and M. Stewart. 1995. Informational report on the risk of transmission of brucellosis from infected bull bison to cattle. Greater Yellowstone Interagency Brucellosis Committee, Missoula, Montana.

Maichak, E. J., B. M. Scurlock, J. D. Rogerson, L. L. Meadows, A. E. Barbknecht, W. H. Edwards, and P. C. Cross. 2009. Effects of management, behavior, and scavenging on risk of brucellosis transmission in elk of western Wyoming. Journal of Wildlife Diseases 45:398-410.

McShea, W. J., S. L. Monfort, S. Hakim, J. Kirkpatrick, I. Liu, J. W. Turner, Jr., L. Chassy, and L. Munson. 1997. The effect of immunocontraception on the behavior and reproduction of white-tailed deer. Journal of Wildlife Management 61:560-569.

Meagher, M., and M. E. Meyer. 1994. On the origin of brucellosis in bison of Yellowstone National Park: a review. Conservation Biology 8:645-653.

Merrill, J. A., E. G. Cooch, and P. D. Curtis. 2006. Managing an overabundant deer population by sterilization: effects of immigration, stochasticity and the capture process. Journal of Wildlife Management 70:268-277.

Miller, L. A., J. C. Rhyan, and M. Drew. 2004. Contraception of bison by GnRH vaccine: a possible means of decreasing transmission of brucellosis in bison. Journal of Wildlife Diseases 40:725-730.

Montana Fish, Wildlife, and Parks. 2010. Bison translocation, bison quarantine phase IV environmental assessment decision notice. Helena, Montana. <http://fwpiis.mt.gov/content/getItem.aspx?id=41815>. Accessed April 3, 2010.

National Park Service. 2006. Management policies 2006. U.S. Department of the Interior, Washington, D.C.

Nicoletti, P., and M. J. Gilsdorf. 1997. Brucellosis – the disease in cattle. Pages 3-6 in E. T. Thorne, M. S. Boyce, P. Nicoletti, and T. J. Kreeger, editors. Brucellosis, bison, elk, and cattle in the greater Yellowstone area: defining the problem, exploring solutions. Wyoming Game and Fish, Cheyenne, Wyoming.

Nuñez, C. M. V., J. S. Adelman, C. Mason, and D. I. Rubenstein. 2009. Immunocontraception decreases group fidelity in a feral horse population during the non-breeding season. Applied Animal Behaviour Science 117:74-83.

Olsen, S., N. Cheville, R. Kunkle, M. Plamer and A. Jensen. 1997. Bacterial survival, lymph node changes, and immunologic responses of bison (*Bison bison*) vaccinated with *Brucella abortus* strain RB51. Journal of Wildlife Diseases 33:146-151.

Plumb, G. E., P. J. White, M. B. Coughenour, and R. L. Wallen. 2009. Carrying capacity, migration, and dispersal in Yellowstone bison. Biological Conservation 142:2377-2387.

Powers, J. G., D. L. Baker, M. M. Conner, A. H. Lothridge, T. L. Davis, and T. M. Nett. 2007. Effects of GnRH immunization on reproduction and behavior in female Rocky Mountain elk. Proceedings International Conference on Fertility Control for Wildlife 6:36-37.

Proffitt, K. M., P. J. White, and R. A. Garrott. 2010. Spatio-temporal overlap between Yellowstone bison and elk – implications for wolf restoration and other factors for brucellosis transmission risk. Journal of Applied Ecology 47:281–289.

Ransom, J. I., B. S.Cade, and N. T. Hobbs. 2010. Influences of immunocontraception on time budgets, social behavior, and body condition in feral horses. Applied Animal Behaviour Science 124:51-60.

Rhyan, J. C., K. Aune, T. Roffe, D. Ewalt, S. Hennager, T. Gidlewski, S. Olsen, and R. Clarke. 2009. Pathogenesis and epidemiology of brucellosis in Yellowstone bison: serologic and culture results from adult females and their progeny. Journal of Wildlife Diseases 45:729-739.

Rhyan, J. C., and M. D. Drew. 2002. Contraception: a possible means of decreasing transmission of brucellosis in bison. Pages 99-108 in T. J. Kreeger, editor. Brucellosis in elk and bison in the greater Yellowstone area. Wyoming Game and Fish, Cheyenne, Wyoming.

Rhyan, J. C., W. J. Quinn, L. S. Stackhouse, J. J. Henderson, S. R. Ewalt, J. B. Payeur, M. Johnson, and M. Meagher. 1994. Abortion caused by *Brucella abortus* biovar 1 in a free-ranging bison (*Bison bison*) from Yellowstone National Park. Journal of Wildlife Diseases 30:445-446.

Roberto, F. F., and D. T. Newby. 2007. Application of a real-time PCR assay for *Brucella abortus* in wildlife and cattle. U.S. Animal Health Association 110:196-199.

Roffe, T. J., L. C. Jones, K. Coffin, M. L. Drew, S. J. Sweeney, S. D. Hagius, P. H. Elzer, and D. Davis. 2004. Efficacy of single calfhood vaccination of elk with *Brucella abortus* strain 19. Journal of Wildlife Management 68:830-836.

Roffe, T. J., J. C. Rhyan, K. Aune, L. M. Philo, D. R. Ewalt, T. Gidlewski, and S. G. Hennager. 1999. Brucellosis in Yellowstone National Park bison: quantitative serology and infection. Journal of Wildlife Management 63:1132-1137.

Rutberg, A. T., and R. E. Naugle. 2008. Population-level effects of immunocontraception in white-tailed deer (*Odocoileus virginianus*). Wildlife Research 35:494-501.

Sanderson, E. W., K. H. Redford, B. Weber, K. Aune, D. Baldes, J. Berger, D. Carter, C. Curtin, J. Derr, S. Dobrott, E. Fearn, C. Fleener, S. Forrest, C. Gerlach, C. C. Gates, J. E. Gross, P. Gogan, S. Grassel, J. A. Hilty, M. Jensen, K. Kunkel, D. Lammers, R. List, K. Minkowski, T. Olson, C. Pague, P. B. Robertson, and B. Stephenson. 2008. The ecological future of the

North American bison: conceiving long-term, large-scale conservation of wildlife. Conservation Biology 22:252-266.

Scurlock, B. 2010. Pinedale elk herd unit test and slaughter pilot project report year four: Muddy, Fall, and Scab Creek feedgrounds, 2009. Wyoming Game and Fish Department, Cheyenne, Wyoming. < http://docs.google.com/viewer?a=v&q=cache:bM_ruc3XN-oJ:gf.state.wy.us/downloads/pdf/RegionalNews/TR_report_2009_Final.pdf>. Accessed April 3, 2010.

Snow, J. 2005. November 3, 2005 electronic mail message to J. MacDonald, Greystone Environmental Consultants, Greenwood Village, Colorado regarding the number of human cases of brucellosis in Wyoming. State Public Health Veterinarian, Wyoming Department of Public Health, Cheyenne, Wyoming.

Talbott, S., J. Logan, and J. Thomas. 2010. Bugling back: brucellosis backlash. Bugle (Mar/Apr):9.

Templeton, J. W., R. Smith, and G. Adams. 1988. Natural disease resistance in domestic animals. Journal of the American Veterinary Medical Association 192:1306-1315.

Thorne, E. T., M. S. Boyce, P. Nicoletti, and T. J Kreeger. 1997. Brucellosis, bison, elk and cattle in the greater Yellowstone area: defining the problem, exploring the solutions. Wyoming Game and Fish, Cheyenne, Wyoming.

Thorne, T., and T. Linfield. 2004. Report of the greater Yellowstone interagency brucellosis committee. U.S. Animal Health Association 107:239-250.

Treanor, J. J. , J. S. Johnson, R. L. Wallen, S. Cilles, P. H. Crowley, J. J. Cox, D. S. Maehr, P. J. White, and G. E. Plumb. 2010. Vaccination strategies for managing brucellosis in Yellowstone bison. Vaccine 28S:F64-F72.

Treanor, J. J., R. L. Wallen, D. S. Maehr, and P. H. Crowley. 2007. Brucellosis in Yellowstone bison: implications for conservation management. Yellowstone Science 15:20-24.

U.S. Animal Health Association. 2006. Enhancing brucellosis vaccines, vaccine delivery, and surveillance diagnostics for elk and bison in the greater Yellowstone area: a technical report from a working symposium held August 16-18, 2005 at the University of Wyoming. T. Kreeger, and G. Plumb, editors. The University of Wyoming Haub School and Ruckelshaus Institute of Environment and Natural Resources, Laramie, Wyoming.

U.S. Department of Agriculture. 2008a. United States achieves cattle brucellosis class free status. Washington, D.C.

U.S. Department of Agriculture. 2008b. National brucellosis elimination zone proposal. Animal and Plant Health Inspection Service, Veterinary Services, Fort Collins, Colorado.

U.S. Department of Agriculture. 2009. Notice of availability of a bovine brucellosis program concept paper. Federal Register 74:51115-51116.

U.S. Department of the Interior, National Park Service and United States Department of Agriculture, Forest Service, Animal and Plant Health Inspection Service. 2000. Record of decision for final environmental impact statement and bison management plan for the State of Montana and Yellowstone National Park. Washington, D.C.

U.S. Department of the Interior, National Park Service and U.S. Department of Agriculture, Forest Service, Animal and Plant Health Inspection Service, and the State of Montana, Department of Fish, Wildlife, and Parks, Department of Livestock. 2008. Adaptive adjustments to the interagency bison management plan. National Park Service, Yellowstone National Park, Wyoming.

White, P. J., R. L. Wallen, C. Geremia, J. J. Treanor, and D. W. Blanton. 2010. Management of Yellowstone bison and brucellosis transmission risk – implications for conservation and restoration. Yellowstone National Park, Mammoth, Wyoming.

Wilmers, C. C., and W. M. Getz. 2005. Gray wolves as climate change buffers in Yellowstone. PLoS Biology 3:571-576.

Wyoming Game and Fish Department. 2009. Elevated brucellosis rates in Cody elk prompt more research. <http://gf.state.wy.us/wildlife/Brucellosis/index.asp>. Accessed March 16, 2009.

Young, E. J., and M. J. Corbel. 1989. Brucellosis: clinical and laboratory aspects. CRC Press, Inc., Boca Raton, Florida.

Zanto, S. 2005. Montana Public Health and Safety Division, Public Health Laboratory, personal communication with L. Bambrey, Greystone, August 3, 2005.