The National Park Service

YELLOWSTONE NATIONAL PARK

MONITORING AND RESEARCH ON BISON AND BRUCELLOSIS

Prepared by:
P. J. White, Chief, Wildlife and Aquatic Resources Branch
Rick Wallen, Manager, Bison Ecology and Management Program
John Treanor, Manager, Yellowstone Wildlife Health Program

April 2015

The successful conservation of Yellowstone bison from about two dozen animals in 1901 to about 4,900 animals in 2014 has generated substantial debate among management agencies and stakeholder groups regarding bison abundance and distribution, and the potential transmission of the disease brucellosis (which causes abortions) from bison to domestic cattle. As a result, there is an ongoing need to estimate key parameters of bison and brucellosis dynamics, and evaluate the likely effects and effectiveness of management activities. This report updates findings regarding a suite of long-term monitoring and research activities that are intended to inform adaptive management and decision making related to the management of Yellowstone bison pursuant to the Interagency Bison Management Plan, as adjusted. This plan and documents related to it are available at http://ibmp.info/library.php.

The various types of actions in the Interagency Bison Management Plan to conserve Yellowstone bison while lessening the risk of brucellosis transmission to cattle in Montana can be grouped into three general categories: 1) conserving a viable population of wild, wide-ranging bison and the ecological processes that sustain them; 2) managing brucellosis transmission risk from bison to cattle; and 3) reducing the prevalence and transmission of brucellosis in bison. In 2008, we developed a suite of monitoring and research activities to provide timely and useful information to help develop adaptive management adjustments to bison management. The following paragraphs summarize findings from these categories and activities.

Conservation (Preserve a Functional, Wild Bison Population)

<u>Estimate the abundance, demography, and limiting factors for the overall bison population and two primary subpopulations (i.e., central and northern breeding herds).</u>

National Park Service (NPS) biologists estimate bison abundance, age and sex structure, and recruitment in the central and northern breeding herds each summer. Results are documented in annual count reports posted at http://ibmp.info/. A sample of 30 to 60 radio-collared bison is maintained annually to estimate condition, distribution, group sizes, habitat use, movements, pregnancy, and survival. These findings are released periodically in published articles.

Biologists from the NPS and Montana State University estimated demographic rates for 80 adult female bison in the central herd during 1995-2006 (*Geremia et al. 2009, Demography of central Yellowstone bison: Effects of climate, density and disease. Pages 255-279 in Garrott et al., editors. The ecology of large mammals in central Yellowstone: Sixteen years of integrated field studies. Elsevier, San Diego, California*).

- Females previously exposed to brucellosis had significantly lower pregnancy rates across all age classes than unexposed bison. Birth rates were high and consistent for unexposed females, but lower for young females previously exposed to brucellosis.
- There was a pronounced decrease in survival for bison more than 12 years old. Exposure to brucellosis indirectly lowered survival because these bison were often culled when they attempted to leave the park due to concerns about transmission to cattle.
- Adult female survival decreased when the number of bison in the central herd exceeded 2,000-2,500 animals, which was exacerbated during winters with deep snow pack because more bison moved outside the park. The vast majority of radio-marked bison culled at the north and west boundaries during 1998-2006 came from the central herd.
- The effects of brucellosis on bison survival and birth rates lowered the growth rate in the central herd. The growth rate would likely increase by more than 15% if brucellosis could be substantially suppressed.

Biologists from the NPS and Colorado State University synthesized information and interpreted results from a spatially explicit model of the Yellowstone system (*Plumb et al. 2009, Carrying capacity of bison in Yellowstone National Park, Biological Conservation 142:2377-2387*).

- Bison abundance has not exceeded estimates of the food-limited carrying capacity of about 6,200 in Yellowstone. However, more bison migrate earlier to lower-elevations during winter as numbers increase and weather factors interact with density to limit nutritional intake and foraging efficiency.
- A gradual expansion of the winter range as bison numbers increased enabled relatively constant population growth and increased food-limited carrying capacity.
- Current management actions should attempt to preserve bison migration to essential winter range areas within and adjacent to the park, while actively preventing dispersal and range expansion to outlying areas where the State of Montana does not tolerate bison.
- A population of 2,500-4,500 bison should satisfy collective interests concerning the park's forage base, bison movement ecology, retention of genetic diversity, brucellosis risk management, and prevailing social conditions.

NPS biologists contributed to a chapter on conservation guidelines for population, genetic, and disease management of American bison for the International Union for Conservation of Nature (*Gates et al. 2010, American bison: Status survey and conservation guidelines 2010, International Union for the Conservation of Nature, Gland, Switzerland*).

- Overarching principles for conserving bison were to (1) maximize the number of bison in a population, (2) promote wild conditions and behaviors in areas where bison are exposed to natural selection and management interventions are minimized, (3) preserve genetic integrity by maintaining lineages, and (4) monitor demographic processes, herd composition, habitat, and associated ecological processes.

NPS biologists develop population models using data collected from Yellowstone bison during 1970-2014 to estimate the abundance, composition, and trends of each breeding herd and evaluate the relative impacts of harvests and other types of management removals (*Geremia et al. 2014, Population dynamics and adaptive management of Yellowstone bison, National Park Service, Yellowstone National Park, Mammoth, Wyoming*).

- NPS biologists conduct population counts and age and gender classifications of the central and northern breeding herds during June and early July. Weather forecasts and population and migration models are used to predict herd abundances and compositions at the end of the upcoming winter, and numbers of bison migrating to the park boundary.
- Since 2011, biologists have recommended removal objectives for bison based on abundance and demographic (age, herd, sex) goals to reduce numbers towards 3,500 while maintaining more than 1,000 bison in each breeding herd, similar proportions of males to females, and an age structure of about 70% adults and 30% juveniles.
- Management tools used to reduce bison numbers include public and treaty harvests in Montana, shipments of bison to meat processing facilities, and the transfer of bison to research facilities. No quarantine facilities or terminal pastures are currently available.

Biologists from the U.S. Geological Survey, Northern Rocky Mountain Science Center, investigated the pregnancy rates of bison in central Yellowstone based on necropsies at the western boundary during 1997 to 2003 (*Gogan et al. 2013, Pregnancy rates in central Yellowstone bison, Journal of Wildlife Management 77:1271-1279*).

- Pregnancy rates of bison increased with body weight and age, which are highly correlated indicators of body condition that strongly influence the probability of pregnancy.
- There was some evidence most bison did not breed successfully in sequential years, with most pregnancies occurring in bison at least 3 years old that were not lactating.
- During some years, lactating bison may not be able to achieve a critical body fat to support pregnancy by autumn if weather conditions (e.g., drought) or high herbivore densities (i.e., competition) contribute to marginal summer nutrition.
- Pregnancy rates of females appeared unaffected by brucellosis exposure.

Biologists from the NPS and Syracuse University collaborated during 2012-2014 to quantify forage production and consumption at several study sites across the northern grasslands in Yellowstone National Park (*Wallen et al. 2015, Ecological role—bison relations with other animals and effects on grassland processes. Pages 107-117 in White et al., editors. Yellowstone bison—Conserving an American icon in modern society. Yellowstone Association, Yellowstone National Park, Wyoming*).

- Consumption of above-ground biomass in and near the Lamar Valley exceeded 70%, yet gross annual production was higher compared to areas where grazing was excluded.
- Bison repeatedly grazed the same areas and above-ground biomass at the end of summer was approximately 10% of that available in areas where grazing was excluded.
- Monitoring will continue due to concerns about bison consuming such high proportions of the grassland during summer that the effective use of traditional wintering areas by other migratory ungulates such as elk is reduced.
- Since 2008, more elk spend winter on lower elevation areas outside Yellowstone than on areas of the northern grassland within the park. At the same time, bison migrations to lower elevation areas near the northern park boundary have become more regular.

NPS biologists and their colleagues published a book entitled *Yellowstone's Wildlife in Transition* (*White et al. 2013, Harvard University Press, Cambridge, Massachusetts*) that contains chapters about the status and ecology of bison, as well as their management history and current challenges. Chapters with information pertinent to Yellowstone bison include:

- *Understanding the past: The history of wildlife and resource management in the greater Yellowstone area* (*Olliff et al.*, pages 10-28);
- *Scale and perception in resource management: Integrating scientific knowledge* (*Becker et al.*, pages 29-44);
- *Population dynamics: Influence of resources and other factors on animal density* (*White and Gunther*, pages 47-68);
- *Predation: Wolf restoration and the transition of Yellowstone elk* (*White and Garrott*, pages 69-93);
- *Competition and symbiosis: The indirect effects of predation* (*Garrott et al.*, pages 94-108);
- *Climate and vegetation phenology: Predicting the effects of warming temperatures* (*Wilmers et al.*, pages 147-163);
- *Migration and dispersal: Key processes for conserving national parks* (*White et al.*, pages 164-178);
- *Assessing the effects of climate change and wolf restoration on grassland processes* (*Frank et al.*, pages 195-205);
- *Balancing bison conservation and risk management of the non-native disease brucellosis* (*Treanor et al.*, pages 226-235); and
- *The future of ecological process management* (*White et al.*, pages 255-266).

NPS biologists and their colleagues published a book entitled *Yellowstone bison—Conserving an American icon in modern society* (*White et al. 2015, Yellowstone Association, Yellowstone National Park, Wyoming*) that contains chapters about the status and ecology of bison, as well as their management history and current challenges. Chapters with information pertinent to Yellowstone bison include:

- *The population* (*Blanton et al.*, pages 1-18);
- *Brucellosis* (*White et al.*, pages 19-44);
- *Historical perspective* (*Wallen et al.*, pages 45-66);
- *Seasonal distributions and movements* (*Geremia et al.*, pages 67-82);
- *Reproduction and survival* (*Geremia et al.*, pages 83-96);
- *Nutritional ecology* (*Treanor et al.*, pages 97-106);
- *Ecological role* (*Wallen et al.*, pages 107-118);
- *Adaptive capabilities and genetics* (*Wallen et al.*, pages 119-130);
- *Cultural importance* (*Wallen et al.*, pages 131-140);
- *Current management* (*White et al.*, pages 141-158); and
- *The future* (*White et al.*, pages 159-178).

Biologists from the NPS and Colorado State University integrated short-term research on processes with long-term monitoring data to construct a Bayesian state-space model that evaluated the effects of brucellosis and alternate management strategies on the population

dynamics of Yellowstone bison (*Hobbs et al. 2015, State-space modeling to support management of brucellosis in the Yellowstone bison population, Ecological Monographs, accepted*).

- Brucellosis transmission was more dependent on the portion of the population that was infectious (frequency dependent) than the number of infectious individuals in the population (density dependent).
- About 60% of adult females tested positive for previous exposure to brucellosis, but only 8-12% were infectious. Estimates of population growth rate (λ) for the infected population averaged 1.07 compared to 1.11 for the population without the disease.
- The annual removal of 200 bison previously exposed to brucellosis increased the probability of reducing transmission below 50% by 110 times relative to taking no action. Likewise, vaccinating 200 unexposed bison each year increased the probability of achieving a 50% reduction in brucellosis transmission by 30 times compared to no action.
- However, high levels of uncertainty in implementing these management actions due to random variations in the number of bison accessible for capture or vaccination from year-to-year substantially reduced the probability of achieving goals compared to no action.
- Managers should use an adaptive management approach to implement management actions over a relatively short time frame (3-5 years) and frequently reevaluate the effects and effectiveness of these actions in response to new data and model forecasts.

Biologists evaluated the effects of brucellosis on the demography and population dynamics of African buffalo in South Africa (*Gorsich et al. 2015, Context-dependent survival, fecundity and predicted population-level consequences of brucellosis in African buffalo, Journal of Animal Ecology doi: 10.1111/1365-2656.12356*).

- The annual prevalence of brucellosis in the population ranged from 9-48% and increased with age until reaching maturity at six years. Buffalo previously exposed to brucellosis had poorer body condition, higher mortality, and lower reproductive success. There was no association between brucellosis and pregnancy or calving.
- The estimated growth rate (λ) of the population was 1.00 when 30% of buffalo were exposed to brucellosis and 1.11 without brucellosis. Infection can decrease population growth rates, but effects depend on demographic and environmental conditions.

<u>Describe migratory and dispersal movements by bison at a variety of temporal and spatial scales in and outside the park.</u>

Biologists from the NPS and Montana State University quantified annual variations in the magnitude and timing of migration by central herd bison during 1971-2006 and identified potential factors driving this variation (*Bruggeman et al. 2009, Partial migration in central Yellowstone bison. Pages 217-235 in Garrott et al., editors. The ecology of large mammals in central Yellowstone: Sixteen years of integrated field studies. Elsevier, San Diego, California*).

- Bison were partially migratory, with a portion migrating to the lower-elevation Madison headwaters area during winter while some remained year-round in or near the Hayden and Pelican valleys.
- There was significant bison migration to the Madison headwaters area before the Hayden and Pelican valleys were fully occupied and abundance approached the food-limiting carrying capacity of these valleys.

- After the central herd exceeded 2,350 animals, the number of bison spending winter in the Hayden and Pelican valleys appeared to stabilize, while bison continued to migrate to the Madison headwaters area. Also, more bison migrated earlier as density increased.
- Some bison migrated outside the west-central portion of the park between the summer and winter counts each year when the central herd exceeded 2,350 bison, perhaps relocating to northern range.
- The timing and magnitude of bison migration were accentuated during years of deep snow pack that limited access to food.

Biologists from the NPS and Montana State University quantified how snow, topography, habitat attributes, and roads influenced the travel patterns and non-traveling activities of 30 radio-marked, adult, female bison from the central herd during three winters (*Bruggeman et al. 2009, Bison winter road travel: Facilitated by road grooming or a manifestation of natural trends? [pages 603-621], Effects of snow and landscape attributes on bison winter travel patterns and habitat use [pages 623-647]. In Garrott et al., editors. The ecology of large mammals in central Yellowstone: Sixteen years of integrated field studies. Elsevier, San Diego, California*).

- Bison were less likely to use a given place on the landscape for traveling or feeding as snow pack increased. However, bison eventually had to use areas with deeper snow as the overall snow pack increased on the landscape.
- The spatial network of bison was largely defined by bison traveling along streams between foraging areas. Also, the probability of travel was higher in areas of variable topography that constrained movements (e.g., canyons).
- Road grooming (i.e., snow packing) for over-snow vehicle recreation had a minimal influence on bison travel and habitat use compared to snow pack, topography, and habitat attributes on bison choice of travel routes and habitats for feeding and resting.

NPS biologists develop migration models using data collected from Yellowstone bison since 1990 to evaluate relationships between bison population size, forage biomass, winter severity, and migration (*Geremia et al. 2014, Spatial distribution of Yellowstone bison – winter 2015, National Park Service, Yellowstone National Park, Mammoth, Wyoming*).

- Weather forecasts and population and migration models are used to forecast the numbers of bison migrating to the park boundary from the central and northern herds.
- Migration beyond the northern park boundary is affected by herd size, accumulated snow water equivalent, and aboveground dry biomass. Migration beyond the western park boundary suggest additional drivers (e.g., learning) strongly influence migration (*Geremia et al. 2011, Predicting bison migration out of Yellowstone National Park using Bayesian models, PLoSOne 6:e16848*).
- A strategy of sliding tolerance whereby more bison are allowed beyond park boundaries during severe climate conditions may be the only means of avoiding episodic, large-scale reductions to the Yellowstone bison population in the foreseeable future.

<u>Estimate the existing heterozygosity, allelic diversity, and long-term probabilities of genetic conservation for the overall bison population and identified subpopulations.</u>

Biologists from the NPS and the University of Montana evaluated if bison from the central and northern breeding herds were genetically differentiated based on mitochondrial and

microsatellite DNA from fecal samples (*Gardipee 2007, Development of DNA sampling methods to assess genetic population structure of greater Yellowstone bison, University of Montana, Missoula*).

- There was significant genetic differentiation in mitochondrial DNA between bison sampled from the northern and central breeding herds, likely due to strong female fidelity to breeding areas.

Geneticists at Texas A & M University used 51 nuclear markers to evaluate existing genetic variation in 11 federal bison herds (*Halbert and Derr 2008, Patterns of genetic variation in US federal bison herds, Molecular Ecology 17:4963-4977*).

- Most herds, including Yellowstone, have maintained high levels of genetic diversity despite the severe bottleneck in the late 1800s when bison were almost extirpated.
- Satellite herds should be established to further protect lineages with high levels of genetic diversity that are geographically isolated, such as Yellowstone.
- The existing genetic diversity of plains bison is unevenly distributed among NPS and Fish and Wildlife Service herds, and as a result, should be carefully managed to ensure long-term conservation.

NPS biologists provided information to the Department of the Interior for review by scientists from government agencies and non-governmental organizations with professional population geneticists and the development of guidance for the genetic management of federal bison populations (*Dratch and Gogan 2010, Bison conservation initiative: Bison conservation genetics workshop: Report and recommendations. Natural Resource Report NPS/NRPC/BRMD/NRR—2010/257, National Park Service, Fort Collins, Colorado*).

- With the exception of Yellowstone, current bison populations are not large enough (more than 1,000 bison) to preserve genetic variation over centuries.
- Yellowstone bison have relatively high allelic richness and heterozygosity compared to other populations. Also, Yellowstone is one of a few populations with no evidence of prior interbreeding with cattle.
- The Yellowstone population represents a unique genetic lineage that should be replicated elsewhere by establishing satellite populations.

Biologists from the NPS reviewed a study by Pringle (*2011, Widespread mitochondrial disease in North American bison. Nature Precedings 07 February*) that concluded some Yellowstone bison have deleterious genetic mutations, and as a result, “are predicted significantly impaired in aerobic capacity, disrupting highly evolved cold tolerance, winter feeding behaviors, escape from predators and competition for breeding."

- Bison with haplotype 6 in their mitochondrial genome carry a double mutation that affects two genes: Cytochrome b and ATP6. These bison are primarily found in the central breeding herd based on recent genetic sampling. This inherited mutation could affect their production of energy (i.e., ATP produced by mitochondrial oxidative phosphorylation). Bison with haplotype 8 in their mitochondrial genome do not carry the double mutation and are primarily found in the northern breeding herd.
- Even if the genetic sequences and analyses reported by Pringle (2011) are correct, genetic mutation does not automatically equal genetic disease. There are multiple compensating

mechanisms in biological systems that combine to overcome theoretical metabolic deficiencies (Dr. James Derr, Texas A & M University, personal communication).

- Also, there is direct evidence that even if Yellowstone bison have some sort of genetic deficiency, it has not been manifested through any biologically significant effect on their ability to survive. Estimated annual survival rates and birth rates for adult female bison were quite high during 1995-2014; especially given the severe, prolonged, high-elevation winter conditions and predator-rich environment in and near Yellowstone National Park.

NPS biologists worked with geneticist Dr. James Derr at Texas A&M University to test the hypothesis of Pringle (2011) that mutations in bison with maternal haplotype 6 have reduced capacity in their mitochondria to produce energy through normal physiological pathways.

- Live tissue samples from four haplotype 8 bison and two haplotype 6 bison were subjected to an *in vitro* oxidative phosphorylation test. Preliminary findings indicated no difference between the two haplotype groups of Yellowstone bison in their ability to produce energy at the cellular level.
- However, similar analyses of tissues collected from bison-cattle hybrids indicated they had a lower ability to produce energy at the cellular level.
- Yellowstone bison likely use alternate physiological mechanisms to produce energy and overcome mutations that could reduce this ability.

Biologists from the NPS and the University of Montana conducted a mathematical modeling assessment that provided predictive estimates of the probability of preserving 95% of the current level of genetic diversity in Yellowstone bison (*Pérez-Figueroa et al. 2012, Conserving genomic variability in large mammals: Effect of population fluctuations and variance in male reproductive success on variability in Yellowstone bison, Biological Conservation 150:159-166*).

- Variations in male reproductive success had the strongest influence on the loss of genetic diversity, while the number of alleles per locus strongly influenced the loss of alleles.
- Fluctuations in population size did not substantially increase the loss of genetic variation when there were more than 3,000 bison in the population. The retention of 95% of allelic diversity for at least 100 years was likely with moderate-to-high variations in male reproductive success, population sizes greater than 2,000 bison, and five alleles per locus.
- The retention of 95% of allelic diversity for centuries is likely with a fluctuating population size that increases to more than 3,500 bison and averages around 3,000 bison.

Biologists from the NPS and the University of Montana conducted DNA extractions with fecal samples collected from Yellowstone bison in the northern and central breeding herds during 2006 and 2008 (*Wallen et al. 2013, Population substructure in Yellowstone bison. Yellowstone National Park, Mammoth, Wyoming*).

- Mitochondrial DNA analyses revealed a higher frequency of haplotype 8 in the northern breeding herd and significant genetic differentiation among northern and central herds. Microsatellite DNA analyses revealed allele frequencies with low levels of subdivision between the central and northern breeding herds.
- These results suggest the population has historically had two genetically distinguishable breeding groups with strong female philopatry and male-mediated gene flow. However, radio-marked adult females provided evidence of substantial emigration between breeding groups during 2007-2014.

- The long-term monitoring of microsatellite allele and mitochondrial haplotype frequencies will be necessary to track genetic diversity and population substructure.

A geneticist from Arizona State University provided recommendations for the maintenance of genetic diversity in conservation herds of plains bison (*Hedrick 2009, Conservation genetics and North American bison (Bison bison), Journal of Heredity 100:411-420*).

- Yellowstone bison have high genetic diversity compared to many other populations of plains bison due to many founders and multiple founder sources. Also, they represent one of only a few bison populations with no evidence of interbreeding with cattle.
- A population size of 2,000 to 3,000 bison was recommended to avoid inbreeding depression and maintain genetic variation. This census number could include two or more herds with significant genetic exchange between them.
- Yellowstone bison were the only population with an effective population size high enough to avoid inbreeding depression and maintain genetic variation.

Geneticists sequenced the mitochondrial DNA genome from 43 American bison and domestic cattle to analyze phylogenetic relationships (*Douglas et al. 2011, Complete mitochondrial DNA sequence analysis of Bison bison and bison-cattle hybrids: Function and phylogeny, Mitochondrion 11:166-175*).

- Findings supported the inclusion of the *Bison* genus within the *Bos* (or cattle) genus.
- Current populations of plains and wood bison do not have significantly different mitochondrial gene sequences and should not be considered subspecies.

In a study partially funded and supported by the NPS, geneticists investigated the potential for limited gene flow across the Yellowstone bison population using blood and hair samples primarily collected from bison at the northern and western boundaries of the park during the winter migration period, well after the breeding season (*Halbert et al. 2012, Genetic population substructure in bison at Yellowstone National Park, Journal of Heredity 103:360-370*).

- Two genetically distinct subpopulations (central, northern) were identified based on genotypic diversity and allelic distributions. The differentiation between subpopulations was only slightly less than that between populations which have been geographically and reproductively isolated for over 40 years.
- Culling bison without regard to possible subpopulation structure has the potential long-term consequence of reducing genetic diversity and permanently changing the genetic constitution within subpopulations and across the Yellowstone population.

NPS biologists disputed some of the assumptions and inferences made by *Halbert et al.* (*2012*) and suggested that human manipulation had created and maintained much of the observed population subdivision and genetic differentiation (*White and Wallen 2012, Yellowstone bison—should we preserve artificial population substructure or rely on ecological processes? Journal of Heredity 103:751-753*).

- The genetic differences between bison in the central and northern regions of Yellowstone were likely created when a northern herd was restored in 1902 from bison of unrelated breeding descent compared to the endemic herd that survived in central Yellowstone.
- When the population of Yellowstone bison reached about 5,000 bison, emigration and gene flow between the breeding herds increased and is now much higher than suggested

by *Halbert et al.* (*2012*). Allowing bison to migrate and disperse between central and northern breeding herds is in the best interest of the bison population for the long term.

- The NPS should allow ecological processes such as natural selection, migration, and dispersal to prevail and influence how population and genetic substructure is maintained in the future. The existing population and genetic substructure may be sustained over time through natural selection or it may not.

Geneticists at Colorado State University investigated natural resistance to brucellosis in Yellowstone bison by attempting to identify resistant and susceptible genotypes using the prion protein gene (*Herman 2013, Genetic natural resistance to brucellosis in Yellowstone National Park bison (Bison bison): A preliminary assessment, Colorado State University, Fort Collins, Colorado*).

- Analyses failed to support the findings of *Seabury et al.* (*2005, Bison PRNP genotyping and potential association with Brucella spp. seroprevalence. Animal Genetics 36:104-110*) regarding a significant association between the prion protein gene and bison testing positive for *Brucella* exposure.
- Management of brucellosis based on genetic screening would require further studies of the bison genome with representative samples from both breeding herds and equally distributed sex and brucellosis serology ratios.
- An evaluation of 42 microsatellite loci indicated Yellowstone bison retain high genetic diversity and a high percentage of adult animals contribute offspring.
- There was no evidence of cattle genes in Yellowstone bison.

Biologists from the NPS collaborated with geneticists at Texas A & M University to estimate the overall diversity of mitochondrial DNA haplotypes in 20 DNA samples from bison in central and northern Yellowstone (Dr. James Derr, Texas A & M University, personal communication).

- Eight mitochondrial DNA haplotypes were identified, including the two previously known haplotypes (6 and 8) in nearly equal proportions and six new haplotypes for Yellowstone bison. Four haplotypes had nucleotide sequences from the indigenous bison from central Yellowstone, while four haplotypes were apparently from bison introduced to northern Yellowstone in 1902 from the Pablo-Allard herd in northern Montana.

<u>Promote cooperative conservation in bison management by partnering with states, Native American tribes, and others interested in bison health and recovery.</u>

During 2005 through 2008, 214 Yellowstone bison calves that tested negative for brucellosis exposure were transferred from the NPS to the Animal and Plant Health Inspection Service and Montana Fish, Wildlife & Parks. These bison were moved to a research quarantine facility north of Yellowstone National Park to evaluate if they would remain free of brucellosis through at least their first pregnancy and calving (*Clarke et al. 2014, Feasibility of quarantine procedures for bison (Bison bison) calves from Yellowstone National Park for conservation of brucellosis-free bison, Journal of the American Veterinary Medical Association 244:588-591*).

- The quarantine feasibility study (2005 through 2010) was successful and the surviving original bison and their offspring are considered brucellosis-free by the State of Montana and the Animal and Plant Health Inspection Service.

- The State relocated 87 of these bison to the Green Ranch owned by Turner Enterprises in February 2010 and another 61 bison to the Fort Peck Reservation in March 2012.
- In August 2013, the Fort Peck Assiniboine and Sioux Tribes transferred 34 Yellowstone bison to the Fort Belknap Reservation. In November 2014, 139 Yellowstone bison were transferred from the Green Ranch to the Fort Peck Reservation in Montana.

An analysis of the genetic diversity of 38 Yellowstone bison quarantined on the Green Ranch was conducted using microsatellite data (*Derr and Dobson 2012, Yellowstone quarantine herd comparison to National Bison Range herd, DNA Technologies Laboratory, Texas A & M University, College Station*).

- The levels of heterozygosity and average alleles per locus at 26 polymorphic loci were relatively high and similar to the overall Yellowstone population.
- There was no evidence of introgression from domestic cattle genes.
- Yellowstone bison completing quarantine are extremely valuable for restoring conservation populations with high genetic diversity and no introgression of cattle genes, but should not be introduced into existing herds with evidence of cattle hybridization.

Geneticists at Colorado State University evaluated the genetic diversity of 89 Yellowstone bison quarantined to determine if they would remain free of brucellosis (*Herman et al. 2014, Genetic analysis of a Bison bison herd derived from the Yellowstone National Park population, Wildlife Biology 20:335-343*).

- Genetic diversity at 42 microsatellite loci was high in the quarantined bison and similar to the overall Yellowstone population. The risk of genetic loss in the near future is low.
- The genetic diversity within Yellowstone bison completing quarantine should provide a strong foundation for augmenting or restoring satellite herds and preserving plains bison.

In September 2012, the Superintendent of Yellowstone National Park signed an agreement with the InterTribal Buffalo Council for occasionally transferring some Yellowstone bison to them for transport to meat processing facilities and subsequent distribution of bison meat and other parts to Native American tribes. Similar agreements were reached with the Confederated Salish and Kootenai Tribes during 2013, Nez Perce Tribe and Northwestern Band of the Shoshone Nation during 2014, and Eastern Shoshone Tribe and Northern Arapaho Tribe during 2015.

In September 2012, the NPS reinitiated consultation with the U.S. Fish & Wildlife Service under Section 7(a)(2) of the Endangered Species Act and its implementing regulations (50 CFR Part 402.16) regarding the hazing of Yellowstone bison and its potential effects on threatened grizzly bears, as well as new information on decreases in key grizzly bear foods. The NPS prepared a biological evaluation that provided updated information, an evaluation of potential effects, and descriptions of mitigation actions that should minimize potential adverse effects. NPS biologists concluded that bison hazing operations may affect, but are not likely to adversely affect, listed grizzly bears. The Fish & Wildlife Service concurred with this conclusion in December 2012.

In 2012, staff at Yellowstone National Park worked with the federal, state, and tribal agencies involved with the management of Yellowstone bison to develop a protocol that describes the requirements, roles, and responsibilities that would apply when live Yellowstone bison are

transferred from the NPS to Native American tribes or other recipients to be transported to slaughter facilities, terminal pastures, or quarantine facilities.

NPS historians evaluated existing records for evidence that Native Americans hunted or were permitted to hunt in Yellowstone National Park during the twentieth century. They also researched the history and chronology of bison, elk, and bear meat from Yellowstone being distributed to various Native American tribes after the animals were shot inside park boundaries by NPS staff (*Whittlesey 2013, A brief history and chronology of bison, elk, and bear meat from Yellowstone National Park being distributed to various Indian tribes after the animals were shot inside park boundaries by the National Park Service. Yellowstone National Park, Heritage Research Center, Gardiner, Montana*).

- A search of park collections by archivists, curators, and historians did not find any evidence of Native Americans being given permission to legally hunt within Yellowstone during the twentieth century.
- Bison and elk meat was distributed to various Native American tribes after animals were shot inside the park by NPS personnel during the ungulate reduction program from 1932 to 1967. At times, Native Americans were allowed to butcher carcasses inside the park, which may have led to misperceptions about them hunting bison and elk inside the park.

In March 2015, staff at Yellowstone National Park developed an Environmental Assessment to evaluate establishing a quarantine program for bison at one or more facilities within the park, on tribal lands, or elsewhere. The need for quarantine is to identify brucellosis-free bison from the chronically infected Yellowstone population for relocation to augment or establish populations of plains bison elsewhere for conservation, cultural, and/or commercial purposes. These bison, which are removed from the population to limit population growth pursuant to the Interagency Bison Management Plan, would otherwise be sent to meat processing or research facilities. It is anticipated the assessment will be released for public review and comment during summer 2015.

In March 2015, the NPS and the State of Montana (Montana Fish, Wildlife & Parks and the Montana Department of Livestock) announced they will begin preparing an Environmental Impact Statement for a new plan to manage a wild and migratory population of Yellowstone-area bison, while minimizing the risk of brucellosis transmission between bison and livestock to the extent practicable. The new plan is needed because conditions have changed since implementation of the Interagency Bison Management Plan began in 2001, including agency experience in managing bison and new science. A range of six preliminary draft alternative concepts was developed and disseminated for public comment. These concepts differ in terms of bison abundance, bison tolerance outside of the park, and the tools that could be used to manage the bison population within the park and on lands adjacent to the park.

Risk Management (Lessen Brucellosis Transmission from Bison to Livestock)

<u>Estimate the probabilities (i.e., risks) of brucellosis transmission among bison, cattle, and elk, and the elk feed grounds in Wyoming and northern Yellowstone.</u>

NPS biologists collaborated with colleagues at the Agricultural Research Service and University of Montana to genotype 10 variable number of tandem repeat DNA loci in 58 *Brucella abortus*

isolates from bison, elk, and cattle and test which wildlife species was the likely origin of recent outbreaks of brucellosis in cattle in the greater Yellowstone area (*Beja-Pereira et al. 2009, DNA genotyping suggests recent brucellosis outbreaks in the greater Yellowstone area originated from elk, Journal of Wildlife Diseases 45:1174-1177*).

- Isolates from cattle and elk were nearly identical, but highly divergent from bison isolates. Elk, not bison, were the reservoir species of origin for these cattle infections.

NPS staff collaborated with colleagues at the U.S. Geological Survey and other agencies and universities to assess several plausible hypotheses for observed increases in the prevalence of brucellosis in several free-ranging elk populations of Wyoming (*Cross et al. 2010, Probable causes of increasing brucellosis in free-ranging elk of the Greater Yellowstone Ecosystem, Ecological Applications 20:278-288*).

- Free-ranging elk appear to be a maintenance host for *Brucella abortus* in some areas. Brucellosis prevalence increased from 0-7% in 1991-1992 to 8-20% in 2006-2007 in four herd units not associated with feed grounds.
- These prevalence levels are comparable to units where elk are aggregated on feed grounds and unlikely to be sustained by dispersal of elk from feeding areas with high prevalence or an older age structure.
- The rate of prevalence increase was related to the population size and density of each herd unit. Enhanced elk-to-elk transmission in free-ranging populations may be occurring due to larger winter elk aggregations.
- Elk populations that traditionally did not maintain brucellosis may be at-risk due to increases in abundance. Some Montana populations were 5-9 times larger in 2007 than in the 1970s, with some aggregations comparable to Wyoming feed ground populations.

NPS biologists reviewed and provided comments on a draft of the *Kilpatrick et al.* (*2009, Wildlife-livestock conflict: The risk of pathogen transmission from bison to cattle outside Yellowstone National Park, Journal of Applied Ecology 46:476-485*) article that integrated epidemiological and ecological data to quantify and assess the spatiotemporal risk of brucellosis transmission from Yellowstone bison to cattle under different scenarios.

- The risk of brucellosis transmission from bison to cattle is relatively small, even without management to prevent comingling. The risk rises with increasing bison numbers, deepening snow pack, and the occurrence of thawing and freezing events.
- The risk of transmission will increase as the area bison occupy outside Yellowstone during winter increases and overlaps cattle grazing locations. This risk could be effectively managed at relatively low cost, but existing land uses might hinder solutions.

NPS biologists estimated the timing and location of bison parturition events that may have shed tissues infected by *Brucella abortus* during April to mid-June, 2004-2007 (*Jones et al. 2010, Timing of parturition events in Yellowstone bison—Implications for bison conservation and brucellosis transmission risk to cattle, Wildlife Biology 16:333-339*).

- Abortions occurred from January through May 19, while peak calving (80% of births) occurred from April 25 to May 26. Calving was finished by June 5.
- Parturition events occurred in Yellowstone National Park and on the Horse Butte peninsula in Montana, where cattle were not present at any time of the year.

- Allowing bison to occupy public lands outside the park where cattle are never present until most bison calving is completed will not significantly increase the risk of brucellosis transmission from bison to cattle.
- Allowing bison to occupy public lands outside the park through their calving season will help conserve bison migratory behavior and reduce stress on pregnant females and their newborn calves.

Biologists from the NPS and Montana State University analyzed conditions facilitating contact between bison and elk on a shared winter range in the Madison headwaters area of Yellowstone during 1991 through 2006 (*Proffitt et al. 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*).

- Spatial overlap between bison and elk increased with snow pack and peaked when late-term abortion events and parturition occurred for bison. Wolves contributed to short-term responses by elk that increased spatial overlap with bison, but longer-term responses to wolves resulted in elk distributions that reduced spatial overlap with bison.
- Despite this relatively high risk of transmission, levels of elk exposure to *Brucella abortus* (2-4%) were similar to those in free-ranging elk populations that do not commingle with bison (1-3%), suggesting that *Brucella abortus* transmission from bison-to-elk under natural conditions is rare.
- Management of brucellosis in elk populations could focus on reducing elk-to-elk transmission risk and, to the extent feasible, curtailing practices that increase elk density and group sizes during the potential abortion period.

An NPS biologist developed Bayesian models to estimate rates of incidence and routes of transmission of *Brucella abortus* bacteria among Yellowstone bison during 1995-2010 and assessed the reproductive costs (*C. Geremia, National Park Service, Yellowstone National Park, Mammoth, Wyoming, unpublished data*).

- The median probabilities of horizontal (from unrelated bison) and vertical (from mother) exposure to calves were both 0.10; though the distribution for vertical transmission was skewed left with most of the probability closer to zero.
- Probabilities that adult bison were exposed to brucellosis since the preceding parturition season varied from 0.03-0.37, with incidence increasing with deeper snow pack that likely reflects poorer body condition and perhaps larger aggregations (densities) of bison.
- There was a measureable probability (0.01-0.12) of bison recrudescing from a latent to an infectious state.
- There was a reproductive cost of diminished birth rates following brucellosis infection, with only 59% of exposed and infectious females with calves compared to 79% of unexposed females with calves.
- Brucellosis appears to be maintained through mixed transmission modes (horizontal, vertical) and the duration of infection sometimes extends beyond the acute phase.

NPS and Animal Plant and Health Inspection Service staff and the State Veterinarian of Montana collaborated with colleagues at the University of California-Davis on a spatially-explicit assessment of brucellosis transmission risk among bison, elk, and cattle in the northern portion of the Greater Yellowstone Area (*Schumaker et al. 2010, A risk analysis of Brucella abortus*

transmission among bison, elk, and cattle in the northern greater Yellowstone area, University of California, Davis).

- Population size and winter severity strongly influenced bison movements to lower elevation winter ranges that overlapped with private ranches and federally-regulated cattle grazing allotments. Increasing population size resulted in higher bison densities and more *Brucella* bacteria shed on the landscape.
- Median total risk to cattle from elk and bison was 3.6 cattle-exposure event-days (95% probability interval = 0.1-36.6). The estimated percentage of cattle exposure risk from Yellowstone bison was small (0.0-0.3% of total risk) compared to elk (99.7-100%).
- Bison migration patterns and boundary management operations minimized brucellosis exposure risk to cattle from bison, which supports the continuation of boundary management operations to maintain separation between bison and cattle.
- Transmission risks to elk from elk in other populations or from bison were small. Minimal opportunity exists for *Brucella abortus* transmission from bison to elk under current natural conditions in the northern greater Yellowstone area.
- Management alternatives that reduce brucellosis prevalence in bison are unlikely to substantially reduce transmission risk from elk to cattle. Strategies that decrease elk densities, group sizes, and elk-to-elk transmission could reduce the overall risk to cattle.
- Efforts should reduce the mingling of cattle and elk, especially during the late gestation period for elk when abortions pose a risk for interspecies disease transmission.
- Bison vaccination did not meaningfully reduce *Brucella abortus* transmission risk to cattle. Effective risk reduction strategies included delaying the turn-on dates of cattle grazing allotments, reducing brucellosis prevalence in elk, reducing the number of cattle at-risk, and preventing the mingling of elk and cattle.

Biologists from Montana Fish, Wildlife & Parks estimated the persistence of *Brucella* bacteria on fetal tissue, soil, and vegetation near the northern and western boundaries of Yellowstone National Park during 2001-2003. They also estimated the extent and timing of scavenging on fetuses (*Aune et al. 2012, Environmental persistence of Brucella abortus in the Greater Yellowstone Area, Journal of Wildlife Management 76:253-261*).

- *Brucella* bacteria placed on fetal tissues, soil, and vegetation persisted for 21-81 days depending on ambient temperatures and exposure to sunlight. Bacteria persisted longer in February than May and did not survive beyond June 10th.
- *Brucella* bacteria at naturally contaminated bison birth or abortion sites persisted for up to 43 days on soil and vegetation.
- Fetuses were scavenged by a variety of birds and mammals and more rapidly inside than outside the park.
- Models derived from the data predicted a 0.05% chance of bacterial survival beyond 26 days (95% Credible Interval of 18-30 days) for a contamination event in May.

The University of Montana and collaborators (including the NPS) examined the transmission of *Brucella abortus* between bison, elk, and cattle in the Greater Yellowstone Area using nine variable-number tandem repeat markers on DNA from bacterial isolates (*O'Brien et al. 2013, DNA tracking of recent brucellosis outbreaks in Montana and Wyoming livestock, University of Montana, Missoula, Montana*).

- Haplotype network assessments of genetic relatedness among *Brucella* isolates from 98 tissue samples from geographically distinct areas suggested substantial interspecific transmission between bison and elk populations in both Montana and Wyoming.
- *Brucella* genotypes from a 2008 cattle outbreak in Wyoming matched elk *Brucella* genotypes, indicating elk were the likely source. *Brucella* from two cattle outbreaks (2008, 2010) in the Paradise Valley of Montana had genotypes similar to both bison and elk; though wild bison have not occurred in these areas for more than a century.
- Identical *Brucella* genotypes among many elk populations in Montana suggests brucellosis may have spread through intraspecific transmission, though some infected elk may be immigrants from Wyoming feed grounds or have been exposed by bison.

Staff from the Animal and Plant Health Inspection Service assessed genetic diversity among 366 *Brucella* isolates recovered from bison, cattle, and elk in the Greater Yellowstone Area and Texas during 1998 to 2011 using a variable-number tandem repeat protocol targeting 10 loci in the *Brucella abortus* genome (*Higgins et al. 2012, Molecular epidemiology of Brucella abortus isolates from cattle, elk, and bison in the United States, 1998 to 2011, Applied and Environmental Microbiology 78:3674-3684*).

- Isolates from a 2005 cattle outbreak in Wyoming displayed profiles matching those of strains recovered from wild elk in Idaho and Wyoming. Also, isolates associated with cattle outbreaks in Idaho in 2002, Montana in 2008 and 2011, and Wyoming in 2010 primarily clustered with isolates recovered from wild elk.
- Elk play a predominant role in the transmission of *Brucella abortus* to cattle located in the Greater Yellowstone Area.

Staff from the Animal and Plant Health Inspection Service and Colorado State University evaluated the potential for venereal transmission of *Brucella abortus* in bison by determining if unexposed female bison would become infected following vaginal inoculation or artificial insemination with inoculum containing *Brucella abortus* strain 19 (*Uhrig et al. 2013, Evaluation of transmission of Brucella abortus strain 19 in bison by intravaginal, intrauterine, and intraconjunctival inoculation, Journal of Wildlife Diseases 49:522-526*).

- Four of eight female bison that were intravaginally inoculated converted to being positive for *Brucella* antibodies, but these animals were not infected at necropsy six months later.

Staff from the Animal and Plant Health Inspection Service and Montana Fish, Wildlife & Parks evaluated if Yellowstone bison bulls shed an infective dose of *Brucella abortus* in semen (*Frey et al. 2013, Evaluation of bison (Bison bison) semen from Yellowstone National Park, Montana, USA, bulls for Brucella abortus shedding, Journal of Wildlife Diseases 49:714-717*).

- *Brucella abortus* was cultured from the semen of three (9%) of 33 bulls with antibodies indicating previous *Brucella* exposure, though not at concentrations considered infective.
- Eight bulls had lesions of the testes, epididymis, or seminal vesicles consistent with *Brucella abortus* infection.
- Bulls testing positive for *Brucella abortus* exposure were more likely to have non-viable ejaculate (8/33) than bulls testing negative (2/15).

<u>Estimate age-specific rates of bison testing positive and negative for brucellosis exposure (serology) and infection (culture).</u>

Staff from the Animal and Plant Health Inspection Service collaborated with colleagues to determine the course of *Brucella abortus* infection in female Yellowstone bison and their offspring (*Rhyan et al. 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*).

- Annual conversion rates from negative to positive for brucellosis exposure were relatively high (23%) for calves and juvenile bison, but only 6% for all adult female bison and 11% for adult females that began the study testing negative for exposure.
- Antibodies for *Brucella* were not protective against infection, even for calves that passively received them from their infected mother's colostrum.
- Antibody levels remained relatively constant in adult bison, with a slow decrease over time. Only two bison converted from positive to negative for *Brucella* antibodies.
- Infected bison aborted and shed viable bacteria. The risk of shedding *Brucella* bacteria was highest for bison during the 2 years following conversion from negative to positive.
- Even if their mothers tested positive for brucellosis exposure, most calves tested negative by 5 months of age. There was no relationship between the antibody status of the mother and the tendency of a calf to convert to positive during the study.

Biologists from the NPS and the University of Montana investigated whether *Yersinia enterocolitica* serotype *O:9* causes false-positive reactions in brucellosis serological tests for bison using culturing techniques and multiplex PCR (*See et al. 2012, Yersinia enterocolitica: an unlikely cause of positive brucellosis tests in greater Yellowstone ecosystem (Bison bison), Journal of Wildlife Diseases 48:537-541*).

- *Yersinia enterocolitica* was not detected in samples of feces collected from 53 Yellowstone bison culled from the population and 113 free-roaming bison from throughout the Greater Yellowstone Ecosystem.
- *Yersinia enterocolitica O:9* cross-reactivity with *Brucella abortus* antigens is unlikely to cause false positive serology tests in bison, as has been documented with elk.

NPS and Animal and Plant Health Inspection Service staff sampled more than 400 bison shipped to meat processing facilities during winter 2007-2008 and integrated age-specific serology and culture results for *Brucella abortus* to estimate probabilities of active infection using a Bayesian framework (*Treanor et al. 2011, Estimating probabilities of active brucellosis infection in Yellowstone bison through quantitative serology and tissue culture, Journal of Applied Ecology 48:1324-1332*).

- Infection probabilities were associated with age in bison less than 5 years old and elevated antibody levels in older bison. Many Yellowstone bison become infected *Brucella abortus* early in life, but typically recover as they grow older.
- Fluorescent polarization assay (FPA) values for antibodies in serum were higher in bison that were culture positive compared to bison that were culture negative; supporting that active infection is associated with increased antibody production.
- Age and FPA values could be used to identify and remove captured bison with active infections that most likely contribute to brucellosis maintenance in the population, while keeping bison that contribute to herd immunity and reduce brucellosis transmission.

Estimate the timing and portion of removals from the central and northern herds each winter, including the portion of removals from each age and sex class and calf-cow pairs.

NPS staff compared assumptions and predictions of the Interagency Bison Management Plan with observed impacts and changes since implementation began in 2001 (*White et al. 2011, Management of Yellowstone bison and brucellosis transmission risk – Implications for conservation and restoration, Biological Conservation 144:1322-1334*).

- Intensive management near conservation area boundaries maintained separation between bison and cattle, with no transmission of brucellosis.
- However, brucellosis prevalence in the bison population was not reduced and the management plan underestimated bison abundance, distribution, and migration, which contributed to larger culls of bison than anticipated.
- Large culls during 2006 and 2008 primarily affected the central breeding herd, reduced the number of females, and lessened productivity.

Document bison use of risk management zones outside the northern and western boundaries of Yellowstone and commingling with livestock during the likely brucellosis-induced abortion period for bison each spring.

Annual bison use of habitat outside the northern and western boundaries of Yellowstone National Park, and any mingling with livestock, is documented in the annual reports for the Interagency Bison Management Plan (http://ibmp.info/).

Biologists from the NPS and Colorado State University developed a state-space model to support decisions on bison management aimed at mitigating conflict with landowners outside the park (*Geremia et al. 2014, Integrating population- and individual-level information in a movement model of Yellowstone bison, Ecological Applications 24:346-362*).

- Global Positioning System telemetry locations were integrated with 22 years (1990-2012) of aerial counts to forecast monthly distributions and identify factors driving migration.
- Wintering areas were located along decreasing elevation gradients and bison accumulated in wintering areas prior to moving to areas progressively lower in elevation.
- Bison movements were affected by time since the onset of snow pack, snow pack magnitude, standing vegetation crop, and herd size. Migration pathways were increasingly used over time, suggesting experience or learning influenced movements.
- The model provides probabilistic forecasts of bison movements and seasonal distributions that allow managers to develop strategies in advance and promote sound decision-making that reduces conflict as migratory animals come into contact with people.

Estimate the effects of hazing or temporarily holding bison in capture pens at the boundary of Yellowstone (for spring release back into the park) on subsequent bison movements or possible habituation to feeding.

Forty-five bison were captured during winter 2008 at the Stephens Creek capture facility and released in the spring fitted with radio transmitters. The winter movements of these bison (minus mortalities) were monitored during winters 2009 through 2013 to evaluate if the capture and feeding of bison influenced future migration tendencies towards the park boundary. Results

during these winters with snow packs ranging from mild (2012) to modest (2010, 2013) to severe (2011) suggest few bison are habituated to hay provided at the Stephens Creek capture facility and most bison do not migrate to lower elevations to seek forage until deep snow accumulates at higher elevations (Table 1).

Table 1. Movements of radio-marked bison after release from the Stephens Creek capture facility in spring of 2008.

	Winter 2009	Winter 2010	Winter 2011	Winter 2012	Winter 2013
Percent of marked bison returning to the Gardiner basin	12 of 40 = 30%	2 of 38 = 5%	28 of 34 = 82%	5[1,2] of 29 = 17%	9 of 26 = 34%
Percent of marked bison returning to the Blacktail Deer Plateau, but not migrating as far as the Gardiner basin	16 of 40 = 40%	12 of 38 = 32%	5 of 34 = 15%	18 of 29 = 62%	9 of 26= 34%
Percent of marked bison that remained on interior ranges of the park	10 of 40 = 25%	20 of 38 = 53%	0 of 34 = 0%	6 of 29 = 21%	6 of 26 = 23%
Percent of marked bison that migrated to the west boundary of the park	2 of 40 = 5%	4 of 38 = 11%	1 of 34 = 3%	3[1] of 29 = 10%	2 of 26 = 8%

[1] Three of these bison first migrated to the north boundary before moving to the west boundary later in the winter and were included in both calculations.
[2] Only one of these five bison moved as far north as the Stephens Creek facility during this winter period.

Brucellosis Suppression (Reduce Brucellosis Prevalence)

<u>Determine the strength and duration of the immune response in bison following vaccination for brucellosis via a hand-held syringe.</u>

Through the Civilian Research and Development Foundation, the NPS provided cooperative funding to key Russian vaccine experts to develop the first comprehensive review of scientific laboratory and field studies on the primary Russian brucellosis vaccine derived from *Brucella abortus* strain 82 (SR82), and publish findings in English language peer-reviewed scientific journals (*Olsen et al. 2010, Brucellosis: A transboundary zoonotic disease, Vaccine 28S:F1-F88; Ivanov et al. 2011, A live vaccine from Brucella abortus strain 82 for control of cattle brucellosis in the Russian Federation, Animal Health Research Reviews 12:113-131; Denisov et al. 2013, The Russian experience in brucellosis veterinary public health, Revue Scientifique et Technique Office International des Epizooties 32:229-237*).

- The smooth-rough strain SR82 vaccine combines the desired weak responses on standard tests with high efficacy against brucellosis.
- In 1974, prior to widespread use of strain SR82 vaccine, more than 5,300 cattle herds were known to be infected with *Brucella abortus* across the former Soviet Union.
- By January 2008, only 68 cattle herds in 18 regions were known to be infected, and strain SR82 continues to be the most widely and successfully used vaccine in many regions of the Russian Federation.

NPS biologists collaborated with colleagues from the Animal and Plant Health Inspection Service and Montana State University to measure the cell-mediated immune responses induced by strain RB51 vaccination in bison (*Treanor 2012, The biology and management of brucellosis in Yellowstone bison, University of Kentucky, Lexington*).

- During winter 2008-2009, 12 yearling bison in the quarantine feasibility study were vaccinated by syringe with SRB51. Immune responses were assessed prior to vaccination and at 3, 8, 12, 18, and 21 weeks after vaccination.
- Also, 20 wild, yearling, female bison were captured at the Stephens Creek facility during late winter 2008 and 14 of these bison were vaccinated by syringe with RB51, while six served as non-vaccinated controls. The cell-mediated immune responses of vaccinated bison were analyzed 2 and 6 weeks after vaccination. Thereafter, all 20 bison were released back into the wild during May 2008. During autumn and winter 2008-2009, 14 of the 20 bison in the study were recaptured to measure cell-mediated immune responses 24+ weeks following vaccination.
- Comparisons of immune responses in captive and free-ranging bison indicated there was some protection in approximately 50% of vaccinated yearling female bison. Immune responses were similar between both vaccinated groups, including the proportion of individuals with strong, weak, or no response.
- This individual variation will reduce vaccine efficacy when vaccination is applied at the population level. Seasonal food restriction and loss of body reserves may play an important role in the effectiveness of wildlife vaccination programs because immune responses may be limited when vaccines are delivered to undernourished animals.

Scientists from the Department of Agriculture evaluated the immune responses of captive bison after vaccination and booster vaccination with strain RB51 via syringe (*Olsen et al. 2015, Efficacy and immune responses of bison after booster vaccination with Brucella abortus strain RB51, Clinical and Vaccine Immunology doi: 10.1128/CVI.00746-14*).

- As expected, antibody responses of bison were greater after initial vaccination and booster vaccination as compared to non-vaccinates.
- Vaccinated bison challenged with *Brucella abortus* strain 2308 had fewer abortions and less infection than non-vaccinated bison.
- Booster vaccinates had less infection in fetal and maternal tissues than non-vaccinates. Thus, booster vaccination could enhance herd immunity in bison against brucellosis.

<u>Determine the strength and duration of protective immune response in bison following vaccination for brucellosis via remote delivery (i.e., without capture; e.g. bio-bullet).</u>

During 2003-2005, NPS staff collaborated with Colorado State University and the Agricultural Research Service to develop procedures for vaccine encapsulation and maintaining the structural consistency of projectiles. This effort demonstrated successful proof-of-concept for delivering a degradable ballistic brucellosis live vaccine remotely to bison from a distance of 40 meters using commercial components and a novel hydrogel vaccine carrier (*Christie et al. 2006, Photopolymorized hydrogel carriers for live vaccine ballistic delivery, Vaccine 24:1462-1469*).

Scientists at the Agricultural Research Service reported the ballistic inoculation of bison with bio-bullets containing photopolymerized, polyethylene glycol-based hydrogels with strain RB51 induced a significant cell-mediated immune response similar to syringe injection of the vaccine. However, a second vaccination trial on bison during 2007 indicated poor immunologic proliferation and interferon response compared to syringe injection (*S. Olsen, Agricultural Research Service, unpublished data*). Results also demonstrated bio-bullet failure with

projectiles fracturing or being too soft to penetrate the skin of vaccinates. These inconsistencies between studies regarding the cell-mediated immune responses observed following hydrogel vaccination of bison with RB51 may have been due to differences in the photopolymerization process used to encapsulate vaccine in projectiles (*Olsen et al. 2006, Immunologic responses of bison to vaccination with Brucella abortus strain RB51: Comparison of parenteral to ballistic delivery via compressed pellets or photopolymerized hydrogels, Vaccine 24:1346-1353; Olsen et al. 2006, Immune responses of elk to initial and booster vaccinations with Brucella abortus strain RB51 or 19, Clinical and Vaccine Immunology 13:1098-1103*).

NPS staff collaborated with the University of Utah and the Agricultural Research Service to develop a protocol for pursuing enhancements to the vaccine payload and ballistic delivery system for bison under quality controlled production. The protocol included (1) negotiating supply agreements with various reagent vendors, (2) developing scientific and technical protocols to facilitate technology transfer to a contractor who can procure and produce the entire vaccine component line, (3) initiation and supervision of a production program for bio-bullet vaccine formulations under quality systems validation, and (4) final delivery of ready-to-use bio-bullet vaccine formulations and protocols for field use (*Grainger 2011, Proposal for remote ballistic delivery of Brucella abortus vaccine to wildlife vectors in Yellowstone National Park, University of Utah, Salt Lake City*).

<u>Document long-term trends in the prevalence of brucellosis in bison, and the underpinning effects of remote and/or syringe vaccination, other risk management actions (e.g., harvest, culling), and prevailing ecological conditions (e.g. winter-kill, predation) on these trends.</u>

During 2007-2009, NPS staff developed a wildlife health laboratory in the Heritage and Research Center at Yellowstone National Park for the processing of biological samples and the direct or indirect measurement of disease organisms, immunological indicators, or indicators associated with animal health (e.g., metabolites and hormones). This laboratory enables NPS biologists to maintain sample quality, get timely results, and increase sample sizes. Equipment has been used to culture cells to measure immune responses of brucellosis vaccination in bison and conduct fluorescence polarization immunoassays of serological samples for the diagnosis of brucellosis exposure. The laboratory is certified as a biosafety level-2 facility, which is important for brucellosis vaccination work. However, no work is conducted directly on zoonotic disease agents (e.g., *Brucella abortus*).

Biologists from the NPS, Geological Survey, and Montana State University estimated how many years it would take to detect a change in brucellosis prevalence in bison using three analytical approaches: the single year estimate; the 3-year running average; and regression using all years to date (*Ebinger and Cross 2008, Surveillance for brucellosis in Yellowstone bison: The power of various strategies to detect vaccination effects, Report YCR-2008-04, National Park Service, Mammoth Wyoming*).

- Capture and sampling of more than 200 bison during a given year would be necessary to detect significant changes in prevalence following vaccination, and detection would likely take 5-20 years depending on sample sizes and detection method.

- The ability to detect a change in prevalence is a function of the (1) amount of decrease in prevalence, (2) shape of the prevalence decrease curve, and (3) the sample sizes used for estimating prevalence.
- The single-year estimate approach consistently showed more variation around the median. The regression model tended to be a more powerful approach, though there was more variation around this estimate for the slower decreases in prevalence.
- Testing fewer than 200 bison per year would provide a low probability of detecting a decrease in prevalence to below 40%. Conversely, testing more than 250 bison per year would not significantly improve the probability of detecting a change in prevalence.

Biologists from the NPS and the University of Kentucky developed an individual-based model to evaluate how brucellosis infection might respond under alternate vaccination strategies, including: 1) vaccination of female calves and yearlings captured at the park boundary; 2) combining boundary vaccination with the remote delivery of vaccine to female calves and yearlings distributed throughout the park; and 3) vaccinating all female bison (including adults) during boundary captures and using remote delivery of vaccine (*Treanor et al. 2010, Vaccination strategies for managing brucellosis in Yellowstone bison, Vaccine 28S:F64-F72*).

- Simulations suggested the third alternative would be most effective, with brucellosis prevalence decreasing by 66% (from 0.47 to 0.16) over a 30-year period due to 29% of the population receiving protection through vaccination.
- Under this alternative, bison would receive multiple vaccinations that extend the duration of vaccine protection and defend against recurring infection in latently infected animals.
- The initial decrease in prevalence would likely be slow due to high initial prevalence (40-60%), long-lived antibodies, and the culling of some vaccinated bison that were subsequently exposed to field strain *Brucella* and reacted positively on serologic tests.
- Vaccination is unlikely to eradicate *Brucella abortus* from Yellowstone bison, but could be an effective tool for reducing the level of infection.

The American Bison Society commissioned an objective review of diseased bison issues and management approaches in the Greater Yellowstone and Wood Buffalo Areas (*Nishi 2010, A review of best practices and principles for bison disease issues: Greater Yellowstone and Wood Buffalo areas, American Bison Society Working Paper number 3, Wildlife Conservation Society, Bronx, New York*).

- What should be done is based on mandates, values, and viewpoints, while what can be done is based on existing conditions, technologies, biological feasibility, and economic costs. Managers should consider: 1) doing nothing; 2) preventing transmission; 3) controlling the prevalence and spread of infection; and 4) eradication.
- Management decisions should consider (1) comparative costs and public preferences for various management alternatives, (2) non-market values of wild bison, (3) the demand for bison that are removed from the population, and (4) public attitudes, behaviors, and knowledge of bison, brucellosis, and management.
- Best management practices should be applied within a risk framework that includes adaptive management and evaluation and refinement of livestock and wildlife policies.
- Managers should focus on improving relationships and management by: 1) providing a forum and funding for addressing the issue; 2) developing and using systems thinking skills and modeling; 3) working across boundaries; and 4) engaging stakeholders.

Biologists from the NPS, Geological Survey, and Montana State University developed an individual-based epidemiological model to assess the relative efficacies of sterilization, vaccination, and test-and-remove for reducing brucellosis prevalence in bison (*Ebinger et al. 2011, Simulating sterilization, vaccination, and test-and-remove as brucellosis control measures in bison, Ecological Applications 21:2944-2959*).

- Sterilization and test-and-remove were most successful at reducing prevalence when they were targeted at young, test-positive animals, which are the most likely age and sex category to be infectious. However, sterilization and test-and-remove also required the most effort to implement. Vaccination was less effective, but required less effort.
- The sterilization of 50-100 females per year had little impact on the bison population growth rate when selectively applied and the population growth rate usually increased by year 25 due to the reduced number of brucellosis-induced abortions.
- Initial decreases in prevalence followed by rapid increases occurred in 3-13% of simulations with sterilization and test-and-remove, but not vaccination. This may be due to the interaction of super-spreading events (e.g., one abortion event infects many susceptible bison) and the loss of herd immunity in the later stages of control efforts.
- Vaccination reduces prevalence while maintaining herd-immunity and minimizing the occurrence of super-spreading events. Sterilization and test-and-remove reduce herd-immunity and super-spreading events become more common as the population becomes more susceptible.
- Sterilization provided a mechanism for achieving large brucellosis reductions while simultaneously limiting population growth. However, the field effort required to find the small segment of the population that is infectious rather than susceptible or recovered will likely limit the utility of this approach.

An NPS biologist published a dissertation on the maintenance of brucellosis in Yellowstone bison, including links to seasonal food resources, host-pathogen interaction, and life-history trade-offs (*Treanor 2012, The biology and management of brucellosis in Yellowstone bison, University of Kentucky, Lexington*).

- Brucellosis infection was associated with below-average nutritional condition, with the intensity infection being influenced by seasonal reductions in dietary protein and energy.
- The reproductive strategy of bison is linked with the seasonal availability of food, which increases bison fitness but may have consequences for brucellosis infection.
- Seasonal food restriction may also influence the ability of vaccinated bison to recall protective immune responses when later exposed to *Brucella abortus*.
- The rate of fat metabolism was an important factor influencing the cell-mediated immune response (interferon-γ production). Thus, seasonal reductions in food availability may decrease vaccine efficacy when vaccination is applied at the population level.

During February 2012, NPS managers representing park, regional, and service-wide perspectives met and discussed the applicability and feasibility of using fertility control as an ungulate management tool in NPS units. A review of pertinent scientific information with presentations by experts in fertility control technologies, wildlife population modeling, and moral and ethical considerations preceded the discussion. Guidance for the use of fertility control on ungulates

within NPS units, included (*Powers and Moresco 2013, National Park Service ungulate fertility control workshop report, February 23-24, 2012, Fort Collins, Colorado*):

- Fertility control may be useful, valid, and desirable for small, closed populations of habituated or easily accessible ungulates. It is more acceptable for non-native species and/or in highly altered environments where the influences of humans are prevalent.
- There should be substantial information regarding demography and ecology to forecast the effects of fertility control. Evidence must indicate fertility control will have few negative effects on native species and the ecosystem.
- Potential methods for fertility control should: 1) minimize the need for repeat treatments; 2) be safe for the individual animal; 3) be safe for humans or scavengers that might consume the animal; and 4) be practical and feasible for use.

Economists in Wyoming worked with biologists and the State Veterinarian to evaluate feasible management tools for cattle and wild elk to reduce brucellosis prevalence and transmission risk.

- Cattle producers could take several actions, including (1) fencing haystacks, (2) hazing elk from their property, (3) booster vaccinating adult cattle, (4) spaying heifers, (5) modifying winter feeding schedules, (6) delaying cattle release on summer grazing allotments, and (7) preventing the mingling of cattle and wildlife. Implementing these preventative actions was not cost-effective for cattle producers with herds that faced relatively little risk of brucellosis exposure from elk and costs due to exposure (*Roberts et al. 2012, Cattle producers' economic incentives for preventing bovine brucellosis under uncertainty, Preventive Veterinary Medicine 107:187-203*).
    - Adult booster vaccination of cattle with current vaccines would have to reduce the risk of a brucellosis outbreak by almost 200% (i.e., impossible) to be cost-effective for a producer whose herd faces a 1% chance of contracting brucellosis annually.
    - Only when economic costs due to an outbreak approached $140,000 or risk increased to relatively high levels (e.g., 10-50% per year) was it effective to implement the least-expensive preventative actions such as hazing wildlife and fencing haystacks.
- Three management strategies that could be implemented with wild elk to increase the number of years until a brucellosis outbreak in cattle occurs include: 1) test-and-slaughter by capturing elk and removing animals testing positive for brucellosis exposure; 2) vaccination of calf elk with strain 19; and 3) low-density feeding of elk to avoid aggregations. However, the costs of these management strategies would be extremely high relative to the benefits (*Kauffman et al. 2013, Cost-benefit analysis of a reduction in elk brucellosis seroprevalence in the southern greater Yellowstone area, Report by the University of Wyoming, Wyoming Livestock Board, Wyoming Game and Fish Department, and USDA-APHIS, Veterinary Services. Laramie, Wyoming*).
    - The costs of a brucellosis outbreak in cattle would need to be about $20 million to equal the costs of conducting test-and-slaughter in elk to reduce brucellosis prevalence from about 18% to 5%.
    - The costs of a brucellosis outbreak in cattle would need to be about $8 million to equal the costs of vaccination in elk to reduce prevalence by 1% (i.e., to 17%).
    - The costs of a brucellosis outbreak in cattle would need to be about $560,000 to equal the costs of low-density feeding of elk to reduce prevalence by 10% (i.e., to 8%).

NPS staff and brucellosis experts from around the world contributed articles to *Brucellosis: Recent Developments Towards 'One Health'* by the World Organization for Animal Health to support finding practical and effective solutions for addressing brucellosis at local, regional, and global levels (*Plumb et al. 2013, Brucellosis: Recent developments towards 'one health.' Revue Scientifique et Technique Office International des Epizooties, Volume 32 (1), April 2013*).

- An article entitled *Brucellosis in Terrestrial Wildlife* (*Godfroid et al. 2013, pages 27-42*) reported:
  - No existing brucellosis vaccine has satisfactory efficacy and safety for wildlife. The development of new vaccines, diagnostics, and management practices is necessary to effectively control brucellosis.
  - Brucellosis control in wildlife should rely on good management practices, with management and education balancing conservation, economic, and health issues.
- An article entitled *Recent Developments in Livestock and Wildlife Brucellosis Vaccination* (*Olsen 2013, pages 207-217*) reported:
  - Available vaccines do not consistently prevent infection, can induce abortions, and are infectious to humans. Improved brucellosis vaccines are greatly needed.
  - Vaccine-induced antibody responses in serum are not indicative of long-term immunity for the animal. Investigators should measure increases in specific T cells that produce cytokines.
  - Current vaccines (strains 19, 82, and RB51) consist of live, weakened strains of the bacteria because experiments with vaccines consisting of heat-killed or subcellular fractions of the bacteria have not induced substantial protective immune responses.
  - Strain 19 and RB51 provide little or no protection to elk against brucellosis infection and transmission because vaccinated animals do not develop cellular immune responses. Strain RB51 provides some protection against infection and abortion in bison and cattle, especially when they receive a subsequent booster vaccination.
  - All of these vaccines are most effective at suppressing brucellosis when combined with a strategy of culling individuals testing positive for brucellosis infection.
- An article entitled *Risks of Brucella abortus Spillover in the Greater Yellowstone Area* (*Schumaker 2013, pages 71-77*) reported:
  - Historically, disease regulators believed brucellosis would not persist in elk without transmission from bison or elk dispersing from feed grounds in Wyoming. However, recent surveillance indicates elk in many areas support the disease independently of bison or feed-ground elk.
  - All brucellosis transmissions to cattle since 2004 were traced to wild elk. The risk of transmission from bison to cattle is negligible because of migration to higher-elevation summer ranges and management that limits commingling.
  - The risks of brucellosis transmission are primarily from wild elk that mingle with cattle, and management to suppress brucellosis in bison will not reduce this risk. Thus, management should focus on decreasing densities and group sizes of elk and comingling with cattle that makes brucellosis transmission possible.
- An article entitled *An Ecological Perspective on Brucella abortus in the Western United States* (*Cross et al. 2013, pages 79-87*) reported:
  - Recent transmissions of brucellosis from elk to cattle appear to be due to increased prevalence in elk populations and elk contacts with livestock. Managers should decrease aggregations of elk near cattle during the abortion period for elk.

- The use of brucellosis vaccines on wildlife remains limited by financial, logistical, scientific, and social constraints. There is no easily delivered, highly effective, and safe vaccine for elk. Elk on feed grounds in Wyoming have been vaccinated with strain 19 since 1985 with no decrease in prevalence or abortions.
- It would be extremely difficult and cost-prohibitive to deliver vaccine to bison and elk distributed across the Greater Yellowstone Ecosystem. Suppression efforts would need to be coordinated across jurisdictions for many decades in two species capable of independently sustaining the disease.
- Management options include (1) modifying habitats to minimize mingling of cattle and elk, (2) hunts during late winter to redistribute aggregations of elk near cattle, (3) tolerance for predators and scavengers that remove infectious birth tissues, and (4) shortening the supplemental feeding season in Wyoming and dispersing feed over a larger area.

- An article entitled *Integrating Ecology with Management to Control Brucellosis* (*Treanor 2013, pages 239-247*) reported:
  - Culling of large numbers of Yellowstone bison to decrease the risk of brucellosis transmission to cattle could adversely affect the conservation of bison over time.
  - Food restriction during winter, which also corresponds with late gestation in bison and elk, can limit resources available for immune defense and may be an important factor sustaining brucellosis in wildlife.
  - Managers need to maintain separation between cattle and wildlife, manage habitat to reduce brucellosis transmission, and decrease brucellosis prevalence.
  - One strategy to reduce prevalence would be to vaccinate as many bison as possible for decades. After prevalence decreases, managers could use probabilities of active infection based on age and serum antibody levels to remove animals with a high risk of shedding bacteria, which should be a relatively small portion of the population.
  - This strategy should increase population-level resistance to brucellosis through vaccination, and retain animals that were previously exposed to *Brucella* bacteria but are no longer infectious, without culling large numbers of bison.
- An article entitled *Bovine Brucellosis in Wildlife: Using Adaptive Management to Improve Understanding, Technology and Suppression* (*White et al. 2013, pages 263-270*) reported:
  - Eradication of brucellosis from bison and elk in the Greater Yellowstone Area is not possible or practical with current technology without resorting to ethically and politically unacceptable techniques such as mass test-and-slaughter or depopulation.
  - Adaptive management provides a framework for substantially lowering brucellosis prevalence in wildlife in the face of substantial uncertainties regarding the effectiveness of management techniques and unintended effects on wildlife behavior and demography. Through careful predictions and monitoring of these management actions, understanding of bison and brucellosis will be improved and actions can be adjusted to better achieve desired outcomes.
  - Since it takes approximately 3 years after birth for female bison to become reproductively active and contribute to brucellosis transmission, there is an opportunity to implement management actions such as vaccination combined with the selective removal of likely infectious bison based on age and assay results to reduce

transmission potential. Bison that have been exposed to the bacteria, but recovered from acute infection, could be retained in the population to provide herd immunity.

In February 2013, a panel of scientists from federal, state, academic, and non-governmental entities (1) reviewed what is known about the vaccine-induced immune responses of bison and elk, (2) reviewed the benefits and limitations of existing tools and emerging technologies for suppressing brucellosis prevalence in bison and elk, (3) evaluated whether substantial brucellosis suppression is feasible and sustainable without significantly affecting bison behavior or visitor experience, and (4) provided ideas regarding the future direction of brucellosis suppression activities (*U.S. Department of the Interior, National Park Service and Montana Fish, Wildlife & Parks 2013, Brucellosis science panel review workshop panelist's report, Yellowstone National Park, Mammoth, Wyoming*). At the close of the workshop, the participants shared four consensus conclusions:

- <u>On the merits and need for remote vaccination of free-ranging bison</u>: Best available data does not support that remote vaccination of bison with the currently available vaccines will be an effective tool for suppressing brucellosis in wild bison to a level that changes the IBMP [Interagency Bison Management Plan] management strategies. Available data also suggest remote vaccination will be a very cost ineffective tool for preventing brucellosis spillover to cattle.
- <u>On the potential ecological impacts of remote vaccination</u>: In addition to the foregoing main conclusion that an aggressive remote vaccination campaign for free-ranging bison cannot be justified based on available data, we also discussed other potential collateral consequences of such a program. Our distilled summary of this discussion is as follows:
  - We anticipate that remote vaccination would have behavioral impacts on bison (e.g., reduced tolerance of people, vehicles, etc.).
  - Reduced tolerance for humans and vehicles could lead to shifts in the spatial distribution of bison with resulting effects on landscapes used more or less by bison.
  - Reduced tolerance for humans and vehicles also could have impacts on opportunity for visitors to observe bison and could change how bison react to visitors.
  - Changes in bison behavior and distribution also could have secondary impacts on predator-prey relationships (e.g., increase pressure on other species) and on scavenger relationships.
  - If vaccination were successful in reducing brucellosis in bison, then the net demographic effect would be to increase the bison population (by reducing abortions and increasing annual birth rate). Because it is unlikely that vaccination would eliminate brucellosis completely, we anticipate that such an increase in bison numbers could increase the efforts and fiscal expenditures necessary to maintain effective spatial-temporal separation of bison and cattle.
- <u>On the use of culling in disease and bison population management</u>: Control of the bison population size will most likely include culling or removal, along with hunting, as the main management tools. Past and current culling practices (which have been largely nonselective and opportunistic) have not had an apparent effect on reducing overall bison herd seroprevalence (around 50%). We recognize the potential to use culling as a tool for both interspecies disease risk management and bison population control.
- <u>On the use of fertility control in disease and bison population management</u>: To achieve the current goals of the disease management plan, intervention with contraception is not

needed. However, we acknowledge that fertility control could become a tool for disease control if treated females returning to reproductive status are no longer infectious despite exposure to brucellosis. The available data are insufficient to make a judgment at this time, but we encourage continuation of ongoing research in this area. Experimental results should be combined with modeling to scale contraception effects up to the population level and evaluate this as an alternative disease control approach.

Scientists from the Geological Survey, NPS, and Colorado State University evaluated the efficacy of fertility control as a way to regulate the abundance of wildlife populations (*Ransom et al. 2013, Ecological feedbacks can reduce population-level efficacy of wildlife fertility control, Journal of Applied Ecology 51:259-269*).

- Fertility control may produce unintended changes in demographic rates that decrease the effectiveness of population regulation. The extent and frequency of these effects will depend on the social and reproductive systems and connectivity with other populations.
- Fertility control can induce changes in survival and immigration that compensate for the reduction in births. Fertility control may be more successful at regulating the abundance of small, closed populations that aggregate and are easily accessed.
- Fertility control can result in artificial selection pressures that lead to unintentional genetic consequences. The extent of this selection depends on individual heritability, behavioral traits, and environmental variation.
- Before managers expend effort, funding, and time on fertility control of wildlife, they should consider that many populations can compensate for a reduction in fecundity and minimize reductions in population growth rates.

In 2014, the NPS decided not to implement park-wide remote vaccination of Yellowstone bison because it would likely not achieve desired results and could have unintended adverse effects to the bison population and visitor experience due to:

- The limited understanding of bison immune responses to brucellosis suppression actions such as vaccination;
- The absence of an easily distributed and highly effective vaccine (e.g., 10-15% reduction in infection; short duration of immune protection; cannot vaccinate females in second half of pregnancy);
- Limitations of current diagnostic and vaccine delivery technologies (e.g., inconsistent vaccine hydrogel formulation; short rifle range; no rapid diagnostics for live animals);
- Effects of bison nutrition, condition, and pregnancy/lactation that lessen protective immune responses from vaccination;
- Potential adverse consequences (e.g., injuries; changes in behavior) to wildlife and visitor experience (e.g., wildlife viewing) from intrusive brucellosis suppression activities (e.g., capture; remote vaccination); and
- Chronic infection in elk which are widely distributed and would almost certainly re-infect bison (*Federal Register 79:35567-35568; United States Department of the Interior, National Park Service 2014, Remote vaccination program to reduce the prevalence of brucellosis in Yellowstone bison, Final Environmental Impact Statement, Yellowstone National Park, Mammoth, Wyoming*).

In 2014, the NPS and the Fish and Wildlife Service compiled information on the history, disease status, genetics, and management of bison populations managed by the Department of the Interior (*Sweeney et al. 2014, Bison health management programs in the Department of the Interior. U.S. Fish and Wildlife Service and National Park Service, Department of the Interior, Washington, D.C.*).

- The report compiled information from publications, site visits, and interviews with personnel responsible for bison management.
- The report provided the rationale for current bison management of these populations and the foundation for future monitoring of restored herds.