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WILDLIFE CONSERVATION SOCIETY

A REVIEW OF BEST PRACTICES AND PRINCIPLES FOR BISON DISEASE ISSUES:

Greater Yellowstone and Wood Buffalo Areas

AMERICAN BISON SOCIETY

By John S. Nishi

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The Wildlife Conservation Society saves wildlife and wild places worldwide. We do so through science, global conservation, education and the management of the world's largest system of urban wildlife parks, led by the flagship Bronx Zoo. Together these activities change attitudes towards nature and help people imagine wildlife and humans living in harmony. WCS is committed to this mission because it is essential to the integrity of life on Earth.

Over the past century, WCS has grown and diversified to include four zoos, an aquarium, over 100 field conservation projects, local and international education programs, and a wildlife health program. To amplify this diverse conservation knowledge, the WCS Institute was established as an internal "think-tank" to coordinate WCS expertise for specific conservation opportunities and to analyze conservation and academic trends that provide opportunities to further conservation effectiveness. The Institute disseminates WCS' conservation work via papers and workshops, adding value to WCS' discoveries and experience by sharing them with partner organizations, policy-makers, and the public. Each year, the Institute identifies a set of emerging issues that potentially challenge WCS' mission and holds both internal and external meetings on the subjects to produce reports and guidelines for the institution.

The American Bison Society (ABS), managed by the WCS Institute, works with a broad range of stakeholders to build the scientific and social bases for the long term ecological restoration of bison in North America. ABS and partners address information gaps by initiating research and papers on issues that require further exploration or synthesis, or where policy and guidelines are needed.

The ABS Working Paper Series, produced through the WCS Institute, is designed to share information with the conservation and bison stakeholder communities in a timely fashion. Working Papers address issues that are of immediate importance to helping restore bison and either offer new data or analyses, or offer new methods, approaches, or perspectives on rapidly evolving issues. The findings, interpretations, and conclusions expressed in this Paper are those of the author and do not necessarily reflect the views of the American Bison Society or the Wildlife Conservation Society.

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FOREWORD

The American Bison Society commissioned John Nishi, M.Sc., to review one of the most important impediments to large-scale bison restoration – the presence of transmissible cattle disease in free-ranging bison. Mr. Nishi is the principal of EcoBorealis Consulting Inc., and is also a landscape ecologist with the ALCES® Group. Previously, Mr. Nishi was the bison ecologist for the Government of Northwest Territories and worked with northern communities on bison management issues for over nine years.

The following review focuses on the Greater Yellowstone Area (US) and the Wood Buffalo National Park Area (Canada) as places where there has been a great deal of investment in research, policy, and management activity to try to resolve the diseased bison issue. The management of bison disease issues in and around these two parks has at times been controversial. ABS commissioned this review in an effort to outline best principles that can be more broadly applicable to bison restoration efforts.

Previous drafts of this paper were reviewed by Keith Aune, Wildlife Conservation Society North America Program; Damien Joly, Wildlife Conservation Society Global Health Program; Brett Elkin, Government of Northwest Territories; Terry Armstrong, Government of Northwest Territories; Helen Schwantje, British Columbia Ministry of Environment; and Terry Antoniuk, Salmo Consulting Inc.

EXECUTIVE SUMMARY

Background

The American bison (*Bison bison*) reflects the resiliency of a species that was brought to the brink of extinction at the turn of the 19^{th} century due to widespread market hunting and the accumulated years of systematic slaughter. The creation of Yellowstone National Park in 1872 played a pivotal role in the conservation of plains bison *(B. b. bison)*, while in northern Canada, Wood Buffalo National Park was established in 1922 to protect wood bison *(B. b. athabascae)*. Although today we may consider that bison have been saved from extinction, there is a significant amount of work yet to be done to achieve ecological restoration of bison in North America. Future success will ultimately be defined by the unfolding relationships between humans and bison over the next century.

A key challenge that will influence restoration efforts for bison is our collective ability to manage current and future disease risk at a landscape scale. The greater Yellowstone (GYA) and Wood Buffalo areas (GWBA) in the US and Canada are focal points of intense controversy because the wild bison are infected with "reportable" zoonotic pathogens of livestock origin. Yellowstone bison are infected with brucellosis *(Brucella abortus)* and represent a disease risk to cattle herds around the park in Montana, Wyoming and Idaho. Bison in the GWBA are infected with brucellosis and bovine tuberculosis (*Mycobacterium bovis)* and primarily represent a risk of pathogen transmission to healthy conservation herds of wild wood bison in neighboring jurisdictions of Alberta and the Northwest Territories. Our collective ability (or inability) to develop successful management processes to address the current disease issues in Yellowstone and Wood Buffalo will affect our future capacity to address complex management issues that will inevitably arise with new bison restoration projects in North America.

Goals and Objectives

The goal of this paper was to conduct an objective, strategic level review of diseased bison issues and management approaches in the GYA and GWBA. The aim is to provide a conceptual framework for understanding the issues and illustrate linkages to management options. Specific objectives were two-fold:

1. Describe and summarize case studies in the Greater Yellowstone Area and Greater Wood Buffalo Area to highlight current management issues and explore possible strategies for engaging stakeholders and moving issues forward, and
2. Develop strategic-level recommendations for diseased bison management with implications for bison restoration.

Methodology

The methodology included an extensive search of scientific journals and available 'grey' literature produced primarily by government agencies and non-government organizations. The main purpose was to review studies on the disease ecology of bovine brucellosis and tuberculosis in bison and the history of disease management within the GYA and GWBA. The process also included two site visits to interview wildlife disease experts in the United States and Canada who have been involved in various aspects of research and management of the diseased bison issues in the GYA and GWBA.

The Focus on Best Practices

This paper reviews and contrasts the disease management processes in the GYA and GWBA, and suggests that management of the issue in the GYA is further advanced compared to the GWBA. A major shortcoming in the GWBA has been the lack of a consistent management process with stakeholder engagement over a period that extends for more than a few years at a time. In the GYA, governments and stakeholders have been more involved in implementing management options, but there are still fundamental challenges associated with implementing adaptive management as it applies to brucellosis in the GYA.

A key similarity between the GYA and GWBA has been the focus of research programs to improve scientific knowledge and develop effective best practices. One approach to improving the reliability and value of best practices is to develop and apply them within a broader context of a defined, goal-oriented disease management process. By matching best practices to specific disease management objectives (*ie., laissez faire*, prevention, control, or eradication), the expected effect or contribution of a best practice can be compared to its observed performance, which can then lead to selection of the most reliable and effective best practices. The best practices developed through research and management activities in the GYA and GWBA fit within the following broad categories:

- Passive and active monitoring
- Surveillance
- Education, training, and consultation
- Directed activities against disease
- Mopping up and preventing reintroduction

However, continued focus on improvement of science-based best practices will be insufficient for achieving sustainable long-term management of brucellosis in the GYA, and of brucellosis and tuberculosis in the GWBA. To develop potentially useful recommendations that might apply to these extremely complex problems, this paper focuses on outlining best principles and then possible strategic actions.

Best Principles and a Way Forward

A principle is defined as a basic generalization that is accepted as true and that can be used as a basis for reasoning, conduct, or action. The following principles frame the discussion:

- Focus on measurable goals that specify future (long-term) processes and outcomes necessary for sustainability;
- Recognize that complexity and connectedness are inherent properties that impart resilience to ecosystems;
- Recognize that ecosystems are dynamic and adaptive, and that humans are an important ecosystem component and play an active role in achieving sustainable goals;
- Apply the full range of knowledge and skills from the natural and social sciences as required to address problems;
- Understand and take account of the motives, interests, and values of all users and stakeholders, but not by simply averaging their positions; and
- Facilitate effective communication that is interactive, reciprocal, and continuous.

A conceptual framework (see Figure 7) suggests how systems thinking and other principle-based strategies may be used to chart a way forward to improve collaborative and adaptive management initiatives on the diseased bison issues.

Conclusions and Recommendations

- The diseased bison issues in the GYA and GWBA are 'wicked' problems that have eluded resolution because of their dynamic epidemiology, and the diverse and conflicting mandates and values held by various government agencies and stakeholders. Although the issues are beset by significant technical challenges and knowledge gaps, the human dimensions – a key driver in social-ecological issues – have received comparatively less formal attention than the scientific studies addressing knowledge gaps and the improvement of best practices. The current research and management emphasis on disease ecology could be improved by broadening the scope and collaborating with researchers in the social sciences, including sociologists, economists, and political scientists. Other non-traditional collaborators may include policy makers, planners, managers, community and aboriginal groups, and citizens.

- Development of science-based best practices is useful and should continue, but is not sufficient on its own to contribute meaningfully to resolving the diseased bison issues. Best practices should be considered and applied within a risk framework because risk analysis methodologies can provide logical and quantitative rigor. Development and application of best practices should be considered as one component of a multi-scale, three-point strategy that also includes a formalized collaborative and adaptive management process, and an ongoing evaluation and refinement of livestock and wildlife policy.
- Adaptive management provides the overall framework for developing and implementing strategies to address the diseased bison issues in the GYA and GWBA. Although adaptive management has been identified as the preferred management approach and it has been specified in a myriad of official government agency documents and records of decision, the principal challenge has been to effectively implement the concept on the front lines of these real world 'wicked' problems. One area for improving adaptive management strategies is to clearly define objectives, working hypotheses, assumptions, and predictions of prospective management actions. Only then can an appropriate active or passive implementation design be developed along with a suitable monitoring program.
- A way to move forward from the current situation, which is characterized by recurrent patterns of conflict and controversy centered on the diseased bison issue, is to focus on ways of improving collaborative relationships and adaptive management processes. Several key strategies should be considered:
  - providing a forum, funding and mandate for a long-term process to address the issue;
  - developing and using systems thinking skills;
  - working across boundaries;
  - engaging stakeholders and citizens;
  - developing and using diverse (modeling) tools; and
  - institutionalizing adaptive management.
- At a continental scale, the opportunity for shared learning between the US and Canada should be developed through directed and continued dialogue between the governments and stakeholders involved in the diseased bison issues of the GYA and GWBA. Shared learning would be enhanced through informal and formal collaboration, for example, through workshops and committees.
- Failure to address the bison disease issues by letting outcomes be determined through inaction is an inappropriate management strategy for these valuable wildlife resources. Political, public, and stakeholder support for the development and implementation of disease management strategies is essential. While working towards a long term solution to both issues, initiatives to contain and mitigate disease risk need to be continued and enhanced.

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LIST OF ACRONYMS

ABS	American Bison Society
ADFG	Alaska Department of Fish and Game
APHIS	Animal and Plant Health Inspection Agency Service
BCT	Brucellosis Coordination Team (Wyoming State Governor)
BRCP	Bison Research and Containment Program (Parks Canada)
CBA	Canadian Bison Association
CFIA	Canadian Food Inspection Agency
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
GNWT	Government of the Northwest Territories
GAO	Government Accountability Office (USA)
GOC	Government of Canada
GWBA	Greater Wood Buffalo area
GYA	Greater Yellowstone area
GYT	Government of Yukon Territory
IBMP	Interagency Brucellosis Management Plan
IUCN	International Union for Conservation of Nature
MFWP	Montana Fish, Wildlife and Parks
NPS	National Park Service (USA)
OIE	Office International des Epizooties
PCA	Parks Canada Agency
RAC	Research Advisory Committee (Parks Canada)
SPS	Sanitary and Phytosanitary Agreement
USAHA	United States Animal Health Association
USDA	United States Department of Agriculture
USDI	United States Department of Interior
USFWS	United States Fish and Wildlife Service
USNPS	United States National Park Service
WBNP	Wood Buffalo National Park
WBRT	Wood Bison Recovery Team (Canada)
WCS	Wildlife Conservation Society
WGFD	Wyoming Game and Fish Department
WTO	World Trade Organization
YNP	Yellowstone National Park

GLOSSARY

Adaptive management: a structured, iterative process of optimal decision making in the face of uncertainty, with an aim to reducing uncertainty over time through prior formulation of objectives and hypotheses (*i.e.,* assumptions), followed by systematic monitoring. In this way, management decisions and actions are structured as experiments to facilitate 'learning by doing."

Epidemiology: the study of factors affecting the health and illness of populations, and serves as the foundation and logic of interventions made in the interest of health management and preventive (conservation) medicine.

Reportable disease: also referred to as a notifiable or listed disease; a disease that is designated by the World Animal Health Organization (Office International des Epizooties), and when suspected, the case must be reported to a federal, state/provincial/territorial public health veterinary agency under authority of law. Bovine tuberculosis and brucellosis are listed as "reportable diseases" because they pose serious threats to international trade in livestock, and have important socioeconomic and human health consequences.

Risk Analysis: a science-based, transparent framework that links an appraisal of an animal health hazard(s) to management decisions regarding the health status and movement of the animals. The complete risk analysis process is comprised of four distinct steps that include: hazard identification, risk assessment, risk management, and risk communication.

Risk Assessment: the process of identifying a hazard and estimating the risk presented by that hazard, either in absolute or relative terms. It includes estimates of uncertainty in process, and is an objective, repeatable, scientific process. Quantitative risk assessment characterizes the risk in numerical representations. Qualitative health risk assessments (*i.e.*, where risk is estimated as being negligible, low, medium or high) for wild animal translocations are usually of equal or greater value than numerical assessments (*i.e.*, when complete data are unavailable) and can be of enormous importance to wildlife conservation, domestic animal health and public health (Leighton 2002)

Systems thinking: the art and science of making reliable inferences about system behavior by developing an increasingly deep understanding of underlying structure and complex interrelationships.

Wicked problem: a problem that inherently is difficult to define precisely and is resistant to a clear and agreed solution. Science cannot resolve these dilemmas by filling the gaps in empirical knowledge.

1. INTRODUCTION

1.1 Background

The near extinction of the American bison (*Bison bison*) in recent history is inextricably linked to human exploitation. At the turn of the 19th century, bison were on the brink extinction due to widespread market hunting and the accumulated years of systematic slaughter. The demise of the bison facilitated the relegation of aboriginal peoples to reservations, and the settlement and industrialization of North America by Euroamericans (Isenberg 2000). Within the Great Plains, the once vast herds of plains bison (*B. b. bison*) that numbered between 30 and 50 million, were reduced to a few hundred in scattered remnant herds and pockets of individual animals across their historic range. The role of early conservationists and organizations such as the American Bison Society (ABS) played a key role in preserving the plains bison (Redford and Fearn 2007). The creation of Yellowstone National Park in 1872 was an important undertaking by the United States Government that conserved a remnant population of plains bison. Similarly, the creation of Wood Buffalo National Park in 1922 protected a small population of wood bison *(B. b. athabascae)* in northern Canada.

The important role of these two national parks is undeniable in the early conservation effort for plains and wood bison. In the early 20th century, those combined initial conservation efforts managed to salvage a few remnant herds and scattered survivors. The creation of national parks and preserves and enactment of protective legislation in the United States and Canada[1] provided the first refuges for bison. Although today we may consider that the species has been saved from extinction due to their relative abundance in private and public herds, there is a significant amount of work yet to be done to achieve ecological restoration of bison within North America.

1.2 Opportunities for Bison Restoration

To achieve ecological restoration, large herds of free-ranging bison will need to be re-established in major habitats of the bison's former range and at appropriate spatial scales. Meaningful restoration requires that the ecological relationships between wild bison and their natural environments, associated

[1] The early conservation effort in Canada for plains bison involved the purchase of the Pablo holdings of bison in Montana by the Government of Canada, and transfer of approximately 700 animals from Montana to Elk Island National Park, Alberta in the early 1900s (Ogilvie 1979, and see COSEWIC 2004). Elk Island was intended to serve only as a temporary holding facility for the bison before their ultimate relocation to National Buffalo Park in Wainwright, Alberta. By 1909, all but 48 bison had been relocated to National Buffalo Park – which was eventually depopulated by 1939 (Brower 2008). Elk Island National Park on the other hand has become a cornerstone conservation herd of plains bison in Canada and is managed as a fenced population of around 500 animals (COSEWIC 2004).

guilds of invertebrate and vertebrate communities (including large predators), are restored so that the dynamic process of natural selection continues to shape the evolution of the species (Gates *et al.* 2001). The context of ecological restoration and recovery is well represented by previous and ongoing work by government agencies, non-government environmental organizations, aboriginal communities and private stakeholders (GYT 1998, Harper *et al.* 2000, Gates *et al.* 2001, Sanderson *et al.* 2007, Stephenson *et al.* 2007, GNWT 2009).

Currently at the continental scale, the IUCN (International Union for Conservation of Nature) North American Bison Specialist Group[2] is working on a bison recovery strategy spanning three countries - the United States, Mexico, and Canada - that will provide support and guidance for policy development and conservation planning and implementation for public and private sector projects (Boyd 2003, Gates. pers. comm.). Aligned with the IUCN initiative is the recent strategic work facilitated by the Wildlife Conservation Society[3], which through a series of key meetings and workshops over the past 5 years has re-inaugurated the American Bison Society and resulted in a strong network of public, private and aboriginal stakeholders, and a broad vision for ecological restoration of bison (Redford and Fearn 2007, Freese *et al.* 2007, Sanderson *et al.* 2008). Similarly, there is ongoing work being done by the United States Department of Interior (USDI 2008) and the Canadian Wood Bison Recovery Team (WBRT 2009) to develop comprehensive strategies for recovery and management of plains and wood bison in the US and Canada. In summary, there is a tremendous amount of important work being done to further develop the vision, principles, and methods for the ecological restoration of bison.

Although these initiatives have been based principally on the biological and ecological sciences, taken together they have contributed towards a broader perspective of bison restoration that requires us to consider the inextricable relationship of this large, charismatic mammal to humans and human society. Consequently we must also evaluate and anticipate future opportunities and challenges for its restoration and management through 'big-picture' systems thinking approaches (Richmond 2001, see Box 1) and the holistic lens of a social-ecological systems perspective (*sensu* Holling 2001, Gunderson and Holling 2002, Berkes *et al.* 2003, Olsson *et al.* 2004, see Box 2). In short, ecological restoration of bison will require a solid foundation in the biological and ecological sciences, but future success will ultimately be defined by the unfolding relationships between humans and bison over the next century.

[2] http://www.notitia.com/bison/index.htm

[3] http://www.wcs.org

Box 1. Systems thinking

In contrast to a reductionist approach which strives to understand a system by breaking it down into its components and focusing on highly detailed and mechanistic relationships of isolated parts, systems thinking takes a broader perspective that seeks to understand linkages and interactions among the components and recognizes that complexity is a key aspect. Complexity can be thought of as a function of: a) the number of components in a system or the number of possibilities one must consider in making a decision – combinatorial complexity, or b) the often counterintuitive behavior of systems that arises from interactions of multiple factors over time – dynamic complexity (Sterman 2001). Richmond (1993) defined systems thinking (*i.e.*, systems dynamics) as "*the art and science of making reliable inferences about* [system] *behavior by developing an increasingly deep understanding of underlying structure*". He suggested that there are seven core system thinking skills, that when applied together can provide a means of better understanding system dynamics (Richmond 1993, 2000, 2001).

Systems Thinking skill	Contrasts with...
10,000 Meter (strategic) Thinking – taking a high level (distancing from the detail) view of the system that shows horizontal expanse, but little vertical detail and which can transcend disciplinary &/or organizational boundaries.	*Fine level (tactical) Thinking* – Believing that understanding something means focusing on the fine scale details.
System as Cause Thinking – focusing on those internal elements whose interaction is capable of self-generating system behavior.	*System-as-Effect Thinking* – Choosing to focus on forces outside the system's boundaries as generating dominant effects on the system.
Dynamic Thinking – framing a problem in terms of a pattern of behavior over time; evaluating behavioral patterns and interrelationships of system components over time.	*Static Thinking* – Focusing on particular or specific events.
Operational Thinking – defining the two-way structure of causal relationships and understanding how behavior in the system is generated using the concepts of stocks, flows and connectors.	*Laundry List Thinking* – developing a list of contributing factors that influence or are correlated with some result.
Closed-loop (feedback loop) Thinking – recognizing the two-way structure of relationships and self-generating behavior of feedback loops; viewing causality as an ongoing process, not a one-time event, with the effect feeding back to influence the causes, and the causes affecting each other.	*Straight-Line Thinking* – viewing causality as running one-way, with each cause operating independent from all other causes.
Non-linear Thinking – defining relationships between variables that generate non-linear patterns. Cause and effect patterns may not be closely linked in time, space, or strength.	*Linear Effects Thinking* – viewing causal factors drive an effect by a fixed, proportional magnitude and impacts are realized instantaneously.
Scientific Thinking – recognizing that all models are working hypotheses that always have limited applicability and are subject to continual improvement (or replacement); using simulations to test mental models and hypotheses in a rigorous and objective fashion	*Proving-Truth Thinking* – seeking to prove models to be true by validating them with historical data.
Empathic Thinking - listening, articulating, and emphasizing with others out of respect and genuine interest for their perspectives and input.	*Single-minded Thinking* – focusing on issues out of self-interest, from a rigid and narrow disciplinary (organizational) perspective, or to solely advance a predetermined agenda.

Box 2. A social-ecological systems perspective

The brothers Eugene (Odum 1953) and Howard Odum (Odum 1983) are acknowledged for first applying systems thinking to establish the importance of ecology as a discipline and adopted and further developed the term "ecosystem" first coined by Tansley (1935). Subsequently, system thinkers recognized that ecological complexity often thwarts traditional, command-and-control approaches to managing natural resource-use systems (Holling and Meffe 1996, Ludwig 2001, Walker 2005). Uncertainty resulting from incomplete knowledge of complex dynamics in natural resource systems led Holling (1978) and Walters (1986) to develop the concept and practice of adaptive management, in which management decisions and actions are structured as experiments to facilitate learning by doing. Although the concept of adaptive management has gained widespread acceptance, there are still substantial challenges with on-the-ground implementation (Walters 1997, Lee 1999, Johnson 1999, Stankey *et al.* 2003, Morghan *et al.* 2006).

Research on complex natural-resource management systems has emphasized the need to move beyond the traditional ecosystem concept to explicitly include linkages between ecological systems and the human dimensions of social systems, *i.e.*, systems of governance (and economics), property rights, and access to resources (Costanza *et al*. 1993, Berkes and Folke 1998, Folke *et al*. 2002, Gunderson and Holling 2002, Berkes *et al.* 2003, Olsson *et al*. 2004, Folke *et al.* 2005, Walker and Salt 2006). Social-ecological systems act as complex adaptive systems, and social capacity for responding to and shaping ecosystem dynamics is a powerful feedback mechanism (Folke *et al*. 2005).

The concept of ecosystem resilience (Holling 1973, Gunderson and Holling 2002), which also applies to social-ecological systems, is characterized by: a) the ability of a system to absorb natural and anthropogenic disturbances and still retain its basic structure and function, and b) the degree to which the system is capable of self-organization. In social-ecological systems, an additional aspect of resilience is defined by the system's ability to build and increase the capacity for learning and adaptation by people (Berkes *et al*. 2003). Resilience in social-ecological systems is closely tied to the concept of sustainability and the challenge of meeting current demands without degrading the potential to meet future requirements (Ludwig *et al.* 1997, Walker and Salt 2006). The concept of resilience shifts perspective from the anthropogenic desire to control change in systems assumed to be stable, to sustain and enhance the capacity of social-ecological systems to adapt to change (Folke *et al*. 2002).

There are two useful tools for building resilience in social-ecological systems: 1) structured scenarios (Folke *et al*. 2002), and 2) adaptive co-management (Berkes 2004). In the former, scenarios are used to describe alternative futures and the pathways by which they might be reached. Multiple alternative futures and policy levers are defined that might achieve or avoid particular outcomes, which in turn allows identification of appropriate management actions. Adaptive co-management is a concept that combines networks of government agencies and other stakeholders engaged in a process that views policy as a set of experiments. Adaptive co-management *"requires, and facilitates, a social context with flexible and open institutions and multi-level governance systems that allow for learning and increase adaptive capacity without foreclosing future development options*" (Folke *et al*. 2002).

1.3 Disease – A Key Challenge

A key challenge that will influence recovery and restoration efforts for bison in North America is our collective ability to manage current and future disease risk at a landscape scale, and to maintain resilience of social-ecological systems in light of the associated multidirectional disease risks and pathogen transmission events that may occur between free-ranging bison, other wildlife species, commercial livestock, and humans. Indeed pathogens that occur within a broad continuum of hosts including wildlife, livestock, and human populations are an important issue with global implications for health (Daszak *et al.* 2000, Aguirre *et al.* 2002).

The greater Yellowstone and Wood Buffalo areas in the US and Canada (Figure 1) provide striking examples of how wild bison populations that are infected with "reportable" zoonotic pathogens of livestock origin, *i.e.*, brucellosis *(Brucella abortus)* and/or tuberculosis (*Mycobacterium bovis)* (see Boxes 3 and 4), present significant administrative, political and ecological challenges to national, state/provincial/territorial government agencies, and local stakeholders. In those ecosystems, the presence of infected bison populations is the basis for conflict and has precluded successful and meaningful social-ecological management and restoration of bison at the regional scale (see Box 5). An ironic similarity shared by these two examples is that they are geographically centered on the very same national parks that provided the early protection and basis for bison conservation in the US and Canada.

In short, the presence of those infected wild bison populations that occur primarily within national parks and have real and potential overlap with domestic livestock and other free-ranging wildlife (including other healthy bison herds), presents complex, wicked management problems (*sensu* Rittel and Webber 1973)[4] because the solutions are not apparent, the conflicts are often deep and entrenched, and the fundamental issues are perceived differently by various government agencies and stakeholders (Connelly *et al.* 1990, Peterson 1991, McCormack 1992, Keiter and Froelicher 1993, Wobeser 1994, Ferguson and Burke 1994, Gates *et al.* 1997, Keiter 1997, Thorne *et al.* 1997, Bienen and Tabor 2006, Nishi *et al.* 2006, USGAO 1992, 1997, 1999, 2007, 2008). Consequently, the diseased bison issues pose significant challenges for reasons that cannot be simply or conventionally explained as poor implementation or delivery of management programs by government agencies (Head 2008)[5].

Within the next century, development and implementation of effective and sustainable disease management strategies for those park-centered infected bison populations will be the litmus test of success for large-scale bison restoration efforts in North America. This rationale is based on the assertion that our collective ability to move forward with new bison restoration efforts will be offset by our ability (or inability) to truly resolve the legacies of the past bison disease management mistakes in the greater Yellowstone and Wood Buffalo areas. This assertion is also based on the assumption that disease risk management will be an important aspect of future bison restoration efforts (see USDA 2008, ADFG 2009) and that our collective inability to develop

[4] Rittel and Webber (1973) identified ten primary characteristics of wicked problems:

1. There is no definitive formulation of a wicked problem.
2. Wicked problems have no 'stopping rule', *i.e.* no definitive solution.
3. Solutions to wicked problems are not true-or-false, but viewed as good-or-bad by stakeholders.
4. There is no immediate and no ultimate test of a solution to a wicked problem.
5. Every (attempted) solution to a wicked problem is a 'one-shot operation'; the results cannot be readily undone, and there is no opportunity to learn by trial-and-error.
6. Wicked problems do not have a clear set of potential solutions, nor is there a well described set of permissible operations to be incorporated into the plan.
7. Every wicked problem is essentially unique.
8. Every wicked problem can be considered to be a symptom of another problem.
9. A discrepancy representing a wicked problem can be explained in numerous ways.
10. The planner has no 'right to be wrong', *i.e.* there is no public tolerance of initiatives or experiments that fail.

successful management processes to address the current disease issues in Yellowstone and Wood Buffalo will also handicap many future restoration efforts.

In short, failure or success in addressing the Yellowstone and Wood Buffalo bison disease issues will carry over into our future capacity to address complex management issues that will inevitably arise with new bison restoration projects. It is sobering to realize that despite best intentions and extensive efforts to manage aspects of disease risk in those populations, to date, there has been little meaningful progress in resolving the management issues since the livestock diseases were first officially detected (92 years ago for brucellosis in Yellowstone, and 72 and 53 years ago for tuberculosis and brucellosis in Wood Buffalo, respectively.)

[5] Head (2008) suggests that there may be several reasons for endemic failures and unintended consequences in complex areas of government policy and program delivery:

1. The 'problems' are poorly identified and scoped.
2. The problems themselves may be constantly changing.
3. Solutions may be addressing the symptoms instead of underlying causes.
4. People may disagree so strongly that many solution-options are unworkable.
5. The knowledge base required for effective implementation may be weak, fragmented or contested.
6. Some solutions may depend on achieving major shifts in attitudes and behaviors (i.e. future changed conduct on the part of many citizens or stakeholders); but there are insufficient incentives or points of leverage to ensure that such shifts are realized.

Figure 1. Location of Wood Buffalo National Park (WBNP) in Canada and Yellowstone National Park (YNP) in the United States. The Greater Yellowstone Area (GYA) is shown in gray shading and also includes Grand Teton National Park. A 50-km buffer around WBNP is used to conceptually illustrate the Greater Wood Buffalo Area (GWBA), which includes the Slave River Lowlands.

Box 3. Bovine brucellosis

Brucellosis is an infectious, contagious disease caused by bacterium of the genus *Brucella*. There are six species of *Brucella* that are classified based on differences in host preference and pathogenicity. The three principal pathogenic species are *B. abortus* (bovine brucellosis), *B. melitensis* (ovine and caprine brucellosis) and *B. suis* (swine brucellosis) (Godfroid 2002). Although cattle are the main host of *B. abortus* in North America, the bacterium is able to maintain itself in wildlife species most notably bison (Tessaro 1988, Dobson and Meagher 1996, Williams *et al.* 1997, Cheville *et al.* 1998, Roffe *et al.* 1999, Rhyan *et al.* 2001, Joly and Messier 2004a, Joly and Messier 2005, Rhyan *et al.* 2009). Elk are also susceptible to infection with brucellosis (Thorne et al. 1978a, Thorne et al. 1978b, Thorne 1987, Williams and Barker 2001), but it is likely that artificial winter feeding is the main reason why free-ranging elk populations can maintain brucellosis infection (Cheville *et al.* 1998, Smith 2001, Drew and Etter 2006, Cross et al. 2007, Maichak et al. 2009).

Worldwide, brucellosis remains an important zoonotic disease in humans and its prevention in people depends ultimately on eradication or control of the disease in animals (Corbel 1997). Prevention of human exposure to *Brucella* lies in hygienic precautions during occupational activities, and effective heating of dairy products and proper cooking of potentially contaminated meat. In northern Canada where brucellosis infected bison may be harvested, the most likely route of infection for hunters is accidental transmission of the bacteria through cuts and abrasions in the skin upon contact with the carcass, blood, or other body secretions during field dressing (Tessaro 1989, Young and Nicoletti 1997). Brucellosis is a 'reportable disease' because it has economic implications for agricultural trade. Countries including the USA and Canada that are signatory to international trade rules (WTO 1995, Zepeda *et al.* 2005) have implemented brucellosis control and/or eradication programs for their livestock populations (USDA 2003, GOC 2009).

The pathogenicity of brucellosis in bison is similar in most aspects to that in cattle (Davis *et al.* 1990, Williams *et al.* 1993, Rhyan *et al.* 2001, Thorne 2001, Rhyan *et al.* 2009). In female bison brucellosis results in infertility, uterine infections, premature abortions, retained placenta, or weak calves that die soon after birth (Davis *et al.* 1991, Thorne 2001). Consequently, the risk of disease transmission is greatest during or immediately after an infected female calves or aborts. In males, the disease causes inflammation of the testes and epididymides (Tessaro 1988, Williams *et al.* 1997). The disease may also cause arthritis and hygroma in which inflammation of leg joints may be severe enough to result in crippling or increased susceptibility to predation (Tessaro 1988). Transmission occurs primarily through direct contact when pathogen is shed in high concentrations by infected females during abortion or parturition and is found in placental and uterine fluids. Susceptible animals are infected through contact with infectious uterine fluids, aborted fetuses, or food, water, or soil contaminated by those materials. Calves may become infected through ingestion of infected milk from their dam (Williams *et al.* 1997, Olsen *et al.* 2003). Venereal transmission of *B. abortus* from bovine males to females is not considered important in the epidemiology of brucellosis (Thorne 2001).

Box 4. Bovine tuberculosis

Bovine tuberculosis is a chronic and progressively debilitating disease of cattle caused by infection with the bacterium *Mycobacterium bovis*. The bacterium is a member of the *M. tuberculosis* complex and has an exceptionally wide host range, although many are spillover hosts and unable to maintain infection in a population. Wildlife species that are capable maintenance hosts include badgers *(Meles meles)*, brush-tailed possums *(Trichosurus vulpecula)*, ferrets *(Mustela putorius)*, deer *(Odocoileus virginianus)*, bison (*B. bison)*, African buffalo *(Syncerus caffer)* and water buffalo *(Bubalus bubalis)* (de Lisle *et al.* 2001, Clifton-Hadley *et al.* 2001). In North America, wildlife reservoirs for bovine tuberculosis occur in bison in and around WBNP (Joly and Messier 2004a Joly and Messier 2005), elk and white-tailed deer in Riding Mountain National Park (Lees et al. 2003, Lees 2004, Brook and McLachlan 2006, Nishi *et al.* 2006), white-tailed deer in focal areas of Michigan (Schmitt *et al.* 1997, O'Brien *et al.* 2004b, O'Brien *et al.* 2006, Conner *et al.* 2008) and possibly in Minnesota (Cartensen *et al.* 2007).

Bovine tuberculosis is an important zoonosis that is transmitted from infected livestock to people through inhalation of aerosolized droplets and by ingestion of raw milk (LoBue 2006, Thoen *et al.* 2006). *M. bovis* is recognized as a major public health concern; it is listed as a reportable disease and national eradication programs for cattle herds in the USA and Canada were initiated in 1917 and 1923, respectively (Essey and Koller 1994, Gilsdorf *et al.* 2006, Koller-Jones *et al.* 2006). In northern Canada, people who hunt infected wild bison risk infection with *M. bovis* through accidental inoculation of cuts and abrasions on hands while field dressing an infected bison carcass (Tessaro 1989). O'Brien *et al.* (2004a) outline best practices for minimizing exposure for wildlife professionals who handle and process ungulate carcasses from infected populations.

Bovine tuberculosis is primarily a respiratory disease with inhalation being the principle route of infection, although oral transmission through ingestion is also important (Phillips *et al.* 2003, Kaneene and Pfeifer 2006). In livestock and wild ungulates, infected animals shed the bacteria in body secretions and transmission is usually through direct contact via inhalation of droplets expelled by infected animals or consumption of contaminated feed. Transmission may also occur from mother to fetus through the placenta and umbilicus, or when the newborn offspring consumes its mother's infected milk (Phillips *et al.* 2003). Bovine tuberculosis primarily affects the respiratory system with lesions commonly found in cranial and thoracic lymph nodes and in the alimentary canal (O'Reilly and Daborn 1995, Kaneene and Pfeiffer 2006). In bison, the disease may reduce fertility, weaken infected animals and in advanced cases result in death. Fuller (1966) and Tessaro (1988) estimated that advanced tuberculosis may result in 4-6% mortality in bison; both authors suggested a link between infection with tuberculosis and increased susceptibility to predation by wolves. Recent studies by Joly and Messier (2005) in Wood Buffalo National Park showed that survival and reproduction rates were reduced in female bison that tested positive for both tuberculosis and brucellosis. Heisey *et al.* (2006) conducted further analyses of the Joly and Messier (2005) data and demonstrated reduced survival in tuberculosis-positive bison.

Box 5. Bovine brucellosis and tuberculosis in wild bison: to intervene or not?

The fundamental issue centered on the diseased, free-ranging bison in Yellowstone and Wood Buffalo national parks is that in the absence of management intervention, the respective diseases – brucellosis in Yellowstone, brucellosis and tuberculosis in Wood Buffalo – will likely persist indefinitely in the bison populations. With continued persistence of the diseases in the wild bison herds, there is continued risk that the pathogens could potentially infect humans, other wildlife populations and domestic livestock, *ie*., cattle. The management dilemmas and conflicts arises due to competing mandates, values, and perspectives of various government agencies and stakeholders on addressing the basic issue of **what will be done** to manage the diseases in wild bison.

The question of "what will be done" forms the crux of forward-looking management strategies and action plans, and often initially appears deceptively easy to address. However, aspects of the broader dilemma are revealed when two elements of this seemingly simple question are posed more directly: a) **what should be done** to manage the diseases in wild bison; and b) **what can be done** to manage the diseases in wild bison? The question of "what should be done" is largely based on the values and risk tolerances of individuals, stakeholder organizations, and governments, and is reflected as a dynamic social and political interaction of individuals and institutions. The question of "what can be done" is grounded in objective appraisal using the current state of scientific knowledge and is focused on technical issues such as biological feasibility and economic costs of implementing possible management strategies.

With respect to the question of "what can be done" there are four possible disease management objectives (Wobeser 2002):

1. Do nothing, and take a *laissez faire* approach;
2. Prevent the introduction of disease pathogen(s) to unaffected populations;
3. Control the frequency of occurrence of disease(s) within an existing population, or contain the spatial spread of infection; and
4. Eradicate the disease pathogen(s) from the host population.

In the GYA and the GWBA, the main emphases are on preventing introduction of disease to other populations. In the GYA the focus is on preventing transmission from bison to cattle in Montana by maintaining spatial and temporal separation between the two species and thereby eliminating potential direct and indirect contact of infected bison with livestock. Another key strategy for the GYA is to develop suitable vaccines and vaccine delivery methods to eventually reduce the level of infection in the bison. In the GWBA the focus is on prevention of disease transmission to other nearby bison conservation herds in the Northwest Territories and Alberta that are considered free from infection with bovine brucellosis and tuberculosis. The secondary risk is potential spill back into cattle in northern Alberta. In northern Canada, the principal means of preventing disease introduction has been through establishment and management of large bison-free zones that are situated between the known ranges of infected and non-infected bison populations.

The main challenges with implementing disease management strategies that aim to control or eradicate brucellosis and/or tuberculosis in wild free-ranging bison are due to the fact that available techniques and technologies are still under development, and there remains considerable uncertainty regarding efficacy and feasibility of control and eradication methods at a population scale. Furthermore, since control and/or eradication of the disease pathogens, *B. abortus* and *M. bovis,* also requires intrusive and intense management of the host organism – the bison – there is disagreement and ongoing debate about an acceptable level of management intervention for wild bison that should be undertaken in both the GYA and GWBA. Some examples of disease management objectives and accompanying actions are summarized in Table 5.1.

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Despite the many challenges associated with eliminating brucellosis and/or tuberculosis, there have been several successful cases where healthy bison herds were established from known infected populations. Table 5.2 summarizes many of the known examples in both plains and wood bison. It is worth noting that all cases involving plains bison eliminated brucellosis only, whereas the three wood bison cases attempted to eradicate both bovine brucellosis and tuberculosis.

Table 5.1 Descriptive summary of disease management options for free ranging bison infected with bovine brucellosis and/or tuberculosis.

Wildlife Disease Management Objective	**Management Action (example)**	**Technical Considerations**	
		Pros	**Cons**
Prevention	Bison-free zone	Reduces risk of contact and risk of disease transmission	Does not eliminate disease risk; indefinite monitoring required, minimal and unknown risk reduction without active surveillance
	Maintain spatial & temporal separation between bison and cattle	Reduces risk of contact and risk of disease transmission	Does not eliminate disease risk; indefinite hazing, removal and/or culling of bison required
Control	Vaccination	Reduces prevalence of disease and may lead to eradication over long term depending on efficiency of vaccine and delivery methods; vaccine development research currently a high priority for *B. abortus* in GYA	Difficult to effectively treat entire population; development of effective and safe vaccine for *M. bovis* in bison is unlikely over short and medium term, i.e., 10+ years
Eradication	Test and removal of test-positive animals	Reduces prevalence of disease and may lead to eradication of *B. abortus* over long term if combined with vaccination	Limited effectiveness if population is large and a high proportion of population is not tested repeatedly; requires facilities and repeated handling of animals; will not work for *M. bovis* because of poor test performance on individual animals
	Depopulation of infected population followed by repopulation with healthy bison	Removes disease reservoir and eliminates risk of disease transmission; appropriate genetic salvage would be possible through use of quarantine protocols and reproductive technologies	Logistically difficult to remove infected population; potential impacts on predator-prey dynamics during bison free period; (may not be socially acceptable to stakeholders)

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Table 5.2. Summary of cases in North America where healthy bison herds were salvaged from populations infected with bovine brucellosis and/or tuberculosis. (***Table reads across both pages***.)

Population	Source	Bison Herd Established	Disease Detected	Peak Seropositivity (*B. abortus*)	Disease Eradication Period
Plains Bison (brucellosis)					
Wichita Mountains National Wildlife Refuge, Oklahoma, USA	Fort Niobrara, National Wildlife Refuge, New York Zoo	1907	1964	3% (1969)	1965-1974
Elk Island National Park, Alberta, CAN	Pablo-Allard (Montana)	1909	1945	52% (1959)	1945-1972
Wind Cave National Park, South Dakota, USA	New York Zoo, Yellowstone National Park	1913	1945	85% (1945)	1964-1985
Custer State Park, South Dakota, USA	Private, Tribal, Wind Cave National Park	1914	1961	48% (1961)	1963-1973
Henry Mountain Herd, Utah, USA	Yellowstone National Park	1941	1961	~10% (1961)	1961-1963
MFWP & USDA / APHIS Bison Quarantine Study	Yellowstone National Park	2005	N/A	5% (2005-2006)	2005 - present
Wood Bison (brucellosis and tuberculosis)					
Mackenzie bison herd, Northwest Territories, CAN	Wood Buffalo National Park	1963	1963	52% (1963)	1963
Elk Island National Park, Alberta, CAN	Wood Buffalo National Park	1965	1968	?	1968-1971
Hook Lake Recovery Project, Northwest Territories, CAN	Slave River Lowlands	1996	N/A	~ 22% (1996-1999)	1996-2006

* T. Armstong pers. comm.a, Aune and Rhyan 2006b, Blyth 1995c, Boyd 2003d, Cheville et al. 1998e, Franke 2005f, Gates et al. 2001bg, Gilsdorf 1997h, Himsworth et al. In press ai, Himsworth et al. In press bj, Larter et al. 2000k, Lutze-Wallace et al. 2006l, MFWP 2004m, MFWP 2009an, MFWP 2009bo, MFWP and USDA 2004p, MFWP and USDA 2005q, MFWP and USDA 2006r, Nishi et al. 2001s, Nishi et al. 2002at, Nishi et al. 2002bu, Parks Canada 2005v, Tessaro et al. 1993w, UDWRx, USDIy, Wilson et al. 2000z

(Table 5.2 reads across both pages.)

Disease Eradication Methods	Disease No Longer Detected	Area (km^2)	Current Population Size	Status	References*
Plains Bison (brucellosis)					
Test & removal, population reduction, isolated groups (vaccination of calves stopped in 1973)	1974	174	~600	stable	d, e, f, h
Large-scale population reduction, test & slaughter, vaccination (strain 19 *Brucella*)	1972	240	470-500	stable	c, u, v
Whole herd and calfhood vaccination, test & removal	1985	114	350-450	stable	d, e, f, h, x
Annual vaccination of calves & yearlings, test & removal, herd size reduction	1973	290	~1100	stable	d, e, f, h
Test & removal	1963	1215	~270	stable	d, e, f, y
Quarantine, isolation, test & removal. This is an ongoing collaborative project to salvage brucellosis-free bison from YNP; healthy animals will be used to re-establish bison herds on Indian lands and other locations as part of a broader conservation strategy	2009	188	~140	stable - increasing	b, m, n, o, p, q, r
Wood Bison (brucellosis and tuberculosis)					
Test & removal of reactors, 6 month isolation period. Herd of 18 bison was released in Mackenzie Bison Sanctuary in 1963. Post-mortem and serological testing of 51 and 112 bison (1986-1990) did not detect disease	1990	13000	~1600	stable - declining	a, j, k, u, w
Test & removal, orphaned calves & destroyed all founders	1971	60	~300	stable	c, g, u, v
Captured and orphaned 62 wild-caught brucellosis test-negative neonates, antibiotic treatment of calves, hand-raised calves in isolation.	Brucellosis not detected on serology or post mortem analyses of depopulated herd	0.5	Tuberculosis detected in 2005, remaining herd depopulated in 2005 & 2006	de-populated	i, j, l, s, t, u, z

2. METHODOLOGY

The author conducted an extensive search of literature in peer-reviewed scientific journals and available 'grey' literature produced primarily by government agencies and non-government organizations. The main purpose was to review studies on the management and disease ecology of bovine brucellosis and tuberculosis in bison within the Greater Yellowstone (GYA) and Greater Wood Buffalo areas (GWBA). The review was expanded to include general subject areas of management theory, landscape ecology, and wildlife-livestock disease case studies from other geographies to provide background to the broader issues of addressing wildlife disease at a landscape level and from different disciplinary perspectives. The search resulted in an electronic library that represents over 900 references in a searchable ProCite database (Appendix A).

The author conducted two site visits to interview wildlife disease experts in the US and Canada who have been involved in various aspects of research and management in the diseased bison issues in the GYA and GWBA (Appendix B). Given time and funding constraints, the author interviewed a small subset of wildlife professionals who have been previously or currently involved in diseased bison issues. The objective was to conduct face-to-face unstructured interviews in order to develop an understanding of their experiences, to seek additional sources, and to become familiar with current events and perspectives. A brief visit to the GYA also provided the opportunity to observe bison and elk *(Cervus elaphus)* in Yellowstone National Park and the adjacent landscapes.

3. THE GREATER YELLOWSTONE AREA (GYA)

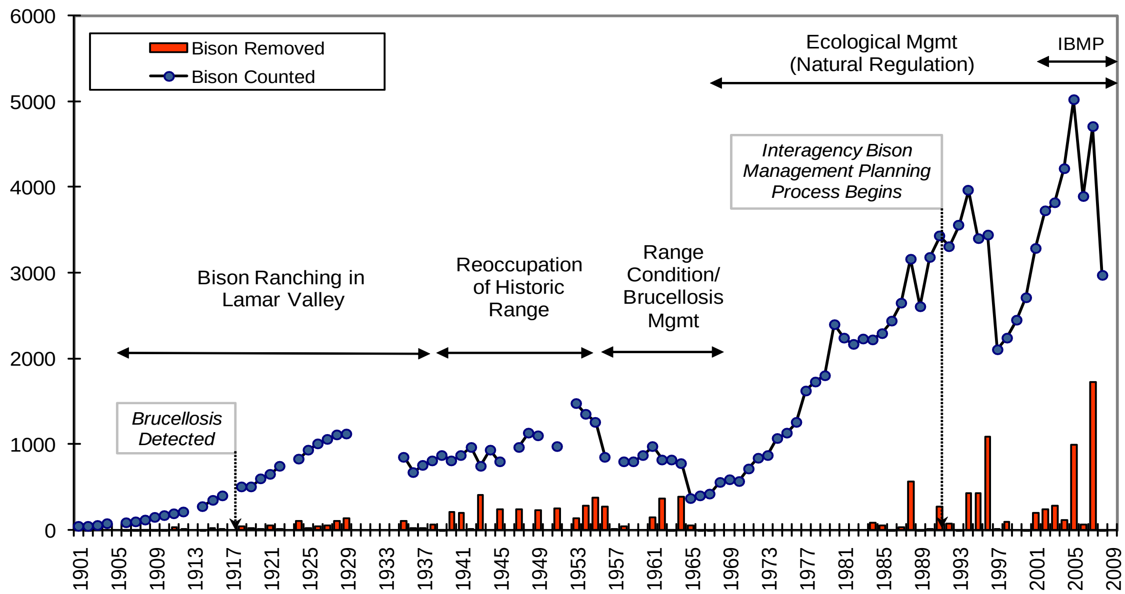
The Greater Yellowstone Area, also referred to as the Greater Yellowstone Ecosystem (GYE), is considered one of the largest functionally intact temperate ecosystems in the world. The GYA spreads over parts of Idaho, Wyoming and Montana and encompasses 76,000 km^2 in the Central Rocky Mountains of the United States (Clark 1999) (Figure 1). The GYA is centered around Yellowstone National Park (8,987 km^2), but also includes Grand-Teton National Park (1,254 km^2), and all or portions of seven national forests, three national wildlife refuges, approximately 20,000 km^2 of private land and over 6,070 km^2 of state lands and Native American Reservations (Lynch *et al.* 2008). For a succinct description of the socio-economic and political history of Yellowstone National Park, and a useful context for the development of current wildlife conservation programs in the broader GYA, please see Inman *et al*. (2008).

3.1 Greater Yellowstone bison

Yellowstone National Park was created in 1872 to protect the unique landscape and natural resources of the Yellowstone region for the benefit and enjoyment of the people (Haines 1974, Inman *et al.* 2008). Despite many of the early challenges posed by enforcing and administering a vast area, the creation of the park protected an isolated remnant population of plains bison that comprised fewer than 40 - 50 animals in 1902 (Meagher 1973). The YNP bison population is comprised of the central and northern herds (Fuller *et al.* 2007a, Olexa and Gogan 2007, Bruggerman *et al.* 2009, Fuller *et al.* 2009, Geremia *et al.* 2009). To increase its numbers, the northern herd was subject to intense animal husbandry practices from 1902 to 1938, which included fall round ups, confinement and winter feeding. A captive herd was also started within the park in 1902 with bison from the Pablo-Allard (n=18) and Goodnight (n=3) herds (Meyer and Meagher 1995). The captive herd was managed intensively until about 1915 after which the captive and wild bison from the northern herd began to intermingle (Meagher 1973, Gates *et al.* 2005).

By the late 1920s, the northern herd had grown to over 1000 animals (Figure 2) (Fuller *et al.* 2007a). In comparison, the central herd was not intensively managed therefore it remained at fewer than 100 animals until the mid 1930s at which time park managers augmented it with 71 animals from the northern herd (Fuller *et al.* 2007a). The Yellowstone bison population was managed at an estimated carrying capacity for the park and the herd was subject to culling and supplemental feeding up until 1968, after which the park instituted a policy of natural regulation.

Figure 2. Trend of bison population size and removals within Yellowstone National Park, 1901-2008 (data sources: 1901-2000, USDI & USDA 2000; 2001-2008, R. Wallen unpub. data).



Brucellosis was first detected serologically in YNP bison in 1917 and the most likely source of infection was cattle (Meagher and Meyer 1994). Despite its exotic origin, brucellosis is an enzootic disease of YNP bison and will likely persist in the absence of direct human intervention. Observed prevalence from serological tests has ranged between 40-60% (Dobson and Meagher 1996, Cheville *et al.* 1998), though only about half (46%) of test positive bison are estimated to be actively infected (Roffe *et al.* 1999). Brucellosis causes a high rate of abortions in the first year of infection, which then decreases in the second year and approaches zero in subsequent years (Peterson *et al.* 1991a, 1991b). Recent analyses by Fuller *et al.* (2007b) and Geremia *et al.* (2009) showed that seropositive females had markedly reduced pregnancy rates compared to seronegative females over all age classes, and suggested that brucellosis may reduce fecundity in chronically infected bison. Despite its effect on female reproduction, brucellosis is not considered an important regulating factor[6] in the demography of YNP bison (Dobson and Meagher 1996, Peterson 1991).

The YNP bison population grew to *ca.* 5000 in 2005, and the most recent survey in 2008 estimated 3000 animals (Wallen 2008) despite removal of over 6800 animals since 1984 (R. Wallen unpub. data). The large scale removals

[6] An increased rate of predation on bison that are infected with *B. abortus* has not been documented for the YNP population (see Becker et al. 2009). Wolves were introduced relatively recently to YNP in 1995 (Smith *et al.* 2009), and bison are less vulnerable and subject to lower rates of predation than elk (Becker et al. 2009, Garrott *et al.* 2009b).

of bison with the aim of reducing brucellosis transmission risk to cattle has affected the demography of Yellowstone bison (Fuller *et al.* 2007b, Olexa and Gogan 2007, Fuller *et al.* 2009, Geremia *et al.* 2009). Kilpatrick *et al.* (2009) showed that after including the effects of culling since 1984, the observed rate of growth of YNP bison has been *ca.* 72 animals per year. Conversely, if culling effects were excluded from analysis the rate of growth in YNP has been approximately 287 animals per year (Kilpatrick *et al.* 2009). Fuller *et al.* (2007b) suggested that if brucellosis were eliminated in YNP bison, birth rates would increase and overall population growth rate could increase by approximately 29%, *ie.*, an increase in the finite rate of increase from $\lambda= 1.07$ to 1.09.

Bison had historically occupied the Jackson Hole area of Wyoming but had been extirpated by the mid-1880s. In 1948, under authority of the State of Wyoming, 20 bison from YNP were reintroduced to the Jackson Hole Wildlife Park (USDI 2007a). In 1950, Grand Teton National Park (GTNP) expanded to include the Wildlife Park and the captive herd of 15-30 bison was managed cooperatively between the National Park Service and the Wyoming Game and Fish Department (Cromley 2000). In 1963, brucellosis was discovered in the herd; all 13 adult animals were destroyed, while four yearlings and five calves that had been vaccinated were kept. The following year, 12 certified brucellosis-free bison from Theodore Roosevelt National Park were added (Cromley 2000). In 1969, the small herd of nine bison was allowed to range freely. In 1975, the Jackson bison herd consisted of 18 animals and they had started to overwinter on the National Elk Refuge (NER). In 1980, the bison began eating supplemental feed provided for elk. This behavioral pattern persists today - bison summer in GTNP and migrate to winter in the NER. Samples collected in the late 1980s showed that the Jackson bison herd had been re-infected with brucellosis either after the herd started wintering in the NER (~1975) or after the herd discovered the winter feeding grounds for elk (USDI 2007a). By 1982, managers had started unsuccessfully hazing bison away from the elk feed lines in order to reduce competition and aggressive interaction between bison and elk. In 1984, managers started feeding bison separately from the elk to reduce conflicts with the elk feeding program. Since 1980, the bison herd has been increasing annually by approximately 10-14%, which translates into a doubling time of 5-7 years. In winter 2006, the herd count was 948 bison (USDI 2007a).

Opportunistic studies in 1989 and 1990 showed that 27 of 35 (77%) Jackson bison were serologically positive or suspect on tests for *Brucella* antibodies (Williams *et al.* 1993). Subsequent estimates of seroprevalence in the herd ranged from 58% to 84% (USDI 2007a) indicating that the Jackson bison herd was a competent maintenance population for *Brucella abortus*. There were some initial management efforts to control population size but they met limited success because the bison were mainly distributed within the park and refuge lands where lethal removal was not permitted until recently.

3.2 Greater Yellowstone elk

The settlement of North America reduced the elk population to approximately 50,000 by the turn of the 20th century with most finding refuge from sport and market hunting in the remote lands around Yellowstone National Park. Expanded land use by growing populations of settlers meant that winter habitat for free-ranging elk was reduced and conflicts occurred as elk ate ranchers' hay. In Jackson Hole, winter feeding was initiated in 1910 and was originally intended to reduce winter mortality and preserve a locally important elk population (Boyce 1989, Cromley 2000, Smith 2001). Winter feeding of elk and bison was also conducted within Yellowstone, but at a smaller scale. By 1912, the National Elk Refuge (NER) was established to preserve remaining winter range for elk and serve as a winter feeding ground for the Jackson elk herd (Boyce 1989). Brucellosis was detected in elk in the NER in 1930 following reports of aborted elk fetuses (Thorne *et al.* 1997). From the 1950s-80s, an additional 22 state-operated elk feedgrounds were established in northwest Wyoming (Smith 2001). Feedgrounds in Wyoming have facilitated winter feeding of approximately 20,000 – 25,000 elk (Smith *et al.* 1997, Dean *et al.* 2004).

There are three feeding sites in northeastern Idaho, two of which are on private land. Brucellosis testing of elk from those feeding sites revealed antibody prevalence that ranged from 12% to 80%; the predominance of *B. abortus* biovar 4 isolated from infected animals suggested that the feedgrounds in northeastern Idaho represented an independent nidus of infection (Etter and Drew 2006). Although Smith *et al.* (1997) reported that there were two private unauthorized feedgrounds in Montana's portion of the GYA, those feeding grounds have since been closed and presently there are no known feedgrounds in Montana, as they are illegal (K. Aune pers. comm.).

A principal drawback of winter feedgrounds is that they concentrate elk in a relatively small area during the late winter and early spring – the time when cows infected with *B. abortus* are most likely to abort and shed bacteria associated with birth fluids and tissues. The high densities maintained during an extended feeding period increase contact rates between uninfected elk and contaminated fetal materials from infected cows after abortion events, allowing the disease to be maintained in a winter-fed population (Thorne 2001, Cross *et al.* 2007, Maichak *et al.* 2009).

In the National Elk Refuge, brucellosis occurs at an average seroprevalence rate of *ca*. 17% (USDI 2007a). In the GYA, elk herds on native winter range with no access to feedgrounds have a brucellosis seropositive rate from 0-3%, whereas herds that winter on feedgrounds show seropositive rates of 25-37% (Smith *et al.* 1997, Ferrari and Garrott 2002, Etter and Drew 2006).

It has been generally thought that under normal conditions (without winter feeding), brucellosis would not be maintained in elk populations because cows seek isolation for calving and consume birthing products at the site, thereby reducing potential rates of exposure and infection (Thorne 2001). However, recent findings by Cross *et al.* (2009) showed that the prevalence of brucellosis in four of five Wyoming elk herd units has increased from 0-6% in 1991/92 to

7-18% in 2006-08, and that the increased prevalence rate was not due to dispersal from feedgrounds, but likely due to increased elk-to-elk transmission in larger winter aggregations on native winter ranges. Consequently, Cross *et al.* (2009) suggested that unfed elk populations may become competent reservoir hosts for *B. abortus* as elk densities increase independent of winter feedgrounds. Therefore, future management scenarios may need to consider factors other than winter feeding, such as hunter access, predator management and its effects on winter elk density, and human population increase and associated changes in land ownership and elk management preferences.

Brucellosis is a serious management concern because it occurs in the GYA elk, and winter feeding is hypothesized to play an important role in maintaining brucellosis infection in elk. The practice of winter feeding also has broader implications for facilitating transmission and establishment of other potential disease pathogens (*ie*., tuberculosis and chronic wasting disease) that may be introduced into the system (Smith 2001, Neff 2004, Peterson 2005, USDI 2007a, Conner *et al.* 2008).

3.3 Disease Management in the Greater Yellowstone Area – brucellosis

For economic and human health purposes, the first cooperative state/federal program in the US to work towards eradication of brucellosis was started in 1934. By 1954, federal funds were appropriated to coordinate the National Brucellosis Eradication Program, and collectively billions of dollars have been spent by federal, state and agricultural industry partners to eliminate the disease in livestock. By 2000, the goal of eradicating brucellosis in livestock was largely realized as only two brucellosis affected livestock herds remained under quarantine at the time (Ragan 2003, USDI, USDA & APHIS 2000).

The presence of brucellosis in GYA bison and elk creates a conflict with the agricultural goal of eradicating *B. abortus* because the infected wildlife is a potential source for re-infection of cattle and domestic bison (Thorne and Kreeger 2003). The issue underlying the brucellosis management controversy in the GYA is the potential ongoing risk of disease transmission from infected bison and elk to cattle herds outside the park; recent cases of brucellosis in cattle herds adjacent to YNP have shown that the risk of spillover is real (Table 1). Since brucellosis is a reportable disease in the US subject to disease eradication measures and surveillance[7] (USDA 2003), spillover of *B. abortus* to cattle herds has economic implications to individual cattle producers and livestock trade at a state[8] and national level.

Brucellosis is maintained in both bison and elk populations in the GYA. It is likely that bison are the primary reservoir wildlife host for brucellosis in the system and capable of maintaining infection under a wide range of densities. It appears that wild elk populations are a secondary reservoir host that are capable of maintaining high incidence of infection when contact rates between infected and susceptible animals are maintained artificially through ongoing winter feeding programs.

[7] For example, the current USDA brucellosis rules (USDA 2003) explicitly define surveillance standards and criteria required to achieve and maintain "Class Free" status for a State or area, which is official recognition that all cattle and captive commercial bison are free of brucellosis. Class Free status facilitates open trade and movement of livestock from and within recognized Class Free states and areas. Depending on the number and frequency of confirmed cases of brucellosis in cattle or captive bison within 12 consecutive months, the USDA designates a state or area with a Class A, Class B or Class C designation. Restrictions on the interstate movement of cattle become more stringent as a state is downgraded from Class Free status. Class C designation is for states with the highest rate of brucellosis, and requires a federal quarantine. Class A and Class B fall between the two extremes of Class Free and Class C status. With a downgraded status, all producers in the state or area are restricted in their ability to move and sell live cattle and commercial bison, and therefore incur lost market opportunities until the state or area regains Class Free status.

[8] For example, the estimated direct industry cost to Montana livestock operations of the State's reclassification from Class Free to Class A in 2008, could range between *ca*. $6 million and $12 million per year (APHIS 2008).

Table 1. Summary of brucellosis cases in cattle herds in the Greater Yellowstone Area

Date	Brucellosis in Montana Cattle	Comments
Jun 1985	Class free status	
May 2007	Brucellosis reactor	7 angus from ranch in Bridger, MT
Jun 2008	Herd tested as part of brucellosis risk mitigation plans for herds near GYA	cow in Paradise Valley, MT
Sep 2008	Reclassified from Class Free to Class A	
Jul 2009	Reclassified from Class A to Class Free	
Date	**Brucellosis in Wyoming Cattle**	**Comments**
1969-1989		Six cases in WY cattle determined to be associated with wildlife; 1969 (reinfected 1977), 1982, 1983, 1984, 1985, 1989
1985	Obtained Class Free status	
Dec 2003	Herd test	31 reactors & 20 suspects in a herd of 395 cattle; infection confirmed by culture of *B. abortus* biovar 1 (Sublette County)
Jan 2004	Trace-out testing of 12 cattle previously sent to feedlot	6 reactors (in 12 cows from Sublette index herd) Washakie County
Feb 2004	Reclassified from Class Free to Class A	
Jun 2004	Brucellosis reactor found on test prior to interstate movement	1 animal in 105 tested positive for *B. abortus* biovar 4 (Teton County)
Oct/Nov 2004	Trace-out testing of three contact herds	4 reactors (1 animal infected) with *B. abortus* biovar 4 (Teton County)
Sep 2006	Regained Class Free status	
Jun 2008	Brucellosis reactor found as part of WY first-point testing at livestock auction markets	2 cows tested positive from herd in Sublette County, WY
2008	Trace-out testing on herd of origin from previous case	Additional reactors found on each of 3 successive herd tests
		NOTE: WY will maintain Class Free status if no additional affected herds are found within 24 months (Jun 2010)
Date	**Brucellosis in Idaho Cattle**	**Comments**
1989	Brucellosis identified	brucellosis identified
1991	Obtained Class Free status	
Apr 2002	Brucellosis reactor found during Herd test	Small herd in Teton Valley tested positive & was quarantined
Oct 2005	Herd test	Infected cattle herd found in Swan Valley
Oct 2005	Trace out testing	Heifer from Swan Valley herd traced to small feedlot near Arco, which was considered a 2nd brucellosis infected herd
Jan 2006	Reclassified from Class Free to Class A	
Jul 2007	Regained Class Free status	

Sources: GYIBC 1997, Boyer 2002, Idaho State Department of Agriculture 2005a, Idaho State Department of Agriculture 2005b, Logan and Oldham 2005, Gilsdorf and Dutcher 2006, Government of Montana 2008, Lutey 2009, APHIS 2009, MDOL 2009, Donch and Gertonson 2009.

Presently, all elk populations in the GYA - representing about 125,000 animals - are variably and chronically infected with *B. abortus.* In the northern GYA, where there are no winter feedgrounds, the prevalence of brucellosis in elk (0-3%) is substantially lower than the elk in the southern GYA that are associated with feedgrounds (25-37%)[9].

3.3.1 The focus on bison in Yellowstone National Park

Since the 1980s, the growth and associated range expansion of the YNP bison population has resulted in increasing numbers of bison moving outside of the park boundary and onto adjacent state owned and private lands (Gates *et al.* 2005). Early efforts to contain bison within the park boundary through hazing proved to be ineffective (Meagher 1989), and removing or killing bison that left the park resulted in divisive controversy[10]. Although the risk of transmitting *B. abortus* from wild bison to cattle was considered very low (Cheville *et al.* 1999) and there had been no documented cases of wild bison transmitting brucellosis to cattle, the perception of disease risk was the basis of concern for agricultural industry and government agencies at the state and federal levels, and the impetus for management actions to prevent bison from leaving the park and comingling with cattle.

In the mid 1980s, the Fund for Animals filed the first of several lawsuits directed at bison management in the GYA (USDI, USDA & APHIS 2000). Although state and federal agencies successfully defended their respective programs, the litigation emphasized the need for coordinated management planning. Coordinated efforts to address brucellosis in wildlife in the GYA began in 1988 (Daniels and Hillman 2003), and in 1990 five state and federal agencies (National Park Service, the Forest Service, the Animal and Plant Health Inspection Service, and the Montana Department of Fish, Wildlife and Parks, and Department of Livestock) announced an intent for a management plan and declared that they would initiate the process of drafting an environmental impact statement (EIS). Between 1991 and 1992, the US Government Accountability Office completed a review of the information on: 1) the scientific evidence that brucellosis can be transmitted from bison and elk to domestic cattle; 2) the economic damage that might be caused by such a transmission; and 3) the management alternatives for preventing or reducing the likelihood of such transmission (USGAO 1992). From 1990 to 1995, state and federal agencies individually or jointly prepared three interim bison management plans and environmental assessments, which was a reflection of divergent agency perspectives rather than convergence on a final plan (K. Aune pers. comm.).

In 1993, the governors from Wyoming, Idaho, and Montana agreed to form a Tri-state interagency Brucellosis Task Force. In 1994, the three governors and several state agencies were joined by the Secretaries of Interior and Agriculture, which led to the formation of the Greater Yellowstone Interagency Brucellosis Committee (GYIBC; Hollingsworth 1998)[11]. The mission of the GYIBC is to protect and sustain the existing free-ranging elk and bison populations in the

[9] Atkinson *et al.* (2007) reported that standard serological tests for brucellosis in elk may be biased through cross-reactivity with the bacterial strain *Yersinia enterocolitica O:9*, which results in false positive results. Based on 311 samples from the Madison Elk Management Unit (collected in 2004-2006), 11.6% were considered test positive based on serological results only. When samples were reclassified after cross-reactivity with *Yersinia* was determined using the Western Immunoblot test, the percentage of positive samples decreased to 1.9% (Atkinson *et al.* 2007). As a result, Idaho and Montana currently rely on the Western Immunoblot test for the final determination of apparent prevalence of elk that have tested seropositive in a series of screening tests; Wyoming presently does not use the Western Immunoblot test to confirm serostatus in elk (Anonymous 2009).

[10] A flashpoint in the controversy occurred during the harsh winter of 1996-1997, when *ca.* 1,100 bison were culled as they moved beyond the park boundary and another 400 died of starvation inside the park (Hollingsworth 1998, Lavigne 2002). Since 1996/97, an additional 3700 bison have been culled, with *ca.* 1000 and 1700 bison occurring in 2005 and 2007, respectively (Figure 2), highlighting the continued controversy associated with killing Yellowstone bison once they leave the park.

GYA while protecting the public interests and economic viability of the livestock industry in the states of Wyoming, Montana, and Idaho and to facilitate the development and implementation of brucellosis management plans for elk and bison in the GYA (Thorne and Kreeger 2003).

In 1995, the state of Montana initiated a lawsuit against the National Park Service and APHIS, in part due to the failure to get a final plan adopted (K. Aune pers. comm.); the case was eventually settled after the parties agreed to complete a long-term bison management plan and EIS (USDI, USDA & APHIS 2000). Native American perspectives as represented by the InterTribal Bison Cooperative (ITBC), and environmental groups such as the Greater Yellowstone Coalition (GYC) (among others) played an unofficial but important role in the EIS process (Hollingsworth 1998, Lavigne 2002).

In 1998, the agencies released a Draft EIS for an Interagency Bison Management Plan (IBMP) for the State of Montana and Yellowstone National Park. Ongoing disagreement between federal and state agencies on management strategies led to the designation of a court appointed mediator to resolve their differences, which led to refinement of the modified preferred option as described in the EIS Final Record of Decision in 2000 (USDI, USDA & APHIS 2000). The agreed upon IBMP was based on an adaptive management program that included intensive monitoring and coordination to create and maintain sufficient separation between bison and cattle in time and space and thereby minimize the risk of brucellosis transmission.

The IBMP included three successive adaptive management steps for managing bison on the northern and western boundaries of Yellowstone National Park, which were intended to incrementally increase tolerance for bison to roam outside of the park. Possible combinations of management actions to achieve specified goals included: hazing bison back inside the Park; capturing and testing bison that entered management areas outside of the Park (seropositives sent to slaughter or to approved research projects, seronegatives released back into management area up to a specified tolerance level); voluntary vaccination of eligible cattle; lethal removals of bison; and construction and use of approved bison quarantine facilities to salvage brucellosis-free bison (USDA 2003, MFWP and USDA 2006). Since there has been no substantial mingling of YNP bison with cattle and there have been no documented occurrences of brucellosis in cattle that can be epidemiologically linked to YNP bison, it is plausible that management actions that were implemented since the 1980s as specified by the IBMP have been successful in ensuring spatial separation between bison and cattle herds (K. Aune pers. comm.).

A recent review by the US Government Accountability Office (USGAO 2008) on progress and performance of the federal and state agencies that are implementing the IBMP concluded that they have made less progress than originally anticipated. The USGAO suggested that the agencies had not adequately implemented adaptive management, and made five specific recommendations:

1. Clearly define measurable objectives to express desired outcomes and refine, revise, or replace the plan and agency operating procedures as needed to reflect these objectives.

[11] Additional references on the history and controversy about brucellosis in the GYA include Keiter and Froelicher 1993, Keiter 1997, USGAO 1992, USGAO 1997, USGAO 1999, USGAO 2007, and USGAO 2008.

2. Systematically apply adaptive management principles to define specific scientific and management questions; identify the activities to be conducted to answer them; develop a monitoring program to assess the impacts of those activities; and incorporate the results into the bison management plan.
3. Establish a single, publicly available repository, on a Web site or at a location easily accessible to the public, that includes all documents reflecting decisions made and actions taken with respect to plan implementation.
4. Report annually to Congress on the progress and expenditures related to the plan's measurable objectives once these have been clearly defined.
5. Appoint a group comprised of a representative from each of the partner agencies or designate one of the five interagency partners (perhaps on an annual rotating basis) as a lead entity for plan oversight, coordination, and administration.

3.3.2 Recent broadening of focus in the Greater Yellowstone Area

Recent events and perspectives have shifted the focus to the broader scale of the entire GYA and the dynamic issues and risks presented by both brucellosis-infected elk and bison in the ecosystem.

3.3.2.1 Cases of brucellosis in cattle transmitted from wild elk

In the GYA, the potential transmission risk of *B. abortus* from wildlife to cattle has focused primarily on bison from Yellowstone National Park because the concern had been that infected bison posed the greatest risk of transmitting disease to livestock. However, confirmed cases of brucellosis in cattle in Wyoming and Idaho and the resultant loss of brucellosis Class Free status in 2004 and 2006, respectively (Table 1) directed attention to elk as a source of disease transmission - these cases had a stronger association to wild elk than to free-ranging bison (Wyoming Brucellosis Coordination Team 2005, T. Roffe pers. comm.). (Wyoming and Idaho regained Class Free status in 2006 and 2007, respectively.) Montana lost its Class Free status in 2008 because two infected cattle herds were found within a two-year period; infected free-ranging elk were thought to be the most likely source of infection (Donch and Gertonson 2009, MDOL 2008). (Montana subsequently regained Class Free status in July 2009 (Table 1).) In sum, these occurrences have increased the management concern regarding the role and importance of free-ranging elk as a greater risk (compared to bison) for transmitting brucellosis to cattle.

In response to the loss of its Class Free status, the Montana Department of Livestock formed a working group that included producers, veterinarians, market operators, and industry organizations, and developed a Brucellosis Action Plan that was implemented in May 2009 (MDOL 2009). Consistent with the principles of zoning and compartmentalization as defined by the Office International des Epizooties (OIE/ World Organization for Animal Health), the plan effectively partitioned Montana into two areas to mitigate and manage potential risk of brucellosis in cattle: Area 1 was considered a special focus area and comprised the seven counties that were adjacent to the north and northwest boundary of YNP and where existing ranching operations shared a common landscape with brucellosis-exposed elk or bison; and Area 2 was comprised of the remaining counties in Montana. A series of required and recommended best management practices were determined for each Area according to four general criteria including:

1. Disease testing (entire herd testing, movement testing, change of ownership / cull cattle testing, aborted fetus testing, and syndromic testing);
2. Vaccination (official calfhood vaccination and adult vaccination);
3. Fencing (game-proof fencing of feed storage areas); and
4. Animal identification and traceability (individual animal identification tags/chips).

From the national agricultural perspective, the USDA's Animal and Plant Health Inspection Service recently released a concept paper describing a new direction for the bovine brucellosis program (USDA 2009). The paper, which is currently available for public review and comment, outlines APHIS's plan to modernize and adapt its national brucellosis program to the current challenges it faces in eradicating the disease from the national cattle herd. It focuses specifically on the ongoing challenges presented by potential disease transmission from wild bison and elk in the GYA, and calls for continued and renewed collaborations with wildlife agencies. Four potential strategies are highlighted:

1. Partnering with State and Federal wildlife agencies to conduct wildlife surveillance in areas with brucellosis-affected livestock;
2. Establishing minimum requirements for a brucellosis mitigation plan that targets wildlife surveillance as part of a comprehensive, national surveillance plan;
3. Developing on-farm mitigations to control disease-transmission risks between wildlife and livestock and to evaluate their effectiveness; and
4. Supporting research to find tools (e.g., vaccination and contraceptives) and strategies (e.g., habitat management) to reduce prevalence of brucellosis in wildlife and implementing those strategies, as appropriate.

3.3.2.2 Collective history of brucellosis research and management builds capacity

Greater Yellowstone Interagency Brucellosis Committee

The single-most important initiative that engendered collaborative capacity to address brucellosis issues in the GYA was the formal creation of the Greater Yellowstone Interagency Committee – GYIBC[12] (Geringer *et al.* 1995, Petera *et al.* 1997). The GYIBC was the natural evolution of the need for multiple state

[12] http://www.gyibc.com

and federal government agencies to formally establish a common goal, mission, and objectives (MOU; Geringer *et al.* 1995) so that agencies could work together and dedicate resources towards management and research initiatives on brucellosis in elk and bison in the GYA. From the outset, the MOU recognized and defined the ecosystem-scale problems that brucellosis infected elk and bison presented to state and federal governments. Consequently, the GYIBC created a strong foundation and collective capacity from which to address ongoing challenges of the brucellosis issue, and initiated two national symposia on brucellosis in the GYA (Thorne et al. 1997, Kreeger 2002).

Strategic planning undertaken by the GYIBC also maintained broader obligations of member agencies to enhance respective brucellosis research and elk and bison management activities. In addition to the directed focus on bison in YNP through the IBMP, substantial field research and management planning has been undertaken by Idaho, Wyoming, and Montana to address the uncertainties and challenges related to brucellosis in elk[13].

Based on the occurrence of brucellosis in cattle herds adjacent to YNP and the likely role of wild elk in transmitting the disease, Idaho, Wyoming and Montana initiated and continue to implement elk-brucellosis management plans. The Idaho Brucellosis Management Plan has three main objectives which include: 1) managing elk populations according to carrying capacity of natural habitat conditions and providing for a sustainable harvest; 2) monitoring elk and livestock for exposure to and/or infection with brucellosis and reduce prevalence in elk to background levels; and 3) ensuring adequate areas of high quality winter/spring range necessary to support elk and to maintain separation between elk and cattle during periods of high risk (Mamer 2004). The Wyoming Brucellosis-Feedground-Habitat program was aimed at reducing the prevalence of brucellosis in elk, and included trapping, testing, and vaccinating animals captured at state feedgrounds and improving elk habitat (Kreeger 2004). Montana also developed an Elk-Brucellosis Management Plan for addressing brucellosis in elk within the Montana portion of the GYA. The major activities included continued serological surveillance of three elk management units, combined with strategic sampling of hunter-killed elk in various management units (Aune 2004).

In 2003, the GYIBC Executive Committee initiated a review of the original MOU and recommended revisions to more aggressively address elimination of brucellosis from the GYA and to formally include Tribal representation through the Inter-Tribal Bison Cooperative (Thorne 2004). By 2006, revisions were added that focused on efforts to eliminate brucellosis from bison and elk, including:

- Necessary agency development of adaptive management disease elimination plans for each affected bison or elk herd unit or population;
- Establishment of measures to evaluate incremental progress in disease elimination efforts; and
- Timelines for plan development and progress evaluation (Moon *et al.* 2006)

[13] For example, see a list of "Recent and Current Research and Projects Pertinent to GYIBC", Online [URL]: http://www.gyibc.com/Reference_Material/research.htm Accessed 28 Oct 2009.

By 2007, the revisions had been accepted by the USDA and USDI and the draft MOU had been forwarded to the Governors of Idaho, Montana, and Wyoming (Donch *et al.* 2008). Although the current status of GYIBC MOU is undetermined, its collaborative legacy appears to have been taken on by the United States Animal Health Association's (USAHA) Committee on Brucellosis which has presented at least four formal resolutions urging federal and state agencies to renew collaboration, funding, and policy reviews in addressing the elk-bison-cattle brucellosis issue in the GYA[14]. The USAHA Committee on Brucellosis has also hosted an international symposium on enhancing brucellosis vaccines, vaccine delivery, and surveillance diagnostics for elk and bison in the GYA (USAHA 2006).

Brucellosis in elk and bison - the southern Greater Yellowstone Area

As described in Sections 3.1 and 3.2, the maintenance of brucellosis in bison and elk in the southern part of the GYA[15] has contributed to the overall risk and occurrence of *B. abortus* spilling back to cattle. In the 1990s, the impetus for disease management in the southern GYA had focused initially on the brucellosis-infected Jackson bison herd. In 1996, the National Park Service and US Fish and Wildlife Service drafted a management plan and environmental assessment that recommended public hunting on the NER and National Forest lands to control the size of the Jackson bison herd. However, a lawsuit in 1998 by the Fund for Animals challenged the destructive management of bison; the lawsuit was successful and prevented implementation of the plan (USDI 2007a). Starting in 1999, subsequent consultation and management planning was expanded to include all aspects of elk and bison management in the NER and Grand Teton National Park. In 2005, a Draft Bison and Elk Management Plan and Environmental Impact Statement was released for public comment; in April 2007, a Record of Decision on the Jackson Bison and Elk Management Plan and Environmental Impact Statement was completed (USDI 2007b).

The Record of Decision selected Alternative 4 for bison and elk management, as it set out to "*adaptively manage habitat and populations to achieve desired conditions over 15 years*" and provided the best opportunity to achieve the following management goals:

- Habitat conservation – provide secure, sustainable ungulate grazing habitat that is primarily of native composition and structure;
- Sustainable populations – contribute to the establishment of healthy elk and bison populations that are resilient to changing environmental conditions;
- Numbers of elk and bison – contribute to Wyoming Game and Fish Department's herd objectives for the Jackson elk and bison herds; and
- Disease management – work cooperatively with Wyoming and others to reduce prevalence of brucellosis in elk and bison order to protect the economic viability of livestock industry.

14 see USAHA Resolutions 30, 34, 73, and 22 Online [URL]: http://www.usaha.org/committees/bru/bru.shtml Accessed 28 Oct 2009.

15 The southern GYA generally comprises Grand Teton National Park / John D. Rockefeller, Jr., Memorial Parkway, the National Elk Refuge, and associated national forests and adjacent state and private lands (see map on p. 5 of USDI 2007a and GYIBC website – Online[URL]: http://www.gyibc.com/images/great_yell_area.jpg Accessed 30 October 2009).

Among other recommendations, the approved management plan called for development of a dynamic and collaborative framework for decreasing the need for supplemental feeding and would establish hunting of bison and elk as a management tool on the National Elk Refuge.

Concomitant with the final stages of the Grand Teton National Park and National Elk Refuge management plan, the Wyoming Game and Fish Department developed a series of best management practices for reducing the risk of disease transmission between brucellosis infected elk and bison and cattle (WBCT 2005; and see Section 5.1), and developed Brucellosis Management Action Plans (BMAP) with specific management strategies for the Jackson bison herd (WGFD 2008) and each elk herd in the Jackson-Pinedale Region (Dean *et al.* 2004, WGFD 2006a, 2006b, 2006c, 2006d, 2007a, 2007b, 2007c). The objectives for the BMAPs were to:

- Document and analyze all available quantitative and qualitative data regarding brucellosis in a herd unit;
- Use available data to develop management actions to reduce risk of brucellosis transmission among bison and from bison to cattle;
- Select appropriate management actions for implementation.
- As there do not appear to be clear and consistent linkages between the WGFD's herd-specific brucellosis management plans for elk and bison and the USDI's (2007a) final management plan and environmental impact assessments, there is an important opportunity to align the federal and state management strategies and actions.

4. THE GREATER WOOD BUFFALO NATIONAL PARK AREA (GWBA)

Wood Buffalo National Park (WBNP) occurs within the boreal forest of northern Alberta and the adjacent Northwest Territories (Figure 1) and is Canada's largest national park (44,807 km^2); it was designated as a UNESCO (United Nations Educational, Scientific, and Cultural Organization) World Heritage Site in 1983. WBNP occurs mostly within the Northern Boreal Plains natural region but also includes representative areas of the Southern Boreal Plains and Northwestern Boreal Uplands. The park is characterized by a mosaic of muskeg, meandering streams, shallow lakes and bogs, and boreal forest. WBNP encompasses the Peace-Athabasca Delta, a large freshwater inland delta which provides wetland habitat for migratory waterfowl and expansive grass and sedge meadows for bison.

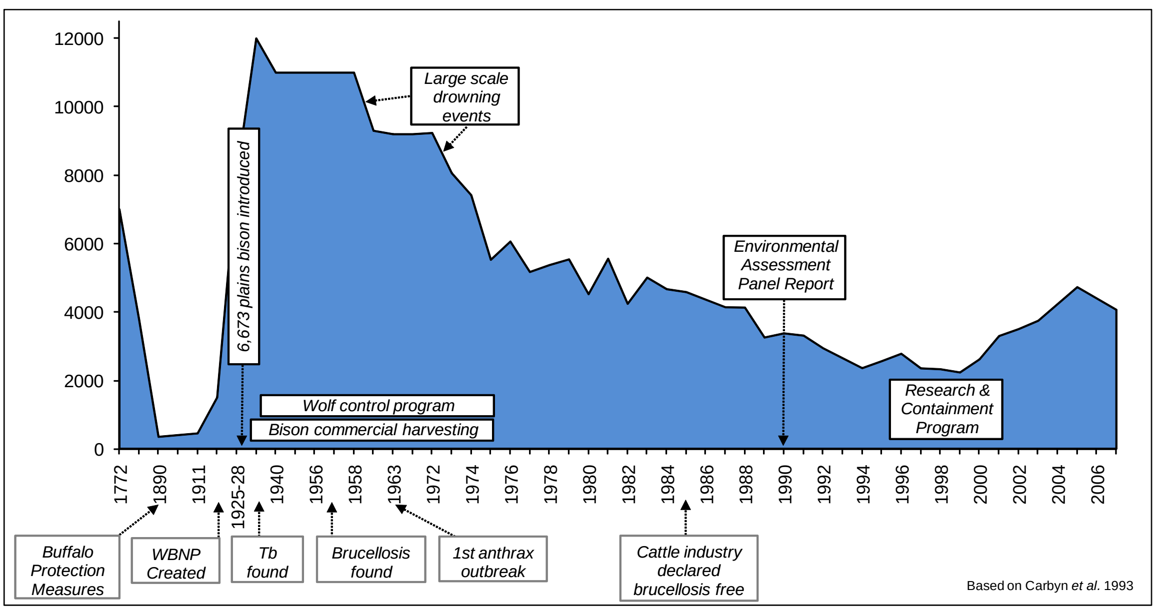
4.1 Greater Wood Buffalo bison

In the late 1890s, only 150 to 500 wood bison (*B.b. athabascae*) remained in northern Canada (Preble 1908, Soper 1941, Gates *et al.* 1994). In 1922, WBNP was created to protect the remaining wood bison, which by that time had increased to *ca*. 1500 animals (Carbyn *et al.* 1993), from further decline and possible extinction (Ogilvie 1979). However, due to an overabundance of plains bison (*B. b. bison*) at the newly created Buffalo National Park near Wainwright in east-central Alberta, the Government of Canada translocated 6600 bison by rail and barge to the southern part of WBNP between 1925 and 1928 (Ogilvie 1979, Carbyn *et al.* 1993, MacEwan 1995, Sandlos 2002, Fuller 2002, Reynolds *et al.* 2003, Brower 2008). The translocation resulted in the irreversible introgression of plains bison genes into the indigenous wood bison population (Wilson and Strobeck 1999).

Unfortunately, the Buffalo National Park herd had been infected with tuberculosis and brucellosis, and despite the selection of primarily subadult animals for shipment, the translocation introduced the bovine diseases into WBNP (Fuller 1962, Carbyn *et al.* 1993, Fuller 2002). Tuberculosis was first recognized in a single WBNP bison in 1937 and in another in 1946 (Connelly *et al.* 1990). Brucellosis was first noted in 1956 (Fuller 1966). Both diseases have maintained enzootic proportions in WBNP bison and are unlikely to disappear without management intervention; Joly and Messier's (2004a) recent data on WBNP bison showed overall apparent prevalence rates of 31% and 45% for brucellosis and tuberculosis, respectively, which is consistent with prevalence data from Tessaro (1988) on bison tested between 1983 and 1985.

Following the introduction of plains bison to WBNP, the population increased rapidly and by 1934 there were *ca.* 12,000 bison in the park. Bison numbers remained between 10,000 and 12,000 over the next 20 years (Figure 3) (Carbyn *et al.* 1993). However, drowning events due to spring floods in 1958 to 1961 and 1974 were followed by a long term population decline for the next 20 years. From 1972 to 1999, the population declined from *ca.* 9200 to 2200 animals for an average rate of decline of 5% per year. The combined effect of wolf predation and disease (*ie.*, bovine brucellosis and tuberculosis) is hypothesized to have played a key role in the decline and persistent low densities of bison in WBNP (Gates 1993, Messier and Blyth 1996, Joly and Messier 2005, and see Peterson 1991, McCormack 1992, Carbyn *et al.* 1993, Bradley and Wilmshurst 2005, Heisey *et al.*2006). The population has since increased to *ca.* 4700 in 2005, while a recent estimate in winter 2007 was *ca.* 4100 animals (R. Kindopp. pers. comm.) (Figure 3).

Figure 3. Trend of bison abundance within Wood Buffalo National Park and summary of key events, 1772-2007 (bison population data source: R. Kindopp, WBNP).



The greater WBNP bison metapopulation consists of populations within WBNP but also includes bison in adjacent areas in the Northwest Territories and northern Alberta. Based on cluster analysis of spatial data from radio-collared bison, Joly (2001) showed that there were five populations of bison within WBNP – Nyarling River (northwest), Little Buffalo (northeast), Hay Camp (east-central), Garden River (southwest) and Delta (southeast). The range of the Little Buffalo population extends outside of WBNP and into the Slave River Lowlands (Northwest Territories) in the area west of the Slave River. The Hook Lake bison population also ranges within the Slave River Lowlands, but occurs on the east side of the Slave River (see Reynolds and Hawley 1987), although the Hook Lake and Little Buffalo populations are demographically linked. In northern Alberta outside of WBNP, local people indicate that bison still occupy areas including the Wabasca and Mikkwa Lowlands, Wentzel River area, Talbot Lake, and the Buffalo Head Hills (Mitchell and Gates 2002). These bison are likely small 'sink' populations with fewer than 50-100 animals and there are virtually no empirical data on population size, distribution, or trends for these herds (Gates *et al.* 2001).

With respect to bison in the Slave River Lowlands (SRL), early accounts indicated that bison occurred in the area during the late 1700s (Hearne 1795). But with the overall decline of wood bison, animals were either extirpated or existed at extremely low density by the early 1900s (Radford in Gates *et al*. 1994). Bison were first observed in the Hook Lake area of the SRL in the 1940s, and were believed to have emigrated out of WBNP (Fuller 1950). The Slave River Reserve was established to protect the bison (Bison Disease Task Force 1988) and the population increased from *ca*. 200 in 1949 (Fuller 1950) to 1700 animals in 1971 (Rippin 1971). In 1955, Slave River Reserve status was removed and hunting was allowed for aboriginals and Northwest Territories residents.

Between 1959 and 1961, there were two big game outfitters operating in the Hook Lake area. In 1962, all resident and non-resident hunts for bison were stopped in the Hook Lake area due to public health concerns following an anthrax outbreak (Bison Disease Task Force 1988). In 1968, after several years without an anthrax outbreak, a quota of 25 bison was established for resident hunters. In 1970, another licensed outfitter was allocated 25 tags for sport hunts in the Hook Lake area (Bison Disease Task Force 1988). Van Camp (1987) estimated that an average of 179 bison per year was hunted in the SRL between 1969 and 1974.

Since 1974, the Hook Lake herd has been declining, and since 1977 the herd has fluctuated at low densities between 200 and 500 animals (Van Camp and Calef 1987). Surveys in 2002 and 2006 (Government of the Northwest Territories unpublished data) in the Hook Lake area documented 600 and 500 animals, respectively. Key factors that have been implicated for the decline and continuous low density of bison in the Hook Lake area are hunting, brucellosis and tuberculosis, wolf predation, and habitat succession (Reynolds and Hawley 1987, Chowns et al 1998). Previous data from SRL bison showed prevalence rates of 22% for tuberculosis (based on a collection of 280 bison in 1964 and 1965) and 38% for brucellosis (based on a sample of 299 bison in 1970 and 1974) (Broughton 1987). Currently, hunting for bison by residents and non-residents is restricted, whereas hunting by aboriginal people is unrestricted, although the average annual hunt by aboriginals is estimated at *ca*. 20-30 animals.

4.2 Disease management in the Greater Wood Buffalo area – brucellosis and tuberculosis

The diseased bison issue in the greater Wood Buffalo National Park area is one of the most long-standing and contentious wildlife management issues in Canada, involving a wide spectrum of stakeholders including the Federal Government, the governments of Alberta and the Northwest Territories, aboriginal communities, livestock producers, and environmental non-governmental organizations. Management progress has been hindered by inconsistent consultation and communication between stakeholders, and overall lack of a long-term management process. Nishi *et al.* (2006) reviewed the various management and/or research oriented processes spanning from the late 1980s to 2005; in the remainder of this section, more recent activities are expanded upon to complete the overview.

Similar to the GYA, the livestock industry has had an important influence on the northern diseased bison issue. Canada began programs to eradicate tuberculosis and brucellosis from domestic livestock in 1907 and 1923, respectively (Connelly et al. 1990, Essey and Koller 1994, Kellar and Doré 1998). In 1985, Canada was declared free of brucellosis in domestic animals (see Kellar and Doré 1998), but continues to have cases of tuberculosis in farmed cervids and sporadic cases in cattle (Rothwell 2000, Koller-Jones et al. 2006). Bison in and around Wood Buffalo National Park remain the primary nidus of brucellosis in Canada (Tessaro et al. 1990), while WBNP bison and wild cervids (wapiti and deer) in Riding Mountain National Park in Manitoba (Lees 2004, Lees et al. 2003) are the wildlife reservoirs for tuberculosis (see Nishi et al. 2006).

The first comprehensive evaluation for managing diseased bison in and around WBNP occurred in 1985 (Carbyn *et al.* 1993). The concern stemmed primarily from the risk of the diseases 'spilling back' (*sensu* Daszak *et al.* 2000) into domestic cattle herds in the area outside of the park, but also from the risk of disease transmission to other free-ranging bison, *ie*., the Mackenzie bison population in the Northwest Territories. In 1988, a Federal Environmental Assessment Panel examined solutions to the northern diseased bison issue and recommended that the best option was to eradicate all free-ranging bison in and around WBNP, and replace them with what were considered to be healthy (and genetically pure) wood bison from Elk Island National Park and the Mackenzie bison herd (Connelly *et al.* 1990). The recommendation was met with widespread public opposition, largely from the local aboriginal/First Nations communities and non-governmental environmental organizations, based on concerns that the proposal would result in a loss of genetic diversity and possible impairment of ecosystem integrity (see Gates *et al.* 1997, Peterson 1991, McCormack 1992).

In the early 1990s, in response to calls for increased local First Nation involvement in management, a Northern Buffalo Management Board was formed. The board included representatives of Treaty 8 Dene Bands in the WBNP area, and government and non-government organizations, and was tasked with developing a management plan for diseased bison. After 18 months of intense, fractious, and often political deliberations (Gates *et al.* 1997), the board concluded that significant information gaps existed in the epidemiology of bovine tuberculosis and brucellosis, the ecological impact of the diseases, and the possible effects of management action on the ecosystem. It recommended that a 3-year, CAD$18 million research program be conducted before any management plan was developed (NBMB 1992). Subsequent funding from the Government of Canada was not forthcoming and the board was dissolved.

In 1996, the Canadian Bison Association (CBA) requested that the Minister of Agriculture and Agri-Food Canada conduct a risk assessment on the potential spread of bovine tuberculosis and brucellosis from bison in and around Wood Buffalo National Park. The CBA was concerned about a translocation of 100 captive bison from a ranch near Fort Resolution, NT, to north central Alberta. Although the herd in question was tested under the requirements of the Captive Ungulate Policy and had received the necessary permits, the CBA maintained that bison (both captive and free-ranging) had a higher risk of exposure than cattle and were concerned about implications for domestic and international markets. The objective of the assessment was to determine the risk of infection with tuberculosis and/or brucellosis from bison in WBNP and surrounding areas during a 12-month period for three "at risk" groups: commercial cattle, commercial captive bison, and free-ranging bison. The assessment concluded that the risk to the cattle industry and commercial captive bison herds was low while the risk to free-ranging bison was much higher. Assuming that the geographic distribution and size of free-ranging bison herds was constant, the risk assessment concluded that, on average, the introduction of infection to wild healthy bison herds would occur no more frequently than once every eight years for brucellosis and once every six years for tuberculosis (APFRAN 1999).

In 1996, the federal Parks Canada Agency initiated a 5-year Bison Research and Containment Program which supported ongoing winter surveillance of a bison control area in the Northwest Territories, and funded field research on disease prevalence, population-level effects of disease, and a landscape-level assessment of bison movements. The objectives of the program were to conduct interim risk management actions and complete additional research that would be used to develop a management plan for diseased bison in and around WBNP. The program established a Research and Advisory Committee (RAC) - a multi-stakeholder group with representatives for local aboriginal interests, environmentalist viewpoints, as well as veterinary and wildlife management perspectives. The importance of incorporating and interpreting "traditional knowledge" was recognized and half the RAC members were from aboriginal communities in and around WBNP. Remaining seats were held by the governments of Alberta and the Northwest Territories, a representative from an environmental non-governmental organization, and a scientific advisor (who was also a member of the Greater Yellowstone Interagency Brucellosis Committee). Through the RAC, two important research projects were completed: the first was on disease ecology and epidemiology of WBNP bison (Joly and Messier 2004a, Joly and Messier 2004b, Joly and Messier 2005) and the second was on bison movement patterns (Gates *et al.* 2001a, Gates and Wierchowski 2003). The research by Gates et al. (2001a, 2003) was intended to inform and update the APFRAN (1999) risk assessment. Despite specific recommendations to complete additional research projects under its original mandate, the RAC was dissolved and the Bison Research and Containment Program was discontinued in 2001.

In 1996, the Hook Lake Wood Bison Recovery Project was initiated by the community of Fort Resolution and the Government of the Northwest Territories as a pilot project to demonstrate feasibility of genetic salvage from bison herds known to be infected with tuberculosis and brucellosis (Gates *et al.* 1998, Nishi *et al.* 2002a, Wilson *et al.* 2005, Nishi *et al.* 2006.) Unfortunately, in 2005, tuberculosis was discovered in the herd (Lutze-Wallace *et al.* 2006, Himsworth *et al.* in prep 'a', Himsworth *et al.* in prep 'b') and despite efforts to conduct a secondary salvage, the captive herd was depopulated in 2006.

Following termination of the Bison Research and Containment Program, and in response to concerns over lack of a management process, the Canadian Bison Association requested follow-up actions from the Federal Government (Matthews 2001, Conacher 2002). In 2001, a Federal Interdepartmental Steering Committee was created and delegated with advancing a consistent vision on management of diseased bison. An Intergovernmental Working Group was also formed with representatives from Federal Government departments and the governments of Alberta and the Northwest Territories. This group was charged with engaging stakeholders at a regional level and to develop a multi-stakeholder consultation and management process. However, the process was short lived, lasting just over a year. A shift in emphasis by the federal government toward developing a National Wildlife Disease Strategy (Environment Canada 2004) and the diagnosis of bovine spongiform encephalopathy in the Canadian cattle herd in May of 2003 contributed to the dissolution of the federal committee.

Ongoing concerns from the Government of Alberta and dialogue with senior managers in Parks Canada resulted in the formation of an Interim Measures Technical Committee (2003-2004), whose objective was to develop an interim risk management strategy for northern Alberta and the adjacent areas of WBNP. Despite completion of a final report (Interim Measures Technical Committee 2004), the recommended management actions were not discussed further with stakeholders, nor were the recommendations implemented.

In 2005, an international workshop was convened by the Parks Canada Agency and Canadian Wildlife Service to evaluate the technical feasibility of depopulation of diseased bison followed by repopulation with healthy wood bison. The workshop participants concluded that eradication of bovine tuberculosis and brucellosis through depopulation followed by repopulating bison in the Wood Buffalo region was technically feasible (Shury *et al.* 2006). Also in 2005, a small inter-agency subcommittee of the Canadian Wildlife Directors' Committee was tasked with developing a strategic path forward on the diseased bison issue. Once completed and approved, the strategy would be advanced to the Ministers for final approval. An objective was to use the

National Wildlife Disease Strategy (Environment Canada 2004) as a basis for a new diseased bison management strategy. To date there has been little reported progress on this initiative.

In 2008, the Government of Alberta initiated a hunt of the Hay Zama bison herd in northwestern Alberta – a conservation herd which was established in 1984 with the translocation of 29 wood bison from Elk Island National Park that has grown to 700 animals (Gates *et al.* 2001b). The herd was established as a collaborative effort of the Alberta Fish and Wildlife Division, Canadian Wildlife Service, and the Dene Tha' First Nation. The objectives for initiating the 2008/2009 hunt were to assess the disease status of the herd, address public safety concerns related to bison-vehicle collisions, and reduce herd size to *ca*. 400-500 animals (Government of Alberta 2008). It is anticipated that these actions will continue because the Government of Alberta has established population management objectives for herd size and distribution to reduce the risk of disease transmission from bison in and around WBNP (G. Hamilton pers. comm.).

The current focus of government wildlife conservation and management agencies in Canada is the completion and formal approval of a new national recovery strategy for wood bison according to requirements under the federal Species at Risk Act. The main objective of the draft plan is to update and define the criteria for downlisting wood bison from its current official status of "threatened" (COSEWIC 2000). In the previous version of the National Recovery Plan, bison herds in and around WBNP that were infected with bovine brucellosis and tuberculosis were considered to be the *"greatest single factor limiting range availability and the potential for further recovery of wood bison in Canada. Eliminating these two bovine diseases from bison herds in the WBNP region would remove the greatest obstacle to the recovery of wood bison in Canada"* (Gates *et al.* 2001). The implication of bovine diseases to the conservation value of infected bison herds has been challenged by the Parks Canada Agency (T. Shury pers. comm.). Consequently, the most controversial aspect of the current planning process for the recovery team has been to determine whether the new recovery strategy should define the presence of the two diseases in bison in and around WBNP as an obstacle to further recovery, or whether the diseased bison will contribute to national recovery objectives and should be included in de-listing criteria (B. Elkin pers. comm.). The issue of whether diseased bison herds represent either a negative or positive contribution to national recovery objectives in Canada is an important distinction that has broad implications for wildlife management agencies in the GWBA. A draft of the new wood bison recovery strategy is currently under review.

5. THE FOCUS ON 'BEST PRACTICES'

In an influential essay on gaining reliable knowledge, Romesburg (1981) argued that wildlife research should be improved through more rigorous application of scientific methodology and increased use of the hypothetical-deductive approach for testing hypotheses. In a similar context for improving wildlife science, Burnham and Anderson (1998), and Anderson *et al.* (2000) advocated use of an information-theoretic paradigm that selected the most appropriate biological model(s), *ie*., hypotheses, from a set of multiple *a priori* candidate models. By emphasizing the need for improved quality of research, Romesburg (1981) and Anderson *et al.* (2000) emphasized a presumed direct relationship between reliable wildlife science and our collective ability to resolve wildlife management issues. Indeed, wildlife management challenges are key drivers for how we prioritize and fund wildlife research.

The linkage between decision making in management issues and a reliable knowledge base is not exclusive to wildlife management, but is a fundamental relationship spanning across all aspects of human endeavor. The need for repeatable methods, approaches and techniques to address real world issues has resulted in the development of what are known as 'best management practices' or 'best practices' throughout a wide spectrum of disciplines. There are numerous discipline- or industry-specific definitions of best practices, but the following best captures the concept:

> *"Best practice is an idea that asserts that there is a technique, method, process, activity, incentive or reward that is more effective at delivering a particular outcome than any other technique, method, process, etc. The idea is that with proper processes, checks, and testing, a desired outcome can be delivered with fewer problems and unforeseen complication. Best practices can also be defined as the most efficient (requiring the least amount of effort) and effective (achieving the best results) way of accomplishing a task, based on repeatable procedures that have proven themselves over time for large numbers of people or organizations"* (Wikipedia 2009).

As an example of best practices, the medical profession has been developing and refining 'evidence-based practice'[16] as a new way of explicitly incorporating scientific evidence from published clinical research into the minds and hands of medical practitioners (Guyatt 1992). The development of 'evidence-based practice' has continued to evolve in the medical field (Sackett *et al.* 1996, Glasziou and Haynes 2005, Scott 2007) and has subsequently been implemented in veterinary medicine (Keene 2000, Shaw 2001, Everitt 2008). The lessons and principles of evidence-based practice have also been applied to wildlife conservation issues (Pullin and Knight 2001, Pullin and Knight 2003) and reinforce the assertion that decisions in wildlife management "*should be based on effectiveness of actions in achieving the objectives as demonstrated by scientific experiment*" (Pullin *et al.* 2004). Similarly with respect to wildlife disease management, Delahay *et al.* (2009) suggest that new approaches are needed because past efforts to manage wildlife diseases were often *"characterized by reactive, unsustainable, and ill-informed interventions that ignored the fundamental importance of the ecology of hosts, pathogens and vectors, and have been out of step with the global imperative to conserve biodiversity."*

5.1 "Best practices" in the GYA

In the GYA, there are many examples of ongoing research that have been undertaken to improve science and develop reliable techniques for addressing brucellosis management issues. Notwithstanding numerous contributions to the scientific literature (examples include Thorne *et al.* 1978b, Morton and Thorne 1981, Davis *et al.* 1990, Peterson *et al.* 1991, Williams *et al.* 1993, Rhyan *et al.* 1994, Meyer and Meagher 1995, Dobson and Meagher 1996, Robison *et al.* 1998, Roffe *et al.* 1999a, Roffe *et al.* 1999b, Cook *et al.* 2000, Rhyan *et al.* 2001, Davis and Elzer 2002, Ferrari and Garrott 2002, Kreeger *et al.* 2002, Olsen and Holland 2003, Olsen *et al.* 2003, Van Houten *et al.* 2003, Cook *et al.* 2004, Bienen and Tabor 2006, Cross *et al.* 2007, Fuller *et al.* 2007a, , Kilpatrick *et al.* 2009, Maichak *et al.* 2009, Garrott *et al.* 2009a, Olsen *et al.* 2009), some specific examples of research for development of best practices in disease management are summarized as follows:

- A review by Cheville *et al.* (1999) provides a strong basis for understanding the current technical challenges of brucellosis management in Yellowstone wildlife.
- Ongoing advances in applied research highlighted by various conferences and meetings (see Kreeger 2003, USAHA 2003, USAHA 2004, USAHA 2005a, USAHA 2005b, USAHA 2007, USAHA 2008, USAHA 2009) reflect the national and international profile and level of funding and effort that has been directed towards improving field techniques for managing brucellosis.
- Assessments and records of decision in formal environmental assessment and management planning processes (and associated reviews) have outlined science-based recommendations for management action (Clark 2000, USIECR, UWIENR and MI 2000, USDI and USDA 2000, USDI,2007a, USGAO 2008).

[16] "Evidence based medicine is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients. The practice of evidence based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research. By individual clinical expertise we mean the proficiency and judgment that individual clinicians acquire through clinical experience and clinical practice" (Sackett *et al.* 1996).

- Bison quarantine facilities and procedures have been developed and approved for capture, testing, and translocation of brucellosis-exposed bison from the GYA (USDA 2003, MFWP and APHIS 2005, MFWP and APHIS 2006, MFWP 2009).
- A quantitative risk assessment on the transmission of *B. abortus* from bison to cattle used available ecological and epidemiological data to estimate likelihood of disease transmission in the northern GYA (Kilpatrick *et al.* 2009). The results suggested two management options for further consideration: zonation of an area within Montana for enhanced brucellosis surveillance; and cessation of cattle grazing in the areas where bison leave the park in winter with compensation provided to affected ranchers. The analysis also highlighted topics for further research including attraction of cattle to bison calving sites and aborted fetuses, and implications of climate change on disease transmission risk as changing snow depths may affect rates of winter mortality or emigration of bison out of the park.
- There has been focused development of specific field-oriented 'best practices' that reflect strategies and actions to reduce risk of disease transmission from GYA wildlife to livestock in Wyoming (WBCT 2005). Most recently, the Montana Department of Livestock in collaboration with the USDA-APHIS, Montana Fish, Wildlife and Parks (MT FWP) completed the final version of the "State of Montana – Brucellosis Action Plan" (MDOL 2009), which recognized the potential role of elk in transmitting disease to cattle and outlined a list of 12 best management practices to reduce the risk of disease transmission from wildlife to cattle.

5.2 "Best practices" in the GWBA

In the GWBA, the concept of best management practices has received comparatively little attention because there has been less emphasis and continuous collaborative work on developing and implementing overall bison disease management strategies. Management of diseased bison in the GWBA remains a controversial issue with presently no long-term regional collaborative process for government and stakeholder engagement. The conspicuous absence of a long-term regional management strategy and process for northern diseased bison exists despite protracted yet variable and discontinuous attention to the issue over the past 20 years.

Nevertheless, throughout the initiatives outlined in Section 4.2, there have been useful contributions that fit within the rubric of 'best practices'. Some examples of contributions to best practices in the GWBA include:

- Delineation and seasonal monitoring of a bison-free zone in the Northwest Territories since 1987 to reduce the risk of contact between infected and non-infected wild bison populations (Gates *et al.* 1994, Nishi 2002);
- Preliminary advancement of risk assessment techniques for understanding risk of disease transmission from infected wild bison herds and developing risk mitigation strategies (APFRAN 1999, Gates *et al.* 2001a, Gates and Wierchowski 2003, Chen and Morley 2005);

- Advancement in understanding disease prevalence and demographic effects of disease in bison (Joly and Messier 2004b, 2005, and see Bradley and Wilmhurst 2005);
- Preliminary development of assisted reproductive technologies as a means of conserving genetic diversity from infected herds (Thundathil *et al.* 2007, Aurini *et al.* 2008);
- Development and evaluation of diagnostics tests (Gall *et al.* 2000, Himsworth *et al.* in prep. b);
- Development of genetic conservation strategies (Wilson *et al.* 2005, McFarlane *et al.* 2006);
- Preliminary assessment of the technical feasibility of disease elimination in WBNP (Shury *et al.* 2006); and
- Reduction in size and disease testing of the Hay Zama wood bison herd in northwestern Alberta to confirm health status, *i.e.,* absence of bovine tuberculosis and brucellosis, and reduce the risk of contact with infected animals from WBNP (Government of Alberta 2008, G. Hamilton pers. comm.).

5.3 Summary of "best practices"

Best management practices can be developed through an adaptive process or one based more on trial and error, but the underlying intent is to develop effective practices that provide repeatable outcomes under a range of conditions. The underlying objectives of the various applied research and management programs in the GYA and GWBA are tied to the development and refinement of new techniques and improved management practices.

The work by the Wyoming State Governor's Brucellosis Coordination Team (BCT 2005) is an example of the recent focus on development of specific best practices related to brucellosis in wildlife within the GYA. The Governor of Wyoming requested that the BCT develop a suite of best management practices (including actions, responsibilities, and timetables where appropriate) by addressing four focal topics:

1. Reclaiming Class Free brucellosis status for cattle, surveillance, and transmission between species;
2. Developing an action plan in the event of a new case of brucellosis in cattle;
3. Addressing human health concerns; and
4. Reducing, and eventually eliminating brucellosis in wildlife, specifically addressing winter elk feedgrounds.

Best practices for infected wildlife focused on activities designed to reduce the overall prevalence of disease, hence the specific consideration of winter elk feedgrounds (BCT 2005). For cattle, the focus was on achieving eradication objectives as set out by the Cooperative State-Federal National Brucellosis

Eradication Program and on preventing the transmission of *B. abortus* from wildlife to cattle. Consequently, the best practices recommended by the BCT for cattle were tied to enhanced surveillance and planning and coordination in the event of another disease transmission event.

A second example of development of specific best practices comes from the recent Brucellosis Action Plan developed by the State of Montana (MDOL 2009). The plan is comprehensive and focused largely on the livestock industry and best practices associated with reducing co-mingling between wild elk and cattle, as well as a series of recommendations for cattle husbandry including vaccination, health monitoring, sampling, and adherence to regulations (Appendix D in MDOL 2009).

As the above two examples show, best practices are often designed to address operational and tactical scale details that have a narrow focus specific to a geographic location, field program, or research protocol. From a wildlife disease perspective of the broader GYA and GWBA, a weakness of best practices is that the recommended actions often address symptoms but do not well address the underlying problems.

One approach for improving the reliability of best practices is to develop and apply them within a broader context of monitoring and other activities associated with a defined, goal-oriented disease management process. For example, Figure 4 shows how monitoring, surveillance, and other activities may change as the focus of disease management objectives shifts from doing nothing (*laissez-faire)*, to prevention, control, or eradication of disease within a population. By placing best practices within the context of a disease management process, the expected effect of a best practice can be compared to its observed performance, which can then lead to selection of the most reliable and effective best practices.

The best practices recommended by the Wyoming Brucellosis Coordination Team (BCT 2005) and the State of Montana (MDOL 2009), along with other research and management activities in the GYA and GWBA (Sections 5.1 and 5.2) can be summarized into the following broad categories (consistent with Figure 4):

Passive and active monitoring

- Enhance veterinary support; coordinate veterinary services at federal and state/provincial levels; monitor disease prevalence of free-ranging populations through field sampling protocols and engagement of hunters to assist with field sampling;

Surveillance

- Improve methodologies and diagnostic tests for disease detection; develop new regulatory rules; report and investigate cattle and wildlife abortions (symptoms of brucellosis);

Education, training, and consultation

- Public consultation: conduct public meetings in the event of a cattle outbreak; develop communication tree and media plan to ensure timely reporting; conduct community meetings as part of ongoing management planning;

- Education and training: develop, implement and distribute an education plan; facilitate interagency collaboration; engage and train community members and hunters in supervised and unsupervised field collections;

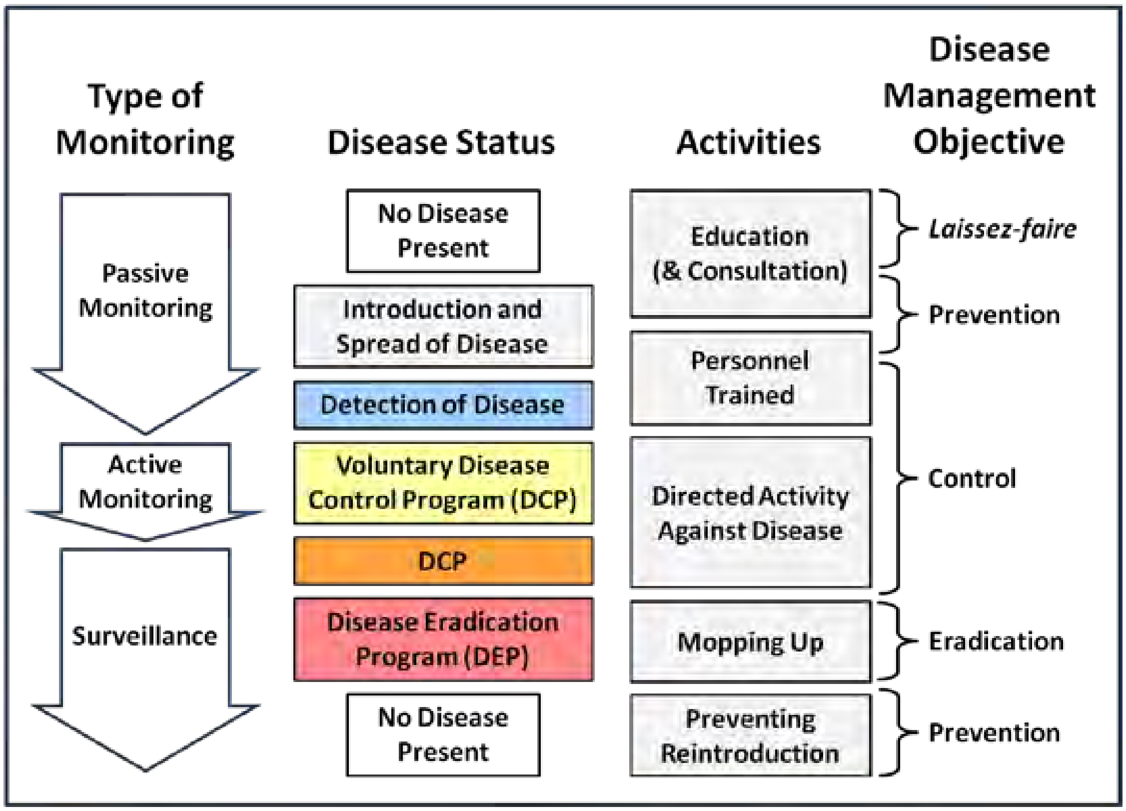
Directed activities against disease

- Response planning: apply formal methods and rules for disease management in livestock herds; clarify roles and responsibilities of agency staff in the event of a new case in cattle; create regulatory decision groups to confirm reactor cases; administer epidemiological tracebacks, conduct and interpret herd tests.
- Bio-safety and human health: develop appropriate protocols and preventative techniques to minimize exposure of people considered to be at high risk (ranchers, veterinarians, hunters, lab workers, abattoir staff)
- Field trials and experiments: develop and validate new treatments (vaccine efficiency, vaccine delivery methods); explore elk feedground management strategies; develop assisted reproductive technologies to salvage genetic diversity from infected populations.
- Quarantine protocols: conduct research and field trials to salvage bison from infected/exposed populations.

Mopping up and preventing reintroduction

- Risk management: undertake cooperative work with producers to minimize spatial and temporal overlap between cattle, bison and elk; haze wild elk (and bison) away from cattle feed storage areas; use fences to exclude wildlife from hay storage yards; delay grazing by cattle on public lands until well past calving season; establish bison-free areas to reduce risk of disease transmission from infected to naïve populations; manage distribution and population size of free-ranging populations.
- Habitat enhancement and habitat acquisition to reduce reliance on winter elk feeding grounds.

Figure 4. A visual model that describes the monitoring and activities associated with a disease control or eradication process from introduction of disease to eradication (adapted from Christensen 2001 and Salman *et al.* 2003). Corresponding disease management strategies as defined by Wobeser 2002 are shown on the right hand side.



The purpose of this section is not to review every recommended best practice in detail but rather to suggest that the epidemiological context behind development and execution of best practices should occur within an explicit disease management framework with clearly defined objectives, so that criteria for success can be defined and evaluated. If this is not done well, the alternative may become a laundry list of best practices that are generically defined and implemented in an *ad hoc* fashion with the overall outcome being reduced effectiveness and efficiency, and little opportunity to learn and evaluate. The use of causal diagrams (Greenland 1999) and general risk analysis approaches provide examples by which best practices could be placed within an appropriate disease management context that facilitates learning and evaluation.

5.4 Application of risk analysis

The World Organization for Animal Health (OIE) establishes recommendations and guidelines for the regulation of trade in animals and products of animal origin. The World Trade Organization (WTO) establishes international trade rules and its Sanitary and Phytosanitary (SPS) Agreement recognizes the OIE as the leading international standard-setter for animal health and animal diseases that are transmissible to humans (zoonoses). The SPS agreement (to which both the United States and Canada are signatories) outlines international guidelines and provisions for member countries to facilitate trade while taking measures to protect the health of humans, animals, and plants (Zepeda *et al.* 2001, 2005).

In cases where there are no specific international standards, or where a member country chooses to apply more restrictive measures on livestock health issues than those outlined by the OIE, the member country has to justify its position through a formal risk analysis (see Box 6). Thus, risk analysis principles and methods have been accepted by the OIE as a scientifically valid and defendable means of establishing policy on animal health (Zepeda *et al.* 2001, Murray *et al.* 2004a and 2004b, OIE 2008). Risk analysis and risk assessments have provided meaningful ways to evaluate and mitigate disease risks in a structured and empirical manner (Vose 2000).

Recent work by the 'Committee on Improving Risk Analysis Approaches Used by the US Environmental Protection Agency' focuses on human health risk assessment (NRC 2009), but its recommendations and conclusions are also relevant to improved decision making in wildlife disease management. The committee's recommendations focus on designing risk assessments that make the best possible use of available science, are technically accurate, and address the appropriate risk management options effectively to inform decision making. Because the committee's recommendations also have direct relevance to improving and integrating risk analysis in wildlife disease management, they are paraphrased below:

- Increased attention to the design of risk assessment in its early stages is needed. An important element of planning and scoping is the definition of a clear set of options for consideration in decision making where appropriate. This should be reinforced by the up-front involvement of decision makers, stakeholders, and risk assessors, who together can evaluate whether the design of the assessment will address the identified problems in a timely manner.
- Uncertainty and variability of parameters in all key computation steps of a risk assessment should be clearly characterized and communicated. Additional guidance is necessary to clearly define an appropriate level of detail needed in uncertainty and variability analyses to support decision making.
- Continued and expanded use of the best, most current science to support and revise default assumptions is encouraged. There should be clear, general standards developed for the level of evidence needed to justify the use of alternative assumptions.
- Risk assessors should draw on other approaches, including those from ecological risk assessment and social epidemiology, to: incorporate interactions between chemical and nonchemical stressors in assessments; increase the role of biomonitoring, epidemiologic, and surveillance data in cumulative risk assessments; and develop guidelines and methods for simpler analytical tools to support cumulative risk assessment.

- To make risk assessments most useful for risk management decisions, the committee recommends a framework for risk-based decision making (see Figure S-1 in NRC 2009) that embeds a risk assessment paradigm into a process with initial problem formulation and scoping, upfront identification of risk management options, and use of risk assessment to discriminate among these options.
- A formal process should be established for stakeholder involvement in the framework for risk-based decision making with time limits to ensure that decision making schedules are met and with incentives to allow for balanced participation of stakeholders, including impacted communities and less advantaged stakeholders.
- A strategic examination of an agency's risk-related structures and processes should be initiated to ensure that it has the institutional capacity to implement the committee's recommendations for improving the conduct and utility of risk assessment. A capacity building plan should be developed that includes budget estimates required for implementing the committee's recommendations, including effectively implementing the framework for risk-based decision making.

5.4.1 Risk analysis as a framework for "best practices" in wildlife disease management

Concomitant with the development of international policy on livestock diseases and trade, there has been increased awareness of disease issues in wildlife management and conservation as they relate to the translocation, reintroduction, and recovery of individual animals and populations (Scott 1988, Karesh 1993, Karesh and Cook 1995, Lyles and Dobson 1993, Woodford and Rossiter 1993, Cunningham 1996, Woodroffe 1999, Deem *et al*. 2000, Deem *et al.* 2001, Lafferty and Gerber 2002, Nishi *et al*. 2002b, Wobeser 2002). Similar to livestock trade, the laws and recommendations regarding animal health for international movement of wildlife are based on the Animal Health Code developed by the OIE, and consequently risk assessment (Box 6) has also been accepted as a tool to evaluate policy options for wildlife health management (Woodford and Rossiter 1993, IUCN 1998, Corn and Nettles 2001, Woodford 2001, IUCN 2002, Leighton 2002, Jackson *et al*. 2009).

An important risk-based principle is that, from a scientific perspective, it is impossible to prove the complete absence of infection in a population and disease freedom cannot be conclusively demonstrated (Zepeda *et al.* 2005). This concept of risk and freedom from infection has important implications for eradication and control of wildlife diseases because it means that it may be impossible to achieve 100% certainty that disease has been eliminated. Therefore from a wildlife disease management perspective, 'eradication' implies that the prevalence of infection has been reduced below detectable levels in a population. Similarly, 'control' implies that apparent prevalence is reduced and managed at or below an acceptable level within the population.

Box 6. Risk analysis

Risk is defined as the probability of occurrence of an undesirable event, and the magnitude of the consequences (Ahl *et al.* 1993). With respect to animal health issues, risk analysis is a science-based, transparent framework and systematic modeling approach that links an appraisal of an animal health hazard(s) to management decisions regarding the health status and movement of animals (Zepeda *et al.,* 2001, 2005). Risk analyses are used by decision makers to address the following key questions (Murray *et al.* 2004a):

- What can go wrong?
- How likely is it to go wrong?
- What are the consequences of it going wrong?
- What can be done to reduce the likelihood and/or consequences of it going wrong?
- Who needs to be informed and engaged in a subsequent course of action?

Consequently, a complete risk analysis is viewed as a holistic process that embraces a series of four distinct steps (see Vose 2000, Leighton 2002, Murray *et al.* 2004a and 2004b), which include:

1. Hazard identification;
2. Risk assessment (qualitative or quantitative);
    - release assessment
    - exposure assessment
    - consequence assessment
    - risk estimations
3. Risk management; and
4. Risk communication.

Risks are identified as hazards, which are events or situations that cause harm, loss, or damage. A hazard is characterized by: the magnitude of harm, loss or damage it causes; the incurred costs should it occur; and its probability of occurrence. An often overlooked characteristic is the 'perception' of risk, which is the degree by which individuals and groups may perceive, define and assess hazards differently (see Macgill and Siu 2004, 2005).

Once the hazard is identified – for wildlife disease issues, the hazard is likely transmission of a disease pathogen – the next step is to conduct a systematic risk assessment that evaluates the likelihood and the biological, environmental, and economic consequences of the entry, establishment or spread of the pathogen from a disease reservoir to a target population (*sensu* Haydon *et al.* 2002). The risk assessment is a logical, reasoned and referenced discussion of the biological pathway(s) for the pathogen to be transmitted into a target population; it explicitly describes the factors and processes that underlie release of the pathogen from the infected population, and subsequent exposure and infection of a naïve target population. Scenario trees are often used to provide the conceptual and analytical modeling framework for estimating the likelihood of pathogen transmission, associated consequences, and overall risk (Murray *et al.* 2004a and 2004b). Risk assessments can be qualitative, in which relative risk is expressed categorically as high, medium, low, or negligible, or quantitative, in which probability distributions are used to estimate variability and uncertainty in model parameters and risk is expressed numerically.

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Risk management is a critical component to the overall risk analysis because it involves the development, incorporation, and evaluation of risk reduction and mitigation practices. Risk management practices are based on the key processes and linkages that have been elucidated through the risk assessment. In essence, the risk assessment defines the current hypotheses and estimates the most likely routes of pathogen transmission; in turn, these hypotheses provide the specific logic for risk mitigation and management practices. Consequently, risk management should be applied using adaptive management principles where management strategies are based on prior hypotheses, and follow-up monitoring evaluates effectiveness of management actions and tests hypotheses (Holling 1978, Walters 1986).

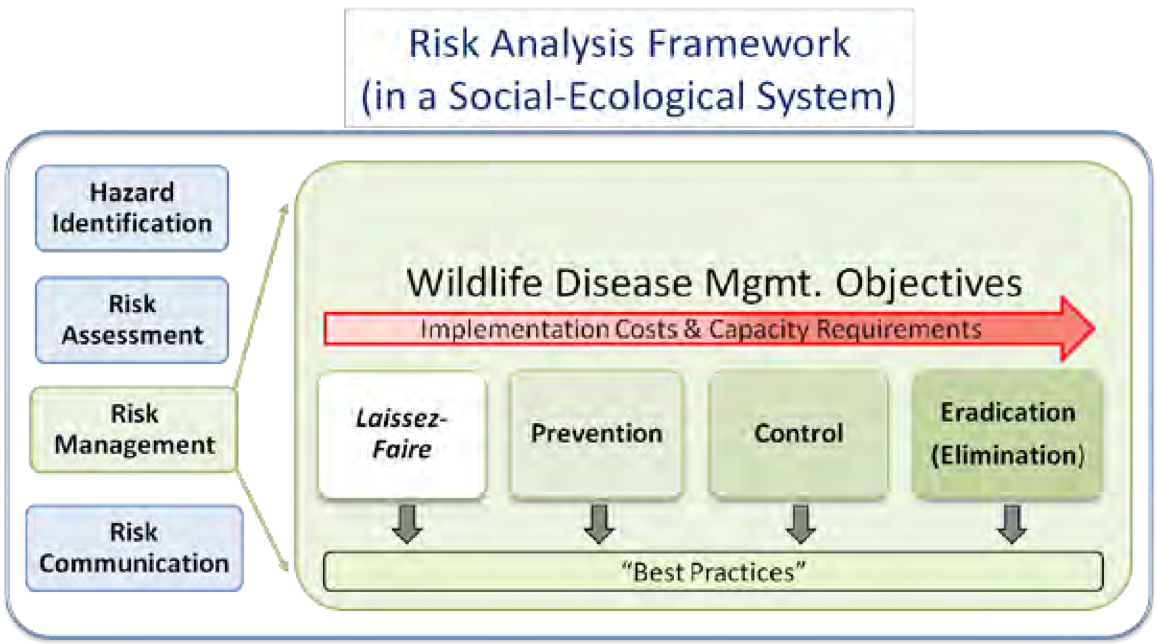
Risk communication is the interactive exchange of information on risk among risk assessors, managers, other stakeholders and the general public. Ideally, risk communication continues throughout the risk analysis process from beginning to end. Risk communication plays a key role in facilitating social interactions among the practitioners and stakeholders such as engagement, dialogue, knowledge sharing, collaboration, and shared learning.

A risk analysis based on modern statistical approaches in veterinary epidemiology can: identify key data gaps; provide a technical and transparent means of incorporating the uncertainty and variability of available data; and estimate the probability of occurrence and consequences of an animal health hazard. Although risk analysis is often considered as primarily a technical exercise that seeks to provide a transparent and science-based means of defining and managing risk, in practice the application of risk analysis to complex issues – such as bovine brucellosis and/or tuberculosis in bison populations within national parks – is beset by challenges that cannot be addressed solely through the judicious application of scientific methodologies.

For example, Macgill and Siu (2004, 2005) suggested that risk issues are intrinsically dynamic and unstable and emphasized that the interaction of apposed social and scientific knowledge was a key driver of risk issues over time and across geographies and cultures. Consequently, the effectiveness of risk analyses can be improved through the positive stabilizing effects gained by placing an emphasis on: new scientific research that increases certainty in scientific knowledge; positive social interactions that build trust between people; and mediation and open communication between stakeholders and managers. Since the acceptability of risk and associated management practices are influenced – often profoundly – by social, political, and economic considerations (Hueston 2003, Macgill and Siu 2005), it is important to conduct risk analyses using a collaborative, multi-stakeholder approach (Macgill and Siu 2005, Zepeda *et al.* 2005, NRC 2009).

The relevance of risk analysis (Box 6) is that it provides a robust framework by which to develop, implement, and evaluate performance of wildlife disease management and risk mitigation practices. For example, after the risk assessment, appropriate disease management objectives (*ie.*, *laissez-faire*, prevention, control, or eradication) can be developed and implemented as part of the risk management step (Figure 5). In this approach, the risk analysis becomes part of an adaptive management process (Box 7) within the domain of a broader social-ecological system, where current and new data are iteratively used to develop, test, and update management objectives and practices on a regular basis. As a result, the consistently reliable management practices become the 'best practices' under appropriate conditions.

Figure 5. Conceptual framework for integrating wildlife disease management objectives and best practices within a risk analysis framework.



Box 7. A working definition of Adaptive Management (from Nyberg 1998)

Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form – "active" adaptive management – employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed. The key characteristics of adaptive management include:

- Acknowledgement of uncertainty about what policy or practice is "best" for the particular management issue;
- Thoughtful selection of the policies or practices to be applied;
- Careful implementation of a plan of action designed to reveal the critical knowledge;
- Monitoring of key response indicators;
- Analysis of the outcome in consideration of the original objectives; and
- Incorporation of the results into future decisions.

For wildlife disease issues, the integration of risk analysis and adaptive management provides at least three benefits:

1. Management objectives and practices are linked to clearly defined epidemiological pathways of pathogen transmission with qualitative or quantitative estimates of likelihood;
2. Management practices can become testable hypotheses by design and through implementation of management programs; and
3. Subsequent monitoring is designed to collect the most appropriate data to evaluate management practices.

5.4.2 Application of risk analysis approaches to bison/elk disease management issues

As described previously (Section 5.4), risk analysis approaches are useful because they require a clear articulation of the hypothesized disease dynamics between reservoir and target populations. The resulting risk models often lead to well-defined hypotheses and assumptions, and model simulations can generate predictions that can form the basis for adaptive management strategies. This section briefly describes three examples of risk models and discusses how they may be applied in an adaptive management context to improve current management strategies in bison/elk disease issues.

Example 1 – Yellowstone bison and cattle

The first example is provided by Kilpatrick *et al.* (2009) who integrated epidemiological and ecological data to evaluate the relative spatio-temporal risk of *B. abortus* transmission from bison to cattle outside YNP. The risk model defined relative risk of disease transmission as a function of the number of cattle multiplied by [fraction of bison outside YNP *x* bison population *x B. abortus* seroprevalence *x* infected birthing rate outside YNP if seropositive (abortions + births) *x* minimum infective period for abortions and births (carcass persistence time, bacterial persistence time)]. Parameters within the risk model were estimated from empirical data. For example, the fraction of bison leaving YNP was correlated to population size and winter severity, and a relationship between seroprevalence of bison for *B. abortus* was fitted with bison population estimates. Infected birthing rates and persistence times (carcasses and bacteria) were determined from previous studies.

Based on their risk model, Kilpatrick *et al.* concluded that the relative risk of transmission of *B. abortus* from bison to cattle had a highly skewed distribution with zero or relatively low risk occurring for most years but occasional years of substantially higher risk. The variables that had the greatest influence on increasing relative risk were bison population size and the occurrence of severe winter climate events. In short, risk of disease transmission was substantially higher when bison were more likely to migrate outside of the park boundary in search of food in winter, which was more likely to occur as bison population size approached carrying capacity (*ie.,* 3000 in this example), and when severe snowfall or icing conditions occurred due to freeze/thaw events (Kilpatrick *et al.* 2009).

Model simulation results lead Kilpatrick *et al.* to recommend two additional management strategies for the northern GYA:

1. Establish a local brucellosis infection status zone for cattle in the Montana portion of the GYA with enhanced disease testing for cattle within the zone, and 'split status' for the rest of Montana;
2. Cease cattle grazing in areas in Montana where bison leave the park and financially compensate farmers and ranchers for lost earnings and wages.

Kilpatrick *et al.'s* (2009) recommendations were based on a quantitative assessment that overall risk of disease transmission between bison and cattle was low. Their evaluation of economic and management costs was based on a comparison of current annual costs for running the IBMP compared to projected annual costs for implementing recommended risk management strategies that were directed specifically at cattle herds within the higher risk areas adjacent to YNP.

In sum, the risk analysis by Kilpatrick *et al.* provides a useful quantitative assessment of risk between infected bison in YNP and adjacent cattle herds in Montana. The risk model framework defines the current understanding of the epidemiological pathway for transmission of *B. abortus* from infected YNP bison to cattle, and provides a clear rationale for spatial and temporal separation between bison and cattle as a primary strategy for risk management. By simulating management scenarios within a dynamic risk model, Kilpatrick *et al.* developed the rationale that risk management strategies aimed at cattle, (*ie.,* zoning and increased surveillance of herds in high risk zones, and removal of cattle from bison winter range areas) would be effective in mitigating disease transmission, reduce the need for hazing and removal of bison, and be less expensive than the current IBMP.

Nevertheless, Kilpatrick *et al.* acknowledged that management of the spatial distribution of YNP bison will continue to be a key issue at a landscape scale, as bison will continue to leave the park in winter as the population grows. Consequently, current techniques in the IBMP for managing winter distribution of YNP bison through a combination of hazing, removals, culling, and hunting will continue to be important management tools in the future. As described by Plumb *et al.* (2009), a key challenge will be to define the spatial scale for management and tolerance for YNP bison (infected with *B. abortus* or not) outside of the park boundaries and to develop management strategies that are based on landscape scale source-sink dynamics. In other words, YNP bison will need to be actively managed according to an accepted spatial distribution relative to park boundaries and acceptable range in population size.

Example 2 – Wyoming elk and cattle

The second example is the bioeconomic risk modeling by Xie and Horan (2009) that integrated disease dynamics of brucellosis in Wyoming elk with economic choices and behavioral dynamics of ranchers for vaccinating cattle herds. The integration of disease dynamics and economic choices resulted in a model that linked infection risks of cattle herds with livestock disease management decisions (*ie.*, to vaccinate or not), which, in turn were related to infection risks presented by abundance of brucellosis-infected wild elk. Xie and Horan's (2009) risk model was comprised of three interactive and dynamic submodels:

1. An elk epidemiological model based on Dobson and Meagher's (1996) Susceptible-Infected-Resistant (SIR) model;
2. A livestock disease model of individual farms based on Levins' metapopulation disease model (1969); and
3. A model of farmer behavioral choices that influenced the state and transition of farms (susceptible, infected, resistant, and empty).

Xie and Horan used their integrated disease and economic model to investigate the relative risk of brucellosis transmission from elk to cattle by simulating four management scenarios including:

1. No elk disease management (no hunting and winterfeeding at current levels);
2. Elk population control (hunting allowed in concordance with WGFD elk population objective for Jackson herd of 11,000);
3. Elk feeding controls only (no winterfeeding); and
4. Elk population and feeding controls (hunting and no winterfeeding).

Model simulation results suggested that net benefits to farmers under different combinations of elk winterfeeding and hunting policies were similar because farmers responded to greater infection risk with a higher vaccination rate for cattle herds, and the costs and benefits of vaccination offset each other (Xie and Horan 2009). Contrary to conventional thinking, results from the SIR elk submodel showed that cessation of winterfeeding may increase the number of infected elk in the population and subsequently present a higher risk of disease transmission to cattle herds. Under a "no winterfeeding" scenario, total infectious contacts among elk may decline but there would be more susceptible elk to become infected and markedly fewer resistant animals. Thus the risk of infectious contacts between elk and cattle may increase as a function of the numerical increase in infected elk combined with the behavioral response of elk to increase depredation of farmers' fields and hay storage if there were no winterfeeding.

The value of Xie and Horan's (2009) risk modeling is that it provides insight on the strong influence and dynamic interaction of farmer behavior and their propensity to vaccinate cattle herds under scenarios with variable risks of exposure to infected elk. Modeling suggested that even if the risk of contact increases between elk and cattle, the overall risk of brucellosis transmission may not increase appreciably because more farmers vaccinate their cattle herds.

Another benefit of Xie and Horan's (2009) risk modeling simulations is the initial development of hypothesis-based predictions and expected outcomes for management strategies that are based on winterfeeding and hunting of brucellosis infected elk, and vaccination of cattle herds. Given further development and collaboration with agencies, this risk modeling approach could lead to development and implementation of formal adaptive management experiments (see Parkes *et al.* 2006) that would be better able to determine the efficiency of management strategies such as vaccinating elk on winter feedgrounds (Dean *et al.* 2004).

From a broader perspective, Xie and Horan's general findings are consistent with two themes that have emerged from the bioeconomic literature where researchers explored the economic aspects of disease management involving wildlife and livestock (Bicknell et al. 1999; Horan and Wolf 2005; Fenichel and Horan 2007). The first theme is that outcomes in ecological and economic systems are jointly determined. The second theme is tied to the issue of allocation of resources to best manage a disease outbreak. For example, in assessing management strategies for tuberculosis in Michigan white-tailed deer and cattle, Horan *et al.* (2008) found that:

> *"optimal* [biosecurity] *controls may target the livestock sector more stringently when the livestock sector exhibits low value relative to the wildlife sector. This is in contrast to conventional wisdom on the issue that controls should primarily target wildlife species that serve as disease reservoirs…. All too often, the goal of pathogen eradication* [in wildlife] *is promoted irrespective of the costs and without due consideration given to mitigation as an alternative strategy that may be pursued."*

Example 3 – Northern wood bison

The third example is the landscape level risk assessment for potential disease transmission from infected wood bison from Wood Buffalo National Park to at-risk bison populations in northern Alberta and the Northwest Territories: 1) commercial cattle herds, 2) commercial captive bison herds, and 3) free-ranging wood bison herds that are considered free from bovine brucellosis and tuberculosis. An initial risk assessment was conducted by the Canadian Food Inspection Agency's Animal, Plant, and Food Risk Analysis Network (APFRAN). It assessed the probability of infection transmission to an animal in a target population, given that invasion and contact had occurred, and the economic consequences of infection (APFRAN 1999).

The APFRAN model defined the risk of infection transmission to be a function of the probability of invasion, probability of contact, and probability of pathogen transmission between an infected bison from the WBNP population and a susceptible animal in a target population. Probability of invasion was based on available radio-telemetry data and was defined by the statistical distribution in rates of movement in free-ranging WBNP bison. The probability of invasion was considered bi-directional between bison in WBNP and other free-ranging bison herds, while it was defined as unidirectional between WBNP bison and fenced, commercial herds. Invasion probabilities were determined based on geometric contact angles and distances between infected WBNP and respective target populations. Given invasion and contact had occurred, probability of transmission of brucellosis and tuberculosis were estimated by true prevalence of infection in WBNP bison, portion of the year when exposure could occur, and the rate of pathogen transmission given that contact animals were infected.

Although the APFRAN (1999) risk-assessment was based on a simple two-dimensional diffusion model of bison movements within the landscape, it concluded that the healthy, free-ranging bison herds (*ie.,* Mackenzie and Hay Zama bison herds) were at greatest risk of disease transmission from the target populations in the GWBA:

- "…one can say with 95% confidence that on average the introduction of infection [bovine brucellosis] would occur no more frequently than once every 8 years if populations and distributions remain at 1998 levels;"
- "…one can say with 95% confidence that on average the introduction of infection [bovine tuberculosis] would occur no more frequently than once every 6 years if populations and distributions remain at 1998 levels;"

The risk assessment highlighted the continued need for active surveillance of the Northwest Territories Bison Control Area (see Nishi 2002) and continued vigilance for dispersing bison between WBNP and the ranges of the Mackenzie and Hay Zama bison herds. The importance of the APFRAN (1999) risk analysis was in its ranking of relative risk of disease transmission to three at-risk groups, with healthy free-ranging bison herds considered to be at highest risk, followed by commercial captive bison and cattle herds respectively[17]. The APFRAN risk analysis also suggested that the relative risk of transmission of tuberculosis was higher than the risk of transmission of brucellosis, largely owing to the temporal window of transmission being shorter for brucellosis, *ie.,* when pregnant infected cows shed bacteria in contaminated fluids and tissues during abortion or calving events. Main shortcomings of the APFRAN risk-assessment were in its simplistic treatment of bison movements on a homogeneous landscape, and a conspicuous absence of data on bison distribution and movement corridors within the landscape.

Because the APFRAN (1999) disease risk assessment was not based on terrain and habitat variability, a follow-up research project was initiated to compile local knowledge on bison movement and distribution around WBNP, define the relative influences of biophysical and management factors, and to integrate quantitative and local qualitative data on biophysical factors into a bison movement model (Gates *et al.* 2001a). The research focused on bison movements and distribution in the region to provide models and maps for informing the development of disease risk management measures and to update the APFRAN (1999) risk model. The results suggested that the highest likelihood for bison dispersal occurred in corridors that were parallel to the Peace River in the area of Fort Vermillion, and with the broadest network of corridors between High Level and WBNP (Gates *et al.* 2001a).

Additional results from Gates and Wierzchowski's (2003) movement corridor analysis indicated that potential movements of bison between WBNP and the Mackenzie bison herd were most likely to occur in the northern section of the Northwest Territories Bison Control Area. Consequently, Gates and Wierzchowski recommended additional aerial surveillance of specific areas within the Bison Control Area based on the propensity of bison to use meadows near lakes and rivers. Because of the ongoing bidirectional risk of invasion and contact between infected bison from WBNP and animals from the Mackenzie bison herd, continuation of aerial surveillance of the Bison Control

[17] The relative ranking of risk and likelihood of infection for nearby, healthy populations of free-ranging bison is a key difference of the GWBA bison disease issue, when compared to the GYA where commercial cattle are the single-most important at-risk target population.

Area during winter is considered to be critically important for early detection of bison in the area and maintenance of spatial and temporal separation.

Although the APFRAN (1999) risk analysis provided a useful conceptual model and initial assessment for the risk of pathogen transmission from infected WBNP bison, there has been no further development or refinement of the risk model to date. Specifically, the geographic results from Gates *et al.* (2001a) have not been incorporated in to a revised version of a landscape-level bison movement risk analysis. Essentially the next step is to develop a spatial risk model that could be used to design bison-free zones and develop associated monitoring efforts. This would be especially useful as an active surveillance strategy to reduce risk of invasion and contact between the WBNP and Hay Zama bison.

The potential contribution of a revised bison movement risk model would lie in its simulation of spatially explicit dispersal corridors along with estimated likelihoods of use. These two parameters would provide inputs in to design and stratification of aerial surveys and allocation of effort to actively monitor areas that are designated as bison-free zones. In the case of establishing and managing bison-free zones to manage risk of invasion, the emphasis of surveillance activities are twofold: the first is to detect early invaders so that they can be removed; and the second is to estimate the likelihood that no bison occurred in an area, *ie.*, a zero or low probability of invasion, given that no bison or bison sign (tracks or feeding craters in snow) were observed over a specified period and quantified level of survey effort. In either case, risk analysis methods would contribute to effective and improved design of surveillance strategies.

5.5 Are "best practices" enough?

Continued development and research into best practices is warranted for specific applications. Best practices have value and benefit because they encourage robust and repeatable risk mitigation or management interventions, but often they may not consistently achieve desired results. Consequently, development of best practices should not be considered a panacea (Ostrom *et al.* 2007) for resolving wildlife disease issues. As noted by Bardach (2003), all 'best practices' are subject to failure. In summary, best practices may often be limited in scope, and developed and implemented over short time frames and small spatial scales.

As described by Wobeser (2007), Delahay *et al.* (2009) and reinforced by Roffe (pers. comm.), the role of wildlife disease researchers is to conduct the necessary scientific research to inform how management options **could** be implemented. In this context continual development and refinement of science-based 'best practices' is necessary to address uncertainties in technical feasibility. However, development of reliable best practices alone is not enough because the issue of what **should** be done is not based only on science, but rather it is driven by values and perspectives of various stakeholders. Therefore the social and economic aspects of wildlife disease management is equally important to the ecological and epidemiological aspects of disease, because human values, judgement, and political influences directly affect the complement of feasible management options and ultimately influence management decisions. In many cases, values of stakeholders or managers can be so entrenched that no additional scientific knowledge will sway their perspective. As Forrester (1995) notes, *"old mental models and decision habits are deeply ingrained; they do not change just because of a logical argument."*

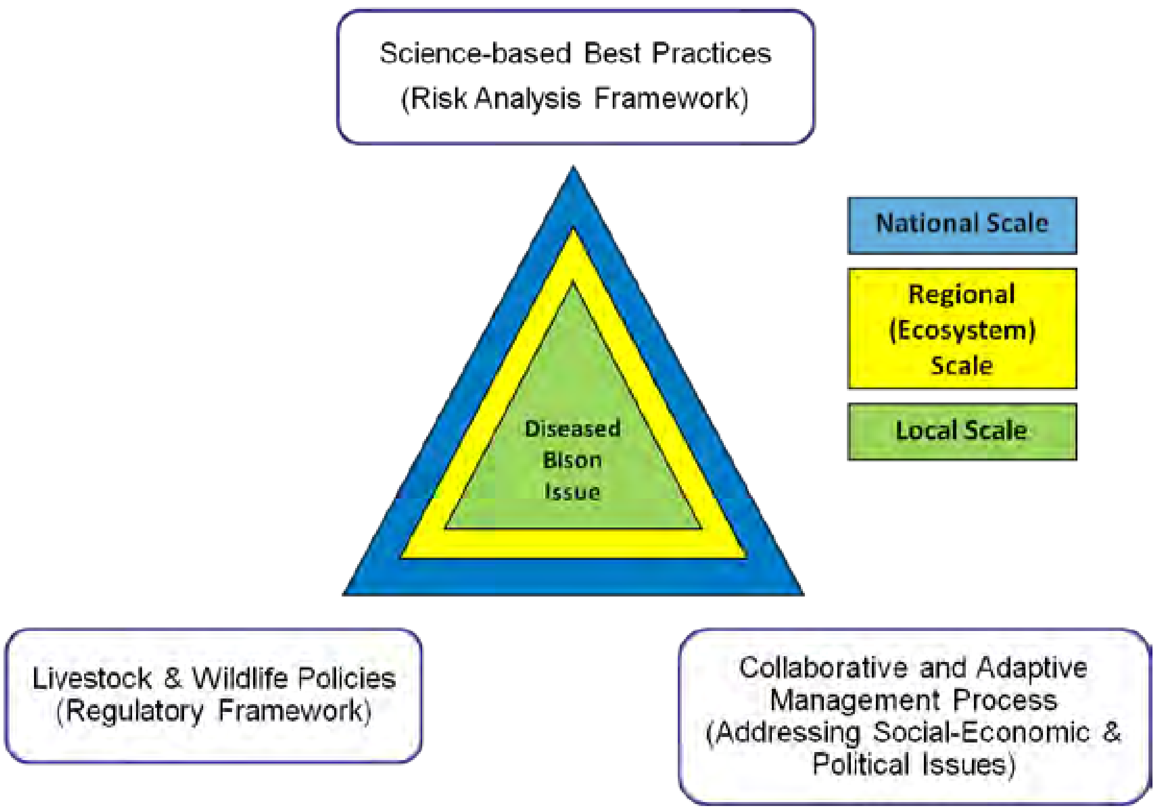
In this broader context, the current paradigm for wildlife management in North America recognizes and emphasizes the democratic representation and involvement of stakeholders and local communities (Mangel *et al.* 1996, Riley *et al.* 2002). The importance of stakeholder involvement and the human dimension to the diseased bison issue in the GYA and GWBA is especially pertinent for aboriginal peoples because their perspective may often be different from other stakeholders and wildlife managers. The aboriginal perspective is likely rooted to their deep relationship with the bison that *"extends back to time immemorial, to creation itself"* (Zontek 2007), and it is based on their belief that man and nature are one and the same; *"we evolved from the bison, we used to be bison. If you accept Darwin, then you should accept this"* (C. Wolf Smoke in Zontek 2007). This relationship emphasizes a human dimension that extends the conventional definition of 'socio-economic values' (see Berkes *et al.* 2003) and reflects the cultural and spiritual tie that some aboriginal people have with bison – a relationship that affects the aboriginal perspective on acceptable management options (Ferguson and Burke 1994, Nabakov and Loendorf 2002, Zontek 2007).

In northern Canada, consultation, shared decision making, and co-management of wildlife and other natural resources with aboriginal peoples is required under comprehensive land claim agreements that have been settled or agreed to in principle (INAC 2003 and see Ferguson and Burke 1994). This fiduciary responsibility of federal, provincial, and territorial government agencies requires serious consideration, and extends much further beyond developing and consulting on technical aspects of implementing 'best practices'.

In addition to the human dimensions of the diseased bison issue in the GYA and GWBA, the existing regulations and policies as they apply to managing diseases in livestock and wildlife also impose constraints and competing objectives that hinder resolution of the issue. As summarized in Sections 3.3, 4.2, and 5.4, regulations and policies for disease management in livestock often conflict with wildlife conservation objectives (see Keiter and Froelicher 1993, Bienen and Tabor 2006, Nishi *et al.* in press), and are usually not well integrated across local, regional, and national scales. Indeed, this is well illustrated by the mandates of different government agencies managing livestock or wildlife populations at state/provincial/territorial versus federal levels in both the GYA and GWBA. Bienen and Tabor (2006) summarized well the history of conflict that has shaped brucellosis policy in the GYA by stating that *"the formulation of existing brucellosis control policies has taken decades, involved numerous lawsuits, and been fraught with hostility between rival interests"* of conservationists and ranchers. In light of the spillover events of brucellosis in cattle herds within Idaho, Wyoming, and Montana (see Table 1), Bienen and Tabor (2006) also emphasized that a key opportunity for improving livestock and wildlife policy across scales in the GYA is the general recognition by state agencies that "*interstate cooperation will be necessary to control brucellosis on an ecosystem scale and that unconnected state efforts are insufficient*."

Given this context, best practices are not enough on their own, but rather they should be considered within a risk analysis framework and as one component of a multi-scale, three-point strategy, which also includes a formalized collaborative and adaptive management process as well as the active review, integration, and refinement of livestock and wildlife health policy (Figure 6). The adaptive management process should be developed *a priori* (as opposed to a knee-jerk response to conflict) as a planned, structured, and long-term collaboration of stakeholders to achieve clearly defined objectives, while the policy review should seek to evaluate, revise, and align livestock and wildlife policies across jurisdictions from local to regional and national scales as lessons are learned through adaptive management.

Figure 6. A three-point strategy for addressing the diseased bison issue highlights the need to adopt a multi-scale, integrated approach that simultaneously considers three basic facets – science-based best practices, the policy and regulatory framework for livestock and wildlife disease management, and a formalized management process – in an *a priori* context.



6. BEST PRINCIPLES

"We cannot solve our problems with the same thinking we used when we created them." Albert Einstein

The preceding section suggests that science-based 'best practices' by themselves are inadequate for achieving sustainable long-term management of brucellosis in the GYA, and brucellosis and tuberculosis in the GWBA. To develop potentially useful recommendations that might apply to complex, wicked problems, such as brucellosis and tuberculosis in wildlife within and around national parks, it is more meaningful to focus on best principles and then to consider strategic actions. In this context a principle is defined as a generalization that is accepted as true and that can be used as a basis for reasoning, conduct, or action.

An emphasis on best principles is similar to the approach used by Bienen and Tabor (2006), who based their strategic recommendations for improving brucellosis management in the GYA on principles for ecosystem management described by Christensen *et al.* (1996). Rather than repeat that commentary, some additional paraphrased principles from Christensen *et al.* (1996) and several principles from Mangel *et al.* (1996) follow:

- Focus on measurable goals that specify future (long-term) processes and outcomes necessary for sustainability;
- Recognize that complexity and connectedness are inherent properties that impart resilience to ecosystems;
- Recognize that ecosystems are dynamic and adaptive, and that humans are an important ecosystem component that play an active role in achieving sustainable goals;
- Apply the full range of knowledge and skills from the natural and social sciences as required to address problems;
- Understand and take account of the motives, interests, and values of all users and stakeholders, but not by simply averaging their positions; and
- Facilitate effective communication that is interactive, reciprocal, and continuous.

Diseased bison issues in both the GYA and GWBA occur within complex social-ecological systems that continually adapt through cycles of change (*sensu* Holling and Gunderson 2002, Walker and Salt 2006). Complex issues in social-ecological systems are characterized by unpredictable events and non-linear relationships, and therefore require a holistic and integrated understanding of humans and nature in order to improve the likelihood of successful management (Holling *et al.*1998, Pennington 2008). Thus, complex systems often present wicked problems (*sensu* Rittel and Weber 1973) of policy because they *"involve deep uncertainties and a plurality of legitimate perspectives"* (Funtowicz *et al.* 1999) and traditional command and control approaches based on linear cause and effect relationships have limited application. Traditional scientific approaches to diseased bison management, combined with a paradigm that assumes ecological or social changes are incremental and predictable over time, are bound to fail over the long term (Walker and Salt 2006).

6.1 A recurrent problem

The diseased bison issues in the GYA and the GWBA represent two of the most long-standing and contentious wildlife management issues in North America, and have been characterized by substantial policy change, public debate, and controversy over multiple decades (Gates *et al.* 1993, Keiter and Froelicher 1993, Keiter 1997, Cheville *et al.* 1999, Nishi *et al.* 2006). Despite obvious differences in geographies and stakeholders, there appear to be recurrent patterns of dynamic interplay between humans, wildlife and livestock populations, and disease pathogen(s).

At a broad scale, this adaptive cycle (*sensu* Holling and Gunderson 2002) is characterized by a triggering event related to either the highlighted presence of the pathogen (*ie.*, GWBA) or actual spillback from wildlife to livestock (*ie.*, GYA). The triggering event(s) results in a cascading response in the social system (*sensu* Westley 2002) and reactive conflict at political, organizational, and stakeholder levels; it drives an *ad hoc* engagement and facilitation process among government organizations and stakeholders that is designed to find and implement an immediate solution, but eventually fails or lands on symptomatic treatment of the problem due to conflicting views and values. The engagement process may initiate a formalized committee or task group, but eventually the process dissipates or transforms, either because the short-term management objectives are realized, political and/or economic motivation is relaxed, or funding is discontinued.

Because the pathogen(s) continue to persist in the wildlife reservoir, the adaptive cycle can play out repeatedly in the social-ecological system at various spatial and temporal scales. Even a cursory review of the bison disease issues in the GYA and GWBA (Sections 3 and 4) show a recurring pattern of social and political conflicts associated with the disease ecology in the respective systems. The recurrent pattern of conflict and controversy has intensified in the GYA with multiple spillback events of bovine brucellosis to commercial cattle herds in the states of Idaho, Wyoming, and Montana over the past five years. However, viewed from another perspective, the current conflicts may present a constructive opportunity to renew and redesign an overall management system that is better capable of learning and adapting (Holling *et al.* 1998). For example, effective alignment and integration of existing (USDI and USDA 2000, USDI 2007a, MDOL 2009) and new brucellosis policy initiatives (Moon *et al.* 2006, USDA 2009) affecting the GYA would have potential to ensure that management programs in the region are more complementary and less contradictory.

7. A WAY FORWARD

The challenge with charting a way forward is that – similar to the unrealistic expectation of implementing 'best practices' to isolated components of a complex problem and expecting overall success – there is no 'silver bullet' for the complex challenges presented by the diseased bison issues in the GYA and GWBA. Rather, this section outlines strategies and actions based on an overview of challenges in the GYA and GWBA and consideration of general principles outlined by Carpenter *et al.* (1996) for ecosystem management and by Mangel *et al.* (1996) for conservation of living resources. The author also considers the novel approaches described by the Australian Public Service Commission (2007) to address wicked problems. The Australian Government report emphasized that new thinking and skills are required to address complex problems and outlined the following principles and strategies (APCS 2007: 35-36):

- Holistic, not partial or linear thinking – thinking that captures the big picture and the full range of interrelationships between causal factors underlying a problem (see Box 1 on systems thinking). True understanding of a problem generally requires multiple perspectives and effective delivery of management actions usually requires the involvement, commitment and coordination of multiple organizations and stakeholders.
- Innovative and flexible approaches – the need for a systematic approach to social innovation by adopting the kind of practices employed by the private sector that integrate policy development and program implementation based on adaptive learning. Focus on developing 'learning organizations' (*sensu* Senge 2006).
- The ability to work across agency boundaries – because wicked problems go beyond the capacity of any one organization to understand and respond to, there is a need to work across agency and disciplinary boundaries.

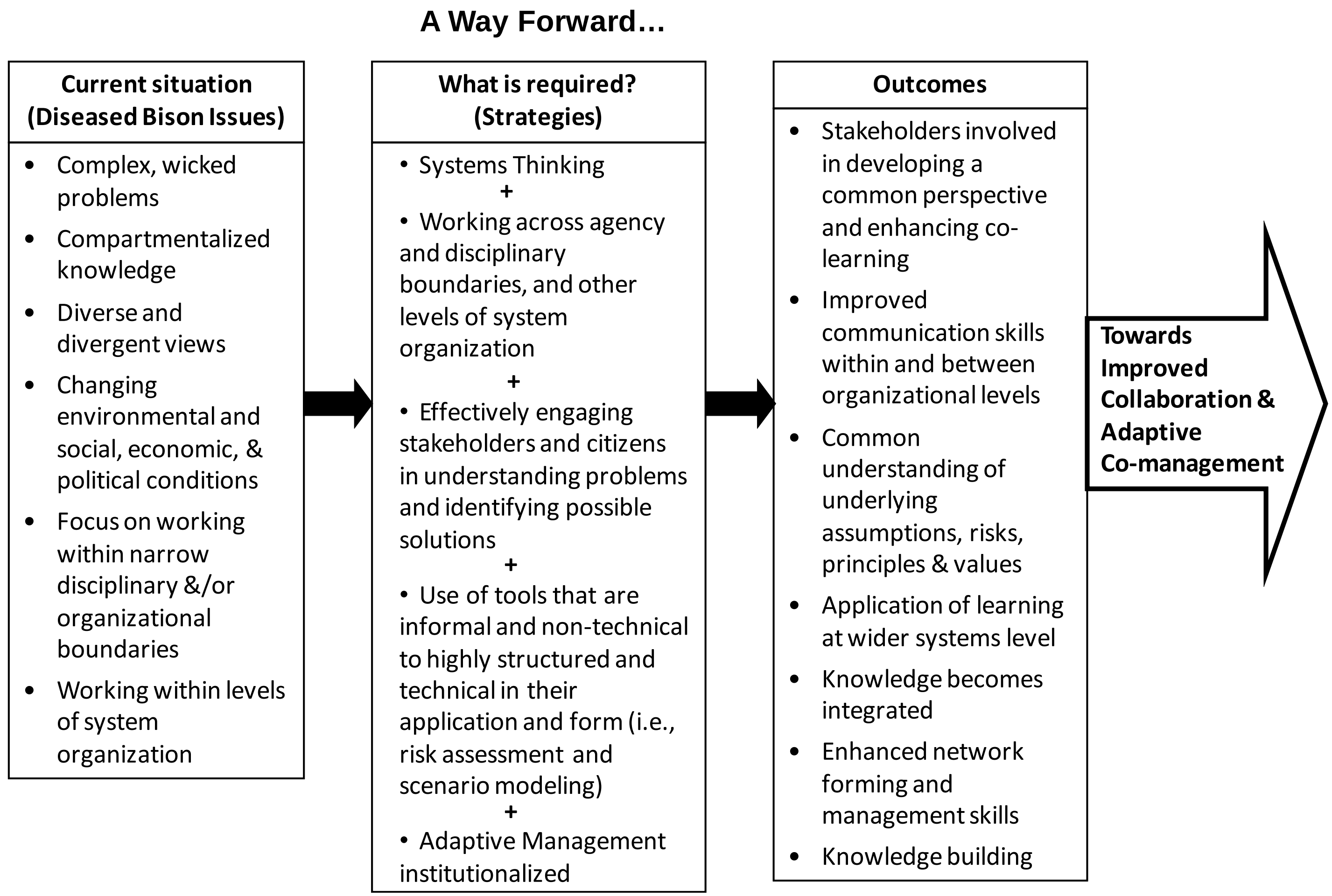
- Increasing understanding and stimulating debate on the application of the accountability framework – accountability frameworks need to be refined so that acceptable levels of accountability are maintained while barriers to innovation and collaboration are minimized.
- Effectively engaging stakeholders and citizens in understanding the problem and in identifying possible solutions –to understand the full complexity of and interconnections between problems, it is necessary to engage all relevant stakeholders. Behavioral changes are more likely if there is a full understanding and ownership of the issues by stakeholders.
- Develop additional core skills – managers and participants will need to develop skills in communication, big picture thinking and negotiation and improve their ability to work cooperatively as part of multi-disciplinary teams.
- A better understanding of behavioral change by policy makers – although the traditional ways by which governments influence behavior of stakeholders and citizens will still be important (*e.g*. legislation, regulation, penalties, taxes and subsidies), additional policy tools will be needed to better engage people in cooperative behavioral change.
- A comprehensive focus and/or strategy – coordinated and sustained effort and resources are required to successfully achieve long term management objectives and address multiple causes of wicked problems.
- Tolerating uncertainty and accepting the need for a long-term focus – politicians, government managers, and stakeholders must accept, understand and tolerate provisional and uncertain solutions to wicked problems; there are no quick fixes and solutions will likely need further policy change or adjustment.

7.1 Recommended framework for improving collaborative and adaptive management

Applying principles described by Christensen *et al.* (1996), Mangel *et al.* (1996), the APSC (2007), and Bosch *et al.* (2007) as a benchmark, a conceptual framework suggests how systems thinking and other principle-based strategies may be used to improve collaborative and adaptive management initiatives on the diseased bison issues (Figure 7). In order to progress from the current situation characterized by recurrent patterns of conflict and controversy, several key strategies should be considered through this framework:

- Develop and use systems thinking skills;
- Work across boundaries;
- Engage stakeholders and citizens;
- Use diverse (modeling) tools; and
- Institutionalize adaptive management.

Figure 7. A recommended framework for applying systems thinking concepts that may help develop a way forward in improving collaboration and adaptive management of diseased bison issues in the Greater Yellowstone and Wood Buffalo areas (based on Bosch et al. 2007, with additional strategies from APSC 2007).



7.1.1 Systems thinking

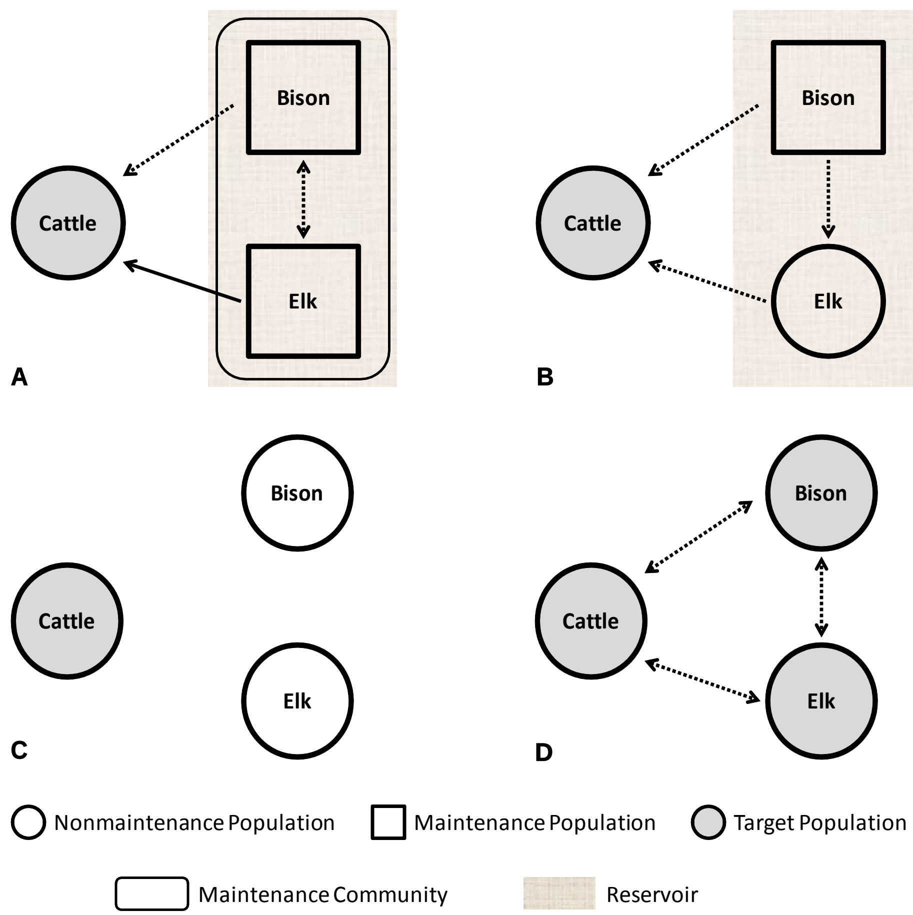
"..we have not yet cracked the challenge of how to bring enough people across the barrier separating their usual, simple, static viewpoint from a more comprehensive understanding of dynamic complexity." Jay Forrester (1995)

The concept of systems thinking was introduced early in the report (Box 1) because it provides the foundation for improving capacity and effectiveness in adaptive management. The need for applying systems thinking to management is illustrated in the GYA where, until recently, management action has focused predominantly on a unidirectional pathway from wild infected bison to commercial cattle herds (USDI & USDA 2000). As outlined by Roffe (pers. comm.), the WBCT (2005), and Bienen and Tabor (2006), evidence suggests that infected elk were the more likely proximate source of pathogen transmission in the recent confirmed cases of brucellosis in cattle in Idaho, Wyoming, and Montana. Interestingly, Keiter and Froelicher (1993) foreshadowed the importance of elk as a disease risk when they succinctly remarked that *"unless brucellosis in elk is also addressed, intensive bison management – either inside or outside the national parks – cannot eradicate brucellosis in park bison. In short, the problem cannot be solved by taking the politically expedient but scientifically unsound approach of addressing only bison as brucellosis carriers while discounting elk as a source of disease."*

Most evidence points to a complex target-reservoir system (*sensu* Haydon *et al.* 2002) in which bison are the primary reservoir host for brucellosis, with elk serving as a spillover host in areas where winter-feeding is not practiced despite comingling with infected bison (Ferrari and Garrott 2002), and as a discrete maintenance host in situations where elk densities are artificially increased through winter-feeding programs (Smith 2001) (Figure 8). However, recent findings of Cross *et al.* (2009) also suggest that unfed elk populations may become competent reservoirs for *B. abortus* when densities increase independent of feedgrounds. Consequently, the inherent complexity in this target-reservoir system requires further consideration and study in order to elucidate epidemiological connectivity, design optimal risk management strategies, and to consider practical feasibility for either controlling brucellosis or managing risk of disease transmission at the landscape scale. Smith (2001) and Bienen and Tabor (2006) outlined possible experimental approaches based on adaptive management.

At a landscape scale, the epidemiological connectivity between true and potential maintenance reservoirs and associated target populations points to a broader systemic potential for disease emergence of novel pathogens. Over the past several decades, a large part of the concern and controversy in the GYA has been focused on brucellosis and the disease risk that infected wild bison present to adjacent cattle herds. This view has been too narrow in scope and should be balanced with a view based on systems thinking that explicitly considers the complexity of the target-reservoir system, the bidirectional risk

Figure 8. Examples of hypothesized target-reservoir systems for brucellosis (*Brucella abortus)* in the Greater Yellowstone Area with symbols and definitions from Haydon *et al.* 2002. Arrows show potential transmission routes of 'spill back' (wildlife to livestock) or 'spill over' (livestock to wildlife) (*sensu* Daszak *et al.* 2000), with dashed lines indicating pathways with higher uncertainty. The first case, A, describes the current situation with the maintenance community comprising both bison and elk populations, with the hypothesis that elk are an independent maintenance population because of high densities maintained by feedgrounds. B shows a hypothesized effect that would occur on the system if elk densities were reduced and were no longer a competent disease reservoir, *i.e.*, through cessation of winter feeding and/or increased mortality through predation and hunting; bison would become the sole maintenance population but elk would still be part of the reservoir. In C, a desired and hypothesized outcome is shown whereby the disease reservoir is eliminated due to a combined management approach that incorporates a successful vaccination program for bison (and possibly elk) and the absence of elk winter feedgrounds. D illustrates that potential connectivity between wildlife and livestock represents bi-directional risk of transmission and that all species in the livestock-wildlife interface may be potential target populations for potential emerging pathogens in the future, such as bovine tuberculosis.



of disease transmission of pathogens other than *B. abortus*, and the implications of a changing landscape due to anthropogenic land uses and environmental drivers. Among others, Neff (2004), Peterson (2005), Cross and Plumb (2007), Cross *et al.* (2007 and 2009), White and Davis (2007) and Conner *et al.* (2008), have steered us in this direction and contributed towards this broader understanding.

7.1.2 Working across boundaries

"Few would doubt that the chances of success of modern conservation efforts are enhanced significantly by multidisciplinary approaches to solving social, economic, political, and biological challenges." Karesh *et al.* (2002)

The emphasis for research on the diseased bison issue has been focused on the natural sciences, *ie*., biology, ecology, and epidemiology. Future collaboration will require deeper cross-disciplinary integration among biologists as well as social, economic, and policy scientists (Hobbs and Lambeck 2002). Other non-traditional research collaborators may include field practitioners, such as policy makers, planners, managers, community and aboriginal groups, and citizens.

The concept of governance as "*the coordination or control of activities undertaken by a variety of actors across a wide spectrum of space, society and economy*" (Wilkie *et al.* 2008) is especially pertinent as we consider meaningful ways of conserving and managing wildlife and landscapes that occur within and extend beyond protected areas. The focus on working solely within protected areas to conserve wildlife cannot persist and there is a need to work effectively outside of parks and reserves in the complex landscapes that are managed for economic development (Wilkie *et al.* 2008).

Governance models and organizational structures must have a deep commitment to helping people grow through team building and shared learning, and to creating the trust and spirit of mutuality this requires (Senge 2006). Any commitment of an organization to work across jurisdictions (interagency collaboration) and disciplines (trans-disciplinary collaboration) has to be deemed 'worthy' in order for people to buy in and invest their personal and professional time (Margerum 2001). In the absence of a true commitment, the outcome over the short term is cynicism, with failure over the long term. Yaffe (1997) also describes how fundamental behavioral tendencies at many levels of human social organization can lead to policy impasses and poor choices in environmental policymaking. Building sustainable and resilient governance systems requires long term commitment (Margerum 2001) across temporal scales that may extend past mandated terms of state/provincial/territorial, federal and aboriginal governments, and professional careers of agency staff, NGOs and other stakeholder organizations. Longer term vision and commitment to management is critical for continued engagement and progress on these issues.

Traditional management structures based on specialization and compartmentalization of tasks and authorities need to be replaced by systems that better facilitate interagency and trans-disciplinary collaboration (Pollock *et al.* 2008). This has been and will continue to be a significant challenge for government agencies that have clear jurisdictional and sectoral responsibilities and mandates, because it may potentially affect power relationships. Nevertheless, there needs to be a stronger emphasis and commitment to collaborative decision making across government agencies and stakeholder groups; changes to institutional structures, reporting relationships and new funding opportunities should reflect and facilitate the commitment to interagency collaboration. One of the recommendations listed by the GAO (2008) was to consider an annual rotation of agencies (within an interagency framework) to lead the group in planning, oversight, coordination, and administration.

Margerum (1999, 2001, 2008) describes in detail some of the necessary considerations and strategies required to develop meaningful collaborative relationships and structures. For example, Margerum (2001) provides an overview of factors affecting organizational commitment to collaborative management, and describes the following list of potential strategies for gaining commitment:

- Legislative – attempts to bring organizations together through changes in power, jurisdiction, or legislative amendments;
- Contractual – an effort to bring a set of organizations together under a joint written agreement or strategy that binds them politically, morally, and sometimes legally;
- Facilitational – use of facilitators (either individuals or organizations) to help convene the parties, manage the process, and support implementation;
- Interorganizational coordination – establish an adaptive system of management with new structures and regular processes, such as continuous information exchange and interaction to facilitate coordination;
- Financial – funds are directed into a common pool so that funding becomes the carrot for organizations to participate in activities for which they might not normally be willing to allocate resources; and
- Interpersonal – reliance on mutual trust and understanding among people involved in the integrated effort leads to mutual understanding about problems, awareness of different views, and interpersonal trust.

In addition to legislation and law enforcement, Wilkie *et al.* (2008) described three other potential strategies for engaging constructively with people and their organizations across administrative and political boundaries:

- Moral argument – focused on education to promote conservation-friendly behavior among human communities;
- Political engagement or campaigning – political lobbying within existing structures of power, *ie.*, government institutions, local landowners, or political interests to gain broader support; and

- Market mechanisms – placing economic value on previously undervalued goods and services to change behaviors in beneficial ways, *ie.*, economic valuation of ecological goods and services.

7.1.3 Engaging stakeholders

"Any ecosystem-scale management strategy developed through public involvement is not just about ecology; it is also about integrating human concerns into natural resource policy decisions. Most knowledgeable observers agree that the ultimate goal must be sustainability, defined broadly in ecological, economic, and social terms." Robert Keiter (2003)

"Applicability of research results is not only a scientific concern to be addressed by scientists alone. It has mainly to do with economic and political policies, with social attitudes, and with cultural perceptions. The probability of translating ecological knowledge into practical application is very low unless the changing context that drives political and environmental decision-making on development and environmental protection is duly considered by scientists." Francesco di Castri (2000)

Acheson (2006) suggests that few generalizations can be made to describe the reasons why humans are unable to manage natural resources, except that failure is traceable to a lack of willingness or ability to solve collective-action dilemmas and produce effective rules. This generalization is applicable to the ongoing dilemma with diseased bison, and diseased bison and elk systems. Consequently, the structure of institutions and governance models is an important component of building sustainable and resilient social-ecological systems. In the absence of a collaborative governance approach (Ansell and Gash 2008), it is expected that conflict and distrust among stakeholders will be the main drivers in the interactive dynamic. The objective of a collaborative approach should be to build the necessary social capital and stakeholder capacity to engage on difficult wildlife management issues and to develop meaningful decisions and policies.

Shindler and Aldred Cheek (1999) conclude that public involvement is an important interactive process for generating enduring relationships and long term support for innovative management options, and propose six key characteristics for citizen-agency interactions:

1. They are open and inclusive,
2. They are built on skilled leadership and interactive forums,
3. They include innovative and flexible methods,
4. Involvement is early and continuous,
5. Efforts result in action, and
6. They seek to build trust among participants.

The principle of engaging stakeholders and the broad goal of maintaining and enhancing resilience in social-ecological systems require a meaningful future role for aboriginal peoples in the management and restoration of bison. Fundamentally, this boils down to restoring sustainable harvesting opportunities as a means of reconnecting cultural and spiritual relationships (Sanderson *et al.* 2008). Ongoing work and commitment to bison restoration through initiatives of the IUCN, WCS-ABS, USDI and WBRT should continue to encourage and facilitate involvement of aboriginal peoples in bison restoration. More specifically, in the GYA, efforts to establish approved quarantine facilities and protocols for salvage of brucellosis-free bison for use by aboriginal peoples in restoration projects is a positive step that needs to follow through to its logical conclusion, *ie.*, translocation of brucellosis-free bison to restoration projects led by or in partnership with aboriginal stakeholders. In northern Canada, settled and unsettled land claim areas with aboriginal peoples have placed a clear and present emphasis on ensuring that traditional land use and sustainable harvesting for consumption provide the basis for resilient social-ecological systems. In the GWBA, this suggests that an adaptive co-management arrangement with improved collaboration and sharing of management authority between federal, provincial, territorial and aboriginal governments will be required. This has implications for developing a co-management governance model that would support sustainable subsistence hunting; an initial step would be to revisit and amend existing legislation which currently restricts harvesting of bison by aboriginal peoples within Wood Buffalo National Park.

7.1.4 Using diverse (modeling) tools

"All decisions are based on models… and all models are wrong." John Sterman (2002)

The application of systems thinking skills is an integral commitment to collaborative and adaptive management. Walters (1997) states that adaptive management "*should begin with a concerted effort to integrate existing interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies. This modeling step is intended to serve three functions: (1) problem clarification and enhanced communication among scientists, managers, and other stakeholders; (2) policy screening to eliminate options that are most likely incapable of doing much good, because of inadequate scale or type of impact; and (3) identification of key knowledge gaps that make model predictions suspect.*"

Scenario analysis approaches (Duinker and Greig 2007) based on development of system dynamic models for wildlife disease management may be useful because they can help managers and stakeholders understand key drivers, relationships, and trade-offs of management options within the context of complex social-ecological systems. System dynamics modeling can be used to simulate and better understand multiple feedback relationships between wildlife, pathogens, livestock, and the environment, and human managers (Neff 2007, Xie and Horan 2009). Modeling can be used to evaluate disease risks based on variable assumptions for epidemiological relationships and under different scenarios for alternative futures (Gross *et al.* 2003).

Within an adaptive management context, scenario analyses and system dynamics models should be considered as learning tools to help make informed management decisions and explore linkages to ecological, social, and economic indicators. Van den Belt (2004) suggests that mediated modeling facilitates integration of expert information and stakeholder participation into a simple but elegant simulation to address complex problems. As an example, Gates *et al.* (2005) developed a novel and useful system dynamics model for simulating the ecological drivers and key assumptions that affect bison migration outside of Yellowstone National Park based on empirical data and expert opinion gained through participatory workshops. Beall and Ford (2007) also highlighted the value of participatory modeling as it encourages stakeholder collaboration; can address objectives that range from problem solving to solution seeking; and can incorporate both qualitative to quantitative data sources. The key point is that to effectively incorporate adaptive management, there must be considerable work invested up front in defining the current understanding and uncertainty of underlying processes and dynamics of the system. Qualitative and quantitative models are a way of defining, *a priori,* the relationships between key drivers and indicators in the system, and of articulating alternate hypotheses for the expected outcomes of management actions. Thus models are useful to help clearly define linkages between working hypotheses and assumptions, and expected outcomes of management actions. Models also help to identify key indicators and ensure that appropriate data are collected in subsequent monitoring.

Risk assessment relies on qualitative or quantitative risk models that explicitly recognize variability and uncertainty in model parameters, and are useful decision support tools. Risk analysis models are a specific type of system dynamics model that may also be used in scenario analyses to inform decisions on animal disease. Critics of risk assessment methodologies often argue that when there are not sufficient data to fully parameterize a risk model – which occurs much of the time – a risk analysis may not be helpful. Quantitative assessments are useful when data exist; however, extensive and detailed quantification is not essential for effective health risk assessment and qualitative analyses may be of equal or greater value than numerical evaluations (Leighton 2002). In the absence of a working qualitative or quantitative risk model, a decision maker must revert to a mental model to inform his/her decision and mental models are simply not capable of capturing and reflecting the complexity and interrelatedness of various risk factors. Therefore, from a decision maker’s perspective, there is value in risk analysis as long as the input data and assumptions are clearly understood, and the disease management objectives are specific and goal-oriented.

7.1.5 Institutionalizing adaptive management

"Because ecosystems are complex and dynamic entities, ecosystem management employs adaptive management techniques to address change and uncertainty. Conceding that our scientific knowledge is limited, adaptive management involves establishing baseline conditions, monitoring the ensuing changes, reevaluating the situation, and then adjusting management strategies to incorporate new ecological information as well as related changes in human values." Robert Keiter (2003)

"Most management institutions tend to resist change and wish to control the process of management as much as possible. Yet, adaptive management considers change and cooperation as inherent to management. Perhaps we need a new institutional paradigm that sees management agencies not as providers of solutions, but as facilitators and partners with citizens (ie., true "civil servants") to help find joint solutions." Barry Johnson (1999a)

As the GAO (2008) suggested, a key aspect of implementing adaptive management is to ensure linkages among steps in the management process. These steps include identifying clearly defined, measurable management objectives; designing and implementing a robust monitoring program to systematically collect information about the impacts of management actions; and making decisions collaboratively among stakeholders about adjustments to management actions based on what is learned. Johnson (1999b), Lee (1999), Shindler and Aldred Cheek (1999), and Williams *et al.* (2007) provide additional insight into implementing adaptive management from operational, organizational, institutional, and stakeholder engagement perspectives.

There is a need to design and implement sustainable models of human institutions for collaborative governance, trans-disciplinary organizational learning, conflict resolution, and adaptive management. This does not mean creation of a new agency that oversees all activities and implements decisions, but rather development of new relationships among current organizations and stakeholders where structure is designed to be sustainable over decadal periods to facilitate continuous involvement, consultation, communication, and learning among a broad group of stakeholders.

Sustainability in this context recognizes that there will be dynamic changes in composition and interactions between public and private organizations, and emphasizes a commitment to continued organizational learning and inter-generational transfer of experience and knowledge – key aspects to adaptive management. However, a key challenge facing organizational commitment to adaptive management is the inevitable changes in power relationships among stakeholders during implementation; ultimately major power inequities can be a barrier to collaborative approaches. Consequently, early negotiations and discussions on overlapping management interests and jurisdictional authorities are important, as well as clear agreement on a vision and objectives for the relationships.

8. GENERAL CONCLUSIONS AND RECOMMENDATIONS

- The diseased bison issues in the Greater Yellowstone and Greater Wood Buffalo National Park areas are longstanding, wicked problems that elude resolution because of their dynamic epidemiology, and the diverse and conflicting mandates and values held by various government agencies and stakeholders on what should be done. Although the issues are beset by significant technical challenges and knowledge gaps, the human dimensions – a key driver in these social-ecological issues – have received comparatively less formal attention than the agenda to conduct scientific studies to address knowledge gaps and improve best practices. The current research and management emphasis on disease ecology could be improved through collaboration and broadening of scope with researchers in the social sciences including sociologists, economists, and political scientists. This integration of research would serve two important functions: 1) it would foster increased trans-disciplinary collaboration and 2) it would promote organizational learning across agencies and stakeholders. Part of this broadening of scope would facilitate recognition and inclusion of local and traditional knowledge from aboriginal and non-aboriginal stakeholders (Dorn and Mertig 2005, Brook and McLachlan 2006).
- Development of science-based best practices is useful and should continue, but is not sufficient on its own to meaningfully resolve the diseased bison issues. Best practices should be considered and applied within a risk analysis framework because risk analysis methodologies can provide logical and quantitative rigor in selecting and evaluating best practices within a specific, goal-oriented disease management context. The development and application of best practices should be considered as one component of a multi-scale, three-point strategy that also includes a formalized collaborative and adaptive management process, and an ongoing evaluation and refinement of livestock and wildlife policy.

- The basis for the adaptive management process should be developed *a priori* as a flexible, but planned and structured collaboration of stakeholders to achieve defined long-term disease management objectives. The policy analysis should seek to evaluate, revise, and align livestock and wildlife policies across jurisdictions from local to regional and national scales as lessons are learned and experience is gained through adaptive management.
- Adaptive management provides the overall framework for developing and implementing strategies and actions to address the diseased bison issues in the GYA and GWBA. Although adaptive management has been identified as the preferred management approach and it has been specified in a myriad of official government agency documents and records of decision, the principal challenge has been to effectively implement the concept on the front lines of these real world wicked problems. One key area for improving adaptive management strategies is to clearly define objectives, working hypotheses, assumptions, and predictions of prospective management actions. Only then can an appropriate active or passive implementation design be developed along with a suitable monitoring program.
- A strategic way forward from the current situation, which is characterized by recurrent patterns of conflict and controversy, is to focus on improving collaborative relationships and adaptive management processes. Several key strategies should be considered:
  - providing a forum, funding, and mandate for a long-term process to address the issue;
  - developing and using systems thinking skills;
  - working across boundaries;
  - engaging stakeholders and citizens;
  - using diverse (modeling) tools; and
  - institutionalizing adaptive management.
- At a continental scale, the opportunity for shared learning across the GYA and GWBA should be actively developed through directed and continued dialogue among the governments and stakeholders involved in these regional issues. Shared learning would be enhanced through informal and formal collaboration, for example through workshops and committees. The benefit of such collaboration was clearly demonstrated when the WBNP Research Advisory Committee included a science advisor from the US National Parks Service who also served on the Greater Yellowstone Interagency Brucellosis Committee. As noted by Huff and Chisholm (1999), although the GYA and GWBA issues have important differences, the science needed for informed decision making is very similar. Funding is extremely limited in relation to the data gaps and prevention of research duplication is mandatory for timely resolutions.

- Failure to address the bison disease issues and letting outcomes be determined through inaction is an inappropriate management strategy for these valuable wildlife resources. Political, public, and stakeholder support for the development and implementation of disease management strategies is essential. While working towards a long term solution to both issues, initiatives to contain and mitigate current disease risk should be continued and enhanced.

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APPENDIX A. BISON DISEASE AND ECOLOGY LIBRARY

An electronic library was submitted to the Wildlife Conservation Society and represents a search of both published scientific papers and 'grey' literature, in the subject areas of bison and disease ecology and includes a total of 974 references. My intent was to cover the general subject areas of epidemiology, landscape ecology, natural history, and management theory extensively enough to consider and research the multidisciplinary nature of the bison disease issues in the greater Yellowstone and Wood Buffalo National Park ecoregions. Although the focus was on brucellosis and tuberculosis in these two regions, I also included literature covering other geographies and pathogens because they provided additional background to the broader issues of addressing wildlife disease issues at a landscape level and from different disciplinary perspectives. I did not conduct a systematic review of the literature, and rather my focus was on recent literature (within the last 10 years) for which electronic references could be selected. Nevertheless, I think the library represents a diverse and broad basis for researching and understanding bison-disease issues in North America from a multidisciplinary perspective.

Instructions for Use

I developed this electronic library using the bibliographic reference manager "ProCite". Since ProCite is proprietary software, the user will need to purchase a licenced copy (http://www.procite.com/) and install it on their computer in order to open the reference database. All references were entered in to the ProCite file titled "0_WCS Bison Disease Review Final" and are available in electronic format on the DVD. It is important to note that a ProCite database is comprised of two required files, one with the extension ".pdx" and the other with extension ".pdt". Both files must be copied on to another drive, if the database is to be copied from DVD on to a hard drive and opened in ProCite.

It is also important that the pdf reference files are located in the same folder as the ProCite database. This will allow the user to highlight a record and open the corresponding reference file by selecting Open File/URL from the ProCite Tools menu, or alternatively by depressing the Ctrl + L buttons simultaneously. All electronic references on the DVD are saved as Adobe Acrobat ".pdf" files and can be opened using Adobe Acrobat Reader which is available for free on the internet (http://www.adobe.com).

APPENDIX B. KEY INTERVIEWS AND SITE VISITS

Date	Contact
20 and 27 Aug 2008	Dr. Keith Aune Senior Conservation Scientist Wildlife Conservation Society 301 N. Wilson Bozeman, MT. 59715
25 Aug 2008	Dr. Glen Plumb Chief, Branch of Fish and Wildlife Yellowstone Center for Resources POB 168 Yellowstone National Park, WY. 82190
20 and 25 Aug 2008	Dr. Rick Wallen Wildlife Biologist Bison Ecology and Management Program POB 168 Yellowstone National Park, WY. 82190
22 Aug 2008	Dr. David Hunter Wildlife Veterinarian Turner Enterprises, Inc. Turner Endangered Species Fund 1123 Research Drive Bozeman, MT. 59718
21 Aug 2008	Dr. Tom Roffe Chief, Wildlife Health US Fish and Wildlife Service Department of Interior Fish, Wildlife and Parks Building 1400 S. 19th Avenune Bozeman, MT. 59718

Date	Contact
26 Aug 2008	Dr. Jack Rhyan Wildlife Disease Investigator US Department of Agriculture Animal and Plant Health Inspection Service Veterinary Services National Wildlife Research Center 4101 Laporte Avenue Fort Collins, CO. 80521
22 Sep 2008	Dr. Todd Shury Wildlife Health Specialist Parks Canada Room 1669B, Dept. of Veterinary Pathology Western College of Veterinary Medicine 52 Campus Drive Saskatoon, SK. S7N 5B4
23 Sep 2008	Dr. Brett Elkin Wildlife Veterinarian Wildlife Division Department of Environment and Natural Resources Government of the Northwest Territories 600, 5102 - 50th Avenue Yellowknife, NT. X1A 3S8
23 Sep 2008	Dr. Gary Wobeser Professor Wildlife Diseases Department of Veterinary Pathology Western College of Veterinary Medicine University of Saskatchewan 52 Campus Drive Saskatoon, SK. S7N 5B4
24 Oct 2008	Dr. Cormack Gates Professor of Environmental Science and Planning Faculty of Environmental Design Professional Faculties Building, Room 2182 University of Calgary 2500 University Drive NW Calgary, AB. T2N 1N4
3 Mar 2009 (Telephone Interview)	Mr. George Hamilton Manager, Priority Species Sustainable Resource Development Government of Alberta 2nd Floor Great West Life Building 9920 - 108 Street Edmonton, AB. T5K 2M4
27 May 2009 (Telephone Interview)	Dr. Terry Armstong Bison Ecologist South Slave Region Department of Environment and Natural Resources Government of the Northwest Territories P.O. Box 900 Fort Smith, NT. X0E 0P0

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ABS Working Paper No. 2
Brodie, Jedediah F. (2008) A Review of American Bison (*Bos bison*) Demography and Population Dynamics. Previously published as WCS Working Paper No. 35.

ABS Working Paper No. 3
Nishi, John S. (2010) A Review of Best Practices and Principles for Bison Disease Issues: Greater Yellowstone and Wood Buffalo Areas.

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Bleisch, William V. (1993) Management Recommendations for Fanjing Mountain Nature Reserve and Conservation at Guizhou Golden Monkey & Biodiversity.

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Hart, John A. and Claude Sikubwabo. (1994) Exploration of the Maiko National Park of Zaire, 1989-1994, History, Environment and the Distribution and Status of Large Mammals.

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Rumiz, Damian and Andrew Taber. (1994) Un Relevamiento de Mamíferos y Algunas Aves Grandes de la Reserva de Vida Silvestre Ríos Blanco y Negro, Bolívia: Situación Actual y Recomendaciones.

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Hodgson, Angie. (1997) Wolf Restoration in the Adirondacks? The Question of Local Residents.

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Bolze, Dorene, Cheryl Chetkiewicz, Qui Mingjiang, and Douglas Krakower. (1998) The Availability of Tiger-Based Traditional Chinese Medicine Products and Public Awareness about the Threats to the Tiger in New York City's Chinese Communities: A Pilot Study.

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Ray, Justina C. (2000) Mesocarnivores of Northeastern North America: Status and Conservation Issues.

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Kretser, Heidi. (2001) Adirondack Communities and Conservation Program: Linking Communities and Conservation Inside the Blue Line.

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Gompper, Matthew E. (2002) The Ecology Northeast Coyotes: Current Knowledge and Priorities for Future Research

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Weaver, John L. (2001) The Transboundary Flathead: A critical Landscape for Carnivores in the Rocky Mountains

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Karasin, Leslie N. (2003) All-Terrain Vehicles in the Adirondacks: Issues and Options

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Clarke, Shelley. (2002) Trade in Dried Asian Seafood: Characterization, Estimation and Implications for Conservation.

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Redford, Kent H. and Michael Painter. (2006) Natural Alliances Between Conservationists and Indigenous Peoples.

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Agrawal, Arun and Kent Redford. (2006) Poverty, Development, and Biodiversity Conservation: Shooting in the Dark?

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Castillo, Oscar, Connie Clark, Peter Coppolillo, Heidi Kretser, Roan McNab, Andrew Noss, Helder Quieroz, Yemeserach Tessema, Amy Vedder, Robert Wallace, Joseph Walston, and David Wilkie. (2006) Casting for Conservation Actors: People, Partnerships and Wildlife.

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Brodie, Jedediah F. (2008) A Review of American Bison (*Bos bison*) Demography and Population Dynamics.

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