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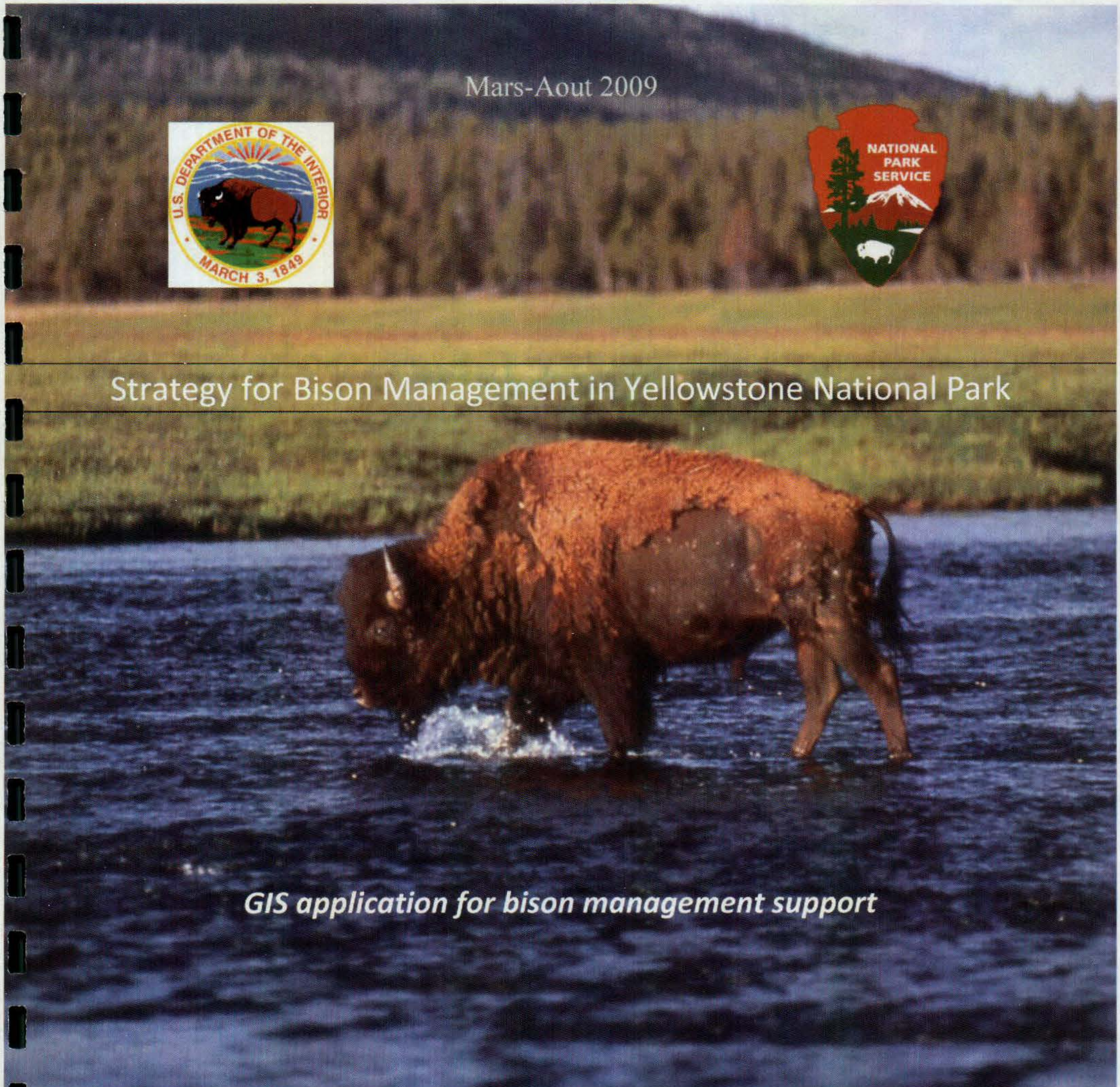

Strategy for Bison Management in Yellowstone National Park

GIS application for bison management support

université PARIS DIDEROT PARIS 7

Agnès de Montjoye

Stage de fin d'études dans le cadre du Master 2 Professionnel Espace et Milieux pour le Parc National de Yellowstone, U.S.A.

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TABLE OF CONTENTS

TABLE OF FIGURES

INTRODUCTION

A controversy like the one surrounding bison migration illustrates the complexities confronting today's land managers, who are responsible for maintaining Yellowstone National Park ecosystems in face of a growing population with increasingly diverse expectations and values.

Historically, Yellowstone bison occupied approximately 20.000 km2 in the headwaters of the Yellowstone and Madison rivers. But nowadays, this area is restricted to the 9000 m2 of YNP boundaries and the main issue for YNP managers about bison is to deal at the same time with the biggest migratory mammal of North America and human presence and activities in the same area.

The bison of Yellowstone National Park are ecologically and evolutionarily significant because they are the last free-ranging herds exposed to natural regulation and selection and the only free-ranging plains bison population on the continent. The movements and population dynamics of large mammal populations as bison need to be viewed at a spatial scale significantly larger than the park itself, in particular because bison respond to regional environmental gradients of forage quality and availability, which are influenced by climate, altitude, snow cover, elevation, vegetation cover, predation, etc. Bison movements naturally ignore Yellowstone National Park boundaries.

Thus, human activities and infrastructure around the park influence bison management and distribution patterns, such as:

- Utilisation exclusive of natural forage for domestic livestock;
- Alteration of large areas of native vegetation (generally the most productive types) for agricultural and livestock feeding purpose;
- Creation of physical or psychological barriers to unrestricted ungulates movements, distribution, and use of habitats (towns, ranches, highways, fences, and activities associated with farming and ranching), etc.

Moreover, bison management is complicated by the brucellosis transmission outside the park. Bison herd in YNP are infected with *Brucella abortus* that typically caused abortions in most affected females. Bison are likely to transmit it to livestock when they exit the park boundaries, especially at the northern boundary where most of the ranches are. No vaccine is highly efficient and neither the way to easily administer this vaccine to free-ranging wildlife.

Bison management overpasses YNP policy and concerns as much YNP managers as ranchers in Montana State. At least 28 federal, state, and local entities manage various activities in the Great Yellowstone Ecosystem (GYE), most of the time with conflicting goals. For that reason, wildlife conservation versus cattle production, management of brucellosis will remain a contentious issue. No management alternative seems to simultaneously meet YNP's goal of minimizing interference by humans and the livestock industry's goal of brucellosis eradication. Management actions to eradicate brucellosis are also limited and a temporal and spatial separation of wild ungulates and livestock seemed incompatible for more than a decade since now.

Finally the task confronting public land managers in and around Yellowstone National Park is how to protect the park's natural values while also accommodation human interests and economical activity. Answering this question raises difficult scientific, philosophical, legal, and economic issues:

- The scientific issues focus on the need to develop a comprehensive understanding of ecological relationship throughout the region as well as better understanding of the cumulative impact that development activity has on the region's ecological systems.
- The philosophical issue is whether public lands and resources should be managed to give priority to nature or exploited and developed for human benefit – a long-standing point of conflict.
- The difficult legal question is how to reconcile fundamentally different legal mandates and policies when official decisions are likely to have adverse environmental or economic impacts on nearby resources, lands and communities.
- The economic issues are challenging public officials to devise resource management plans that will preserve the natural integrity of the region but also

provide sufficient economic opportunities to sustain local economies and ensure a reasonable return to the federal treasury.

How the park answers to that complexity of level induce by Bison management? How to deal with those issues and to reduce conflict around bison management? For Yellowstone National Park, the challenge is to design a new way of improve policy stability, involving all the owners of public and private lands surrounding Yellowstone national park actors concerned by bison management, but also with its own values of conserving the bison ecosystem.

A first part will present the fluctuation in YNP bison management since the creation of the park in 1872, hesitating between "nation enjoyment" and ecosystem preservation. The paradigm for bison management is indeed an increasing demand for democratization of natural resource conservation in the same time as constant reducing areas for migratory bison population management.

A second part will present the YNP efforts to predict range expansion and transboundary movements. Forecasts are necessary to form bison management decisions within and outside the park and geographical information systems (GIS) allowed information to support wildlife management. Bison population are sensitive to variation in several key variables and interactions between variables: forage availability, terrain characteristics (slope, ruggedness, streams), snowpack characteristics, bison density, groomed road, climate events, etc. Being able to predict those contingencies would allow Yellowstone National Park and public and private land owners to address the bison management paradigm: preserve a unique ecosystem and avoid brucellosis transmission.

PARTIE I- The past and present bison paradigm in Yellowstone National Park

A) Bison myth and the harmony of nature

1) Prehistoric presence of the bison in Yellowstone Ecosystem and Native American relationship

Some prehistoric evidence established that bison (*Bison bison*) are native to what is now Yellowstone National Park and the surrounding country (Meagher, 1973). The Lamar Cave, on Yellowstone's northern range, reveals bison bones dating about 3,000 years before present (Hadly, 1995). What was part of the ecosystem where bison evolved for thousands years? Why do they suddenly disappeared form north America during the XIXth century?

Nowadays, efforts at ecosystem management understanding in North America often overlook the role of ancient Native American populations as a significant component of past ecosystems. But archeological research has shown that humans have resided in Yellowstone National Park for more than 10,000 years (Cannon, 1993). Those studies in the northwestern Plains indicate that human predation on bison during the Late Prehistoric Period (1,800-200 years ago) occurred at a large scale. Human populations might have been an extremely significant component of ancient Plains ecosystems. And they were probably the most influential of large predators on bison demography. In comparison, wolf predation was almost insignificant. Estimation evaluates the catches by Late Prehistoric Period hunters-gatherer populations around 200,000 bison per year in the Plains of Montana, while wolves killed roughly 25,000 bison. Wolf predation tends to select calves and old or ill bison, although they are perfectly able to kill animal of all ages. But wolves typically kill a single bison while ancient human hunters killed multiple bison during communal hunts. They usually used strategies that took advantages of the herding behavior.

Assertions of the human predation impact on an ungulate population are possible because of the archeological bison kill sites. At a small proportion of sites, the bone assemblage probably results from a single kill event. However, other sites present a number of kill events and an amount of bones that inform of an elapsed time between successive kills (days, months, or sometimes years) and attest to the occurrence of multiple kill events (Wilson, 1998).

Human predation on bison in the Plains of North America began by at least 11,000 years ago. For example, the Mill Iron site bonebed and campsite, situated in southeastern Montana, dates to about 11,000 radiocarbon years before the present. An excavation there uncovered the remains of some 35 bison (Todd et al., 1996). The bonebed seems to represent a single kill event.
Four others bison kill sites, Bootlegger Trail, Ulm Pishkun, Highwood, and Vore, provide information on the extension of communal bison hunting during the Late Prehistoric Period in the northwestern Great Plains (Frison, 1991).

The Bootleger Trail bison kill site shows the hunters' practices: the bison were apparently killed being driving into a small coulee. The site seems to have been used on several occasions and the entire site contains the remains of roughly 1,485 postnatal bison.

As for the Ulm Pishkun bison kill site, a large cliff jump in central Montana west from the city of Great Falls, the site presents an enormous quantity of bison bone which attracted commercial bone mining activities in the 1940's to sell for fertilizer (Davis, 1978). Recent investigations indicate that bison killing occurred on multiple occasions, from 500 B.P. to 1,000 B.P. Records indicate also that some 225,000 kg of bone were extracted from the site, which might be some 10,000 bison.

The Vore site in the Black Hills of Wyoming presents some 22 separate layers of bones accumulated from bison hunting between approximately A.D. 1500 – 1800 (Reher and Frison, 1980). Those 22 layers might contain skeletal remains of at least 10,000 bison, and perhaps as many as 20,000 or more.

Finally, the records from commercial mining undertaken during the 1940's in the Highwood bison kill site indicate that more than 5,400,000 kg of bison bone, hide and

other tissues were removed from this site (Davis, 1978). A rough estimation would mean some 238,000 bison killed. The deep accumulation of archeological deposits suggests a span of time of at least several centuries.

All these sites demonstrate the human predation at a large scale on bison during the Late Prehistoric Period. The only major bison kill sites were presented, but some 320 other sites exist in Montana. It is normal to think that many other sites disappeared along the geological processes and other forces.
All told, the scale of bison hunting by humans during the Late Prehistoric Period, though difficult to quantify with precision, seems to be very substantial.

The human predation on bison differed from the wolves' one not only in quantity but also in quality. The age of the prey constitutes a major factor. Most of the bison kill sites are dominated by adult and subadult skeletal (excluding calves). Calves (animal in their first year of life) typically have low representation in these bone assemblages. In three of the whole sites presented before, the proportion of calves relative to the total count of individuals varies from 1,4% to 3%. In the Vore bison kill site, that proportion reach 22% (relatively to the estimated number of mature cows). Probably, the ancient hunter-gatherers thought to maximize energy returns from their hunting activities. The few quantity of fat and meat in a calf body make it less attractive than older animals for consumption and calf body with lots of cartilage is harder to conserve than an adult body.

Unlike in human predation, bison calves are killed in a relative high number by wolves compared to adult bison. At Wood Buffalo National Park in Canada, the calves are vulnerable to wolf predation. In 1978-79, calves constituted almost 35% of the bison killed by wolves (145 calves).

Bison female preys dominate in human predation. This might be explained by the nutritional condition of the animals (Speth and Spielmann, 1983). Indeed, bulls and cows differ in the degree and the seasonal timing of when they are in the best or in the poorest nutritional condition. Animals in poor conditions (e.g., low fat reserves) probably would have been less attractive to ancient hunters. Female bison would have been in peak nutritional condition in the fall of the year (Speth, 1983) as probably would have calves. This optimum during that period of the years corresponds to the fall hunts of the

prehistoric Plains hunter-gatherers, who amassed stores of meat to resist the rigorous winter months (Reher and Frison, 1980).

Management implies goals as to maintain a population near some optimum number, or to increase genetic variability, or to sustain a population constant development, etc. Even if attributing a *management* to prehistoric early historic Native American interactions with bison seems exaggerate, there can be no question that humans took a major part on bison ecology over the last ten thousands years. At least, hunting by those Late Prehistoric Period hunter-gatherer peoples probably influenced bison population dynamics more significantly than did predation by wolves or any larger predator, and the Euroamerican expansion across North America altered ecological relations among Native peoples and bison (Fisher and Roll, 1997).

From management to extinction

"The buffalo, our brother, was always here with us, furnishing us food, hides for our clothes, robes for our beds, sinew, bones, everything that they provided for our livelihood. So we have a special relationship historically and religiously with the buffalo that is still strong to us this very day".

Joe Medicine Crow, Absaroke Indian Tribe (Crow), historian and author, 2000

Hunting bison in the southeast Montana was a major element explaining the cultural, economical and environmental transformation during the nineteenth century. How the eradication occurred is not clearly understood yet and lots of long standing myth clouded the complex relationships which existed between Native and EuroAmerican cultures, between hunters and bison, between the environmental conditions and the wildlife.

Two factors might explain the quick depletion/decrease of the great northern bison herd: a natural one, and a human one. How did environmental conditions affect the region's ecology? Were Native Americans "ecological" hunters (Haynes, 1997)?

Climate conditions, grazing intensity, fire, and competition by other herbivores influenced the region's carrying capacity. From 1790 to 1884 (94 year period), tree-ring analysis indicates that 66 years (70%) had average or lower precipitation than the average

precipitation levels, within 23 years experiencing dry to drought conditions (Lawson, 1974). Such climate conditions impact moisture and forage productivity. A period of drought lasting two years or more could reduce productivity by as much as 90% (Albertson et al., 1957). In the same way, fires affected plant growth by as much as 50% in the first year, with full recovery occurring under grazed conditions within 3 or 5 years. As grass productivity declined to below conditions the bison population would slowly follow. So for centuries, bison seasonal movement responded to the availability of grass and water during the summer, and shelter during the winter months.

Three other factors would have discouraged bison population recovery during the second third of the nineteenth century, which are human factors.

The introduction of the horses into the region around the 1730's dramatically changed the relationship between Native American hunters and the bison. Horses allowed Indians greater opportunities to hunt bison. While they were hunting by foot before, trying to isolate one individual from the herd to kill him or to trap them in natural coulee, they were now able to make easier transportation to and from the kill site, to hunt selectively cows over bulls as a preferred meat and hide source, to hunt more regularly and to develop more individualistic hunting methods. First, horses were incorporated into communal hunting methods as explain in the first part, yet by the early 1800's, "buffalo running" had become the dominant hunting technique used by the northwest Plains Indians.

Indians who lived and hunted within the region are estimated to have owned more than 12,000 horses, which would have reduced available forage of 11,000 bison. Horses and Indian presence further affected bison by competing for critical winter and spring foraging areas. As the one time trapper James Beckwourth, who lived with the Crow Indians between 1826-1838 noted: "We had such an immense number of horses that the prairie round our lodges in a few days had the appearance of a closely-mown meadow" (Haynes, 1997).

While horses affected bison by reducing available forage, the fur trade added a second factor to bison population depletion. In 1813, Manuel Lisa transported 3,000 robes to

Saint Louis from the Yellowstone region, and by the 1830's, an estimated 5,000 robes were annually shipped to eastern markets (Baker, 1987; Haynes 1997).

The increase in Native and EuroAmerican hunting expanded annual bison mortality between 10,000 to 20,000 animals on an estimated population of 800,000 to 1.1 million animals. Combined with an annual mortality from Indians hunting of 58,000 bison and a natural mortality of approximately 80,000 bison, it would have mean around 150,000 bison killed yearly, with cows being killed at higher rate than bulls. Indeed, robes were tanned from cows only, further increasing cow mortality and inhibiting calf production.

If these estimations are only approximations, it underlines at least how intensive was the pressure on bison population. This suggest also that mortality probably exceeded annual births during dry conditions of the early 1800's, and that the bison population reached its threshold in the first third of the nineteenth century.

Finally, the third factor was the increasing utilization of the region by Indians and EuroAmericans. Indian bands migrated to the Yellowstone in search of bison as herds were depleted in Canada, the Dakotas, lands west of the continental divide, and the upper Platte River region. American traders, sportsmen, and explorers were also using the region in greater numbers with "fat" bison cows the preferred meat source. Hunting pressure intensified mainly after 1850's. Being bison-dependent, northwest Plains Indians continued to hunt bison at whatever cost. With the Lakota defeat and removal to reservations in 1876, the region experienced a rapid expansion of homesteaders, ranchers, and commercial hide hunters. With the development of a tanning process that turned bison hides into leather, industrial mills and factories had a new source for leather belts to run their machinery and the demand was enormous (Haynes, 1977).

By the summer of 1884, railroads had replaced steambots and EuroAmericans had displaced Indians, as cattle were replacing the bison. This could explain a possible fourth factor, which may have deeply impacted bison recovery: the introduction of exotic bovine diseases. Brucellosis, anthrax, and tuberculosis had infected bison by the late nineteenth century (Flores, 1991).

For centuries, the bison evolved with the northern plains environment, along with human presence and actor of its ecosystem. Seasonal movements responded to the availability of nature, for both bison and Natives. With human use intensification of the "Far West" and the chain of events, hunting bison began an important factor of development, which changed the relationship between bison and its environment.

Ancient human populations may have constituted the most efficient large predator in Yellowstone ecosystem and human predation and manipulation profoundly affected North American bison ecology. Such manipulation includes habitat modification, bison population modification, and deliberate modification of bison behavior (migration, etc.).

2) Presentation of Yellowstone ecosystem

Ecological conditions and terrain modified for human infrastructure define the environmental setting influencing the spatial and population ecology of bison in Yellowstone National Park. But the Yellowstone ecosystems goes further more than the human boundaries designed at the end of the XIX century, and that is one of the ongoing issues for the park managers.

a) Yellowstone National Park

a-1) Establishment of Yellowstone National Park: For the enjoyment of the people and for its landscape characteristics

In 1870, explorers gathered around a campfire by the towering cliffs of the Madison Plateau and discussed what they had seen during their exploration. They realized that this land of fire and ice and wild animals needed to be preserved. The idea of Yellowstone National Parks was born.

Fig. 1. 1957 re-enactment of the Washburn Expedition of 1870

In Camp at the junction of the Firehole and Gibbon Rivers (Madison Junction).

Courtesy of National Park Service Historic Photograph Collection

Source: Haines, 1974.

The Congress established the YNP in 1872, and the Yellowstone National Park Protection Act says "the headwaters of the Yellowstone River... is hereby reserved and withdrawn from settlement, occupancy, or sale... and dedicated and set apart as a public park or pleasuring-ground for the benefit and enjoyment of the people".

For the following years, Yellowstone was "the national park', until the Congress established three more national parks in 1890 (Sequoia, General Grant and Yosemite). In 1906, Congress passed the Antiquities Act, which gave the president authority to establish national monuments. By 1914, the United States had 30 national parks and monuments, each managed separately and administered by three different federal departments – Interior, Agriculture, and War. There wasn't any unified policy or plan for the protection, administration or development of these parks.

Thus in 1916, the National Park Service Organic Act was passed by Congress: " There is created in the Department of the Interior a service to be called the National Park Service, [which]... shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations... by such means and measures as conform to the

fundamental purpose to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations".

A Decade of Environmental Laws

Beginning in the late 1960s, the U.S. Congress passed an unprecedented suite of laws to protect the environment. The laws described here particularly influence the management of our national parks.

The National Environmental Policy Act (NEPA)*, passed in 1970, establishes a national policy "to promote efforts which will prevent or eliminate damage to the environment ... stimulate the health and welfare of man ... and enrich the understanding of ecological systems ..." It requires detailed analysis of environmental impacts of any major federal action that significantly affects the quality of the environment. Environmental assessments (EAs) and environmental impact statements (EISs) are written to detail these analyses and to provide forums for public involvement in management decisions.*

The Endangered Species Act (1973) *requires federal agencies to protect species that are (or are likely to become) at risk of extinction throughout all or a significant part of their range. It prohibits any action that would jeopardize their continued existence or result in the destruction or modification of their habitat.*

The Clean Water Act (1972) *is enacted to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" by prohibiting the discharge of pollutants.*

The Clean Air Act (1970) *mandates protection of air quality in all units of the National Park System; Yellowstone is classified as Class 1, the highest level of clean air protection.*

Fig. 2. Legal Environmental Acts

Source: 2009 Ressources and Issues, Yellowstone National Park, National Park Service.

So when the Congress established the park in 1872, they did it to preserve Yellowstone's geothermal curiosities; it lacked any knowledge or appreciation of ecological realities. Now that ecological connections between the national parks and surrounding lands are better understood, environmental groups and others have begun calling for an ecosystem-based approach to public land management. This ecosystem would be based more on ungulate free ranging, or fire extension. Indeed, neither ungulates nor fires stopped to the park's boundaries during the 1988 summer fires for example, or during the seasonal habitat movements far beyond park boundaries.

Environmentalists argue that the Yellowstone region properly should be labelled the Greater Yellowstone Ecosystem and managed as an integrated ecological entity. This type of management should protect the region's world-renowned natural features, such as wildlife protection, recreational opportunities, and aesthetic views.

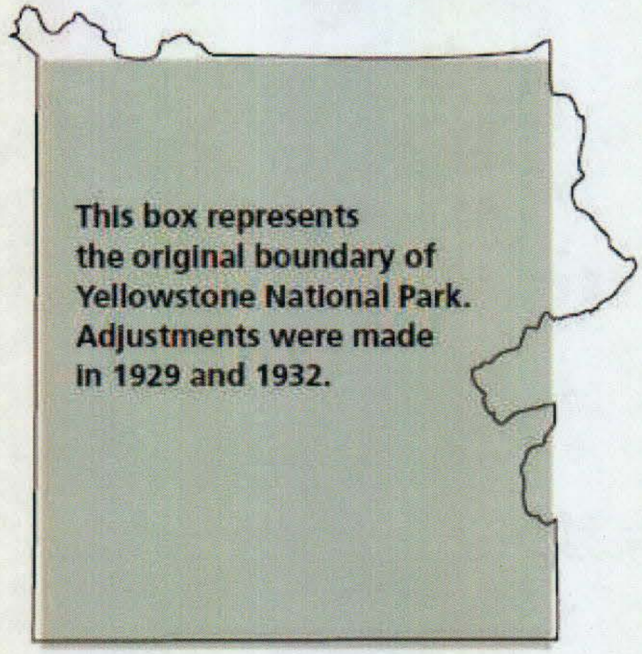


Fig. 3. Adjustments in YNP boundaries

Source: 2009 Ressources and Issues, Yellowstone National Park, National Park Service.

a-2) Geography and geology characteristics of Yellowstone National Park

i. Yellowstone National Park

Yellowstone National Park is 8,983 km² mountainous reserve in the northwest corner of Wyoming, south of Montana, and east of Idaho in the Middle West of the United States. Major rivers in Yellowstone National Park include the Snake, Yellowstone, Gallatin; and Madison, and major lakes include Lewis, Heart, Shoshone, and Yellowstone (Rodman et al. 1996). Mountain ranges in YNP include the Absaroka, Gallatin, and Washburn (Rodman et al. 1996). The continental divide traverses YNP from west to southeast (Magher 1973). Major shrub and grassland valleys in Y include Lamar (part of the northern range in which we are particularly interested), Pelican, Hayden, and the Firehole.

Extensive volcanism and glaciations shaped the landscape of YNP (Meagher 1973). Parts of the Plateau were formed by uplift and erosion during the Precambrian Era, 2.7 billion years ago (Meagher and Houston 1998) and the southern Rocky Moutaints were formed between 100 and 50 million years ago, from late Cretaceous through Paleocene (Despain 1990, Rodman et al. 1996, Meagher and Houston 1998). The Yellowstone area has existed as a terrestrial environment since 90 million years ago. Then, volcanic eruptions further shaped the landscape during the Eocene Era 50 to 40 million years ago (Despain 1990, Meagher and Houston 1998). Sixteen million years ago a plume of magma formed below the earth's crust 600 km southwest of the present Yellowstone plateau and subsequent large volcanic eruptions 2.1, 1.3, and 0.6 million years ago formed the three partially overlapping calderas (large basin volcanic depression) (Meagher and Houston 1998). The current Yellowstone caldera extends from Old Faithful to Mount Washburn in the north and to Yellowstone Lake in the east. It still provide an active heat source in parts of YNP, giving geysers, hot springs, mud pots and fumaroles, in an unusually high concentration (Rodman et al. 1996).

Yellowstone National Park is characterized by a decreasing elevation gradient from east and south to west and north. The centre of the park is generally higher than the northern YNP. In that northern range, highest elevations occur on the Mirror Plateau and Cache Calfee ridge (2500 meters) and decrease through the Lamar Valley (between 2200 and 2100 m) to the Gardiner area (1800 m). The highest elevation in YNP occurs at the central part of the park at the Mary Mountain (2500 m). Both Pelican Valley and Hayden Valley are at 2400 m, and elevation drops in the Firehole (2225 m), to Madison Junction (2100 m), and out to West Yellowstone (2050 m).

ii. Climate

The YNP climate can be divided into four seasons: Springs begins March or April, extends through June, and is characterized by cold to cool nights and warm to cool days. During this period, snow gradually melts and disappears over time and with elevation. Summer is short and occurs during July and August. Even during those two months, snow falls can still occur, and some summits are still cover of snow (e.g. Electric Pick is snow-free for only 2 or 3 weeks at the end of July). Falls begins in September and

extends through October. September is also synonym of important snow falls, and finally, winter begins in November and ends in March-April.

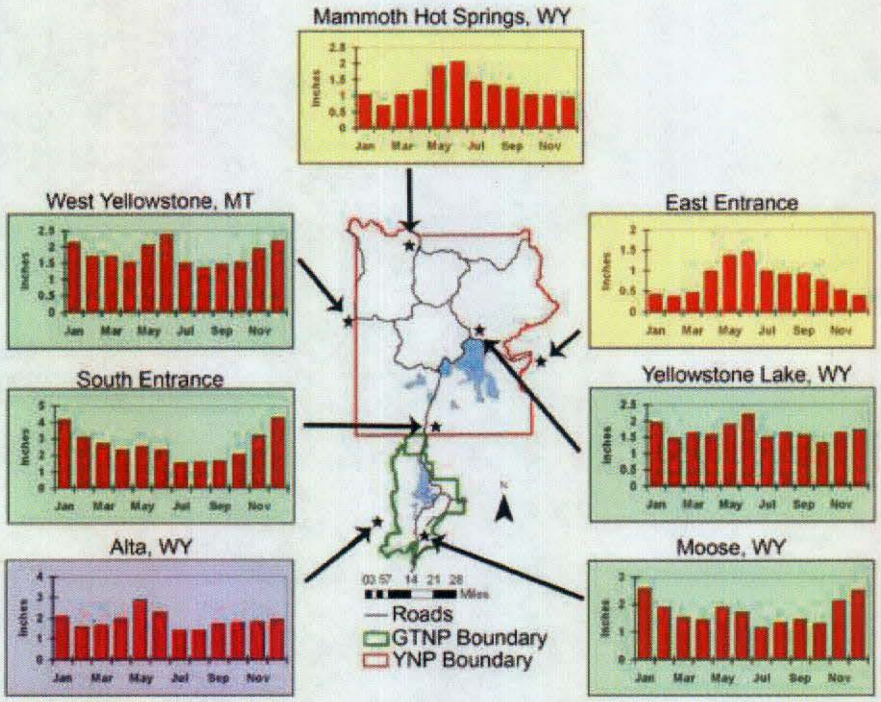


Fig. 4. Average monthly precipitation in Yellowstone (YNP) and Grand Teton (GTNP) national parks during 1948–2007.

Northern and eastern regions (yellow-shaded graphs) have proportionally more precipitation in summer. Southern and western regions (green) have more in winter. The western slopes of the Tetons (blue) are more uniform seasonally.

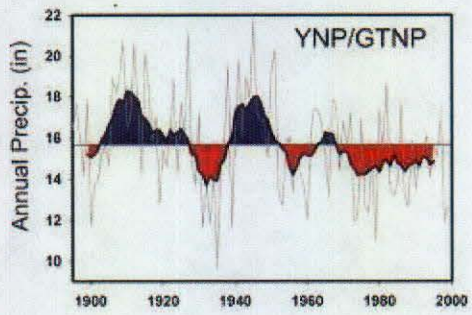


Fig. 5. Regional average precipitation trends for the Greater Yellowstone Area.
The light gray line indicates annual precipitation. The dark line shows the 10-yr moving average. Red and blue shadings show dry and wet periods, respectively.

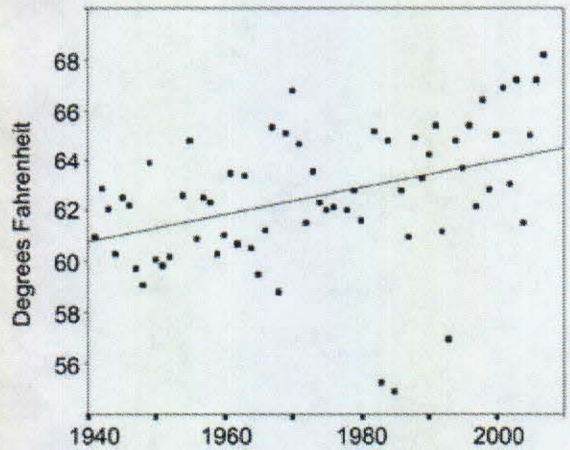


Fig. 6. Average July temperatures at Mammoth Hot Springs, Wyoming (Yellowstone headquarters) during 1940–2007.
July temperatures during 1997–2007 were an average of 3.5°F warmer than during 1940–1950. The line indicates a statistically significant trend. Similar trends have occurred at weather stations throughout the region. July is the reference in the park because it corresponds to the optimum net primary production of vegetation, and represents an major factor in ungulates movements.

Even if precipitation does return to normal, increasing temperatures are likely to cause more frequent droughts in the future, with accompanying increases in fire frequency and severity. Increased evaporation caused by future warming could exacerbate water stress

for plants, and a greater proportion of annual precipitation will likely fall as rain rather than snow. Rather than being stored in the snowpack and gradually released during the year, this rain will be rapidly lost to streams and unavailable for plants. The snow that does accumulate will likely melt more quickly as a result of the predicted warming trends, producing earlier and more intense spring runoff. Total annual stream discharge may remain steady or decline, but as a greater proportion becomes compressed into an increasingly intense spring runoff, streams could be lower in summer months, contributing to water scarcity.

On average, peak runoff in the last 10 years has occurred 10–20 days earlier than historic averages throughout the region, and this trend is considered likely to progress another 20 days by the end of the century .

iii. Vegetation

Two major soil parent materials occur in YNP, rhyolitic and andesitic materials, both derived from bedrock deposited during volcanic events (Despain 1990). Sedimentary deposits also make up some of the soil materials in YNP (Despain 1990). Andesitic and sedimentary soils are richer in nutrients than rhyolitic soils (Despain 1990).

The large valleys of Lamar, Pelican, Hayden, and Firehole all have dense sedge. The slightly higher slopes and levels support bunchgrasses, forbs, and sagebrush (Cf. Annex 3). Shrubs, except sagebrush, are of limited extent generally in these valleys. In most parts of the northern range, extensive grassland and sagebrush are particularly common, although the sizes and aereal coverage of riparian willows and cottonwoods have decreased since the early 1900's.

Approximately 80% of YNP is covered in forest, of which 60% are subalpine-fir (*Abies lasiocarpa*) mixed with lodgepole pine (*Pinus contorta*) communities (Despain 1990). These extensive lodgepole pine forests typically grow on nutrition-poor soils derived from rhyolite. Forest at lower elevations (under 2000 m) is characterized by Limber pine (*Pinus flexilis*) and Douglas-fir (*Pseudotsuga menziesii*). Lodgepole pine, Spruce-fir-pine and Whitebark pine (*Pinus albicaulis*) are characteristic of higher elevation forests (from 2000m, to 2400 m and to 2800 m respectively) (Meagher and Houston 1998).

On the upper plateau levels and mountain slopes, subalpine meadows are found, and even if sagebrush and grasses have changed little at those higher elevations, the cover and the density of sagebrush and other shrubs has been greatly reduced at some lower elevation sites, especially areas near the northern border of YNP.

iv. Fire

Fires are part of the YNP for millennia. Major fires appear to occur every 100-300 year intervals (Klein et al. 2002), usually during dry periods. Smaller fires occurred approximately every 20-25 years in the northern portion of YNP before the initiation of fire-control measures in the late 1800's. Natural fires were suppressed in YNP through most of the twentieth century until that policy changed in 1972.

YNP has been shaped by 9 to 12 major fire events over the last 2,000 years. The fire of 1988 was considered a major fire in scale. It burned roughly 794,000 acres of YNP (Despain 1990), about 36% of YNP, of coniferous forest and sagebrush-grasslands (Turner et al. 1994). Fires can have significant effects on ungulates up to four years post-fire, although effects diminish within this time (Pearson and Turner 1995). Substantial immediate post-fire ungulate mortality can result because of reduced forage and typical drought conditions reducing forage in unburned areas (Turner et al. 1994). In subsequent years, fire may stimulate primary productivity resulting in improved forage quantity (Turner et al. 1994).

v. Wildlife

Humans have used the area that is now YNP since the end of the last glaciation, about 10,000 years ago. This long history of human used has helped to identify that all the major ungulates and predators now occupying YNP, as well as many other small animals, have been present for at least those past 10,000 years. However, it is impossible to estimate historical abundance of those species. All that can be stated with confidence is that they were present in large number enough to remain till present in the YNP.

Reliable population estimates for elk (*Cervus elaphus*) in the northern range became possible with the beginning of aerial surveys in 1952. Before, from the 1930's to the

1960's, the National Park Service hunted elk to reduce their populations because park scientists during this period considered the northern range overgrazing by an excessive population of elk. By the late 1960's, when YNP adopted natural regulation, the northern range elk population had been reduced from some 10,000 to fewer than 5,000 animals. By the late 1980's, as much as 20,000 elk were on the northern range, and approximately 12,000 in 1999.

Other ungulate populations have also fluctuated over time, and apparently, pronghorn are declining with only 200 remaining in the late 1990's.

During various periods after the park was established in 1872, predator populations (e.g. mountain lions) were reduced and wolves were eliminated to be reintroduced in 1995. Today, about 160 wolves reside in YNP, 50 of which are on the northern range. There are about 300 grizzly bears, and between 1,000 to 2,000 black bears.

b) The Great Yellowstone Ecosystem

The general public tends to look at the Yellowstone region as one large national park, but the regional landownership is much more complex. The National Park Service (NPS) and the U.S. Forest Service are the principal landholders in what both agencies now refer to as the Greater Yellowstone Area.

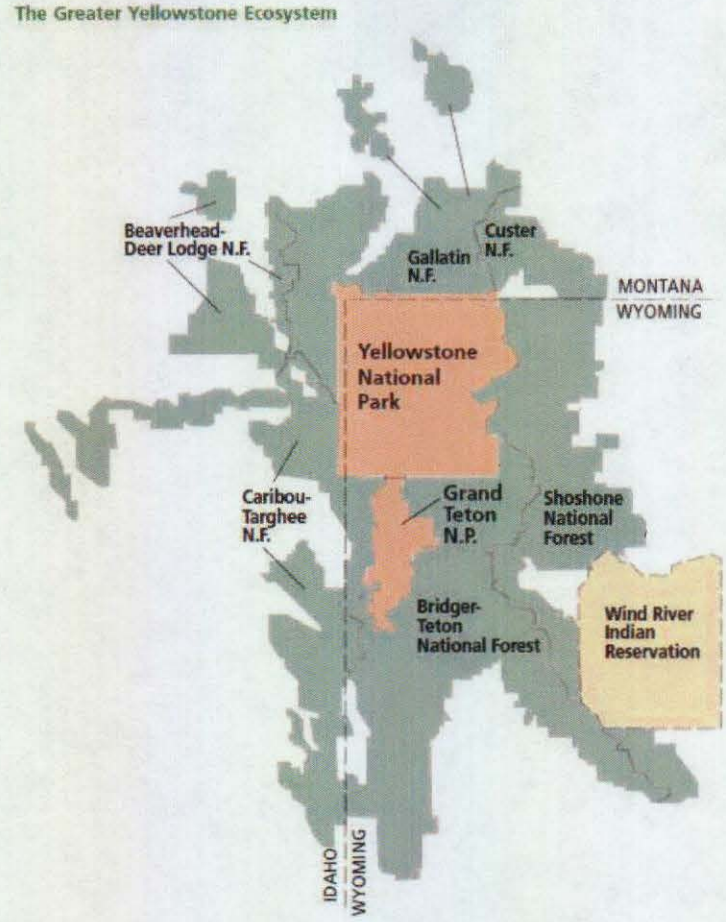


Fig. 7. The Greater Yellowstone Ecosystem

Source: 2009 Resources and Issues, Yellowstone National Park, National Park Service.

The Greater Yellowstone ecosystem is not defined by boundary lines. Neither the wildlife nor these natural features are confined to the national parks. Many species ecosystems are beyond park borders to meet their seasonal habitat needs, just as the geothermal aquifers, river systems, and forests.

Greater Yellowstone area is more than 7.3 million hectares of public and private lands located in the states of Wyoming, Montana, and Idaho. It includes two national parks (Yellowstone and Gran Teton), portions of six national forests (the Bridge-Teton, Shoshone, Targhee, Gallatin, Custer, and Beaverhead), three national wildlife refuges (National Elk Refuge, Red Rock Lakes, and Grays Lake), Bureau of Land Management landholdings, and states and private lands.

National park lands and Forest Service wilderness areas total approximately 2.5 million hectares, but both have two very different missions.

On the one hand, the Forest Service manages its wilderness lands under a preservationist mandate designed to minimize intrusive human activity. The nonwilderness national forest lands are managed under a "multiple-use" mandate, which provides for logging, mining, grazing, and recreational activities as well as wildlife and watershed protection. The region's remaining land is mostly in state or private ownership; it is generally not governed by federal law and is open to development.

On the other hand, the Park Service is obligated both to preserve its lands and to provide for public enjoyment. This duality in park's goals has historically found the agency hesitating between its two obligations.

Yellowstone and Grand Teton national parks are at the center of that vast complex of designated wilderness lands. This park-wilderness complex is considered as the core of a regional ecosystem characterized by an important diversity of wildlife: the largest elk herds in the world reside in Greater Yellowstone, as does the remaining free-roaming bison herds. The region provides habitats for rare or endangered species as the grizzly bear, whooping crane, bald eagle, peregrine falcon, and trumpeter swan (Keiter and Boyce, 1991). The world's largest undisturbed geothermal region, which has dramatically shaped the Yellowstone landscape, is an integral part of the ecosystem. The Greater Yellowstone Ecosystem includes the headwaters of three major river systems, the Snake-Columbia, the Green-Colorado, and the Yellowstone-Missouri. The region's vegetation is as in YNP predominantly lodgepole pine and spruce forests.

Since the early settlers arrived more than a century ago, people have become a ubiquitous presence throughout the Yellowstone region. Some of the initial inhabitants carved ranches and farms out of the wilderness, others sought their fortune in mining, and still others logged the forest for their livelihood. These early economic activities, which largely relied upon public domain resources, continue today, with oil and gas exploration joining mining as an important mineral development activity.

In addition, tourism has become a major industry throughout the region, and recreational use of the public lands has increased dramatically. During the summer months, several million visitors descend on the national parks, swelling the local population to more than

ten times its normal size. And the tourist season is now extending through the winter months, with park visitors, skiers, and snowmobilers all seeking access to what had previously been an undisturbed winter landscape.

- The formidable task confronting public land managers in Greater Yellowstone is how to protect the region's natural values in the same time as human access and recreation and economical activity (Keiter and Boyce, 1991).

The Park Service believes that "a healthy Yellowstone ecosystem will benefit the regional economy most in the long run", but National Forest are not ready to manage their lands as "National Park buffer zone" (Keiter and Boyce, 1991).

Ecosystem concept

The Greater Yellowstone Ecosystem makes reference to scenic beauty, wildlife, and geysers. But that is one perception, the one that impulse the creation of Yellowstone National Park some 130 years ago. Another way to identify the Greater Yellowstone Ecosystem would be to include the two national parks, the national forests, wildlife refugees, etc. But still, neither of these perceptions actually defines the Greater Yellowstone Ecosystem; one is aesthetically oriented, the other geopolitically conceived. The Greater Yellowstone Ecosystem has no definite boundaries, and yet it is bound by its ecological unity or cohesiveness.

An ecosystem is a dynamic, functional ecological unit. Within it, biotic and abiotic factors interact through a wide variety of processes. These interactions maintain a relative balance among four basic components: living organisms, water, atmosphere, and earth. An ecosystem can also be defined as "any part of the universe chosen as an area of interest, with the line around that area being the ecosystem boundary" (Johnson and Agee 1988).

Ecosystem boundaries are usually identified in the context of ecological processes or the spatial distribution of a species, although there will always be some movement of

organisms, nutrients, and energy across these boundaries (McNaughton 1989, Barmore 2003).

The discussion of the Greater Yellowstone Ecosystem is based on the premise that the system is still relatively undisturbed. Compared with highly manipulated agricultural and ranching systems surrounding the ecosystem, it would be true. But the Greater Yellowstone Ecosystem is not undisturbed of human presence. As seen at the beginning, humans were in that geographical area since 11,000 years. To be aware of the human presence and to manage the entire system is a key point, recognizing that ecosystem processes do not stop at jurisdictional boundaries.

The Greater Yellowstone Ecosystem should be wisely managed, which may mean "letting take its course" or utilizing additional environmental protections. Its unifying character, however, requires for manager to consider it as a large single system rather than a mosaic of smaller ecosystems. Separate management might cause the system as a whole to fragment.

The Park was established in 1872 with the aspiration to manage its resources in the common interest, "for all people"; this has not changed (Cromley 2002). The challenge is to design a new way of dealing with complex issues that will reduce conflict, improve policy stability and achieve wise outcomes for society, conservation of ecosystem values, while respecting people who are a part of the Greater Yellowstone Ecosystem (Gates et al. 2005).

Finally, the definition of wildlife management offered by Riley et al. (2002) represents recognition of the requirement for interdisciplinarity and the increasing demand for democratization of natural resource conservation now being experienced worldwide: Wildlife management is "the guidance of decision-making processes and the implementation of practices to purposefully influence interactions among and between people, wildlife, and habitats to achieve impacts valued by stakeholders".

B) Bison Ecology in Yellowstone National Park

1) Bison Home Ranges and Movement Corridors

Migratory movements are often predicated on the need for resources, especially food, which may be affected by biotic and abiotic factors (Gilbert et al. 1970, Maddock 1979, Bergerud 1988, Fryxell and Sinclair 1988, Whitehead 1996, Knight et al. 1999, Geremia et al. 2009). The bison winter range is defined as the common destination winter foraging area and the corridor leading to that range is defined as the common winter movement pathway connecting two ranges within which foraging may occur. Normally, the majority of the group (cows and calves mainly) forages and travels in those areas, rather than any other locations where it might occur. The home range is the familiar area physically visited by bison in a given time interval (Baker, 1978), during normal foraging activities, mating and caring for young. Home ranges vary between seasons and home range might depend on bison sexes. Bison can navigate from one point to another point within a familiar area.

In Yellowstone, 5 bison winter ranges and 5 winter movement corridors are identified.

In northern YNP, there are two ranges:

- The Lamar Valley (230 km^2)
- The Gardiner Basin (100 km^2).

Most of the time, the Lamar Valley and the Gardiner Basin are considered as one entity, called the northern range. But the Lamar Valley is inside Yellowstone National Park, whereas the Gardiner Basin is mainly outside YNP. In the Lamar Valley, bison use mainly flat valley bottoms along the Lamar River and no the steeper upland grassland habitat.

In the central YNP, 3 bison winter ranges are identifies:

- Pelican Valley (55 km^2)

- Mary Mountain (150 km², including Hayden Valley and the Firehole)
- And West Yellowstone (80 km²).

Hayden Valley and the Firehole were grouped together because of historic continuous movements back and forth between the two valleys over the Mary Mountain trail, throughout the winter.

Like Gardiner Basin, the portion of the West Yellowstone bison winter range outside YNP is delineated based on bison exited the park.

The 5 corridors are the primary bison movement pathways between winter ranges. In the northern range, the Gardiner basin to Lamar Valley corridor (GLC) is located along the Yellowstone River and the road from Cook City (North- East of the park) to Gardiner. The Mirror Plateau corridor (MPC) extends from southeastern Lamar Valley to northeastern Pelican Valley and is considered to be infrequently used by bison (Cf. Fig. 9). The reason would be the rugged terrain and the snow deep during winter and even mid winter. The northern range is also connected to central YNP by the Firehole to Mammoth corridor (FMC). The FMC has only recently become a significant pathway for bison movement from the central range to the northern one. The Pelican Valley to Hayden Valley corridor (PHC) connects the two interior central bison ranges.

Bison in Yellowstone function as two semi-distinct herds (Meagher, 1973, 1993, Aune et al. 1998, Taper et al. 2007a, Fuller et al. 2007a, Olexa and Gogan 2007, Geremia et al. 2009). The central herd generally occupies the central plateau of Yellowstone, extending from the Pelican and Hayden Valleys with a maximum elevation of 2,400 meters in the east to the lower-elevation and thermally-influenced Madison headwaters area in the west (Geremia et al.2009). This area contains a high proportion of mesic meadows comprised of grasses, sedges (*Carex spp*), and willows, with upland grasses in direr areas (Craighead et al. 1973).

The northern herd generally uses a decreasing elevation gradient (2,200-1,600 m) extending in the Lamar Valley and the Gardiner Basin. The northern range is drier and warmer than the rest of the par. Bison predominantly feed on graminoids and upland grasses, sedges, and rushes (*Juncus spp*) on the extensive grasslands of the northern range (Geremia et al. 2009).

Bison from the central herd extend between the Madison, Gibbon, and Firehole (MGF) drainages during the winter, and concentrate mainly between the Hayden and Pelican Valley (Hess, 2002, Bruggeman et al. 2006) for the summer range. They congregate in the Hayden Valley for the bredding season (15 July- 15 August), but move between the Madison, Firehole, Hayden, and Pelican valleys during the rest of the year. Some animals from the central herd travel also to the northern portion of Yellowstone and mixed with the northern herd, with most returning to the Hayden Valley for the subsequent breeding period.

Bison from the northern herd reassemble in the Lamar Valley and on adjacent high-elevation meadows to the south for the rut, but move west towards lower elevation areas nearer Mammoth and Gardiner during winter (Geremia et al. 2009). They began migrating to the MGF in late October along the Mary Mountain trail and returned to the summer range in June (Bruggeman et al. 2006).

2) Bison migration and dispersal

Patterns in animal travel are a critical aspect of ecology affecting population level process. Migration, dispersal, and small-scale redistribution movements often predicated upon the need for resources, all influence population dynamics through either direct or indirect causes (Taylor and Taylor 1977, Dobson and Jones 1985, Dingle 1996, Bruggeman et al, 2006).

Normally, migration includes the idea of environment change or a travel over an "ecological distance" from one environment to another (LeResche 1974, Bruggeman et al. 2006). Bison are definitely using an altitudinal gradient in YNP over the seasons. Those large herbivores appear to migrate primarily to access high quality food or to avoid predators. Sometimes both added to strategies to avoid thermal stress, or insect harassment, or even contact with disease and parasite vectors. Bruggeman in 2006 explained that even the streams were of a great influence: "among all the multiple factor that affect bison movements, streams were the most influential landscape feature affecting them, and results suggest the bison travel network throughout central Yellowstone is spatially defined largely by the presence of streams that connect foraging areas".

Meadow complexes and geothermal areas provide also foraging habitats for bison on both ranges, with major foraging areas often connected by corridors either through canyons and/or along streams. There are four geothermal areas in the MGF along with smaller pockets of geothermal activity that reduce snow accumulation and produced longer growing seasons compared to other surrounding areas (Bruggeman et al. 2006). There are also some geothermal influenced areas along the Lamar Valley and the Gardiner Basin as the Mammoth area.

Fig. 8. Bison in thermal areas.
Source: Bison management office, YNP, 2009.

Unlike the migration, the dispersal is the process of the bison population to respond the changing environments. Dispersal occurs when individuals travel beyond their home range boundaries and when they do not return in this area, at least in the short term (Sinclair 1992, Gates et al. 2005). Dispersal plays a major role in population regulation and spatial distribution: it means that there is a pressure on a population that obliged them to disperse themselves. Generally, multiple factors can explain such dispersal and not

only a single cause, but in 1996-97, bison responded to the harsh winter dispersing outside the park at the north and west lower basins.

At the opposite, apparent isolation of bison in separate winter ranges when populations were small likely reflected high availability of forage, low pressure to move or expand, fewer animals to break and maintain a trail. Exploratory movements by those mature bulls subsequently establish annual migration paths to and from peripheral ranges, preceding expansion by cow/juvenile groups along the corridors and then the winter ranges. Yellowstone bison are most widely dispersed in late winter then return to one of three rutting areas by mid July. The largest rutting aggregation is in the Hayden Valley, the second largest in the eastern Lamar Valley, and a small aggregation occurs in small high elevation grasslands on the Mirror Plateau and Cache/Calfee Ridge at the North Entrance.

Next Figure:

FMC: Firehole to Mammoth corridor; FWC: Firehole to West Yellowstone corridor; GLC: Gardiner Basin to Lamar Valley corridor; MPC: Mirror Plateau corridor; PHC: Pelican Valley to Hayden Valley corridor.

Source: C. Gates in "The Ecology of Bison Movements and Distribution in and beyond Yellowstone National Park", 2005.

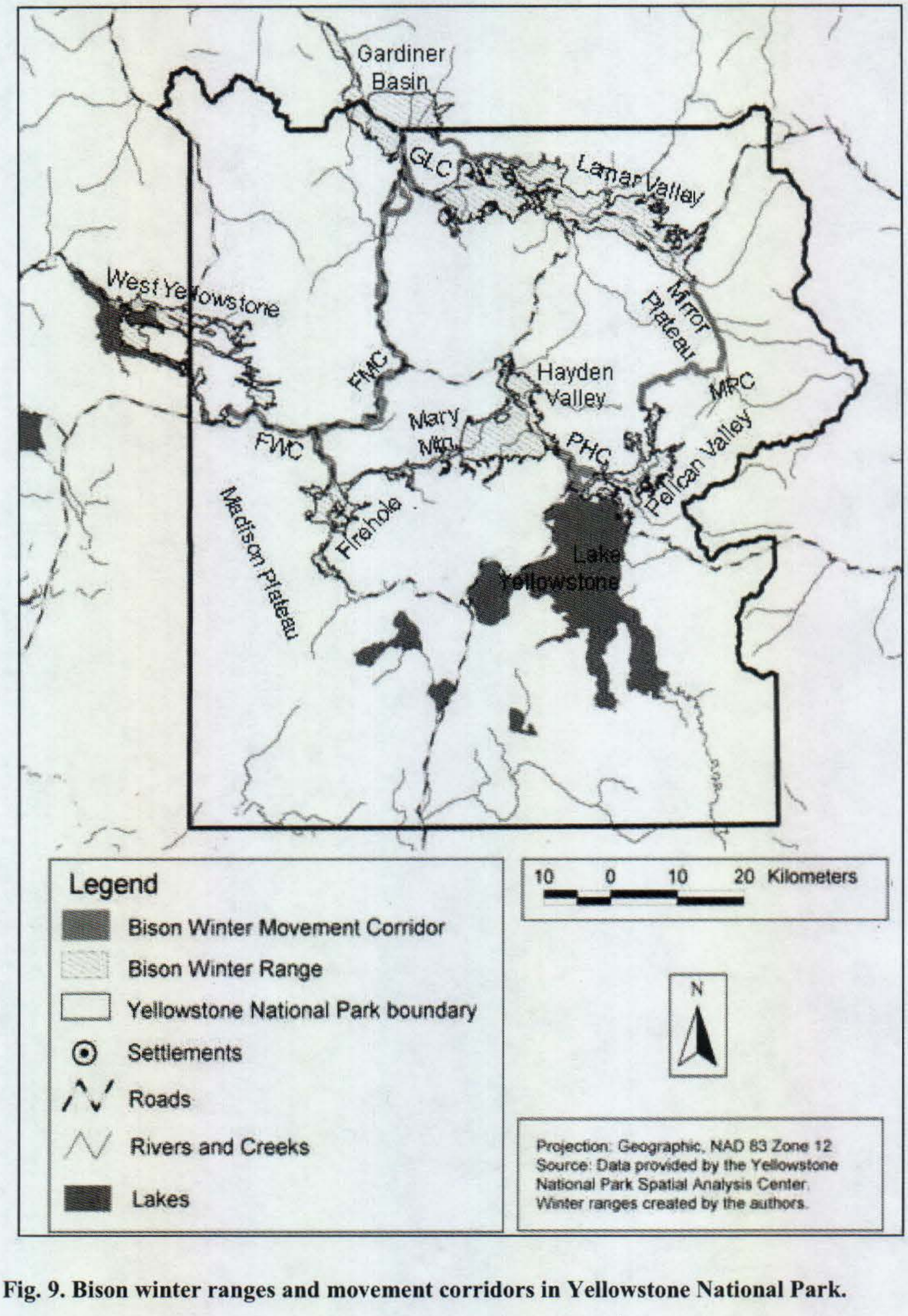


Fig. 9. Bison winter ranges and movement corridors in Yellowstone National Park.

3) Density dependant, factor of bison population regulation?

The bison population, as all every other mammal's one, is regulated by density-dependent factor, among others. As population density increases, mortality and emigration rates increase and the rate of reproduction decreases. Increases in mortality can result from depletion of food supplies because individuals find more difficulties to obtain adequate nutrition. Diseases, whose transmission is facilitated by high population densities and predators, also increase mortality (Sinclair 1989, Royama 1992, Begon et al. 1996). Rates of reproduction may decrease because females cannot obtain enough food to support high rates of pregnancy and because offspring may be born at lower weights and less appropriate times than when food supplies are good. These rates may change gradually with population density, or there may be thresholds at which major changes occur (Fowler 1987; McCullough 1990, 1992).

The combination of these processes tends to cause bison population densities to decline when they are high and to increase when they are low (Committee on Ungulate Management in Yellowstone National Park, 2002). However, this does not guarantee that population densities will stabilize or reach some equilibrium because changes in rainfall, snow accumulation, fires, and other abiotic events may cause large fluctuations in the capacity of the landscape to support the population (Soether et al. 1997, Committee on Ungulate Management in Yellowstone National Park, 2002). After about 75 years of occupying a traditional winter range in northern Yellowstone Park, bison underwent a westward "stress dispersal" during a particularly severe winter of 1975-76 (Meagher 1989*b*). Range expansions occur when population densities are high, suggesting the animals are responding to environmental stress (Gates et al. 2006).

In other words, because the environmental conditions in the landscape may vary considerably, the magnitude of variation in the density of a population by itself cannot be used to assess the importance of density-dependent factors in regulating the size of a bison population. Many ungulate populations are subject to fecundity declines or mortality increases as population density increases. Unharvested ungulates are regulated, at some point, by density dependence (McCullough 1979, Sinclair 1979, Fowler 1981, Gaillard et al. 1998), but it might result of a multitude of factors and be difficult to distinguish the effects of density from those of other influences. The best evidence for

density dependence comes from direct measures of changes in population processes such as mortality, fecundity, and migration (Shenk et al. 1998, Committee on Ungulate Management in Yellowstone National Park, 2002).

Data of bison population are available for only two periods in YNP. The first was from 1902 to 1931, when the population grew from fewer than 100 to more than 1,000 animals. Analyses of this period are complicated by management actions (see Part 1- C-1), which included fencing, artificial feeding, and castration of male claves (Meagher, 1973). From 1931 to 1967, the size of the bison population was controlled by intense culling. The second period of growth was from 1968 to 1994, which ended with the killing of more than 2,000 bison between 1994 and 1998 (see Fig. 13) (Committee on Ungulate Management in Yellowstone National Park, 2002).

Bison in YNP were never allowed to achieve a population that appears to be in equilibrium letting the density dependant factor to express itself.

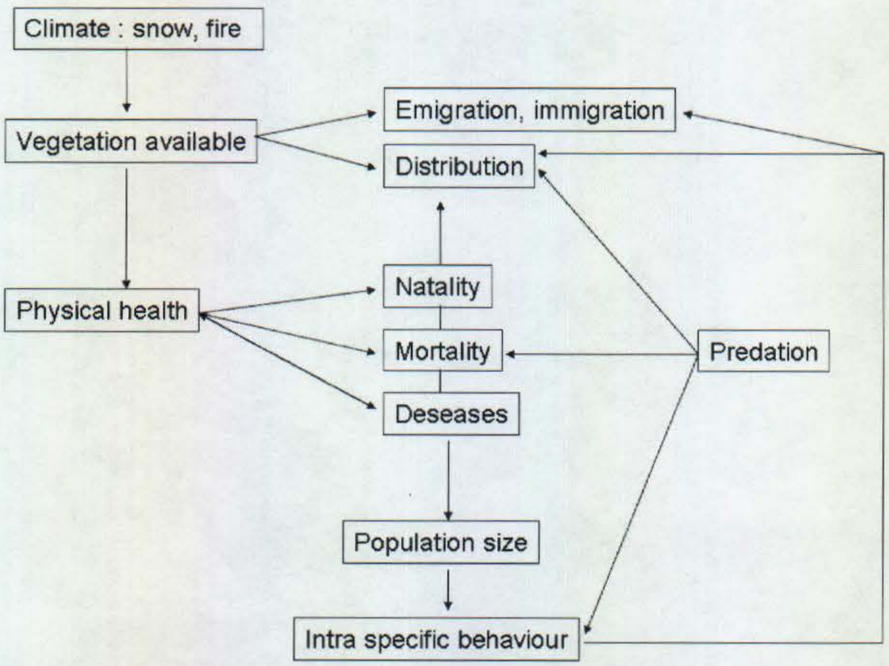


Fig. 10. A generalized model of bison population regulation

Source: Inspired from Barmore W., 2003.

C) The Yellowstone Migration Debate

1) Past bison management strategies: errors and adaptations

By 1840 intermountain bison populations were disappearing, a consequence of unregulated hunting. Indeed, the end of the Civil War produced a large numbers of men looking for work. Only a few investment of money was necessary to be bison runners (term for bison hunter). The number of hunter increased rapidly and by the late 1870s to the mid-1880s, the bison runners themselves knew that the destruction of bison herds was nearly complete. By 1885, there were probably no more than 1,000 bison left in all of North America (JOW, 2006, Vol.45, No 2).

However, bison remained common in the Lamar and Yellowstone Valleys at that same period. The YNP Superintendant's report of 1880 describes 3 different herds in Yellowstone: about 200 summered in the Lamar valley, moving east with the winter; a second herd of 100 bison stayed between the Hoodoo and the Canyon; and a last one about 300 bison along the Madison River. For that herd, the Superintendant precise that this "herd is probably wintered on the Pacific side of the Continental Divide and if so, they are not permanent occupant of the Park, and are therefore likely to be slaughtered by advancing settlers". This comment reflected the pressure on large herbivore populations from unrestricted hunting outside the park (Gates et al, 2005).

Public pressure _getting more and more concerned over excessive hunting and declining numbers of bison_ finally caused the Congress to act in 1886, in assigning the U.S. army to establish a command in the park to protect wildlife and geothermal features. They took charge of the park and immediately began to impose law and order on an unruly landscape (YNP 2000, Plumb and Sucec 2006). Even so, by 1901, park records announce only 25 wild bison remained in the Pelican Valley (Meagher 1973).

In 1902, the Congress allowed fifteen thousand dollars to buy bison in order to keep them in a fenced enclosure in the park. A captive herd was established near Mammoth Hot Springs that included three bulls from Texas and eighteen cows from western Montana. The captive bison herd grew and the operation was moved to the central Lamar

Valley, in the site known as the 'Buffalo Ranch', where the Lamar herd was managed until 1952.

The 21 bison from Montana and Texas were imported to restore the species of the park, and together with the remnant wild herd of approximately 22 animals, they formed the foundation stock for the present day population.

Between 1907 and 1912, the imported captive herd was maintained in fenced pastures in the Buffalo Ranch. The captivity included feeding, culling, castration, selection, and predator control. In 1913, the bison were released during the day to graze freely and brought back for the night. By 1915, the herd had increased to 259 animals. As the Lamar herd expanded its summer pastures (they were herding for the fall), it mingled with the wild herd moving into the high country of the upper Lamar Valley from Pelican Valley. After 1932, there was no attempt to keep the two herds separate.

Although the Lamar herd was essentially wild by 1930, it was still fed during the winter months, a practice continued until 1952. Albright (1944:8, Gates et al. 2005) offered the following reason for winter feeding:

"... The Lamar River herd if not fed in periods of deep snow or under blizzard storm conditions will move down the valley and out of the park into towns and farms and in such drifts there is always the possibility of excessive losses of bison as well as great property damage by the restless hungry animals".

Protected form predation and from starvation, the herd increased rapidly, reaching approximately 1100 bison by 1930 (Meagher, 1973).

In 1932, the Department of the Interior issued a wildlife policy developed six years earlier in which it was recognized that ungulate populations would be kept within the carrying capacity of the range by limiting their size. The "average winter carrying capacity" on the northern range was estimated around 250 bison. Reductions increased during 1932 to 1936 during which time 979 bison were removed at an annual rate of 196 per year. In 1937, 488 bison remained on the northern range (Grimm 1939, Gates et al, 2005) and the Director of the Park Service accepted a recommendation to maintain the northern range bison herd at 350 and the central population at 300. This objective remained in place until the mid 1960s. Sizeable reductions were carried out on the

northern winter range about every second year; 1748 bison were removed from the northern range between 1944 and 1965. In 1966, only 66 bison were counted in the Lamar Valley. Between 1964 and 1968, 1673 bison were removed from the central herds. The plan was described by the YNP as a "reduction and brucellosis control program" whose intention was to allow for 'range improvement' and reducing the prevalence of *Brucellosis abortus* infection. At the end of the range management era in 1968, 160 bison were counted in the Pelican winter range and 188 in the Mary Mountain range (Meagher, 1973).

At the same time, confronted with a public outcry against elk reductions on the northern range, the Secretary of the Interior appointed a panel of scientists under the direction of Starker Leopold to review elk population management. Published in 1963, the Leopold Report provided the impetus for a profound change in Park Service management policy. The Committee concluded:

> "As a primary goal, we would recommend that the biotic associations within each park be maintained, or where necessary recreated, as nearly as possible in the condition that prevailed when the area was first visited by the white man. **A national park should represent a vignette of primitive America."**

Finally, in 1968, the National Park Service shift away intensive management in the National Parks, and declared that they "should be managed as ecological entities providing for restoration, protection and maintenance of native complexes" (Gates et al 2005), allowing large mammal populations in the park to self-regulate in relation to ecological conditions. This form of management has been referred as the equivocate term of 'natural regulation' policy.

With the cessation of population management, bison population subsequently began to increase rapidly within the park, expanding their range expansion. From 1970 to 1981, a period relatively free of perturbations, the Mary Mountain bison herd increased at a slightly low rate of 0.13., while for the same period, the Northern range bison herd increased at a rate of 0.072 (see Fig. 11 and 12).

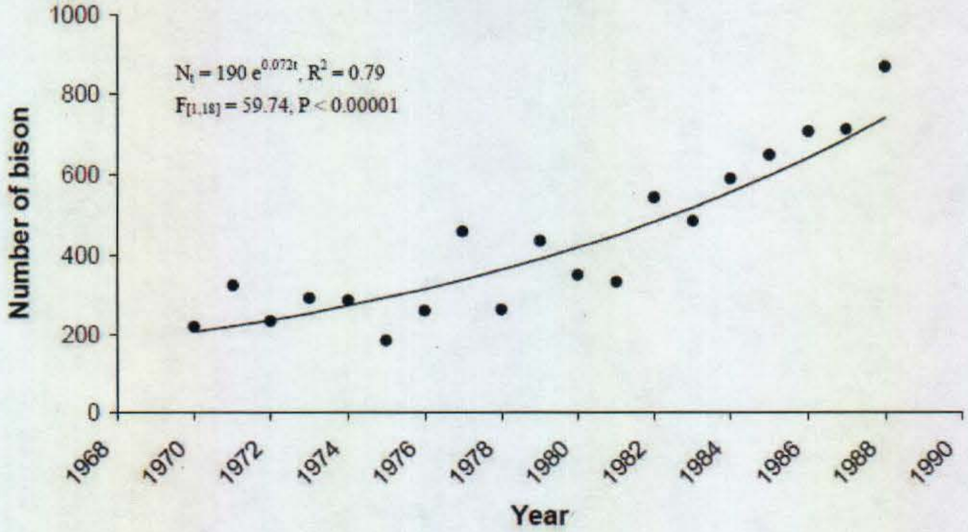


Fig. 11. Increase in the YNP Northern Range bison population during 1970-1988.

Source: M. Meagher, M. Taper and C. Jerde, in Gates et al., 2005.

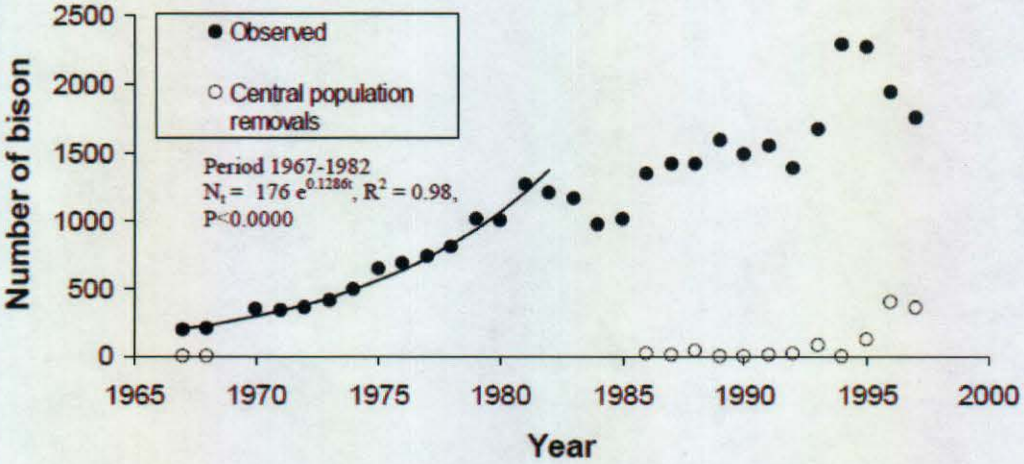


Fig. 12. Growth of the central bison population during 1967 to 1982.

Source: M. Meagher, M. Taper and C. Jerde, in Gates et al., 2005.

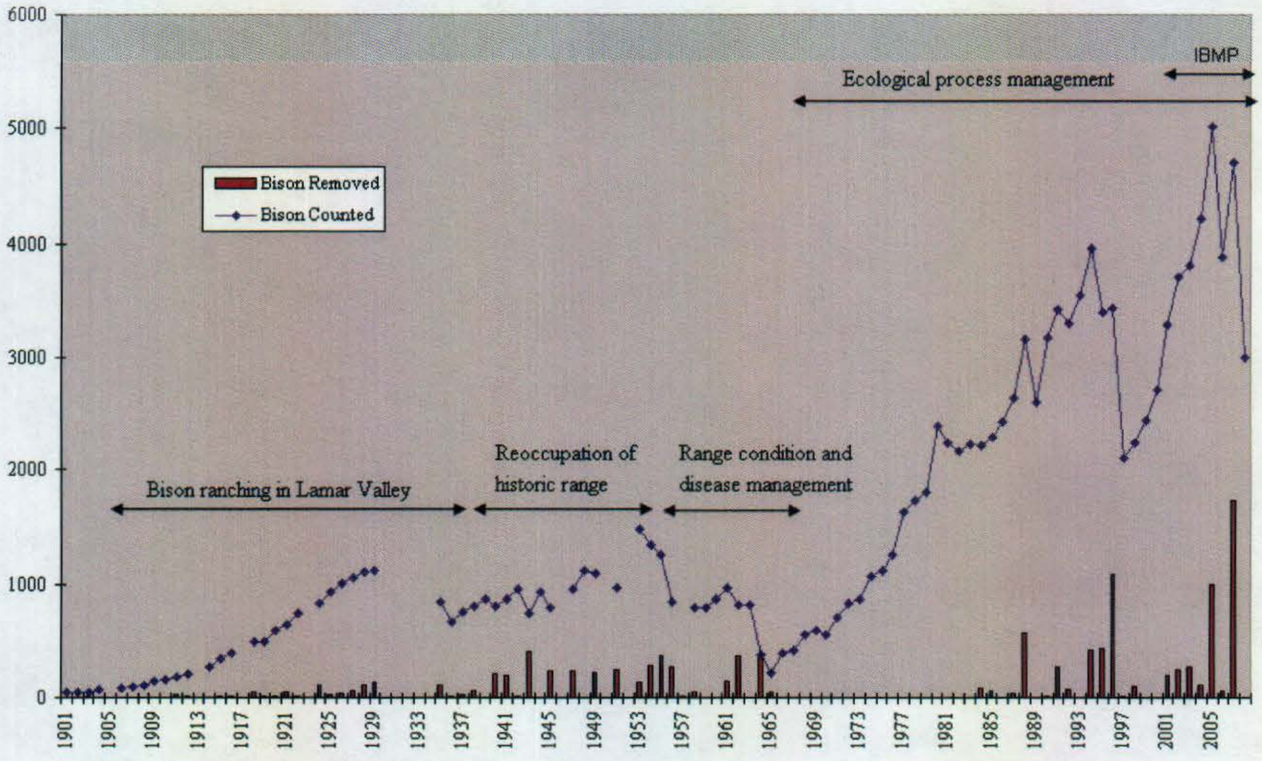


Fig. 13. Time series of counts and removals for bison in Yellowstone National Park during 1901-2008. Counts occurred in the summer of the year indicated, while removals occurred during the following winter and spring.

Source: Plumb, G.E. et al.

2) Brucellosis diffusion: political and economical impacts

a) The disease and its impacts

As the bison herds dramatically increased during the three and a half decades after the end of the intensive management era in 1968, disease rapidly emerged as a new predominant management concern for bison under the control of the NPS. Bison in YNP are infected with the bacterium *Brucella abortus,* the causative agent of brucellosis (Meagher and Meyer 1994), a disease that causes abortion in cattle and is of significant economic and political interest to the livestock industry.

Between 1911 and 1922, several outbreaks of hemorrhagic septicaemia occurred in Yellowstone bison, killing between 9-15 percent of the introduced herd. The bacterial bovine disease brucellosis was detected in Yellowstone National Park in 1917 and has since remained chronic with seroprevelance rates near 40 to 50 percent (Skinner and Alcorn 1942-1951, JOW, 2006, Vol. 45, No.2).

During the 50s and 60s, Yellowstone National Park tried to manage those infected bison herd by direct population reduction through shooting in the field, capture, disease test, and slaughter of seropositive bison.

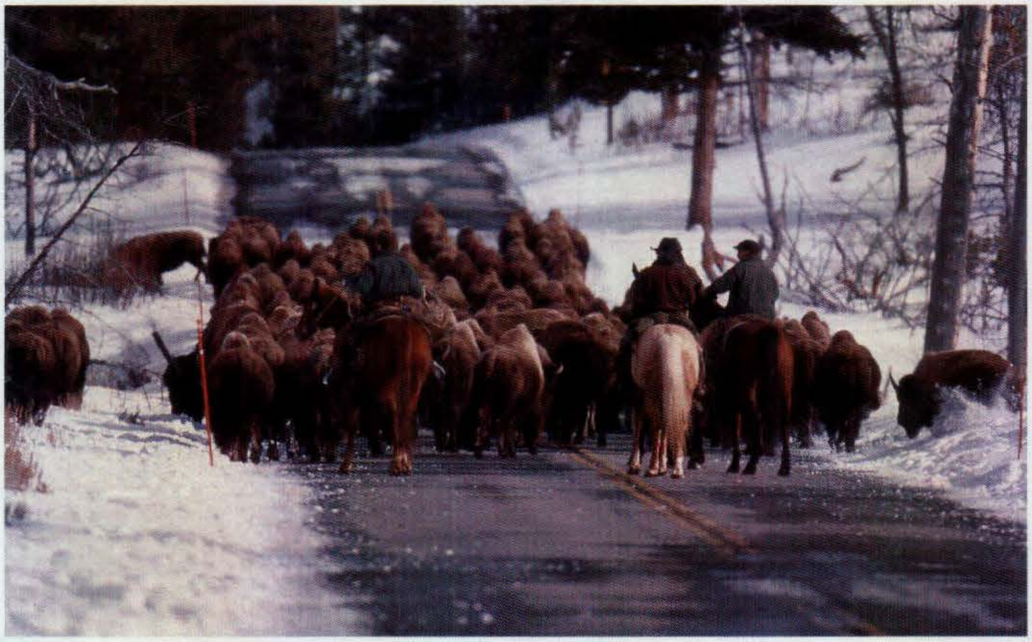


Fig. 14. Bison hazing from Montana State to Yellowstone National Park.

Source: Bison management office, YNP, 2009

Concerns over transmission of brucellosis from bison to domestic cattle had heightened by 1988. In the winter of 1996–1997, which had deep snows, more than 1,000 bison were slaughtered when they migrated outside the park and however seronegative animals were still being detected. At this time, park managers decided to cease these management tactics after it became apparent that eradication of brucellosis could entail elimination of wild and free-ranging bison.

Brucellosis is endemic in bison as well as elk herds in YNP, and typically causes abortion of the first pregnancy after infection in most infected females, elk and bison. Epididymitis and orchitis (both are inflammations) may occur in bison bulls (Williams et al. 1993, Rhyan et al. 1997).

Population consequences of brucellosis on elk and bison on the northern range are not specifically known. Loss of 7% to 12% of the calf crop has been estimated for elk in the Jackson elk herd (south of Yellowstone National Park in the Great Yellowstone Ecosystem), where brucellosis is endemic (Herriges et al. 1989, Smith and Robbins 1994).

Some studies indicate that approximately 50% of the Yellowstone bison are exposed prior to reproductive maturity (Treanor et al. 2007, Garrott et al. 2009). This early exposure may allow immature bison to develop resistance to infection, and reduce the occurrence of *Brucella*-induced abortions (Meyer and Meagher, 1997). Calves may acquire infections in utero or through ingesting contamined milk (Nicoletti 1980, Garrott et al. 2009). However, vertical transmission through infected birth tissues does not explain the differences in seroprevalence observed in adult male (75%) and females (49%) bison (National Park Service, Garrott et al. 2009).

The primary way of transmission is oral contact with tissues of individuals by touching, licking or ingestion of contamined fluids and tissues associated with abortion or birth (Cheville et al. 1998, Gates et al. 2005).

Population density is important for understanding the dynamics of brucellosis in bison and the likelihood that it will be maintained. In severe and even during normal winters, animals are essentially confined to feedgrounds because of limited native winter range or because deep snows preclude them from leaving. Because animals stand body-to-body while eating, a birthing or abortion event of an infected bison could expose large numbers of animals to *B. abortus*.

Some other analyses suggest that the combined effect of brucellosis on pregnancy and birth rates resulted in lower fecundity across all ages. Chronic brucellosis infection may lower growth rate by more than 15%. Additionally, brucellosis exposure indirectly lowered bison survival because more bison were culled due to concerns regarding transmission to cattle when bison attempted to migrate to lower elevation areas outside the park. These effects of brucellosis on the demography of Yellowstone bison are evident in time series data that indicate the population grew at a much slower rate than their biological potential during 1970-2000, even though densities were relatively low and per capita food resources should have been relatively high (Gates et al. 2005, Guller et al. 2007a, Garrott et al. 2009).

b) The Interagency Bison Management Plan: a ten years process.

The future management of Yellowstone bison is highly debated and contingent upon the management of brucellosis. The spread of brucellosis carried by bison to domestic livestock outside of the park has an important economic impact, and much attention and controversy has been directed at the disease.

Bovine brucellosis is a zoonosis, i.e. a regulated disease because of its ability to infect humans. A national program to eradicate the disease from cattle was established by the U.S. Department of Agriculture (USDA) in 1934. Since then, several billion dollars in federal, state and private funds have been spent on the program. The Animal Plant Health Inspection Service of USDA certifies states as brucellosis-free, class A, B, or C, depending on the frequency of occurrence of infected cattle herds in the state. The state of Montana worked aggressively to eradicate brucellosis from its cattle herds beginning in 1952. It attained brucellosis free status in 1985 after an expenditure of more than $30 million by the industry (Montana Department lo Livestock, Gates et al. 2005).

YNP was engaged for a time with the U.S. Department of Agriculture on brucellosis testing and management in the bison herd since the early days of the national brucellosis eradication program, in the ranching herd of the Lamar Ranch. But brucellosis testing and herd reductions were not conducted in the park after the winter of 1965-66.

YNP had few years later to institute a boundary control program at the request of State veterinarians from Montana, Idaho and Wyoming to the Department of the Interior. They were concerned by the YNP bison population to increase in the absence of reductions in the park, leading to greater numbers moving into surrounding areas outside the park where cattle graze (Montana Department of Livestock). Shooting bison around the boundaries was also authorized for park personnel.

During the winter of 1984-1985 Montana State personnel removed 88 bison that wandered beyond the northern boundary. The Montana State legislature designated bison as a game animal and authorized a hunting season. In protest, the Fund for Animals sued the National Park Service for allowing bison to move into Montana where they could be killed. Authorized public hunting continued in Montana until 1991 when the Montana

State legislature rescinded the authority for a hunting season in response to a strong national outcry against hunting bison exiting the park. Hunters had taken approximately 680 bison on lands adjacent to the park during the intervening six year period while hunting was permitted.

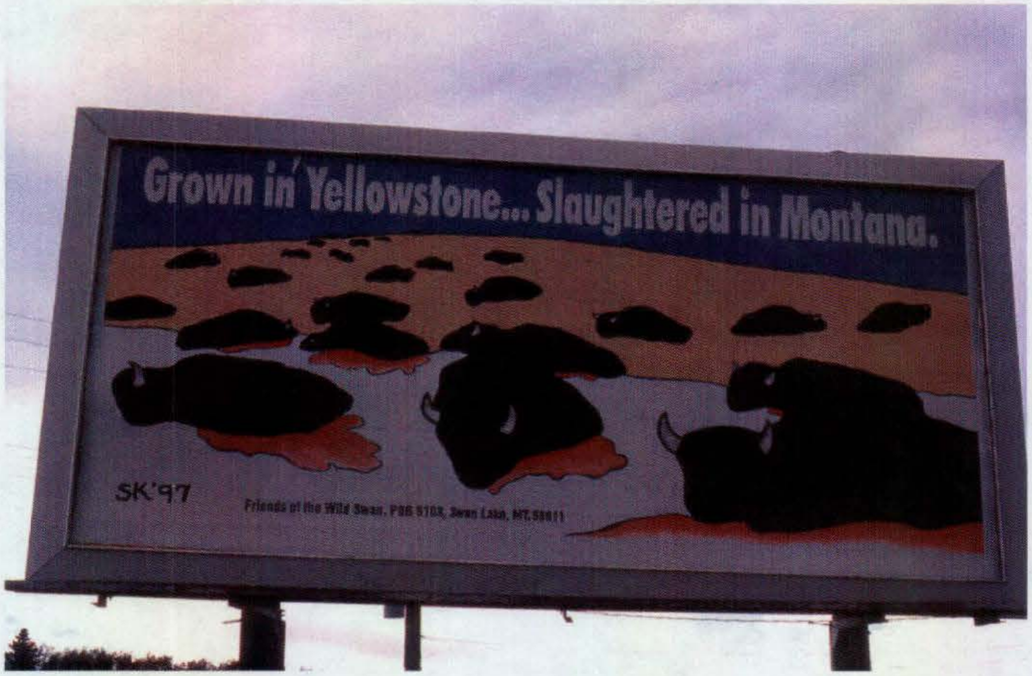


Fig. 15. Public outcry about YNP bison migration management.

Source: Bison management office, YNP, 2009

Effective management of bison moving from Yellowstone National Park into Montana requires cooperation among all affected state and federal agencies. When bison move between YNP and Montana, they also move between different jurisdictions with different management objectives.

Five agencies _ National Park Service, U.S. Department of Agriculture and Forest Service, Animal and Plant Health Inspection Service (APHIS), the State of Montana Departments of Livestock (DoL), and Departments of Fish, Wildlife and Parks (FWP) _ are working for more than a decade to address the management of bison through the development of a long-term cooperative and multi-agency management plan. The Notice of Intent to prepare this Interagency Bison Management Plan (IBMP) was published in the Federal Register in 1989. Since then, many temporary and interims plans or Environmental Impact Statement (EIS; in 1990, 1992, 1994, 1995, 1996, etc.) were

prepared to manage bison outside the park, trying to find an agreement between the 5 jurisdictions.

For example, the settlement of 1995 was an agreement between the NPS and State of Montana to prepare actions for bison management as: capture and removal of bison moving north of the park boundary; construction of capture facilities; all bison testing positive for exposure to *B. abortus* and pregnant females would be shipped to slaughter; test negative bison would be marked and released, etc.

But to find an agreement for a Final Environment Impact Statement between the five jurisdictions wasn't without conflicts. For example, in 1994, while the first interim plans were in effect and in response to the presence of brucellosis-exposed bison in Montana, APHIS questioned whether the Montana State Veterinarian had sufficient control to prevent circumstances in which transmission of brucellosis from bison to cattle might occur and threatened to down-grade Montana's brucellosis class-free status. Another example: in 1999, before finishing the Final Environment Impact Statement (FEIS), the disclosure to public for the IBMP, a notice from Montana indicated that the federal agencies intended to proceed to complete the Final EIS without the State of Montana as a co-lead agency (Interagency Bison Management Plan for the State of Montana and Yellowstone National Park, 2000).

The federal agencies released their Final Environment Impact Statement (FEIS) for bison management for the State of Montana and YNP in 2000. After more than ten years of negotiations, the plan was finally adopted:

- The plan provides for actions in Yellowstone National Park, the Gallatin National Forest, and private lands on the north and west boundaries of Yellowstone National Park.
- The primary tool is the spatial and temporal separation of cattle and bison.
- The number of bison will be limited in the boundary areas in the Gardiner basin and near West Yellowstone.
- The intensity of management will increase as bison move toward the edges of management Zone 2 (zone nearest the park in Montana in each boundary area).

- In the spring the agencies will haze bison back into the park when snow and weather typically allow bison to move back into the interior of the park.
- If hazing is unsuccessful, bison that do not return to the park will be captured or shot.
- Hazing, capture, test and slaughter operations, or quarantine of bison that remain outside the park after specified haze-back dates are the steps to follow.
- Vaccination of bison and cattle will be used to reduce risk and to work toward the eventual elimination of brucellosis in bison. The delivery system and development of a safe and effective vaccine require further research.

Management of brucellosis will remain a contentious issue, because of ecosystem conservation goal versus the ranching industry's goal of brucellosis eradication. The ongoing issues is the number of agencies implied in Bison management with their own values, mandates, and jurisdictions.

c) Different jurisdiction for a same bison management plan: example of the Forest Service and the National Park Service.

At one level, the Yellowstone controversies are focused on the National Park Service's management policies, particularly its commitment to letting natural processes prevail on parks lands. But at another level, the controversies involve the appropriate level of development on the public and private lands surrounding Yellowstone National Park. In the national forests, theses controversies focus on such issues as wilderness designation, oil and gas exploration, timber harvesting levels, and livestock grazing allotments. On the private lands, the controversies involve the level and intensity of development appropriate to the surrounding natural setting (Keiter and Boyce, 1991).

To regard these issues in isolation or as unrelated matters, however, would be a mistake. Park Service management decisions, whether involving resident wildlife or natural fire, have profound influences on surrounding communities and neighbouring landowners.

Similarly, the U.S. Forest Service's wilderness designation, mineral leasing, timber harvesting, and grazing policies have significant environmental consequences for wildlife and adjacent parks lands, as well as economic repercussions within nearby communities. In fact, almost all of the Yellowstone region lands are ecologically interconnected in complex and dependent relationships, just as the local communities are directly connected to the surrounding public lands and resources. The Greater Yellowstone public lands represent a test case for redefining mankind's role in wildland areas of ecological importance (Keiter and Boyce, 1991), because the same issues are surfacing across the nation's public domain, and the resolution of Yellowstone controversies will have a pronounced influence on how similar problems are addressed elsewhere in the United States and maybe throughout the world.

The Forest Service is divided in two: Wilderness lands and National Forests. The Forest Service manages its wilderness lands under a preservationist mandate designed to minimize intrusive human activity, whereas the Park Service is obligated both to preserve its lands and to provide for public enjoyment, a dual mandate that has historically found the agency wavering between its two obligations. The nonwilderness national forest lands, which also total approximately 2.5 million hectares, are managed under a "multiple-use" mandate, which provides for logging, mining, grazing, and recreational activities as well as wildlife and watershed protection. The region's remaining land is mostly in state or private ownership; it is generally not governed by federal law and is open to development (Keiter and Boyce, 1991).

National forests are to be managed for multiple-use values. "Multiple uses" means that commodity uses, such as oil and gas development, timber production, and livestock grazing, must be considered important and legitimate uses of the federally managed lands. In fact, the national forest system was created for two primary multiple-use purposes: to furnish a continuous supply of timber for the citizens of the United States and to protect and improve favourable conditions of water flows.

National parks, on the other hand, are to be managed for preservation purposes, wildlife habitat, and recreation values. Additionally, legislation directing national park planning does not contain any requirements to address community stability.

The U.S. Forest Service and the National Park Service are "re-creating" the land management policies for several million hectares through the coordination efforts of the Greater Yellowstone Coordinating Committee. The GYCC was formed in response to what the Forest Service claimed was criticism from members of Congress and environmental groups about the disjointed land management policies by the federal agencies in the Greater Yellowstone Ecosystem. Membership in the GYCC consists of the Forest Service regional foresters from the Northern, Intermountain, and Rocky Mountain regions; the Forest Service supervisor from the six affected national forests; the Rocky Mountain regional director of the National Park Service; and the Park Service superintendents for the Gran Teton and Yellowstone national parks.

To requests from the National Park Service and others that the Bureau of Land Management 's (another Department of the Interior agency) San Juan resource management plan provide protective management of key lands adjacent to Canyon-lands National Park, the bureau directly responded that "we do not manage public lands as a 'buffer zone' to the park". The BLM offered only the following explanation: "The NPS Organic Act[1], as amended, states that NPS is to leave [parks] 'unimpaired for the enjoyment of future generations'. This law does not address the administration of [BLM] public lands, whether in proximity to an NPS unit or not; it does not require the Secretary to leave [BLM] lands unimpaired to preserve park values. To the contrary, the Congress provided that [BLM] lands are to be managed for multiple use and sustained yield, whether in proximity to an NPS unit or not".

d) Zone 1, 2 and 3: Adaptive Management Adjustments

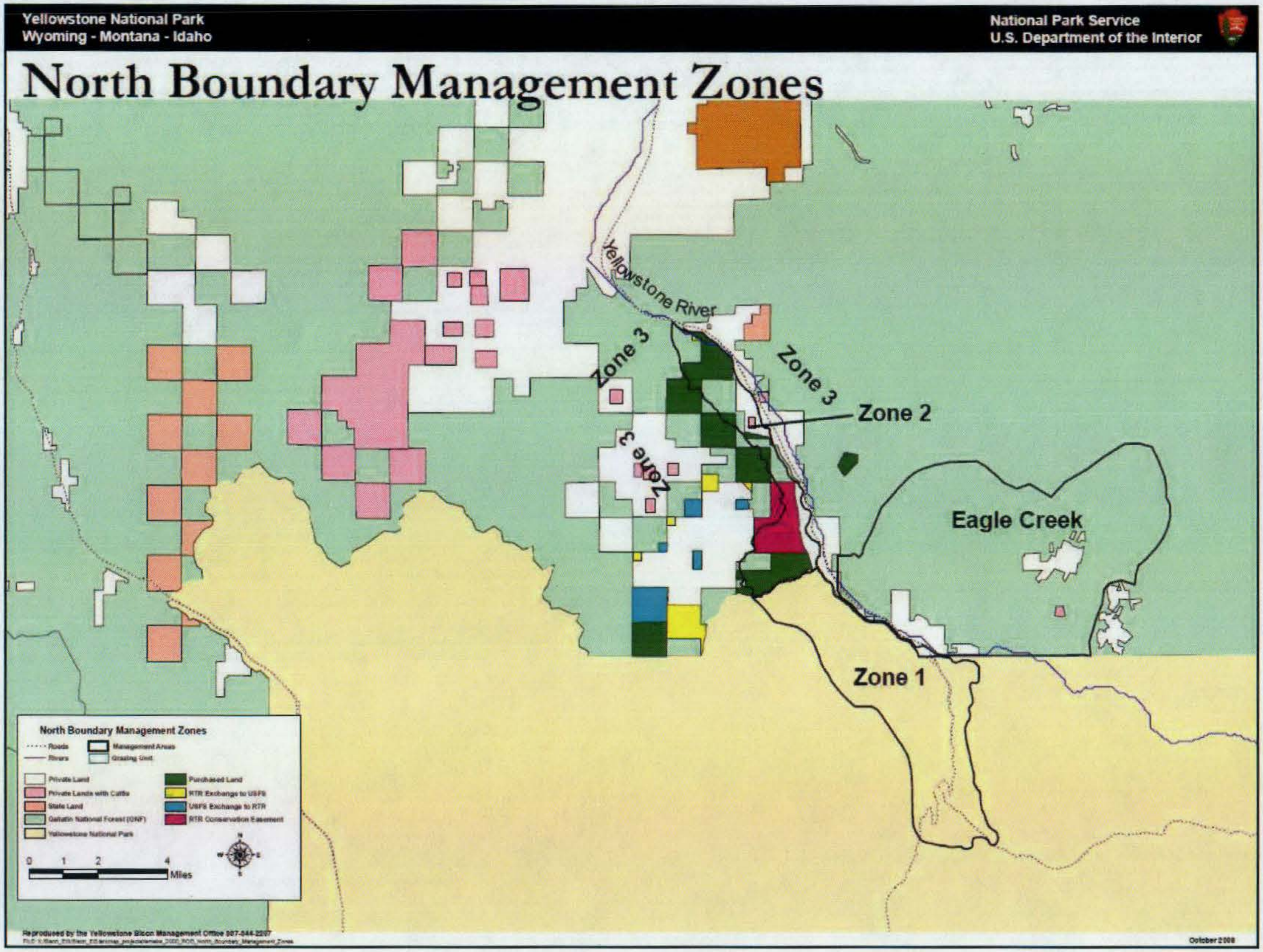
The Interagency Bison Management Plan identifies site-specific, cooperative management strategies for the Western Boundary area and portions of the Northern Boundary area, the locations from which bison traditionally move from YNP into Montana. Within each management area, several strategies will be employed to maintain temporal and spatial separation between bison and cattle. Each of the management areas

[1] *The Congress had mandated in the 1916 National Park Service Organic Act that the national park system is to remain "unimpaired for the enjoyment of future generations". The Congress then has strengthened it in reaction of the ineffective protection of Redwoods National Park: "no authorisation of activities may cause any derogation of the values and purposes of our national parks".*

is stratifies into zones and, as bison move further from the park, management will become increasingly more restrictive. The plan incorporates brucellosis vaccination of bison and cattle to reduce the seroprevalence of brucellosis in bison and reduce the susceptibility of cattle to brucellosis.

For the Western and northern boundaries, three management zones have been defined. Zone 1 is entirely within YNP. Zone 2 is comprised primarily of federal lands that are immediately adjacent to YNP and where cattle are free during winter in the western boundary, and includes lands acquired by the federal government from Royal Teton Ranch through purchase and conservation easements for the northern boundary. Zone 3 is further from YNP and no bison would be tolerated in Zone 3 or they would be subject to hazing, capture and lethal removal.

During Step 1 of the plan, the agencies will haze bison from Zone 2 back into Zone 1. Zone 1 allows managers to forecast of the bison population numbers likely moving in Zone 2. After hazing is no longer effective in moving bison back into Zone 1, the agencies will attempt to capture all bison that enter Zone 2. All captured bison will be tested for brucellosis. Seropositive ones will be shipped to slaughter or used in jointly approved research. Captured calves and yearlings (less than 2 years old) will be vaccinated. Bison that have been tested and determined to be seronegative will be marked and released. The agencies tolerate about 100 bison in Zone 2 and are permitted outside YNP until May 15 to the fall when cattle are removed. Pregnant bison are not allowed to leave Zone 1 until cattle have been removed from Zone 2.


Yellowstone National Park
Wyoming - Montana - Idaho
National Park Service
U.S. Department of the Interior
North Boundary Management Zones
Yellowstone River
Zone 3
Zone 3
Zone 3
Zone 2
Zone 1
Eagle Creek
North Boundary Management Zones
Roads
Rivers
Management Areas
Grazing Unit
Private Land
Private Lands with Cattle
State Land
Gallatin National Forest (GNF)
Yellowstone National Park
Purchased Land
RTR Exchange to USFS
USFS Exchange to RTR
RTR Conservation Easement
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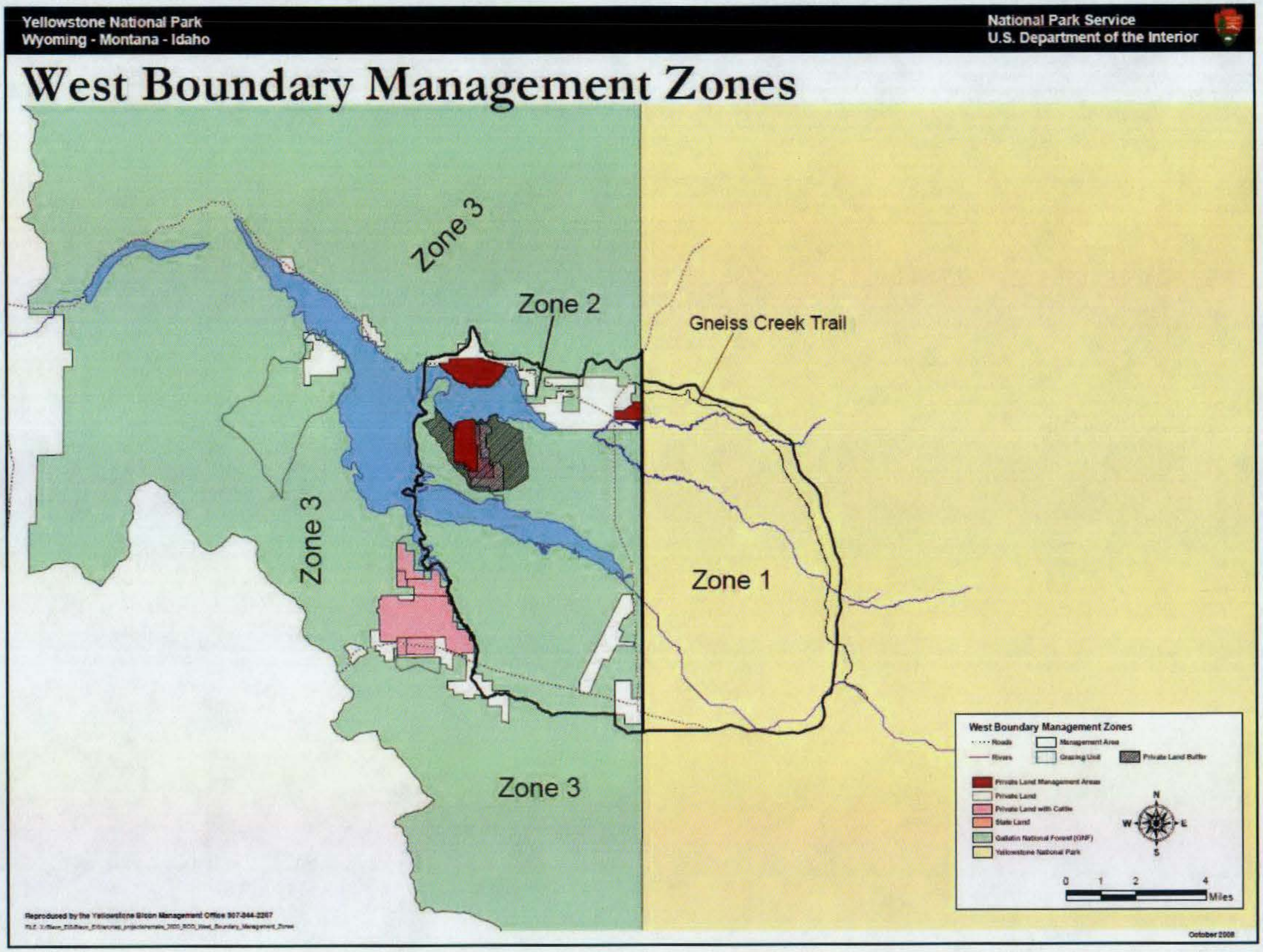
Reproduced by the Yellowstone Bison Management Office
October 2008


Yellowstone National Park
Wyoming - Montana - Idaho
National Park Service
U.S. Department of the Interior
West Boundary Management Zones
Zone 3
Zone 2
Gneiss Creek Trail
Zone 3
Zone 1
Zone 3
West Boundary Management Zones
Roads
Rivers
Management Area
Grazing Unit
Private Land Buffer
Private Land Management Areas
Private Land
Private Land with Cattle
State Land
Gallatin National Forest (GNF)
Yellowstone National Park
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October 2008

PART II - Modelling support for Wildlife Monitoring: GIS application to bison management in Yellowstone National Park.

What is at stake protecting free ranging bison herds for YNP? Why and how preserving Bison in Yellowstone National Park? Bison are considering by biologist to be a keystone species of the plains. With their individual size and numbers, they have a significant impact on the ecology wherever they lived (JOW, 2006, Vol. 45, No.2). But some studies (Freese et al. 2007 in Plumb et al 2009) documented that the North America bison is ecologically extinct across its former range, and to conserve the last remaining wild and free-ranging bison in YNP is necessary to conserve their genetic integrity and ecological role.

Yellowstone bison can be characterized as a single population with two genetically distinguishable breeding groups or subpopulations (Halbert 2003, Gardipee 2007, Plumb et al. 2009). Analyses estimate that between 2500 and 4500 bison (Geremia, pers. comm.) likely are needed in both central and northern breeding herds to retain enough genetic diversity to enable bison to adapt to a changing environment through natural selection and mutation (Gross and Wand 2005, Gross et al. 2006, Freese et al. 2007, Plumb et al. 2009). Also, many thousands of bison are likely necessary to fully express their ecological role through the creation of landscape heterogeneity, nutrient redistribution, competition with other ungulates, prey for carnivores, habitat creation for grasslands birds and other species, provision of carcasses for scavengers, stimulation of primary production, and opened access to vegetation through snow cover (Freese et al. 2007, Sanderson et al. 2008, Plumb et al. 2009).

The YNP bison population also carries the pathogenic bacterium *Brucella abortus*, which is infectious to cattle and people. The organism has been the subject of a national eradication program spanning over 70 years and costing an estimated $3.5 billion in public and private funds. Federal and state agencies are nowadays fearful of the risk of transmission of brucellosis from bison to cattle, and organized some management strategies to manage bison movement outside Yellowstone National Park.

The special relationship of bison to human adds also a layer of complexity to the story of the bison. Bison is synonym of physical, spiritual and mythical images of power, and has an iconic position among many groups of people (JOW, 2006, Vol. 45, No.2), Indian people as well as other non-Indians. Bison have represented the myth of the West, wildness, and nature. The main alternative that YNP offers in conserving bison is to maintain a wild herd. It is possible that if bison lose this status of wild free ranging herd to be only a domestic herd, bison will also lose their powerful symbol. When people come to YNP, it is to experience the West and to experience a natural environment (meaning a wild one) with wildlife to observe.

After that observation, it appears necessary to maintain the Yellowstone bison herd as a free and wild one, not limited to arbitrary boundaries, but free to move in their ecological area outside YNP. This is the aim with Bison adaptive management adjustments in the West and North entrances and for the very first time since more than a decade of negotiations and alternative management assessments, YNP managers see an opportunity first to increase bison tolerance in Montana and second to use the Zone 2 more freely because no cattle would be grazing there this year (Geremia, pers. comm.).

Understanding factors influencing the bison movement in those adaptive management areas is of first importance to form bison management decisions within and outside the park. Habitat assessment is typically GIS-based; it involves selecting data layers likely to be of value in developing predictive models for the occurrence and distribution of bison depending on the ecological condition. The use of remotely sensed data, together with other spatial datasets integrated within a GIS environment helps to obtain better information, and leads to better decision making. In GIS, data about real-world objects is linked to a map, and can be use using different information, following different steps: identify the problem to solve, determine the requirements, show spatial information, manage and modify the data, determine methodology and sequence of operations, and finally evaluate and interpret the results.

A) The Forage Production Model to forecast bison movements

Bison movement and distribution depend on many contingencies. Trying to model those contingencies as a support for wildlife monitoring, the National Aeronautics and Space Administration (NASA) Ames Research Center developed a model for Yellowstone National Park, built upon plant production model and snow cover analyses. The model should be able to deliver timely estimates of forage production and year-round forage availability across the Northern Range, to help decision makers about bison management. The result should be a near real-time monitoring capability for bison management for foraging patches, including predictions from years to years.

1) Migration and Forage Availability

Bison population and spatial movements depend on variations of several variables and of the interactions between those variables. Forage production on the summer range is one of the critical components of winter survival. When forage production is good, females with young produce abundant milk, and the young of the year enter winter in good physical shape and at a heavier weight than on years with poorer summer forage.

Bison respond to spatial and temporal variation in forage quality by selecting for higher quality (Bennet & Dahlgren 1982, Coppock et al 1983, Coppock & Detling 1986, Plumb & Dodd 1993). Additionally, wallowing by bison directly impacts perennial vegetation and provides a refuge for flora different from that on surrounding grassland (Coppock et al 1983, Colins & Barber 1985, Coppock & Detling 1986, Plumb & Dodd 1993). Bison tend to avoid patches dominated by forbs and browse. This suggest that, at a patch scale, bison respond to reduced feeding time per day by momentarily maximizing intake of high-quality, randomly distributed graminoids (Plumb & Dodd 1993).

Being able to predict movements timing over the year and bison population size migration is a key issue for YNP managers, as well ecological as political, social and economical.

a) What is the Forage Production Tool?

Spatial heterogeneity due to variables as weather, soils, vegetation, plant growth, and herbivores dispersal plays critical role in most grazing ecosystems. Those variables can be readily represented on actual landscapes using geographic information system (GIS) data. The purpose of the Forage Production Tool is to predict forage availability based on a modeling approach linking:

- 7 monthly averages Temperature, from April to October considered as the natural vegetation growing season.
- 7 monthly averages Precipitation, from April to October considered as the natural vegetation growing season.
- 7 monthly average solar radiations, from April to October considered as the natural vegetation growing season.
- Vegetation production (NDVI) (yearly information).

The combination of those information sources should permit explanatory assessments of the effects of heterogeneous forage availability on bison movements across the landscapes.

b) Temperature and Precipitation Data

Precipitation and temperature maps were generated from the PRISM Climate Group Data. PRISM Climate Group was established at Oregon State University (OSU) to provide spatial climate research, education, analysis and mapping services for institutions in the United States and abroad. It started as a research program aligned with the Oregon Climate Service (OCS) in 1993. PRISM Climate Group is committed to producing climate maps and many of their mapping activities involve use of the PRISM model, developed by Daly. The model uses point measurements of precipitation, temperature, and other climate elements to produce continuous, digital coverages using the elevation-corrected spatial interpolation.

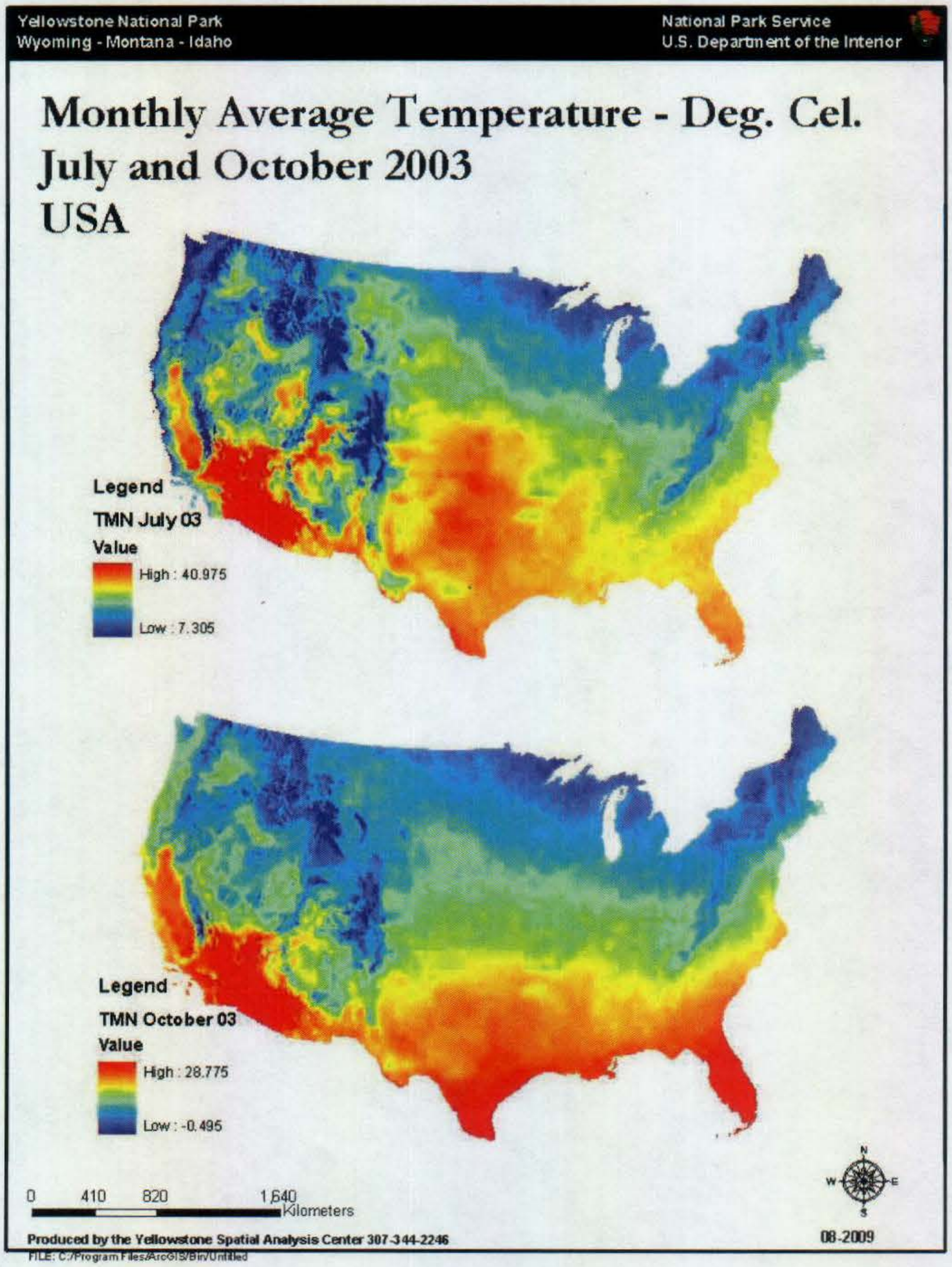

Fig.16. Example of raster image obtained with the PRISM data.

Projection: Projected Coordinate Systems- Continental- US National Atlas Equal Area.

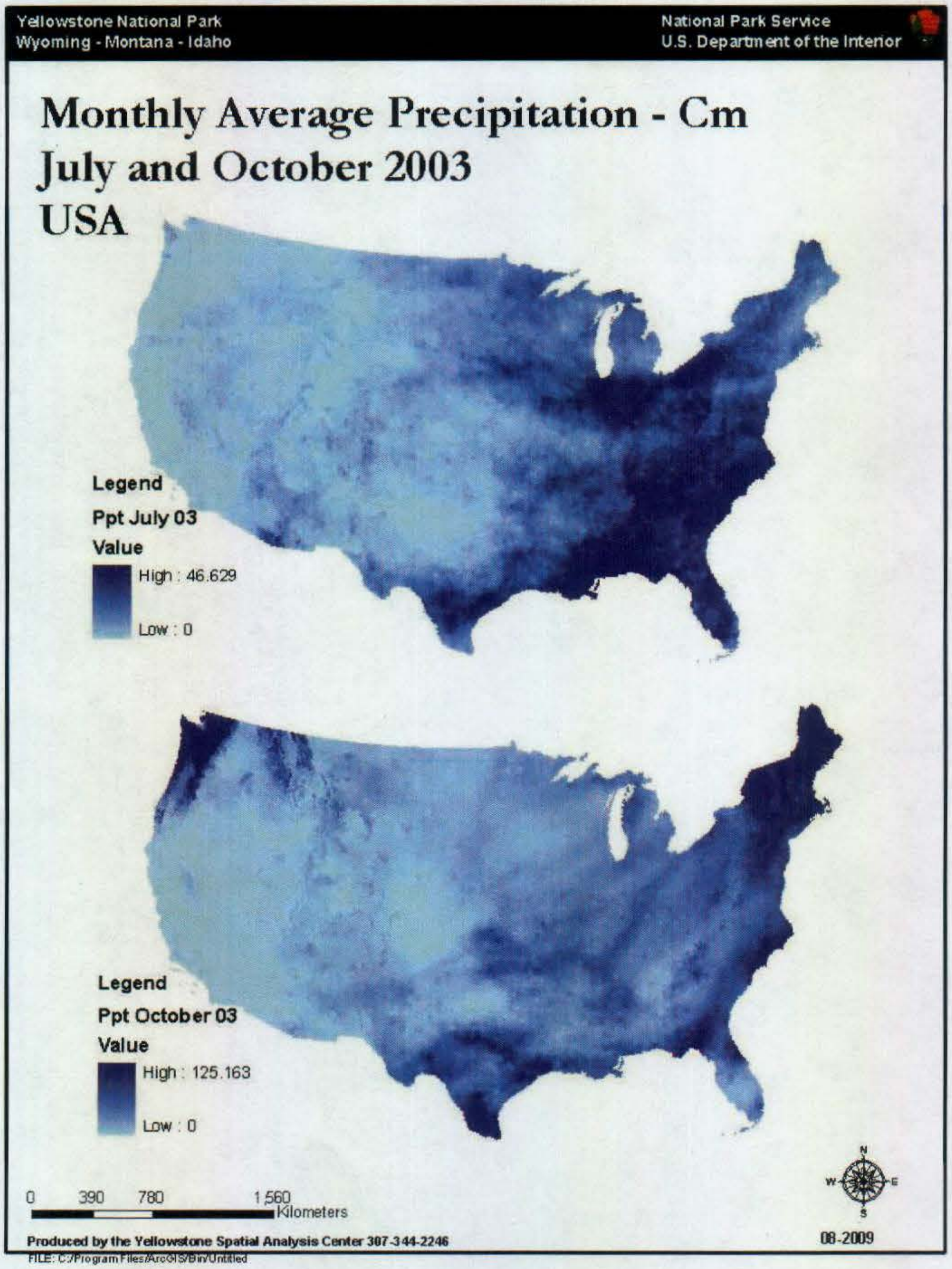

Fig.17. Example of raster image obtained with the PRISM data.

Projection: Projected Coordinate Systems- Continental- US National Atlas Equal Area.

c) Solar and NDVI Data

Solar radiation and NDVI were obtained from the scientists at the National Aeronautics and Space Administration (NASA) Ames Research Center. To support ecological management in YNP and in collaboration with the Yellowstone Ecological Research Center (YERC), the Creekside Center for Earth Observation (CCEO), and ESRI, they have created a 30-meter solar distribution model in Yellowstone National Park using tools in the ArcGIS Spatial Analyst extension.

Incoming solar radiation (insolation) received from the sun is the primary energy source that drives many of the biological processes. Understanding that at a landscape scale is key to understanding natural processes. The solar radiation analysis tool in ArcGIS enables to map physical and biological processes as they are affected by the sun and analyze the effects of the sun over a geographic area and for a specific period.

This project makes use of high-resolution (30-meter) U.S. Geological Survey digital elevation model (DEM) data, Western Regional Climate Center (WRCC) observations, and Natural Resources Conservation Service SNOwpack TELemetry (SNOTEL) measurements. With this large collection of data layers, the challenge is to model the solar radiation for each 30-meter pixel using a methodology that considers many spatial and temporal factors related to atmospheric conditions.

The sun radiation is modified as it travels through the atmosphere by topography and surface features. At landscape scales, topography is the major factor that determines the spatial variability of insolation. Variation in elevation, orientation (i.e., slope and aspect), and the shadows cast by topographic features modify the amount of solar radiation received at different locations. Then, this radiation is intercepted at the earth's surface as direct, diffuse, and reflected components. Direct radiation is intercepted unimpeded, in a direct line from the sun. Diffuse radiation is scattered by atmospheric constituents, such as clouds and dust. Reflected radiation is reflected from surface features (cf. Fig.18). The sum[2] of the direct, diffuse, and reflected radiation is called total or global solar radiation.

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[2] Generally, direct radiation is the largest component of total radiation, and diffuse radiation is the second largest component. Reflected radiation generally constitutes only a small proportion of total radiation. The

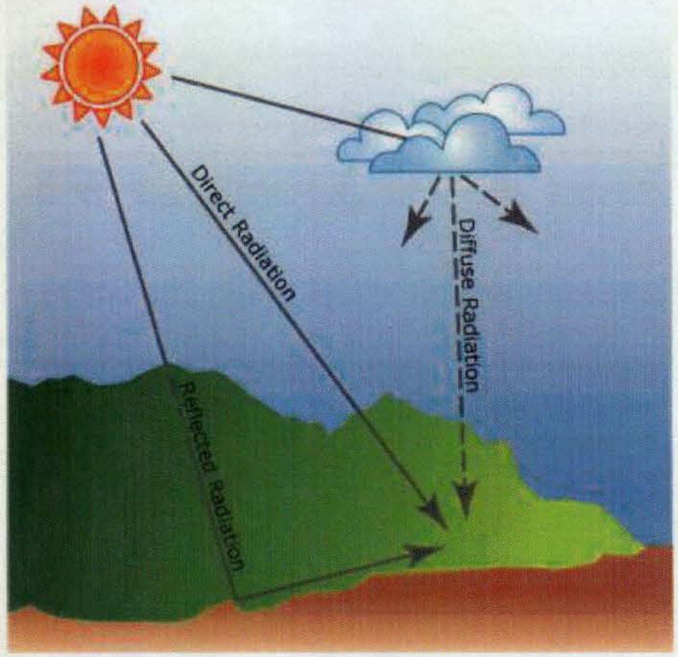

Fig. 18. Radiation on the Earth

Source : ESRI web-site.

The solar radiation tools can perform calculations for geographic areas. The model involves four steps:

1- An upward-looking **hemispherical viewshed** is calculated based on topography.
2- The viewshed is overlaid on **a direct sunmap** to estimate direct radiation.
3- The viewshed is overlaid on **a diffuse skymap** to estimate diffuse radiation.
4- The process is repeated foe every location of interest to produce **an insolation map.**

An upward-looking hemispherical viewshed for every location is calculated from the digital elevation model. A hemispherical viewshed looks like a fish-eye photograph and provides a view of the entire sky from ground level. The following image depicts an upward-looking hemispherical (fisheye) photograph, which provides a view of the visible sky and the sky directions obstructed by the surrounding topography and surface features. This is similar to the view from the ground looking up in all directions. The resultant

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solar radiation tools in ArcGIS Spatial Analyst do not include reflected radiation in the calculation of total radiation.

viewshed characterizes whether sky directions are visible (shown in white) or obstructed (shown in gray). The viewshed is shown overlaid on a hemispherical photograph to demonstrate the theory.

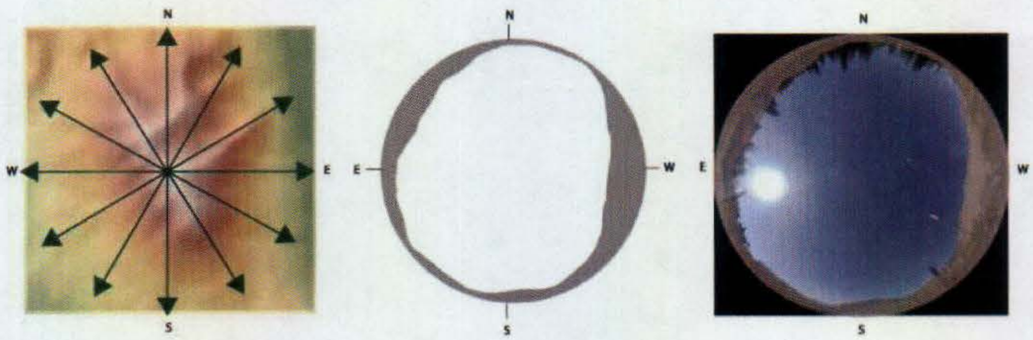


Fig. 19. The upward-looking hemispherical viewshed.

Source: Esri web-site.

Direct insolation for a location is calculated using the viewshed and a sunmap of the study area. A sunmap is a raster representation that displays the sun track or apparent position of the sun as it varies through the hours of the day and through the days of the year. The same view one might see by looking up and watching the sun's position as it moves across the sky over time. It consists of discrete sectors defined by the sun's position at particular intervals during the day (hours) and time of year (days or months). For each sunmap sector, a unique identification value is specified, along with its centroid zenith and azimuth angle.

Diffuse radiation originates from all sky directions as a result of scattering by atmospheric components (clouds, particles, and so forth). To calculate diffuse radiation for a particular location, a skymap is created to represent a hemispherical view of the entire sky divided into a series of sky sectors defined by zenith and azimuth angles. Each sector is assigned a unique identifier value, along with the centroid zenith and azimuth angles. Diffuse radiation is calculated for each sky sector based on direction (zenith and azimuth).

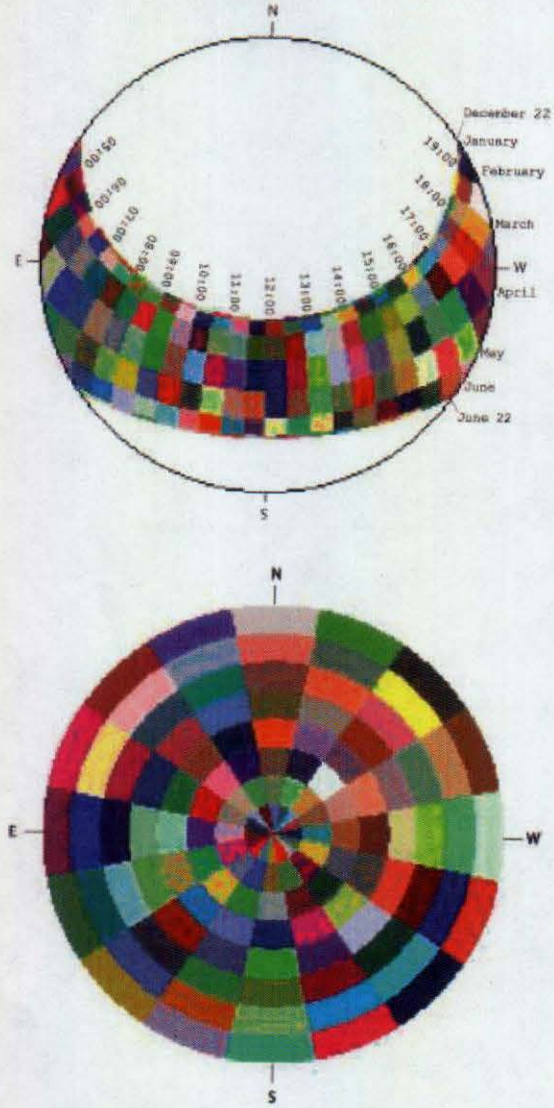


Fig. 20. The sunmap and the skymap calculation.

Source : Shengli Huang.

This first figure is a sunmap for 45° N latitude calculated from the winter solstice (December 21) to summer solstice (June 21). Each sun sector (colored box) represents the sun's position using 1/2 hour intervals through the day and monthly intervals through the year. It should be noted that the image is in the same hemispherical projection as upward-looking viewsheds. The position of the sun is represented as it moves across the sky during the time of day and time of year.

The second figure below is a skymap with sky sectors defined by 8 zenith divisions and 16 azimuth divisions. Each color represents a sky sector, or portion of the sky, from which diffuse radiation originates.

During the insolation calculation, the viewshed raster is then overlaid with the sunmap and skymap rasters to calculate diffuse and direct radiation received from each sky direction. The topographic shadow effect is accounted for by gap fraction. Gap fraction is the proportion of unobstructed sky area in each sector. The final map shows the maximum amount of sun exposure during the growing season (April–October).

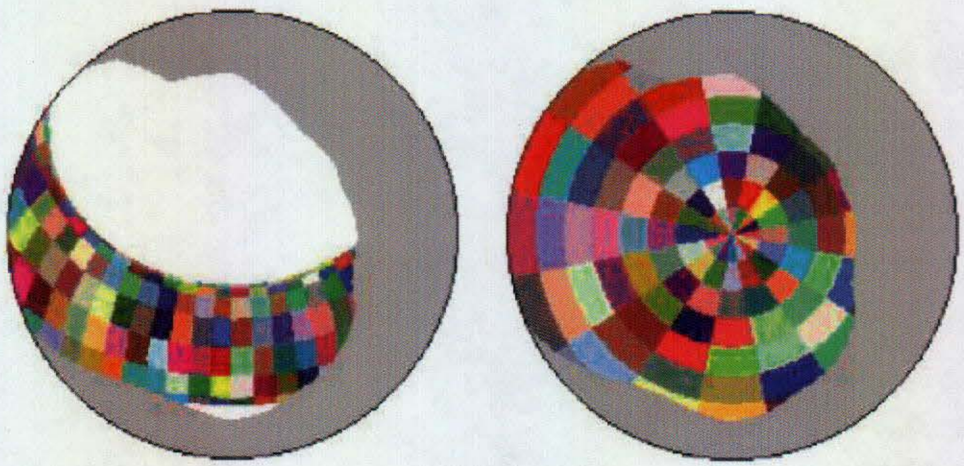


Fig. 21. Overlay of viewshed with sunmap and skymap.

Source: Shengli Huang

(Grey represents obstructed sky directions).

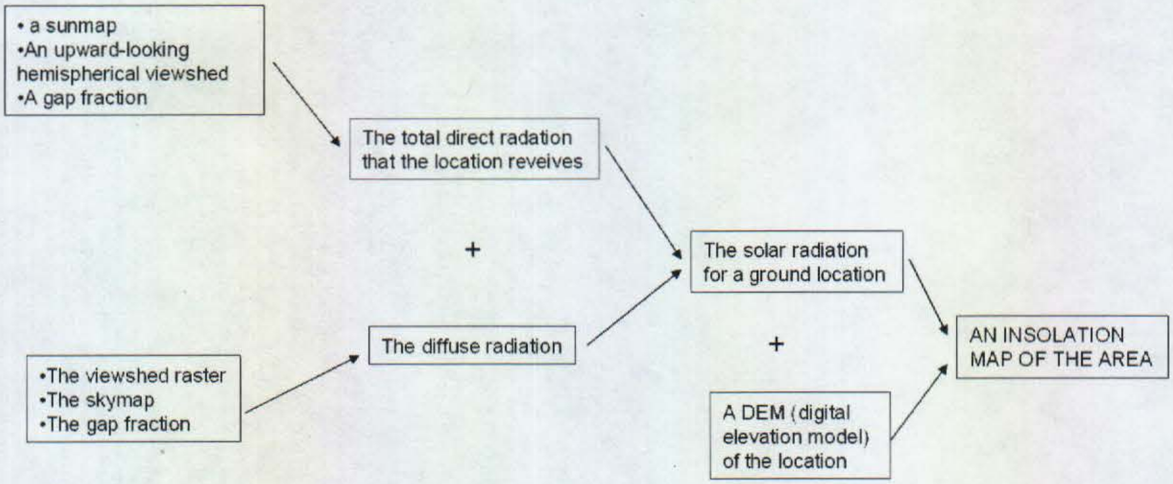


Fig. 22. The solar radiation analysis tool: data methodology to map and analyze the effects of the sun over a geographic area for specific time periods.

Source: inspired from Shengli Huang.

The solar radiation tools in ArcGIS, which provide many default and optional parameter inputs, enabled managers to select the best local optimal applications: slopes, aspect, topography, altitude, latitude, etc.

Improvements in landscape management and bison migration also depend on increased understanding of ecological processes within the carbon, nutrient and hydrological cycles. Remotely sensed data provides key inputs to models those variables.

The Normalized Difference Vegetation Index (NDVI) is well correlated with biomass. Because healthier plants of a given species tend to have greater biomass, it is a good measure of plant vigor. Since the NDVI values that indicate healthy or stressed conditions vary for species, the index is best used to compare conditions of growing in different areas in the same region such as YNP: NDVI values over the growing season provide a useful quantitative estimate of production. NDVI values increase when the plants first emerge to when they reach their maximum development, called peak-of-green (because it is when the leafy part of the plants are most fully developed and the green

reflectance is at a maximum). The NDVI value then declines as the plant matures and goes to seed.

Global-coverage multispectral data at high resolutions from Landsat TM (30 m pixels) are of high enough resolution to be useful in vegetation identification and assessment. Vegetation cover identification is based on spectral characteristics, image texture, and knowledge of the developmental stages of each type of vegetation in the specific area. Remote sensing analyses commonly use indices calculated from digital multispectral image data. The widely used Normalized Difference Vegetation Index (NDVI) is calculated from two bands of multispectral image data, the visible red band (red) and near-infrared (NIR) bands as follows:

$$NDVI = (NIR - red) / (NIR) = red)$$

Vegetation characteristics change during the growing season and July is considered the month of optimum temperature and thus the month of peak greenness in the northern hemisphere.

Once combined all the inputs (temperature, precipitation, insolation, NDVI), the CASA Express tool model generated a 7 monthly Net Primary Production (NPP; vegetation growth) maps by at 30-meter (Landsat) spatial resolution over a single growing season. NPP is then crossed with the vegetation cover classification from the YERC (Shengli Huang et al.) to give the Forage Production in grams of above-ground dry biomass per square meter).

This tool generates a choice of two maps versions of forage production for the year, which can represent the aboveground biomass potentially available to herbivores:

- A first forage version output map uses a pixel-based calculation. This forage map assumes that vegetation forage biomass is distributed evenly over the entire pixel area. While it assumed that most of this pixel-based forage biomass is growing as herbaceous cover over a given area, no corrections have been made in this forage version for the presence of shrub and bare ground fractions.
- A second forage version output map uses patch-based calculation. This forage map assumes that vegetation forage biomass is not distributed evenly over the entire pixel

area, but is instead clumped into smaller patches based on the estimated grass cover fraction.

The second one seems to be more appropriate for bison migration analyze, giving a more accurate value of the pixel for vegetation cover identification.

2) Bison movement data acquisition

Overlaying the data obtained from GPS collars will now allow key questions about movement ecology to be addressed, including the timing and extent of movements.

Two kinds of bison data can be obtained. A first kind is bison population data (Cf. Fig. 23). It concerns only a large scale and let managers to look at the general trends. To get those data, they combined the total number of bison registered during culls (captured or shot by agency, transported to slaughter), harvest (state and treaty hunter take) and numbers of bison held (within containment facilities and released into the park during spring). This measure may slightly underestimate the total number of animals exiting the park and to implement previsions, aerial surveys of bison are added to the previous data.

A second type of bison data is individual animal data source (Cf. Fig. 24), thanks to GPS and telemetric collars on bison. Those kinds of collars are only in female. Individual bison patterns allows to look at more little scale and at bison movement characteristics in a specific area (speed, distance, turn angle, etc.). Movement characteristics are important because they permit to understand if bison are grazing and thus walking on little distances or if bison are migrating, going straight and fast.

One aspect that the model doesn't consider is the cloud cover that affects the NDVI and thus the forage production values (e.g. in 2004. Cf. Fig. 25). It is necessary then to correct that before considering the final result.

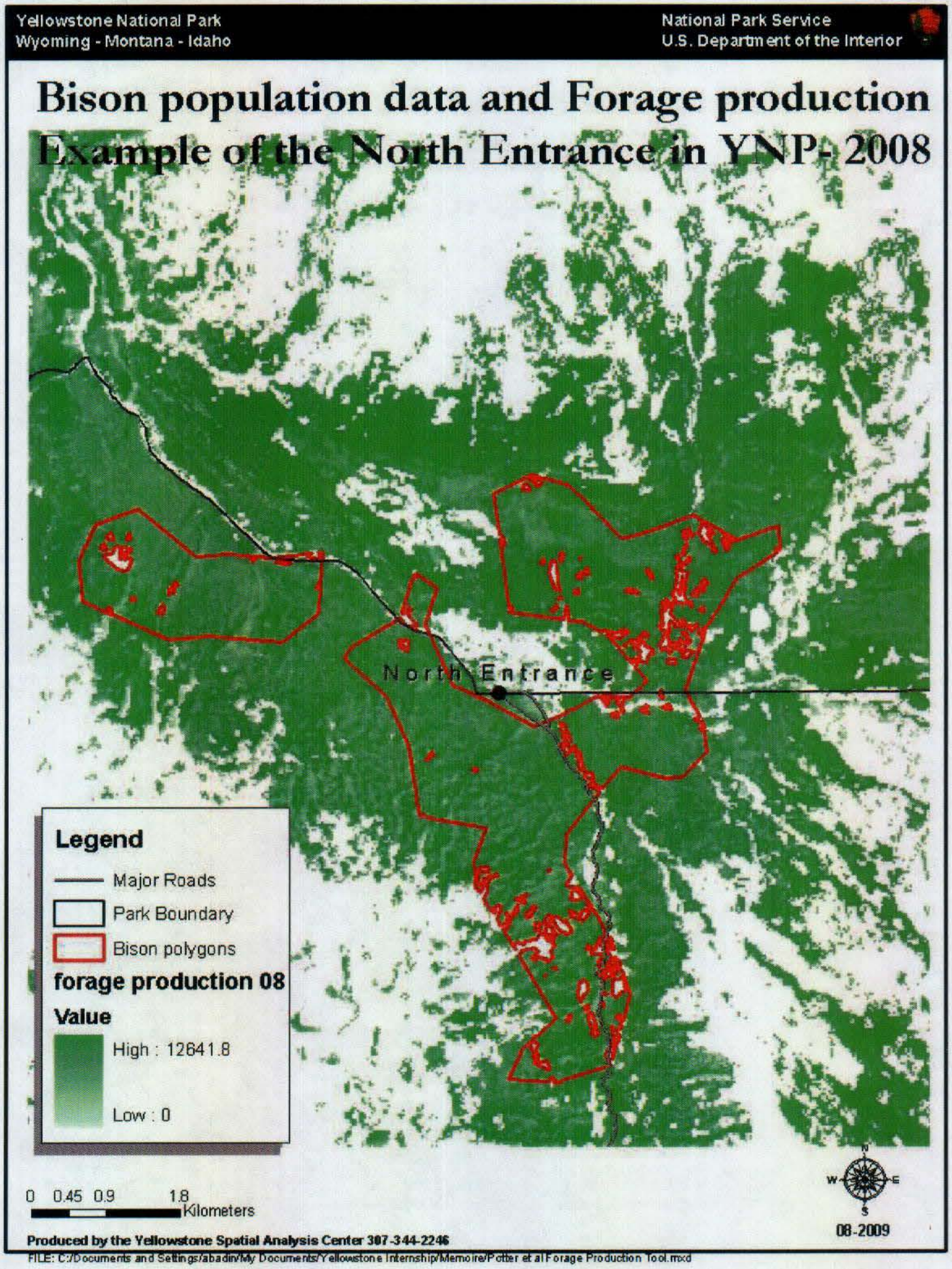


Fig. 23. Example of bison data: the bison polygons.

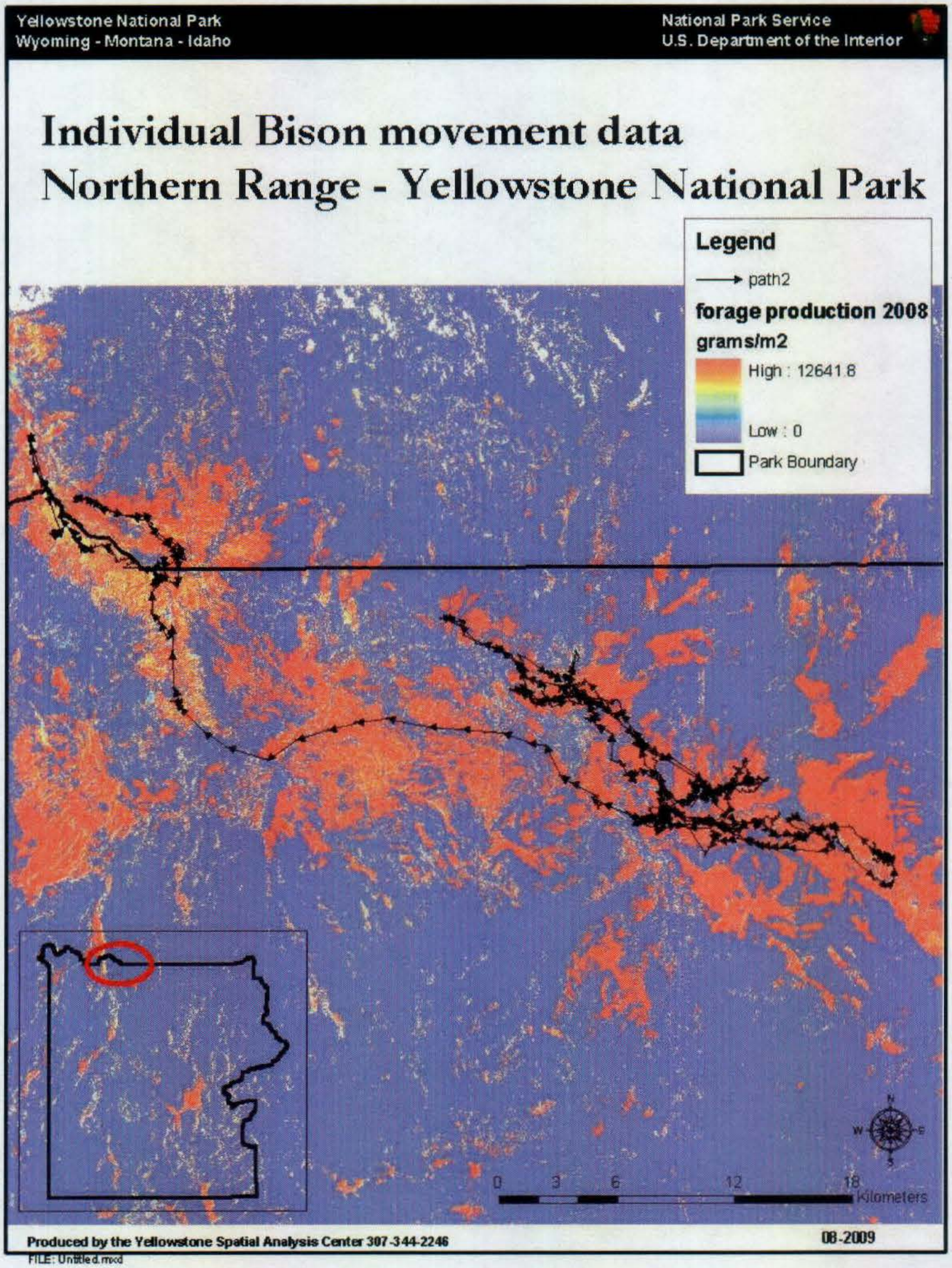


Fig. 24. Example of bison data: GPS and telemetric data.

3) First results

In overlaying the forage production data from 1990 to 2008 and the bison polygons data for the same period, we can notice the decrease of forage quality selection by bison. This might be explaining by the successive dry years happening in YNP at the beginning of the decade.

	PATCH			PIXEL		
	Northern Herd	Central Herd	Park Average	Northern Herd	Central Herd	Park Average
1990	644.44	499.72	565.48	331.11	346.49	339.50
1991	466.15	394.15	426.87	247.03	276.50	263.11
1992	675.70	554.59	611.14	353.90	381.52	368.62
1993	722.41	632.25	666.51	372.73	436.28	412.14
1994	582.91	553.39	566.92	305.37	378.94	345.21
1995	485.45	357.33	416.34	243.16	244.76	244.02
1996	522.80	449.84	483.09	276.06	312.17	295.71
1997	510.51	440.86	472.51	272.19	306.33	290.82
1998	476.37	425.68	448.71	249.98	294.98	274.53
1999	488.85	451.64	468.55	255.54	312.69	286.72
2000	282.28	318.64	302.12	169.18	229.11	201.88
2001	312.53	327.21	320.53	179.89	231.69	208.13
2002	302.97	304.61	303.87	171.68	215.33	195.50
2003	373.20	382.64	377.63	200.93	273.45	234.99
2005	159.52	264.83	216.78	94.02	175.99	138.59
2006	189.76	345.39	274.67	127.74	248.49	193.63
2007	439.66	382.00	408.20	231.59	266.71	250.75
2008	488.06	463.24	474.56	263.39	317.42	292.78
2004	473.8156	568.3035	519.5921	225.3825	399.8891	309.9256

Fig. 25. Results of the forage production maps from 1990 to present.

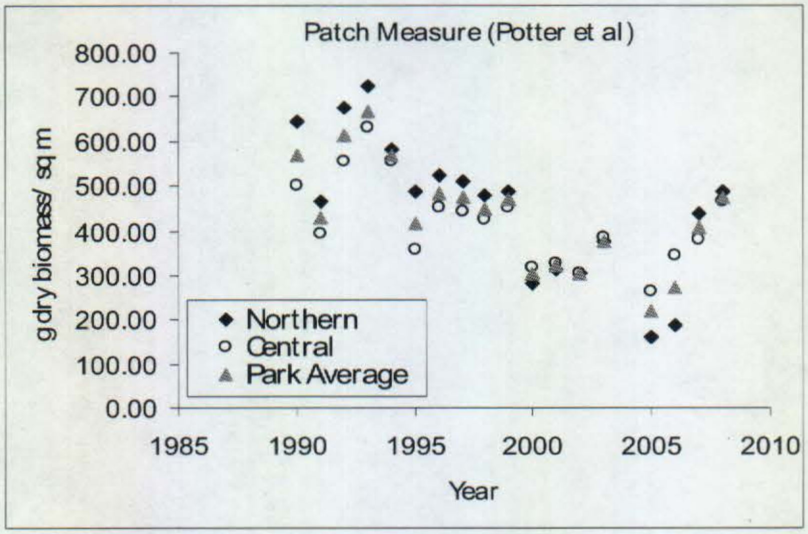


Fig. 26. Forage production use by bison in Yellowstone National Park.

Those are only ideas that the park would need then to analyze more profoundly, at a large scale first and at a little scale then. GPS data are available for 10 years only and don't allowed decision maker to have a general overview over the past.

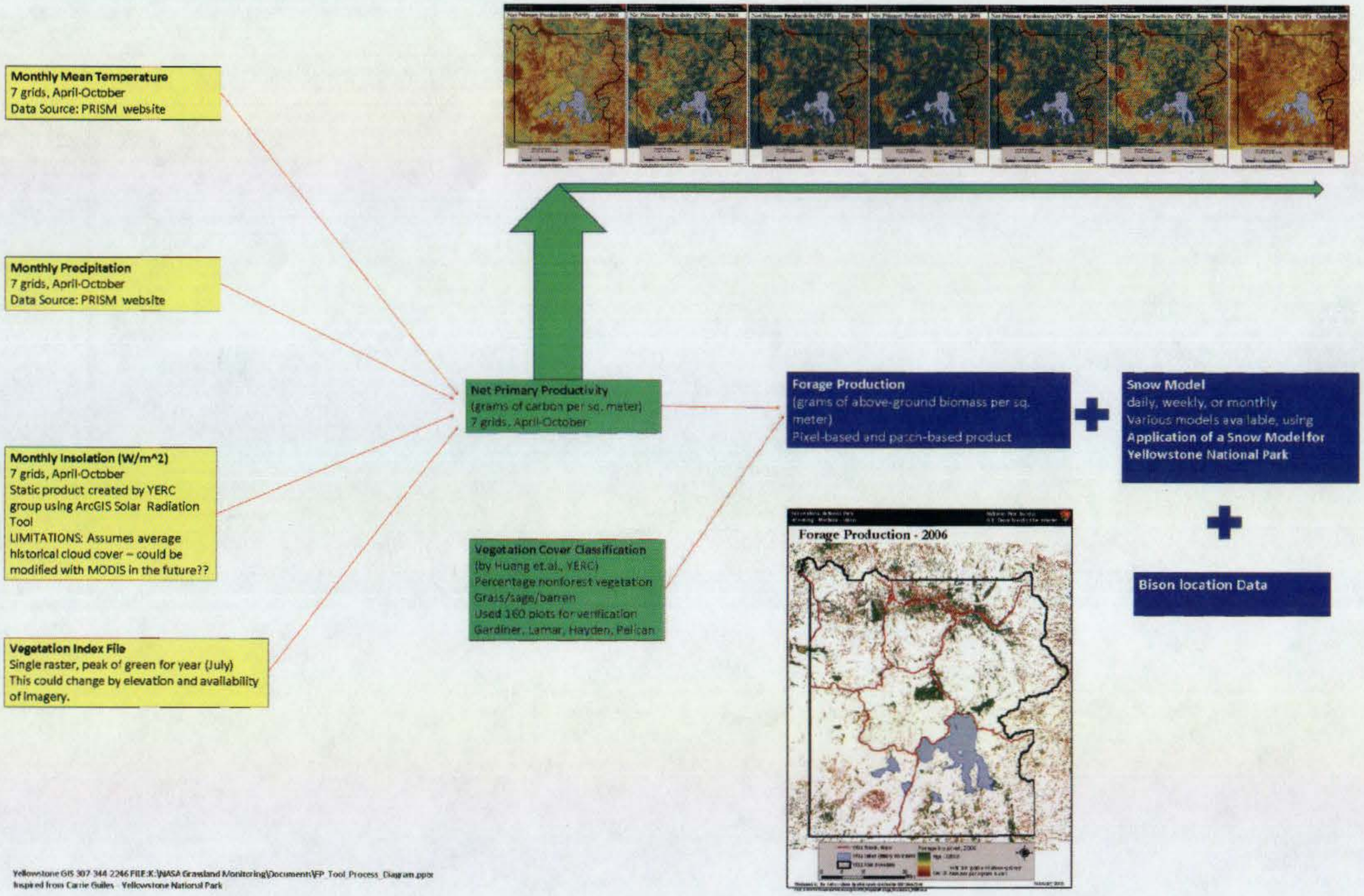
If forage quality decrease, bison population should decrease also. But since 1990, the bison population passed from 1000 to 5000. It is possible that bison respond in the negative forage quality by expanding their range, inside the park but also outside the park. What is the threshold value for forage quality that will keep the bison inside the park? If one year is especially dry, should we be prepared to have large bison movements outside the park few years later? How many years later?

A next step for YNP will be to compare bison polygons year by year to see how those polygons and change and expand or not. This would allow also knowing how big a range for a certain amount of bison is (density of bison per square meter). Another necessary comparison would be with the snow cover. Forage availability provides information on bison movement for a part of the year. To get information for the whole year will allowed more accurate forecasts. Moreover, the two models (Forage Production and Snow Cover) should conduct to the same deduction.

In general, bison begin regularly leaving park boundaries when the population exceeds about 2,500 animals in each herd; when the population was more than 3,000, the number of bison leaving YNP was highly related to snow water equivalent[3] (SWE). Finally, the bison population numbered about 2,400 animals seems to be a pivotal year in terms of growth and movement. Taken independently, each of these lines of evidence is weak, but taken together, they provide a consistent picture of the response of bison movement within YNP.

[3] The snow water equivalent of a snowpack is one of the most important measurements of a snowpack from a hydrologic standpoint because it is a direct measure of the liquid water content of a snowpack. When some or all of this water is released during the seasonal melt, it becomes an important component of local surface water and groundwater budgets. In some areas of the world (e.g. some regions of the western United States), snowmelt provides the majority of annual groundwater recharge, so monitoring of snow water equivalent of snowpacks is an important part of water resources management.

Forage Production Tool – Inputs and Products



Yellowstone GIS 307 344 2246 FILE:K:\NASA Grassland Monitoring\Documents\FP_Tool_Process_Diagram.pptx
Inspired from Carrie Guiles – Yellowstone National Park

B) Other contingencies to take in account

In the precedent part, we consider the forage availability to be the main element influencing bison ecology, especially bison migration. But to be able to make precise forecast, other contingencies should be integrated, such as the snow characteristics (depth and pack), the effects of human activities within the park, or the reintroduction of a super-predator (the wolf) in 1995.

1) The snow cover factor

The proportion of bison migrating each winter is explained by density-independent climate factors that limit their access to food. The numbers and timing of bison migrating from the summer range to the winter range is directly related to snow cover. Snow conditions (e.g. depth and density) in Yellowstone National Park restrict forage availability, increases energy costs of foraging, alters habitat selection, movement patterns, increases energy costs and vulnerability to predators (Meagher 1973).

Most precipitation reaches Yellowstone National Park along prevailing westerlies and much of it in the form of snow. Snow accumulation begins mid to late October and persists until late March, to early April. Mean duration of snow cover is 213 days at 7,000 ft (2,133 m; Despain 1990) and total precipitation (snow and rainfall) is typically greater at high elevations and greater in the western portion of YNP compared to the east. Previous studies indicate that snow conditions are more severe (i.e. deeper) in central YNP than the northern range (Meagher 1973). Thus, measurable snow is rarely before November 1st and usually is gone by June 15th at all sites. The site of Gardiner rarely registers any SWE. The northern range is drier and warmer than the rest of the park, with mean snow water equivalents decreasing from 30 to 2 cm along the east-west elevation gradient. In the depth of winter, SWE predictions can be as high as 190 cm (75 inches) at the highest elevations in the park. The crossing of forage availability and snow water equivalent with bison movement data should provide information all the year long and on the northern range where bison are the more likely to get out the park.

Yellowstone bison spend the majority of their time finding and eating forage during winter, with nearly one-third of that time spent displacing snow to reach forage (Meagher 1989, Bruggeman 2006, Bruggeman et al. 2009). Thus, snow is the primary factor that reduces foraging efficiency and bison prefer patches with minimal snow pack compared to the surrounding landscapes. As snow depth increases, the availability foraging area for Yellowstone bison is reduced to only few and limited areas at lower elevations and on thermal areas, even though many geothermal contain only poor quality forage (Meagher 1989, Bruggeman 2006, Bruggeman et al. 2009). Also, snow melts earlier at lower elevations and, as a result, there is earlier green-up and energy-efficient foraging opportunities while upper-elevation portions of the winter range are still covered with snow (Bjornlie & Garrott 2001, Bruggeman et al. 2006, Plumb et al. 2009). This last point explains bison transboundary migration outside the park in the north entrance.

Deep, dense hair (cf. Fig.x.) allows bison to cope with intense cold (Peters and Slen 1964, Lott 1979, Plumb & Dodd 1993) and bison calves present a metabolic-rate reduction when they are exposed to intense cold (-30 degrees Celsius). In that way, they reduce their energy expenditure when cold stress and food limits are imposed (Chrisopherson et al. 1978, Plumb & Dodd 1993). Thermoregulation through habitat selection is also a successful behavior pattern that allows bison to live with extreme temperatures (Belovsky & Slade 1986, Plumb & Dodd 1993).

In Pelican Valley bison were observed foraging through snow depth of 102-114 cm and moving to areas with lower snow cover when depths exceeded 127 cm (Meagher 1971). Van Camp (1975) suggested impediment of movement by adult bison starts at snow depths of 65-70 cm. Turner et al. (1994) estimation was that beyond a snow depth of 180 cm, foraging ceased (Gates et al., 2005).

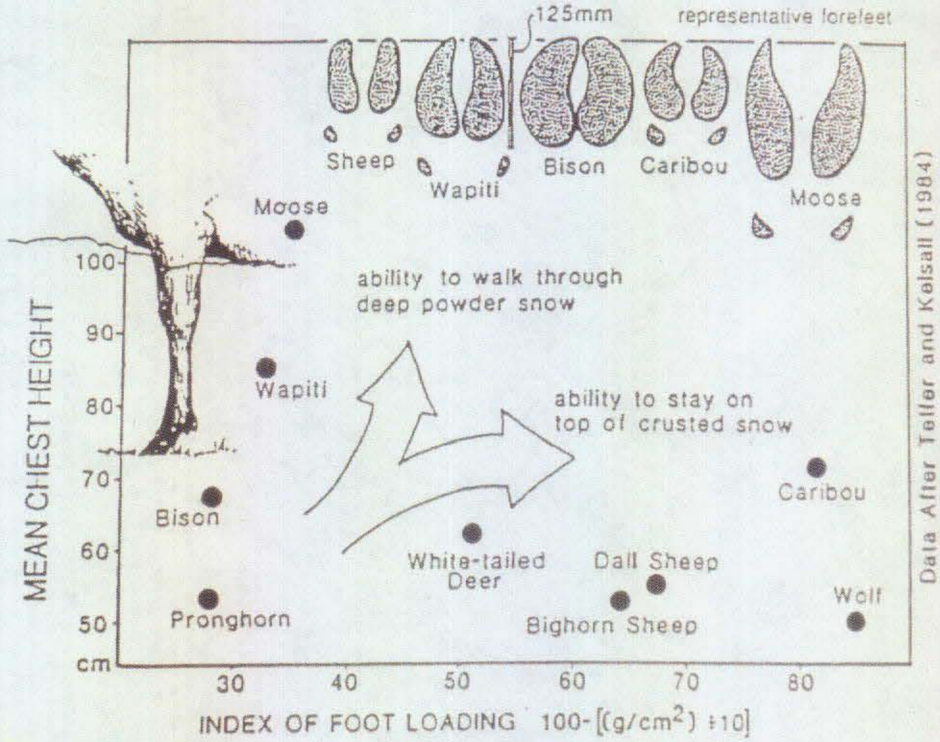


Fig. 27. Foot and leg adaptations to snow.

Source: K. Altenhofen.

Large mammals are not equally restricted by deep snow. When snow reaches the chest (this depends on leg lengths), an animal can no longer lift its legs above the snow surface, and this consumes a great deal of energy. Foot loading, the ratio of weight to surface area of the foot, is also important. Some animals are able to walk on the snow surface. Both leg length and foot loading are important in the degree of snow tolerance characteristic of each ungulate group. This figure shows how bison excel at neither and how poorly there are adapted to deep snows.

The fact that bison continued to feed in areas with deeper snow (level and gentle slopes) in spring shift to nearly snowfree sites reflects response to early availability of green plant growth rather than an inability to cope with the deeper snow that still persisted on previously preferred sites.

Bison remove snow from underlying forage mostly by pushing it aside with their heads, and their mouths are in immediate contact with exposed vegetation. This strategy greatly reduces trampling of forage and the unnecessary trampling of snow associated with pawing (Pruitt, 1959). The feeding behaviour of bison permits them to feed on sedge meadows where snow is deeper but less dense and hard, and where plant biomass is much greater than on other grasslands (Van Camp 1975). However, severely crusted snow probably is a major winter hazard for bison some winters.

But snow alone cannot explain alone bison movements. Simulated numbers of bison outside the western boundary during 1980-1997 were significantly but variably affected by the snow, little affected by population size, and strongly affected by an interaction between snow and population size (Courghenour 2005, Garrott et al. 2009).

2) The grooming road debate

The effects of road grooming in winter on bison movements and population dynamics is also particularly controversial (National Park Service et al. 2000). Human infrastructure influences bison movements in other seasons as well, but since the early 1990s, concern has been expressed that grooming of roads in the park for over-snow vehicle (OSV, e.g., snowmobiles, coaches) use from December to March has facilitated bison movements within and between ranges, including boundary areas. Roads and other linear features (i.e. powerlines and telephone lines) have been in place in YNP since at least the early 1900's. Infrastructure and other facilitation of winter use (i.e. road grooming) have been in place in YNP since the late 1970's, and since 1949, the public has had the opportunity to visit the park during winter using OSVs. The current controversy over the effects of winter use of groomed roads by bison reflects the tension between the NPS' dual mandates.

Protection of the environment and the wildlife in the park represents one issue in the debate over winter use and recreation and economic interests another one. A substantial winter recreation industry has developed around winter access to the park, contributing significantly to the regional economy. Proposals to restrict this activity create a severe outcry from this sector. Over the decades, motorized winter recreation increased from

2000 in 1970's to more than 100 000 riders per winter during the mid 1990's (Gates et al., 2005) and concurrently, counts of central Yellowstone bison increased from 500 to more than 3000 animals (NPS 2000, Bruggeman et al. 2007).

The energy saved by bison travelling on packed snow in combination with better access to foraging habitat, results in increased population growth and range expansion. Meagher (1989*b*:674) offered the first testimony concerning the effects of roads on winter range expansion: "Use of the plowed road for relatively easy and energy-efficient travel probably facilitated learning and a rapid increase in numbers." The following effects on the YNP bison population would be:

- groomed roads provide movement corridors facilitating travel within traditional foraging areas;
- groomed roads induce major shifts among previously isolated population sub-units;
- groomed roads induce range expansion;
- groomed roads reduce the energy cost of displacing snow during movements within and between winter ranges;
- energy saved from the reduced cost of transport mitigates winter kill and enhances calf survival, resulting in a higher rate of population increase than would otherwise occur.

Also, no data were collected on bison distribution and travel before road grooming began, and therefore, no true experimental control of bison road travel exists before bison gained their foraging areas. As a result, it is impossible to conclude if groomed roads facilitated range expansion and bison are now familiar with destination ranges at lower elevations (Bruggeman et al., 2007) using special pathways. Another suggestion would be that streams will be the most influential landscape feature affecting the bison winter travel network (Bruggeman et al., 2007).

The NPS identified a need to address this issue: 1) to produce an unbiased and independent assessment of the state of knowledge of the ecology of bison movements and distribution; 2) to provide recommendations for adaptive management of uncertainties and gaps in knowledge. But one of the central causes of ongoing conflict is probably not a lack of knowledge but a lack of policy process by which people and institutions can be constructively engaged in integrative decision making using the best available science.

3- The Wolf predation?

Wolves in the northern Rocky Mountains were listed as endangered under the federal Endangered Species Act in 1974. Many scientists favored reintroduction over natural recolonization as a means of restoring wolves to the GYE. However, because of extensive controversy, wolves were not reintroduced to YNP until more than 20 years after they were listed as endangered (Bangs et al. 1998). In 1995, 14 wolves in three packs captured in Alberta, Canada, were introduced to YNP. In 1996, another 17 wolves in four packs captured in British Columbia, Canada, were introduced to YNP. In 1997, 10 pups and 3 adults from a pack captured in northwestern Montana (because they were chasing livestock) were released in the park (Bangs et al. 1998).

Wolves are more successful killing elk than bison; bison were killed in 7% of 57 interactions compared to 21% of 372 interactions between wolves and elk (Smith et al. 2000). Elk outnumbered bison in YNP and in three years of study in the Madison-Firehole area, Jaffee and Garrot (2001) located 101 definite and 29 probable wolf kills, including 70 elk calves, 34 cow elk, nine bull elk, one unknown adult elk, 13 bison calves, one cow bison, and one unknown bison.

Future effects of predation on bison population dynamics in YNP is an important research focus. During the period after wolf eradication in the Greater Yellowstone Ecosystem, bison and elk became more sedentary (Berger 1991, Gates et al. 2005). It is suggested that wolf predation on bison will continue to increase in the Central ranges, but not on the northern range as long as elk are relatively more abundant there. The Yellowstone wolves have been returned to an ecosystem that existed without them for much of the past century. Adjustment of the system to the presence of wolves is likely to take many years, as the wolves and the other components of the ecosystem adjust to one another (Klein 1995, Berger et al. 2001, Gates et al. 2005). Wolves will probably alter their patterns of prey selection, pack structure, movements, and population dynamics as the density, distribution, predation avoidance behavior, and population structure of their prey species change. Similar to the numerical response seen in other wolf–prey systems

(Messier 1996, Gates et al. 2005), wolf populations in other bison areas were shown to respond numerically to increasing bison population size.

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as population size increase (Gates et al., 2005). Range expansion may delay responses to food limitations since new ranges provide additional forage and limitations will become apparent primarily when new ranges can no longer be colonized (Messier et al. 1998, Plumb et al. 2009).

Furthermore, the bison population of YNP is likely approaching or has recently reached a state of dynamic equilibrium possibly not seen since the early 1800s. Conclusions formed about spatial and population ecology of bison when the population was increasing or at low densities cannot be readily applied to the dynamics of a population in dynamic equilibrium around a higher range of densities. The system is dynamic and continues to evolve, thus requiring systematic monitoring of key variables and continuation of basic research on ecosystem process (Gates et al., 2005).

What is the future of bison in YNP?

2) Definition of "Natural" for Yellowstone National Park

The Yellowstone bison herd had become the only free-ranging herd in the United States, and thus, the YNP played a key role in restoring bison and removing the threat of their extinction that existed by the late 1800s. Intensive management of bison within the park was the practice until the NPS announced in 1968 a policy of "natural regulation" of wildlife populations, meaning free of direct human manipulation. The intent is to allow the biological and physical processes within the park to function without human influence. But hazing, hunting, removals, still happen when bison outsides the park boundaries. What is « natural regulation »? What is the definition of "natural" for Yellowstone National Park?

First, changes in management of wildlife in YNP since its establishment reflect the changes in attitudes toward wildlife that have taken place among the American public.

Concern about the decline of wild ungulates developed a national conservation movement. At that time large carnivores were viewed as undesirable by most of the public, because they killed both domestic livestock and wild ungulates. As a reflection of

this public sentiment, although other wildlife species were protected within the park, control of predators by park managers began in the nineteenth century and became intensive between 1900 and 1935, resulting in the extirpation of wolves and probably mountain lions (about 130 were killed during that period, Tom Oliff, pers. comm. Cf. Annex. 3). At the opposite, the ungulates, because of their attractiveness to park visitors and the opportunities that existed to observe them, were considered a primary justification for the park's existence and thus were the focus of management efforts. Surprisingly, bears, which were considered a threat to human interests outside of the park, were appreciated by park visitors, who were allowed to view them at garbage feeding sites until the practice was discontinued in 1943.

By the middle of the twentieth century, there was a broadening appreciation for wildlife among the public. This increased interest in wildlife and the importance of natural environments for wildlife and some interventions have been allowed. For example, to restore natural predation processes, wolves were reintroduced. To gain a better understanding of ungulate ecology in the park, there has been some manipulation of animals and vegetation through live capture, the equipping of animals with radio transmitters, and the use of fenced enclosures to assess plant growth in the absence of grazing and browsing.

But one ongoing debate still focuses on whether the "natural" in natural regulation includes humans as part of nature. Humans have, since their arrival in the area, been important agents of change and "natural" can not be objectively defined. Animals do not have free access to the adjacent areas of the park that formerly were available to them as migration corridors and winter range. For these reasons, true natural regulation in YNP—to let nature takes its course with no human intervention—seems impossible.

Although YNP's natural regulation policy attempts to minimize human intervention within the park, this does not characterize the policies that affect ungulates when they are outside the park. In other words, YNP is an ecological island whose processes are influenced by human activities in the surrounding area. These activities, which strongly influence YNP wildlife, include agriculture, ranching, and hunting. Thus, even if there were no human intervention within YNP, ecological processes there would be profoundly

influenced by human activities elsewhere. In this sense, management can, at most, be only partly natural.

A more realistic definition of natural regulation as practiced by NPS in YNP would be to attempt to minimize human effects on the natural systems of the park. The National Park Service 1988 Management Policies describes the management strategy as "natural environments evolving through natural processes minimally influenced by human actions." However, NPS has other policy mandates within YNP that might not be consistent with natural regulation. For example, the National Park Organic Act of 1916 prescribes that "the fundamental purposes of said parks is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations". Under this policy, research is undertaken to satisfy NPS mandates to better facilitate management of visitors to the park, minimizing their impact on wildlife and vegetation.

Is it possible to maintain a road system within the park, with associated public facilities and services, "to provide for the enjoyment" of the three million visitors who currently visit the park annually, without affecting the scenery, vegetation, and animal life? In the past, management of wildlife within YNP has been driven by the view that first, national parks exist for public enjoyment and appreciation. More recently, management philosophy tends toward ecosystem management in priority, trying to concentrate public presence along the developed areas in the park or along the road axes (Tom Oliff, pers. comm. Cf. Annex 3).

In addition to human-caused changes, the ecology of YNP has been profoundly influenced by changes in the physical environment. Of these, climate change has been the most important driving factor during the past 10,000 years.

Climate changes complicate management strategies because they make it especially difficult to predict the likely consequences of any human interventions as well as the consequences of not intervening. Biodiversity is a dynamic ecosystem characteristic that fluctuates naturally or in response to human activity (Noss and Cooperrider 1994, Gates et al.). Changes caused by changes in population dynamics of ungulates may affect not

only dominant landscape features, such as aspen or sagebrush, but also vast numbers of associated organisms, and how much human activity has done in the Great Yellowstone ecosystem (GYE) is poorly understood. For example, if YNP decided to maintain tree-sized aspen in the park, putting exclosures around some stands would be less potentially disruptive than eliminating ungulates or reducing their numbers.

3) Policy versus Practice

Natural regulation as a policy for YNP (Schullery 1997, YNP 1997, Pritchard 1999) implies that if a change in the ecosystem is natural, then management intervention is inappropriate. On the other hand, if a change is due to a management policy implemented by the park, then there is justification for repair or restoration of that change or impairment. Under a policy of natural regulation, such an argument is important, because the appropriateness of the park's management actions depends on whether they are consistent with the policy. If natural regulation were only a practice, the debates could focus on the actions and their outcomes. In addition, adaptive management might be easier to undertake.

YNP resource managers consider the northern range to be in acceptable condition and the role and numbers of ungulates and other wildlife appropriate for a national park, and the best available scientific evidence does not indicate that ungulate populations are irreversibly damaging the northern range. In addition, several significant changes have been made in the northern range in recent years, including the reintroduction of wolves and expansion of the winter range outside the park; the long-term influence of these changes cannot yet be determined. Thus, YNP resource managers could continue to manage the northern range as they are now. That is, YNP managers would continue to let the populations of elk, bison, and other ungulates fluctuate without any direct (inside Yellowstone) controls, letting a combination of weather, predators, range conditions, and external controls (e.g., outside-the-park hunting, land uses, and population reduction by state agencies, such as the Montana Department of Livestock's program for bison) influence the population numbers.

YNP's northern range ecosystem is dynamic and ecosystems change in unpredictable ways. Experimentation and time are necessary to YNP managers for understanding their

ecosystem on the long term and to allow them to observe the influences of the addition of a top predator and more available winter range. It will require careful monitoring to obtain full value from the experiment and to detect potentially serious changes in the ecosystem before they become severe or even irreversible.

CONCLUSION

The extinction of more than half of the large mammals in the Americas was attributed to a combination of climate change and human predation. Native Americans were highly efficient predators and the arrival of horses conjugated with technological improvements in firearms and ammunition accelerated the extermination of plains bison throughout most of its range.

Nowadays, the two major issues associated with Yellowstone National Park bison management are primarily a consequence of the successful recovery and expansion of bison as a wildlife species and conflicts resulting in the arbitrary park boundaries within a large ecosystem in which people also live.

As bison number increased, seasonal migrations along altitudinal gradients within YNP became the norm, with some bison in both the central and northern herds moving from higher-elevation summer ranges to lower-elevation during autumn through winter, until bison returned to summer ranges in June (Bruggeman, 2009). But bison affected by *Brucella abortus* are not desirable outside the park and to manage the risk of brucellosis transmission from Yellowstone bison to livestock, the federal government and State of Montana agreed to the Interagency Bison Management Plan (IBMP) in 2000, after more than a decade of negotiations and alternatives plans. This plan established guidelines for implementing hazing, test-and-slaughter, hunting, and other actions affecting bison abundance and distribution near the park boundary (Department of the Interior 2000, Plumb et al. 2009). The IBMP established also two zones of intensive, adaptive, risk management outside the northern and western boundaries of the park where limited numbers of bison are allowed under various contingencies. For each zone, 3 different degrees of bison management and tolerance correspond to 3 different areas: zone 1 inside the park, zone 2 adjacent to the park boundaries and zone 3 with zero tolerance of bison presence.

Without the intensive management intervention, there is little doubt that bison would have continued to expand their winter range and dispersed to suitable habitat areas

outside the northern and western boundaries of the park. But brucellosis risk-management removals at the park boundary, combined with other natural mortality contingencies, temporarily reduced the density of bison and likely diminished the density dependent effects on demography and movements (Plumb et al. 2009).

The modeling project of forage availability with bison movement data should let decision maker being able to number bison population size in those adaptive management areas and to manage this movements better for the two objectives of preserving a free-wild bison herd and to avoid brucellosis transmission. The model confirms the empirical knowledge about bison migration: the distribution, quantity, and quality of available food, food habits, and the direct influence of the snow regime (blizzards, the condition of the snow cover as it affects travel, etc.), human facilities, or predation, primarily determine the distribution of ungulates and their selection of habits during winter and early spring. Being able to make understand those issues to an external public could potentially make YNP relationship with other agencies or the public being easier: the lack of policy process is one of the central causes of ongoing conflict. People and institutions can be constructively engaged in integrative decision making using the best science knowledge provides by GIS results. Models are not "right" in a predictive sense, but rather are "reasonable" in their structure, assumptions, and relationships. Simulation modelling allows users to gain better insight into the dynamics of a system and their greatest value lies in offering a "what-if" simulation tool for stakeholders to explore alternative futures in good conditions.

Thus, the problems at the boundaries of Yellowstone are likely to continue, challenging society and policy makers with a bison population that exits the park in response to density and climate effects. If vaccination plans are implemented and successful at reducing brucellosis, then population growth rates will likely increase and exacerbate bison dispersals. Efforts to deal with the linked problems of bison/brucellosis/cattle and winter use/bison movements have suffered fractured government jurisdiction, inadequate policy process and low levels of public involvement, leading to intense conflict. Recent advancements in natural resource policy processes offer promise for dealing with complex problems such as bison management in the Greater Yellowstone Area. A pragmatic, procedurally rational integrative policy-oriented process is needed for

organizing agencies and citizens to work together to use multidisciplinary knowledge for integrative decision-making.

The recent development of hunting of Yellowstone bison in Wyoming and Montana, outside of YNP, enhances their stature as wildlife. Within this range of abundance, management agencies should continue to prioritize conservation of bison migration to essential winter range areas within and adjacent to the park, while also actively preventing dispersal and range expansion via hunting, outside YNP, and periodic brucellosis risk-management. Hunting could be nowadays considered as part of bison ecosystem and as a predator considering that wolf impact is minor in bison population (Glenn Plumb, pers. comm. Cf. Annex 3.). Long-term monitoring of the predators and ungulates within the Yellowstone ecosystem provides a unique opportunity to greatly expand knowledge about interspecies relationships among upper trophic levels. Because the same issues are surfacing across the nation's public domain, the resolution of Yellowstone bison movement controversy will have a pronounced influence on how similar problems are addressed elsewhere in the United States and throughout the world. In short, Yellowstone National Park represents a laboratory for redefining human role in wild ecosystems.

BIBLIOGRAPHIE

Altenhofen, K., 1999. *Catastrophic Events in North American Bison Populations: A Historical Geographical Overview with Implication For future management.* South Dakota State University, Master of Science, thesis, pp.195.

Aronoff, S., 2005. *Remote Sensing for GIS Managers.* ESRI Press, pp. 487.

Barmore, Jr., William J., 2003. *Ecology of ungulates and their winter range in northern Yellowstone National Park: Research and Synthesis*, 1962-1970. National Park Service, Mammoth Hot Springs, Wyoming. 524 pp.

Beltrán, J.,2001. *Pueblos Indígenas y Tradicionales y Áreas Protegidas: Principios, Directrices y Casos de Estudio.* UICN, Gland, Suiza y Cambridge, UK y WWF Internacional, Gland, Suiza.139pp.

Bruggeman, J., Garrott, R., White, P.J., Watson, F. and Wallen, R., 2007. *Covariates affecting spatial variability in bison travel behavior in Yellowstone National Park.* Ecological Applications 17:1411 – 1423.

Callenbach, E., 2000. *Bring back the buffalo: a sustainable future for America's Great Plains.* Berkeley, University of California Press.

Committee on Ungulate Management in Yellowstone National Park, 2002. *Ecological Dynamics on Yellowstone's Northern Range,* Board on Environmental Studies and Toxicology, Division on Earth and Life Studies, National Research Council, National Academy Press, Washington, D.C., 198 pages.

Division of Interpretation, 2008. Annual Yellowstone Resources and Issues, National Park Service and Yellowstone National Park, 200 pp.

Dingman, S.L., 2002. *Physical Hydrology.* Prentice-Hall, pp. 176.

Gates, C., 2005. *The Ecology of bison movements and distribution in and beyond Yellowstone National Park.* Faculty of Environmental Design, University of Calgary, Alberta. 329 pp.

Garrott, R., Eberhardt, L., White, P.J. and Rotella, J., 2003. *Climate-induced limitation of a large herbivore population.* Canadian Journal of Zoology 81, pp. 33–45.

Garrot, R., White, P.J., and Watson, G., 2009. *The Ecology of Large Mammals in Central Yellowstone: A Synthesis of 16 years of Integrated Field Studies.* Academic Press, pp. 693.

Geremia, C. et al, 2009. *Migration, Culls, and Harvest of Bison Beyond Yellowstone National Park.* Yellowstone National Park, Wyoming, 50 pp.

Haines, A.L., 1974. *Yellowstone National Park – Its Exploration and Establishement.* U.S. Department of the Interior, National Park Service, Washington, 356 pp.

Héritier, S. & Laslaz, L., 2008. *Les Parcs nationaux dans le monde: Protection, gestion et développement durable.* Ellipses. 312 pp.

Keiter, R. & Boyce, M., 1991. *The Greater Yellowstone Ecosystem: redefining America's Wilderness Heritage*. Yale University Press. 412 pp.

Magoc, C., 2000. *Yellowstone: the creation and selling of an American landscape.* Albuquerque, University of Mexico Press.

Meagher, M., 1973. *The bison of Yellowstone National Park.* National Park Service, Science Monograph Series, No 1. 161 pp.

Plumb, G.E., 1991. *Foraging Ecology of Bison and Cattle on a Northern Mixed Prairie.* Ph. D., Department of Range Management, 137 pp.

Plumb, G.E., et al., 2009. *Carrying capacity, migration, and dispersal in Yellowstone bison.* Biol. Conserv. , doi:10.1016/j.biocon.2009.05.019.

Plumb, G.E. & Dodd, J., 1993. *Foraging Ecology of Bison and Cattle on a Mixed Prairie: Implications for Natural Area Management.* Ecological Applications, 3 (4), 1993, pp. 631-643.

Plumb, G.E. & Sucec, R., 2006. *A Bison Conservation History in the U.S. National Parks*, Journal of the West, Vol.45, No.2, 105 pp.

Pucek, Z. et al, 2004. *European bison (Bison bonasus): current state of the species and strategy for its conservation*, Convention of the conservation of European wildlife and natural habitats (Bern Convention). Strasbourg, Council of Europe.

Smith, R. & Siegel, L., *Windows into the earth: the geologic story of Yellowstone and Gran Teton national parks*. Oxford University Press.

Smith, D.W., Mech, L.D., Meagher, M., Clark, W.E., Jaffe, R., Phillips, M.K. and Mack, J.A., 2000. *Wolf-bison interactions in Yellowstone National Park*. Journal of Mammalogy 81, pp. 1128–1135.

UICN, 1992. *World Congress on national parks and protected areas: a review of national systems, IVth World Congress on national parks, Venezuela, Caracas*. UICN, Gland, Suiza y Cambridge, UK y WWF Internacional, Gland, Suiza.

Boyd, D. P. 2003. *Conservation of North American bison: status and recommendations*. M.S. thesis, Faculty of Environmental Design, University of Calgary, Alberta.

Irby, L. R. and Knight, J. R., eds., *Proceedings of the International Symposium on Bison Ecology and Management*. Bozeman, Mont.: Montana State University.

U.S. Department of the Interior (USDOI), National Park Service, and U.S. Department of Agriculture (USDA), Forest Service. 2000a. *Bison management for the state of Montana*

and Yellowstone National Park, Final Environmental Impact Statement for the Interagency Bison Management Plan for the State of Montana and Yellowstone National Park. Vol. 1. August 2000.

_____, 2000b. Record of decision for the final environmental impact statement and bison management plan for the state of Montana and Yellowstone National Park. December 2000.

ANNEXEXES

ANNEXE 1- Chronology of Significant Events in Yellowstone National Park's History

Year/Period	Event
1860s	Period of extensive fires (Romme and Despain 1989)
Before 1870	Evidence of substantial elk use of the northern range, at least in summer (Houston 1982)
1872	Yellowstone National Park declared first national park (organic act)
1869–1883	Extensive market hunting; ungulates and carnivores greatly reduced (YNP1997)
1883	Public hunting within YNP prohibited (YNP 1997)
1886	U.S. Calvary assigned to protect the park; beginning of effective control of hunting (Houston 1982, YNP 1997)
1894	Lacey Act enacted, prohibiting all hunting and killing of wildlife except dangerous animals (Schullery 1997)
1900–1935	Intensive control of predators; wolves extirpated (YNP 1997)
1902	Few bison remained in YNP; population supplemented from domestic bison herds (Meagher 1973)
1917	Brucellosis detected in YNP bison (Mohler 1917)
1918	U.S. National Park Service assumed control of YNP (YNP 1997)
1920s	"Too many elk in park"; active management to control population. Increasing concern about overgrazing (YNP 1997)
1920s	Reported decline in white-tailed deer population from about 100 to few or none (Skinner 1929)
1920–1960	Commercial definition of over-grazing applied to YNP; intensive population control of elk and bison (YNP 1997)
1923–1929	Elk removed primarily by hunting outside park; probably 10–15,000 elk on northern range (Houston 1982)
1930s-present	Very little recruitment of aspen on the northern range
1960s	Period of most intensive elk population control and population reduction (YNP 1997)
1963	Leopold report published (Leopold et al. 1963)
1968	YNP adopts policy of "natural regulation"; intensive regulation of elk and bison ends (Cole 1971)
1969–1981	Period of rapid increase in elk population from ~4,000 to ~16,000 (Houston 1982)
1969–1995	Bison population expands from ~400 to ~4,000 (YNP 1997)
1986	Congress funds study of "overgrazing" in the northern range
1988	Extensive fires in YNP
1988–1989	Severe winter reduces elk and bison populations
1995	Reintroduction of wolves
1996–1997	Severe winter; slaughter of 1,000 bison as they left YNP

ANNEXE 2- Northern Mixed Prairie Forage Composition

Source: Plumb & Dodd, 1993.

Graminoids:
Andropogon gerardii : big bluestem
Bouteloua curtipendula
Bouteloua gracilis : blue grama
Buchloedactyloides
Calamovilfa longifolia
Muhlenbergia cuspidata
Panicum virgatum: switchgrass
Schizachyrium scoparium: little bluestem
Sorghastrum nutans: indiangrass

Grasses:
Ambrosia psilostachya
Astragalus crassicarpus: ground plum
Mellilotus officianalis: yellow sweet clover
Medicago sativa
Psoralea argophylla: silverleaf scurf
Solidago Canadensis
Sphaeralcea coccinea
Tragopogon dubius

Forbs/Legumes:
Amorpha canescens: leadplant
Glychyrhizza lepidota: American licorice

Browse

ANNEXE 3- INTERVIEWS

July 30th 2009, Glenn Plumb- Chief, Natural Resources in Yellowstone National Park.

What is "Natural Regulation"? What is "natural" definition for the National Park Service (NPS) and for the Yellowstone National Park (YNP)? Is there a distinction between Yellowstone National Park policy and practice?

First, the phrase Natural Regulation – the regulation is not a statue. It's not a law regulation. It's about ecological feedback regulation. So the theory is that here at Yellowstone, we're a "northern temperate ecosystem" we're central continental and we exist on an elevational gradient of several thousand meters. And the idea was put forward in the 1960s that perhaps the park was of sufficient size that the ungulates, primarily, and there are 7 wild ungulates that use the park, would express their ecologies in a natural feedback process regulation. So think of regulation as a feedback mechanism and that the natural, and think of natural as evolved, so I think of natural regulation as the evolved feedback. So in this ecosystem there are evolved relationships that have taken hundreds of thousands of years between the ungulates and climates and grass and productivity of the forage and the snow melt and all of that. And the idea was put forward that the ungulates would reach some sort of dynamic equilibrium with their food and regulate it, or feedback, from snow and also from hunting. But that the hunting, instead of occurring inside the park, would occur outside the park. So that the evolved forage production, snow feedback would stimulate or underpin migration. That the animals would, when they reached the sufficient number of abundance, they would react to winter by migrating downhill. And what would happen then? They'd migrate outside the park so that they could be hunted. And the hunting would serve as a feedback to mortality and that abundance then and the migration (the abundance of the animals and the subsequent migration), would reach some dynamic equilibrium, but with hunting. And acknowledging that humans have always harvested ungulates in this landscape. But with the creation of the park and the forbidding of hunting in the park as a core principle, then the hunting had to occur outside of the park. For the animals to be outside the park, they must migrate. And if they're going to migrate, they probably need to be in sufficient numbers, to actually be a little bit crowded amongst themselves to provoke the migration. So that's the natural regulation. It's not a pure, no humans, no management kind of scenario. This is very much an idea that requires the presence and activity of humans.

How much change are we willing to allow in our parks, in terms of climate change?

What I do know is that the stewardship of the park, the conservation of the park, the management of the park, in face of climate change, if we see certain kinds of phenomenon or expressions of global climate change to regional changes downscale to local processes or different weather patterns and such, it will affect the park. IT will affect the northern Rockies. So what does the park do about that? One, the first thing we do, we make a deliberate commitment to serving as a benchmark so one can make a strong argument that the park is a relatively intact ecosystem and the effects of climate change on its own or interactive with other things like changes in landscape use, changes in invasive species those could be interactive. But regardless of the interacting stressors or how it plays out, the park, I think, we've invested so much time and energy to preserve

this place, that we should use it as a laboratory, a benchmark for our understanding of the outcomes of these kinds of stressors and we should try to connect what we know about the park, say pre- and post climate change, changes in trajectories of processes, changes in abundance of species, we should try to connect that, I think, in a gradient. So if you think of Yellowstone as the top of the watershed, as a wild land, and you think of Bozeman as a rapidly growing urban environment, a former agricultural landscape, a former pastoral people kind of landscape. You can draw a line from Yellowstone to the Gallatin Valley, and pretty much see the overall processes that are occurring across the entire northern Rockies. And we should be able to measure and document all kinds of biological and physical signals that will tell us what's going on with these processes. And it shouldn't just be descriptive, it should be mechanistic. It should be nested in experiments there to do with water, soil, air chemistry, biodiversity, floristic, terrestrial, aquatic, you know, vertebrate and invertebrate. So I believe that the park should make a commitment to that, and we have, we have been selected as the core site for the northern Rockies, for the national ecological observatory network, which is called NEON. And we're trying to make that commitment to anchor the park to help the country understand those kinds of things. Now that's a big kind of… we contribute that way. What are we going to do ourselves? Well. If we're going to hold onto a natural regulation kind of natural feedback and the world changes, will Yellowstone change? Absolutely. Will some things go away and other things increase? Probably. Are some of the resources here, um, have they changed in the very long evolved history of the park? Yes. Aspen have been present and been not present, present and not present. We have a new paper that just came out, a very good scientific paper, on the periodicity of beaver dams. Showing that there may be a thousand years or more between intervals of high beaver activity and then long periods with low to no beaver activity. So part of our challenge is to understand these long term, the range of natural variability. And if we see something stepping outside of the range of natural variability I think we have an obligation to mitigate it. If there are some things that are maybe within the range of natural variability, but we have never seen it before or it causes concern and causes people to feel bad that the aspen trees aren't there, well then we have to think carefully about that.

So here's the example, and that's what up there on my board right there. We know right now that the climate change scenarios for the high altitude streams and lakes suggest changes in water inputs, changes in periodicity of snow melt, changes in flow regimes, potentially higher temperatures for waters, changes in hydrology that's going to be tied to water inputs by the climate regime. What's going to happen? That's going to have effects on fish. And right now we have lake trout that were introduced into Yellowstone Lake. And even without climate change those lake trout would deserve to be challenged and mitigated. We need to not have those because they are going to threaten the survival of the native trout. But climate change, combined with that exotic fish, potentially could interact, and drive the local trout to near extinction. So what do I need to do? I need to think about climate change. And I need to spend a ton of money killing those lake trout, getting them out of the lake, and then preserve the resilience of the native fisheries and maybe even improve it by more restoration, spread the fish out in more streams so that when climate change comes I don't have all my eggs in one basket, and I don't have all my fish in one spot. So I can be proactive in anticipating climate change by improving the resilience of the native biodiversity so that if there is any adaptation kind of possibility that we preserve that, because we at the park here can't stop climate change if it's going to happen, but we can preserve our ability to adapt and if we're doing that then we can reach out and form partnerships with larger areas of the Greater Yellowstone and say "we should all be doing this for our fish, because we all want fish." Regardless of

whether we want wolves or bison we all want fish, so our strategy should be commensurate across the whole region to conserve these fish.

What do you aim to in bison management? What is the future of bison management in YNP?

I'll give you a quote. My answer is here, in the last paragraph. "We propose that the Yellowstone Bison population vary in abundance…" and other societal constraints which are property damage and things like that. So we recommend a conservation paradigm that says we're not just going to preserve the standing animal, we are going to preserve the population and their evolved ecology, population ecology of mortality, survival, birth, death, that kind of stuff. We need to preserve their migration which is a phenomenon, but it's also a nutrient transport mechanism. They go up high, they graze, they defecate, they come down, they die at low elevations or they die at high elevations. There is a big nutrient bio-geochemical thing going on there that effects soil development. There's a lot of dung and urine being moved around by these animals. So the migration and its ecological relevance and the genetics, I think, personally the other societal constraints mentioned in there and elaborated it there. I think bison need to be hunted. I think they should be outside the park in large enough numbers that wild bison can be hunted. They are a wonderful meat source for people who need that. And if you're successful and a good hunter, it contributes to community building. People who like to hunt they band together, they do things together. Hunting can be a good thing. And then we have to manage Brucellosis, which isn't going away. So we have to manage that interface of Brucellosis and our livestock industries, which are important. So we propose a conservation paradigm in here that satisfies a variety of interests. And that's what I think we should be doing.

Why bison management is so different in West Yellowstone and at the North Entrance?

Well they're different ecosystems. Gardiner is around 5000 ft elevation, 10 in or 24 cm of precipitation. Very dry. Classic winter range. So you think about winter range for migration. A winter range is dry, windswept, and not a lot of snow. So animals will move down, and as soon as they find a snow free area even though the grass isn't that tall, and dry, they'll move around and munch, munch, munch. It's maybe better for them just not to have the snow. So Gardiner is in the rain shadow of the Gallatin Mountains. Very dry. Cold. Doesn't get a lot of snow, you know? West Yellowstone is higher elevation. Gets a lot of snow. Snow piles up very deep. It's a different soil type up there, it's a volcanic soil.

August 12th 2009, Tom Oliff, Chief, Yellowstone Center for Resources (YCR). Yellowstone National Park.

How much change are we willing to allow in our parks, in terms of climate change?

And that's when the army was here from 1886-1916 or really about 1918, they left and came back. And the biggest issue there was that hunting and poaching had wiped out large animal populations. I mean you think about that time and we had just wiped out 30 million bison and there were 1000 bison left in the west. Passenger pigeons ________ fishing and that kind of thing so I think their charge was game preservation. They were stopping poaching. They got laws in place. When the park service took over in about 1916-1918 (there was about a two year transition) until 1968, I call it the era of game management. And that's where all the states are now – they're still managing for herd sizing – they using hunting and we use direct reductions. And I think in both of those eras another sort of paradigm over there is that "predators are bad and ungulates are good" and so in that era of game preservation, kind of splitting those two eras, we killed _____ we wiped out the world population by 1920. Grizzly bears were low, I don't know how many we killed. We killed about 120-130 mountain lions. We killed over 4000 **tylers** (?) didn't dent their population (rabbit?). This whole idea that you have to manage animals, you have to manage the system. It's like a big ranch and you have to control predators. Sort of a game management era. And then in 1968 we had this tectonic shift and it actually came out of the thinking of the Serengeti (spelling?) that left to their own devices ecosystems have managed themselves for 11,000 years and that maay not be a bad way to think about managing an ecosystem, instead of managing certain species, manage the processes and let the outputs, you know the numbers of animals, kind of work themselves. And a huge shift based on not a whole lot of information. I've asked Mary to write up a Yellowstone Science article on the reasoning and how they got there. Partly it was a result of having to change because in the early 60s we started using elk reductions and they were wildly unpopular. We'd kill 1500-3500 elk every winter trying to keep the elk population below 3000 and they were as unpopular as bison managing is today and there were Congressional hearings and all that stuff. So there was a need to do something different at the same time there was this scienctist – Tony Sinclair and Graham Coffrin coming out of Africa and the Serengetti looking at how ecosystems regulated themselves. And I actually have a fourth era and I call it the era of Restoration and you'd want to put the date at 1995 when wolves came back, but I actually put it at 1984 when peregrine falcons came back. And this, the day of age we're in, we're seeing this big landscape scale impacts to ecosystems and climate change and invasives and landuse change and I think more and more we're restoring things. It started with peregrine falcons in 84 and wolves in 95 and grizzly bears have been being restored since 73 or 74 you know restoration of terrestrial and aquatic systems. You know aquatic systems are really messed up around here because from 1894-1913 we put non native fish in a lot of places and they've just taken over. Through 1958 we actually took eggs out of Yellowstone Lake from Cutthroat Trout. There's a lot of restoration needed in acquatic systems. And some of the terrestrial systems, for the most part of our terrestrial systems are pretty good. The Gardiner basin is the exception. It was homesteaded before it was added to the park. The park was established in 1872 before there was really anybody out here for the most part some miners. The Gardiner basin was homesteaded, vegetation cover was all changed. It's a pretty tough environment anyway, it's ____ desert, we get about 10 inches (25 cm) of precipitation every year. There's a lot of restoration being done.

What is the right balance between 'nation enjoyment' and wildlife management?

I started my career looking at the impacts of recreational and recreation use on resources and I'm ending my career thinking that, I think we over estimate of those impacts earlier on. So I do a lot of work on campsites, backcountry campsites of the size of this room. , where there would be bear avoidance. It's not great, but it's not affecting the ecosystem. Things like climate change, invasive species, putting fish where they're not supposed to be, taking them from where they're supposed to be, killing all our predators, I mean we really, DDT, the use of DDT wiped out a lot of our eagles, ospreys, peragrins. It almost has to be a larger scale to have this really broad scale impact. The thing about visitor use in Yellowstone, it's so tightly controlled, and it's all along the roads. So you have impact along the roads and (remove???) about a hundred animals a year. Hardly anybody goes into the backcountry and when they do they pretty much stay on trails and camp in designated campsites. We know the resources in general, the vegetation and wildlife both, do better when you're concentrating use and it's regular and predictable. So it doesn't feel like we're completely out of wack with our visitor use because it is so tightly controlled. It's not as tightly controlled as Africa. When we had the Kenyans over, they were amazed that we let people get out of their cars because they don't. We had 3 million visitors this year we had 2.5 million back in the mid 1990s , I don't see an impact in that ½ million visitors. They're doing the same thing – driving their cars along the road. It's so tightly controlled that it mitigates some of the impacts you normally get. It doesn't mean that you don't have trampled areas by roads and the Lamar Valley has gotten trampled because of wolf watchers, but to me those are so subtle.

SUMMARY

Bison in Yellowstone National Park is the last free-ranging herd of North America. Bison population size and migration movement are influenced by both density dependent factors and density independent ones. To determine which percentage each one contributes in the bison ecology is a key challenge for YNP. Indeed, bison respond to pressure (human and natural) by migrating in lower elevation outside the park where forage availability is higher. But bison in Yellowstone National Park are infected by *Brucella abortus*, a disease that typically causes birth abortion in ungulates. When bison exite the park, they are likely to transmit the disease to livestock grazing near the park boundaries. It is as much a scientific as an economical and social issue that creates conflicts between public and private lands owners. To address the bison management dilemma of increasing bison tolerance outside the park and to avoid brucellosis transmission, YNP try to find the best management policy possible. One of the tools that might help decision maker is the Forage Production Tool, a GIS application create by the NASA in the order to help YNP in wildlife monitoring.

Key-words: Bison migration, Yellowstone National Park, brucellosis, forage production? Geographical Information System, wildlife management, Montana State, natural regulation.