THE ECOLOGY OF BISON MOVEMENTS AND DISTRIBUTION IN AND BEYOND YELLOWSTONE NATIONAL PARK

A Critical Review With Implications for Winter Use and Transboundary Population Management

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April 2005

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ACKNOWLEDGEMENTS

The history and enormity of issues leading to this study have touched the professional or personal lives of a broad spectrum of Americans, including federal and state civil servants and citizens who care passionately about the integrity of Yellowstone National Park, bison conservation, or protection of livestock against reinfection with a zoonotic organism nearing eradication in the industry. Given the strong polarization among interests involved in these environmental conflicts, the authors feel privileged to have been welcomed by key informants to engage in exploration of their knowledge and insights, and in many cases to have been provided with unpublished data contributing to our assessment and recommendations. Foremost among those we wish to acknowledge as contributing to the assessment is Dr. Mary Meagher, whose passionate concerns for the conservation of Yellowstone bison and the integrity of the Yellowstone Park ecosystem have been uncompromising. We encourage her to continue analyzing the as yet unrealized potential of a data set spanning more than 30 years, complimented by experience in the Yellowstone ecosystem exceeding the duration of most professional careers in wildlife management. In contrast, Rick Wallen, the current bison biologist with the National Park Service, is just beginning to develop a research and management program. We thank Rick for contributing information and his insights to the assessment and hope in return that the report contributes to the development of his program. We are grateful to both Rick Wallen and Dr. Doug Smith for the experience and insights we gained while riding the Mary Mountain Trail with them in October 2004. Finally, we wish to acknowledge the enormous contribution to the project by Traci Weller of Bozeman, Montana. Traci organized and scheduled the interviews and workshops, recorded the dialogue and prepared transcripts. Her competency and humor sustained us through the arduous interview schedule.

CONTENTS

3

ENVIRONMENTAL SETTING

Ecological conditions, other biota, and terrain modified for human infrastructure needs define the environmental setting influencing the spatial and population ecology of bison in and around Yellowstone National Park. The purpose of this chapter is to describe baseline environmental conditions relevant to bison ecology in YNP. Much of this information was required input for the YNP bison movement and distribution model described in Chapter 6. Here we provide information useful for placing the bison/winter road use and bison/brucellosis issues into an ecological context by reviewing the past and present environmental setting of the park.

Geography and Geology

Yellowstone National Park is a 8,983 km^2 mountainous reserve in the northwest corner of Wyoming, USA (Figure 3.1). It is part of the Greater Yellowstone Ecosystem (GYE), which encompasses more than 7.3 million hectares of public and private land in Wyoming, Montana and Idaho (Keiter 1991). The headwaters of three major continental-scale watersheds originate in the GYE: the Mississippi-Missouri, Snake-Columbia and Green-Colorado (Marston and Anderson 1991). Five percent of YNP is covered by water; major rivers 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 (Meagher 1973). Major shrub and grassland valleys in YNP include Lamar (part of the northern range), 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). Some of the oldest geologic materials in YNP are Precambrian gneisses and schists (Rodman et al. 1996). The Laramide orogeny, between 100 and 50 million years ago (late Cretaceous through Paleocene), formed the southern Rocky Mountains (Despain 1990, Rodman et al. 1996, Meagher and Houston 1998). The Yellowstone area has existed as a terrestrial environment since 90 million years ago (Despain 1990). 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 (Meagher and Houston 1998). As North America drifted southwest, the plume of magma shifted northeast and eventually became positioned beneath the Yellowstone plateau (Meagher and Houston 1998). Subsequent large volcanic eruptions 2.1, 1.3 and 0.6 million years ago formed three partially overlapping calderas (Meagher and Houston 1998). The Yellowstone calderas (large basin-shaped volcanic depressions more or less circular in form) extend from Old Faithful to Mount Washburn in the north and to Yellowstone Lake in the east (Meagher and Houston 1998). They still provide an active heat source in parts of YNP, giving rise to an unusually high concentration of geothermal features (geysers, hot springs, mud pots and fumaroles; Rodman et al. 1996) and influencing bison habitat. YNP has also undergone at least 3 extensive glaciations that have affected most of the park (Rodman et al. 1996).

Northern and central YNP are characterized by a decreasing elevation gradient from east to west. Northern YNP is generally lower in elevation than central regions of the park. In the northern range, highest elevations occur on the Mirror Plateau and Cache Calfee ridge (2500 m) and decrease through upper (2200 m) and middle (2100 m) Lamar Valley to the Gardiner area (1800 m). The highest elevation in central YNP occurs at Mary Mountain (2500 m). 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). Along the road from Madison Junction to Mammoth, elevation increases at Norris (2300 m) and Swan Lake Flats (2250 m) before dropping at Gardiner.

Bison Winter Ranges and Movement Corridors

Bison winter ranges and movement corridors were defined by key informants during semi-directive interviews (see Chapter 1) conducted in Montana and Wyoming in July 2004. A bison *winter range* was defined as a common destination winter foraging area. A *corridor* was defined as a common winter movement pathway connecting two ranges within which foraging habitat and foraging may occur. Ranges and corridors were defined by key informants as areas where the majority of mixed groups (cows and calves) forage and travel, rather than all locations where they may occur. These structures were illustrated on maps by key informants then digitized using a Geographic Information System (GIS). During digitization, habitat classification maps for YNP (Despain 1990) and outside YNP (United States Geological Survey - Land Use Land Cover (USGS – LULC), Anderson et al. 1976) were overlaid on air photos. Classified habitat and unclassified open shrub-grasslands were digitized within the bison range defined by key informants to insure inclusion of all suitable habitats available to bison within that range; non-habitat areas (e.g. forests) were not included in the range. Maps of digitized bison winter ranges and movement corridors were returned to interviewees during validation workshops held in Montana and Wyoming in October 2004 to verify accuracy and modify as necessary.

Key informants identified 5 bison winter ranges and 5 winter movement corridors in YNP (Figure 3.2). In northern YNP, two ranges were identified, Lamar Valley (233.80 km^2) and Gardiner basin (98.35 km^2). Many key informants considered Lamar Valley and Gardiner basin as one continuous range, i.e. the northern range. However we separated these ranges so we could illustrate bison use of ranges exterior (Gardiner basin) and interior (Lamar Valley) to YNP. One key informant questioned the definition of Lamar Valley range because his telemetry location data for 1995 - 2001 indicated that bison used only flat valley bottoms within Lamar Valley during this period, whereas our delineation of Lamar Valley included steeper upland grassland habitat. However, all other key informants agreed with including upland grasslands. Indeed, one long term data set suggests that bison are increasingly using upland habitat[2].

The portion of the Gardiner basin bison winter range outside YNP was delineated based on current bison management policy documents (United States Department of the Interior (USDOI), National Park Service (NPS) 2000). Bison could move beyond the Gardiner basin boundary to other foraging areas, however, they are not tolerated outside the Gardiner basin range because of concerns about brucellosis transmission risk from bison to cattle. Bison are culled if they travel past the boundary. Additionally, only 100 bison are tolerated within the Gardiner basin range before culling is implemented (USDOI, NPS 2000).

Three bison winter ranges were defined in central YNP: Pelican Valley (55.16 km^2), Mary Mountain (151.8 km^2, including Hayden Valley and the Firehole), and West Yellowstone which spans the boundary of the park (79.93 km^2). Hayden Valley was grouped with the Firehole because of historic continuous movements back and forth between the two valleys over the Mary Mountain trail, throughout the winter (the assumption that the Mary Mountain Trail is unlike other corridors is assessed in Chapter 5). Like Gardiner basin, the portion of the West Yellowstone bison winter range outside YNP was delineated based on bison management policy and reflects where 100 bison are tolerated before culling actions are taken (USDI, NPS 2000) as opposed to where bison could move if allowed to expand freely (see Figure 3.1 for location of capture facilities).

Digitized corridor maps were overlaid on a digital elevation model to illustrate terrain ruggedness (Figures 3.3 to 3.7). Grassland habitat, geothermal areas and linear features (i.e. roads and power lines) are also illustrated on the corridor maps. The 5 corridors (Figure 3.2) are the primary bison movement pathways between winter ranges described by key informants. In the northern range, the Gardiner basin to Lamar Valley corridor (GLC) is located along the Yellowstone River and the road from Cooke City to Gardiner (Figure 3.3). It consists of two routes, one following the Yellowstone River, the other along the paved road. The Mirror Plateau corridor (MPC) extends from southeastern Lamar Valley to northeastern Pelican Valley (Figure 3.4) and was considered by key informants to be infrequently used by bison during mid winter because of deep snow and rugged terrain. The northern range is also connected to central YNP by the Firehole to Mammoth corridor (FMC; Figure 3.5). The FMC has only recently become a significant pathway for bison movement from the central range to the northern range (Chapter 5). The Pelican Valley to Hayden Valley corridor (PHC; Figure 3.6) connects the two interior central bison ranges. Bison exit the western boundary of YNP via the Firehole to West Yellowstone corridor (FWC; Figure 3.7).

The length of each corridor was determined by measuring the distance from one end of the corridor to the other. The FMC was the longest winter movement corridor, almost double the length of the next longest, the MPC; the next longest corridor was the FWC, followed by the GLC and PHC (Table 3.1).

[2] Interview with Chris Jerde, 24 June 2004, Edmonton, Alberta.

Climate

The YNP climate can be divided into four seasons (Despain 1990). Spring begins March or April, extends through June, and is characterized by cold to cool nights and warm to cool days, during which snow gradually melts and disappears over time with elevation. Summer is short and occurs during July and August. Fall begins in September and extends through October, and winter begins in November and ends in March - April.

Present winter climate in YNP has been described as severe, long and cold (Meagher 1971, Meagher and Houston 1998). Mean annual temperature is 4.3°C at Mammoth (1900 m) and 0.2°C at Lake Yellowstone (2360 m; Meagher and Houston 1998).

Climate data is collected at various SNOTEL, snowcourse and Climate (CLIM) stations in and around YNP (Figure 3.8). CLIM stations measure daily minimum and maximum temperature, daily precipitation, and snow depth. A snow course is a designated permanent site where snow depth and its water content are measured. SNOTEL stations measure and transmit daily snow water equivalence from snow pillows, total precipitation accumulated from October 1 each year, and air temperatures.

Snow

Most precipitation reaches the GYE along prevailing westerlies (Marston and Anderson 1991), much of it in the form of snow (Despain 1990). Snow accumulation begins mid to late October and persists until late March, to early April (Despain 1990). Mean duration of snow cover is 213 days at 7,000 ft (2,133 m; Despain 1990). Snow water content and total precipitation is typically greater at high elevations and greater in the western portion of YNP compared to the east (Despain 1990, Delgiudice et al. 2001). Previous studies indicate snow conditions are more severe (i.e. deeper) in central YNP than the northern range (Meagher 1973, Delgiudice et al. 2001).

Snow conditions (e.g. depth and density) can have a significant impact on ungulate foraging, movements and survival. In YNP, snow may influence forage availability, energy expenditure during movements and foraging, ability to travel, vulnerability to predators and nutritional status of ungulates, including bison (Meagher 1973, Turner et al. 1994, Mech et al. 2001, Delgiudice et al. 2001, Meagher et al. 2002). The effect of deep snow on reducing forage availability to ungulates, prompting migratory movements to lower elevations, was noted in YNP as early as 1937-38 (Grimm 1939). This is a critical concern in the current management challenge of minimizing contact between bison and cattle as they disperse northward and westward across park boundaries during harsh winters.

Snow Water Equivalence (SWE, cm) and snow depth (cm) was obtained from CLIM stations (National Oceanic and Atmospheric Administration, National Climatic Data Center, http://lwf.ncdc.noaa.gov/oa/ncdc.html. accessed Jan. 11 2005), snowcourses (United States Department of Agriculture, National Water and Climate Center, http://www.wcc.nrcs.usda.gov/snowcourse/. accessed Jan. 11 2005) and SNOTEL stations (United States Department of Agriculture, National Water and Climate Center, http://www.wcc.nrcs.usda.gov/snow/. accessed Jan. 11 2005) in and around YNP. SWE is a measure of the amount of water stored in snow (Farnes et al. 1999); it integrates snow depth and snow density. SWE has been used to assess winter severity in previous studies on ungulates in YNP (e.g. Bjornlie and Garrott 2001, Delgiudice et al. 2001).

We used SWE and snow depth and density data to compare winter severity between years and between bison winter ranges. We compared yearly historical February 15th measures of SWE (Figure 3.9) and snow depth (Figure 3.10) between the northern range (Mammoth, Tower Falls, Lamar Ranger Station climate stations) and central YNP (Hebgen Dam, West Yellowstone, Old Faithful, Canyon, and Lake Yellowstone climate stations). We also compared mean annual SWE (Figure 3.9) and snow depth (Figure 3.10) between climate stations.

We used February 15th SWE to compare snow conditions between ranges and years. SWE on this date is representative of snow conditions for the winter (Figure 3.12). Snow was deeper and SWE was greater in central YNP than the northern range (Figure 3.9 and Figure 3.10). Mean February 15th SWE values for central YNP were approximately 20 cm compared to 7.5 cm on the northern range. Mean snow depth in central YNP was approximately 100 cm. The maximum was approximately 160 cm, close to the maximum at which bison may cease foraging (Turner et al. 1994). The minimum was approximately 40 cm, below the level where snow begins to limit access to forage (Turner et al. 1994). Mean snow depth in the northern range was approximately 40 cm, with maxima close to 90 cm and minima close to 10 cm in some years.

We considered two spatial models of YNP snowpack (Wockner et al. 2002 and Watson et al. (u.d.) (F. Watson, California State University-Monterey, pers. comm.) to predict mean February 15th SWE for each bison winter range and movement corridor. We compared the output of each model to data collected at climate stations (Figure 3.11) to identify the model that most accurately predicted SWE for each bison winter range. The Wockner et al. (2002) model creates historical daily interpolated SWE maps for the entire YNP. It considers characteristics (elevation, slope, aspect, and vegetation) of a location (100 m x 100 m) and interpolates an SWE value for that location based on the actual SWE data measured at SNOTEL stations and data from 28 additional snow measurement sites. The model can create an SWE map for YNP each day from 1981 to 1999. The Watson et al. (u.d.) LANGUR snow model also generates historical predictive snow maps for YNP. Elevation, aspect, slope, land cover type, canopy cover, mean annual temperature and ground heat flux of each location (228 m x 228 m) are used to interpolate SWE values. The LANGUR model also considers maximum and minimum daily temperature and precipitation data from up to 5 SNOTEL sites in and around YNP. The LANGUR model was calibrated with three snow core data sets collected from 2001-2004 and SWE measured at six SNOTEL sites in YNP from 1993-2004. Mean February 15th bison winter range SWE values from each model were compared to actual mean February 15th SWE measured at climate stations. The climate station closest to, or that best represented snow conditions for a particular bison winter range was associated with that range for comparison to the models. The model that best emulated SWE was used to calculate mean SWE values for each bison winter range and movement corridor. Overall, the Wockner et al. (2002) model best emulated actual SWE data at stations (Figure 3.11). The Wockner et al. (2002) model predicted SWE in the northern range and Pelican Valley closer to measured SWE than LANGUR. The LANGUR model estimated SWE higher for the northern range than observed at Mammoth and Tower Falls climate stations. A possible explanation is that snow core measurements used to calibrate the LANGUR model were collected in central YNP and none were collected on the northern range. Meagher (1971) indicated snow in Pelican Valley is deeper than at Lake

Yellowstone where measurements are recorded. However, LANGUR predicted a lower SWE value for Pelican Valley than measured at the Lake Yellowstone climate station, and similar to the northern range. The Wockner et al. (2002) model predicted higher SWE values in Pelican Valley than the LANGUR model. A possible explanation why LANGUR predicted low SWE values in the central range is the model was calibrated with snow core data from 2001-2004, a period of below average snowfall (see Figure 3.9 and Figure 3.10).

We used the Wockner et al. (2002) model to calculate SWE for each bison winter range and movement corridor because it better simulated the difference in SWE between northern and central YNP and the severity of snow conditions in Pelican Valley. Estimated mean SWE for February 15 from the Wockner et al. (2002) model (Table 3.2) was highest in the Mary Mountain range (20 cm), followed by Pelican Valley (19 cm), West Yellowstone (17 cm), Lamar Valley (9 cm) and Gardiner basin (6 cm). Estimated SWE values illustrate the strong difference in snow conditions between the northern range (less snow) and central YNP (more snow). Along movement corridors (Table 3.1), SWE was highest along the FWC (17 cm) and FMC (17 cm). The MPC (16 cm) also had a high SWE value. SWE along the PHC (13 cm) was relatively low and SWE along the GLC (3 cm) was very low.

In addition to snow depth and SWE, other characteristics of snow pack can affect forage availability to ungulates. Key informants identified snow crusting as an important constraint on forage accessibility for bison, making it difficult to crater. Snow hardness (the initial resistance to deformation per square unit area; McClung and Schweizer 1996) is affected by temperature, wind speed, type of snow, rain on snow, and incoming shortwave radiation (Kozak et al. 2002, Pomeroy and Brun 2001). Key informants identified a major crusting event during the winter of 1996-1997, when the temperature increased above 0˚C for about one week, during which time it also also rained. A subsequent decrease in temperature caused the snow to freeze. After this event, many bison moved from interior YNP winter ranges to boundary park ranges, and a precipitous decline in population occurred primarily due to culling (Peacock 1997*a*). Crusting due to December rainfall was also noted in YNP in the winter of 1937-1938 (Grimm 1939).

We were unable to find a published method for predicting snow crusting events from historical climate data, so we developed a method. Data on temperature, snow depth and precipitation from various climate stations in and around YNP are collected by the National Oceanic and Atmospheric Administration National Data Center, (http://nndc.noaa.gov/). We used data from 4 stations, Gardiner, West Yellowstone, Lake Yellowstone and Tower Falls for November, December and January, from 1981 to 2004, except for Tower Falls, which had data for the period 1989 to 2004. Each station was associated with a bison winter range, Gardiner for Gardiner basin, Tower Falls for Lamar Valley, West Yellowstone for West Yellowstone and Lake Yellowstone for Pelican Valley and Mary Mountain. For each station, we identified sequences of days from November 1 to January 31 when initial temperature was below or equal to 0˚C followed by an increase in temperature to > 0˚C for at least 3 days, of which at least one day was greater than 5˚C, followed by a temperature decrease to below or equal to 0˚C. Of those sequences, we identified those that had a snow depth greater than or equal to 30 cm. We considered that 30 cm was a threshold below which snow cover did not influence access to forage. Finally, we identified those sequences where precipitation during the > 0˚C days was > 0 mm. For clarity, the criteria were designed to identify freeze/thaw/freeze events when at least 30 cm of snow was on the ground and precipitation fell as rain. We were unable to use other factors such as wind to predict crusting events because data were not available. Using these criteria, we determined the probability of a crusting event in a year for each bison winter range (Table 3.4). Gardiner basin (0.08) had a very low probability of a crusting event. Crusting events were rare at Gardiner basin because snow is rarely above 30 cm. West Yellowstone (0.29) had the second lowest probability of a crusting event. The central interior bison winter ranges (0.42) had the same probability of crusting events because the same climate data was used. The probability of crusting was highest in the Lamar Valley (0.56). Based on information provided by key informants, crusting events occur more often in Lamar Valley than central bison ranges.

Geothermal activity can also modify snow pack. YNP has the highest density of geothermal features in the world (U.S. Department of the Interior, National Park Service, http://www.nps.gov/yell/pphtml/subnaturalfeatures 23.html). Geothermal features generate heat that can dramatically reduce snow cover and lengthen the growing season, both at geothermal basins and along the banks of streams and rivers influenced by warm water (Meagher 1973, Despain 1990), thus improving forage availability at these sites (Bjornlie and Garrott 2001). Geothermal sites and geothermally influenced shorelines may therefore be key refugia for bison during severe winters (Despain 1990, Meagher et al. 2002).

A digitized map of geothermal areas was provided by the Spatial Analysis Center, Yellowstone National Park (unpubl. data). In central YNP, geothermal areas are common but are uncommon in the northern range. Total area and percentage of area geothermally influenced were calculated for each bison winter range (Table 3.2). Mary Mountain bison (21.9 km^2; 14.4%) had the greatest total area and percentage of area geothermal features, with many of them occurring in the Firehole. Pelican Valley (2.7 km^2; 4.8%) also had a relatively high amount of geothermally influenced habitat, although notably less than Mary Mountain. Lamar Valley and Gardiner basin had insignificant geothermal influence on bison habitat (< 1%). West Yellowstone had no geothermal influence based on spatial data provided by the Spatial Analysis Center, Yellowstone National Park. In contradiction, Craighead et al. (1973:38) described the importance of geothermal springs in the Duck Creek and Cougar Creek area for elk in winter.

Each bison movement corridor was randomly sampled for geothermal areas 1,000 times using a random point generator (Jenness 2003) in GIS. The proportion of random samples that fell on geothermal areas and associated geothermally influenced rivers was used to calculate relative frequency of thermal areas for each corridor (Table 3.1). Geothermal features occurred most frequently along the FWC (0.092). The FMC (0.052) also had a relatively high proportion of geothermal features. The MPC and PHC had a very low proportions of geothermally influenced areas (0.001), and no geothermals occurred along the GLC.

Summer Precipitation

Summer drought can reduce forage production and thus forage quality and quantity available to ungulates during the subsequent winter (Merrill and Boyce 1991). The sum of June and July precipitation can be used as a relative index of winter forage available to ungulates on winter range (Farnes et al. 1999). Mean monthly precipitation for June and

July was obtained from SNOTEL and CLIM stations in YNP. The Canyon SNOTEL station (data from 1981-2003) was used to calculate mean summer precipitation for the Mary Mountain bison winter range. Madison SNOTEL station (data from 1968-2003) was used to calculate mean summer precipitation for West Yellowstone bison winter range (the West Yellowstone SNOTEL station had only 4 years of precipitation data). Gardiner CLIM station was used to calculate mean summer precipitation for Gardiner basin bison winter range, Tower Falls CLIM station was used to calculate mean summer precipitation for Lamar Valley bison winter range and Lake Yellowstone CLIM station was used to calculate mean summer precipitation for Pelican Valley bison winter range. Mean monthly precipitation for June and July from 1971-2000 was obtained from CLIM stations; raw data was not available. Standard deviation was therefore not available for CLIM stations but was estimated based on the coefficient of variation for the mean at Canyon and Madison SNOTEL stations.

Summer precipitation was highest in West Yellowstone (11.05 cm), followed by Mary Mountain (10.9 cm), Pelican Valley (9.8 cm), Lamar Valley (9.7 cm), and Gardiner basin (6.3 cm), which had the least precipitation (Table 3.6). On average, summers were drier on the northern range than central YNP.

Vegetation, Forage Production, and Utilization

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).

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

Nonforested plant communities were described in detail by Despain (1990). Nonforested communities occur throughout the park, typically in areas underlain with andesite or sedimentary rock (Despain 1990). Big sagebrush (*Artemesia tridenta*)/Idaho fescue (*Festuca idahoensis*) is the most abundant sagebrush-grassland type in YNP (Klein et al. 2002). Other grassland communities include Idaho fescue/bearded wheatgrass (*Agropyron subsecundum*), Idaho fescue/Richardson's needlegrass (*Hesperostipa richardsonii*), Idaho fescue/Bluebunch wheatgrass (*Pseudoroegnaria spicatum*) and Bluebunch wheatgrass/Sandberg's bluegrass (*Poa secunda*; Klein et al. 2002).

Geothermal activity can produce tropical conditions, providing habitat for tropical plant species (Despain 1990). Plant species growing in geothermally influenced areas vary depending on temperature and include, mosses (50˚F to 65˚F), grasses (25˚F to 50˚F) such as Nuttall's alkali-grass (*Pucinellia nuttalliana*), thermal western witchgrass (*Panicum capillare*), poverty danthonia (*Danthonia spicata*), winter bentgrass (*Agrostis spp.), cheatgrass (*Bromus tectorum*) and bluegrasses (*Poa* spp.), and herbs (23˚F to 37˚F) such as hairy golden-aster (*Chrysopsis villosa*), sheep sorrel (*Rumex acetosella*), fireweed (*Epilobium angustifolium*), Canada thistle (*Cirsium arvense*) and spar-leaf fleabane (*Erigeron* spp.; Despain 1990). Plant communities associated with geothermal sites in the Madison-Firehole area consist of aquatic macrophytes (*Myriophyllum* spp., *Ranunculus aquatilis* and *Potamogeton* spp.) and spike rush (*Eleocharis rostellata*) communities (Garrott et al. 2002).

Ungulate herbivory has important impacts on grassland dynamics in YNP. In the northern range, grazing stimulates aboveground production of grasslands by promoting nutrient cycling and enhancing N and NO_3^- availability to plants (Frank and Evans 1997, Frank 1998, Singer and Schonecker 2002). Migratory movements of ungulates in the northern range, from lower elevations in the spring to high elevations in the summer, represents tracking nutritionally rich forage as it shifts spatially to higher elevations as the season progresses (Frank and McNaughton 1993, Frank 1998). Seasonal migration allows vegetation to recover from herbivory (Frank 1998).

Fire

YNP has been shaped by 9 to 12 major fire events over the last 2,000 years and major fires occur at roughly 100-300 year intervals (Klein et al. 2002). The fire of 1988 was considered a major fire in scale. It burned roughly 794,000 acres of YNP (Despain 1990) 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 and palatability (Turner et al. 1994).

Bison Habitat and Forage

Mary Meagher (Bison biologist, retired, Yellowstone National Park, pers. comm.) identified important bison winter habitat from among Despain's (1990) habitat classes for YNP. Important winter habitat for bison included shrub-grasslands consisting of Idaho fescue, bearded wheatgrass, bluebunch wheatgrass, sandberg's bluegrass, shrubby cinquefoil (*Dasiphora floribunda*), richardson's needlegrass, tufted hairgrass (*Deschampsia cespitosa*), big sagebrush and silver sagebrush (*Artemesia cana*). Wet meadows consisting of willows (S*alix* spp.) and sedges (*Carex* spp.) and vegetation associated with thermal areas (hotsprings vegetation) were also identified as important bison forage during the winter (Table 3.5).

Mean annual above ground primary production (forage production) was calculated for each bison winter range (Table 3.2). Tom Olenicki (Montana State University, pers. comm.) provided data on vegetation productivity (mean ± s.d, data collected during summers of 1998, 1999 and 2000) from a study conducted in Hayden Valley. Additionally, he estimated thermal area vegetation productivity as approximately 1,000 kg/ha, with a high degree of variation. Olenicki's data was comparable to data from other studies on vegetation productivity in YNP (Table 3.6). We identified the vegetation class used by Olenicki (Montana State University, pers. comm.) most comparable to each of Despain's (1990) habitat classes and USGS - LULC (Anderson et al. 1976) classes then assigned a corresponding productivity value. For each bison winter range, mean and standard deviation productivity of each habitat class within the range was multiplied by the arial proportion of that habitat class in the range. The proportional mean productivity of all habitat classes was then summed to calculate the annual weighted mean productivity for each bison winter range.

The area of each habitat type and percentage of each habitat type was calculated for each bison winter range (Table 3.5). Mean annual productivity (Table 3.2) was highest in Pelican Valley (1881 kg/ha), followed by West Yellowstone (1613 kg/ha), Mary Mountain (1327 kg/ha), Lamar Valley (1123 kg/ha) and Gardiner basin (1104 kg/ha), which had the lowest productivity. On average, forage production was higher in central YNP than the northern range.

Habitat proportion was calculated for each bison movement corridor by randomly sampling 1,000 pixels (30x30 m) in each corridor using a random point generator (Jenness 2003) in GIS and determining the proportion of the sample that was habitat. Habitat occurred most frequently along the GLC (0.724), followed by the PHC (0.510), MPC (0.431), FMC (0.372) and FWC (0.250), which had the lowest frequency of habitat (Table 3.1).

Other Wildlife

A variety of ungulate species, in addition to bison, use YNP seasonally or year round, including elk (*Cervus elaphus*), pronghorn (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), moose (*Alces alces*), bighorn sheep (*Ovis canadensis*) and mountain goats (*Oreamnos americanus*). Large carnivores in YNP include grizzly bears (*Ursus arctos*), black bears (*U. americanus*), mountain lions (*Puma concolor*), and wolves (*Canis lupus*). Coyotes (*C. latrans*) are also present in YNP.

Habitat overlap between ungulates was compared on the northern range between 1967 to 1970 and 1986 to 1988 by Singer and Norland (1994). Habitat overlap between bison and other ungulate species had increased since the 1960's (the end of population regulation of bison inside YNP), likely due to a rapid increase in populations and range expansion by elk and bison (Singer and Norland 1994). Intraspecific competition for forage also increased between elk and bison (Singer and Norland 1994).

Predation on bison by wolves and grizzly bears occurs in YNP; predation by grizzly bears is extremely rare (Wyman 2002, Varley and Gunther 2002, Smith et al. 2000). Currently, predation by wolves on bison does not limit bison subpopulations in YNP (D. Smith, Wolf Biologist, YNP, pers. comm.). Elk are the primary prey for wolves in YNP because they are more abundant and easier to kill (Smith et al. 2000). However, predation rates on bison vary in the park and are higher in central YNP compared to the northern range because elk are much less abundant in central YNP, particularly during the winter (Smith et al. 2000, D. Smith, Wolf Biologist, YNP, pers. comm.). In central YNP, because of the small and likely decreasing population of elk (Garrott et al. 2002), wolves are taking an increasing number of bison (D. Smith, Wolf Biologist, YNP, pers.

comm.). Therefore, there is potential for this predator prey system to evolve to a state similar to that reported in Wood Buffalo National Park where bison are the main prey and other ungulates occur at low densities (Carbyn et al. 1993). Bison carcasses also provide an important food source for scavengers, particularly grizzly bears (Green et al. 1997, Mattson 1997).

Anthropogenic Features

YNP was established March 1, 1872 as "…a public park or pleasuring ground for the benefit and enjoyment of the people." (Schullery et al. 1998). Infrastructure development has been ongoing since then to meet demands for increasing use. A summary of development of roads and buildings in YNP is provided below. For a detailed account see Culpin (1994) and Culpin (2003).

In 1872-73 there were two routes entering YNP, one through the north entrance to Mammoth Hot Springs and the other through the west entrance via Madison Canyon to the Lower Geyser Basin. In 1877, the first road over Mary Mountain was "cut" by Maj. Gen. O. O. Howard during his pursuit of Chief Joseph. Superintendent Norris built roads in YNP from 1877-1881 and was credited with building nearly 2/3 of the Grand Loop, including road sections from Mammoth to Lower Geyser Basin, Upper Firehole Geyser Basin to Yellowstone Lake and Mammoth to the west entrance, via Forks, Great Falls, Yellowstone Lake and Forks of the Firehole River. As early as 1883, Lt. Dan C. Kingman of the U.S. Army Corps of Engineers expressed concern about overdevelopment of the park. He prioritized building high quality roads and improving existing ones over building new roads. In addition to improving much of the existing road system, Kingman completed the Golden Gate pass, a new road from the Firehole to Upper Geyser Basin and a road from Norris Geyser Basin to Beaver Lake. The philosophy of developing quality roads over quantity was maintained throughout the history of the park, although often difficult to achieve due to budget constraints.

From 1883 to 1886, the Yellowstone National Park Improvement Company built hotels at Mammoth, Upper Geyser Basin, Canyon and Lake Yellowstone. By 1886 telephone lines were installed to all hotels. Prior to 1924, government buildings and hotels had separate telephone poles and lines, each running down opposite sides of the roads. In 1924, park managers decided to remove the old poles and lines and put up new joint lines away from the roads, cutting through the forest.

In 1910-11, a road was constructed along the Gallatin River, from Taylor's Fork to West Yellowstone by Gallatin County. The road between Bozeman and West Yellowstone was opened to automobiles in 1914. On August 1, 1915 the first automobiles were permitted to enter YNP. 1926 to 1939 was one of the most significant periods in the history of road development in YNP; 249 of the 558 km road system received a bituminous surface, 154 km of which were on the Grand Loop. Development of and visitation to YNP slowed drastically during WW II, but visitation increased rapidly after the war. Subsequent deterioration of the park infrastructure system led to MISSION 66 endorsed by President Dwight D. Eisenhower, cabinet and congress in 1955. MISSION 66 was a program to improve conditions of the national park system to maximize its use and provide protection of assets by 1966, the 50th anniversary of the creation of the NPS. Part of the proposal was to provide adequate roads and trails, facilities and interpretation.

Motorized Oversnow Vehicle Winter Use History

Motorized Oversnow Vehicle (OSV) use was introduced to YNP in 1949 (Yochim 1998*a,b*) but regular OSV use in the park was not established until the 1960's and 1970's. The road from Mammoth to Cooke City was occasionally plowed during the latter 1930's; plowing was more frequent after WW II. By the 1960's, the road was plowed almost daily, as conditions dictated[3]. As early as 1930, local businesses asked the NPS to plow all roads in the park to allow year-round access[4]. The NPS declined the request, citing that roads were too poor to permit extensive plowing, plowing would be too hazardous, and facilities in the park interior were not winterized (Yochim 1998*a*).

The first permit for a snowcoach operator to bring tourists into YNP (Yochim 1998*a*) was granted to a businessman in West Yellowstone in 1955 (Aune 1981, Bjornlie and Garrott 2001). In January 1963, three private snowmobiles entered the park for the first time and the following winter the first snowmobile rally was held at West Yellowstone (Aune 1981, Yochim 1998*b*). By 1967, snowcoaches operated out of both Mammoth Hot Springs and West Yellowstone (Aune 1981). NPS issued regulations to confine snomobiles to snow-covered roadways; they were not allowed in back country areas or on frozen lake surfaces[5]. In 1967, a congressional hearing was held in Jackson, WY (USDI, NPS 1968) in response to public pressure for winter plowing of roads and concerns over winter use in YNP (Yochim 1998*a*). At this meeting, park managers concluded that use of interior roads by OSV's was preferable to park-wide snow plowing of roads, and that OSV travel would be restricted to roads (Yochim 1998*a*).

The actual date when Yellowstone Park Company began grooming roads for snowcoaches is lost to historians, but was probably in the 1960s. In 1971 the NPS assumed responsibility for road grooming to facilitate access to the park and restrict OSV's to roads (Aune 1981, Yochim 1998*a*, Bjornlie and Garrott 2001). In 1971, the snow lodge at Old Faithful was opened for its first winter operation (Aune 1981, Yochim 1998*a*). Most OSV activity was initially concentrated in the west end of the park, therefore grooming only occurred on these roads (Yochim 1998*a*). By 1973, all roads were groomed as needed but grooming occurred more frequently on roads where OSV use was higher (i.e. the west side of the park; Yochim 1998*a*). In 1976-77, more consistent grooming of the east entrance road began resulting in a marked increase in OSV use of east side roads (Yochim 1998*a*). By the late 1970's, all snow covered roads were in constant use, with the exception of the Tower to Canyon route across Mt. Washburn. Public winter use was permitted from December 1st through the third week of March, depending on snow conditions, with highest levels of use over the Christmas holiday season and from February into the first week of March[6]. Spring opening of roads by snowplows began in March. Grooming practices have remained roughly the same since

[3] Interview with M. Meagher, 15 July 2005, Gardiner MT.
[4] Comment made by M. Yochim in factual review of a draft of this report, 8 April 2005.
[5] Comment provided by Yellowstone Natonal Park personnel in factual review of a draft of this report, 8 April 2005.
[6] *supra* note 3

grooming began, with the entire width of the two lane road groomed[7]. Grooming typically occurs between 3 pm and 2 am (Kurz et al. 2000).

Currently, roads are closed from early November to mid- December to all but YNP personnel (Bjornlie and Garrott 2001), with the exception of the road from Gardiner to Cooke City through the Lamar Valley, which is plowed and open to the public year round. In mid-December, roads are opened to the public and groomed as needed (typically every night) until the end of the OSV season in early to mid-March when all roads are plowed. Then roads are once again closed to all but YNP personnel until mid-April (Bjornlie and Garrott 2001).

Winter use has increased rapidly since YNP began grooming roads (Figure 3.13). Much of the growth has occurred because of increasing numbers of snowmobiles entering YNP. Recently, winter use impacts on park resources and wildlife have become major and controversial issues in YNP. Several studies (e.g. Kurz et al. 2000, Bjornlie and Garrott 2001, Meagher et al. 2002, Davis et al. 2004) have been conducted on the effects of winter use on wildlife and other park resources.

Conclusions

There were notable distinctions between ecological conditions on the five bison winter ranges and five bison movement corridors in YNP, which may differentially affect bison ecology and movement. The Gardiner basin and Lamar Valley ranges were functionally a continuous range, following an elevational gradient represented in winter severity (SWE). In central YNP, bison range is made up of several distinct shrub-grassland valleys connected by corridors. Climate, particularly snow conditions, was noticeably different between northern and central YNP bison ranges. Snow conditions are less severe in the northern range compared to the central. Additionally, the northern range is drier than central YNP. Predictably, forage production and habitat composition varies between the ranges, with distinct differences between northern bison winter ranges and central ranges. The area and proportion of geothermally influenced areas, which can affect snowpack, was much higher in central ranges compared to the northern range, which had negligible geothermal influence. Assessment of the study area indicated there are distinct and important differences between bison winter ranges, most evident in differences between the central and northern YNP ranges.

Anthropogenic features, such as roads and road grooming, have been present in the YNP landscape roughly as they are now for several decades. Roads and other linear features (i.e. powerlines and telephone lines) have been in place in YNP since at least the early 1900’s. Winter use by humans is a more recent phenomenon, but developed quickly after its introduction in 1949. Infrastructure and other facilitation of winter use (i.e. road grooming) have been in place in YNP since the late 1970’s. Human use of YNP in winter (Figure 3.13) has grown simultaneously with the bison population (Chapter 5), providing opportunity for confusing causes and effect.

[7] *supra* note 3

Table 3.1. Attributes of bison movement corridors. The proportion of habitat and geothermal features was based on 1000 random samples of 30x30 m pixels in each corridor. GLC: Gardiner basin to Lamar Valley corridor; MPC: Mirror Plateau corridor; PHC: Pelican Valley to Hayden Valley corridor; FMC: Firehole to Mammoth corridor; FWC: Firehole to West Yellowstone corridor.

	Bison Movement Corridor				
	GLC	**MPC**	**FWC**	**FMC**	**PHC**
Corridor length (km)	13.5	30.5	21.1	59.4	8.3
% Habitat	72.4	43.1	25.0	37.2	51.0
% Geothermal areas	0	0.1	9.2	5.2	0.1

Table 3.2. Attributes of bison winter ranges. Summer precipitation was based years of data from the following stations: 1971-2000 from the Gardiner, Tower Falls, and Lake Yellowstone CLIM stations representing Gardiner basin, Lamar, and Pelican ranges respectively; 1961-2003 from the Canyon SNOTEL station representing Mary Mountain; and 1968-2003 measurements for the Madison Plateau SNOTEL station representing West Yellowstone winter range.

	Winter range				
	Gardiner basin	**Lamar Valley**	**West Yellowstone**	**Mary Mountain**	**Pelican Valley**
Area (km^2)	98.34	233.8	79.93	151.83	55.16
Geothermal area (km^2)	0.05	0.3	0	21.93	2.67
Summer precipitation (cm) $\pm$ s.d	6.3 + 2.8	9.7 + 4.3	11.1 + 4.3	10.9 + 5.3	9.8 + 4.3
Forage production (kg/ha) $\pm$ s.d.	1104 $\pm$ 534	1123 $\pm$ 519	1613 $\pm$ 598	1327 $\pm$ 627	1881 $\pm$ 682
Area (km^2) sedge meadow	0	11.64	2.15	14.22	4.57

Table 3.3. Mean (s.d.), minimum and maximum February 15th SWE values for each bison winter range and movement corridor in Yellowstone National Park. Values were calculated from simulations on February 15th of each year from 1982 to 1999 using the Wockner et al. (2002) snow pack simulation model. All maximum values occurred in 1997. All minimum values occurred in 1987, with the exception of the GLC, which occurred in 1991. GLC: Gardiner basin to Lamar Valley corridor; MPC: Mirror Plateau corridor; PHC: Pelican Valley to Hayden Valley corridor; FMC: Firehole to Mammoth corridor; FWC: Firehole to West Yellowstone corridor.

Range or corridor	**SWE (s.d..) (cm)**	**Max. SWE(cm)**	**Min. SWE (cm)**
Gardiner basin	6 ± 2	10	3
Lamar Valley	9 ± 3	16	5
Pelican Valley	19 ± 6	36	12
Mary Mountain	20 ± 7	40	12
West Yellowstone	17 ± 6	31	8
GLC	3 ± 1	4	1
MPC	16 ± 5	30	10
PHC	13 ± 6	27	9
FMC	17 ± 5	32	10
FWC	17 ± 6	33	9

Table 3.4. Annual probability of a snow crusting event in each bison winter range.

Station	Bison range	Years	Number of years with ≥ 1 snow crusting event	Annual probability
Gardiner	Gardiner basin	1981-2004	2	0.09
West Yellowstone	West Yellowstone	1981-2004	7	0.30
Lake Yellowstone	Pelican Valley	1981-2004	10	0.43
Lake Yellowstone	Mary Mountain	1981-2004	10	0.43
Tower Falls	Lamar Valley	1989-2004	9	0.60

Table 3.5. Area (km^2) and percent of total range area (brackets) of each habitat type in each bison winter range in Yellowstone National Park.

	Winter range				
Habitat Type	**Gardiner basin**	**Lamar Valley**	**West Yellowstone**	**Mary Mountain**	**Pelican Valley**
Idaho Fescue/ Tufted Hairgrass	0 (0)	0 (0)	0 (0)	1.78 (1.18)	0 (0)
Idaho Fescue/ Bearded Wheatgrass	0 (0)	5.52 (2.36)	1.66 (2.08)	0.14 (0.09)	0 (0)
Idaho Fescue/ Bearded Wheatgrass - sticky	0 (0)	44.95 (19.22)	0 (0)	0 (0)	0.15 (0.26)
Idaho Fescue/ Bluebunch Wheatgrass	0 (0)	6.77 (2.89)	4.56 (5.70)	0.81 (0.53)	0 (0)
Idaho Fescue/ Richardson's Needlegrass	0 (0)	6.48 (2.77)	0 (0)	0 (0)	0 (0)
Big Sagebrush/ Idaho Fescue	19.66 (19.99)	57.94 (24.78)	3.34 (4.18)	2.63 (1.74)	1.12 (2.03)
Big Sagebrush/ Idaho Fescue - sticky	0 (0)	94.17 (40.28)	11.99 (15.00)	53.92 (35.51)	3.66 (6.63)
Big Sagebrush/ Bluebunch Wheatgrass	4.75 (4.83)	0 (0)	0 (0)	0 (0)	0 (0)
Silver Sagebrush /Idaho Fescue	0 (0)	0 (0)	0 (0)	45.07 (26.69)	27.27 (49.44)
Bluebunch Wheatgrass/ Sandbergs Bluegrass	6.51 (6.62)	0 (0)	0 (0)	0 (0)	0 (0)
Shrubby Cinquefoil	0 (0)	0.29 (0.12)	0 (0)	0 (0)	0 (0)
Hotsprings Vegetation	0 (0)	0 (0)	0 (0)	29.56 (19.47)	2.30 (4.16)
Tufted Hairgrass/ Sedge	0 (0)	12.71 (5.44)	6.82 (8.53)	8.53 (5.62)	9.70 (17.59)
Tufted Hairgrass/ Sedge - Sedge bogs	0 (0)	0 (0)	0 (0)	0 (0)	2.68 (4.86)
Sedge Bogs	0 (0)	4.98 (2.13)	2.69 (3.36)	9.37 (6.17)	8.28 (15.02)
Willow/Sedge	0 (0)	0 (0)	8.15 (10.20)	0 (0)	0 (0)
Herbaceous Rangeland	57.67 (58.63)	0 (0)	29.26 (36.60)	0 (0)	0 (0)
Shrub and Brush Rangeland	9.76 (9.92)	0 (0)	0.29 (0.36)	0 (0)	0 (0)
Mixed Rangeland	0 (0)	0 (0)	6.38 (7.99)	0 (0)	0 (0)
Nonforested Wetland	0 (0)	0 (0)	4.79 (5.99)	0 (0)	0 (0)

Table 3.6. Annual above ground primary production (APP) measured by several vegetation studies conducted in Yellowstone National Park.

Vegetation type	APP (kg/ha)	Location of study	Period of study	Source
Bluegrasses (Poa spp.)/Sedges (carex spp.)	708 (forage available)	Gibbon Meadows	October 1996	Dawes 1998/ Dawes and Irby 2000
Kentucky bluegrass (Poa pratense)/mixed forbs	240 (forage available)	Terrace Springs	October 1996	Dawes 1998/ Dawes and Irby 2000
Big Sage (Artemisia tridentata)/bluebunch wheatgrass (Agropyron spicatum)	288 (forage available)	Four-mile site	October 1996	Dawes 1998/ Dawes and Irby 2000
Beaked spike-rush (Elocharis rostella)	492 (forage available)	Fountain Flats Drive	October 1996	Dawes 1998/ Dawes and Irby 2000
Wetsern wheatgrass (A. smithii)/sedge/rush (Juncus spp.)	948 (forage available)	Midway Geyser Basin	October 1996	Dawes 1998/ Dawes and Irby 2000
Beaked spike-rush (Elocharis rostella)	1509 (forage available)	Old Faithful Interchange	October 1996	Dawes 1998/ Dawes and Irby 2000
Festuca Idahoensis/Lupinsis sericeus	NA	Crystal Creek	snow-free period 1988	Frank and McNaughton 1992
Phleum pratense/Poa pratense	5130 (ANPP)	Lamar Valley	snow-free period 1988	Frank and McNaughton 1992
Bromus inermis	2320 (ANPP)	Lamar Valley	snow-free period 1988	Frank and McNaughton 1992
Carex rostrata	5390 (ANPP)	Slough Creek	snow-free period 1988	Frank and McNaughton 1992
Festuca Idahoensis/Lupinsis sericeus	850 (ANPP)	Crystal Creek	snow-free period 1989	Frank and McNaughton 1992
Phleum pratense/Poa pratense	3800 (ANPP)	Lamar Valley	snow-free period 1989	Frank and McNaughton 1992
Bromus inermis	2040 (ANPP)	Lamar Valley	snow-free period 1989	Frank and McNaughton 1992
Carex rostrata	5890 (ANPP)	Slough Creek	snow-free period 1989	Frank and McNaughton 1992

Artemisia tridentata/Festuca Idahoensis	1014	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Artemisia cana/Festuca Idahoensis	1245	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Artemisia tridentata/Festuca Idahoensis-Danthonia intermedia phase	1296	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Artemisia cana/Festuca Idahoensis-Danthonia intermedia phase	1426	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Artemisia tridentata/Agropyron caninum.	1650	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Festuca Idahoensis/Agropyron caninum	867	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Festuca Idahoensis/Deschampsia cespitosa	1314	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Ridge top Poa sandbergii	894	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Artemisia tridentata/Poa sandbergii	894	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Potentilla Fruticosa/Deschampsia cespitosa	1938	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Artemisia cana/Deschampsia cespitosa	2001	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Calamagrostis canadensis	2577	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Deschampsia cespitosa	1884	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Wet carex spp.	3315	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Deschampsia cespitosa/Carex	2832	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Salix/carex	3074	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Hotsprings Vegetation (estimate)	1000	Hayden Valley	1998/1999/2000 - summer	Olenicki pers. comm.
Artemisia tridentata/Festuca Idahoensis/Psuedoroegneria spicata/Poa pratensis/Stipa comata	1140	Lamar Valley	Summer 1996	Tracy and Frank 1998

Poa pratensis/Phleum pratense/Agropyron caninum/Deschampsia caespitosa/Carex sp./Calamagrostis sp.	2259	Lamar Valley	October 1990	Turner et al. 1994
Artemesia tridentata/Phleum pratensis/Bromus carinatus/Agropyron caninum/Geranium visoscisimum/Potentilla sp./Carex sp.	1122	Lamar Valley	October 1990	Turner et al. 1994
Artemesia tridentata/Agropyron caninum/Agropyron spicatum/Bromus sp./Potentilla sp./Stila ap.	631	Lamar Valley	October 1990	Turner et al. 1994
Artemesia tridentata/Agropyron spicatum/Koeleria cristata/Festuca idahoensis/Chrysopsis villosa/Stipa comata/Danthonia sp./Poa sp./Sedum sp.	520	Lamar Valley	October 1990	Turner et al. 1994
Live grasses	3030 (aboveground biomass - unfenced)	Lamar Valley	August 1987	Coughenour 1991
Live grasses	1550 (aboveground biomass - unfenced)	Lamar Valley	September 1987	Coughenour 1991
Live grasses	1790 (aboveground biomass - unfenced)	Lamar Valley	July 1988	Coughenour 1991
Live grasses	3380 (aboveground biomass - unfenced)	Blacktail	August 1987	Coughenour 1991
Live grasses	2320 (aboveground biomass - unfenced)	Blacktail	September 1987	Coughenour 1991
Live grasses	2940 (aboveground biomass - unfenced)	Blacktail	July 1988	Coughenour 1991

Live grasses	2140 (aboveground biomass - unfenced)	Stevens Creek	August 1987	Coughenour 1991
Live grasses	1800 (aboveground biomass - unfenced)	Stevens Creek	September 1987	Coughenour 1991
Live grasses	1630 (aboveground biomass - unfenced)	Stevens Creek	July 1988	Coughenour 1991
Grasslands	4270 (aboveground biomass - unfenced)	Blacktail	May 1998	Augustine and Frank 2001
Grasslands	3240 (aboveground biomass - unfenced)	Lamar Valley	May 1998	Augustine and Frank 2001
Grasslands	3800 (aboveground biomass - unfenced)	Stevens Creek	May 1998	Augustine and Frank 2001

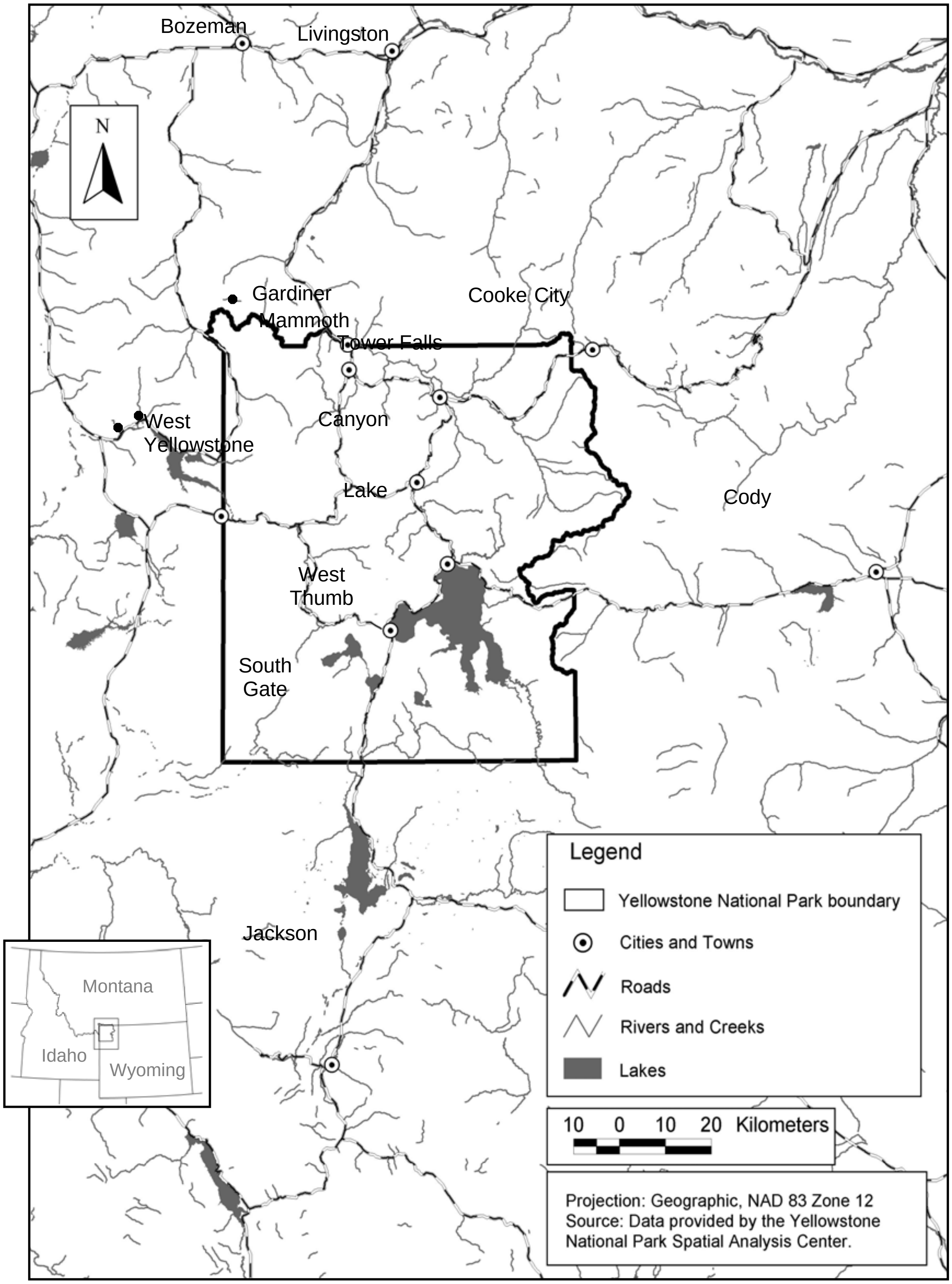


Figure 3.1. The Greater Yellowstone Area (GYA). Inset map (lower left) indicates location of the GYA. Black dots represent locations of bison capture facilities.

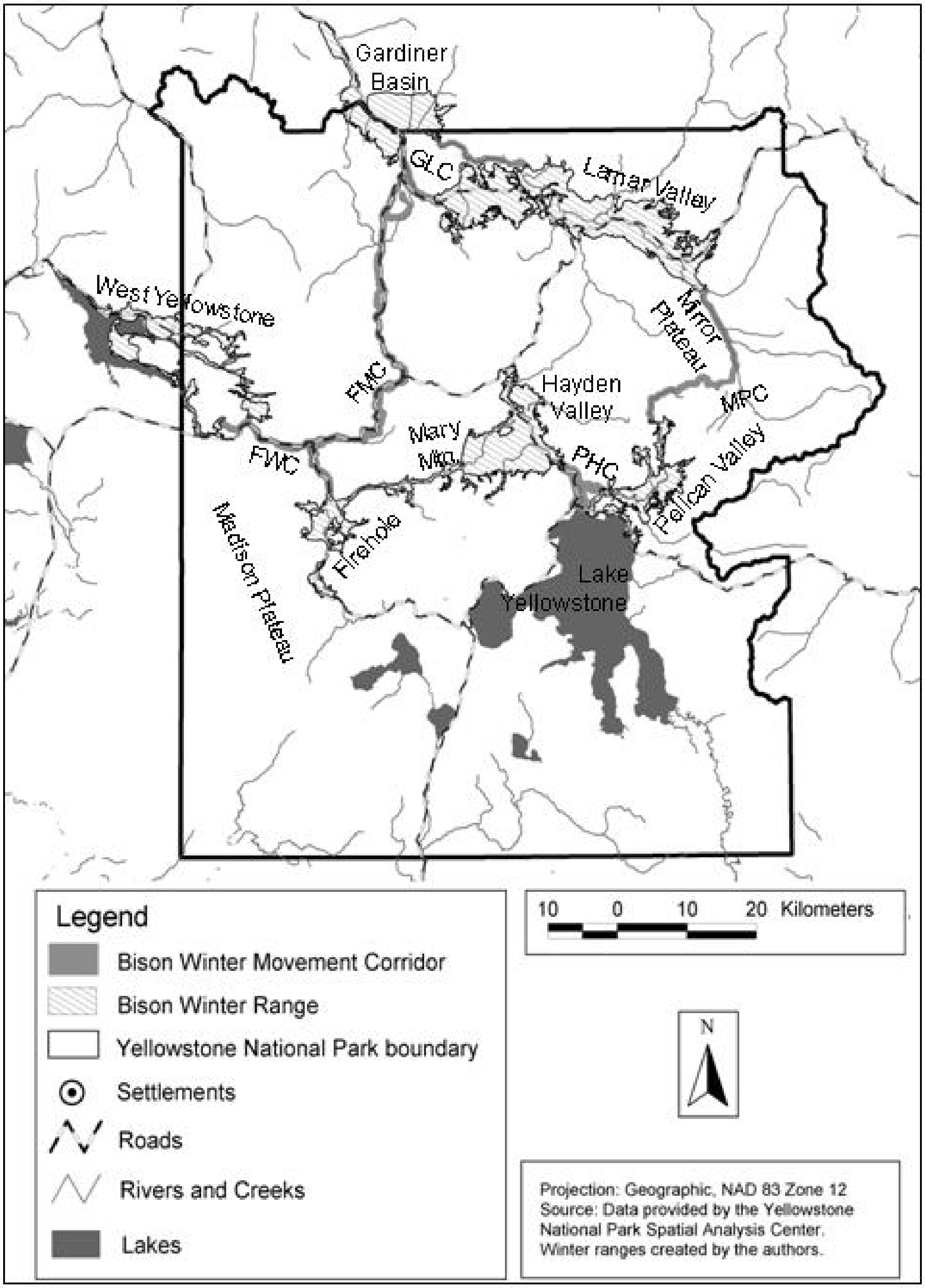


Figure 3.2. Bison winter ranges and movement corridors in Yellowstone National Park. FMC: Firehole to Mammoth corridor; FWC: Firehole to West Yellowstone corridor; GLC: Gardiner Basin to Lamar Valley corridor; MPC: Mirror Plateau corridor; PHC: Pelican Valley to Hayden Valley corridor.

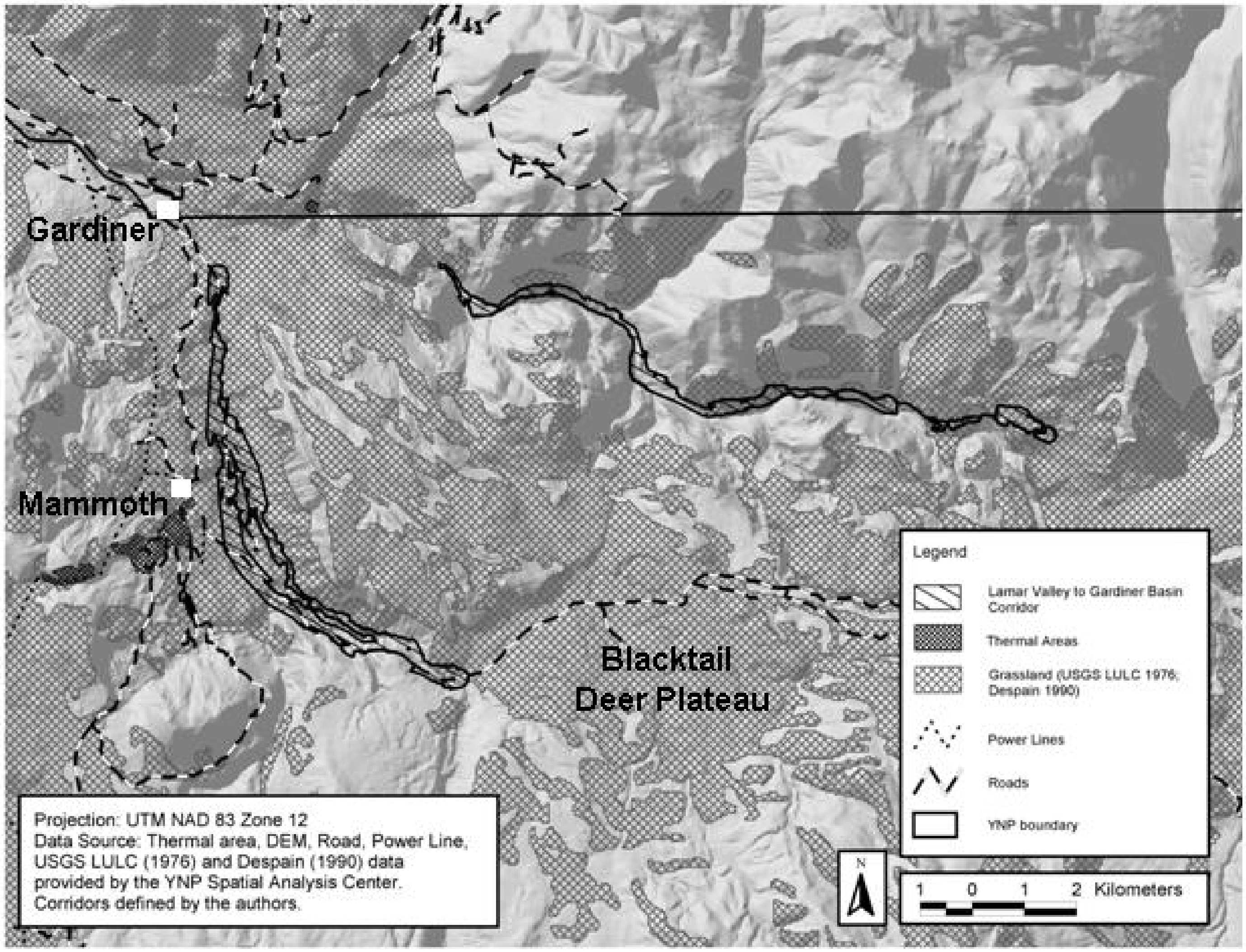


Figure 3.3. The Gardiner Basin to Lamar Valley winter movement corridor. Corridors were delineated based on interviews with Mary Meagher, July 15, 2004, and a workshop with Yellowstone Center for Resources personnel, October 20, 2004.

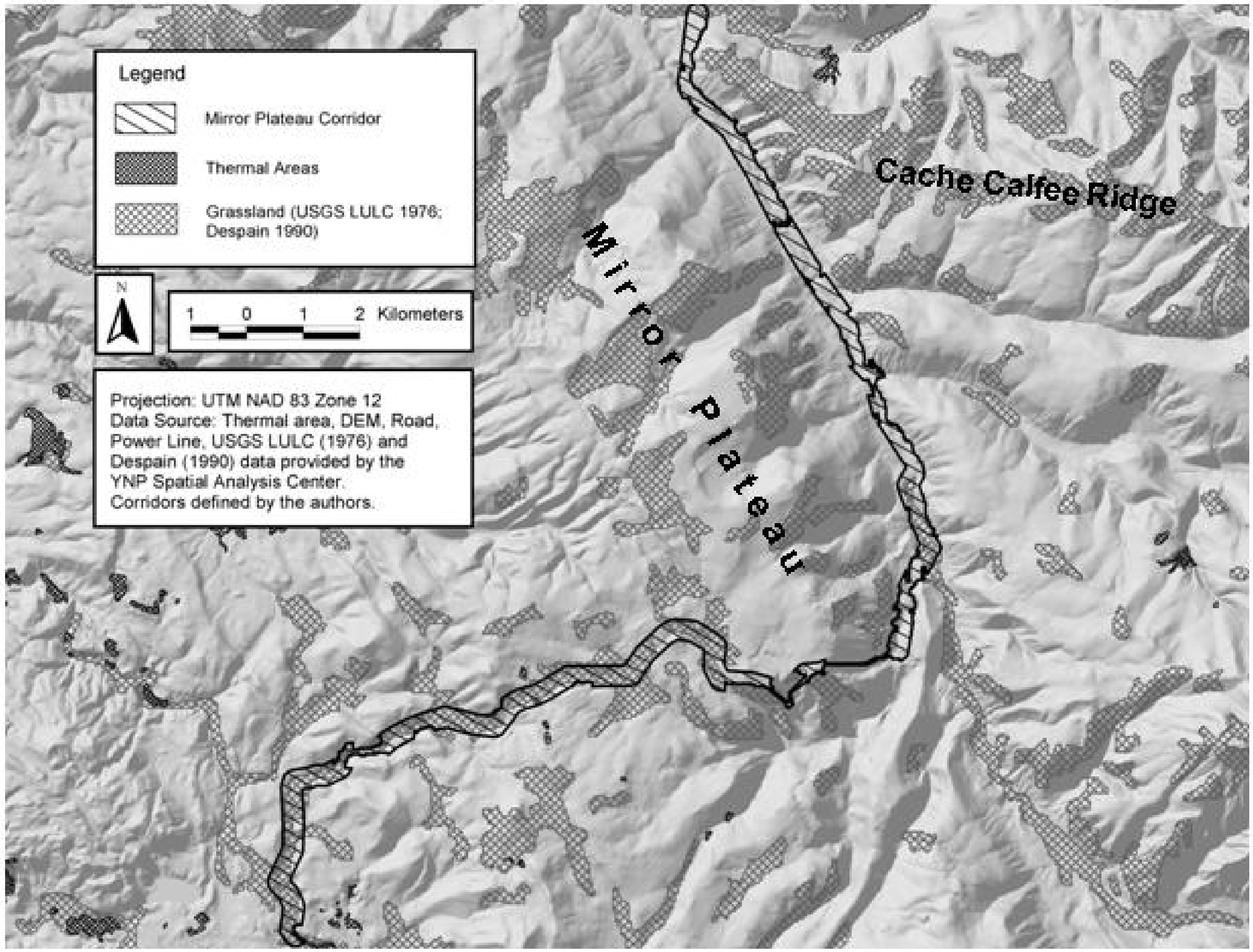


Figure 3.4. The Mirror Plateau winter movement corridor. Corridors were delineated based on interviews with Mary Meagher, July 15, 2004, and a workshop with Yellowstone Center for Resources personnel, October 20, 2004.

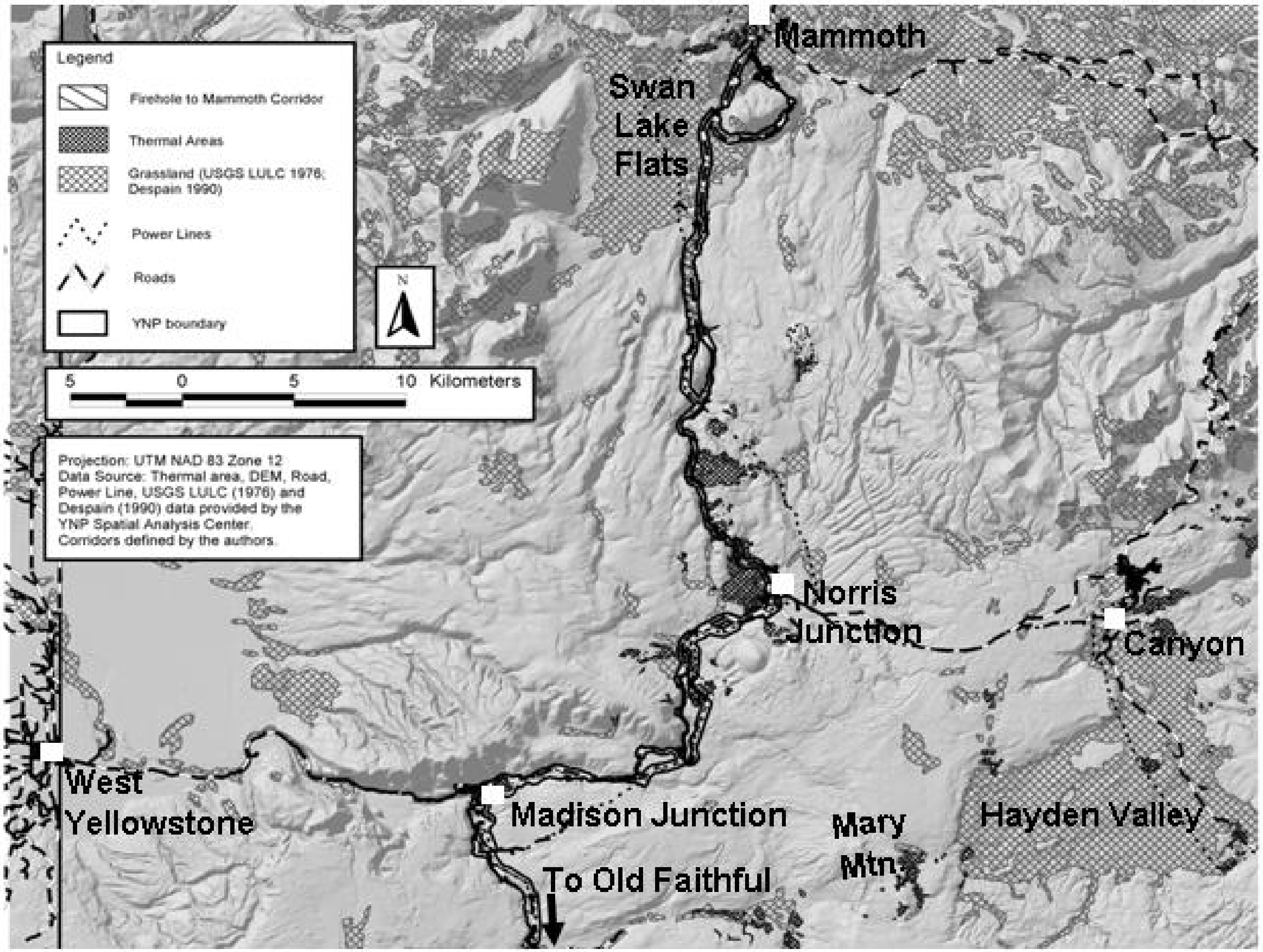


Figure 3.5. The Firehole to Mammoth winter movement corridor. Corridors were delineated based on interviews with Mary Meagher, July 15, 2004, and a workshop with Yellowstone Center for Resources personnel, October 20, 2004.

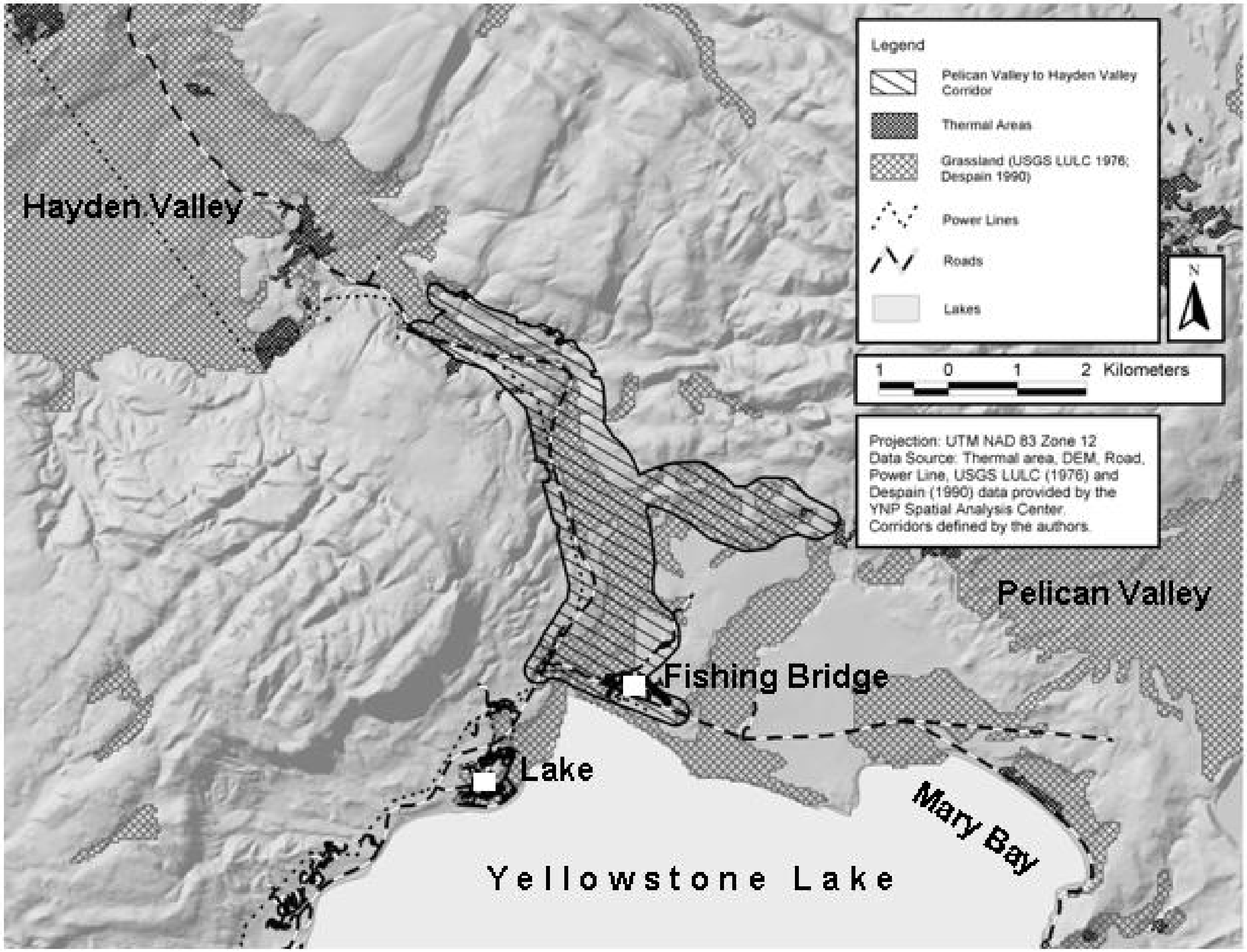


Figure 3.6. The Pelican Valley to Hayden Valley winter movement corridor. Corridors were delineated based on interviews with Mary Meagher, July 15, 2004, and a workshop with Yellowstone Center for Resources personnel, October 20, 2004.

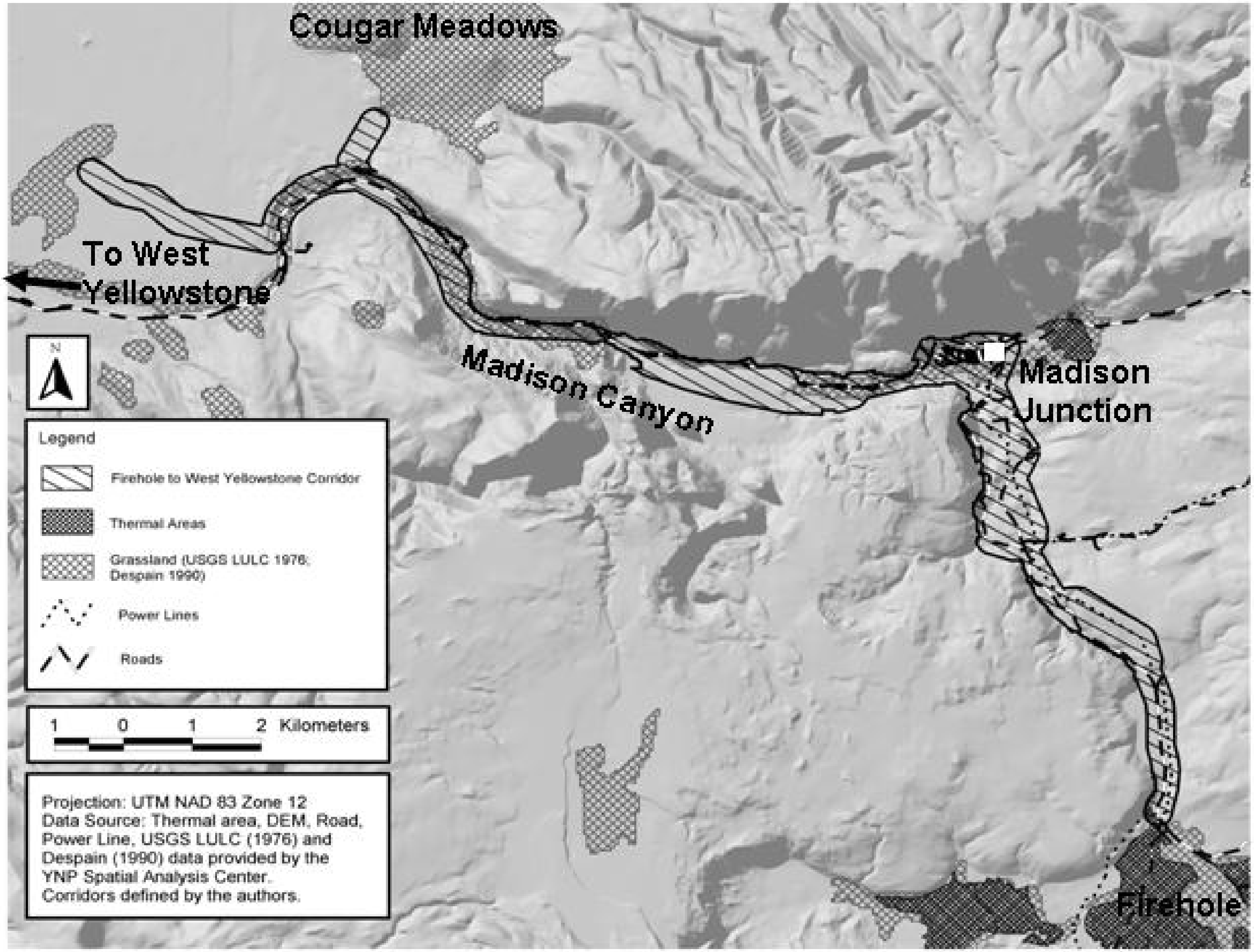


Figure 3.7. The Firehole to West Yellowstone winter movement corridor. Corridors were delineated based on interviews with Mary Meagher, July 15, 2004, and a workshop with Yellowstone Center for Resources personnel, October 20, 2004.

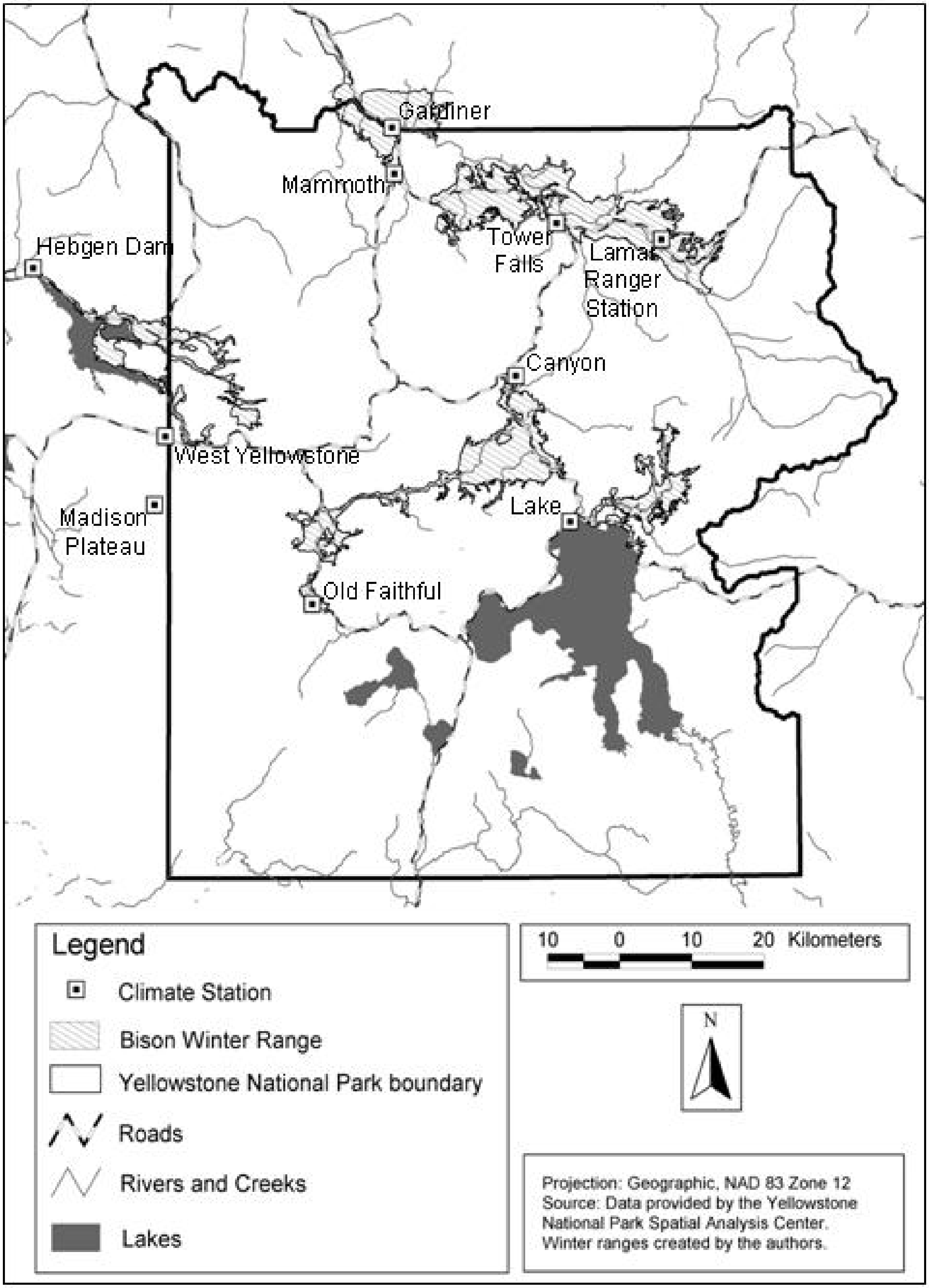


Figure 3.8. Locations of climate stations used for weather data.

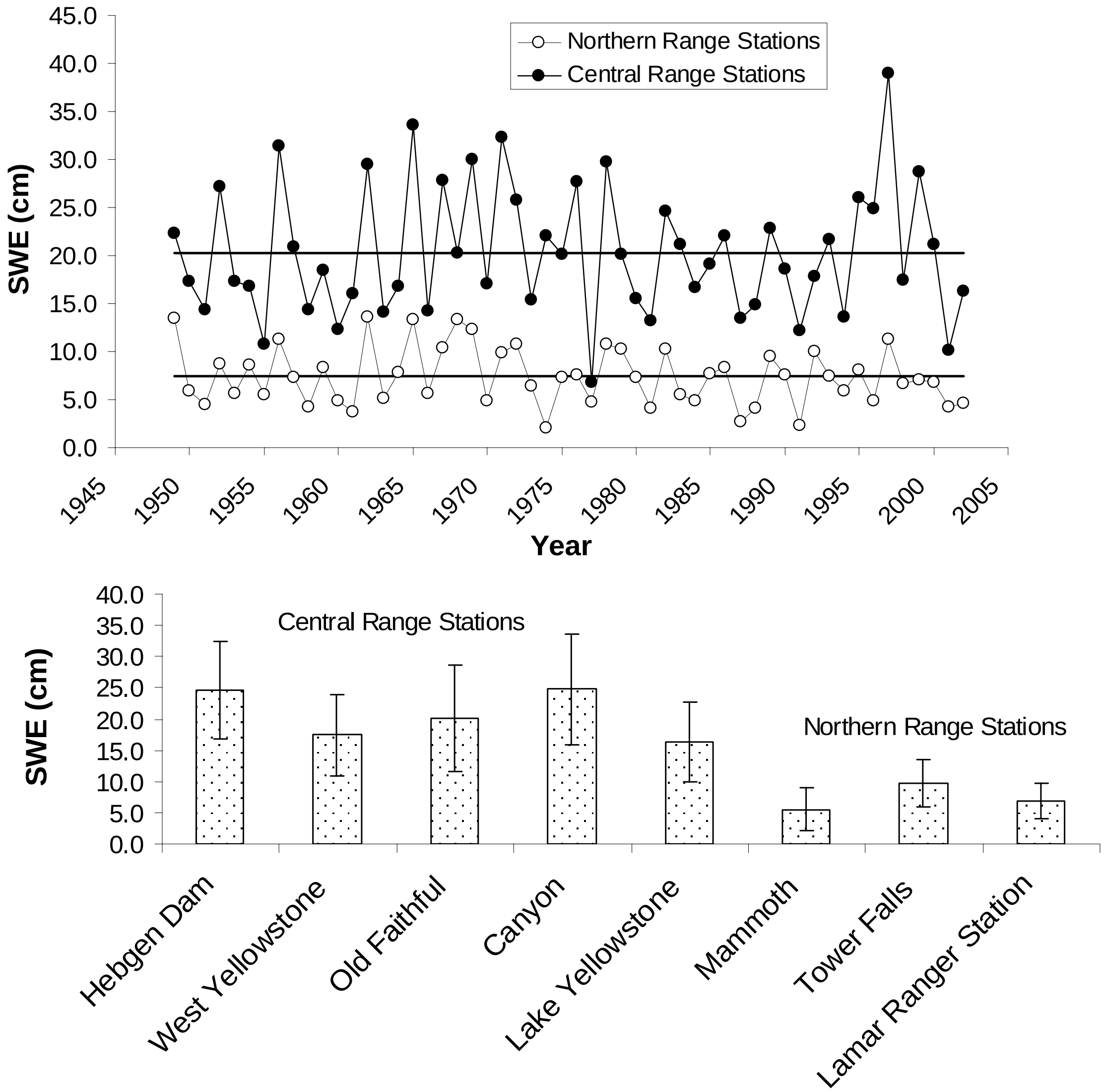
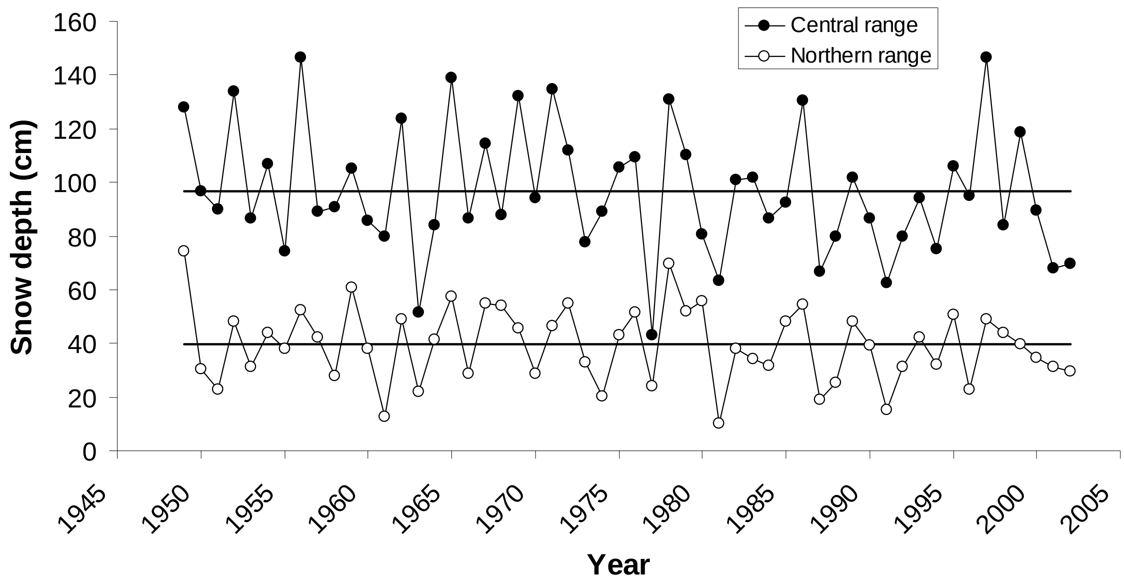


Figure 3.9. Annual and long term average snow water equivalence (cm) ± s.d. in mid-February on Central and Northern bison ranges in Yellowstone National Park based on available station records between 1949 and 2002. Central range stations included west to east: Hebgen Dam, West Yellowstone, Old Faithful, Canyon, and Lake Yellowstone. Northern Range stations included west to east: Mammoth, Tower Falls, Lamar Ranger Station.



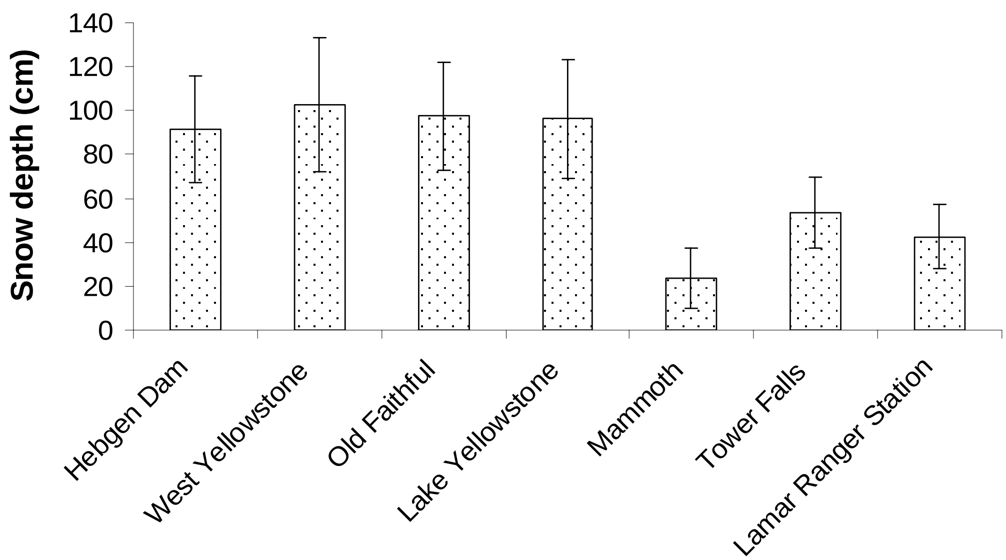


Figure 3.10. Annual and long term average snow depth (cm) ± s.d. on the ground in mid-February on Central and Northern bison ranges in Yellowstone National Park based on available individual station records between 1949 and 2002. Central range stations west to east: Hebgen Dam, West Yellowstone, Old Faithful, and Lake Yellowstone. Northern Range stations west to east: Mammoth, Tower Falls, Lamar Ranger Station.

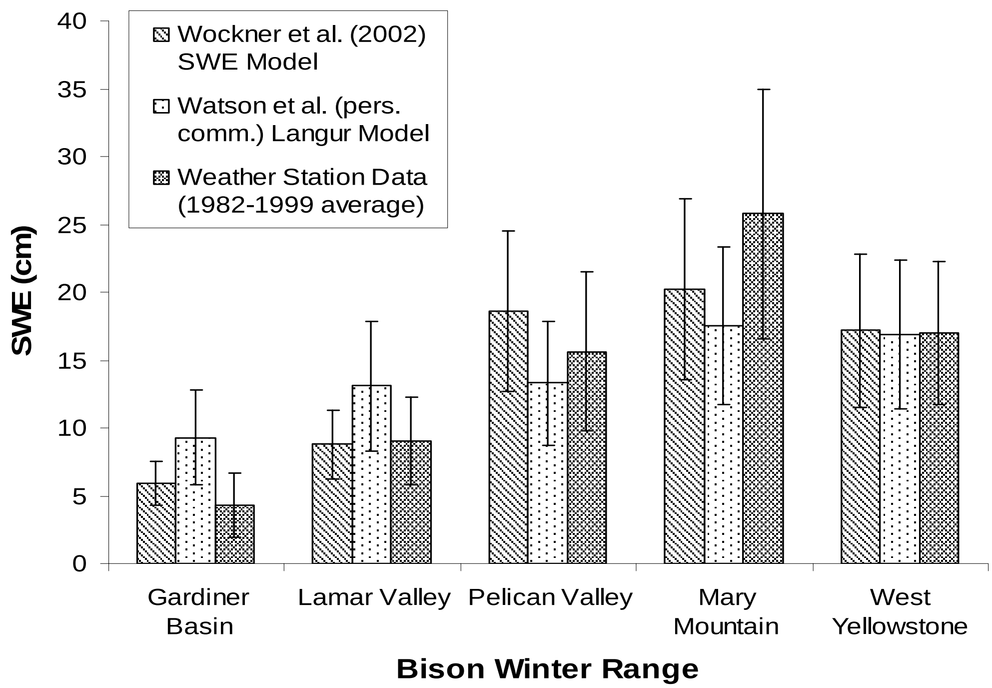


Figure 3.11**.** Mean $\pm$ s.d. estimated and actual February 15th SWE values for each bison range from 1982-1999. Estimated values were derived from the Wockner et al. (2002) snow model and the Langur (Watson et al. pers. comm.) snow model. Actual data comes from weather stations in YNP. Mammoth CLIM station was used for Gardiner basin range, Tower Falls CLIM station was used for Lamar Valley range, Lake Yellowstone CLIM was used for Pelican Valley, Canyon SNOTEL station was used for Mary Mountain range and West Yellowstone SNOTEL station was used for West Yellowstone range.

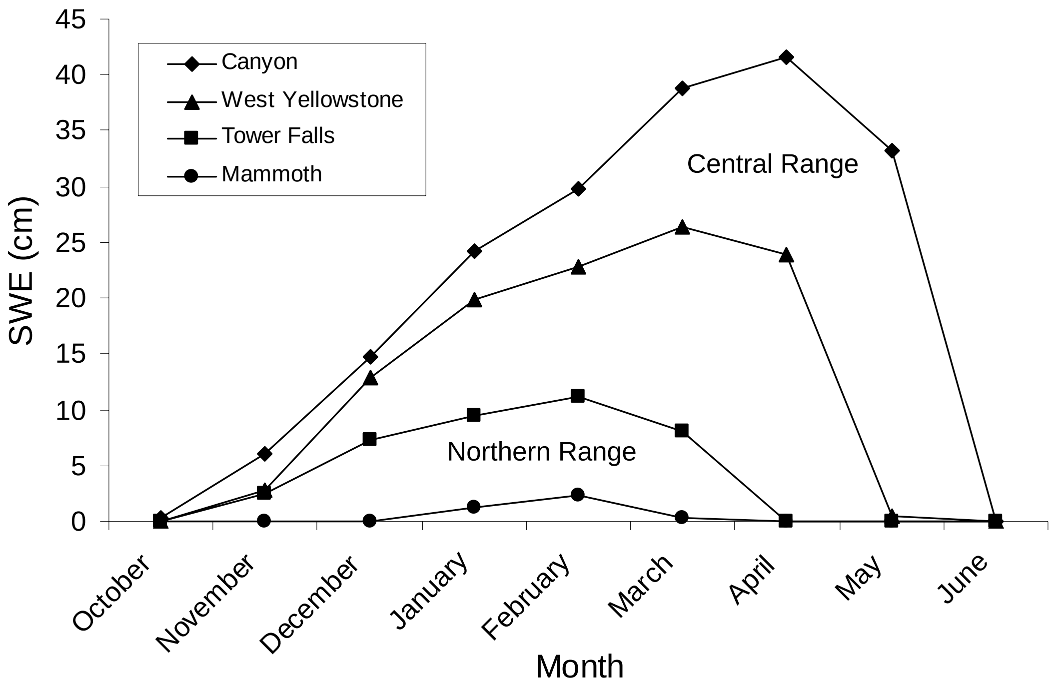


Figure 3.12. Mid-month (15th) SWE at selected climate stations in Yellowstone National Park in the winter of 1994-1995.

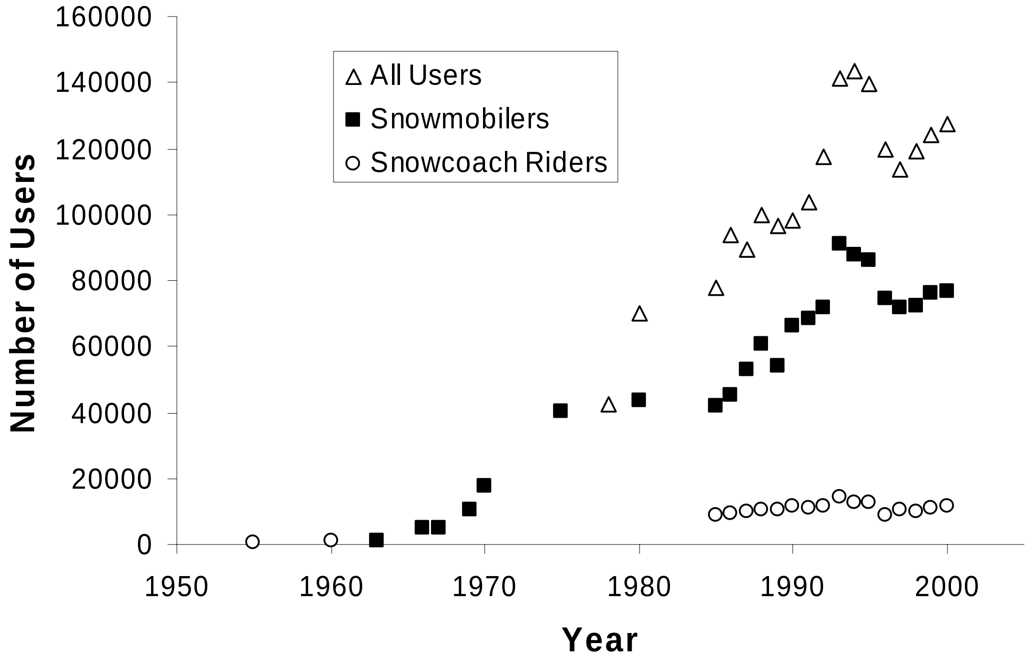


Figure 3.13. Number of winter users, snowmobilers and snowcoach riders entering YNP annually. Data from: USDI-NPS EIS (2000), Greater Yellowstone Winter Visitor Use Management Working Group (1999), Yochim (1998*a*), USDI-NPS (1990), and Snowmobile Briefing Books (1976 to 1978).