National Park Service
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Natural Resource Stewardship and Science

Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway

Natural Resource Condition Assessment

Natural Resource Report NPS/GRYN/NRR—2012/550

ON THE COVER
Peaks of the Grand Tetons and wildflowers, Grand Teton National Park
Photograph by: Christopher M. McGinty, Utah State University

Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway

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Some or all of the work done for this project preceded the revised guidance issued for this project series (Natural Resource Condition Assessments) in 2009/2010.

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Executive Summary

This natural resource condition assessment for Grand Teton National Park (GRTE) and John D. Rockefeller, Jr. Memorial Parkway provides a synthesis of available data and knowledge to address current conditions within and surrounding the park. This work synthesizes extant data and information in order to help park resource managers formulate management strategies that will protect and enhance park natural resources.

This report is accompanied by spatially explicit maps and GIS databases relevant to the natural resources that have been evaluated. Park personnel identified the following themes as pertinent to assess the condition of the park:

- Air Quality
- Climate
- Hydrology
- Forest Health
- Insects and Disease
- Invasive Species
- Land Cover and Land Use
- Soundscapes
- Water Quality
- Wildlife

The evaluation of each theme appears as individual sections in Chapter 3. Table 1 contains a brief synopsis of the assessment of each theme.

Table 1. Summary of the condition and trend of natural resources described in this assessment.

Natural Resource		Summary and General Condition/Trend
Air Quality	Atmospheric Deposition	▪ GRTE is in compliance with federal air quality standards for atmospheric deposition; however, scientific studies have suggested that even relatively low levels of atmospheric deposition can affect high-elevation ecosystems. ▪ High elevation lakes in GRTE are sensitive to acidification, with half of the lakes having lower acid neutralizing capacity concentrations. ▪ Based on National Park Service (NPS) Air Resources Division (ARD) air quality criteria and NPS Air Atlas estimates, the condition of atmospheric deposition (total wet deposition) ranges from not a concern to a moderate concern; however, in ecosystems potentially sensitive to nitrogen and sulfur compounds, the deposition condition may be adjusted up one category, thereby rendering the atmospheric deposition a significant concern in some areas. ▪ Presently, atmospheric deposition at GRTE is inferred from monitoring data collected in Yellowstone National Park (YELL). It has been suggested that deposition estimates are not likely to adequately characterize conditions in GRTE; therefore, an NADP sampler will be placed at the Teton Science School by late spring 2011.
	Ozone	▪ GRTE is in compliance with the federal ozone concentration standard for human health; however, scientific evidence suggests that this standard may not be protect ozone-sensitive plant species. ▪ Current estimates indicate that ozone concentrations and cumulative doses in GRTE are low or at levels not known to cause injury to vegetation. ▪ Based on NPS ARD air quality criteria and NPS Air Atlas estimates, the condition of ozone in GRTE is a moderate concern. ▪ Since ozone concentrations for GRTE are inferred from data collected in YELL, it has been suggested that an ozone monitor in GRTE would determine how well monitoring in YELL has represented conditions in GRTE. Therefore, an ozone monitor will be installed at the Teton Science School and should be operational by late spring 2011.
	Visibility	▪ Visibility in GRTE is considered superior to that of many other areas and national parks in the United States; however, it is deemed a moderate concern based on NPS ARD air quality criteria and NPS Air Atlas estimates. ▪ Visibility in GRTE is monitored at a number of locations in Wyoming as part of the IMPROVE network; the IMPROVE monitor closest to GRTE is near Yellowstone Lake. ▪ Trends in annual deciview suggest that visibility in YELL is improving at statistically significant levels during the 20 percent clearest days; however, there are no statistically significant trends during the 20 percent haziest days. ▪ Although the IMPROVE monitor in YELL is used to infer conditions in GRTE, it has been suggested that the monitor may not be characteristic of visibility in GRTE because of significant differences in terrain and wind flow patterns. Consequently, a camera and nephelometer will be installed at the Teton Science School to monitor visibility.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource		Summary and General Condition/Trend
Climate	Change Points and Trends in Historical Climate Record	▪ Recent warming trends are evident in the observed historical climate record for GRTE. ▪ While the observed increases may be small, the timing of increases, during the winter and spring snowmelt period or during periods of annual moisture stress, highlights the potential for serious alteration of the regional water cycle if current trends continue. ▪ This analysis was performed on only one climate station, so more widespread comparison to other long-term records would bolster the findings.
	Spatial Patterns of Change	▪ Recent warming trends are evident in the observed climate record for GRTE. ▪ While the observed increases may be small, the timing of increases, during the winter and spring snowmelt period and their spatial distribution, highlights the potential for serious alteration of the regional water cycle if current trends continue. ▪ Uncertainty associated with these estimates comes from the generalized topographic models used in the PRISM data set; it remains unclear how precisely the PRISM data set captures local patterns of variation.
	Trends in Surface Area of Glaciers	▪ The Teton Range is host to ten named glaciers and a number of undifferentiated glaciers or perennial snow fields; the majority of these glaciers face north and east and lie in the shadow of major peaks. ▪ An evaluation of three glaciers—Teton, Middle Teton, and Teepe—indicated a 25 percent reduction in surface area from 1967 to 2006. The three glaciers also lost a total volume of 113 million cubic feet between 1967 and 2002. ▪ However, preliminary analyses suggest that not all glaciers in the Teton Range have experienced shrinking following a series of warmer or drier years, and expansion following a series of cooler or wetter years. Instead, observations suggest that local climate, slope, aspect, and seasonal weather fluctuations influence patterns of glacial expansion and retreat within the Teton Range.
	Jackson Lake Ice-Off Dates	▪ Trends in lake ice dynamics are valuable indicators that can be related to climate condition. Some research indicates that lake phenology is a reliable measurement of local climate condition, and in some cases, it has been considered a more robust measure than air temperature. ▪ During the period from 1933 to 2009, the earliest thaw date for Jackson Lake occurred in 1934 on April 19, and the latest thaw date occurred in 1975 on June 2; the mean ice off date was May 11. ▪ A basic linear regression analysis suggests that there is no statistical significance in the ice-off date from 1933 to 2009; however, there is a slight decreasing trend (negative slope values) that may suggest the ice-off date may be occurring earlier in the year.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource		Summary and General Condition/Trend
Hydrology	Trends in the Timing of Spring Snowmelt Runoff of Pacific Creek	▪ Changes in spring runoff timing for Pacific Creek over a 63-year period (1945-2008) were evaluated; mean daily discharge data were used for an analysis of covariance and were related to climate trends over the same period of time. ▪ The date of the center of mass (i.e., the date within the year at which 50 percent of the spring runoff is greater than 266 cubic feet per second) occurs approximately 11 days earlier than it did in the mid-twentieth century, and the date of the annual instantaneous peak occurs approximately 15 days earlier than it did in the mid-twentieth century.
	Undeveloped Rivers and Streams by Watershed	▪ GRTE has a total of 1,153.54 miles of river and stream shoreline, with 74.21 miles (or 6.43 percent) impacted by road development and associated human activities. ▪ Several watersheds on the western side of GRTE are not impacted by road development and associated human activities. ▪ The Snake River-Spread Creek watershed has both a high number of miles of undeveloped shoreline and a relatively low percentage of undeveloped shoreline; while this seems contradictory, it can be explained by the fact that this watershed has numerous rivers and streams.
Forest Health	Forest Patch Size by Watershed	▪ Data from the Northwest Gap Analysis Program and data from the vegetation map prepared by GRTE personnel were utilized for regional and local assessments of forest patch size. ▪ The analysis suggested that the most fragmented watersheds in the study area are Spread Creek, Teton Creek, and Upper Lewis River; conversely, the least fragmented watersheds are DeLacy Creek, Elliot Creek, and Jackpine Creek.
	Whitebark Pine Distribution and Regeneration	▪ Whitebark pine populations are declining throughout their range from a combination of infestations by a native insect, mountain pine beetle, an introduced fungal disease, white pine blister rust, and altered climate conditions. ▪ Within GRTE, whitebark pine covers 26,619 acres; within approximately one-third of the stands, whitebark pine is considered the dominant species. ▪ Between 2007 and 2010, the mortality of whitebark pine increased from 17 percent to 31 percent, with beetle activity as the primary culprit. ▪ Whitebark pine regeneration is evident, but the abundance varies. In 2010, whitebark pine regeneration ranged from zero to 2,280 seedlings per hectares, with 96 percent of the seedlings being rust free. ▪ The status and condition of whitebark pine in GRTE and throughout its range are changing rapidly. The future distribution of whitebark pine in GRTE is unknown and will reflect the biology and ecology of whitebark pine, combined with the effects of mountain pine beetle and blister rust impacts.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource		Summary and General Condition/Trend
Insects and Disease	Mountain Pine Beetle	▪ The current tree mortality and trends caused by native bark beetles within GRTE mirrors the epidemic levels reported throughout much of western North America. ▪ According to aerial insect and disease detection surveys, mountain pine beetle is responsible for the majority of damage in GRTE during years 2006 (1,797 acres), 2008 (23,268 acres), and 2009 (20,733 acres). ▪ Although bark beetles are a natural part of forest regeneration, given the current rates of mortality in some forest ecosystems, the ability to recover and regenerate may be interrupted or may threaten local extinction.
	Blister Rust	▪ Blister rust is well established throughout the Greater Yellowstone Ecosystem (GYE) and GRTE, where it has reduced cone production and accelerated the mortality and decline of whitebark pine. ▪ From baseline surveys conducted in 2004 and 2007, the proportion of live trees with blister rust in the GYE was 20 percent. Surveys conducted in 2008 and 2009 suggested that the proportion of trees infected by blister rust increased to 24.9 percent and 39.8 percent, respectively. ▪ Blister rust severity (i.e., the mean number of cankers per live whitebark pine) increased from 11.7 percent to 22.7 percent between 2007 and 2010.
Invasive Species	Distribution and Extent of Cheatgrass	▪ Cheatgrass is an annual exotic grass that has invaded vast expanses of land in the Intermountain West of the United States. Although cheatgrass occurs more frequently in lower, warmer locations, it has been reported in GRTE and surrounding landscapes. ▪ The spatial distribution of cheatgrass was modeled based on multi-temporal vegetation indices and topographic layers, and the likelihood of occurrence of cheatgrass was modeled based on vegetation indices, topographic layers, and climatic layers. ▪ Current distribution of cheatgrass within GRTE is limited to valley bottoms coincident with developed areas to the southeast of Jackson Lake. The potential, however, extends farther north and west into valley bottoms directly east and west of Jackson Lake. ▪ Results for the modeled spatial distribution of cheatgrass yielded an accuracy of 83 percent (using training data) and 67 percent (excluding training data); results for the likelihood of occurrence of cheatgrass yielded an accuracy of 87 percent. ▪ Increases in cheatgrass may impact fire return intervals, and may subsequently result in monocultures. However, changes in ecosystem health may be more a function of an alteration of precipitation regimes. Cheatgrass will have greater success in areas of winter precipitation and summer drought that coincides with the southern portion of the study area where cheatgrass has been mapped.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource		Summary and General Condition/Trend
Invasive Species (continued)	Terrestrial Invasive and Exotic Plants by Watershed	▪ A comprehensive geodatabase of the locations of exotic plants in GRTE and surrounding areas was previously prepared by park personnel. ▪ Data from the geodatabase were spatially joined to the watershed shapefile; a cross-tabulated query was generated to summarize how many exotic locations were found in each watershed. ▪ Snake River-Stewart Draw, Lake Creek-Fall Creek, and Lower Jackson Lake watersheds have the greatest number of occurrences.
Land Cover and Land Use	Land Cover and Land Use Change	▪ To assess land cover and land use change, the 1992-2001 Retrofit Land Cover Change Product from the National Land Cover Dataset was used. ▪ During the period of analysis, the land cover conditions in the study area remained largely unchanged; nearly 98 percent of the land showed no change between the two years. ▪ Transitions from forest, ice/snow, and barren to grassland, in addition to grassland to forest, represent the majority of shifts in the land cover. ▪ The vast majority of the transitions occurred on the highlands of the Teton Range and in the southeast (Upper Gros Ventre River watershed).
	Anthropogenic Land Use by Watershed	▪ Vegetation datasets from the Northwest Gap Analysis Program and GRTE were used to extract anthropogenic land use classes—developed, pasture, and cultivated cropland. ▪ Within GRTE, the Snake River-Stewart Draw watershed has the greatest percentage of urban area, and Moose Creek, Moran Bay, and Owl Creek, have the least or no amount of urban area. ▪ Within the study area, the Snake River-Stewart Draw. Elliot Creek-Teton River and Lower Trail Creek watersheds have the highest percentages of developed area.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource	Summary and General Condition/Trend
Soundscapes	▪ GRTE is one of several national parks that have initiated acoustical studies. ▪ Between October 2002 and April 2008, a total of 43,534 hours of sound data were collected from 22 recording sites distributed throughout GRTE. ▪ Ambient sound levels vary considerably throughout GRTE, depending on location, time of year, and time of day. ▪ Sounds of summer consist of running water (44 percent), bird vocalizations (42 percent), vehicles and other motors (36 percent), and wind (17 percent). During winter, silence prevails in GRTE (35 percent), with occasional wind (19 percent), followed by motorized vehicles (18 percent). ▪ Sounds associated with aircraft and over-snow vehicles are two primary management concerns in GRTE; however, over-snow vehicle use within GRTE has decreased both in permissible locations of use and numbers of vehicles in recent years.
Water Quality	▪ Synoptic studies and surface water monitoring suggest that water quality in and adjacent to GRTE is generally good. ▪ The water quality, as measured by trophic state, is very good, and none of the alpine, moraine, Colter Bay, or valley lakes sampled from 1995 to 1997 revealed signs of accelerated eutrophication. ▪ Data from routine monitoring at sites of the Snake River in GRTE during water years 1998 to 2002 and data from a synoptic study of stream water quality in five eastern tributaries of the Upper Snake River indicated that water quality was generally good. ▪ Data from the 2006 study of stream water quality in four eastern tributaries of the Upper Snake River also suggested stream water quality was generally good.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource		Summary and General Condition/Trend
Wildlife	Amphibians	▪ Three amphibian species are widespread and locally common to abundant in GRTE: tiger salamander, boreal chorus frog, and Columbia spotted frog. Boreal toads are less widespread and common, and northern leopard frogs have vanished from the area. The non-native American bullfrog occurs at Kelly Warm Springs. ▪ Only a few years of amphibian data exist on which to assess population status and trends; the Greater Yellowstone Network Amphibian Monitoring Program has only recently been finalized. ▪ From 2007 to 2009, the boreal chorus frog was the most widely detected amphibian in GRTE catchments, and the boreal toad was the most rarely detected. During 2008 and 2009 field seasons, no leopard frogs or bullfrogs were found. ▪ Based on sampling, the occurrence of amphibians is better described as widespread, but in limited and unevenly distributed suitable wetland breeding habitats. ▪ Threats to amphibian populations in the GYE include ranavirus and Chytridiomycota.
	Landbirds	▪ In GRTE, landbird species include sparrows, finches, swallows, woodpeckers, nuthatches, flycatchers, warblers, vireos, hawks, eagles, and falcons. ▪ An estimation of landbird species within GRTE was derived by comparing a National Park Service list of all bird species in the park against two sources of landbird classifications; 136 landbird species were identified. ▪ Knowledge on the status of landbirds in GRTE with respect to species density and richness is limited, but a Greater Yellowstone Inventory and Monitoring Network landbird monitoring pilot program (2005-2008) was developed to measure landbird species metrics in five habitats of concern—alpine, aspen, riparian cottonwood, riparian willow, and sage-steppe. Data analyses are provisional and incomplete.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource			Summary and General Condition/Trend
Wildlife (continued)	Birds of Concern	Bald Eagle	▪ Bald eagles were placed on the Endangered Species Act in 1978 as a result of habitat loss, shooting, and poisoning by the pesticide DDT. ▪ GRTE has been actively monitoring bald eagles since the 1970s. ▪ Data collected since 1987 indicate that there is an expanding population of bald eagle pairs in GRTE, with increases in geographic distribution and the number of occupied territories. ▪ In 2007, the bald eagle was delisted from the Threatened and Endangered Species List. ▪ Although it is estimated that the number of nesting pairs will continue to increase, human activity, development, organochlorines, heavy metals, organophosphates, and carbamate pesticides could affect population and survival.
		Great Blue Heron	▪ The great blue heron has a restricted and vulnerable habitat and is sensitive to human disturbance. Great blue herons have been monitored in GRTE since 1987. ▪ The highest reported number of active nests in the park was in 1992 with slightly less than 60 nests. ▪ Occupancy in the park has varied widely, with overall productivity declining and many rookeries becoming inactive over time.
		Osprey	▪ Following bans on the use of chemical pesticides in the 1970s, osprey populations have rebounded to near-historical abundance levels in most areas. ▪ The osprey is considered a Species of Special Concern in GRTE due to its ecological importance as an indicator species. ▪ Osprey monitoring in the park began in 1972; trends over the last few decades suggest that the number of osprey territories has slightly declined, but the number of young per occupied nest has increased. ▪ Osprey populations are threatened by logging, the conversion of habitat into farmland, shooting, and electrocution by power transmission lines.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource			Summary and General Condition/Trend
Wildlife (continued)	Birds of Concern (continued)	Peregrine Falcon	▪ Peregrine falcon populations were severely affected by the widespread use of pesticides and by the 1960s, peregrine falcons were considered extirpated from the GYE. Surveys conducted in the late 1970s concluded that no peregrine falcon nests were occupied in Idaho, Montana, or Wyoming; subsequently, peregrine falcon reintroduction programs were initiated. ▪ The first verified nesting attempt in GRTE occurred in 1987, and the first successful breeding occurred in 1988. Despite an abundance of potential nest sites within GRTE, peregrine falcon populations in the park have remained relatively small. Productivity has been low but relatively stable over the last 15 years. ▪ Threats to peregrine falcons include environmental contamination and human disturbance.
		Greater Sage-Grouse	▪ The range of greater sage-grouse has been greatly reduced over the past 200 years; it is estimated that they occupy approximately 56 percent of their historical range. ▪ Even with decades of monitoring data, it has been difficult to substantiate a population trend for greater sage-grouse because of variations in survey efforts; however, the data suggest that between 1949 and 2003, a precipitous decline in greater sage-grouse counts, both within GRTE and throughout Jackson Hole, occurred. ▪ Although populations are well below historic averages and have showed an overall decreasing trend since surveys were initiated, annual counts have been showing a slight increase since 1999. ▪ Greater sage-grouse declines have been correlated with predation and with habitat loss and fragmentation that has resulted from fire, livestock grazing, and land development.
		Trumpeter Swan	▪ By the early 1930s, it was estimated that only 69 trumpeter swans remained south of the United States-Canada border. Since 1940, the species has been recovering slowly. ▪ Annual territory occupancy, nesting status, and cygnet survival has been monitored in GRTE since 1987. ▪ The number of occupied trumpeter swan sites in GRTE has slowly increased over the last 10 years, but the number of nesting pairs has not increased commensurately. Rates of nest success and cygnet survival have trended upward over the last 20 years. ▪ Few new nest sites have been established and swan pairs have disappeared from some traditional sites that had been occupied for decades. Reasons for these changes may include drought, human activities, and increased predation.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource			Summary and General Condition/Trend
Wildlife (continued)	Fishes		▪ Fish assemblages in GRTE are typical of intermountain cold waters and consist of relatively few species. It is estimated that there are 13 native fish species and five non-native fish species in the park. ▪ The primary threat to native fish populations in GRTE has been the introduction of non-native fish species that may suppress native fish populations through competition, hybridization, or predation. ▪ Native cutthroat trout species, including Yellowstone and Snake River cutthroat trout, are keystone species in the GYE that are threatened. ▪ During the past few decades, fish stocking programs have been gradually eliminated and attempts to restore fisheries have been made. ▪ In 2004, an inventory of the distribution of cutthroat trout and non-native trout in the Snake River and its tributaries was completed; the inventory rendered valuable information on the location of fish species both within and near GRTE and identified areas for management concern. ▪ Irrigation diversions, mostly in the eastern and southern portions of the park, have heavily impacted some cutthroat trout spawning streams.
	Mammals	Bighorn Sheep	▪ Bighorn sheep once numbered in the millions in the western United States; however, catastrophic declines occurred in the late 1800s and early 1900s as a result of overgrazing by domestic livestock, hunting, diseases, and human development. ▪ Historically, the herd in the Teton Range was part of a complex of several native herds, but many of the herds became extirpated. ▪ Presently, the bighorn sheep population in the Teton Range persists as a small herd; population dynamics are strongly affected by year-to-year variations in lamb and yearling survival. The population in the Teton Range was estimated at 100 to 150 in 2007. ▪ Since sheep populations in the GYE are small and isolated, populations are vulnerable to inbreeding and disease. ▪ Limited winter range will likely have the greatest impact on the long-term survival of bighorn sheep in the Teton Range; therefore, providing secure winter range and minimizing human disturbance may be essential for the sustainability of the herd in GRTE.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource			Summary and General Condition/Trend
Wildlife (continued)	Mammals (continued)	Elk	▪ By 1900, elk had disappeared from more than 90 percent of their original range and the remaining populations occupied western mountains. ▪ When settlers arrived in Jackson Hole, there may have been as many as 25,000 elk, but development in the Jackson Hole Valley has significantly reduced elk habitat. ▪ In 1912, Congress set aside land adjacent to the town of Jackson that would eventually become the National Elk Refuge. Elk populations rebounded and approximately half of the Jackson elk herd (5,600-7,500 elk) spends the winter there. ▪ Surveys in GRTE suggest that since 1990 the elk population has remained stable, and elk distribution has remained similar to past years. ▪ Although the National Elk Refuge has helped the Jackson elk herd recover, it has contributed to high levels of brucellosis; consequently, management objectives include maintaining the Jackson elk herd at 11,000 and a targeted summer elk population in GRTE of 1,600.
		Gray Wolf	▪ In most western societies, wolves became the target of systematic extermination campaigns by governments and private individuals. ▪ Wolves were routinely killed in the GYE in order to protect the well being of more desirable animals, and by the 1930s, the species had been nearly extirpated from the lower 48 states. ▪ A wolf recovery program was initiated in YELL in the early 1990s; the first wolves were observed in GRTE in 1997. ▪ The Jackson area wolf population grew from 11 to 76 between 1999 and 2009, at which time six packs were resident to the area. ▪ Although wolf populations appear to be growing, human-related mortalities and sarcoptic mange are continuing threats.
		Grizzly Bear	▪ Prior to Euro-American settlement, the grizzly bear occupied most of western North America; however, by 1975, grizzly bears were extirpated from all but two percent of their historic range in the lower 48 states. ▪ The grizzly bear remains in a few isolated locations in the lower 48 states, with the GYE and northwestern Montana being the only areas south of Canada in which significant populations remain. ▪ In 1982, the U. S. Fish and Wildlife Service completed the first Grizzly Bear Recovery Plan; subsequently, the grizzly bear populations in the GYE began to rebound in the late 1980s and early 1990s. By 1998, the grizzly bear population was estimated at 344. ▪ From 1998 to 2003, the grizzly bear population grew at an annual rate of four to seven percent, and the range of the population expanded by nearly 50 percent. The estimated population in 2010 in the GYE was at least 603. ▪ Grizzly bear-human conflicts and limited high-quality food resources are continuing threats.

Table 1. Summary of the condition and trend of natural resources described in this assessment (continued).

Natural Resource			Summary and General Condition/Trend
Wildlife (continued)	Mammals (continued)	Moose	▪ Moose are a relatively new species in the GYE; it is believed that they entered Wyoming from Montana and Idaho within the past 150 years. ▪ Forest fire suppression, restrictions on moose hunting, and moose transplantation has contributed to their increased population and distribution. ▪ Since moose are usually found alone or in small family groups, accurate estimates of population size and distribution are difficult to obtain. ▪ Mid-winter counts suggest that the current trend of wintering moose is downward; the population has declined over the last several decades for unknown reasons, but several studies suggest that moose are nutritionally limited as a result of habitat degradation. ▪ The management goal for moose in GRTE is to maintain populations and the habitat on which they rely.
		Pronghorn	▪ During the nineteenth century, pronghorn populations were severely reduced due to hunting, habitat loss, and fencing. Populations were estimated at 13,000 animals in the 1910s before conservation programs began to reverse the trend. ▪ As of 2000, the continental population was estimated at 800,000, of which 400,000 were found in Wyoming. ▪ The current summer pronghorn population in the Jackson Hole valley and the Gros Ventre drainage is estimated at 300 and has remained relatively stable in recent years. ▪ Concerns about the long-term viability of the pronghorn herd in GRTE exist because their migration corridor traverses an area of rapidly expanding development; excessive development in critical portions of the migration route could lead to the extirpation of the species from GRTE.

Chapter 1. Introduction

Natural Resource Condition Assessment Background Information

This Natural Resource Condition Assessment (NRCA) is a document that has been specifically designed to answer the following question:

Based on existing scientific data and information, what can be said about the current condition of the natural resources in Grand Teton National Park (GRTE) and the John D. Rockefeller, Jr. Memorial Parkway (JODR)?

This inquiry is a consequence of the progression of National Park Service (NPS) policies and mandates (NPS, 2010a). The core of these policies and mandates exists within the National Park Service Organic Act of 1916. This Act established and defined the mission of the NPS to be:

"*…to promote and regulate the use of the Federal areas known as national parks, monuments and reservations hereinafter specified…by such means and measures as conform to the fundamental purposes of the said parks, monuments and reservations, which purpose is 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.*"

While the Organic Act defines the National Park Service mission, it is the Government Performance and Results Act of 1993 (GPRA) that governs how progress toward accomplishing that mission will be evaluated. Under GPRA, goals must be stated in terms of "objective, quantifiable, and measureable" results or outcomes that can be directly tied to the agency mission. These outcomes must be periodically reviewed, and the goals revisited, so that progress toward accomplishing the mission can be assessed.

The 1998 National Park Omnibus Management Act directed the NPS to "*…establish baseline information and to provide information on the long-term trends in the condition of National Park System resources*." This mandate in turn led to the Natural Resources Challenge in 2000, which directed the national parks to focus on the preservation of the nation's natural heritage through science, natural resource inventories, and expanded resource monitoring. The National Park Service created the Inventory and Monitoring (I&M) Networks, which oversee the systematic gathering of natural resources information in the parks, as a key component of the Natural Resources Challenge. The I&M Networks are guided by five major long-term goals (Jean et al., 2005; NPS, 2010b):

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of "abnormal" conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other altered environments.

- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.

- Provide a means of measuring progress toward performance goals.

The NRCA program provides a mechanism for reporting on progress towards these goals for individual parks.

Natural Resource Condition Assessment Purpose and Use

The purpose of this NRCA is to provide an assessment of the condition of the natural resources in Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway. More specifically, this NRCA offers an overview of resource conditions in GRTE and JODR at a particular point in time. Because ecological processes cross administrative boundaries, this overview also addresses physical, ecological, and historical characteristics of the surrounding region that influence resource conditions within the parks.

A successful NRCA provides useful scientific insights into current resource conditions and some of the factors influencing those conditions. These insights have practical value to park managers tasked with identifying priorities and knowledge gaps. In addition, the deliberate effort to integrate resource condition assessments across multiple spatial scales and disciplines can contribute to more comprehensive strategic resource stewardship planning. Because they require the specification of reference conditions, current condition assessments can provide the basis for describing and quantifying a park's desired resource conditions. Finally, NRCAs can also help parks report "resource condition status" performance and accountability measures, as may be required by the United States Department of Interior ("land health" goals) and the Office of Management and Budget ("natural resource condition" scorecard).

Chapter 2. Park Description

Park and Landscape Setting

Located in northwestern Wyoming, Grand Teton National Park protects an iconic Rocky Mountain landscape and an impressive complement of native wildlife. The windswept granite summits of the Teton Range rise more than 7,000 feet (2,135 meters) above the valley of Jackson Hole, which is in turn bisected by the winding Snake River. This spectacular landscape encompasses a broad diversity of natural environments, from glaciers and alpine meadows, montane forests and riparian woodlands, to the sagebrush steppe and grasslands of the valley floor.

The John D. Rockefeller, Jr. Memorial Parkway provides a natural link between GRTE and Yellowstone National Park (YELL) and contains features characteristic of both areas. In the parkway, the Teton Range tapers to a gentle slope at its northern edge, while rocks borne of volcanic flows from YELL line the Snake River and form outcroppings scattered atop hills and ridges.

Grand Teton National Park was first established in 1929 and was subsequently expanded in 1943 and 1950. The park currently comprises 310,521 acres (125,717 hectares) and receives 3.7 million visitors per year (NPS, 2010c). The 23,778-acre (9,626-hectare) John D. Rockefeller, Jr. Memorial Parkway was established in 1972 to commemorate the philanthropic activities of John D. Rockefeller, Jr. and his generous donations of lands to the National Park System. The John D. Rockefeller, Jr. Parkway is managed as a recreation area under the administration of GRTE. For the purposes of this document, references to "GRTE" hereafter refer to both Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway.

Grand Teton National Park and JODR are located in the heart of an 18-million-acre (7.3-million-hectare) ecoregion commonly referred to as the Greater Yellowstone Ecosystem (GYE) or Greater Yellowstone Area (GYA). The GYE is managed as an ecological unit through cooperative agreements that recognize the diverse mandates of the constituent land management agencies.

Most of the land immediately surrounding GRTE is in federal ownership. Yellowstone National Park constitutes the northern boundary of the parkway, and the Caribou-Targhee and Bridger-Teton National Forests together comprise the western, southern, and eastern boundaries of GRTE, respectively. The National Elk Refuge (NER) is situated on the southeastern boundary of GRTE in Jackson Hole (Figure 2.1).

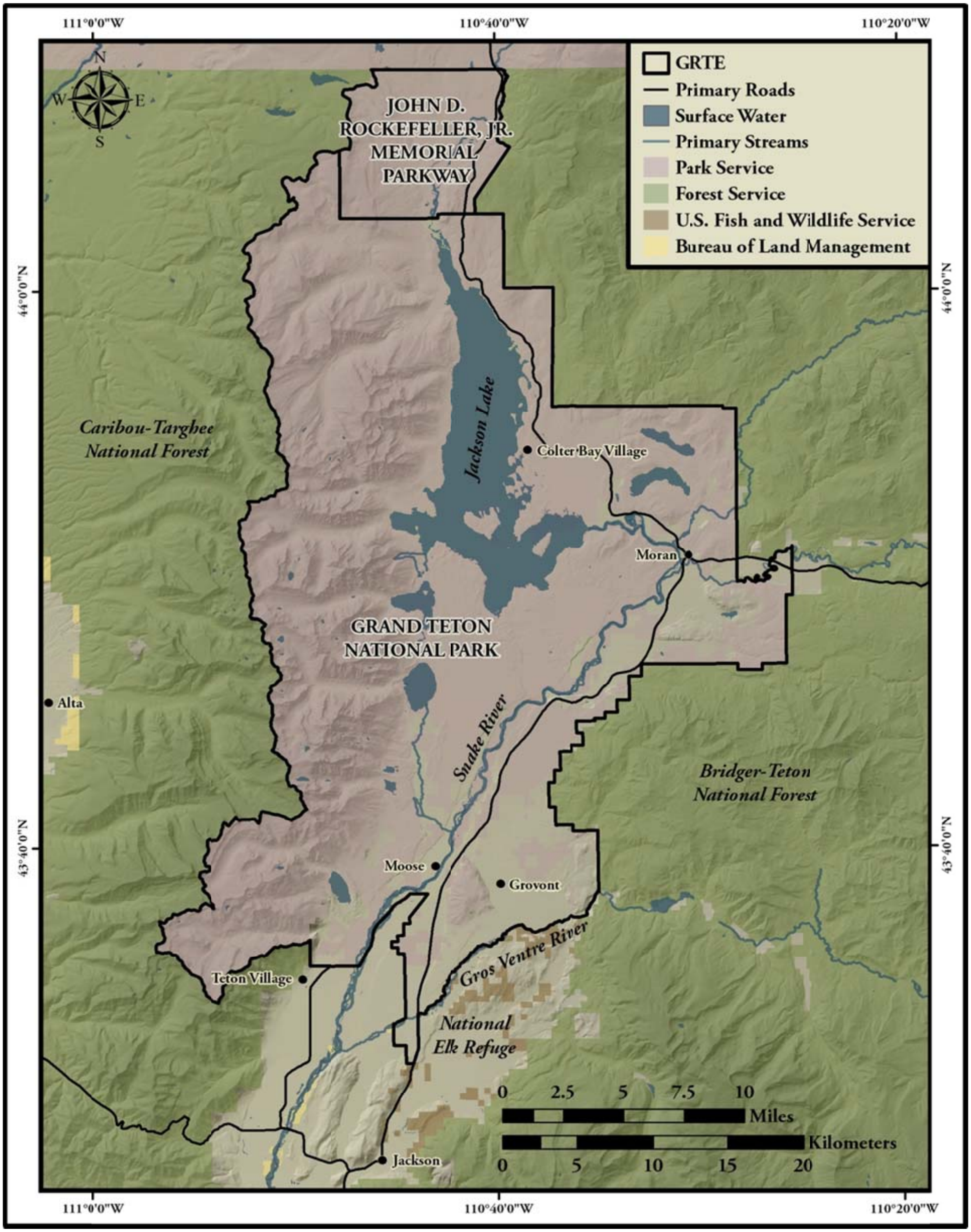

Figure 2.1. Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway vicinity map.

Grand Teton National Park encompasses 135,680 acres (54,931 hectare) of recommended wilderness, mostly along the spine of the Teton Range, with an additional 20,320 acres (8,227 hectare) of potential wilderness (NPS, 2004a). The United States Forest Service administers the Vinegar Hole, Jedediah Smith, and Teton Wilderness Areas, situated to the northwest, west, and northeast, respectively. Developed areas include the Jackson Hole Ski Area (Teton Village) along the southern park boundary, the Grand Targhee Resort Ski Area near the western park boundary, the Jackson Hole airport in the southern extreme of GRTE, and the city of Jackson, Wyoming.

Climate

Although the climate in GRTE may be described as semiarid montane, the extreme differences in elevation and complicated topographical features generate a wide variety of mesoclimates and microclimates, as evidenced by the wide variety of plant communities that can be found in the park. Mean annual precipitation at low elevations in the park increases from south to north, being about 15, 21, 23, and 31 inches (38, 53, 58, and 79 centimeters) at Jackson, Moose, Moran, and the northern boundary of JODR, respectively. Much of this precipitation occurs as snow. Average snowfall in the park is 191 inches (485 centimeters), but expected snowfall amounts vary widely with elevation and location (NPS, 2010c).

Jackson Hole experiences long, snowy, and bitterly cold winters. Snow often blankets the landscape from early November to late April. The coldest temperature ever recorded in GRTE was minus 66 degrees Fahrenheit (minus 54 degrees Celsius). However, daytime temperatures can be mild (above 40 degrees Fahrenheit/four degrees Celsius) for brief periods during winter. Summers tend to be brief but relatively warm, with average July maximum temperatures of 78 degrees Fahrenheit (26 degrees Celsius) and occasional highs above 90 degrees Fahrenheit (32 degrees Celsius) (Hektner et al., 2000; NPS 2010c). Final spring frosts are common in June and autumn frosts first occur in early September, resulting in a very short growing season. Subfreezing temperatures can occur at any time of the year.

Geomorphology and Geology

Grand Teton National Park is justifiably famous for the dramatic topography of the Teton Range, which rises precipitously from the sagebrush-dominated valley floor (6,400 feet/1,950 meters) to the windswept granite summit of Grand Teton (13,770 feet/4,198 meters). The Teton Range is an active, fault-block mountain front that is 40 miles (65 kilometers) long and seven to nine miles (11 to 14.5 kilometers) wide. The Teton Range includes 12 peaks over 12,000 feet (3,658 meters) (Smith and Siegel, 2000).

The Teton fault stretches the entire length of the eastern front of the Teton Range. Between 10 and 13 million years ago, this region began to stretch and the Earth’s crust broke along faults, tilting the mountains skyward and dropping the valley floor. This faulting and tilting of blocks created the abrupt eastern front that faces Jackson Hole and the gentler slope that characterizes the western side of the Teton Range. While the summit of the Grand Teton towers 7,000 feet (2,134 meters) above the valley floor, total vertical displacement across this fault may be more than 23,000 feet (7,000 meters). The floor of Jackson Hole has dropped 16,000 feet (4,878 meters), more than twice as much as the mountains have risen (Smith and Siegel, 2000).

The core of the Teton Range consists of metamorphic gneisses and schists and igneous granite and pegmatite rocks. Intermittent volcanic activity during much of the last 50 million years has produced an inter-layering of volcanic and sedimentary rocks. Volcanic rock that originated from massive eruptions in YELL covered the very north end of the Teton Range and the northeastern end of Jackson Hole as recently as 1.5 million years ago (Smith and Siegel, 2000).

Glaciers began scouring and sculpting the Teton landscape approximately two million years ago. Large masses of ice have flowed from the topographic high of the Yellowstone Plateau down into the valley of Jackson Hole numerous times. Fingers of ice, pulled by gravity, also flowed from the high Teton peaks down into the valley. Extensive and repetitive glacial activity, beginning about 250,000 years ago and lasting until about 9,000 years ago, is responsible for the present rugged form of the Teton Range and the canyons that penetrate it. Glacial debris from the surrounding mountains accumulated in the valley floor. Grand Teton National Park contains many features created during the Ice Age, such as piedmont lakes, U-shaped canyons, knife-like ridges, kettles, and moraines (Smith and Siegel 2000). More than a dozen small glaciers and perennial ice fields still occupy deep, protected recesses in the Teton Range.

Water

Approximately 10 percent of GRTE is covered by surface water. The park contains more than 100 alpine lakes, ranging in size from one to 60 acres (0.4 to 24 hectares), many above 9,000 feet (2,744 meters) in elevation. Seven morainal lakes—Jackson, Leigh, String, Jenny, Bradley, Taggart, and Phelps (from north to south)—are distributed along the base of the Teton Range. There are more than 100 alpine and backcountry lakes within the park boundaries.

Jackson Lake is the largest lake in the park at 25,540 acres (10,340 hectares) with a maximum depth of 438 feet (134 meters). Jackson Lake is operated by the Bureau of Reclamation (BOR), which retains exclusive control of the flow and utilization of water in the reservoir, except water reserved for Snake River fisheries. The BOR built the first log crib dam on Jackson Lake in 1906. From 1911 to 1916, this dam was replaced by a far more substantial cement structure and earthen dike, which raised the lake level by 39 vertical feet (11.9 meters). From 1984 to 1989, the Jackson Lake dam was reinforced, and the earthen dike improved, in response to concerns following the 1976 failure of the Teton Dam in Idaho (NPS, 2000a).

The Snake River and its tributaries make up the hydrologic system of GRTE and JODR. Hydrologic boundaries have been delineated by the United State Geological Survey (USGS). Each hydrologic unit is identified by a unique Hydrologic Unit Code (HUC) consisting of two to 12 digits based on the levels of classification in the hydrologic system. A hydrologic unit describes the area of land upstream from a specific point on the stream that contributes surface water runoff directly to the outlet point. The hierarchy of Hydrologic Unit Codes is Regions (HUC 2), Sub-regions (HUC 4), Basins (HUC 6), Sub-basins (HUC 8), Watersheds (HUC 10), and Sub-watersheds (HUC 12). Regions (HUC 2) are major land area and are often referred to as first level watersheds. Sub-watersheds (HUC 12) are the smallest unit and are often referred to as sixth level watersheds. In GRTE, the Snake Headwaters is the primary sub-basin (Figure 2.2). Watersheds include Snake River-Moose Creek, Pacific Creek, Snake River-Spread Creek, Buffalo Fork, Lower Gros Ventre River, and Snake River-Fall Creek.

All surface and groundwater in the park drain into the Snake River, which originates in the highlands of the Teton Wilderness Area, flows north and west through part of YELL, south through JODR, and into Jackson Lake in GRTE. From Jackson Lake, the Snake River flows east and then south for about 25 miles (40 kilometers) before crossing the southern boundary of GRTE.

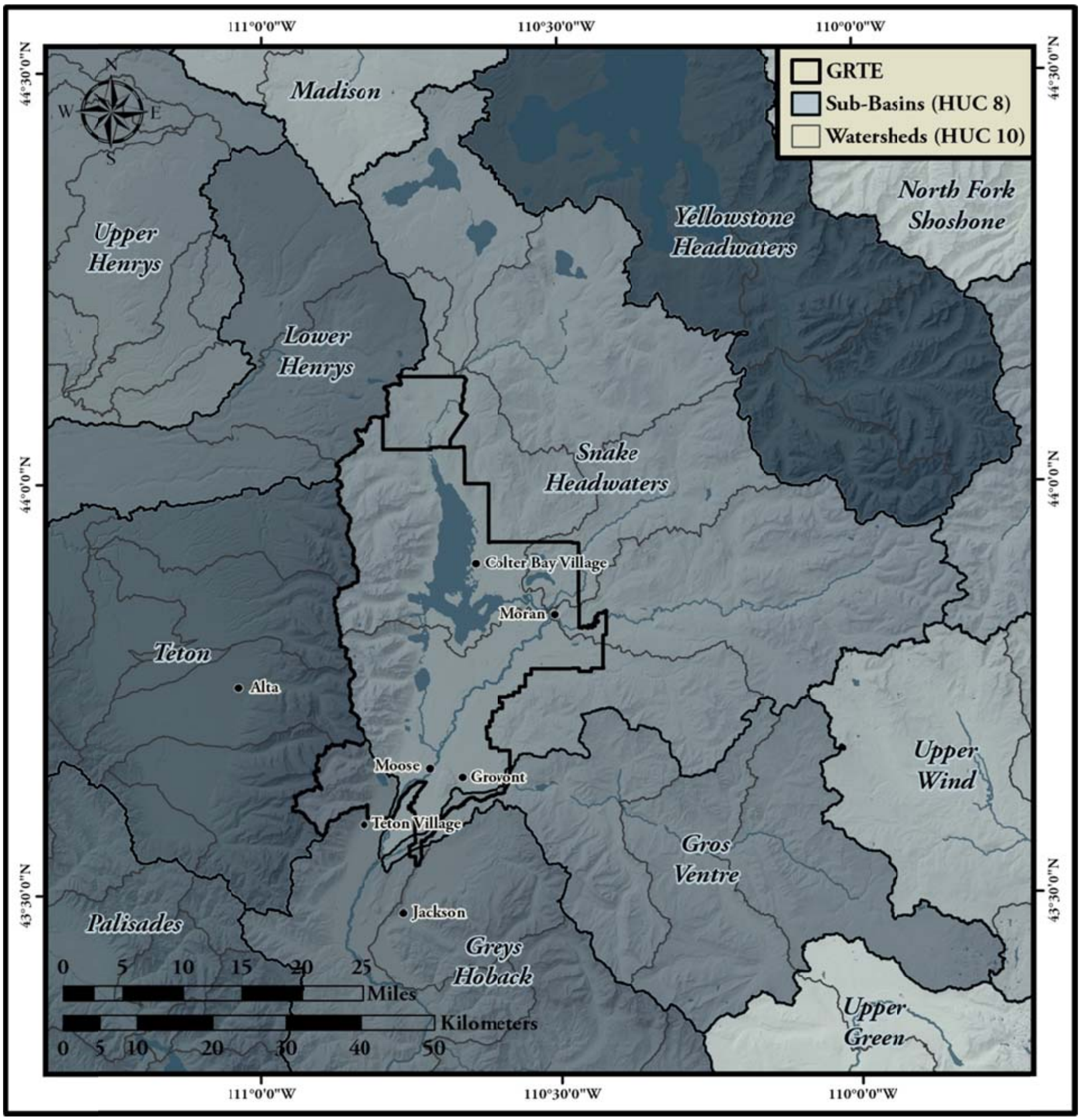

Figure 2.2. Location of Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway in the context of sub-basins (HUC 8) and watersheds (HUC 10).

Flora and Fauna

More than 1,200 species of vascular plants and over 200 species of fungi occur in GRTE or in nearby Teton County, Wyoming (Shaw, 1992; Haynes, 2005). Of these, about 139 non-native plant species have been documented (Haynes, 2005). The U.S. Fish and Wildlife Service has identified one threatened plant species, Ute Ladies-tresses (*Spiranthes diluvialis*), as possibly occurring in GRTE, but it has never been found within the park (Hektner et al., 2000).

The Snake River floodplain, which dominates the valley floor of the park, currently supports stands of riparian forest dominated by cottonwoods (*Populus* spp.), willows (*Salix* spp.), and quaking aspen (*Populus tremuloides*). Terraces rising above the floodplain are primarily covered by sagebrush (*Artemisia* spp.) and grasses. The forests consist mainly of lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), and quaking aspen at lower elevations, while Engelmann spruce (*Picea engelmannii*), whitebark pine (*Pinus albicaulis*), and subalpine fir (*Abies lasiocarpa*) inhabit higher elevations (Jean et al., 2005).

Several species of fish have been documented in GRTE. The Snake River fine-spotted cutthroat trout (*Oncorhynchus clarkii* spp. or *Oncorhynchus clarkii behnkei*), the only trout native to the park, is part of a morphologically distinct group (possibly a race) of cutthroat trout found only in the Snake River in the Jackson Hole area. Four introduced trout species presently inhabit portions of the upper Snake River drainage in the park: lake trout (*Salvelinus namaycush*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*). A relict population of leatherside chub (*Lepidomeda copei*) exists near the mouth of the Buffalo Fork River – the only known population of this species in the Snake River drainage (Hektner et al., 2000).

Grand Teton National Park has been home to six species of amphibians: Columbia spotted frogs (*Rana luteiventris*), boreal chorus frogs (*Pseudacris triseriata maculata*), boreal toads (*Bufo boreas boreas*), tiger salamanders (*Ambystoma tigrinum melanostictum*), northern leopard frogs (*Rana pipiens*), and bullfrogs (*Rana catesbiana*). Northern leopard frogs are now believed to be extinct in the area. Bullfrogs were introduced just outside the park but have become established at Kelly Warm Springs.

There are currently four confirmed species of reptiles in GRTE. The most common reptile in the park is the wandering garter snake (*Thamnophis elegans vagrans*). Valley garter snakes (*Thamnophis sirtalis fitchi*) and rubber boas (*Charina bottae*) are much less frequently encountered. All three species of snakes typically live near areas of water. The only confirmed species of lizard in GRTE is the northern sagebrush lizard (*Sceloporus graciosus graciosus*), an inhabitant of dry and rocky sagebrush that was not confirmed in the park until 1992 (Koch and Peterson, 1995).

Almost 300 species of birds have been observed in the park. Some of the more prominent include white pelicans (*Pelecanus erythrorhynchos*), great blue herons (*Ardea herodias*), trumpeter swans (*Cygnus buccinator*), Canada geese (*Branta canadensis*), sandhill cranes (*Grus canadensis*), golden eagles (*Aquila chrysaetos*), bald eagles (*Haliaeetus leucocephalus*), ospreys (*Pandion haliaetus*), great gray owls (*Strix nebulosa*), sage-grouse (*Centrocercus urophasianus*), common ravens (*Corvus corax*), Clark's nutcrackers (*Nucifraga columbiana*), several species of woodpeckers, and a wide variety of songbirds.

The most charismatic and emblematic animals in the Greater Yellowstone Ecosystem are mammals. Grand Teton National Park is home to 61 species of mammals, including elk (*Cervus elaphus*), moose (*Alces alces shirasi*), bison (*Bison bison*), pronghorn (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), grizzly bears (*Ursus arctos*), black bears (*Ursus americanus*), gray wolves (*Canis lupus*), coyotes (*Canis latrans*), mountain lions (*Puma concolor*), river otters (*Lutra canadensis*), wolverines (*Gulo gulo*), beavers (*Castor canadensis*), pika (*Ochotona princeps*), yellow-bellied marmots (*Marmota flaviventris*), and a wide variety of bats, ground squirrels, tree squirrels, mice, shrews, and other less conspicuous mammals. With the recent return of gray wolves to GRTE, all mammals present before European settlement currently occur in the park. Mountain goats (*Oreamnos americanus*) and raccoons (*Procyon lotor*), species that are native to other parts of North America but not native to the Greater Yellowstone Area, occur in low numbers.

Grand Teton National Park supports five animal species that have required protection under the Endangered Species Act (Table 2.1) (NPS, 2010d). The bald eagle, American peregrine falcon, and grizzly bear have been recently delisted but are currently being monitored and managed to prevent relisting. Bald eagles currently nest within GRTE, and American peregrine falcons have nested in GRTE in the past. The grizzly bear is expanding its range throughout the park. Although potential habitat for Canada lynx occurs within GRTE, any animals that may occur within the park are likely to be transients (NPS, 2004a). Gray wolves became established in the park in 1999, approximately 70 years after the species' extirpation from the GYE.

Table 2.1. Species that occur within Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway that receive Endangered Species Act protections.

Common Name	Scientific Name	Listing Category	Status In Park	Taxa
Bald Eagle	*Haliaeetus leucocephalus*	Delisted/Monitored	Current	Bird
American Peregrine Falcon	*Falco peregrines anatum*	Delisted/Monitored	Current	Bird
Grizzly Bear	*Ursus arctos horribilis*	Delisted/Monitored	Current	Mammal
Canada Lynx	*Lynx canadensis*	Threatened	Current	Mammal
Gray Wolf	*Canis lupus*	Experimental	Restored	Mammal

Human Uses

The park also displays evidence of a rich and varied human history dating back some 10,000 years. Early Native Americans used the landscape and its resources for subsistence; they hunted, fished, conducted ceremonial activities, and left traces in their pathways and campsites. Hundreds of archeological sites have been found in the small portion of the park that has been surveyed. Park scientists are still learning about the park's prehistory, from archeological research as well as ethnographic studies involving oral history interviews with American Indian tribes that still maintain traditional ties to native resources and special sites on the landscape.

More recent development in the valley of Jackson Hole has left its mark through an array of new roads and park facilities, as well as more than 300 historic structures, districts, and landscapes, many of which are still in use. These include working livestock ranches, dude ranches, and hobby ranches; visitor accommodations, such as Jenny Lake Lodge and Jackson Lake Lodge, designated a National Historic Landmark in July 2003; the park's original headquarters located at Beaver Creek; and the Murie Ranch, which was owned and occupied by noted naturalist-conservationists Adolph, Olaus, and Mardy Murie.

Resource Stewardship Context

Park History and Enabling Legislation

The enabling legislation of an individual park provides insight into the natural and cultural resources and resource values for which it was created to preserve. Along with national legislation, policy and guidance, a park's enabling legislation provides justification and, in some cases, specific guidance for the direction and emphasis of resource management programs (Jean et al., 2005).

The original Grand Teton National Park, set aside by an act of Congress in 1929, preserved a pristine landscape by protecting the Teton Range and six glacial lakes (Leigh, String, Jenny, Bradley, Taggart, and Phelps) situated along the base of the mountains. The enabling legislation that established this first incarnation of Grand Teton National Park in 1929 stated that the park was

"*… dedicated and set apart as a public park or pleasure ground for the benefit and enjoyment of the people of the United States under the name of the Grand Teton National Park of Wyoming*."

The Jackson Hole National Monument, decreed by Franklin Delano Roosevelt through presidential proclamation in 1943, combined land administered by the Teton National Forest, other federal properties including Jackson Lake, and a 35,000-acre (14,164-hectare) donation by John D. Rockefeller, Jr.

On September 14, 1950, the original 1929 Grand Teton National Park and the 1943 Jackson Hole National Monument (including Rockefeller's donation) were united into a new Grand Teton National Park, creating the present-day boundaries. This new Grand Teton National Park was established "*...for the purpose of including in one national park, for public benefit and enjoyment, the lands within the present Grand Teton National Park and a portion of the lands within Jackson Hole National Monument.*"

The total authorized area of Grand Teton National Park is 310,521 acres (125,717 hectares) in Teton County, northwestern Wyoming. The laws creating GRTE mandated the National Park Service to protect native plant life, protect native animal life, and to protect scenic views and geologic features of the Teton Range and Jackson Hole. The park preserves natural and cultural resources in perpetuity and makes this valuable part of America's heritage available to nearly four million visitors each year for their experience, enjoyment, understanding, and appreciation.

In 1972, Congress dedicated the John D. Rockefeller, Jr. Memorial Parkway to recognize the late philanthropist's significant contributions to several national parks, including Grand Teton, Acadia, Great Smoky Mountains, and Virgin Islands. The John D. Rockefeller, Jr. Memorial Parkway was established "*...for the purpose of commemorating the many significant contributions to the cause of conservation in the United States, which have been made by John D. Rockefeller, Jr., and to provide both a symbolic and desirable physical connection between the world's first national park, Yellowstone, and the Grand Teton National Park.*"

The legislation designates JODR as the 82 miles (134 kilometers) between West Thumb in YELL and the south entrance of GRTE. The management area between the two parks includes 23,778 acres (9,626 hectares), and is 6.2 miles (10.2 kilometers) in distance between the parks. The law creating JODR mandated the National Park Service to conserve scenery, conserve natural and historic resources, and provide for responsible use of resources.

In summary, the purpose of Grand Teton National Park is to:

- Preserve and protect the spectacular scenery of the Teton Range and the valley of Jackson Hole;

- Protect a unique geologic landscape that supports abundant diverse native plants and animals and associated cultural resources;

- Protect wildlands and wildlife habitat within the Greater Yellowstone Area, including the migration route of the Jackson elk herd; and to

- Provide recreational, educational, and scientific opportunities compatible with these resources for enjoyment and inspiration.

Similarly, the purpose of the John D. Rockefeller, Jr. Memorial Parkway is to:

- Commemorate the many significant contributions of John D. Rockefeller, Jr. to the cause of conservation; and to

- Provide both a symbolic and desirable physical connection between Grand Teton National Park and Yellowstone National Park.

Park Significance

The significance of Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway can be stated as follows:

- The iconic mountain landscape of the Teton Range rises dramatically above the flat valley of Jackson Hole, creating a compelling view that has inspired people to explore and experience the area for thousands of years. The sudden rise of rugged peaks contrasts with the horizontal sagebrush flats. Glacial lakes at the foot of the mountains reflect and expand the view. Opportunities to view and impressive array of wildlife are extraordinary. The awesome grandeur of the ever-present Teton Range under changing weather and seasons provides the superlative setting for unmatched visitor experiences.

- Grand Teton National Park preserves one of the world's most impressive and highly visible fault block mountain ranges, which abruptly rises 7,000 feet (2,134 meters) and is juxtaposed with landscapes shaped by glacial processes and braided river geomorphology. The Teton Range is one of the continent's youngest mountain ranges, yet exposes some of the oldest rocks on earth.

- Grand Teton National Park and John D. Rockefeller Jr. Memorial Parkway are at the heart of one of the earth's largest intact temperate ecosystems, with a full complement of native Rocky Mountain plants and animals, including grizzly bears, wolves, North American bison, pronghorn, and one of the world's largest elk herds.

- The park and parkway represent one of the most notable conservation stories of the twentieth century and continue to inspire present and future generations. The formation of the park, a process that took more than half a century, was a struggle between private economic interests and a concern for conserving the Teton Range and valley floor. From prehistoric times to present day, numerous diverse cultures, cultural trends, and cultural values influenced the Teton Range and Jackson Hole valley.

  - Within the park and parkway, visitors can easily experience peaceful solitude, wilderness character, and a rare combination of outdoor recreational and educational activities, world-renowned wildlife and landscapes, and the cultural amenities of a vibrant community throughout the year. Visitors of all abilities and interests can enjoy opportunities for physical, emotional, and inspirational experiences in an unspoiled environment.

  - As part of the Greater Yellowstone Ecosystem, the park and parkway offer easily accessible and unparalleled opportunities for scientific research and educational study of temperate zone natural systems and processes in a range of elevations, and human relationships to these systems. The relatively pristine landscape serves as a "control" or baseline for scientific study.

Park Resources

The significance statements can be translated into a list of fundamental resources and values that must be maintained and protected (Table 2.2).

Non-Conforming Uses

Grand Teton National Park is unique among national parks because of several non-conforming uses that occur within park boundaries. These historical legacies are a consequence of the compromises that were needed to secure the expansion of the park boundaries in 1950.

The Jackson Hole airport, located within park boundaries, serves several commercial airlines and is the busiest airport in northwest Wyoming. This is the only commercial airport within a national park. Not surprisingly, the air and ground traffic associated with the airport has a significant effect on soundscapes within the park (Burson, 2008).

The enabling legislation also permits grazing and trailing of domestic livestock within GRTE. Six permittees graze domestic livestock on 24,792 acres (10,037 hectares) of the park. Legislation passed in 1997

Table 2.2. Resources and values for Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway.

Scenery	• Natural beauty, wildlife, clean air, relative lack of development • Sagebrush flats provide platform for viewing
Geologic Processes	• Teton and other faults • Ongoing glacial/hydrologic processes • Volcanic history and linked underground geothermal features and systems • Braided river geomorphology
Ecological Communities	• Geography, location, size, and connectivity • Extreme topography in a small area – diverse vegetation communities • Full complement of native birds and mammals – natural predator-prey interactions reflect the health of the ecosystem • Natural disturbances – fire, landslides, flooding, drought, insect infestations – allowed to influence the landscape
Aquatic Resources	• Lakes, free-flowing water • Riparian habitat for native species, including Yellowstone cutthroat trout and Snake River cutthroat trout • Clean water, including Outstanding Natural Resource Waters
Cultural History and Resources	• American Indian use and spiritual reverence • History of fur trade and westward expansion, reflected in place names, paintings, photographs, homestead structures, and dude ranches • Story of "crucible of conservation" evident in structures such as the Maude Noble cabin and Murie Ranch, and the Rockefeller Parkway • Mountaineering history of the Teton Range
Visitor Experience in an Outstanding Natural Environment	• Spectacular setting and quality natural environment • Opportunities to observe wildlife • Full spectrum of access, ability level, activities, year-round • Wilderness character, opportunities for solitude, natural lightscapes, natural soundscapes

authorized the continuation of some grazing rights in the park following the completion of a grazing and open space study.

The 1950 enabling legislation for GRTE specifically mandated active elk management within park boundaries: "*...a program to insure the permanent conservation of elk within the Grand Teton National Park established by this Act. Such program shall include the controlled reduction of elk in such park by hunters licensed by the State of Wyoming and deputized as rangers by the Secretary of the Interior, when it is found necessary for the purposes of proper management and protection of the elk.*" Grand Teton National Park administers an elk reduction (hunt) within designated portions of the park as part of a cooperative interagency management program for the Jackson elk herd, one of the two largest elk herds in the world, numbering 14,000 to 18,000 animals (USDI, 2007). In addition, the herd is infected with brucellosis, a disease that induces abortion in both wild and domestic ungulates. The native Jackson bison herd, numbering approximately 600 animals, is also infected with brucellosis, and domestic livestock interests complicate management of the herd. Hunting is also permitted within JODR, in accordance with federal and Wyoming laws.

Grand Teton National Park also contains Jackson Lake, which is operated by the Bureau of Reclamation (BOR). The BOR retains complete and exclusive control of the flow and utilization of water in the reservoir, including the right to raise and lower the water level at will. The Wyoming Game and Fish Department has purchased sufficient water to maintain a minimum of 280 cubic feet per second flow for the Snake River for fisheries maintenance (Hektner et al., 2000).

Threats and Stressors

Although GRTE serves as a refuge for numerous flora and fauna, natural resources face a variety of threats from within and beyond park boundaries. Perhaps most significantly, changes in climate can have wide-ranging impacts on ecosystems, from alterations in species distributions to species extinctions and altered fire regimes.

The Clean Air Act classifies Grand Teton National Park as a Class I Airshed – areas that should meet the strictest standards for air quality and visibility. Nevertheless, water quality in the parks is threatened by atmospheric nitrogen deposition, in addition to changes in hydrologic regime, and exotic species introduction. Ozone, nitrogen, sulfur, and organochlorine compounds in the form of atmospheric deposition can become concentrated in the snow pack at high elevations and affect water chemistry. High-elevation watersheds in GRTE are thought to be especially sensitive to atmospheric deposition (particularly nitrogen), primarily due to their underlying thin soils and resistant bedrock that limit acid-neutralizing capacity (Kashian, 2004). Other forms of pollution, including trace elements, mercury, and pesticides, may also threaten aquatic resources in the Greater Yellowstone Area.

In addition, changes in hydrologic regimes can result from climate change, diversions, and damming. This can lead to flow alteration, changes in water temperature, and shifts in community composition (Kashian, 2004).

The integrity of biological systems is threatened in numerous ways within the park. Most notably, changes in species composition, including numbers and types of species inhabiting ecosystems in the parks, are a threat to native species viability and trophic cascades. The introduction of non-native species, both terrestrial and aquatic, can often lead to widespread invasion of habitat for native species. In addition, the introduction of exotic diseases and insect outbreaks can lead to the destruction of native plant and animal species or their habitat. For example, whirling disease (*Myxobolus cerebralis*), New Zealand mud snails (*Potamopyrgus antipodarum*), and lake trout have been introduced to the system and have led to the decline of native aquatic communities (Jean et al., 2005).

Ecosystem patterns and processes can be disrupted by changes in land use, another issue of concern. Increases in the size of surrounding cities and towns can lead to habitat fragmentation, which may adversely affect species that migrate outside of park boundaries, as their migration routes can be lost and important habitat may be unavailable. These impacts are especially devastating to those species that have large home ranges.

Increases in human use inside the parks may also impact flora and fauna. Grand Teton National Park receives approximately 3.7 million visitors annually, representing a challenge for both protecting natural resources and providing adequate visitor facilities. Heavy visitation and other human uses create a variety of stresses, including degradation of natural quiet and visitor experiences, impacts associated with park infrastructure, impacts to air and water quality (and their associated impacts to native species), competition for resources between domestic livestock and native species, and the spread of non-native and exotic invasive plants.

Chapter 3. Condition Assessment

Air Quality

Air quality is a pressing nationwide concern, but it is a particular concern in areas managed by the National Park Service because visitation is largely dependent upon the protection of the resources that draws people there (NPS, 2007a). Additionally, 48 national parks, including GRTE and YELL, are identified as Class I Airsheds under the Clean Air Act (NPS, 2008a; NPS, 2009a). Class I Airsheds are one of three designated areas (Class I, II, and III Airsheds) that were identified in 1977 when amendments were made to the Clean Air Act. These designations were developed to ensure that significant deterioration of air quality in those areas where air quality was superior to national standards was prevented. Each designation restricts emissions of particulate matter, sulfur dioxide, and other air pollutants to differing degrees. Class I Airsheds, which generally include national parks over 6,000 acres and national wilderness areas over 5,000 acres, have the strictest restrictions (NOAA, 2010; USFWS, 2010a).

Within Class I Airsheds, federal land managers and planners have identified air quality related values (AQRVs) to ensure that air quality management strategies provide resources the highest level of protection. Air quality related values are scenic, cultural, physical, biological, ecological, and recreational resources that may be adversely affected by changes in air quality. The primary goal of identifying and inventorying AQRVs is to provide specific information regarding the effects of air pollution (NPS, 2005a; NPS, 2008a). Sensitive AQRVs specific to GRTE are headwater lakes and streams, night skies, soils, vegetation, and visibility (NPS, 2007b).

A variety of air pollution sources may affect air quality in GRTE and YELL. Pollutants from regional energy development, such as electric utility power plants, oil and gas processing, coalbed methane wells, and industrial fossil-fuel combustion, are a significant source. Agricultural industries, such as animal feeding operations, are also another source of pollution, as substantial emissions of ammonia are released. Other sources of air pollution include wood burning stoves and fireplaces, automobiles, and snowmobiles. Although the majority of air pollution that impacts park resources is emitted from sources outside of parks, air pollution is also emitted inside of parks from various sources, such as visitor automobiles and wildfires (NPS, 2008a; NPS, 2007c).

Pollutants emitted directly from sources are primary pollutants. These include sulfur dioxide, nitrogen oxides, particulate matter, and volatile organic compounds. Pollutants that are formed as a result of chemical reactions in the atmosphere are secondary pollutants. These include sulfates, nitrates, and ozone (NPS, 2007c). Both primary and secondary pollutants can cause an array of ecological, human health, economic, and visibility impacts. Ecological effects may include modification of nutrient cycles, changes in the chemical composition of soil and water, and alteration of vegetation communities (NPS, 2007d). Human health effects may include decreased lung and cardiovascular function when exposed to pollutants for prolonged periods of time (NPS, 2007e). Economic effects may include decreased revenue for parks and adjacent communities (NPS, 2007a). Visibility effects may include impairment of scenic views and decreased enjoyment by park visitors (NPS, 2007f).

Air quality is extensively monitored in the United States. There are several federally supported national air quality monitoring networks (NSTC, 1999). The National Park Service (NPS) Air Resources Division (ARD) administers an extensive Air Monitoring Program that measures air pollution levels in national parks. The purpose of the program is to establish current air quality conditions, to assess long-term trends of air pollutants that affect park resources, and to evaluate national and regional air pollution control policies. The Air Monitoring Program consists of a network of air monitoring stations in almost 70 national parks across the country. The program has three primary components: atmospheric deposition (dry and wet), gaseous pollutants (primarily ozone), and visibility (NPS, 2009b).

The NPS ARD has developed an approach for assessing air quality within national park units. To assess condition, the ARD uses all available monitoring data (NPS, EPA, state, tribal, and local monitors) over a five-year period to generate interpolations for the continental United States. The interpolations allow the National Park Service to derive estimates of air quality parameters at all park units, including those without on-site monitoring, such as GRTE (NPS, 2010e). Tabular and spatial estimates of air quality parameters, specifically the three primary components of the Air Monitoring Program, are provided by the NPS Air Atlas.

Atmospheric Deposition

Atmospheric deposition is the process whereby airborne pollutants, such as sulfur dioxide, nitrogen oxide, ammonia, and mercury, are transported from a ground-based source and deposited on the surface of land or water. After transport and transformation in the atmosphere, pollutants are deposited by means of dry or wet deposition (NPS, 2009c). Dry deposition is the portion of atmospheric deposition that settles as dust on dry surfaces during periods of no precipitation. Wet deposition is the portion of atmospheric deposition that is dissolved in cloud droplets and deposited during precipitation events (EPA, 2007a).

Once pollutants, particularly nitrogen and sulfur compounds, are deposited into ecosystems via atmospheric deposition, acidification, fertilization, and eutrophication may occur (NPS, 2007g). Acidification of soils, lakes, and streams can result in changes in community structure, biodiversity, reproduction, and decomposition (NPS, 2007d). Although nitrogen is an essential plant nutrient, excess nitrogen from atmospheric deposition can serve as a fertilizer. A surplus of nitrogen can stress ecosystems by overstimulating growth and modifying soil chemistry. These changes can favor the growth of some plants and inhibit the growth of others, leading to alterations of plant species composition and abundance. The deposition of nitrogen can also contribute to nutrient enrichment, or eutrophication, in aquatic ecosystems. Nutrient enrichment may cause the formation of algal blooms, the loss of plant and animal diversity, and unfavorable conditions that may eradicate fish. Additionally, changes in water chemistry can affect amphibians, aquatic vegetation, and invertebrate communities (NPS, 2007g).

Heavy metals, such as mercury, and semi-volatile organic emissions from both regional and local sources are also a significant concern. Geothermal activity in YELL is a source of mercury in the Greater Yellowstone Ecosystem, but the amount of mercury cycling in the atmosphere, soils, lakes, and streams has increased as a result of human activities, such as burning coal for electricity and burning municipal, hazardous, and medical waste. Mercury is emitted into the atmosphere in the form of elemental or inorganic mercury; however, when it is deposited, biological processes can convert the bio-unavailable forms into methylmercury, which is toxic (NPS, 2006a). Methlymercury can bioaccumulate in the food chain, causing behavioral, neurological, and reproductive effects in fish, birds, and wildlife (NPS, 2007d).

Methods

To assess the condition of atmospheric deposition in GRTE, literature, scientific studies, air quality monitoring data, and NPS Air Atlas estimates were examined. Although atmospheric deposition at GRTE is not monitored on a year-round basis, generalization about atmospheric deposition can be made based on scientific studies; data obtained from the United States Geological Survey (USGS) Rocky Mountain Snowpack Chemistry Program, the Clean Air Status and Trends Network (CASTNet), and the National Atmospheric Deposition Program (NADP); and estimates from the NPS Air Atlas.

Studies conducted by Corbin and Woods (2004) and Nanus et al. (2005) evaluated the potential effects of atmospheric deposition on alpine lakes in GRTE and YELL. The USGS Rocky Mountain Snowpack Chemistry Program, which includes 52 long-term monitoring sites along the Continental Divide, has evaluated seasonal deposition at GRTE since 1993 (NPS, 2008a). The purpose of this monitoring program is to determine annual concentrations and depositional amounts of selected nutrients and other constituents in snow resulting from atmospheric deposition, determine long-term trends, and to support investigations of impacts of atmospheric deposition on local and regional ecological systems (USGS, 2010).

Estimates of atmospheric deposition for GRTE are based on monitors located in YELL and can be obtained from the NPS Air Atlas. Dry deposition has been monitored in YELL (Site YEL408 – Water Tank Station) since 1996 as part of the Clean Air Status and Trends Networks (CASTNet). CASTNet was developed to establish an effective monitoring and assessment network to determine the status and trends of air pollution levels. CASTNet measures ambient concentrations of gaseous phase pollutants and aerosols, such as sulfate, nitrate, ammonium, sulfur dioxide, and nitric acid, in conjunction with meteorological parameters that are needed to estimate deposition velocities and fluxes, such as wind speed, wind direction, and relative humidity. The United States Environmental Protection Agency (EPA) administers the CASTNet program, but the National Park Service cooperatively manages 19 of the sites (EPA, 2007a; NSTC, 1999).

Wet deposition has been monitored in YELL (Site WY08 – Tower Falls Station) since 1980 as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). The NADP/NTN was established with the goal of providing data on the amounts, trends, and geographic distributions of acids, nutrients, and base cations in precipitation. The network currently provides a long-term, high-quality database that is useful for assessing the magnitude of wet deposition. The NADP/NTN collects weekly precipitation samples that are analyzed for pH, conductivity, cations (hydrogen, calcium, sodium, magnesium, potassium, and ammonium), and anions (sulfate, nitrate, and chloride). The network consists of over 200 sites and is cooperatively funded and operated by over 100 organizations, including eight federal agencies (NADP, 2009a; NSTC, 1999).

Mercury deposition is monitored at YELL (Site WY08 – Tower Falls) through the NADP Mercury Deposition Network (MDN). The MDN joined the NADP in 1996 to assess and measure the concentration of mercury in rain and snow and the mercury loading to ecosystems through precipitation (NSTC, 1999). The MDN is the only network providing a long-term record of total mercury concentration and deposition in precipitation in the United States and Canada. The MDN collects weekly precipitation samples that are analyzed for total mercury, and since 1995, 23 of the sites have been evaluated for methylmercury (NADP, 2009b).

<u>Results</u>

Although GRTE and YELL are in compliance with federal air quality standards for human health, scientific studies and monitoring data have raised concerns about how air quality may be affecting ecosystems within the region. It has been suggested that even relatively low levels of atmospheric deposition in high-elevation ecosystems can leach nutrients from soil, injure vegetation, and acidify and fertilize lakes and streams (NPS, 2009a). Research has indicated that high-elevation ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, and southern California are generally the most sensitive to atmospheric deposition because their physical characteristics, such as thin and rocky soils, sparse vegetation, short growing seasons, and snowmelt dominated hydrology, limit acid neutralization and nitrogen absorption (NPS, 2007g; NPS, 2009a).

Corbin and Woods (2004) evaluated the effects of atmospheric deposition on the water quality of 12 high alpine lakes in GRTE (Alaska Basin, Amphitheater, Bradley, Delta, Granite Basin, Holly, Mica, Snowdrift, Solitude, Sunset, Surprise, and Trapper). It was concluded that many of the high elevation lakes in GRTE are sensitive to acidification, with half of the lakes having lower acid neutralizing capacity concentrations (less than 100 microequivalents per liter (μeq/L)). Surprise Lake, Amphitheater Lake, Delta Lake, and Lake Solitude had acid neutralizing capacity concentrations below 50 μeq/L. Lakes in basins with granitic and/or metamorphic bedrock, such as Lake Solitude and Mica Lake, are the most sensitive to acidification, particularly when the basin contains a high proportion of young debris. Additionally, seasonal melt from glaciers may increase sensitivity to acidification by increasing the nitrogen flux in late summer. Lakes with basins that are at least primarily underlain by limestone bedrock, such as Alaska Basin Lake, Snowdrift Lake, and Sunset Lake, are the least sensitive to acidification.

Nanus et al. (2005) estimated the sensitivity of 400 alpine and subalpine lakes in GRTE and YELL to acidification from atmospheric deposition based on statistical relations between acid neutralizing capacity concentrations and basin characteristics. Acid neutralizing capacity concentrations were measured at 52 lakes in GRTE and 23 lakes in YELL, and basin characteristics (topography, geology, vegetation, and soils) were derived from GIS data.

Multivariate logistic regression models were developed, and resultant probability equations for acid neutralizing capacity concentrations less than 50 μeq/L (0 to 50), less than 100 μeq/L (0 to 100), and less than 200 μeq/L (0 to 200) were applied to lake basins greater than 2.47 acres (one hectare) in GRTE (106 lakes) and YELL (294 lakes). A higher percentage of lakes in GRTE (36 percent) than in YELL (13 percent) were predicted to be sensitive to atmospheric deposition. The lakes that exceeded 60 percent probability of having an acid neutralizing capacity concentrations less than 100 μeq/L were predicted to have the greatest sensitivity to atmospheric deposition of contaminants (Nanus et al., 2005).

The results reported by Nanus et al. (2005) are consistent with the findings from a comparison of snow chemistry in GRTE and YELL. Snowpack chemistry data derived from the USGS Rocky Mountain Snowpack Chemistry Program at GRTE were compared to snow chemistry data from NADP and CASTNet stations in YELL. The assessment suggested that pollutant concentrations are higher in the snowpack in GRTE; therefore, estimates from monitoring stations in YELL may not adequately represent conditions in GRTE where deposition may be higher (NPS, 2006b).

Atmospheric deposition data obtained from the Rocky Mountain Snowpack Chemistry Program (Garnet Canyon Station), CASTNet Program (Water Tank Station – YEL408), and the NADP/NTN Program (Tower Falls Station – WY08) are displayed in Figures 3.1 through 3.4. Most of these data were analyzed and reported in the study conducted by Corbin and Woods (2004). According to Corbin and Woods (2004), the NADP monitoring data at Tower Falls in YELL suggested that sulfate concentrations in atmospheric deposition had been declining. This decline was consistent with region-wide trends and had been attributed to increased regulation of emissions from coal-fired power plants and a decline in the number of metal smelters in the region. In terms of nitrogen deposition, Corbin and Woods (2004) suggested that there was an absence of a trend at the Tower Falls site in YELL. However, data since the publication of the scientific study in 2004 would suggest that nitrogen levels are slowly increasing, albeit significantly less than what has been reported in other areas in the western United States. In terms of ammonium deposition, a large increase has been observed at the Tower Falls site. This increase has been attributed to the proliferation of ammonium-based fertilizers on agricultural soils (Corbin and Woods, 2004).

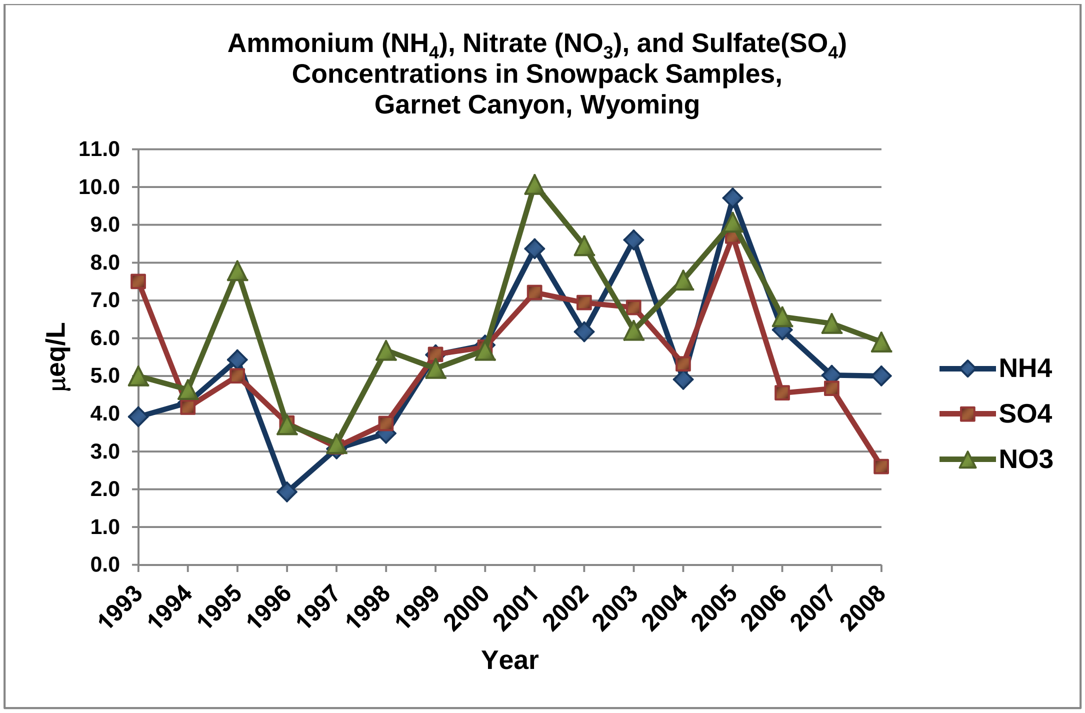

Figure 3.1. Ammonium, nitrate, and sulfate concentrations in snowpack samples at Garnet Canyon, Wyoming (1990-2008). Trends suggest increasing ammonium and nitrate levels, but decreasing sulfate levels. Source: USGS Rocky Mountain Snowpack Chemistry Monitoring Program (USGS Colorado Water Science Center).

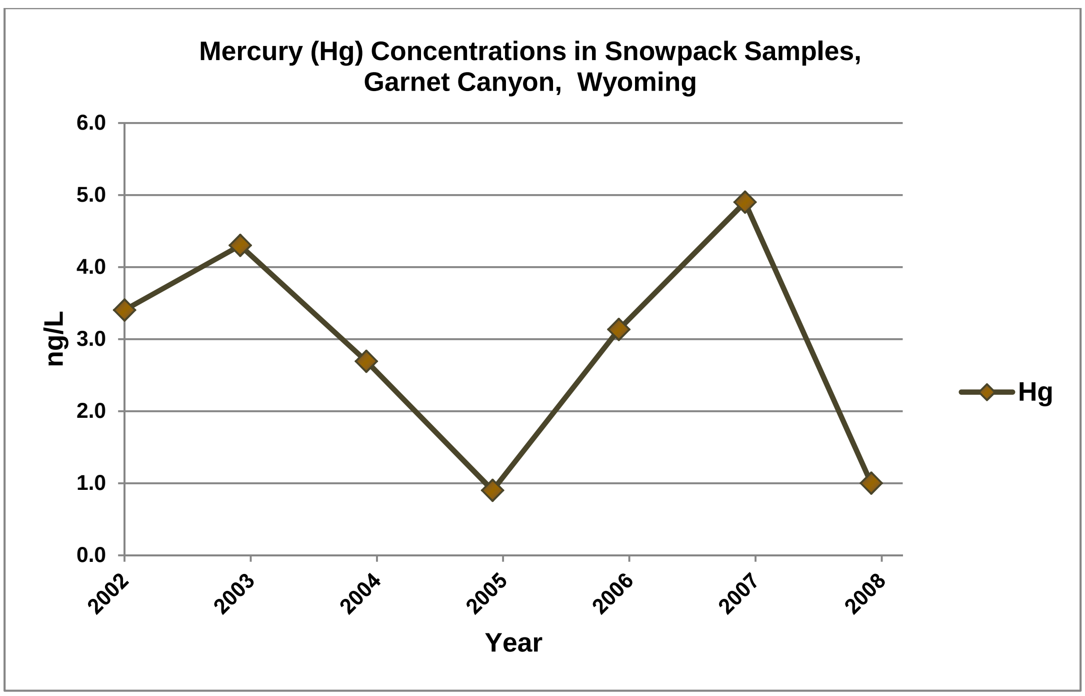

Figure 3.2. Mercury concentrations in snowpack samples at Garnet Canyon, Wyoming (2002-2008). Temporal timeframe of data may not be sufficient to discern if a trend exists. Source: USGS Rocky Mountain Snowpack Chemistry Monitoring Program (USGS Colorado Water Science Center).

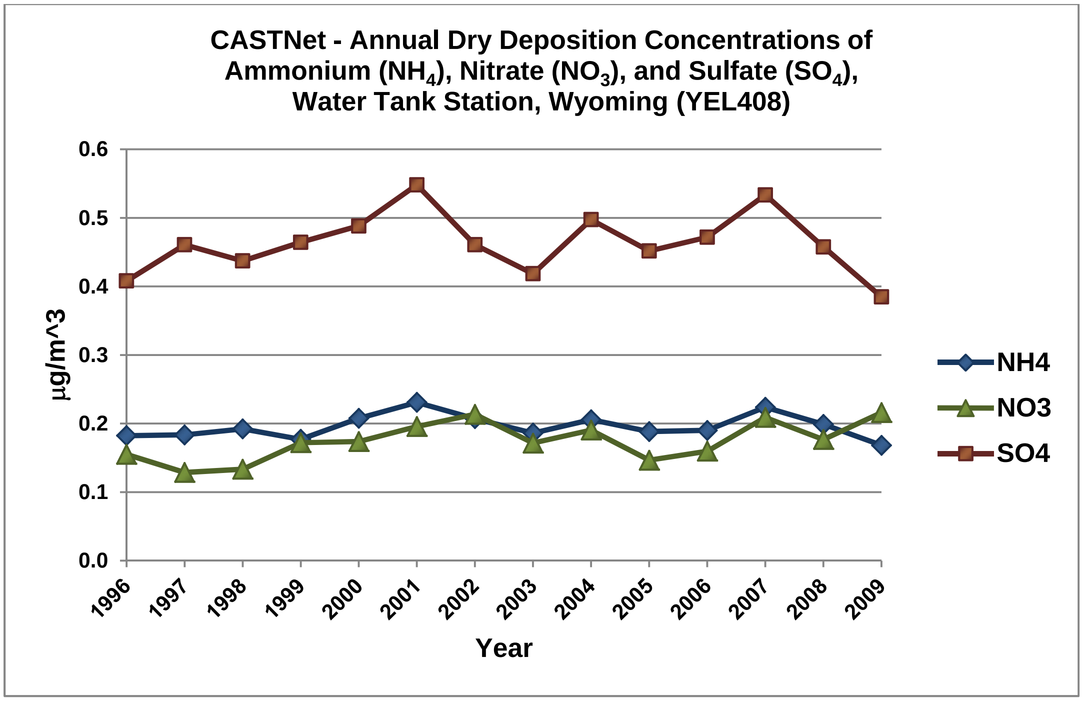

Figure 3.3. Ammonium, nitrate, and sulfate (dry deposition) concentrations at Water Tank Station, Yellowstone National Park, Wyoming (YEL408). Daily data was merged into annual data for the purpose of displaying any potential yearly trends. Source: CASTNet data served by the Visibility Information Exchange Web System (Colorado State University).

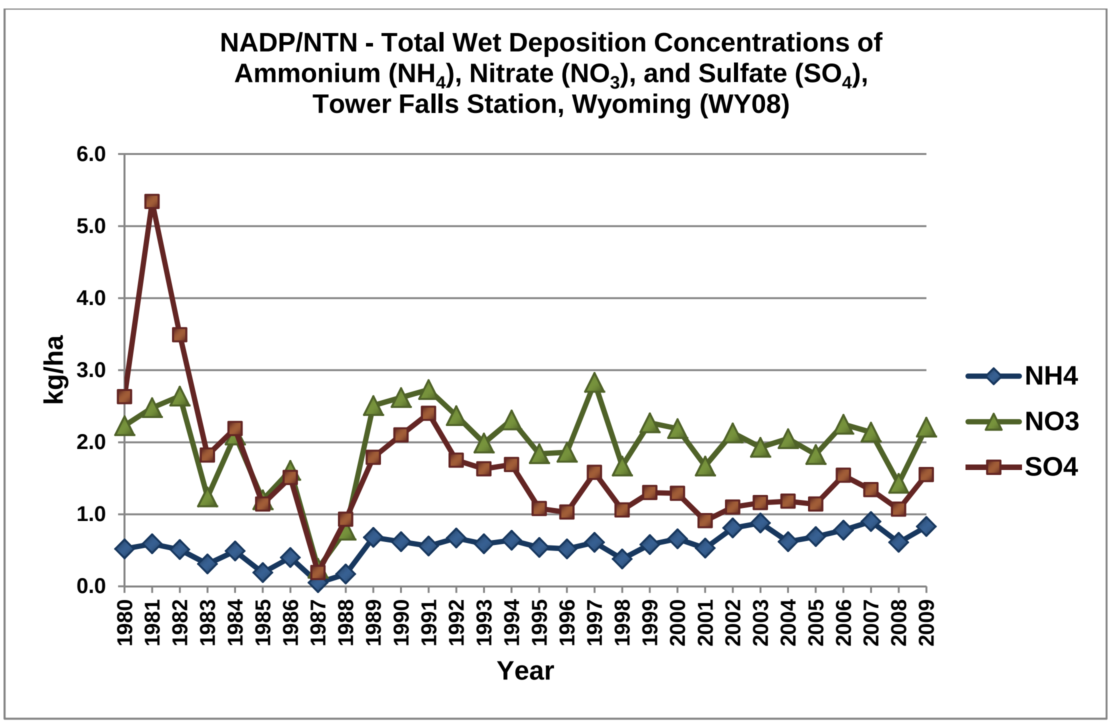

Figure 3.4. Ammonium, nitrate, and sulfate (total wet deposition) concentrations at Tower Falls, Yellowstone National Park, Wyoming (WY08). Trends suggest decreasing sulfate levels, and slightly increasing ammonium and nitrogen levels. Source: National Atmospheric Deposition Program (NADP).

Based on NPS ARD air quality criteria and NPS Air Atlas estimates (Tables 3.1 and 3.2), the condition of atmospheric deposition (wet deposition data) in GRTE and YELL is good to moderate. Wet deposition data are obtained from NADP monitors. If the resulting five-year average is greater than 3.0 kg/ha/yr, then atmospheric deposition is a significant concern; if the average is between 1.0 kg/ha/yr and 3.0 kg/ha/yr, then atmospheric deposition is a moderate concern; and if the average is less than 1.0 kg/ha/yr, then atmospheric deposition is not a concern. However, national parks with ecosystems potentially sensitive to nitrogen and sulfur compounds, such as alpine and subalpine lakes, tundra, and lichen communities in GRTE, the deposition condition may be adjusted up one category. Therefore, in some instances, atmospheric deposition could be a significant concern (NPS, 2010e). Figures 3.5 through 3.7 present the corresponding atmospheric deposition spatial data from the NPS Air Atlas for the 2001 to 2005 five-year average.

Table 3.1. Wet deposition estimates for Grand Teton National Park and Yellowstone National Park.

Grand Teton National Park Wet Deposition Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
NH_4 (kg/ha)	0.55	0.77	0.82	0.82
NO_3 (kg/ha)	2.31	2.33	2.49	2.47
SO_4 (kg/ha)	1.43	1.49	1.59	1.60
Total-N Wet Deposition (kg/ha/yr)			2.55	2.2
Total-S Wet Deposition (kg/ha/yr)			1.17	1.0
Yellowstone National Park Wet Deposition Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
NH_4 (kg/ha)	0.58	0.74	0.78	0.76
NO_3 (kg/ha)	2.29	2.09	2.23	2.14
SO_4 (kg/ha)	1.36	1.27	1.42	1.39
Total-N Wet Deposition (kg/ha/yr)			2.28	1.7
Total-S Wet Deposition (kg/ha/yr)			0.97	0.7

Source: NPS Air Atlas 5-Year Air Quality Estimates.

Table 3.2. Dry deposition estimates for Grand Teton National Park and Yellowstone National Park.

Grand Teton National Park Dry Deposition Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
NH_4 (kg/ha)	0.22	0.24	0.23	0.22
NO_3 (kg/ha)	0.73	0.72	0.69	0.67
SO_4 (kg/ha)	0.45	0.46	0.43	0.43
Yellowstone National Park Dry Deposition Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
NH_4 (kg/ha)	0.22	0.23	0.22	0.21
NO_3 (kg/ha)	0.66	0.64	0.63	0.60
SO_4 (kg/ha)	0.39	0.39	0.40	0.39

Source: NPS Air Atlas 5-Year Air Quality Estimates.

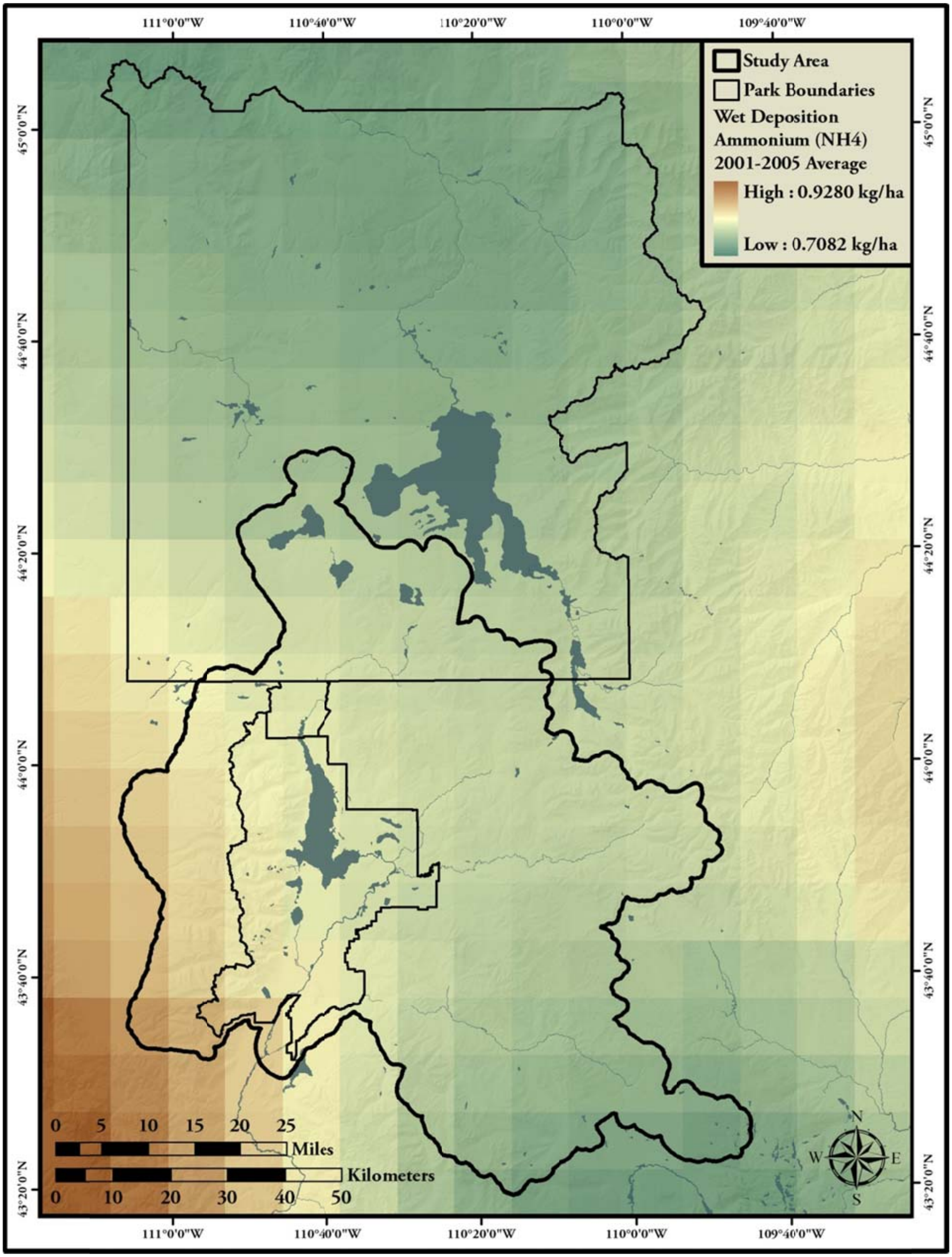

Figure 3.5. Interpolated ammonium (wet deposition) concentrations (2001-2005 average). Source: NPS Air Atlas data served by the NPS GIS Data Store.

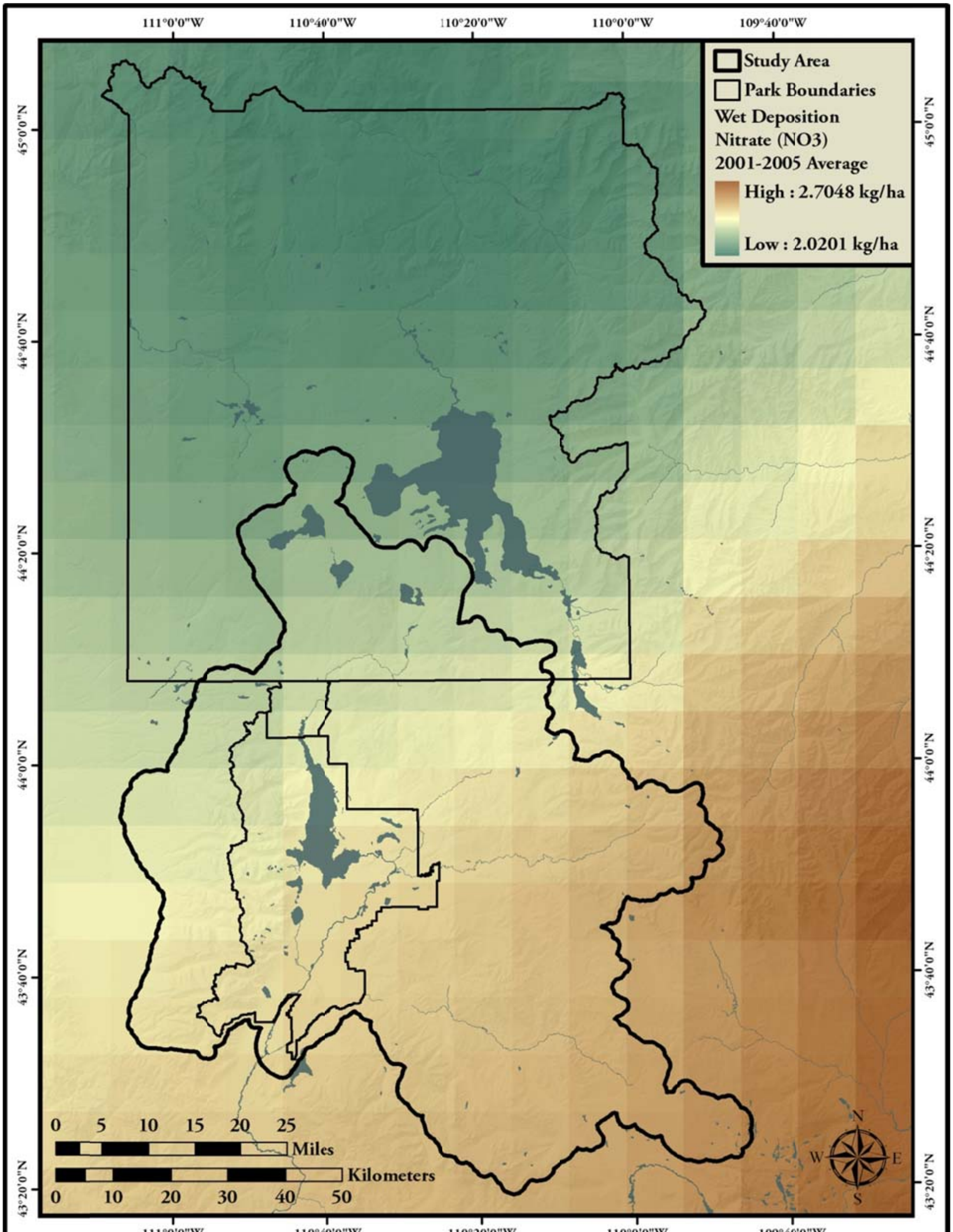

Figure 3.6. Interpolated nitrate (wet deposition) concentrations (2001-2005 average). Source: NPS Air Atlas data served by the NPS GIS Data Store.

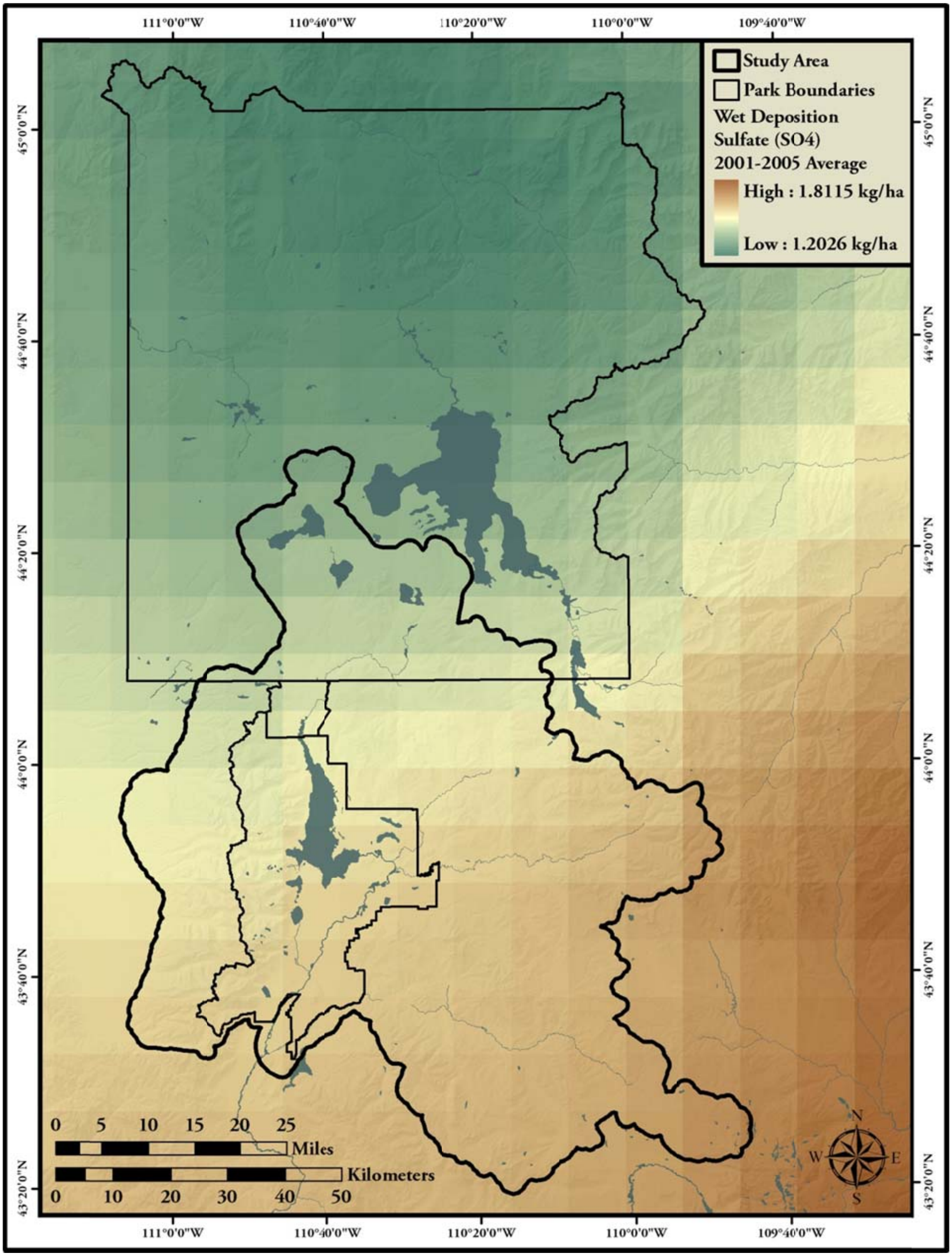

Figure 3.7. Interpolated sulfate (wet deposition) concentrations (2001-2005 average). Source: NPS Air Atlas data served by the NPS GIS Data Store.

Summary and Conclusions

GRTE and YELL are in compliance with federal air quality standards for human health; however, research and monitoring data have raised concerns about how sulfur dioxide, nitrogen oxide, ammonia, and mercury may be affecting other aspects of ecosystems. Research has demonstrated that high-elevation ecosystems, such as alpine and subalpine lakes, tundra, and lichen communities, are generally the most sensitive to atmospheric deposition due to their limited ability to neutralize acid deposition and absorb excess nitrogen. Many of these nutrient poor ecosystems have experienced changes in plant species and soil nutrient cycling due to atmospheric deposition (NPS, 2007g; NPS, 2009a).

Headwater lakes, soils, and vegetation are important AQRVs in GRTE, as they are sensitive to changes imposed by atmospheric deposition. Headwater lakes are potentially sensitive to atmospheric deposition of sulfur and nitrogen compounds, especially when limestone bedrock is absent (NPS, 2005a; Corbin and Woods, 2004). Their snowmelt hydrology also makes them vulnerable to episodic acidification, and possibly chronic acidification. High-elevation soils are also poorly buffered and sensitive to acidification. In some areas, nitrogen deposition has altered soil nutrient cycling and vegetation species composition. Native species that have evolved under nitrogen-poor conditions are being replaced by invasive species that are able to utilize increased levels of nitrogen (NPS, 2005a).

Since high-elevation watersheds are susceptible to changes caused by increasing atmospheric deposition, it has been recommended that the National Park Service conduct annual monitoring of target lakes in GRTE, especially Delta Lake, Surprise Lake, Amphitheater Lake, Lake Solitude, and Mica Lake. Additionally, it has been suggested that an investigation into the mechanism of nitrate deposition into glacially-fed lakes, particularly Delta Lake, be conducted (Corbin and Woods, 2004).

Presently, atmospheric deposition at GRTE is inferred from monitoring data collected at YELL. It has been suggested that deposition estimates in YELL are not likely to adequately characterize conditions in GRTE. A comparison of snowpack chemistry data from the USGS Rocky Mountain Snowpack Chemistry Program and snow chemistry data from NADP and CASTNet stations in YELL indicated that pollutant concentrations are higher in the snowpack in GRTE (NPS, 2006b). Therefore, recommendations to install an NADP monitoring station in GRTE have been made to better monitor the effects of atmospheric deposition within the park (Corbin and Woods, 2004). Accordingly, an NADP sampler is being placed at the Teton Science School and should be operational by late spring 2011 (E. Porter, ARD, pers. comm.).

Ozone

Ozone (O_3) is a gaseous atmospheric constituent that is found in two layers of the atmosphere, the troposphere and stratosphere. The troposphere is the first and lowest layer of the Earth’s atmosphere that extends from the Earth’s surface to approximately seven miles (11 kilometers). The stratosphere is the second layer of the Earth’s atmosphere that extends from approximately seven miles (11 kilometers) above the Earth’s surface to 31 miles (50 kilometers) (EPA, 2006a; EPA, 2003a). Ozone has the same chemical structure (three oxygen atoms) in both the troposphere and stratosphere, but in the troposphere, ozone is considered a pollutant, and in the stratosphere, it is considered a beneficial protective layer (EPA, 2003a; EPA, 2009a).

In the stratosphere, ozone is naturally created by the interaction between solar ultraviolet radiation and molecular oxygen (O_2). Stratospheric ozone plays an integral role in the stratospheric radiative balance because it provides a protective layer shielding the Earth from harmful ultraviolet radiation. Stratospheric ozone concentrations change throughout the year as stratospheric circulation changes with seasons (EPA, 1999a; EPA, 2009a).

In the troposphere, ozone is produced through a series of complex photochemical reactions involving nitrogen oxides and volatile organic compounds. Unlike other pollutants, ozone is not emitted directly into the air by specific sources. Motor vehicle exhaust, industrial emissions, gasoline vapors, and chemical solvents, as well as natural sources emit nitrogen oxides and volatile organic compounds that contribute to the formation of ozone in the troposphere. Solar radiation exacerbates the formation of tropospheric, or ground-level, ozone. Consequently, ozone may be more common during summer months or in areas with extended snow cover (EPA, 2006a; EPA, 2003a; M. George, ARD, pers. comm.). Ground-level ozone is also more common in urban areas due to the elevated presence of vehicles and industrial facilities; however, rural areas are also subject to increased levels as a result of atmospheric processes, land use, and topography (EPA, 2006a; EPA, 2003a).

Ground-level ozone can cause numerous health and environmental effects. Scientific studies have linked ground-level ozone exposure to a variety of health problems. Ozone can irritate respiratory systems; it can reduce lung function, making it more difficult to breathe deeply; it can aggravate asthma, often triggering attack that may require medical attention; it can trigger allergies, such as those from pollen, dust mites, fungus, and pets; and it can inflame and damage the lining of the lungs. Additional studies have demonstrated that ozone can aggravate chronic lung disease, such as emphysema and bronchitis, and reduce the immune system's ability to fight off bacterial infections in the respiratory system. Repeated exposure to ground-level ozone may also permanently scar lung tissue, particularly in children, adults who engage in vigorous outdoor activities, and those with asthma and other respiratory diseases (EPA, 1999a, EPA, 1999b).

Ground-level ozone can have detrimental effects on vegetation and ecosystems. It can interfere with the ability of plants to produce and store food for growth, and it can make plants more susceptible to certain diseases, insects, other pollutants, such as ammonium, nitrate, and sulfate, and other environmental stressors, such as harsh weather (EPA, 2008a). Ozone injury can present as black or purple spots (stipple) or leaf browning (necrosis) in broadleaf plants and yellow or white bleached spots (chlorotic mottle or needle tip burn) in conifers. Ozone may also cause premature senescence (NPS, 2006c). These damages may affect the appearance of vegetation in national parks, forests, recreational areas, and cities and substantially reduce agricultural crop and commercial forest yields (EPA, 2008a).

Methods

To assess the condition of ground-level ozone concentrations in GRTE, literature, scientific studies, and ozone monitoring data were evaluated. Although ozone is not monitored at GRTE, some assumptions can be made based on scientific studies, data obtained from monitoring stations in YELL, and estimates from the NPS Air Atlas. Studies conducted by the National Park Service Greater Yellowstone Network (NPS, 2004b) and Kohut (2007) assessed the risk of foliar injury from ozone on vegetation in several national parks. An additional study conducted by Jaffe and Ray (2007) evaluated ozone trends for 11 rural and remote sites in the western United States, including three sites in Wyoming (YELL, Pinedale, and Centennial).

Ozone concentrations are recorded at hourly intervals in YELL (Site YEL408 – Water Tank) through the CASTNet and Gaseous Pollutant Monitoring Programs (GPMP). The primary objectives of the GPMP are to establish existing or baseline concentrations and assess trends in air quality in National Park Service units; determine compliance with National Ambient Air Quality Standards (NAAQS); assist in the development and revision of national and regional air pollution control policies affecting park resources; and identify air pollutants that may injure or damage park natural resources (NSTC, 1999). The GPMP has typically concentrated on determining levels of two gaseous air pollutants, ozone and sulfur dioxide, but other gaseous pollutants, such as nitrogen compounds and toxic organic compounds, are becoming of interest because they may contribute to physiological and morphological changes within park resources (NPS, 2009d).

Ozone monitoring data collected in national parks is recorded using EPA reference or equivalent methods and standards. In most instances, this allows for comparisons of National Park Service data, data collected by state and local air pollution control agencies, and data collected by the EPA (NPS, 2009d). All data are used to determine compliance with NAAQS and to assess regional air pollution control policies (NPS, 2009b). NAAQS for ground-level ozone have been established by the EPA under the Clean Air Act. The Clean Air Act established two types of national air quality standards – primary and secondary. Primary standards set limits to protect public health, including the health of sensitive populations, such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings (EPA, 2010a).

In July 1997, the EPA revised the former 1-hour ozone standard and replaced it with a more protective 8-hour standard at a level of 0.08 parts per million (ppm) or 80 parts per billion (ppb). The 1997 0.08 ppm (80 ppb), 8-hour primary standard is met at an air quality monitor when the 3-year average of the annual fourth-highest daily maximum 8-hour average ozone concentration is less than or equal to 0.08 ppm (80 ppb). In March 2008, the EPA again revised the ozone standard. The 2008 ozone standard is set at a level of 0.075 ppm (75 ppb) averaged over an 8-hour period. This standard is met at an air quality monitor when the 3-year average of the annual fourth-highest daily maximum 8-hour average ozone concentration is less than or equal to 0.075 ppm (75 ppb) (Table 3.3) (EPA, 2009b). Although this standard was revised in 2008, numerous appeals persuaded the EPA to reconsider the 0.075 ppm (75 ppb) standard. In January 2010, the EPA announced plans to reconsider the 2008 revision (EPA, 2010b; EPA, 2009c). The proposed revision would lower the primary standard from 0.075 ppm (75 ppb) averaged over eight hours to somewhere in the range of 0.070 to 0.060 ppm (70 to 60 ppb) averaged over eight hours (McCarthy, 2010).

Table 3.3. Primary and secondary standards established by the EPA under the Clean Air Act. The EPA revoked the 1-hour standard in all areas, but some areas have continuing obligations under the standard.

Primary Standards		Secondary Standards	
Ozone Level	**Averaging Time**	**Ozone Level**	**Averaging Time**
0.075 ppm/75 ppb (2008 standard)	8-hour	0.075 ppm/75 ppb (2008 standard)	8-hour
0.08 ppm/80 ppb (1997 standard)	8-hour	0.08 ppm/80 ppb (1997 standard)	8-hour
0.12 ppm/120 ppb	1-hour	0.12 ppm/120 ppb	1-hour

Two additional standards have been proposed to monitor the effects of ozone on vegetation. The two ozone exposure metrics, W126 and SUM06, are cumulative and represent seasonal sums of ozone concentrations over three months during daylight hours from 8:00 a.m. (0800 hours) to 8:00 p.m. (2000 hours). The W126 is a weighted sum of 24-hour ozone concentrations from April to October. This sum preferentially weights higher ozone concentrations where ozone concentrations above 0.04 ppm (40 ppb) are weighted with increasing significance. The SUM06 is the running 90-day maximum sum of all one-hour average ozone concentrations greater than or equal to 0.06 ppm (60 ppb). Scientists have suggested threshold levels for each metric (NPS, 2009e; NPS, 2009f; Kohut, 2007) (Tables 3.4 and 3.5).

Table 3.4. Threshold level ranges for ozone exposure metrics by type of injury. Metrics are reported in parts per million-hours.

Type of Injury	Type of Vegetation	W126	Sum06
Growth Reduction	Tree seedlings—natural forest stands	7-13 ppm-hr	10-15 ppm-hr
	Tree seedlings/saplings–plantations	9-14 ppm-hr	12-16 ppm-hr
Visible Foliar Injury	Plants in natural ecosystems	5-9 ppm-hr	8-12 ppm-hr

Source: Gaseous Pollutant Monitoring Program Annual Data Summary (2008).

Table 3.5. Threshold level ranges by vegetation type for the two distinct metrics.

Metric	Type of Vegetation	Threshold
SUM06	Natural ecosystems	8-12 ppm-hr (foliar injury)
	Tree seedlings	10-16 ppm-hr (1-2% reduction in growth)
	Crops	15-20 ppm-hr (10% reduction in 25-35% of crops)
W126	Highly sensitive species	5.9 ppm-hr
	Moderately sensitive species	23.8 ppm-hr
	Low sensitivity	66.6 ppm-hr

Source: Greater Yellowstone Network (NPS, 2004b).

Evaluation of the metrics is often conducted within the context of ozone-sensitive species. A comprehensive list of ozone-sensitive and bioindicator plant species for parks in the eastern and western United States was developed in 2003 during a workshop conducted by the National Park Service. Bioindicator species are those that exhibit foliar symptoms in the field at ambient ozone concentrations (NPS, 2006c). They can serve as a sign for plant communities with respect to potential ozone impacts. Most national parks, including GRTE and YELL, contain ozone-sensitive species (NPS, 2004b; Kohut, 2007).

Results

Ground-level ozone monitoring data in National Park Service units revealed that of the 161 park units that have representative ozone monitoring, 148 units have stable or improving trends. While some national parks in the western United States have improving or stable trends, several parks, such as Death Valley, Mesa Verde, Glacier, Rocky Mountain, and North Cascades, have degrading ozone levels. In the 2008 Air Quality in National Parks Annual Performance and Progress Report, long-term progress in ozone concentrations were evaluated using the annual fourth-highest 8-hour daily maximum ozone concentration, rather than the 3-year average that is used by the EPA. While statistically significant degrading trends were observed in a few national parks in the western United States, no statistically significant trends were found in YELL (NPS, 2004b).

Although no statistically significant trends were reported for YELL in the 2008 Air Quality in National Parks Annual Performance and Progress Report, the NPS ARD has defined criteria for estimating the condition of ozone within national parks. To determine an estimate of ozone condition, the five-year average of the annual fourth-highest 8-hour ozone concentration is determined for each park from the interpolated values. If the resulting five-year average is greater than 0.075 ppm (75 ppb), then ozone is a significant concern; if the average is between 0.06 and 0.075 ppm (60 and 75 ppb), then ozone is a moderate concern; and if the average is less than 0.06 ppm (60 ppb), then ozone is not a concern (NPS, 2010e).

Based on the values defined by the ARD, ozone is a moderate concern in YELL and GRTE. Tabular data from the National Park Service Air Atlas (Table 3.6) indicate that the most recent (2004 to 2008) fourth-highest daily maximum 8-hour average for GRTE was 66.8 ppb, whereas the most recent fourth-highest daily maximum 8-hour average for YELL was 64.6 ppb. These estimates also indicate that both the fourth-highest daily maximum 8-hour average and the second-highest daily maximum are higher in GRTE than YELL. Mean ozone levels for the four five-year periods for both GRTE and YELL are very similar and well below the national standard of 75 ppb, with an average of 42.3 ppb in GRTE and 42.7 ppb in YELL based on the four five-year averages (Figure 3.8). Figures 3.9 through 3.11 present the corresponding ozone spatial data from the NPS Air Atlas for the five-year average from 2003 to 2007.

Table 3.6. Summary of ozone metrics for Grand Teton National Park and Yellowstone National Park.

Grand Teton National Park Ozone Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
2nd Highest Daily Maximum (ppb)	83.4	80.1	79.3	79.3
4th Highest 8-Hour (ppb)	70.8	67.7	67.4	66.8
Mean Ozone (ppb)	42.9	41.8	41.4	43.1
Number of Hours > 0.1 ppm (100 ppb)	1.6	1.0	0.7	1.2
Yellowstone National Park Ozone Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
2nd Highest Daily Maximum (ppb)	76.4	72.7	72.5	72.8
4th Highest 8-Hour (ppb)	67.2	64.2	64.1	64.6
Mean Ozone (ppb)	43.5	42.2	42	43.1
Number of Hours > 0.1 ppm (100 ppb)	0.4	0.3	0.2	0.4

Source: NPS Air Atlas 5-Year Air Quality Estimates.

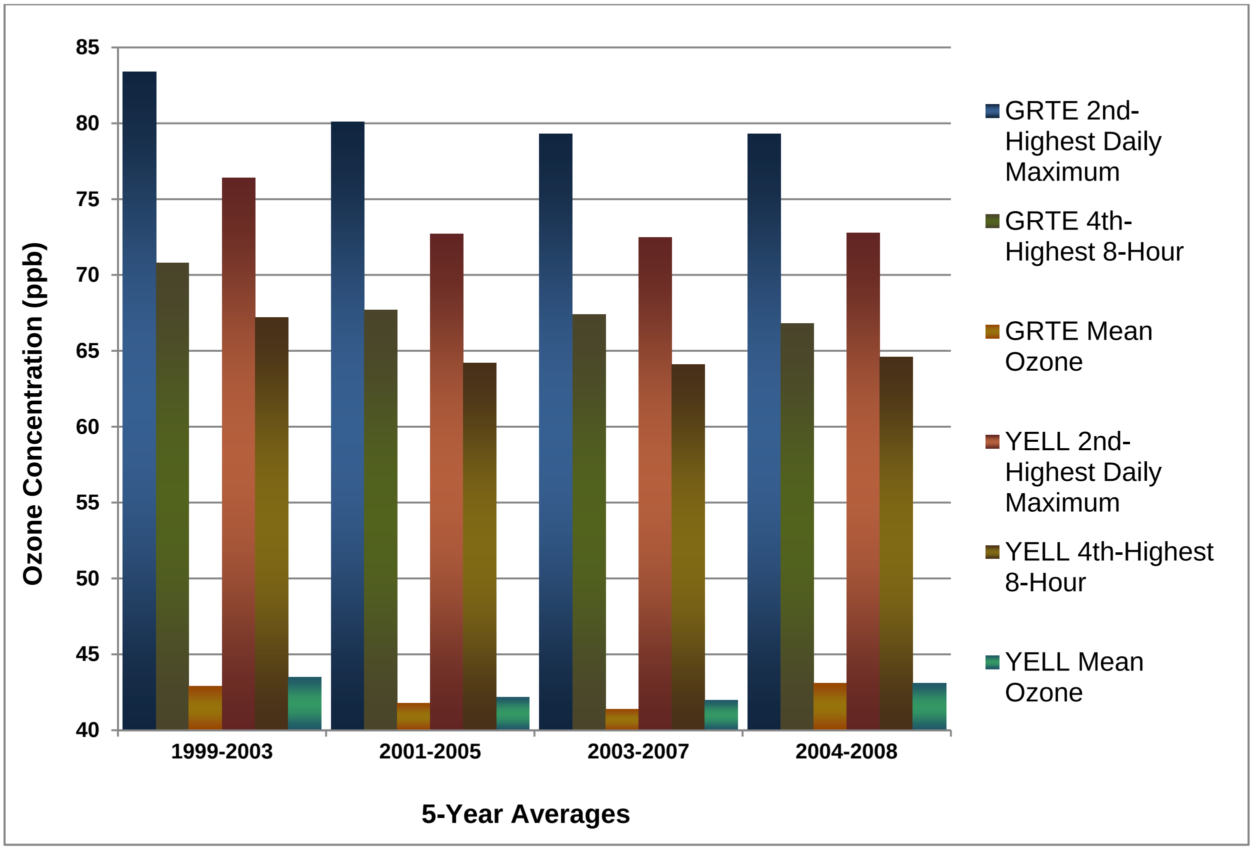

Figure 3.8. Second-highest daily maximum, fourth-highest daily maximum 8-hour average, and mean ozone for Grand Teton National Park and Yellowstone National Park. Source: NPS Air Atlas 5-Year Air Quality Estimates.

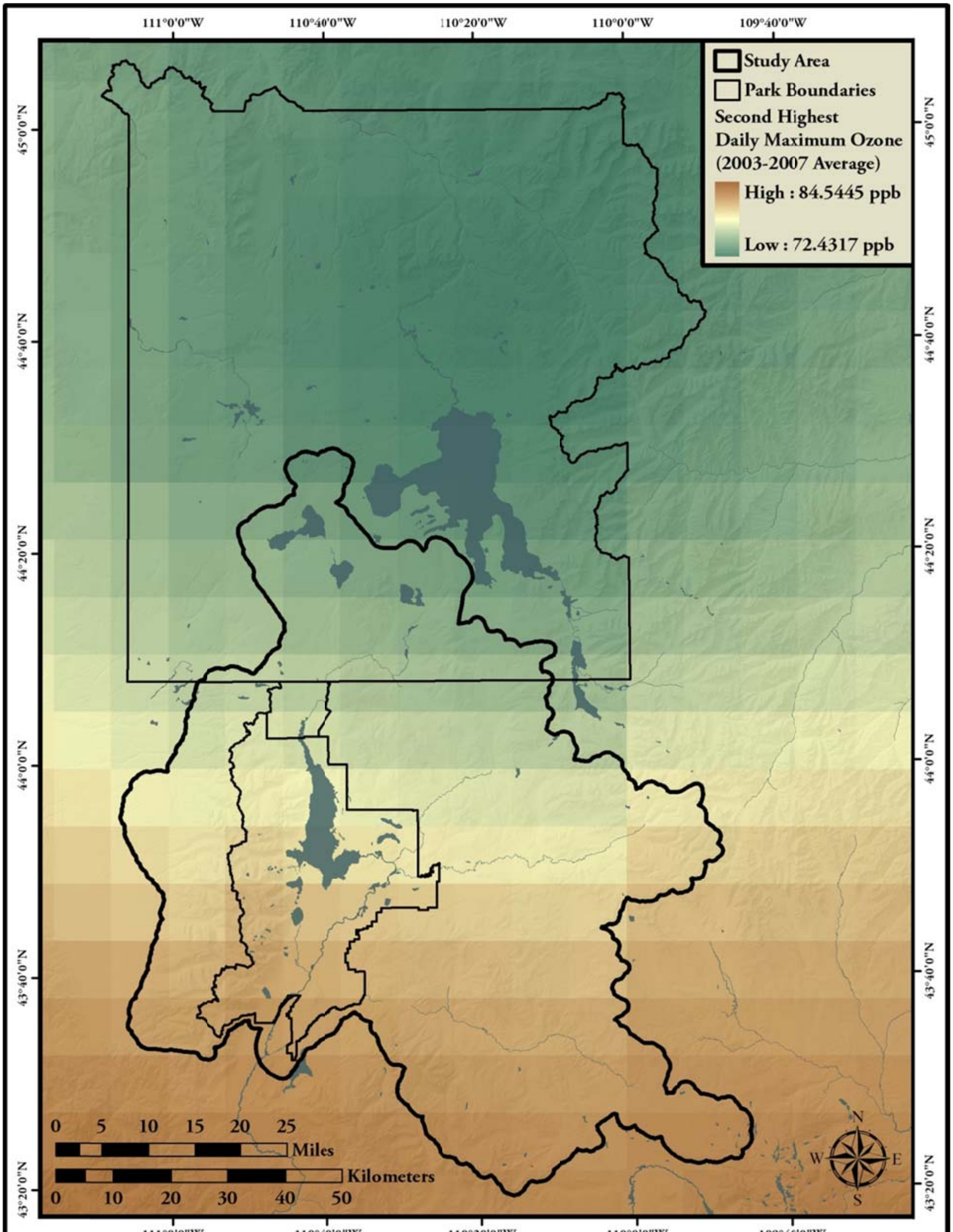

Figure 3.9. Interpolated second-highest daily maximum ozone in parts per billion (2003-2007 average). Source: NPS Air Atlas data served by the NPS GIS Data Store.

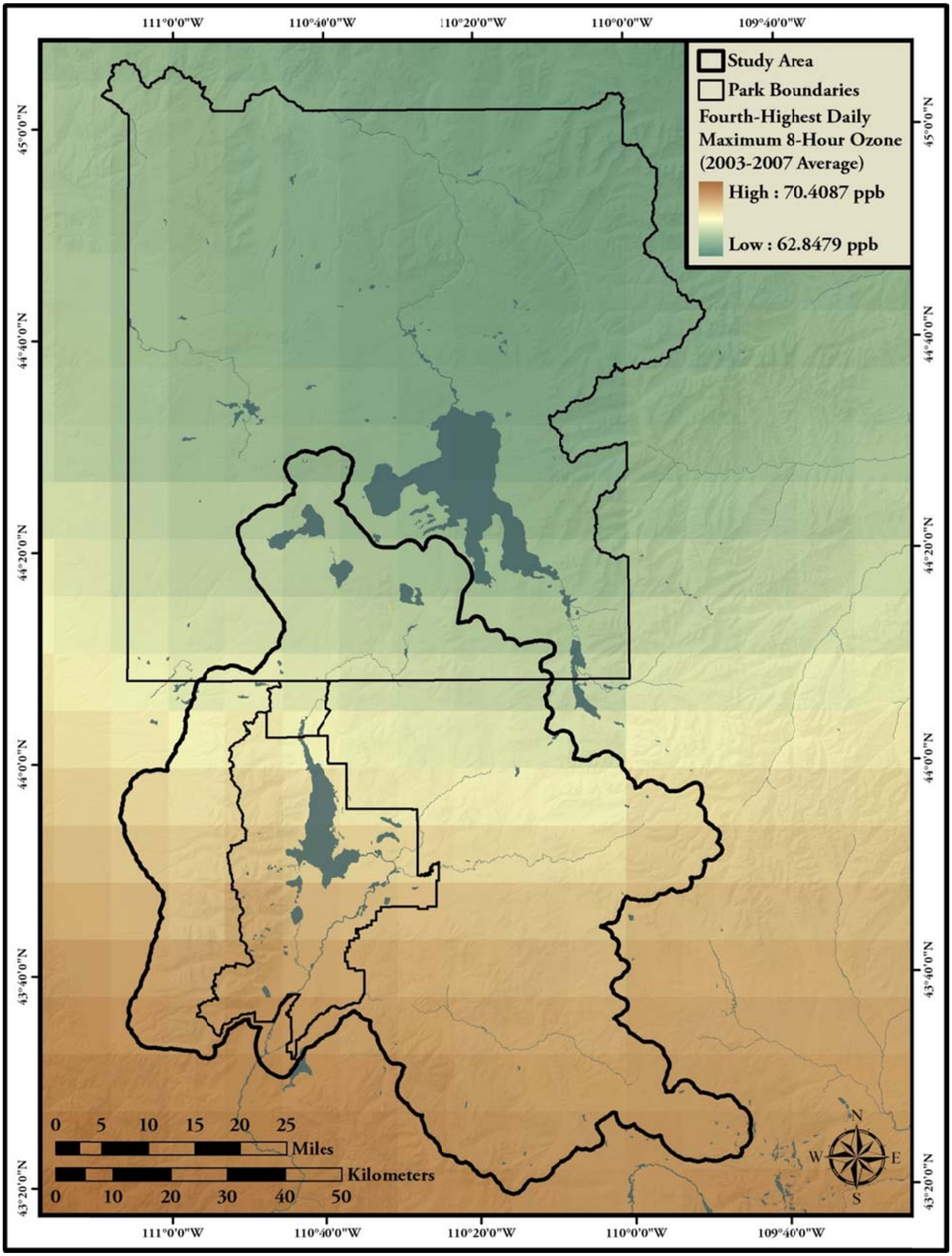

Figure 3.10. Interpolated fourth-highest daily maximum 8-hour ozone in parts per billion (2003-2007 average). Source: NPS Air Atlas data served by the NPS GIS Data Store.

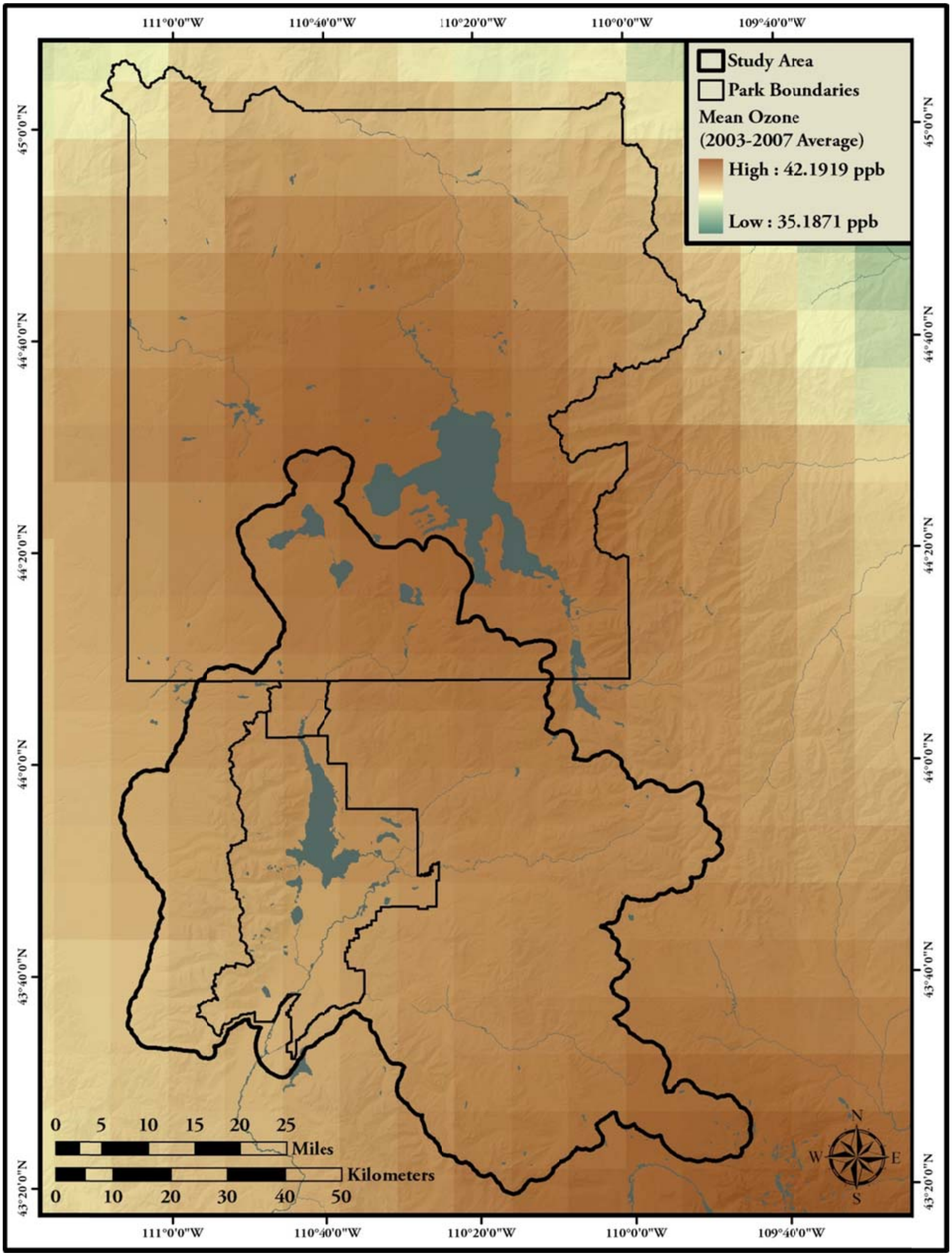

Figure 3.11. Interpolated mean ozone in parts per billion (2003-2007 average). Source: NPS Air Atlas data served by the NPS GIS Data Store.

Although GRTE and YELL are in compliance with federal ozone concentration standards for human health, scientific evidence suggests that this standard may not be protective enough for ozone-sensitive plant species (Table 3.7). Current estimates in YELL and GRTE indicate that ozone concentrations and cumulative doses are low or at levels not known to cause injury to vegetation (Kohut, 2007). Trends analyses conducted by Jaffe and Ray (2007), evaluating the time period from 1987 to 2004, indicated that deseasonalized daytime monthly means of ozone in YELL were increasing. Ozone monitoring data also suggested that a significant increase occurred in YELL between 1993 and 2002 (NPS, 2008a). However, the latest trends analyses conducted by the NPS ARD, evaluating the time period from 1999 to 2008, suggested that ozone levels in YELL are improving (NPS, 2010f).

Table 3.7. Ozone-sensitive species within Grand Teton National Park and Yellowstone National Park.

National Park	Scientific Name	Common Name	Sensitivity Category
Grand Teton	*Amelanchier alnifolia*	Saskatoon serviceberry	Sensitive**
	Apocynum androsaemifolium	Spreading dogbane	Bioindicator*
	Apocynum cannabinum	Indian hemp	Sensitive**
	Artemisia ludoviciana	Silver wormwood	Bioindicator*
	Aster engelmannii	Engelmann's aster	Suspect***
	Physocarpus malvaceus	Mallow ninebark	Bioindicator*
	Populus tremuloides	Quaking aspen	Bioindicator*
	Rubus parviflorus	Thimbleberry	Sensitive**
	Salix scouleriana	Scouler's willow	Bioindicator*
	Sambucus racemosa	Red elderberry	Bioindicator*
	Symphoricarpos albus	Common snowberry	Bioindicator*
	Vaccinium membranaceum	Thinleaf huckleberry	Bioindicator*
Yellowstone	*Apocynum androsaemifolium*	Spreading dogbane	Bioindicator*
	Apocynum cannabinum	Indian hemp	Sensitive**
	Fraxinus pennsylvanica	Green ash	Sensitive**
	Physocarpus malvaceus	Mallow ninebark	Bioindicator*
	Populus tremuloides	Quaking aspen	Bioindicator*
	Rhus trilobata	Skunkbush sumac	Sensitive**
	Rubus parviflorus	Thimbleberry	Sensitive**
	Salix scouleriana	Scouler's willow	Sensitive**
	Vaccinium membranaceum	Thinleaf huckleberry	Bioindicator*

Source: NPS and USFWS.
*Bioindicator species for ozone injury meet all or most of the following criteria: species exhibit foliar symptoms in the field at ambient ozone concentrations that can be easily recognized as ozone injury by subject matter experts; species ozone sensitivity has been confirmed at realistic ozone concentrations in exposure chambers; species are widely distributed regionally; and species are easily identified in the field.
**Sensitive species are those that typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or are species for which ozone foliar injury symptoms in the field have been documented by more than one observer.
***Suspect species are those for which there is some evidence of sensitivity, but species do not meet certain criteria for sensitive species.

Based on ozone exposure estimates from the NPS Air Atlas (Table 3.8), foliar injury and growth reduction may be occurring within GRTE and YELL. The SUM06 threshold for natural ecosystems whereby visible foliar injury may occur is eight to 12 ppm-hr, and the threshold for tree seedlings whereby growth reduction may occur is 10 to 16 ppm-hr. SUM06 estimates for the four five-year periods suggest that foliar injury may be occurring, as all values are greater than 12 ppm-hr. Growth reduction may be occurring as well since all values are greater than 10 ppm-hr. The W126 threshold for highly sensitive species is 5.9 ppm-hr; therefore, bioindicator species, such as spreading dogbane and quaking aspen, may be experiencing foliar injury and growth reduction in GRTE and YELL.

Table 3.8. Ozone exposure estimates for Grand Teton National Park and Yellowstone National Park.

Grand Teton National Park Ozone Exposure Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
SUM60 (ppm-hr)	19.8	14.8	15.2	13.4
Total W126 (ppb-hr)	38080.2	32760.9	32737.5	32735.6
W126 3-month cumulative 12 hour (ppm-hr)	-	-	12.8	11.3
Yellowstone National Park Ozone Exposure Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
SUM60 (ppm-hr)	15.2	10.4	10.3	9.5
Total W126 (ppb-hr)	36363.1	31440.0	30898.3	30754.6
W126 3-month cumulative 12 hour (ppm-hr)	-	-	10.2	9.2

Source: NPS Air Atlas 5-Year Air Quality Estimates.

Summary and Conclusions

Ground-level ozone is a common pollutant that produces an array of health and environmental effects, even at relatively low levels. Ozone can aggravate and trigger respiratory diseases as well as cause foliar injury and growth reduction in plants. Ozone concentrations in GRTE and YELL are currently at relatively low levels; however, some scientific studies and data suggest that ozone levels may be increasing in YELL and GRTE. Some researchers also presume that ozone levels within the Greater Yellowstone Network during the growing season may be high enough to cause biomass loss in sensitive species.

Since ground-level ozone is produced through a series of complex photochemical reactions involving nitrogen oxides and volatile organic compounds, numerous national programs are being implemented to reduce nitrogen oxide and volatile organic compound emissions from vehicles, industrial facilities, and electric utilities. Programs are also aimed at reducing pollution by reformulating fuels and commercial products, such as paint and chemical solvents that contain volatile organic compounds (EPA, 2010c). Although programs may aid in improving nationwide air quality, ozone concentrations in YELL and GRTE may continue to increase to levels that may affect human health and ecosystem function (NPS, 2008a).

A study conducted by Peterson et al. (1998) that summarized ambient air quality in GRTE suggested that ozone, wet deposition, visibility, and sulfur dioxide monitors be installed in the park since no ambient air quality monitoring is conducted in the park. Preliminary data from monitors in GRTE can determine how well monitoring in YELL and Air Atlas estimates have represented conditions in GRTE. Recommendations to install monitors have been accepted. In addition to an NADP sampler, an ozone monitor will be installed at the Teton Science School and should be operational by late spring 2011 (E. Porter, ARD, pers. comm.).

Visibility

Visibility is one of the primary air quality attributes that is associated with national parks and wilderness areas because it often affects observer perception. One of the mandates of the National Park Service, since its inception, is to conserve the scenery within park units, but whether or not scenery in national parks can be enjoyed is highly dependent on visibility. Unfortunately, visibility is adversely affected by air pollution, and in turn, visibility affects how national parks and wilderness areas are enjoyed and appreciated by observers (NPS, 2007h).

Visibility is defined as the greatest distance at which an observer can see and identify prominent objects against the horizon. However, visibility, as it relates to the management of visual resources found in national parks and wilderness areas, also involves observer psychophysical processes, such as the recognition and appreciation of color, form, detail, texture, and contrast. Whether visibility is defined in terms of visual range or in terms of some parameter related to how an observer perceives a visual resource, it has been acknowledged that visibility is impaired by gaseous air pollution and particulate matter. Because visibility is impaired by air pollution, it can be a good indicator of general air quality (Malm, 1999).

Gaseous air pollution and particulate matter can create a white or brown haze that affects how far and how well features and scenic vistas can be seen. Haze is produced when sunlight encounters fine particulate matter in the atmosphere that scatters and absorbs light. Image-forming information from an object is reduced, via light scattering and absorption, as it passes through the atmosphere to the observer. As the number of fine particles in the atmosphere increases, more light is absorbed and scattered, resulting in less clarity, color, and visual range (Malm, 1999).

Five types of fine particles contribute to haze: sulfates, nitrates, organic carbon, elemental carbon, and crustal material (EPA, 2010d). Sulfate particles form from sulfur dioxide gas that is predominantly released from coal-burning power plant and other industrial sources, such as smelters, industrial boils, and oil refineries. In humid environments, sulfate particles increase to a size that is very efficient at scattering light, thereby exacerbating the problem. Nitrate particles form from nitrogen oxide gas that is released from virtually all combustion activities, especially those involving cars, trucks, off-road engines (e.g. snowmobiles, construction equipment, lawn mowers, and boats), and power plants. As with sulfate particles, nitrate particles scatter more light in humid environments. Organic carbon particles are emitted directly into the atmosphere and also form from gaseous reactions. Sources of organic carbon particles include vehicle exhaust, solvent evaporation, and fires. Elemental carbon particles are smaller than other particles and tend to absorb rather than scatter light. These particles are commonly referred to as soot and are directly emitted into the atmosphere from combustion activities. They are especially prevalent in diesel exhaust and smoke from burning wood and wastes. Crustal material (soil dust) enters the atmosphere from dirt roads, fields, and other open spaces as a result of wind, traffic, and other surface activities (IMPROVE, 2001).

These five types of particles can manifest as a layered haze, a uniform haze, or a plume. A layered haze is a confined layer of pollution that results in a visible discontinuity between the haze and the background. A layered haze often occurs in conjunction with temperature inversions. A uniform haze is an overall reduction in air clarity across the horizon and is present from the ground to a height well above the tallest features of the landscape. A uniform haze often covers large geographic areas. A plume is a mass of air pollution from a specific source. Plumes and plume-like layers often take shape under certain meteorological conditions where the air is stable or constrained (NPS, 2007h; IMPROVE, 2001).

Methods

To assess the condition of visibility in GRTE, literature, visibility monitoring data, and NPS Air Atlas estimates were evaluated. As with atmospheric deposition and ozone monitoring, visibility is not monitored in GRTE, but is monitored in YELL near Yellowstone Lake. The monitoring station is YELL is used to infer visibility condition for three Class I Airsheds: YELL, GRTE, and Red Rock Lakes (IMPROVE, 2002).

The National Park Service and the EPA first began long-term visibility monitoring at selected national parks in 1979. In 1985, a national visibility monitoring program was established called the Interagency Monitoring of Protected Visual Environments (IMPROVE) program. The IMPROVE program is a cooperative effort led by a Steering Committee of representatives from the EPA, Forest Service, National Park Service, Fish and Wildlife Service, Bureau of Land Management, National Oceanic and Atmospheric Administration, and several interstate air quality management organizations (NPS, 2007i). The goals of the IMPROVE program are to measure current visibility and aerosol conditions in mandatory Class I Airsheds, identify chemical pollutants, and document long-term visibility trends. Additionally, with the enactment of the Regional Haze Rule that requires state and federal agencies to develop and implement air quality protection plans to reduce the visibility impairment pollution in 156 national parks and wilderness areas, the IMPROVE program provides visibility monitoring representative of all visibility-protected Class I Airsheds (NPS, 2007i; EPA, 2009d).

Three types of visibility measurements are generally recorded at IMPROVE monitoring sites: scene, optical, and particle. Previously, many IMPROVE monitoring stations photographically documented the appearance of the scene under various levels of visibility. Scenic conditions were monitored by automatic camera systems that took photographs three times a day. Presently, web cameras are used to document the appearance of the scene under various levels of visibility. Images are generally uploaded to a web site every 15 minutes. Optical monitors record the characteristics of the atmosphere and the ability of the atmosphere to scatter and/or absorb light. Optical monitoring instruments used in the IMPROVE program include transmissometers, which measure the attenuation of light over a given distance, and nephelometers, which measure light scattering in a sampled volume of air. Particle monitors measure the composition of visibility-reducing aerosols and consist of four independent sampling modules. Three modules collect fine particles ($PM_{2.5}$), while the fourth collects both fine and coarse particles (PM_{10}). Particle monitors measure mass, chemical elements, sulfate, nitrate, organics, and elemental carbon (NSTC, 1999; NPS, 2007i).

Since visibility changes on a daily basis, the daily results are analyzed to determine what conditions were like on the days with the best visibility (20 percent clearest) and worst visibility (20 percent haziest). Air samples can be analyzed for types of pollutants and sources of pollution found on the clearest and haziest days. Scenic conditions are reported in standard visual range and deciviews. The standard visual range is an expression of visibility impairment defined as the distance in miles or kilometers at which an object disappears from view (ADEQ, 2010). The deciview is a visual index designed to be linear with respect to perceived visual air quality changes over its entire range. In mathematical terms, it is a 10 percent change in the light extinction equation reading. The higher the deciview, the less an observer can see into the distance (IDEQ, 2010a). Optical conditions are reported in inverse megameters (Mm^{-1}). An inverse megmeter is the direct measurement for visibility impairment. It is the amount of light scattered and absorbed as it travels over a distance of one million meters (ADEQ, 2010). Particle conditions are reported in micrograms per cubic meter ($\mu g/m^3$).

Visibility in YELL has consistently been monitored since 1988 using an aerosol sampler (1988 to present), a transmissometer (1989 to 1993), a nephelometer (2002 to present), and an automatic 35 millimeter camera (1981 to 1982; 1986 to 1995; 2002-2003). The camera in YELL was located on the northern shore of Yellowstone Lake, east of the Lake Village Ranger Station. From 1986 to 1989, it was aligned to capture images of the Overlook Mountain Vista, and in 1989, the camera was realigned to view Avalanche Peak. Photographic documentation in YELL was discontinued in 2003. (IMPROVE, 2002). Presently, there are no web cameras documenting visibility in YELL or GRTE (M. George, ARD, pers. comm.), but one will be installed at the Teton Science School by late spring 2011 (E. Porter, ARD, pers. comm.).

<u>Results</u>

In many national parks and wilderness areas, the visual range has been substantially reduced by air pollution. According to the EPA, the average visual range in the eastern United States has decreased from 90 miles to 15 to 20 miles, whereas in the western United States, visual range has decreased from 140 miles to 35 to 50 miles (EPA, 2009e). Although visual range has markedly decreased within in many national parks and wilderness areas, probably over historical time frames, analyses conducted by the National Park Service suggest that visibility improved or was stable during the 1998 to 2007 time period. In the 2008 Air Quality in National Parks Annual Performance and Progress Report, it is indicated that of the 147 parks evaluated, visibility (based on the 20 percent haziest days) is stable in 144 parks, improving in two parks, and degrading in one park (NPS, 2009f).

Visibility in GRTE and YELL is considered superior to that of many other areas and national parks in the United States, but it is still occasionally impaired by haze. Even a slight layer of haze can affect two important and sensitive AQRVs: visibility and dark night skies. The air pollution that contributes to daytime haze also often degrades dark night skies, lessening the ability of viewers to observe stars. Dark night skies are considered an important AQRV in GRTE because they possess cultural, scenic, natural, and scientific values (NPS, 2007b). In addition to affecting visibility and dark night skies, haze also contributes to declines in socioeconomic activities. Surveys and studies suggest that visitors notice haze and it detracts from their enjoyment and time spent in national parks (NPS, 2007a).

Trends in annual deciview suggest that visibility in YELL is improving at statistically significant levels during the 20 percent clearest days; however, there are no statistically significant trends during the 20 percent haziest days (NPS, 2009f). In a baseline condition study conducted by the Idaho Department Environmental Quality, it was estimated that the average visual range in YELL, based on IMPROVE data from 2000 to 2004, was approximately 74 miles (119 kilometers) or 12.07 deciviews on the haziest days. The natural conditions were estimated at 124 miles (200 kilometers) or 7.12 deciviews (IDEQ, 2010b).

Data from the IMPROVE website indicate that scenic conditions in YELL from 1991 to 2008 ranged from 14.98 deciviews to 1.82 deciviews and from 55.95 miles (90.04 kilometers) to 187.35 miles (301.51 kilometers). During the 20 percent clearest days (referred to as Group 10 values by the IMPROVE program), average visibility was 3.06 deciviews or 167.78 miles (270.02 kilometers). During the 20 percent haziest days (referred to as Group 90 values by the IMPROVE program), average visibility was 12.10 deciviews or 73.14 miles (117.70 kilometers) (Figures 3.12 and 3.13).

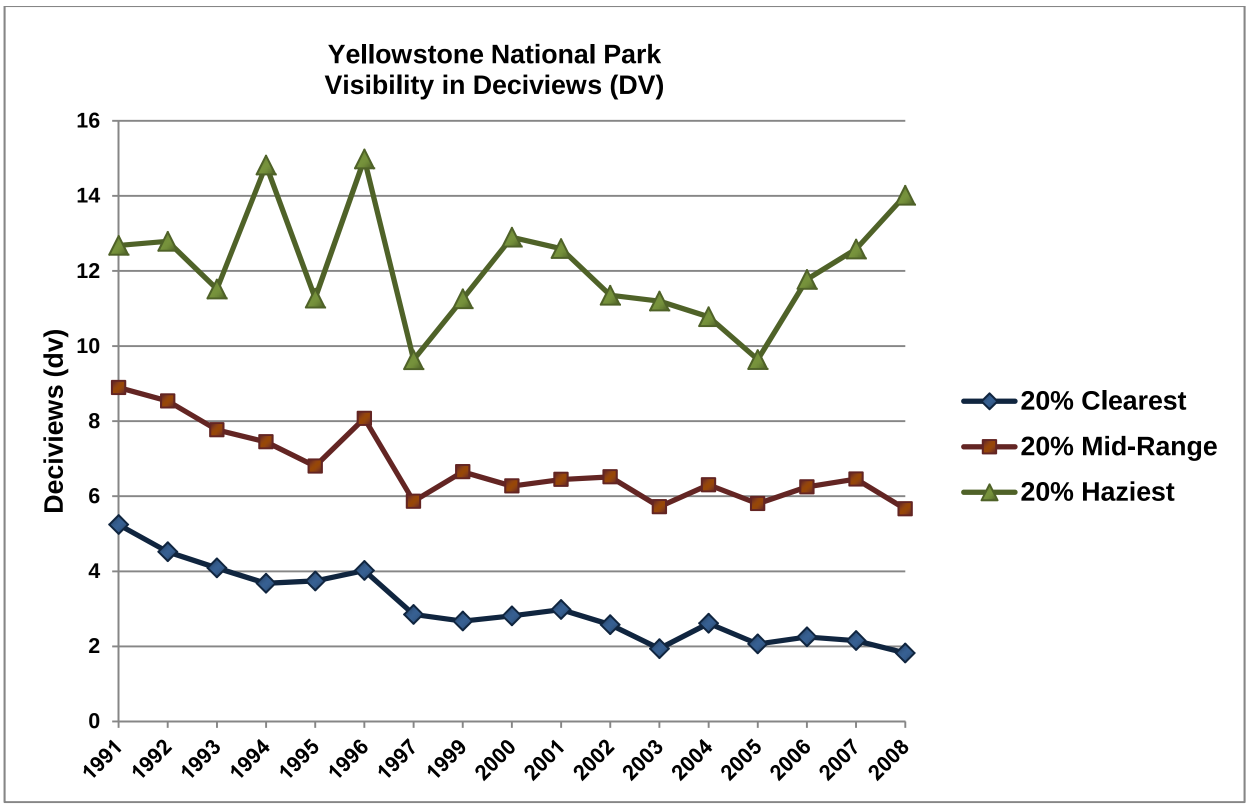

Figure 3.12. Trends in visibility, measured in deciviews, for Yellowstone National Park (1991-2008). Data for 1998 was not available. Source: IMPROVE.

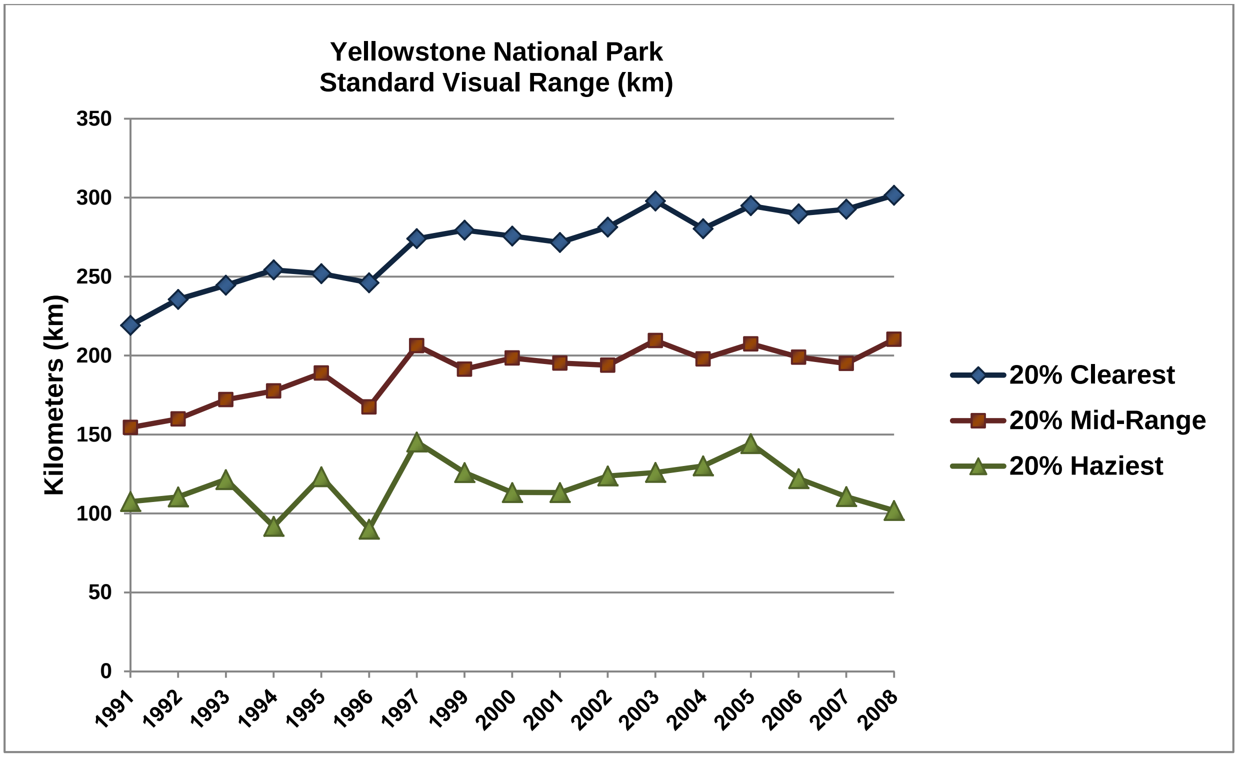

Figure 3.13. Trends in standard visual range, measured in kilometers, for Yellowstone National Park (1991-2008). Data for 1998 was not available. Source: IMPROVE.

According to the NPS ARD, visibility condition for national parks is based on the deviation of the Group 50 values from the estimated natural visibility conditions. Group 50 values are the means of the visibility observations falling within the range of the 40^{th} through the 60^{th} percentiles (NPS, 2010e), or the 20 percent mid-range values as indicated in Figures 3.12 and 3.13. If visibility is greater than eight deciviews above estimated natural conditions, then it is considered a significant concern; if the visibility is between two and eight deciviews above estimated natural conditions, then it is considered a moderate concern; and if visibility is less than two deciviews above estimated natural conditions, it is in good condition (NPS, 2010e). Based on the values defined by the NPS ARD, visibility is a moderate concern in YELL and GRTE. The 2004 to 2008 five-year estimate indicates that the G50 visibility value minus natural conditions was 3.3 deciviews in GRTE and 3.4 deciviews in YELL (Table 3.9).

Table 3.9. Visibility estimates for Grand Teton National Park and Yellowstone National Park.

Grand Teton National Park Visibility Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
G50 Visibility minus Natural Conditions (dv)	-	-	3.3	3.3
20 Percent Haziest Days (Mm^{-1})	25.6	24.2	26.6	28.2
20 Percent Clearest Days (Mm^{-1})	4.4	3.7	3.3	3.3
Yellowstone National Park Visibility Estimates				
Averaging Period	**1999-2003**	**2001-2005**	**2003-2007**	**2004-2008**
G50 Visibility minus Natural Conditions (dv)	-	-	3.4	3.4
20 Percent Haziest Days (Mm^{-1})	25.3	23.6	25.1	27.0
20 Percent Clearest Days (Mm^{-1})	4.4	3.7	3.4	3.3

Source: NPS Air Atlas 5-Year Air Quality Estimates.

Optical conditions, as measured in inverse megameters (Mm^{-1}), represent the amount of light scattered and absorbed as it travels over a distance of one million meters. Data from the IMPROVE website report total light extinction and particle light extinction. In YELL, from 1991 to 2008, total light extinction ranged from 14.41 inverse megameters to 48.06 inverse megameters. During the 20 percent clearest days, average light extinction was 16.88 inverse megameters, and during the 20 percent haziest days, average light extinction was 35.94 inverse megameters (Figure 3.14). Air Atlas estimates indicate that the particle light extinction is slightly increasing among five year averages during the 20 percent haziest days (Table 3.9). This suggests that, on average, there are slightly higher concentrations of particles in the atmosphere during the 20 percent haziest days. Conversely, estimates based on the 20 percent clearest days suggest that particle concentrations may be decreasing. In both GRTE and YELL, estimates of particle light extinction have decreased from 4.4 inverse megameters to 3.3 inverse megameters (Table 3.9). Figures 3.15 and 3.16 present the spatial data from the NPS Air Atlas of the 20 percent haziest and 20 percent clearest days for the five-year 2001 to 2005 average.

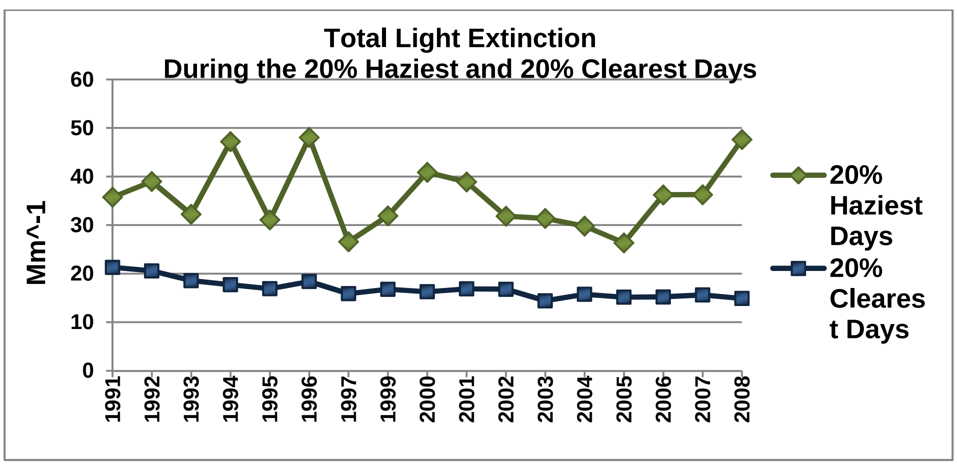

Figure 3.14. Trends in total light extinction, measured in inverse megameters (Mm-1), for Yellowstone National Park (1991-2008). Data for 1998 was not available. Source: IMPROVE.

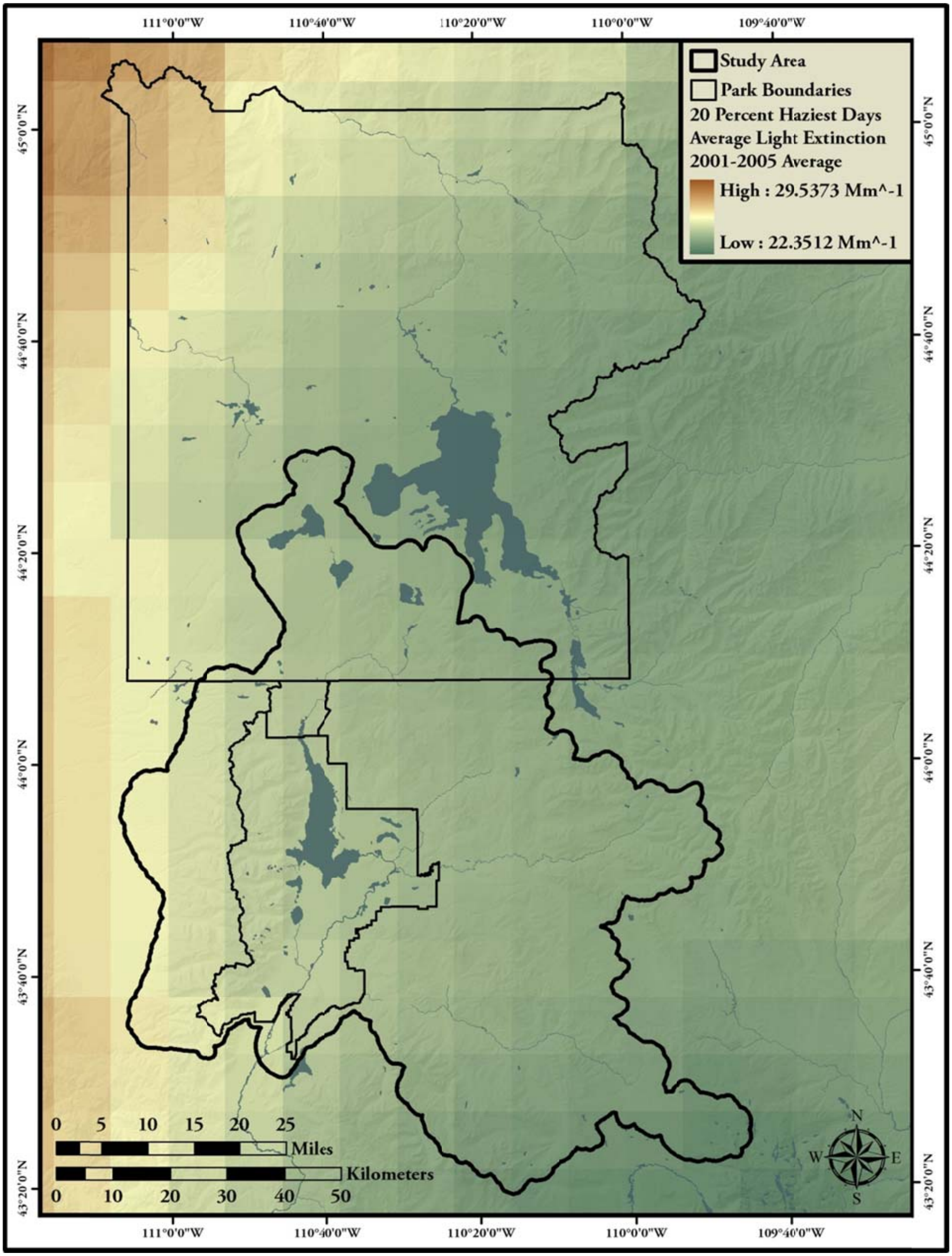

Figure 3.15. Interpolated average light extinction, in inverse megameters (Mm-1), for the 20 percent haziest days (2001-2005 average). Source: NPS Air Atlas data served by the NPS GIS Data Store.

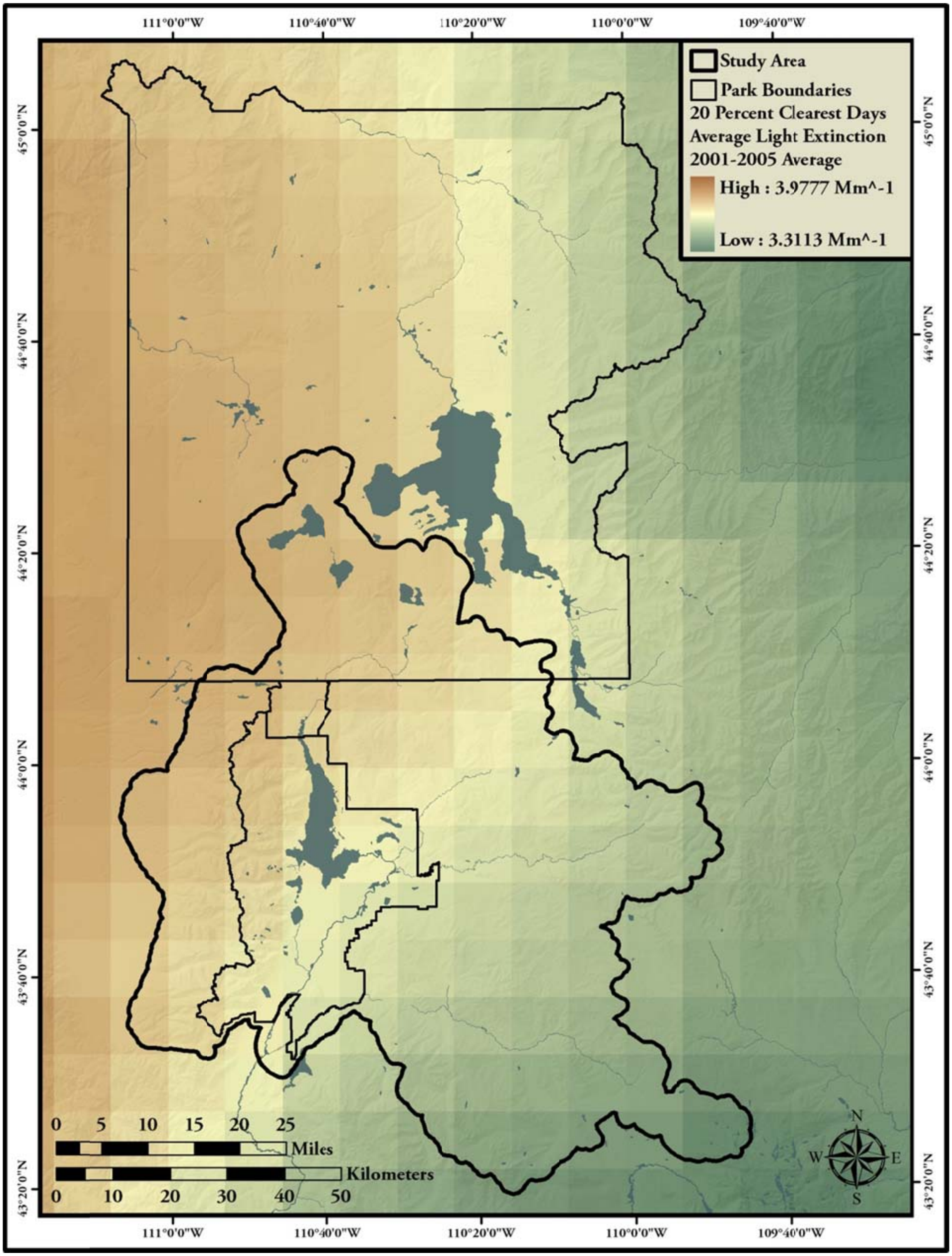

Figure 3.16. Interpolated average light extinction, in inverse megameters (Mm-1), for the 20 percent clearest days (2001-2005 average). Source: NPS Air Atlas data served by the NPS GIS Data Store.

Particle concentrations, as measured in micrograms per cubic meter (μg/m[3]), are quantified in order to determine the composition of visibility-reducing aerosols. As previously indicated, three modules collect fine particles ($PM_{2.5}$) and a fourth module collects both fine and coarse particles (PM_{10}). Particle monitors measure mass, chemical elements, sulfate, nitrate, organics, and elemental carbon. Figure 3.17 displays the IMPROVE data for particle concentrations in YELL from 1991 to 2008. The data suggests total particulate matter (PM_{10}) concentrations are generally decreasing, but fine particulate matter ($PM_{2.5}$) concentrations are relatively stable. Of the particles measured, the most widely fluctuating are coarse mass and organic mass.

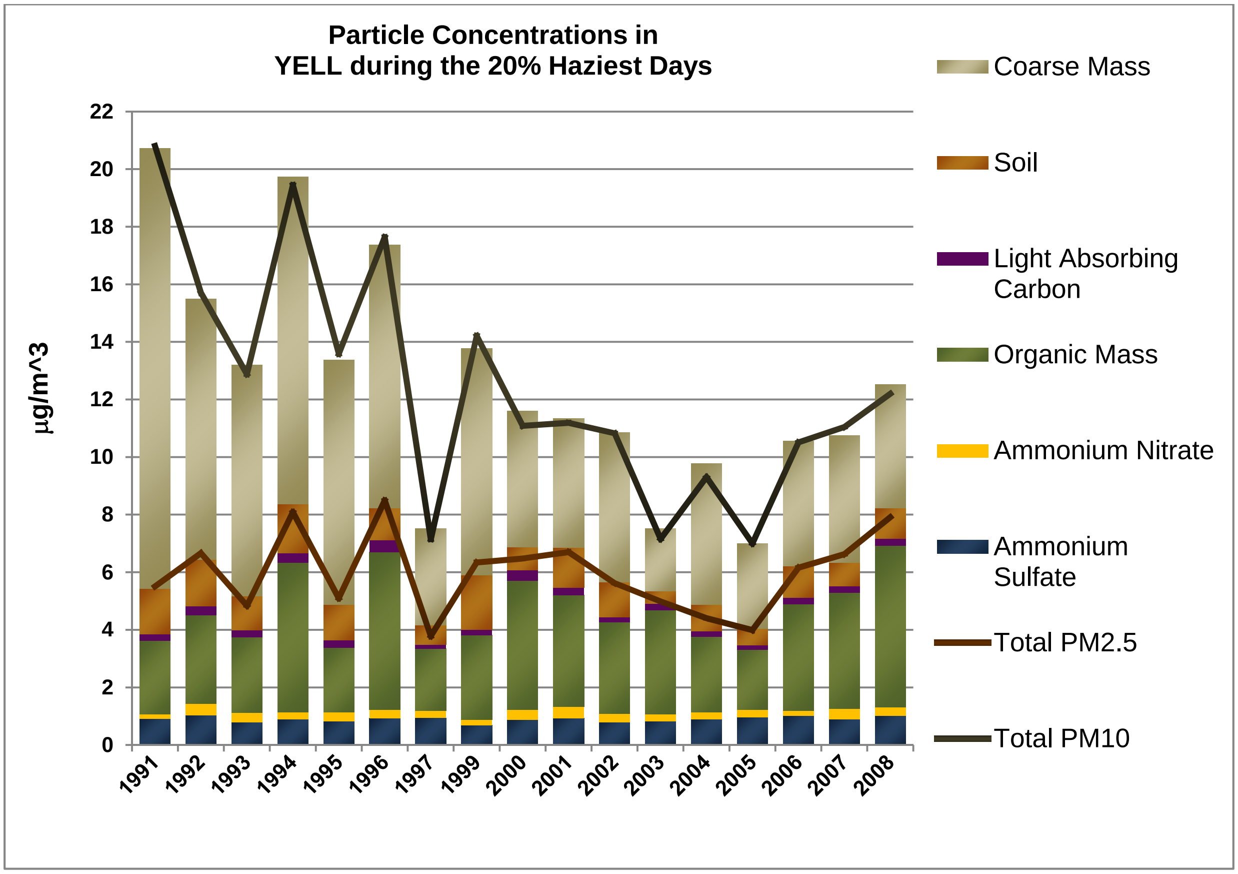

Figure 3.17. Trends in particle concentrations, measured in micrograms per cubic meter (μg/m3), for Yellowstone National Park (1991-2008). Data for 1998 was not available. Source: IMPROVE.

Summary and Conclusions

Visibility is an important air quality attribute in national parks because it affects visitor perception, enjoyment, and socioeconomic activities. Visibility is impaired by gaseous air pollution and particulate matter, such as sulfates, nitrates, organic carbon, elemental carbon, and crustal material. Pollutants and particles in the atmosphere often create atmospheric haze that impairs clarity, color, and visual range. Visibility is monitored by the IMPROVE network, an interagency and interstate air quality management organization that measures current visibility and aerosol conditions in mandatory Class I Airsheds, identifies chemical pollutants, and documents long-term visibility trends. Three types of visibility measurements are generally recorded at IMPROVE monitoring sites: scene, optical, and particle.

As with atmospheric deposition and ozone monitoring, visibility is not monitored in GRTE; however, it is monitored at a number of locations in Wyoming as part of the IMPROVE network. The IMPROVE monitor closest to GRTE is located near Yellowstone Lake in YELL. The 2008 Air Quality in National Parks Annual Performance and Progress Report and IMPROVE monitoring data suggest that visibility in GRTE and YELL is considered better to that of many other areas and national parks in the United States, but it is still deemed a moderate concern based on NPS ARD standards.

IMPROVE data indicates that during the 20 percent haziest days average visibility was 12.10 deciviews or 73.14 miles (117.70 km). In contrast, during the 20 percent clearest, average visibility was 3.06 deciviews or 167.78 miles (270.02 km). Air Atlas estimates indicate that the 2004 to 2008 five-year estimate of the G50 visibility value minus natural conditions was 3.3 deciviews in GRTE and 3.4 deciviews in YELL. These values suggest that visibility can be improved in the area. According to the Idaho Department of Environmental Quality, states must work to improve visibility in YELL by 4.95 deciviews by the year 2064 in order to comply with the Regional Haze Rule. This goal suggests an improvement from a current visual range of approximately 74 miles (119 km) to 124 miles (200 km) in the future (IDEQ, 2010b).

Although the IMPROVE monitor in YELL is used to infer conditions in GRTE, it has been suggested that the monitor may not be characteristic of visibility conditions in GRTE because of significant differences in terrain and wind flow patterns. Therefore, recommendations to install an IMPROVE sampler in the Bridger Wilderness have been made because it may better characterize conditions in GRTE (NPS, 2008a). In addition to the camera that will be installed at the Teton Science School in late spring 2011, a nephelometer will be installed to monitor visibility (E. Porter, ARD, pers. comm.).

Climate

Climate is a set of long-term, average meteorological conditions that occur over several decades or longer. Unlike weather, which fluctuates and is difficult to predict, climate is relatively stable and predictable (NPS, 2009g). Climate is a dominant factor in the Greater Yellowstone Ecosystem, as it drives many of the physical and ecological processes. Climate has a profound effect on the geomorphic processes and is a primary determinant in vegetation zonation and animal distribution (NPS, 2006d).

The climate in the Greater Yellowstone Ecosystem is complex and encompasses environments ranging from alpine zones to lower-elevation basins (NPS, 2006d). Three climate zones span YELL and GRTE, with each having a distinct seasonal precipitation pattern. The northern and eastern areas of YELL are classified as a summer wet zone whereby approximately 40 percent of the precipitation occurs from May to July and 18 percent occurs in the winter. The southern portion of YELL and the eastern Tetons are classified as a winter wet zone whereby the majority of the precipitation occurs in the winter. Approximately twice as much precipitation occurs in the winter wet zone as compared to the summer wet zone. The western slopes of the Tetons comprise the third climate zone whereby precipitation occurs more uniformly throughout the year. This area is generally wetter than the other two zones due to orographic precipitation (NPS, 2009g).

Change Points and Trends in the Historical Climate Record

As a semi-arid ecosystem, GRTE is sensitive to changes in the magnitude (mean) and range (maximum to minimum) of annual climate. These factors influence the distribution and availability of water resources as well as the length and extent of the annual growing season for plants and animals. Elements of the water cycle are critical for the maintenance of alpine glaciers within GRTE as well as the river channel morphology whose rapids, pools, and runs contribute (rafting, fishing, sediment transport) to the iconic local landscape and regional economy.

Methods

Data were obtained from the National Climate Data Center (NOAA), the PRISM Climate Group web server at Oregon State University, and regional state and federal weather station data sources from the Utah Climate Center at Utah State University. All analyses were performed using the basic statistical packages within the open-source statistical software R Project for Statistical Computing (R Development Core Team, 2010).

The local historical climate record begins in the late nineteenth century and runs through the present day. Potential changes may include increases or decreases in the mean values (magnitude) over the entire record, changes in the year-to-year variation, or changes in the amount of seasonal variation within each year. Any year-to-year variation or trends must be separated from normal summer highs and winter lows as well as approximate decadal (three to seven year) cycles of warmer and colder climate due to El Niño Southern Oscillation (ENSO) or episodic volcanic events.

A longer record is useful for identifying climatic shifts and trends in the context of long-term variability and cyclic patterns that may span decades or longer. This analysis rested on the simplifying assumption that climate patterns could be decomposed into three components (Seasonal + Trend + Remainder). Using the entire historical record of monthly maximum and minimum temperatures as well as total precipitation, seasonal highs and lows anticipated each year were estimated and removed from each time series. Locally estimated scatterplot smoothing (LOESS) was then used to track trends and to detect change points (as a distinct change in magnitude or range) in each time series by smoothing variation over decadal spans.

Despite the utility of a long-term climate record, individual weather stations remain able to capture only local estimates of broader climatic patterns across space. More recent attempts to augment site-based perceptions of climate use sophisticated computer algorithms for estimating the pattern of temperature and precipitation between ground observations, providing mapped estimates of climatic conditions for every four square kilometers (i.e. the PRISM data set; Daly et al., 2008). With average values computed for the entire Snake River basin upslope of GRTE and Jackson Hole, it was possible to compare regional values to local measurements. This extensive climate data was also used to assess regional trends in seasonal patterns of temperature and precipitation. The primary research question was whether there are identifiable changes in regional annual or seasonal temperature and precipitation patterns that are corroborated by the historical observations at specific locations.

Although management options for National Park Service staff to control climatic factors within the park are limited to nonexistent, understanding the park's climatic context is relevant for assessing the vulnerability of certain ecosystems to further management action (including inaction) and identifying ecosystems that may experience chronic stress as a result of gradual shifts or alterations to seasonal patterns of snowmelt, plant green up, or water use.

<u>Results</u>

Representative examples of climate time series for the weather station at Moran, Wyoming, are shown in Figures 3.18 through 3.20. The trend line for monthly temperature maxima clearly shows an increase starting in the mid-1970s, with the exception of an anomalous drop in annual maxima corresponding to the eruption of Mount St. Helens in 1980 and dips following an exceptionally strong El Niño year in 1982-1983. The trend for monthly minima does not show a clear pattern of increase since 1970 but may indicate a slight decrease since the beginning of the record, whereas there is no apparent trend for monthly precipitation.

Figure 3.21 shows recent regional averages (1971-2000) superimposed on the long-term historical climate record. Although the trends for monthly temperature maxima and precipitation match well, there is a clear discrepancy between the monthly temperature minima time series. Further examination suggests that the station at Moran, Wyoming, lies in a portion of the regional landscape that is not warming as fast (or, in fact, at all) when compared to the rest of the region.

With the presumption that regional measures are a good approximation of local patterns, Figures 3.22 through 3.24 show isolations of recent seasonal trends. Specifically, Figure 3.22 illustrates that the increase in maximum temperatures in Figure 3.21 is due largely to increases in winter and spring temperatures, whereas Figure 3.23 suggests that conspicuous differences in summer and fall minima are obscured in Figure 3.21 by high variability in spring and longer term cycles in winter, and Figure 3.24 shows what may be a slight tendency towards less summertime precipitation despite little trend across annual data.

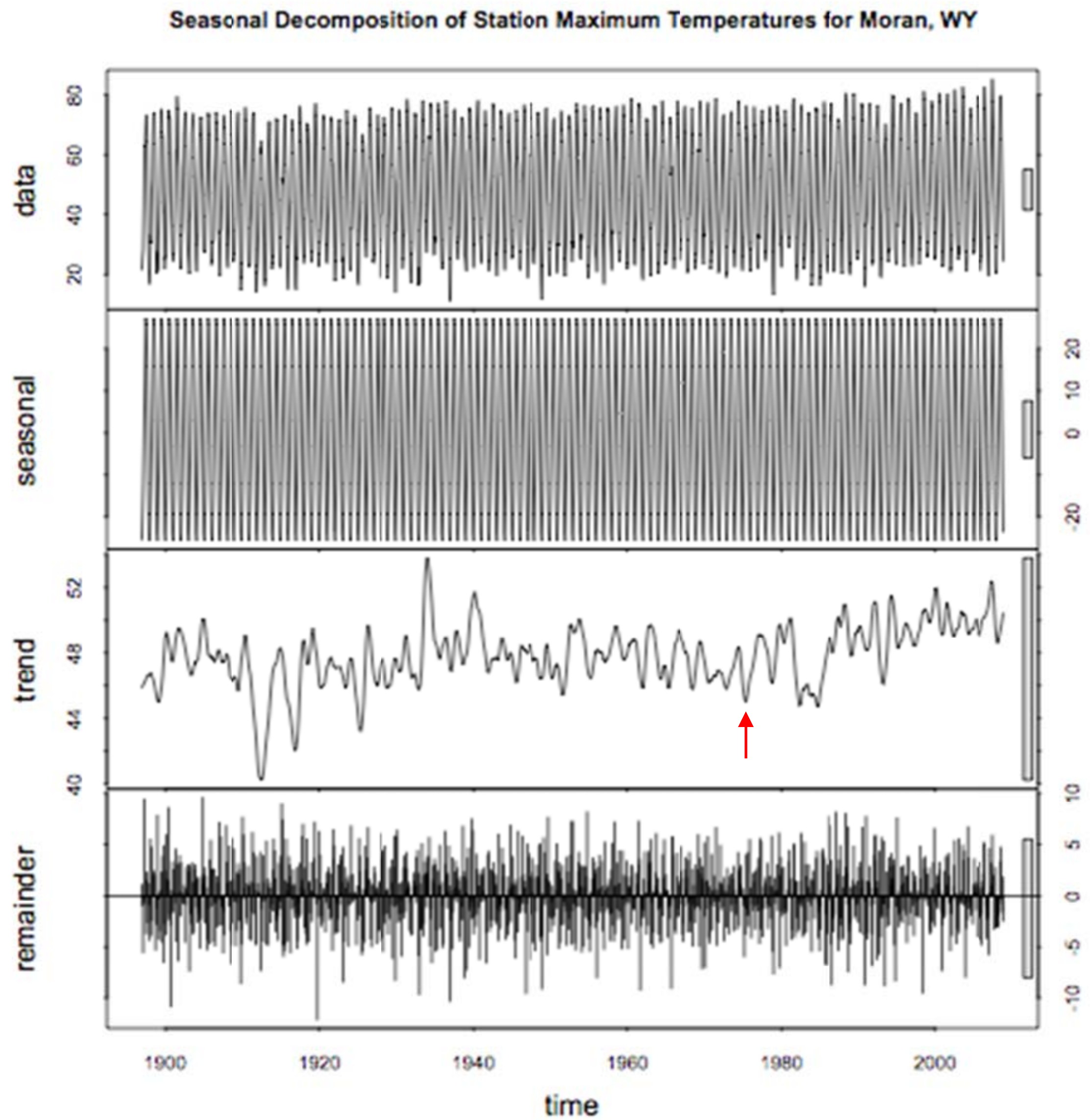

Figure 3.18. Seasonal decomposition of long-term monthly maximum temperatures in degrees Fahrenheit for Moran, Wyoming showing estimated change point (arrow). After the mid-1970s, an increase in maximum temperature is evident in the long-term record.

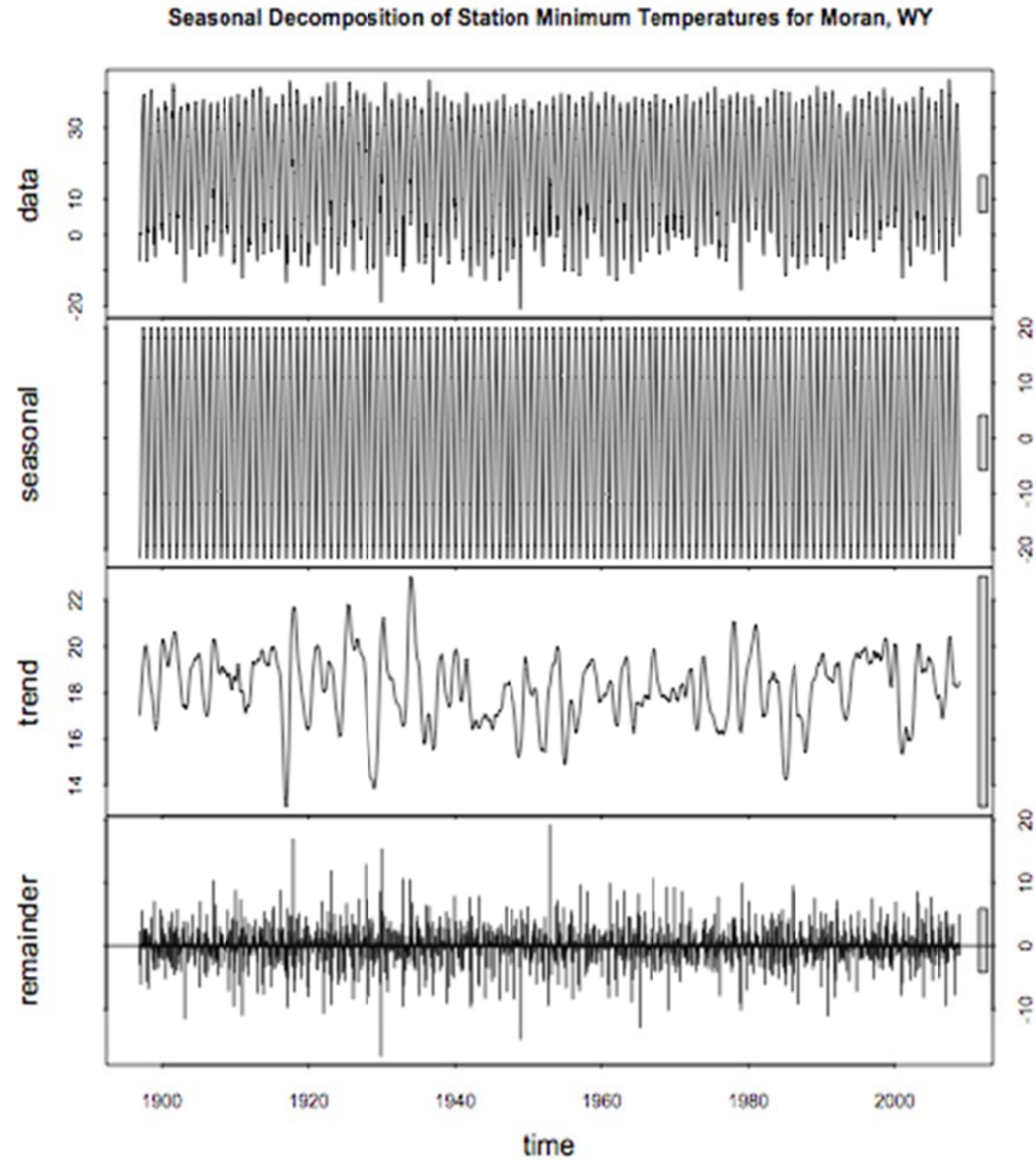

Figure 3.19. Seasonal decomposition of long-term monthly minimum temperature in degrees Fahrenheit for Moran, Wyoming. No clear changes are evident in this series.

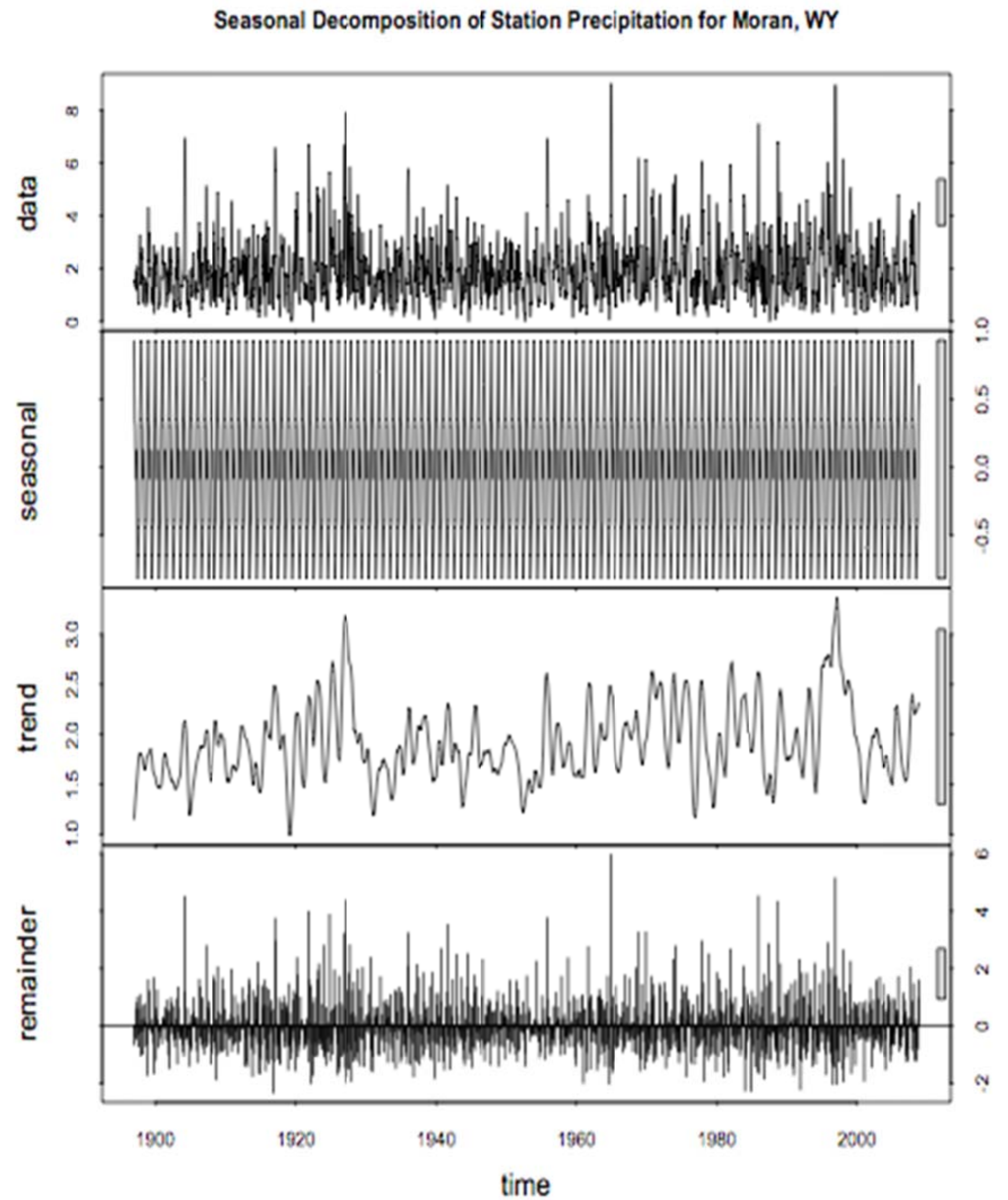

Figure 3.20. Seasonal decomposition of long-term monthly precipitation in inches for Moran, Wyoming. No clear changes are evident in this series.

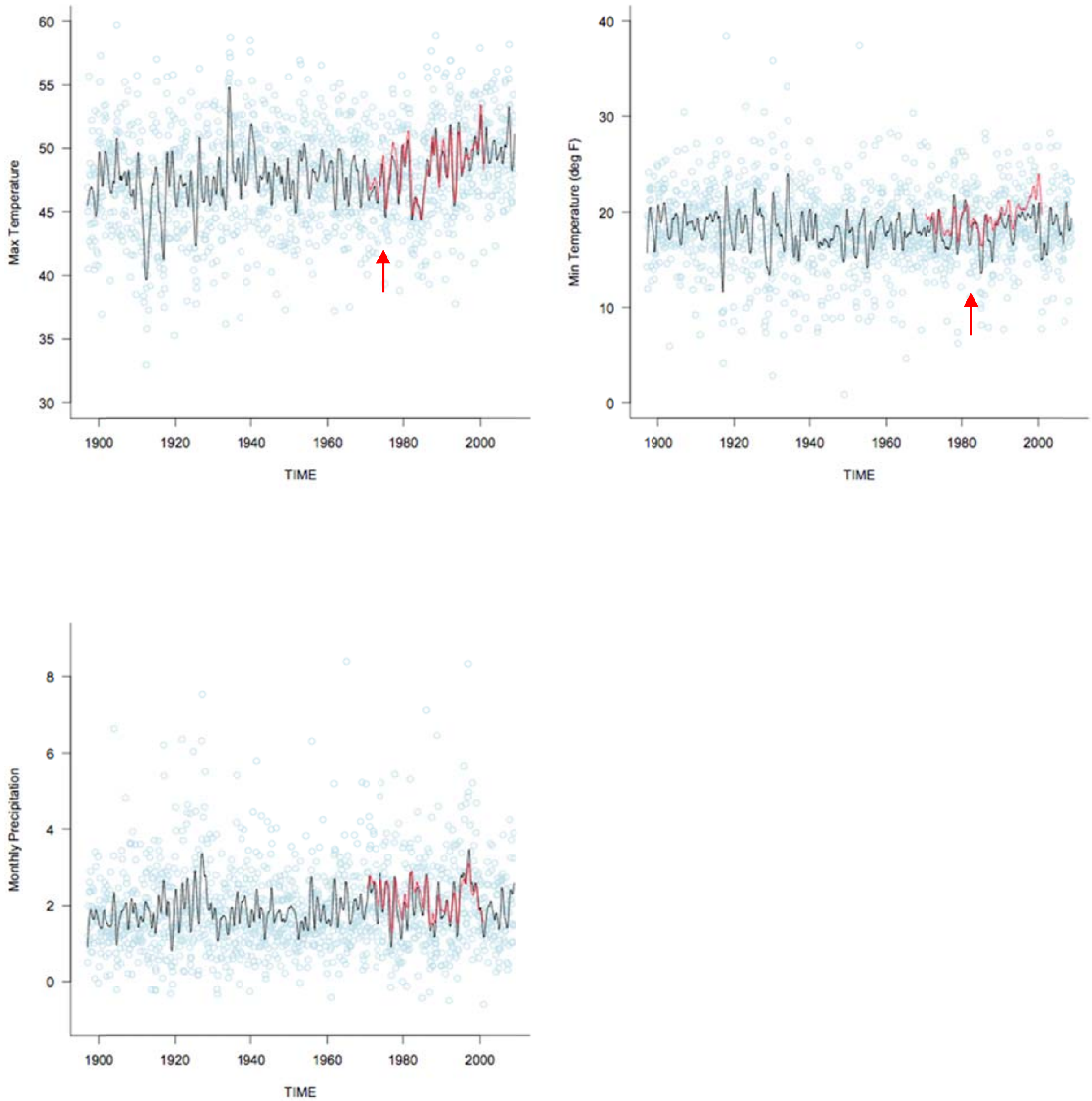

Figure 3.21. Seasonal trends in long-term monthly temperature (maximum and minimum; degrees Fahrenheit) and precipitation (inches) for Moran, Wyoming, showing recent (1971-2000) regional trends overlain in red. Arrows denote estimated regional change points in red lines.

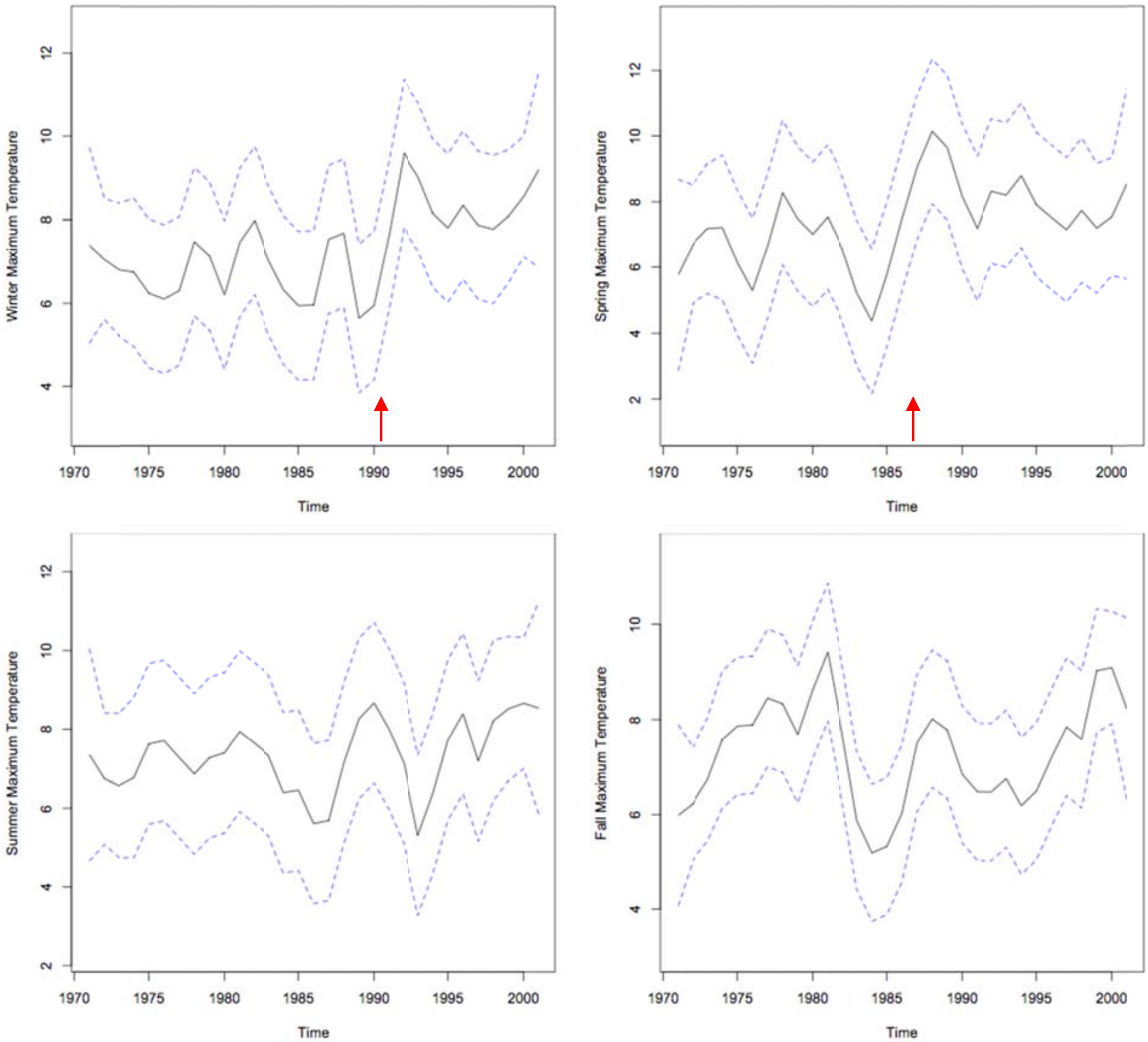

Figure 3.22. Recent (1971-2000) seasonal trends, 90 percent confidence limits (blue dotted lines), inter-annual means (dashed green lines) and estimated change points (red arrows) for average monthly temperature (degrees Celsius) maxima for Teton region.

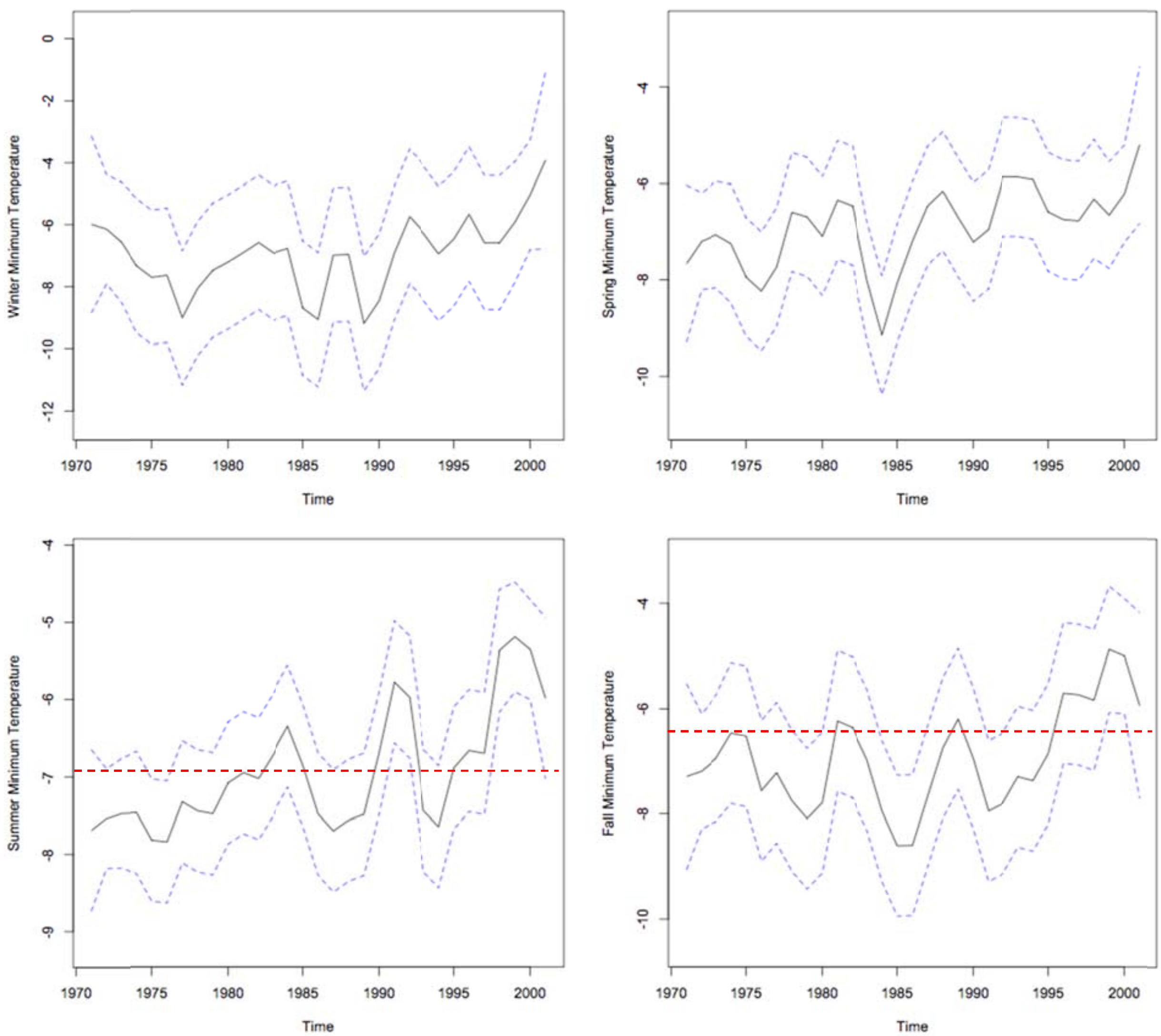

Figure 3.23. Recent (1971-2000) seasonal trends and 90 percent confidence limits (blue dotted lines) for average monthly temperature (degrees Celsius) minima for Teton region. Inter-annual changes in the time series may be considered significant when the lower (or upper) confidence limit exceeds the upper (or lower) limit from a previous year (dashed red lines).

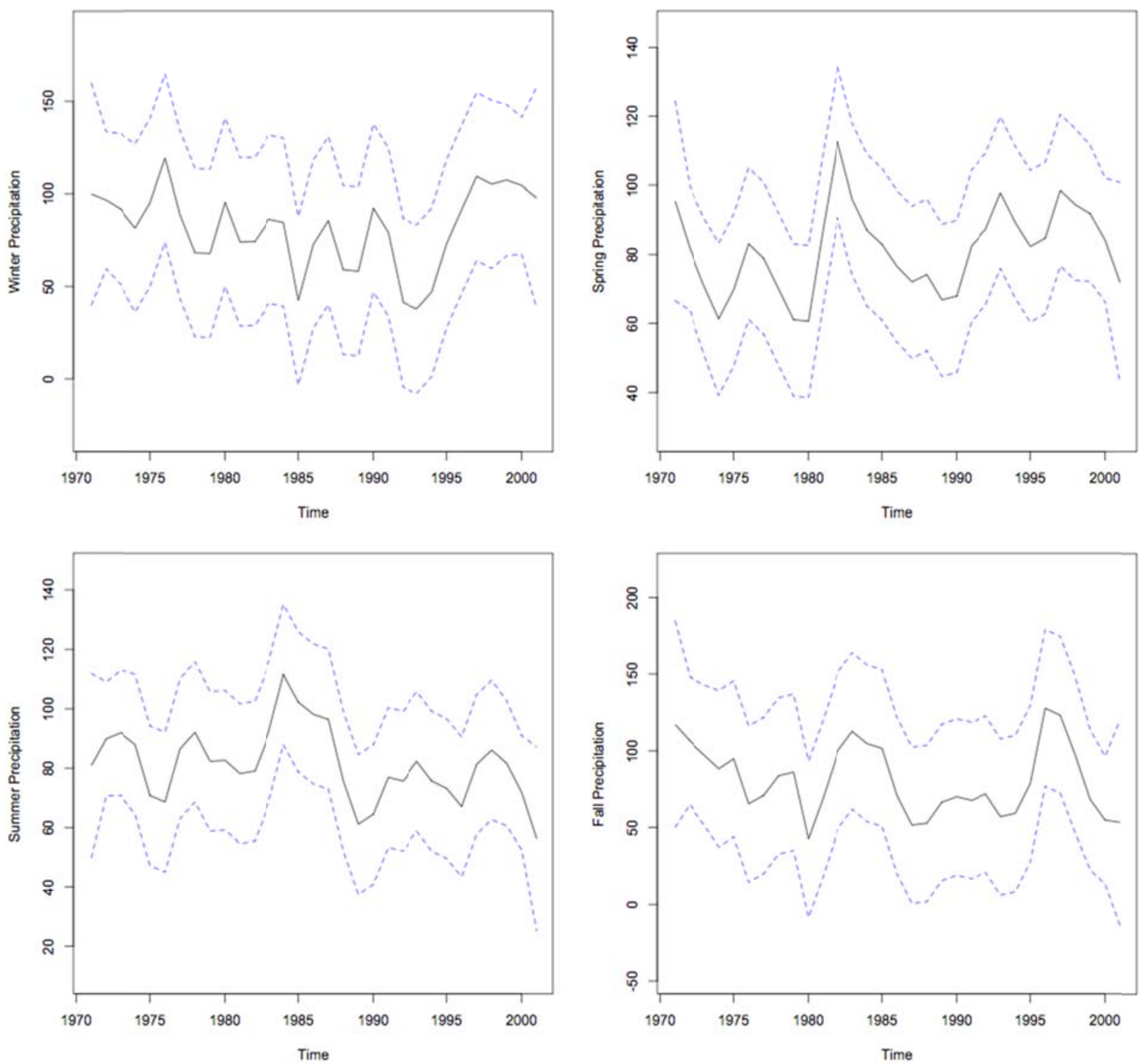

Figure 3.24. Recent (1971-2000) seasonal trends and 90 percent confidence limits (blue dotted lines) for average monthly precipitation (mm) for Teton region.

Summary and Conclusions

Although the mechanisms driving many of the observed patterns remain unclear, recent warming trends are evident in the observed historical climate record for GRTE. While the observed increases may be small, the timing of the increases, during the winter and spring snowmelt period or during periods of annual moisture stress, highlights potential for serious alteration of the regional water cycle if current trends continue. This long-term analysis was performed on only one climate station, so more widespread comparison to other long-term records in the region would bolster the findings described here. A key assumption is that historical climate patterns over the past century can be used as reference to detect change. While this may be subject to debate in the broader climate change literature, as the past century represents the conditions under which present day park visitors know GRTE, such assumptions may well be reasonable.

Spatial Patterns of Climate Change

As a semi-arid ecosystem, GRTE is sensitive to changes in the magnitude (mean) and range (maximum to minimum) of annual climate, as these factors influence the distribution and availability of water resources as well as the length and extent of annual growing season for plants and animals. Elements of the water cycle are critical for the maintenance of alpine glaciers within GRTE as well as the river channel morphology whose rapids, pools, and runs contribute (rafting, fishing, sediment transport) to the iconic local landscape and regional economy. Summaries of broad regional trends alone may obscure substantial differences in climate trends in local landscapes, which may decouple the behavior of local tributary watersheds of the Snake River.

Methods

Data were obtained from the PRISM Climate Group web server at Oregon State University and converted to ASCII text files for analysis. All statistical analyses were performed using the basic statistical packages within the open-source statistical software R Project for Statistical Computing (R Development Core Team, 2010). Regression slopes and p-values were then imported into ESRI ArcGIS 9.3 for spatial interpretation and further analysis.

Analysis of the historical climate record suggests increases in regional temperatures (maxima and minima) averaged across the Snake River basin starting in the mid-1970s. However, topographic variation among tributary watersheds of the Snake River drainage (Figure 3.25) can substantially influence local climatic patterns. Interpolation models use topography to estimate temperature and precipitation between ground observations across landscapes with large amounts of relief (i.e. the PRISM data set; Daly et al., 2008). Maps of the PRISM climate data set were used to assess how closely local landscapes reflect regional climatic trends from 1971 to 2000.

The analysis rested on the simplifying assumption that climate patterns could be decomposed into three components (Seasonal + Trend + Remainder). Potential trends must be distinguished from normal seasonal highs and lows as well as approximate decadal (three to seven year) cycles of warming and cooling due to El Niño Southern Oscillation (ENSO), or episodic volcanic events. Using the record of monthly maximum and minimum temperatures as well as total precipitation, seasonal cycles were estimated and removed from each time series. Locally estimated scatterplot smoothing (LOESS) was then used to smooth anomalous values and detect trends and change points in each time series remainder over five year spans.

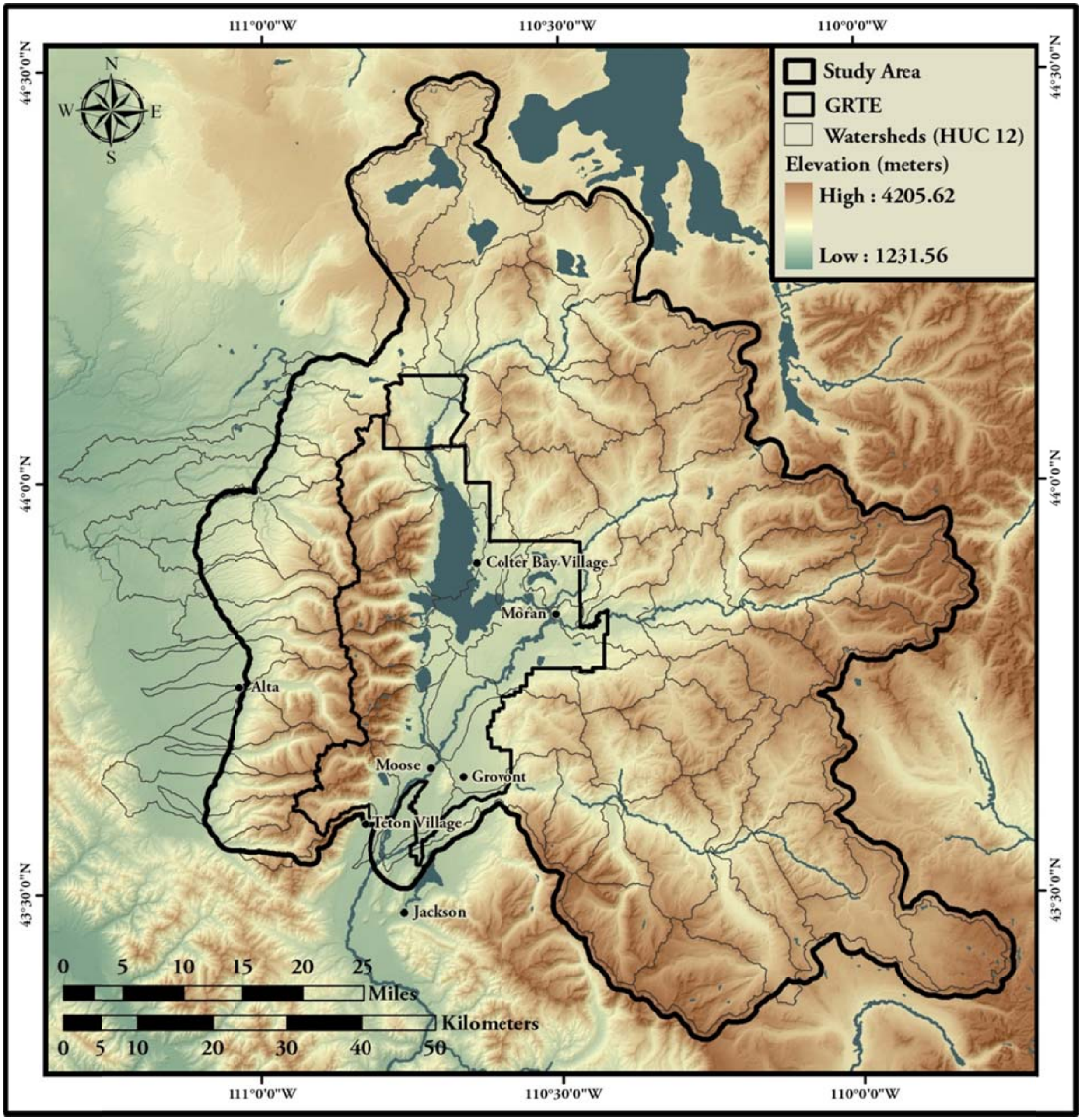

Figure 3.25. Topographic relief of the Teton region study area defined by watershed boundaries and Grand Teton National Park.

Analyses of regional trends suggest increases in temperature maxima and minima, but not for precipitation. After extracting seasonal cycles of temperature or precipitation, differences between regional means and local (approximately four square kilometer) cell values were analyzed for trends using simple linear regression. This analysis assumes that either local areas have the same relationship to the regional mean through time (e.g. they are always warmer or colder) or that this relationship changes without a predictable pattern. An increasing trend would suggest the regional mean is increasing faster than local areas (e.g. slower local warming or no local change), whereas a decreasing trend might indicate an even more rapid rate of local change than the regional pattern would suggest (i.e. a hotspot for change).

Although management options for National Park Service staff to control climatic factors within the park are limited to nonexistent, understanding the park's climatic context is relevant for assessing the vulnerability of certain ecosystems to further management action (including inaction) and identifying ecosystems that may experience chronic stress as a result of gradual shifts or alterations to seasonal patterns of snowmelt, plant green up, or water use.

Results

Average monthly temperature maxima, minima, and precipitation across the study region are shown in Figures 3.26 through 3.28. As expected, mountainous areas show the lowest maximum and minimum temperatures and lower valleys show the highest values, but areas with the lowest maxima are not necessarily those with the lowest minima. Precipitation exhibits a similar spatial pattern where the Teton Range and Yellowstone Plateau experience the most precipitation, creating drier rain shadows in more easterly valleys.

Figures 3.29 through 3.31 show the seasonally decomposed regional trends of monthly maximum and minimum temperature and precipitation throughout the study period, respectively. Both temperature summaries suggest increasing trends across the 30-year study time span starting at different times, whereas no trend is evident in the precipitation record.

Figure 3.32 provides an example of how regional means and local climate values were analyzed for a single four square kilometer pixel. Monthly temperature maxima for this local landscape were corrected for expected seasonal variation, subtracted from corresponding regional averages, and the difference was tracked through time. If regional temperature averages increased faster than local changes, a large positive trend would be obtained (blue areas in Figures 3.33, 3.34, 3.36, and 3.37). Negative trends (red areas in Figures 3.33, 3.34, 3.36, and 3.37) occurred when local temperatures rose faster than regional averages. In this case, the local maximum temperatures rose from approximately 1.5 degrees Celsius (2.7 degrees Fahrenheit) to 0.5 degrees Celsius (0.9 degrees Fahrenheit) below the regional average across the study period, indicating a very rapid warming. For precipitation values, significant trends occurred when local landscapes experienced a consistent change distinct from the inconsistent regional pattern.

Trends in local precipitation (Figures 3.33 through 3.35) suggest an increase in the southeastern portion of the study area has been offset by a corresponding decrease in precipitation over the Teton Range. In contrast to the homogenization of thermal patterns, the Snake River Valley has not experienced an increase in local precipitation even though it remains one of the driest parts of the study area, and overall precipitation decreases more than doubled increases, suggesting a gradual drying of the basin.

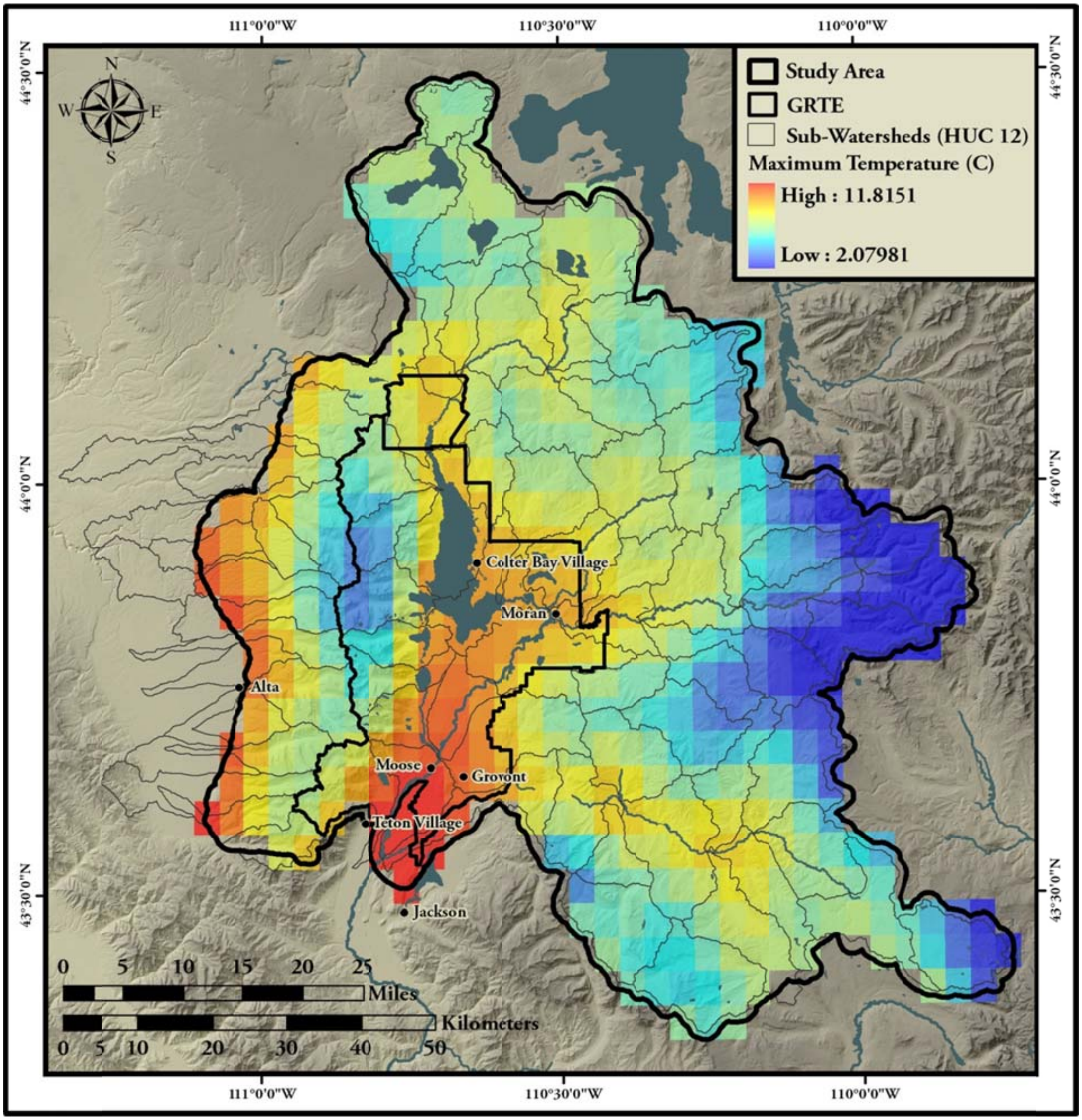

Figure 3.26. Regional average of recent (1971-2000) monthly maximum temperature (degrees Celsius).

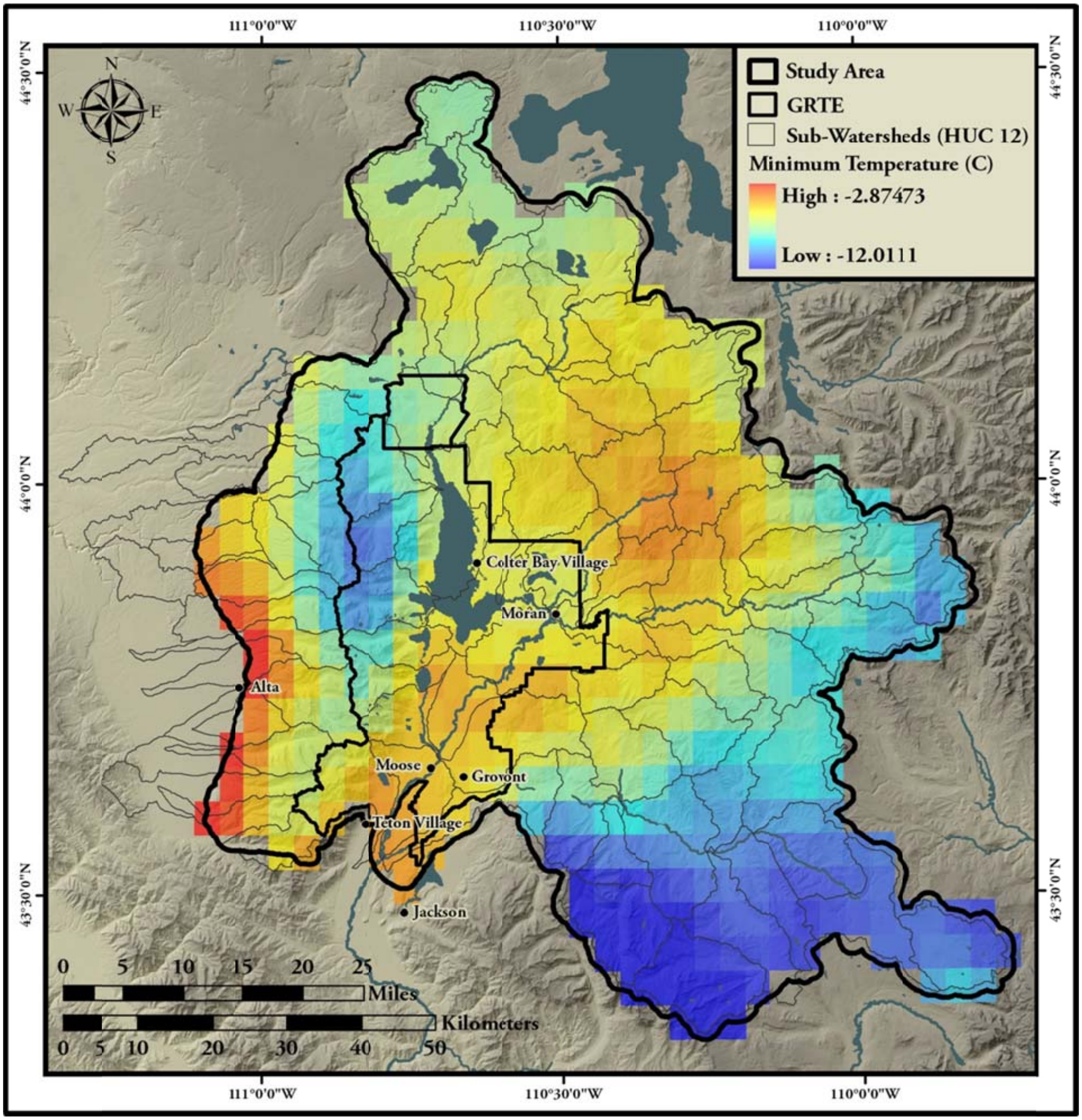

Figure 3.27. Regional average of recent (1971-2000) monthly minimum temperature (degrees Celsius).

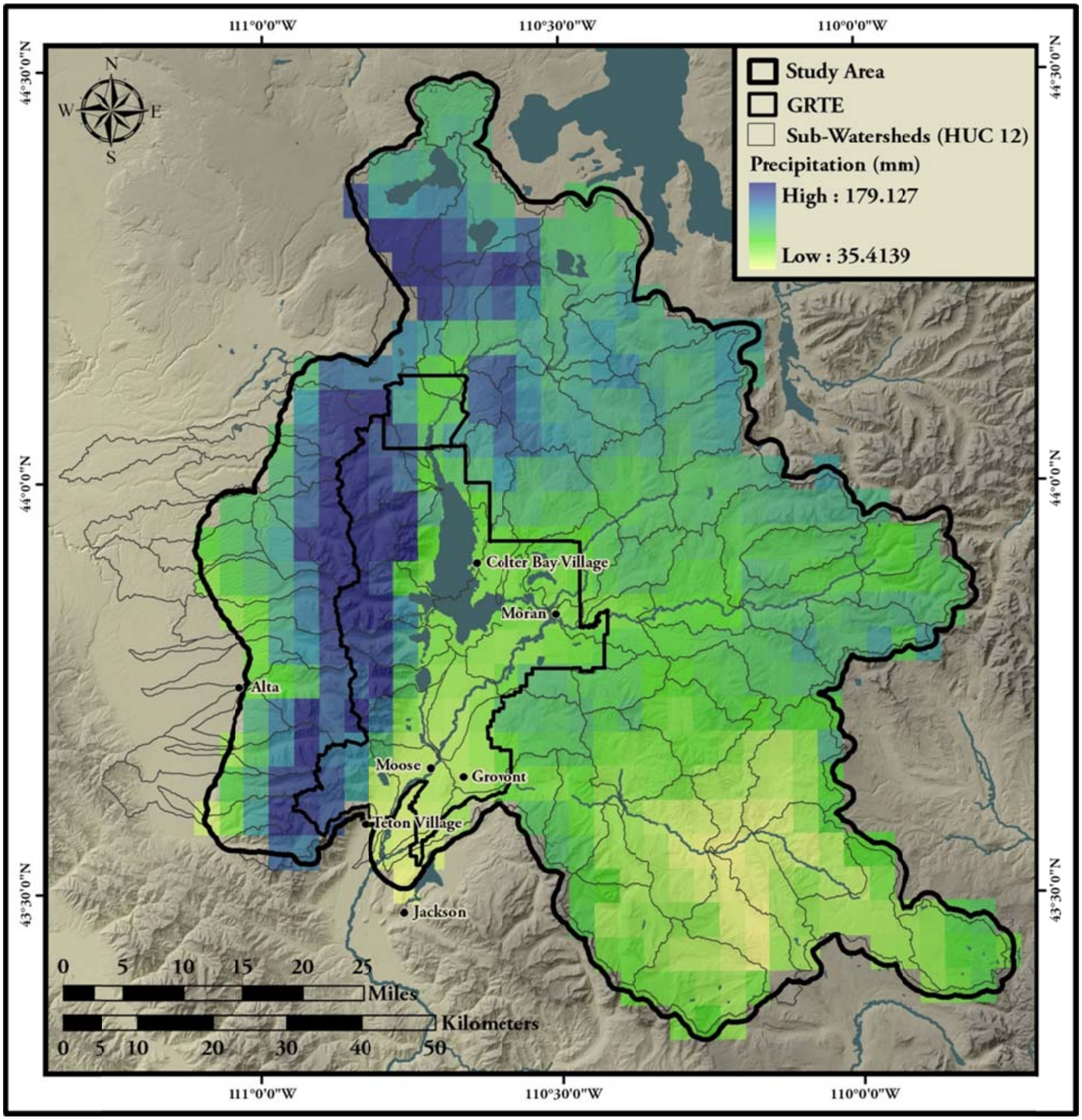

Figure 3.28. Regional average of recent (1971-2000) monthly precipitation (mm).

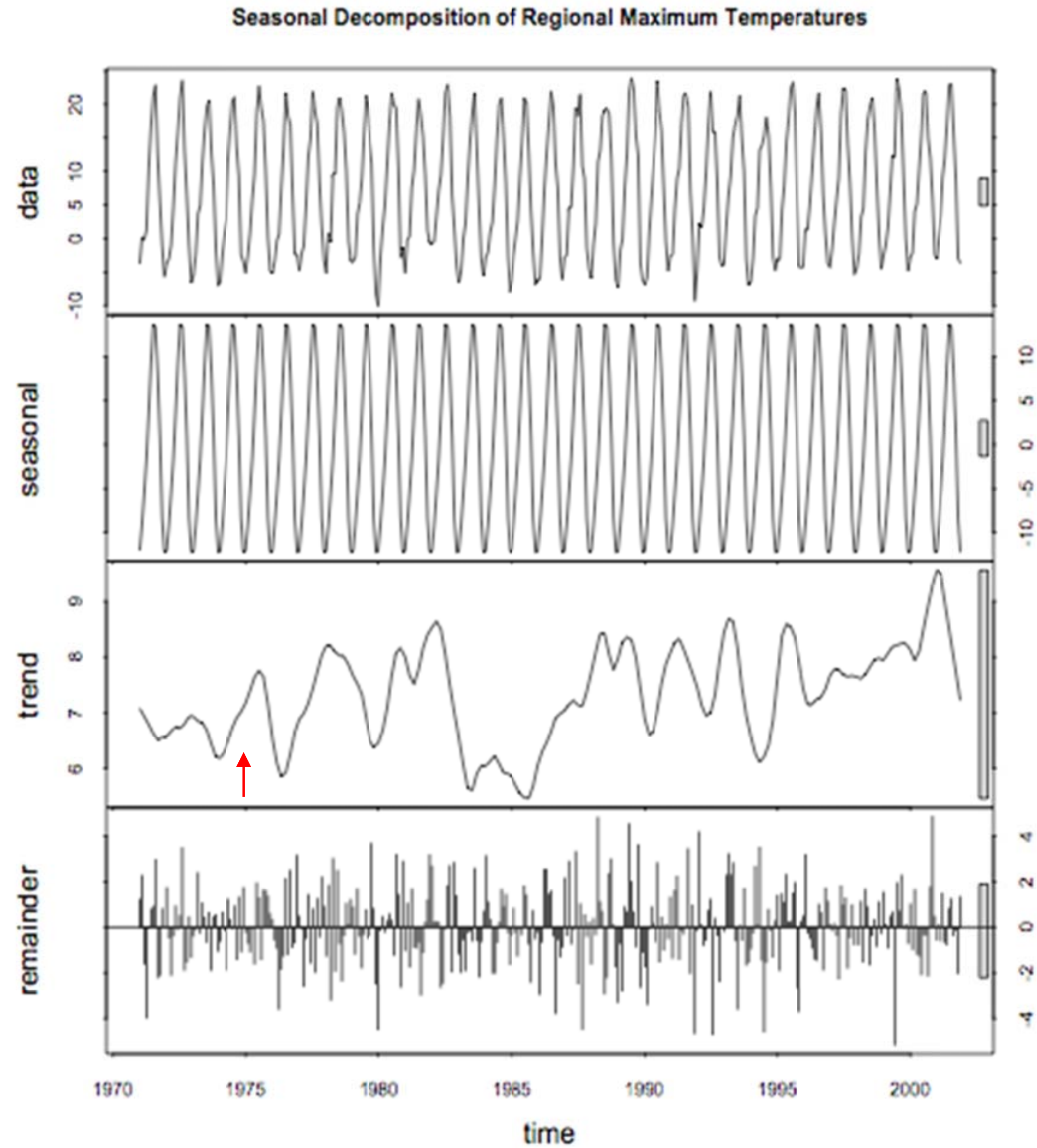

Figure 3.29. Seasonal decomposition of regional monthly maximum temperature (degrees Celsius) record for Teton region showing estimated change point (red arrow).

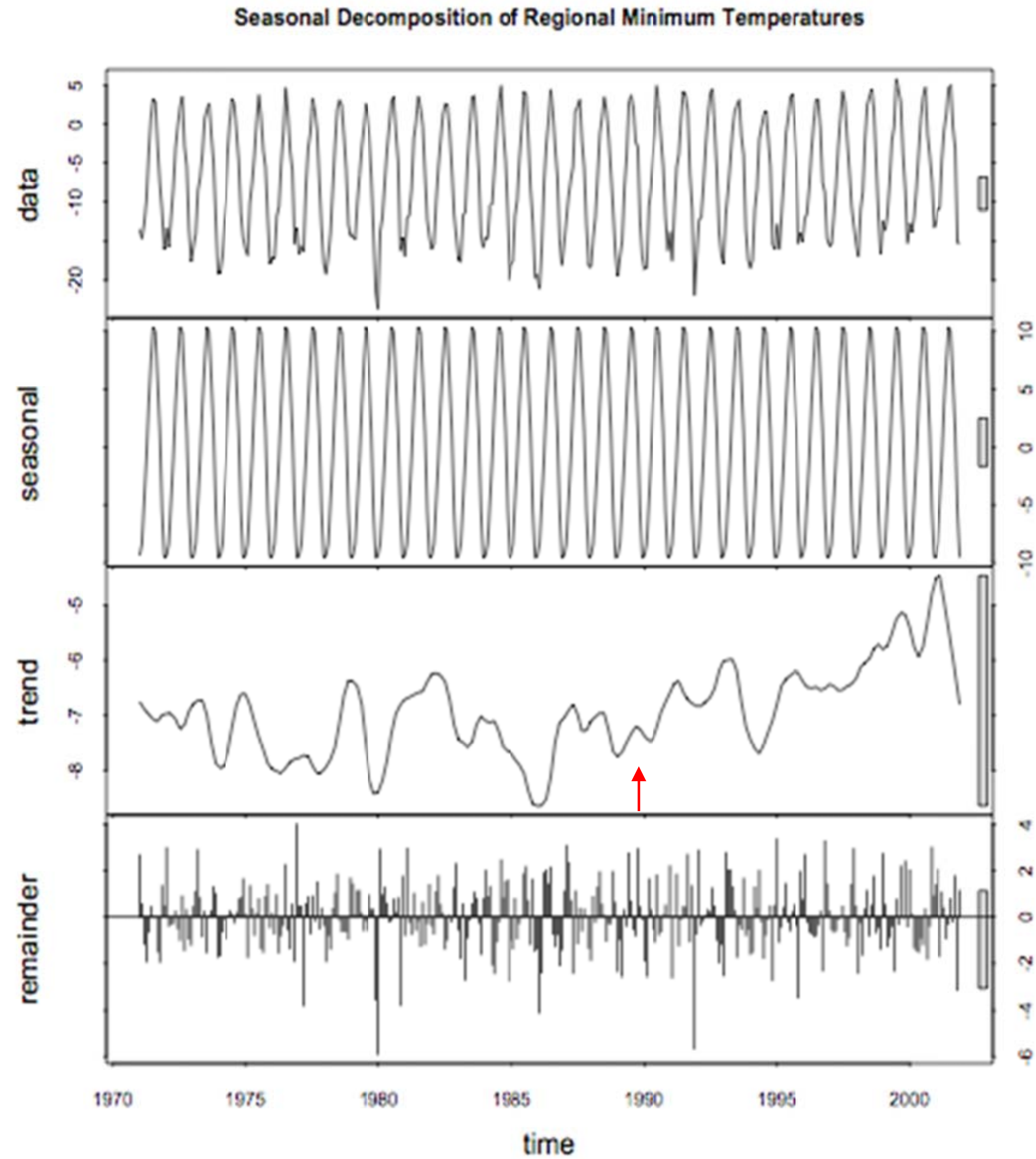

Figure 3.30. Seasonal decomposition of regional monthly minimum temperature (degrees Celsius) record for Teton region showing estimated change point (red arrow).

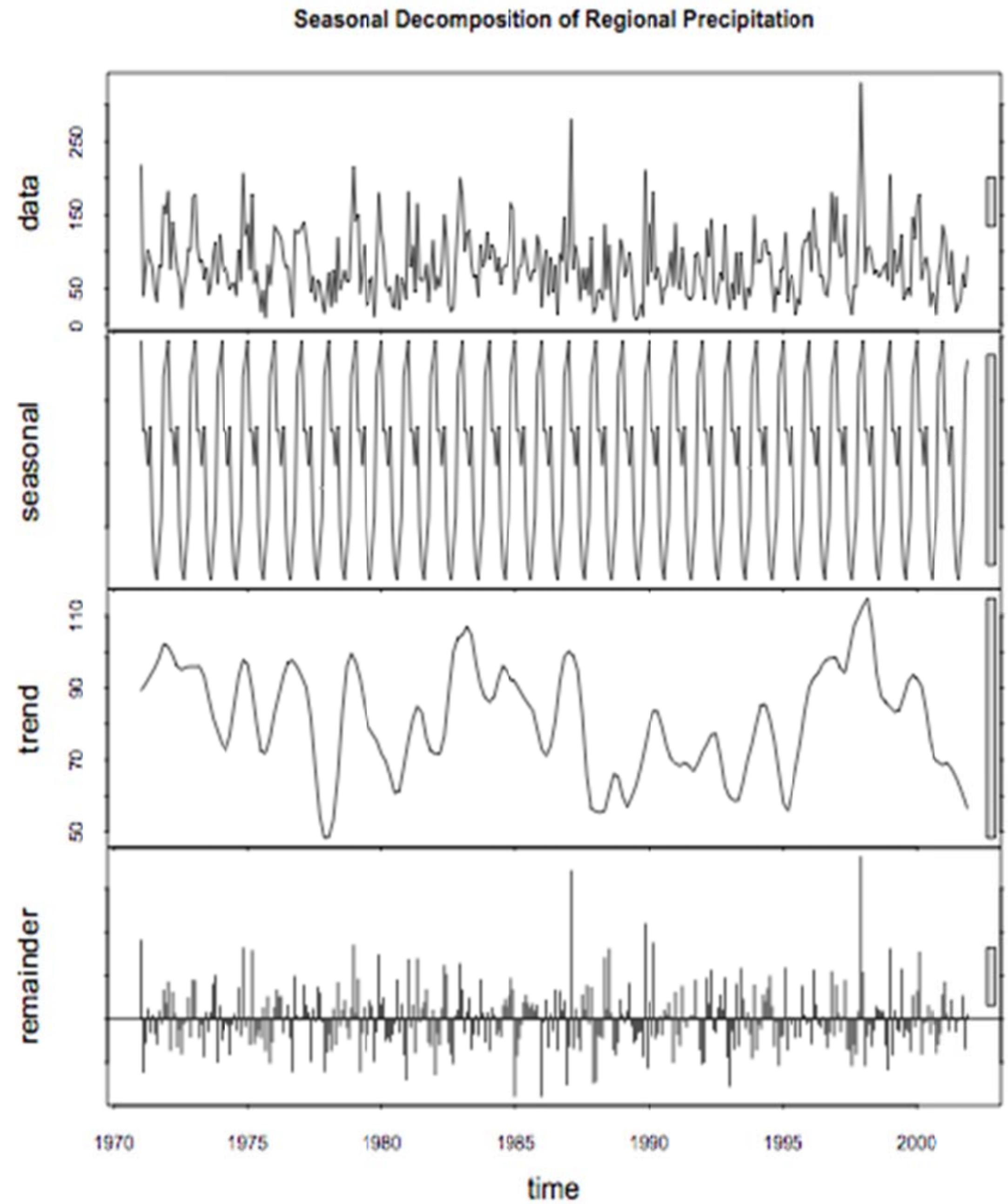

Figure 3.31. Seasonal decomposition of regional monthly precipitation (mm) record for Teton region.

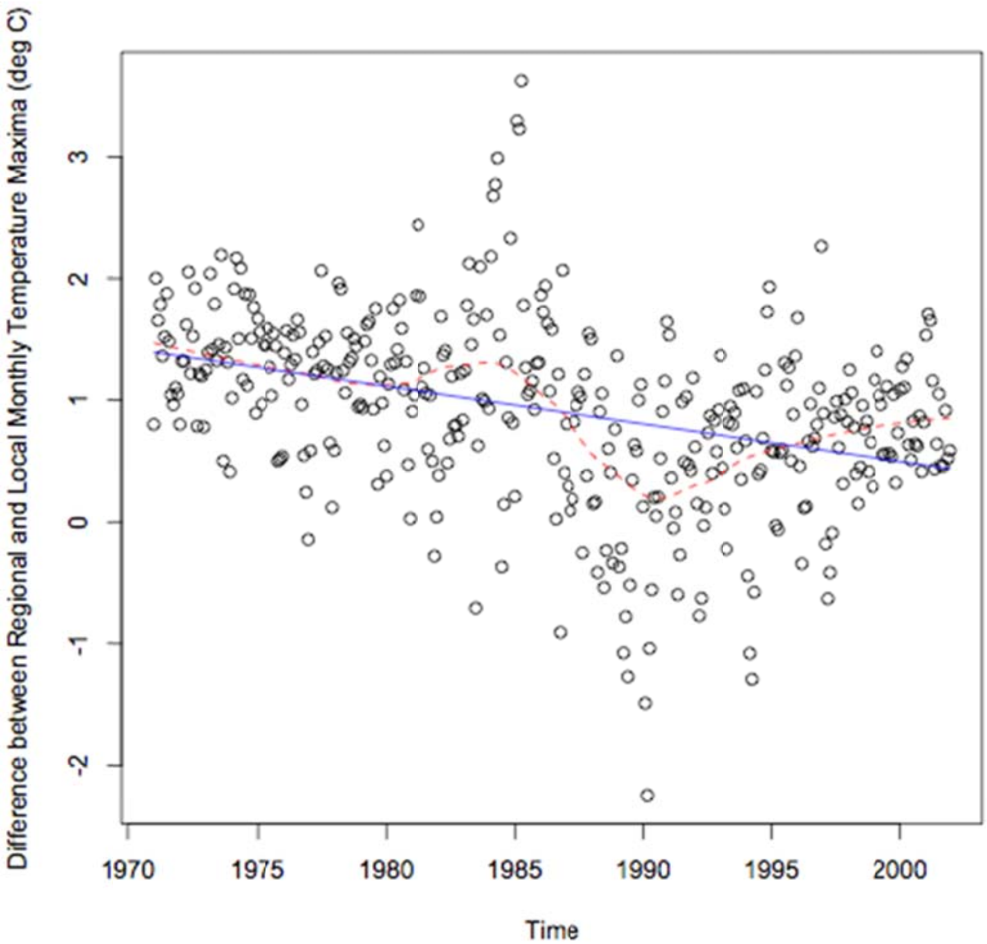

Figure 3.32. Scatterplot showing example trend in the difference between regionally averaged monthly temperature maxima and locally estimated temperature values. Blue line describes a decreasing linear trend, dashed red line shows locally estimated scatterplot smoothing (LOESS) fit indicating some cycles of variation in the rate of decrease.

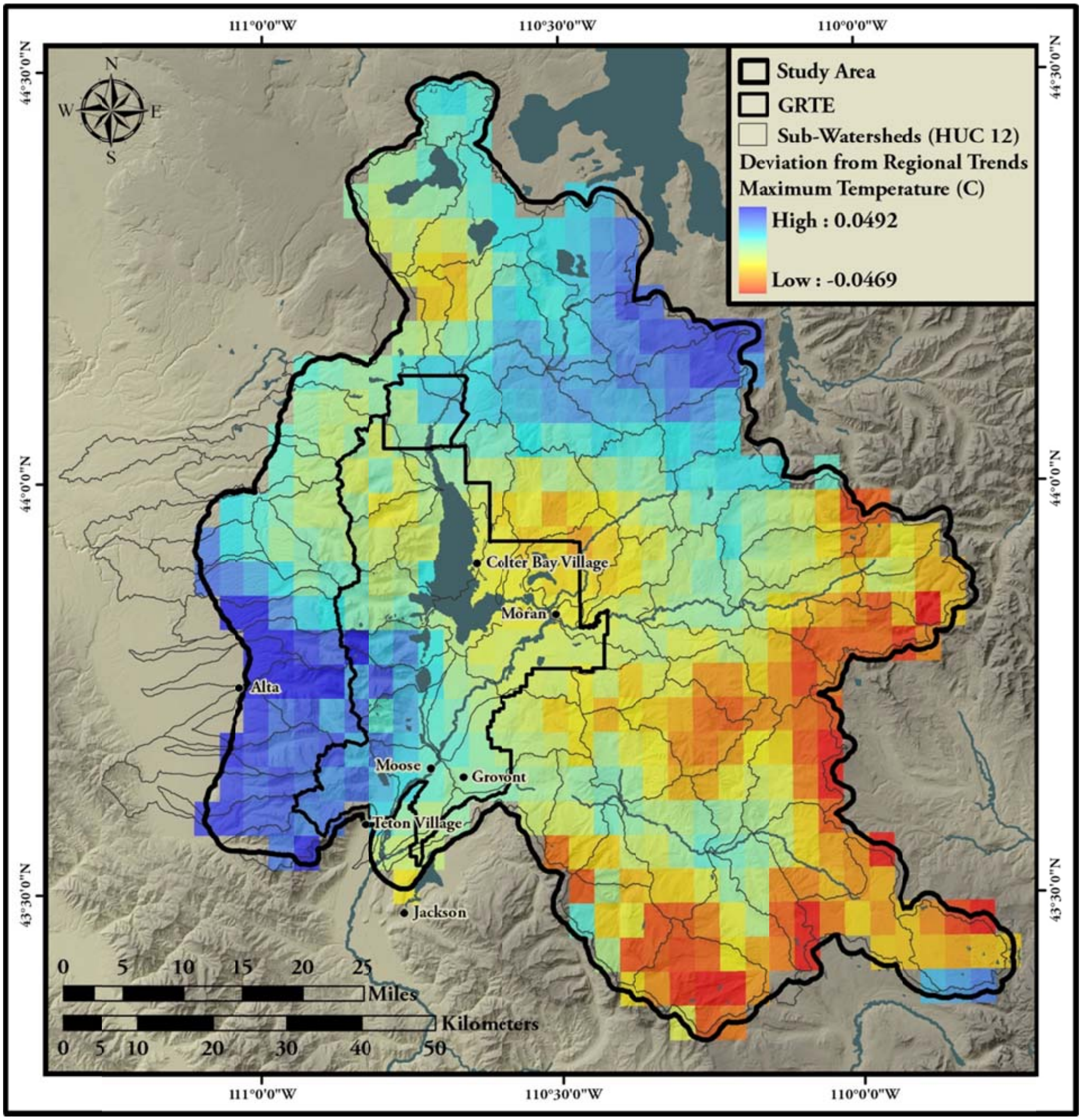

Figure 3.33. Recent (1971-2000) trends in difference between local climate and regional averages. Positive values (blue) indicate a slower rate of warming (or no change) relative to regional trends, whereas negative values (red) indicate a more rapid warming.

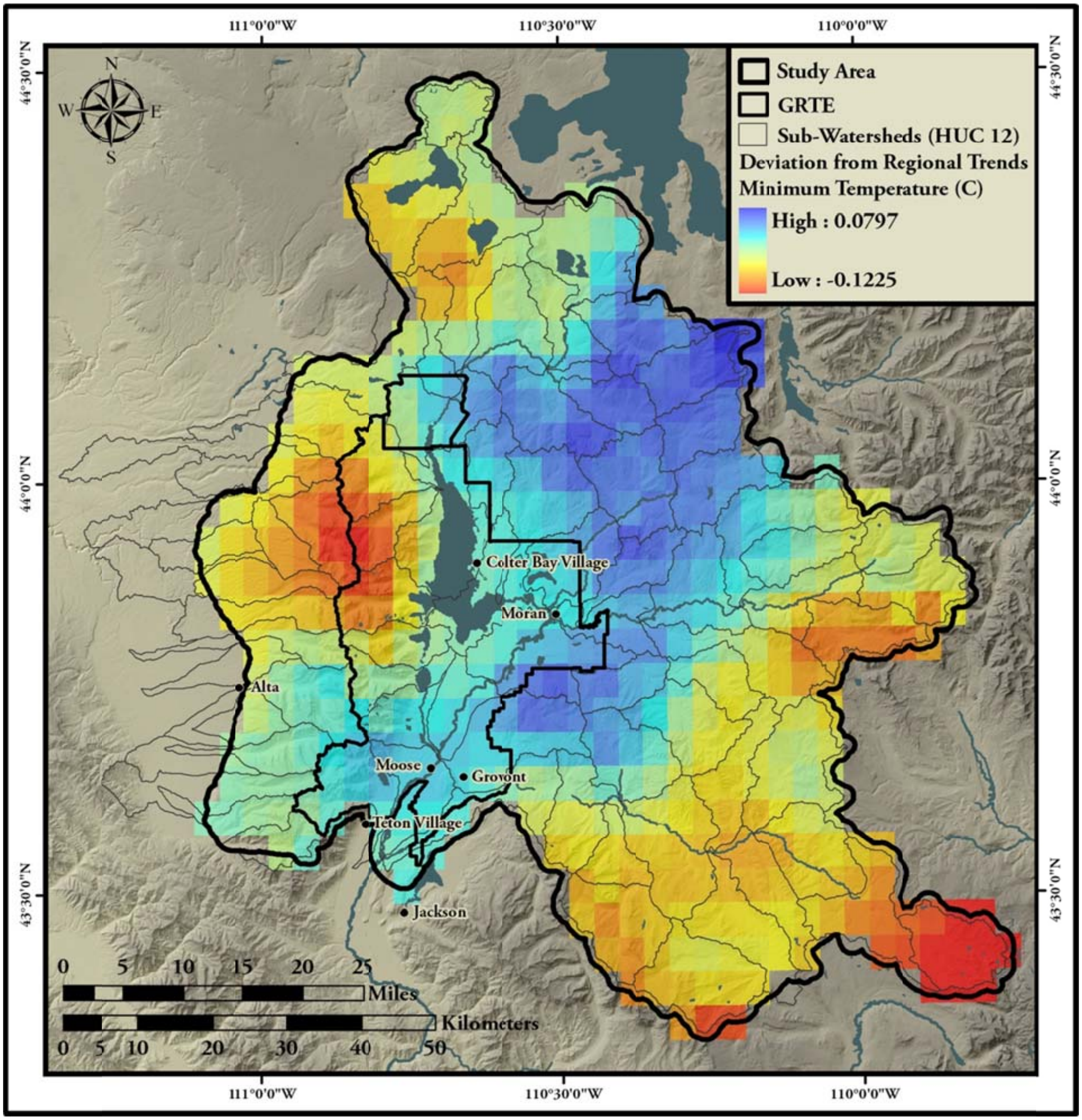

Figure 3.34. Recent (1971-2000) trends in difference between local climate and regional averages. Positive values (blue) indicate a slower rate of warming (or no change) relative to regional trends, whereas negative values (red) indicate a more rapid warming.

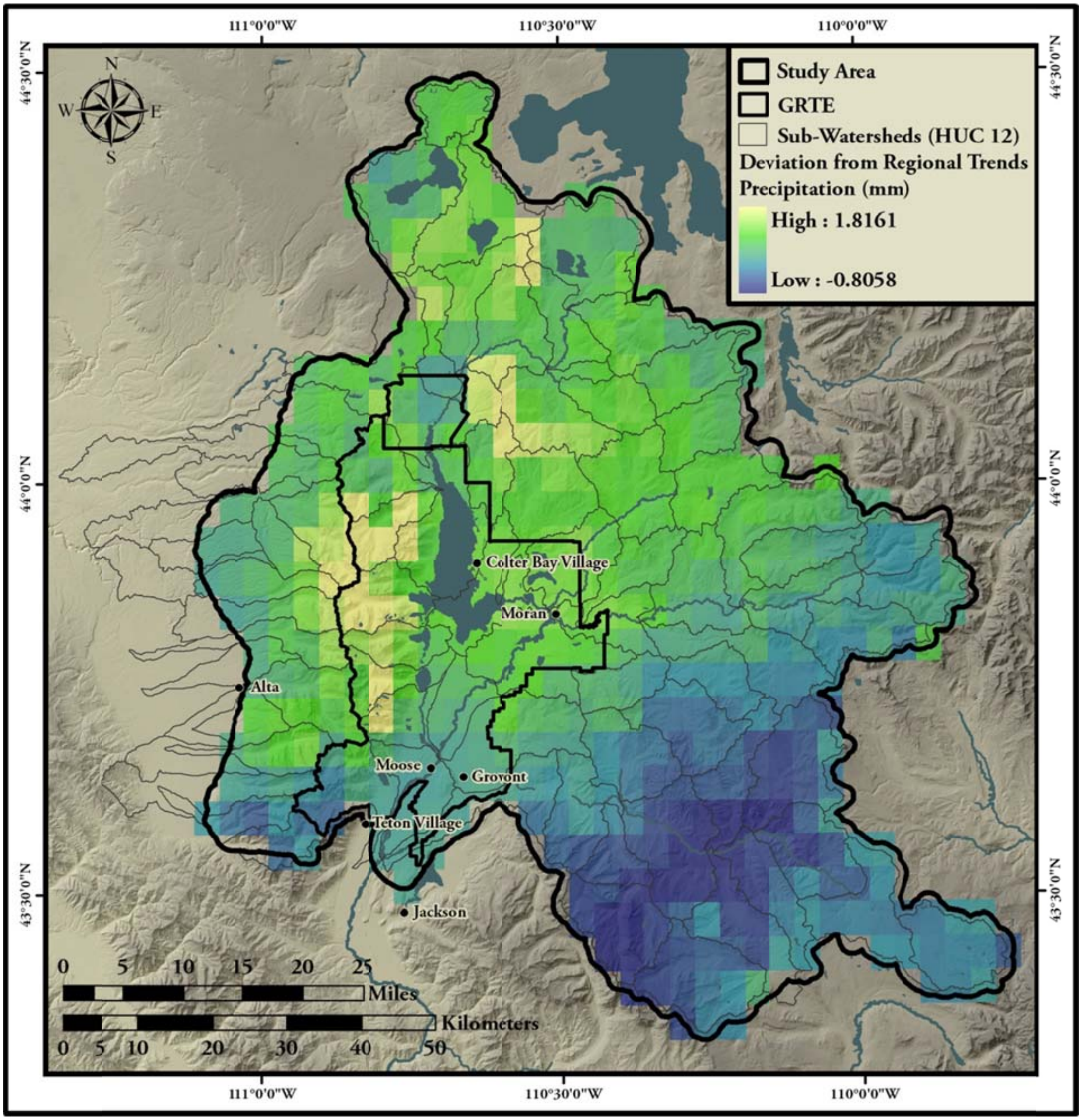

Figure 3.35. Recent (1971-2000) trends in difference between local climate and regional averages. Extreme values indicate a significant departure (positive = drier, negative = wetter) from unchanging regional patterns.

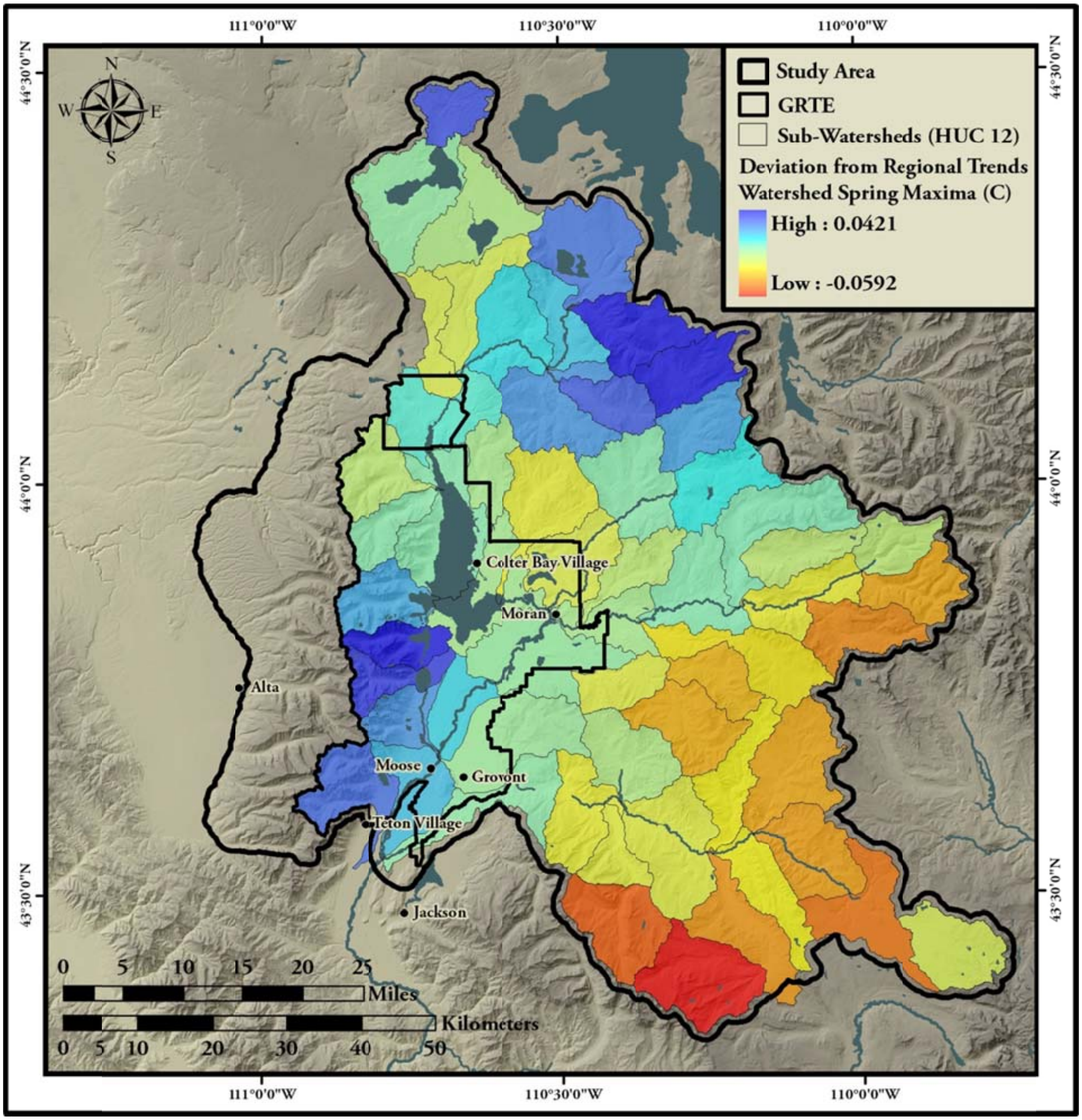

Figure 3.36. Recent (1971-2000) trends in average difference between local climate and regional means for the Snake River tributary watershed segments. Positive values (blue) indicate a slower rate of warming (or no change) relative to regional trends, whereas negative values (red) indicate a more rapid warming.

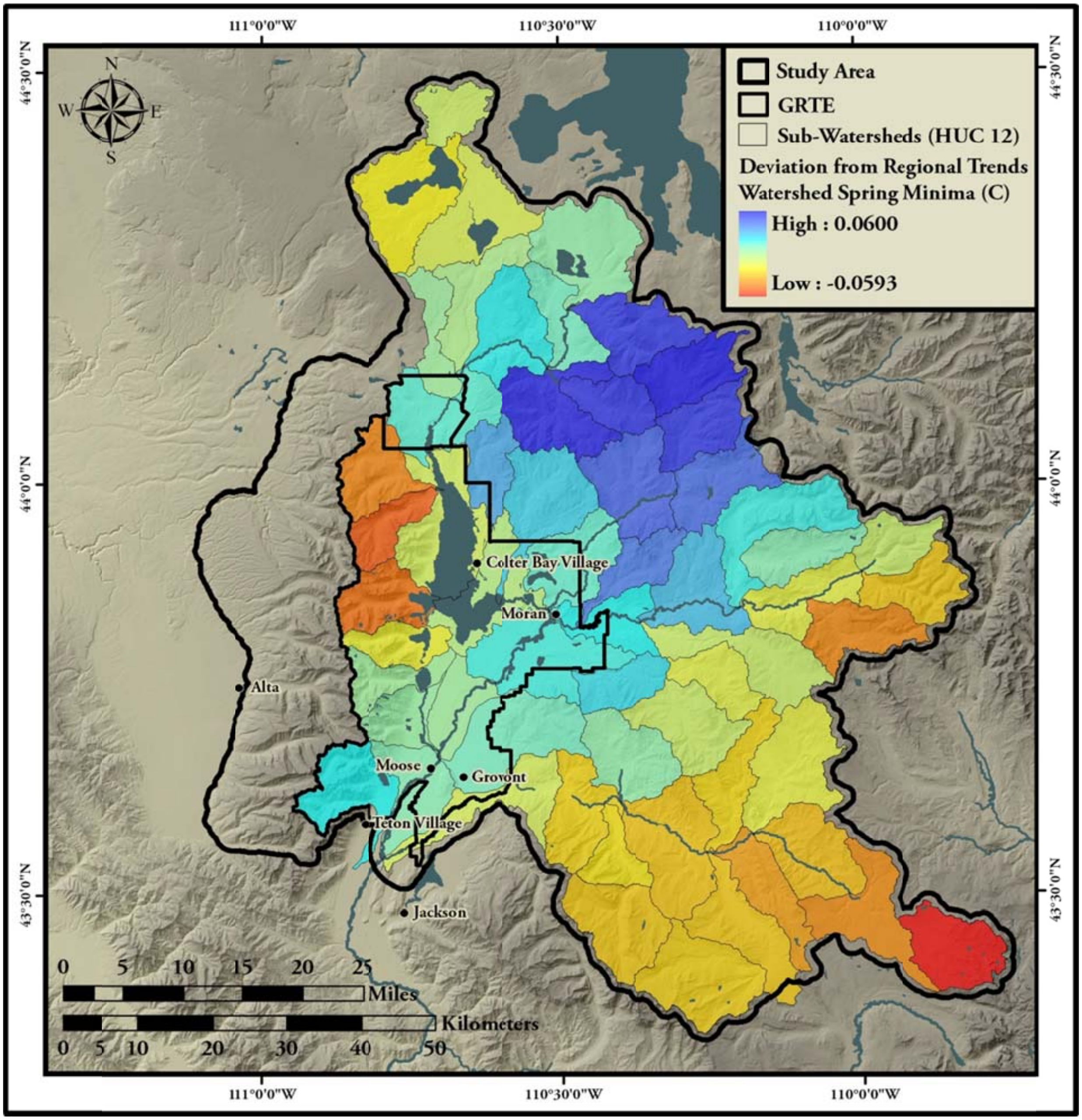

Figure 3.37. Recent (1971-2000) trends in average difference between local climate and regional means for the Snake River tributary watershed segments. Positive values (blue) indicate a slower rate of warming (or no change) relative to regional trends, whereas negative values (red) indicate a more rapid warming.

Figures 3.36 through 3.38 summarize the patterns from Figures 3.33 through 3.35 by tributary watershed segment. The broader climatic trends suggest that the period from 1971 to 2000 produced a pronounced warming trend in the northern Teton Range combined with reduced precipitation. This combination should exacerbate the retreat of alpine glaciers. Notably, the Pacific Creek drainage in the north central portion of the basin has experienced lower temperature increases relative to the rest of the region with a pronounced drying. Pacific Creek supplies the majority of sediment to the Snake River below Jackson Lake Dam. In contrast, the southeastern tributaries appear to have experienced accelerated warming and more precipitation relative to regional patterns. If similar trends continue, earlier spring snowmelt and flooding in the southeastern tributaries and later sediment delivery by Pacific Creek may be expected. Such changes could potentially lead to pronounced sediment accumulation in the Snake River main stem, and alteration of river channel morphology.

Summary and Conclusions

Although the mechanisms driving many of the observed patterns remain unclear, recent warming trends are evident in the observed climate record for GRTE. While the observed increases may be small, the timing of the increases, during the winter and spring snowmelt period and their spatial distribution highlights potential for serious alteration of the regional water cycle if current trends continue. Uncertainty associated with these estimates comes from the generalized topographic models used in the PRISM data set. It remains unclear how precisely they capture local patterns of variation, or whether the general trend towards homogenization is a real phenomenon or the result of models based on spatial averages. In the end, the most effective test of these uncertainties would be strategically placed weather stations.

Trend in Surface Area of Glaciers

Glaciers are perennial masses of snow and ice that form in locations where the winter accumulation (snowfall) exceeds summer ablation (melting). The upper portion of the glacier where more snow accumulates than is lost each year is called the accumulation zone. In contrast, the lower portion of the glacier where more snow is lost than accumulates is called the ablation zone. When ablation is exactly balanced with accumulation, a glacier is in equilibrium and is neither advancing nor retreating (NPS, 2010g).

Because the two processes of accumulation and ablation are driven by the atmospheric environment, glaciers are important indicators of climate change (Hodge et al., 1998). The distribution of glaciers is a function of mean annual air temperature and annual precipitation, in addition to the terrain which influences incoming net radiation and accumulation patterns. Changes in atmospheric conditions, such as solar radiation, air temperature, precipitation, wind, and cloudiness, influence accumulation and ablation rates (NPS, 2010g; Zemp et al., 2008).

One of the most accurate measures of glacier change is mass balance. Mass balance quantifies the mass changes of a glacier because it accounts for the difference between accumulation and ablation. Mass balance is determined by measuring the amount of snow accumulation during winter and ice ablation the following summer. The difference between these two parameters is the mass balance. If ablation is greater than accumulation, than the mass balance of the glacier is negative and the glacier volume has decreased (NPS, 2010g). Although mass balance is often the most accurate

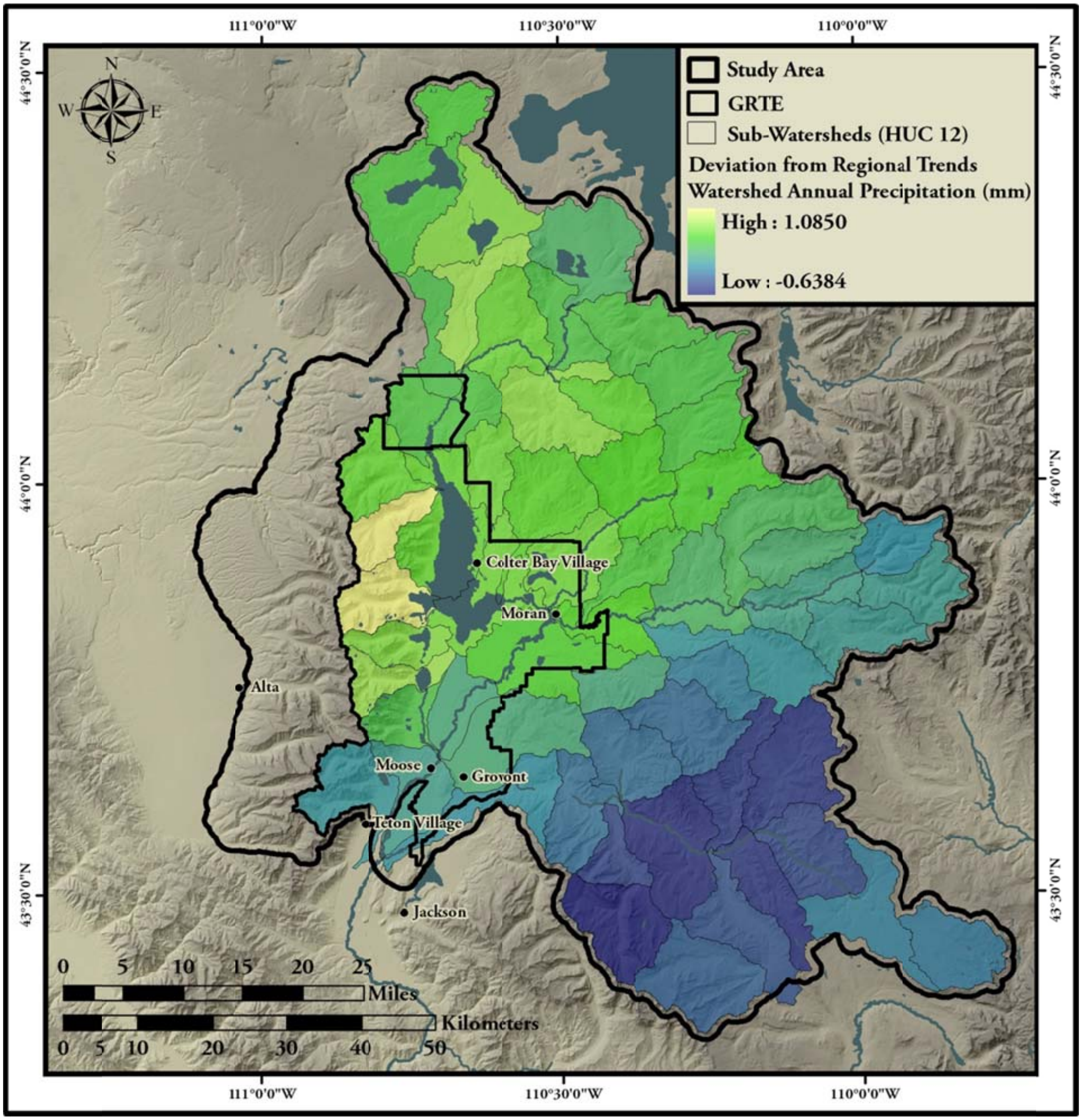

Figure 3.38. Recent (1971-2000) trends in average difference between local climate and regional means for the Snake River tributary watershed segments. Extreme values indicate a significant departure (positive = drier, negative = wetter) from unchanging regional patterns.

measurement of glacial change, it is difficult to measure (WWF, 2003). Therefore, glacier change is often monitored by recording the position of the glacier terminus. The measured distance to the ice front from a fixed position is the most common method. Repeat ground-based, aerial, or satellite photography is also used as an indicator of change (NPS, 2010g).

In the United States, glaciers are found in the Rocky Mountains, the Sierra Nevada

Range, the Cascade Range, and throughout Alaska. Glaciers in the Rocky Mountains and western coastal ranges have experienced considerable losses, and melting is rapidly accelerating in southern Alaska (WWF, 2003; EPA, 2010e). Since Glacier National Park was established in 1910, approximately two thirds of the glaciers have disappeared (Hall and Fagre, 2003). South Cascade Glacier in coastal Washington lost 62 feet (19 meters) of ice thickness between 1976 and 1995. Nearly all glaciers in Alaska are melting, and thinning rates are more than twice than those seen in previous decades (WWF, 2003). In 2007, the Intergovernmental Panel on Climate Change (IPCC) reported that glaciers are melting worldwide in response to higher temperatures since 1970, and in the United States, glacial melting is concentrated in national parks, a handful of which contain the vast majority (Saunders et al., 2009).

Methods

To evaluate the condition of glaciers in GRTE, a review of literature was conducted. The report *Teton Glacier Study, Final Report: Glacial Change in Grand Teton National Park* provided the primary source of information. The purpose of the study was to create a database of information about glaciers in GRTE by quantifying the glacial area change and glacial volume change for three selected glaciers in the Teton Range (Tootle et al., 2010).

Results

The Teton Range in northwest Wyoming is host to ten named glaciers (Figure 3.39 and Table 3.10). Additional undifferentiated glaciers or perennial snow fields exist, but they remain unnamed. According to the *Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway Geologic Resources Inventory Report,* the 1968 U.S. Geological Survey topographic map identified an additional 136 undifferentiated glaciers or perennial snow fields (NPS, 2010h). The ten named glaciers and remaining glaciers and snow fields likely formed during a cool period called the Little Ice Age that lasted from 1400 to 1850. Scientific evidence suggests that during a warm period following the Pleistocene Ice Age, the massive glaciers that once filled the valleys in the Teton Range melted; therefore, the existing glaciers are not remnants from the Ice Age, but are glaciers that formed during the Little Ice Age (NPS, 2006e).

The ten named glaciers include: Falling Ice, Middle Teton, Petersen, Schoolroom, Skillet, Teepe, Teton, and the three Triple Glaciers. Triple Glaciers, Skillet, and Falling Ice are located on Mount Moran; Petersen Glacier is located up the north fork of Cascade Canyon; Schoolroom Glacier is located up the south fork of Cascade Canyon east of Hurricane Pass; Teton Glacier is located below the north face of Grand Teton; Middle Teton Glacier is located on the northeast flank of Middle Teton; and Teepe Glacier is located below the northeast face of Teepe Pillar. With the exception of Falling Ice Glacier, which has a southeast exposure, these glaciers face north and east and lie in the shadow of major peaks and occur at elevations ranging from 10,000 feet to 11,500 feet (3,048 to 3,505 meters) (Fryxell, 1935). Falling Ice Glacier persists because of the depth of its cirque and the protection it receives from huge glacial horns along the southeastern slope of Mount Moran, which block direct sunlight for a significant portion of the day (NPS, 2010h).

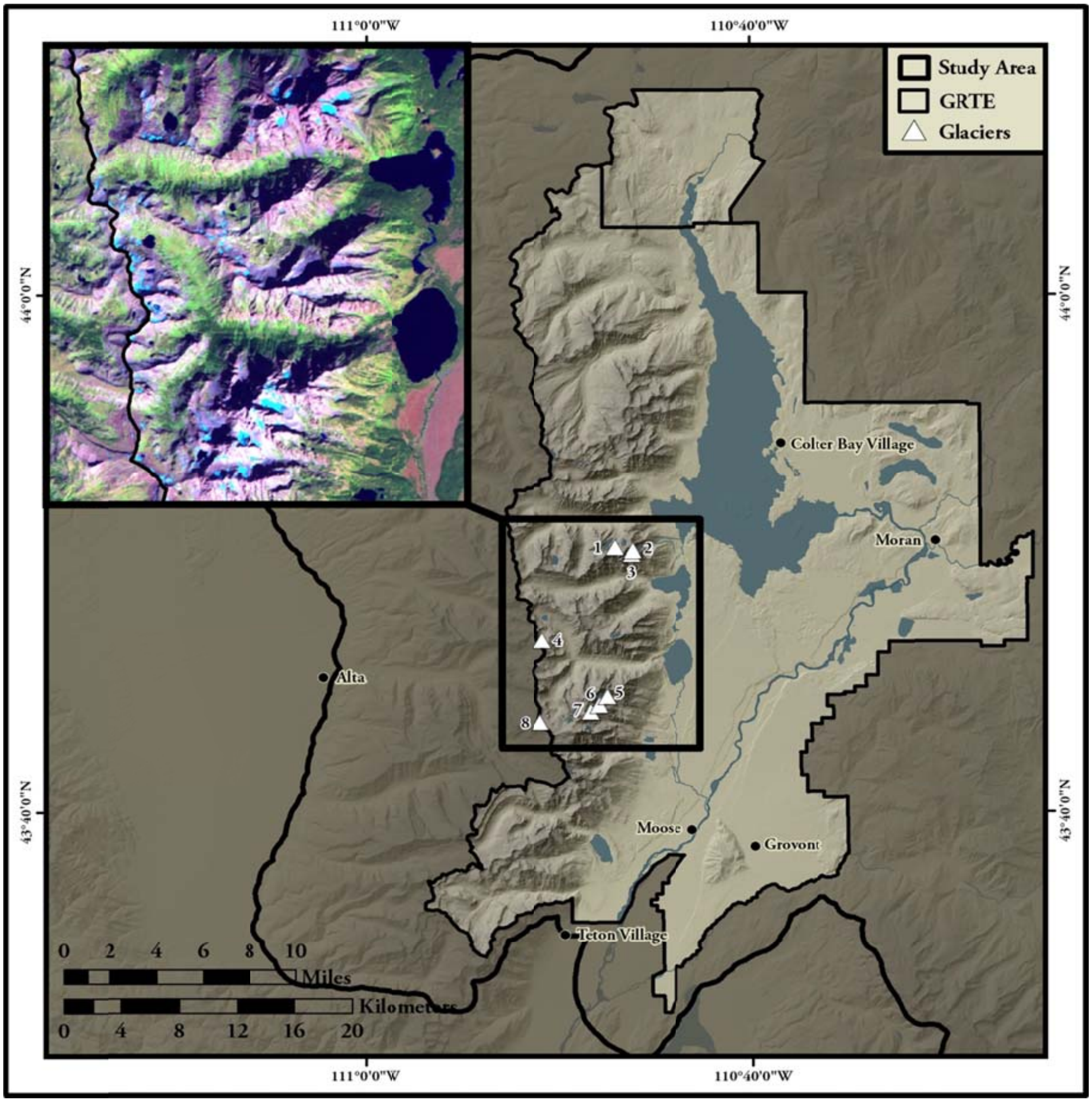

Figure 3.39. Location of glaciers in the Teton Range. Map subset in upper left corner is a Landsat TM satellite image from 18 September 2009. Band combination (5, 4, 2) has been used for mapping glaciers using satellite imagery. The bright blue areas are glaciers or masses of snow and ice.

Table 3.10. Named glaciers in the Teton Range.

Number on Map	Glacier	Location
1	Triple Glaciers	North Face of Mount Moran
2	Skillet Glacier	East Face of Mount Moran
3	Falling Ice	Southeast Face of Mount Moran
4	Peterson Glacier	North Fork of Cascade Canyon (Above Mica Lake)
5	Teton Glacier	Shadow of Grand Teton
6	Teepe Glacier	Northeast Face of Teepe Pillar
7	Middle Teton	Northeast Flank of Middle Teton
8	Schoolroom	South Fork of Cascade Canyon (East of Hurricane Pass)

Although glaciers in the Teton Range were not scientifically studied until 1926 when Fritiof Fryxell surveyed the range, it has been suggested that glaciers in this region have been receding since the 1850s, or approximately the end of the last Little Ice Age. In 1963, John C. Reed, Jr. completed an extensive survey of Teton Glacier that included area measurements and depth estimates. Upon reevaluation of the glacier in 1964, it was determined that the glacier had lost over 1.5 feet (46 centimeters) in depth (Tootle et al., 2010). Reed also used a 1929 photo taken by Fryxell to estimate changes in glacier extent. The photo taken by Fryxell showed the ice surface of Teton Glacier at 40 to 50 feet (12 to 15 meters) below the crest of the terminal moraine. The change in glacier extent between the 1929 photograph and the analysis conducted by Reed showed that the glacier had retreated about 600 feet (183 meters) and stood as much as 200 feet (61 meters) below the crest of the terminal moraine in 1963 (NPS, 2010h).

Subsequent research indicated that between 1963 and 1966, Teton Glacier increased in thickness and advanced about 50 feet (15 meters). Findings by Williams (1999) showed that Teton Glacier began to advance in 1955 after 31 years of retreat. Between 1955 and 1998, it was estimated that Teton Glacier increased by 26 feet (eight meters) in thickness and 66 feet (20 meters) in length (NPS, 2010h). More recently, Tootle et al. (2010) conducted a study to assess glacial area and volume changes using aerial photography between the time period from 1967 to 2006. Three glaciers were selected for analysis, including: Teton Glacier, Middle Teton Glacier, and Teepe Glacier. Teton Glacier was selected because it is the largest glacier in the range; Middle Teton Glacier was selected because it is one of the larger glaciers in the range; and Teepe Glacier was selected because it is a smaller glacier located between Teton and Middle Teton glaciers.

The study revealed that the three glaciers decreased from a total surface area of 129.97 acres (0.526 square kilometers) in 1967 to a total surface area of 97.61 acres (0.395 square kilometers) in 2006, a reduction in surface area of 32.37 acres (0.131 square kilometers) or 25 percent during the time period from 1967 to 2006 (Tables 3.11 and 3.12). Middle Teton Glacier lost 13.34 acres (0.054 square kilometers), Teton Glacier lost 10.87 acres (0.044 square kilometers), and Teepe Glacier lost 8.15 acres (0.033 square kilometers). In terms of percentage of area, Teepe Glacier lost 60 percent, Middle Teton Glacier lost 25 percent, and Teton Glacier lost 17 percent. The three glaciers lost a total volume of 113.0 million cubic feet (3.20 million cubic meters) between 1967 and 2002. Middle Teton Glacier lost the most volume at 47.3 million cubic feet (1.34 million cubic meters). For both area and volume, the greatest loss occurred between 1983 and 1994. The area loss for that time period was estimated at 1.54 percent per year and the volume loss was estimated at 5.3 million cubic feet (0.15 million cubic meters) per year (Tootle et al., 2010).

Table 3.11. Glacier areas and associated errors for 1967, 1983, 1994, 2002, and 2006.

Glacier	Year	Area (km^2)	Error (km^2)
TETON	1967	0.259	0.005
	1983	0.234	0.002
	1994	0.215	0.006
	2002	0.215	0.004
	2006	0.215	0.004
MIDDLE TETON	1967	0.212	0.003
	1983	0.207	0.003
	1994	0.164	0.004
	2002	0.160	0.003
	2006	0.158	0.007
TEEPE	1967	0.055	0.002
	1983	0.054	0.003
	1994	0.032	0.001
	2002	0.026	0.001
	2006	0.022	0.001

Source: Tootle et al., 2010; Table 2

Table 3.12. Average rate of area loss shown as percent per year between four study periods.

Year	Total Area of Three Glaciers (Km^2)	Area Loss Between Listed Dates (%)	Number of Years Between Dates	Average Rate of Area Loss Between Dates (%/Year)
1967	0.526			
1983	0.495	-5.9	16	-0.37
1994	0.411	-17.0	11	-1.54
2002	0.401	-2.4	8	-0.30
2006	0.395	-1.5	4	-0.37

Source: Tootle et al., 2010; Table 5

Preliminary analyses conducted by Reynolds and Thackray (2010) suggest that not all glaciers in the Teton Range have experienced shrinking following a series of warmer and/or drier years, and expansion following a series of cooler and/or wetter years. Schoolroom Glacier tends to exhibit a clear response to climatic fluctuations, whereas Falling Ice Glacier, Skillet Glacier, and Triple Glaciers do not. Schoolroom Glacier experienced growth between 1994 and 2001, likely responding to a three-year period with much higher amounts of precipitation. The glacier retreated from 2001 to 2006 after a series of years with higher than average summer temperatures and a four-year period of below average precipitation. It then expanded from 2006 to 2009 following a few years with above average precipitation. In contrast, between 1994 and 2006, Falling Ice Glacier, Skillet Glacier, and Middle Triple Glacier retreated, while East Triple Glacier expanded and West Triple Glacier maintained the same area. Between 2006 and 2009, Falling Ice Glacier, Skillet Glacier, and West Triple Glacier expanded while East and Middle Triple Glaciers retreated. Reynolds and Thackray (2010) indicate that these observations suggest that local climate, slope, aspect, and seasonal weather influence patterns of glacial expansion and retreat within the Teton Range.

Summary and Conclusions

Higher temperatures, less snowfall, and earlier snowmelt will expectedly cause further declines in mountain snowpack and distribution of glaciers, leading to profound effects. In many national parks, snow-covered mountains and glaciers provide some of the most spectacular scenery, but with less snow and glaciers in national parks, visitation may be decreased and winter recreational opportunities, such as skiing and snowmobiling, may be reduced. Diminishing snowpack and glaciers will also impact late-season water supplies and availability. The meltwater from glaciers is normally a reliable source of water in late summer for ecosystems and agricultural communities. Historically, glaciers have provided a buffer against low flows in dry, warm summers, but with the absence of glaciers, perennial streams may become ephemeral streams and late-season water supplies may become limited. With less water in rivers, aquatic and riparian life may become jeopardized and there may be fewer recreational opportunities for boating, rafting, kayaking, and fishing (Saunders et al., 2009).

Jackson Lake Ice-Off Dates

Ecosystem responses to climate change are expected to occur at different temporal and spatial scales. Seasonal events, such as freeze-thaw cycles, snowpack formation, and snowmelt, will show a great deal of variability (Spencer et al., 2008). Although changes in seasonal events are and will be variable, measurements of their dynamics are some of the most sensitive indicators of climate change. Snow and ice are an important part of the global climate system; therefore, changes in snow cover, snowpack, arctic sea ice, the position of glacier fronts, and lake and river ice duration are very useful climate change indicators within the hydrologic system and cryosphere (Latifovic and Pouliot, 2007).

Variability and trends in lake ice dynamics, such as ice-on and ice-off dates and ice duration, are valuable indicators that can be related to climate condition and lake physical characteristics. Some research indicates that lake phenology is a reliable measurement of local climate condition, and in some cases, it has been considered to be a more robust measure than air temperature (Latifovic and Pouliot, 2007; Livingstone, 1997). In addition, some records of ice-on and ice-off dates predate temperature records, providing an important indicator of past climatic conditions (IceWatch, 2008). Prior to scientific investigation, observations of lake ice dynamics were made for religious and cultural reasons and for practical reasons concerned with transportation over ice or open water (Magnuson et al., 2000).

Lake ice-on and lake ice-off dates are the annual dates in the autumn and spring when winter lake ice forms and melts, respectively. Lake ice generally forms when autumn snowfall and lowering air temperature decrease water temperature. Surface water eventually cools to 39.2 degrees Fahrenheit (4.0 degrees Celsius), the temperature at which water density is greatest. The dense water sinks and the lighter surface water cools until the entire lake mass reaches 39.2 degrees Fahrenheit (4.0 degrees Celsius). A lighter layer of water forms on the surface and cools to 32.0 degrees Fahrenheit (zero degrees Celsius), at which point a thin layer of skim ice forms. When this takes place, it is possible that the entire surface of a lake will freeze over within a few hours on a still cold night. Maximum ice thickness depends on air temperature, snow cover, and duration of cold weather (Spencer et al., 2008).

Break-up of lake ice begins in the spring when days become longer and warmer. Ice begins to decay when it becomes isothermal (the same temperature throughout) at 32.0 degrees Fahrenheit (zero degrees Celsius). Generally, the top and bottom of the ice layer melt simultaneously, but sometimes melting occurs inside the ice layer along vertical ice crystals. Internal melting, in conjunction with thermal absorption from open water, light winds, and gentle waves, accelerate the melting process. As with lake ice formation, lake ice break-up and thaw can occur rapidly, with large lakes becoming ice free within a few days. The lake ice-off date is recorded when all lake ice cover melts. This date is primarily dependent on air temperature, cloud cover, and wind, but upstream conditions, such as heavy rains and snowmelt, can influence melting rates and times (Spencer et al., 2008).

Several studies have used lake ice-on and ice-off dates as measures of climatic variability and change. For instance, Hodgkins et al. (2005) assembled and analyzed ice-off dates from 29 lakes in New England with 64 to 163 years of records. Analyses indicated that ice-off dates have become significantly earlier in New England since the 1800s. Ice-off dates changed between 1850 and 2000 by nine days in northern and mountainous areas of New England (primarily northern and western Maine) and by 16 days in more southerly locations. Hodgkin et al. (2005) surmised that the lake ice-off dates in the northerly and mountainous regions are less sensitive to changes in air temperatures than ice-off dates in more southerly areas because there are typically higher amounts of snow on the lake ice in northerly and mountainous areas in late winter and early spring.

Another study conducted by Magnuson et al. (2000) evaluated changes in freeze and thaw dates for lakes and rivers throughout the northern hemisphere. The study evaluated 39 sets of data across 26 sites. Some sites only had records of freeze dates, some sites only records of breakup dates, and 13 sites had records of both dates. The data spanned the time period from 1846 to 1995. The analyses revealed that over the 150-year period, changes in freeze dates average 5.8 days later per 100 years and changes in breakup dates averaged 6.5 days earlier per 100 years. The changes in freeze and breakup dates over 150 years corresponded to an increase in temperature of approximately 2.16 degrees Fahrenheit (1.2 degrees Celsius) (Magnuson et al., 2000).

<u>Methods</u>
Jackson Lake ice-off data, provided by GRTE, were evaluated to determine if any discernible trends in average ice-off date were evident. The ice-off data spans the time period from 1933 to 2009. A basic linear regression analysis was conducted in S-PLUS Statistical Analysis Software and a graphical interpretation was generated in Microsoft Excel.

<u>Results</u>
Jackson Lake is one of the largest high altitude lakes in the United States at an elevation of 6,772 feet (2,064 meters). It is one of the several morainal lakes that lies at the base of the Teton Mountain Range. In 1911, Jackson Lake Dam was built at the outlet, raising the lake level by 40 feet (12 meters) (Retallic, 2009). The Snake River, which originates in the Teton Wilderness, flows into GRTE at the northern end of Jackson Lake, and empties out of the lake at Jackson Lake Dam. Presently, Jackson Lake is approximately 12.4 miles (20 kilometers) long, 3.2 miles (5.2 kilometers) wide on average, and has a maximum depth of 438 feet (134 meters). The water of Jackson Lake averages below 60 degrees Fahrenheit (15.6 degrees Celsius) even during the

warmest summer months and can freeze to more than six feet (1.8 meters) in the winter.

During the period from 1933 to 2009, the earliest thaw date occurred in 1934 on April 19, and the latest thaw date occurred in 1975 on June 2. The mean ice-off date for this time period was May 11. In 2009, the lake ice-off date was recorded on the May 16 (Figure 3.40). Using the entire dataset, the linear regression yielded a coefficient of determination (R^2) of 0.0139 and a p-value of 0.3068. When the data is grouped by decade, the mean ice-off dates ranged from May 3 to May 16. The linear regression for the grouped data yielded a coefficient of determination (R^2) of 0.0781 and a p-value of 0.5027. While these values suggest that there is not statistical significance in the ice-off date from 1933 to 2009, there is a slight decreasing trend in both instances (slope values of -0.043 and -0.419) that suggest the ice-off date may be occurring earlier in the year (Figures 3.41 and 3.42).

<u>Summary and Conclusions</u>

While no stark changes in lake ice-off date are evident in a linear regression analysis, it does appear that the lake ice-off date may be occurring earlier in the year. However, more in depth statistical analysis incorporating ancillary variables, such as temperature and precipitation, may be required to discern these trends. The graph displaying the data grouped by decade shows that the mean ice-off date for the years 2000 to 2009 is earlier by at least six days than any of the other averaged decades. The lack of a clear trend line may also be attributed to some of the hypotheses suggested and research conducted by Hodgkins et al. (2005) that indicates that lake ice-off dates in the northerly and mountainous regions are less sensitive to changes in air temperatures than ice-off dates in more southerly areas because there are typically higher amounts of snow on the lake ice in northerly and mountainous areas in late winter and early spring.

Nonetheless, even if lake-ice off dates for Jackson Lake are variable, changes in air temperature and lake phenology over time can affect the physical, chemical, and biological characteristics of water bodies. Ice influences heat and moisture dynamics between the water bodies and the atmosphere, and reduced ice cover can increase evaporation, water temperature, and sunlight penetration. Summer oxygen levels and important elements of the food chain may be modified as a result (Hodgkins et al., 2005).

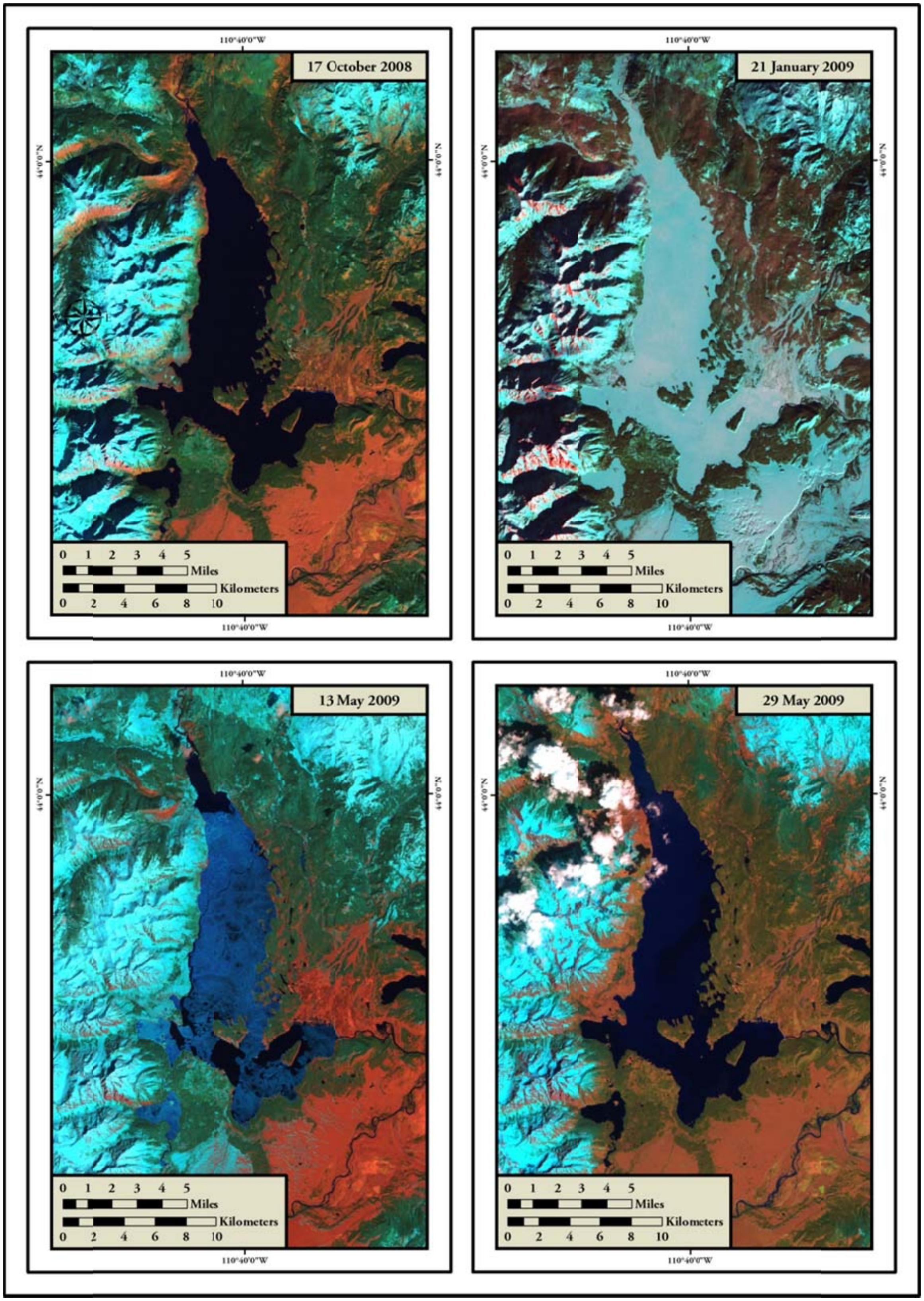

Figure 3.40. Time series of Landsat TM imagery from 17 October 2008 to 29 May 2009 displaying lake ice-off and ice-on seasons. In 2009, the ice-off date was recorded on May 16th.

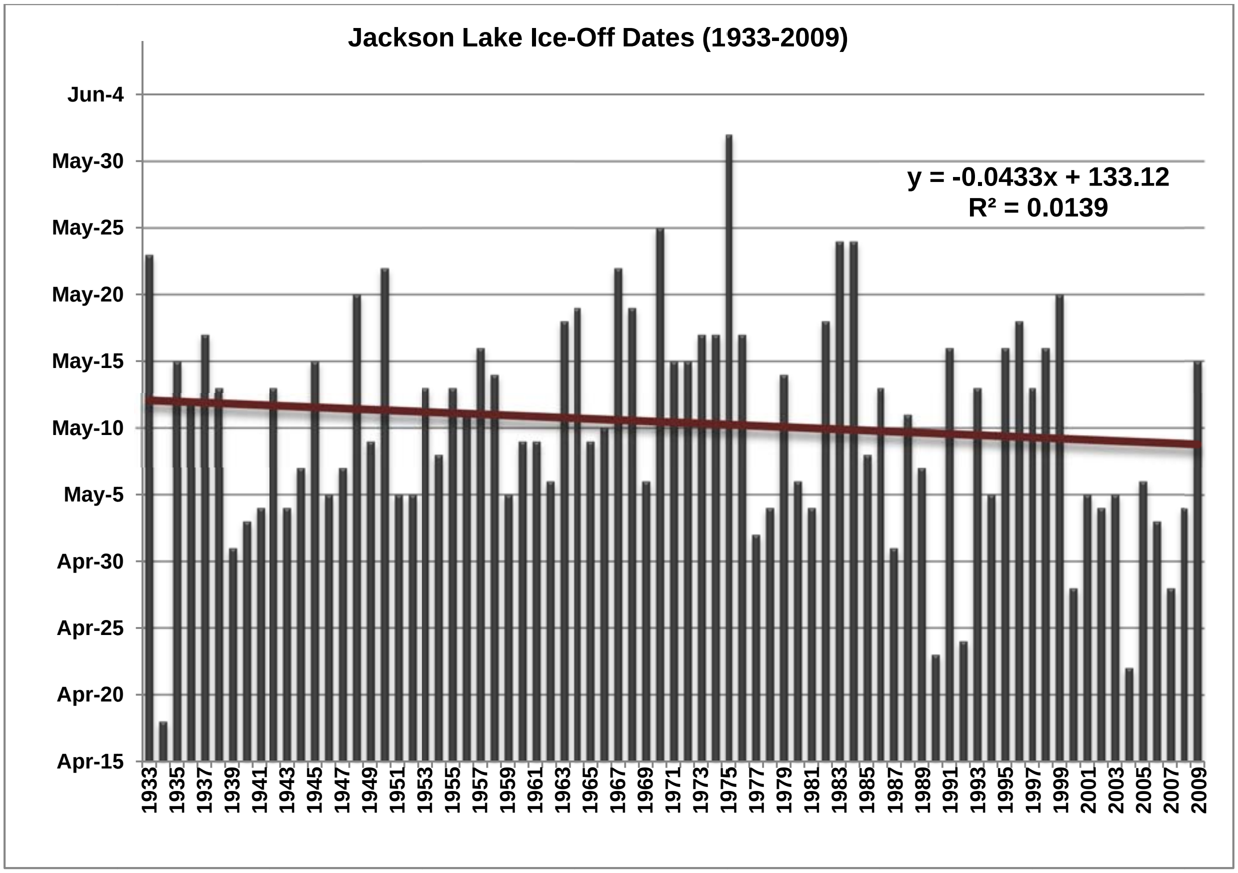

Figure 3.41. Jackson Lake ice-off dates (1933-2009) displaying regression equation and trend line.

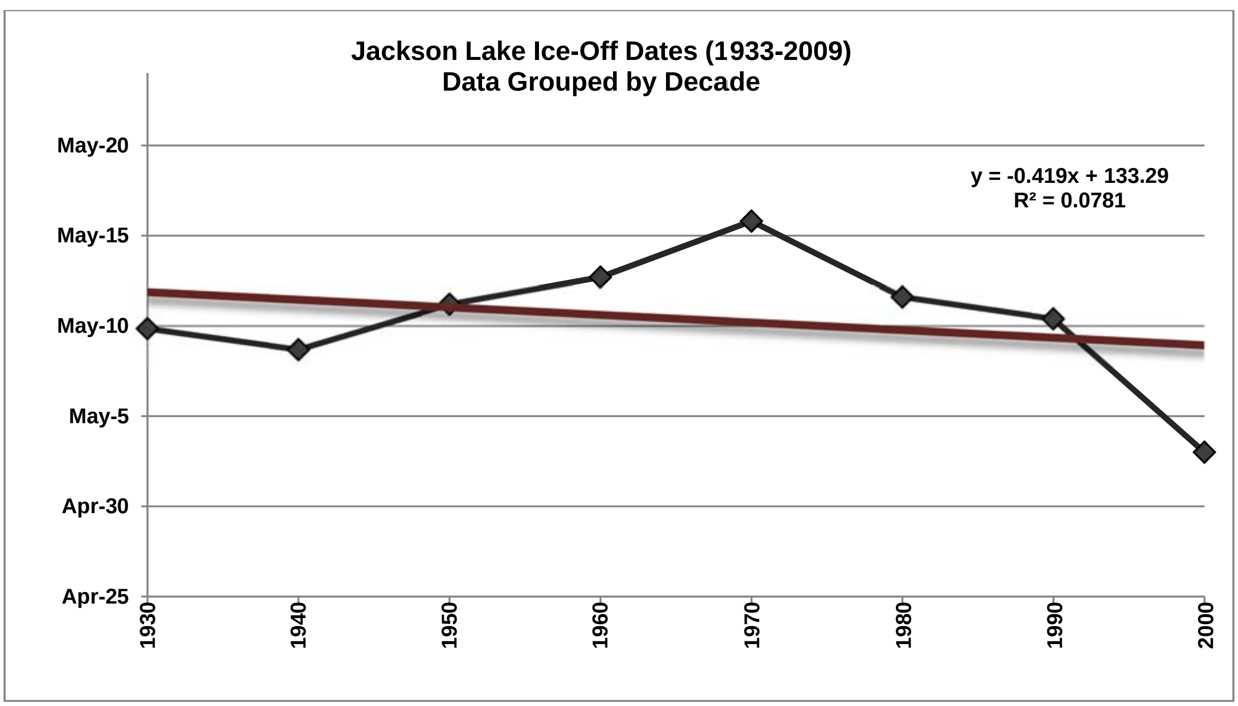

Figure 3.42. Jackson Lake ice-off dates (1933-2009) grouped by decade.

Hydrology

The Snake River and its tributaries make up the fluvial system of GRTE and JODR. Although the Snake River is one of the smallest major drainages in Wyoming, it carries the largest average volume of any river in the state. The Snake River begins within the Absaroka volcanics near the southern boundary of YELL. The river flows north into YELL, where it meanders westward and is joined by the Lewis River before looping south into JODR. The Snake River flows into GRTE at the northern end of Jackson Lake, where topographic features control its course, and empties out of the lake at the Jackson Lake Dam. The river then travels southwest through Jackson Hole (NPS, 2010h). The Snake River, as it flows out of Jackson Lake and through GRTE, is a braided, meandering stream with a well-developed alluvial system consisting of generally coarse, gravel- and cobble-sized material (Clark et al., 2004).

The general hydrology of the Snake River and its tributaries in GRTE is typical of mountainous areas in Wyoming. Peak streamflows occur in late spring and early summer with the melting of annual snowpack. Groundwater typically sustains flows in perennial streams throughout the remainder of the year. Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, Ditch Creek, the Gros Ventre River, Horse Creek, and the Hoback River are the primary eastern tributaries in and south of GRTE. Cottonwood Creek, Taggart Creek, Lake Creek, Granite Creek, Fish Creek, Mosquite Creek, and Fall Creek are primary western tributaries in and south of GRTE. While Cottonwood Creek, Fish Creek, Mosquito Creek, and Fall Creek are primary western tributaries to the Snake River, Taggart Creek is a tributary to Cottonwood Creek, Lake Creek is a tributary to Fish Creek, and Granite Creek is a tributary to Lake Creek (Clark et al., 2004; Clark et al., 2007).

Trends in the Timing of Spring Snowmelt Runoff of Pacific Creek, 1945 to 2008

Changes in temperature and precipitation, potentially caused by climate change, can influence snowpack, snowmelt runoff, and the timing and magnitude of floods. In the western United States, approximately 60 percent of the annual flow originates from snowmelt, and changes in the water cycle could play a significant role in water management (Serreze et al., 2001). Previous studies have evaluated changes in the timing of snowmelt runoff. Moore et al. (2007) assessed changes in the timing of runoff over 55 years at 21 gages in the headwaters of the Columbia and Missouri Rivers. The analysis suggested that there was a negative trend in measures of runoff timing over the period from 1948 to 2003, signifying that snowmelt runoff is occurring earlier in the year than it did during the mid-twentieth century.

Methods

Changes in spring runoff timing for Pacific Creek over a 63-year period were evaluated. Mean daily discharge data from gage 13011500 (Figure 3.43) were used for an analysis of covariance and were related to climate trends over the same time period. An analysis of covariance was performed using mean daily discharge data for the time period of 1945 to 2008. The years from 1976 to 1978 were excluded from the analysis because discharge data were not recorded during parts of those water years. A simple linear regression analysis ($y = mx + b$, where m is the slope of the line and b is the y-intercept) was conducted in order to find the relationship between the time, in years, and the measure of runoff timing.

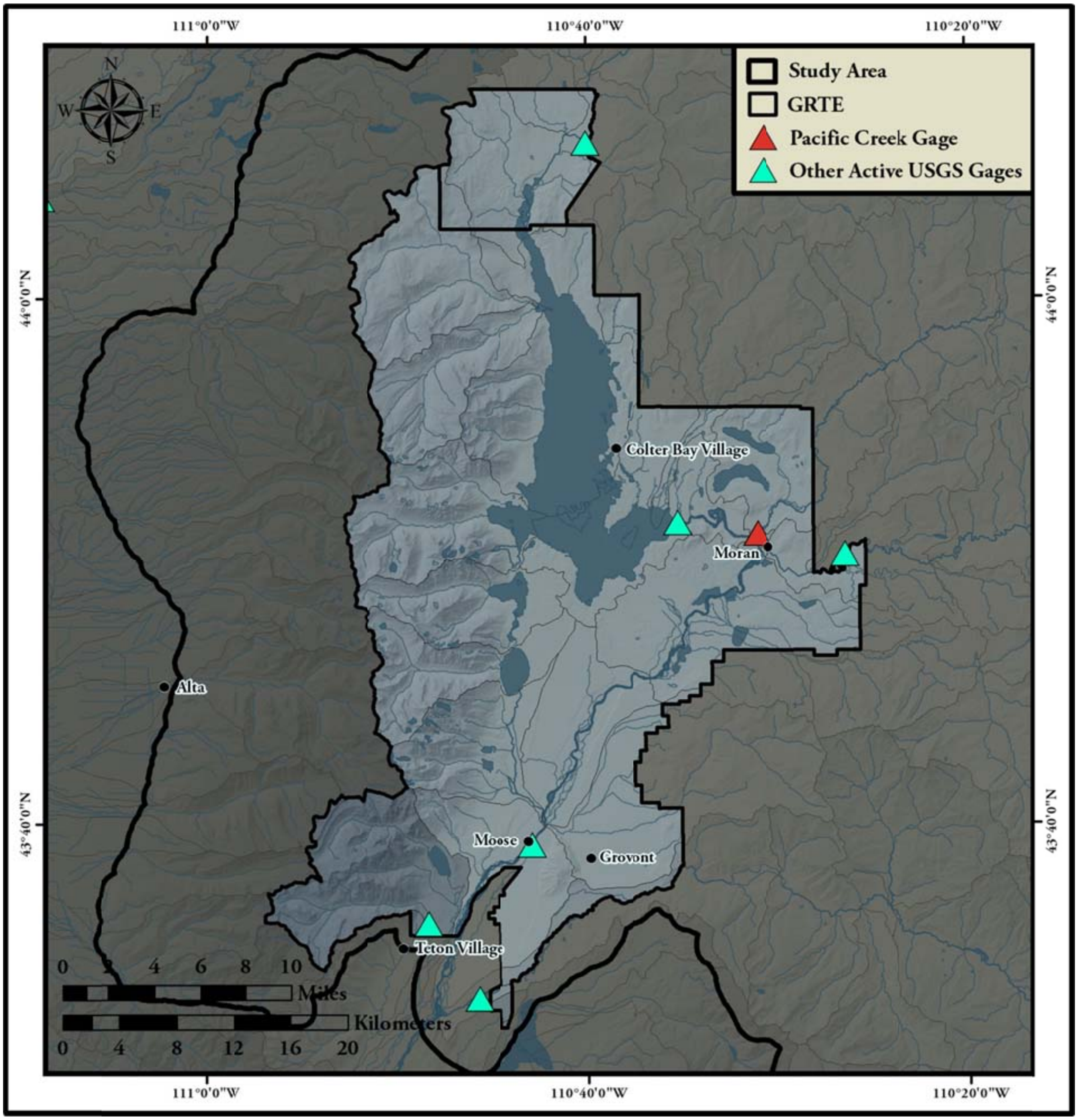

Figure 3.43. Location of Pacific Creek gage (USGS gage 13011500) and other active USGS gages. Data source: USGS (Stewart et al., 2006).

Total flows and total spring runoff flows were analyzed. Spring snowmelt runoff flows were defined as those greater than 266 cubic feet per second (7.5 cubic meters per second), which is the long-term annual mean discharge. These higher flows occur during spring, although a small percentage (less than 0.1 percent) of these higher flows occur later in summer and fall.

The center of mass used for the analysis was calculated as the 50th percentile of all days with flows greater than 266 cubic feet per second (i.e. the center of mass is the date within the year at which 50 percent of the spring runoff flood is greater than 266 cubic feet per second). The total flood spring runoff represents the summation of all flows greater than 266 cubic feet per second.

The total flood runoff was normalized by dates of center of mass to make the total flood runoff and the center of mass directly comparable. The residuals of the normalized flood runoff were calculated and their trend over the studied period of time was examined.

Results

The center of mass of snowmelt runoff occurs approximately 11 days earlier than it did in the mid-twentieth century. This finding is supported by (1) analysis of time series of the residuals of normalized total flood runoff ($\alpha = 0.05$) and (2) analysis of time series of the data of center of mass ($\alpha = 0.10$).

Analysis of total flood runoff itself showed no change over the studied period of time (Figure 3.44). The timing of the snowmelt flood was evaluated in relation to the magnitude of each year's flood. The total flood runoff, normalized by the dates of the center of mass, showed a strong positive relationship ($\alpha = 0.01$) (Figure 3.45). As was expected, the larger total spring snowmelt runoff occurs later in the year. Thus, a more robust analysis of changes in the timing of snowmelt flood involves accounting for the differences in the magnitude of each flood. Time series of the residuals of normalized total flood runoff shows that floods are occurring earlier in the year than in the mid-twentieth century ($\alpha = 0.05$). The change was characterized by a negative linear trend ($y = -0.1721x + 338.1$; $R^2 = 0.2081$) (Figure 3.46).

The second analysis had a slightly smaller level of significance ($\alpha = 0.10$), but it demonstrated a similar trend between the time and measures of spring runoff timing. The trend between the calculated center of mass and year also showed a shift toward earlier dates (Figure 3.47). The negative linear relationship, characterized by equation $y = -0.1719x + 493.6$ and $R^2 = 0.1409$, showed that the center of mass occurs approximately 11 days earlier in 2008 than in 1945 with a significance level of $\alpha = 0.10$.

The analysis of annual instantaneous peak showed greater changes in timing than the analysis of the center of mass. The annual instantaneous peak flow now occurs approximately 15 days earlier than in the mid-twentieth century. Although there is large variability in the time of the annual peak flow, the linear regression relationship between year and date of the peak is statistically significant ($\alpha = 0.10$) (Figure 3.48). The negative slope is given by the equation $y = -0.2451x + 635$ with $R^2 = 0.1492$. On average, the peak occurs by about three days earlier per decade.

Analysis of the day of the start of spring runoff also showed a shift to earlier dates. The spring runoff starts approximately 11 days earlier now than it did during the mid-twentieth century ($\alpha = 0.10$). However, this shift in timing is more uncertain and is dependent on spring weather (Moore et al., 2007).

Summary and Conclusions

Changes in spring runoff timing for Pacific Creek over a 63-year period (1945-2008) were evaluated. Mean daily discharge data from gage 13011500 were used for an analysis of covariance. The date of the center of mass of the spring runoff flood occurs approximately 11 days earlier than it did in the mid-twentieth century, and the date of the annual instantaneous peak occurs approximately 15 days earlier than it did in the mid-twentieth century.

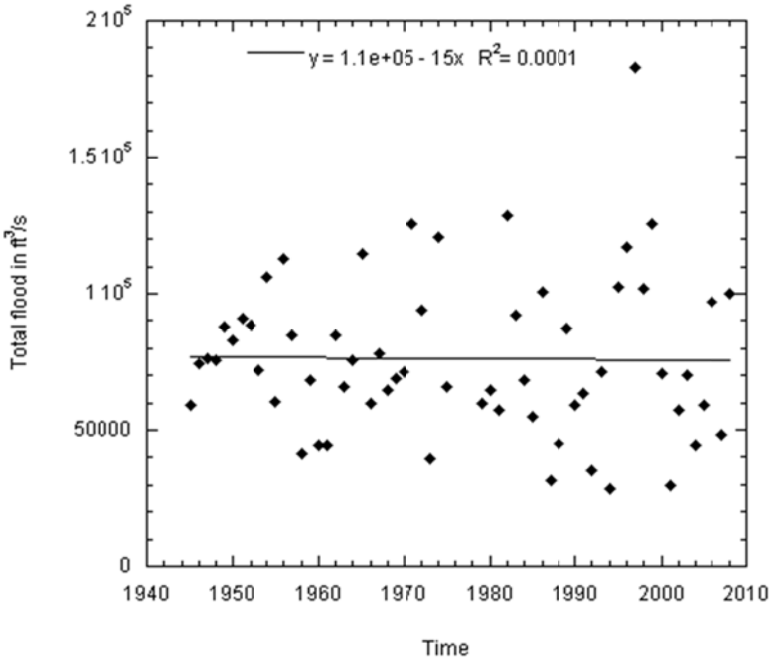

Figure 3.44. Time series of the total flood runoff over the studied period of time (1945-2008).

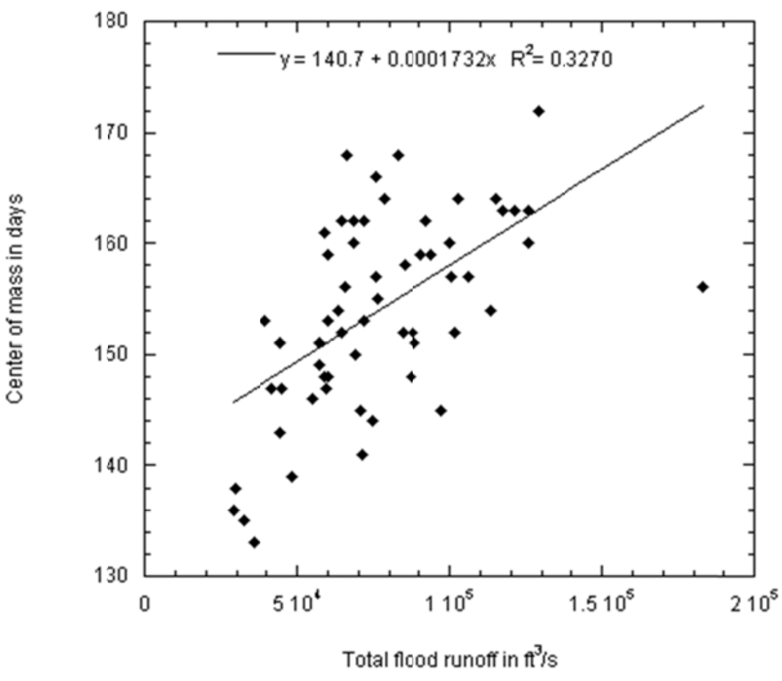

Figure 3.45. Total flood runoff, normalized by center of mass.

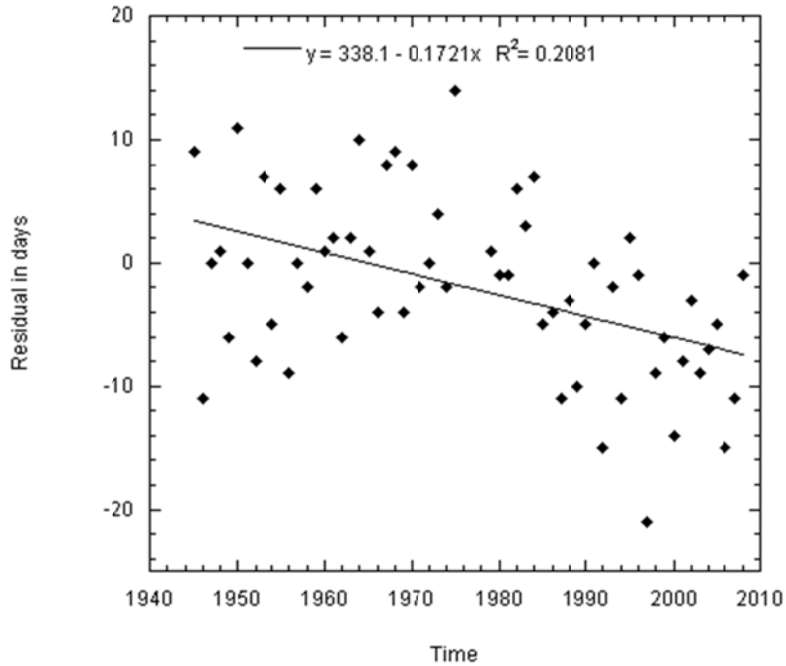

Figure 3.46. Residuals of normalized total flood runoff over the studied period of time (1945-2008).

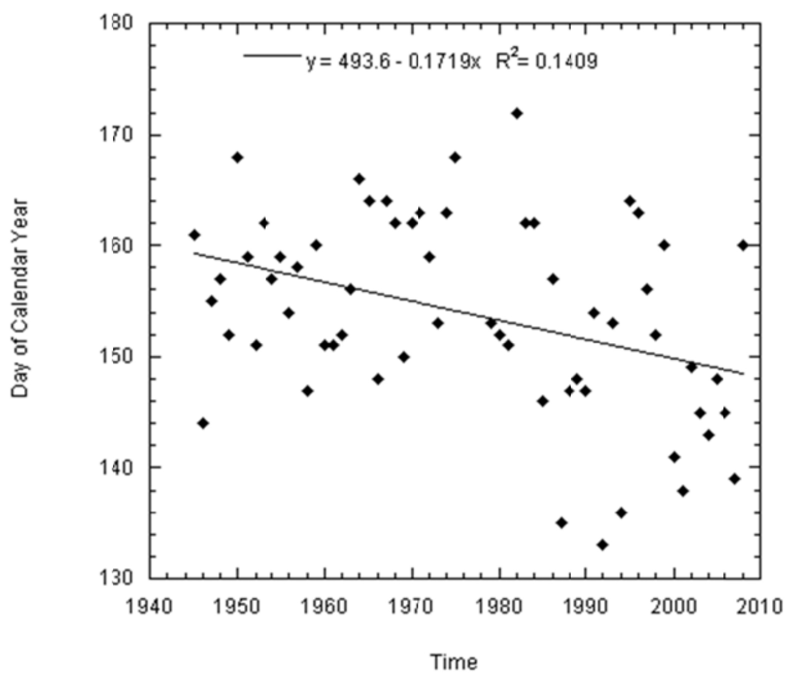

Figure 3.47. Time series of the center of mass for spring runoff flow over the studied period of time (1945-2008).

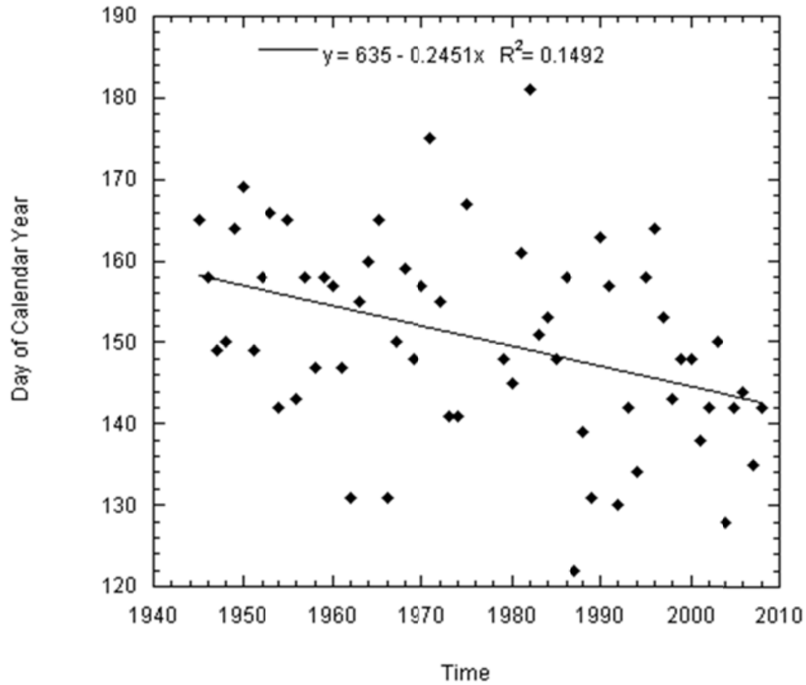

Figure 3.48. Time series of the day of the peak over the studied period of time (1945-2008).

Undeveloped Rivers and Streams by Watershed

The objective of this study was to assess the relative influence of human activity on rivers and streams within the GRTE. While there are many possible approaches to assess human activity and its influence on natural systems, an approach that lends itself to relatively simple GIS analysis was adopted. Readily available GIS data from the Wyoming Geographic Information Science Center (WyGISC) was utilized. Since roadways are a significant conduit for human activity, and because many built structures are proximal to roadways, roadways were used as a surrogate measure of human activity. To assess the impact of human activity on rivers and streams, the length of rivers and streams that are impacted by roadways was measured.

Methods

All roads in the park were buffered 100 meters (328 feet) on either side, yielding a 200-meter (656-foot) road impact zone. Free-flowing rivers and streams were intersected with the road impact zone to identify river and stream segments influenced by human activity (Figure 3.49). The segments of rivers and streams impacted by human activity were subtracted from the total length of rivers and streams to produce the length of free-flowing undeveloped shoreline. These were summarized by watershed.

Results

Table 3.13 identifies the total length of free-flowing undeveloped shoreline and the proportion of rivers and streams in each watershed that have undeveloped shoreline. Figure 3.50 depicts the relative condition of rivers and streams in the park by watershed, as measured by miles of undeveloped

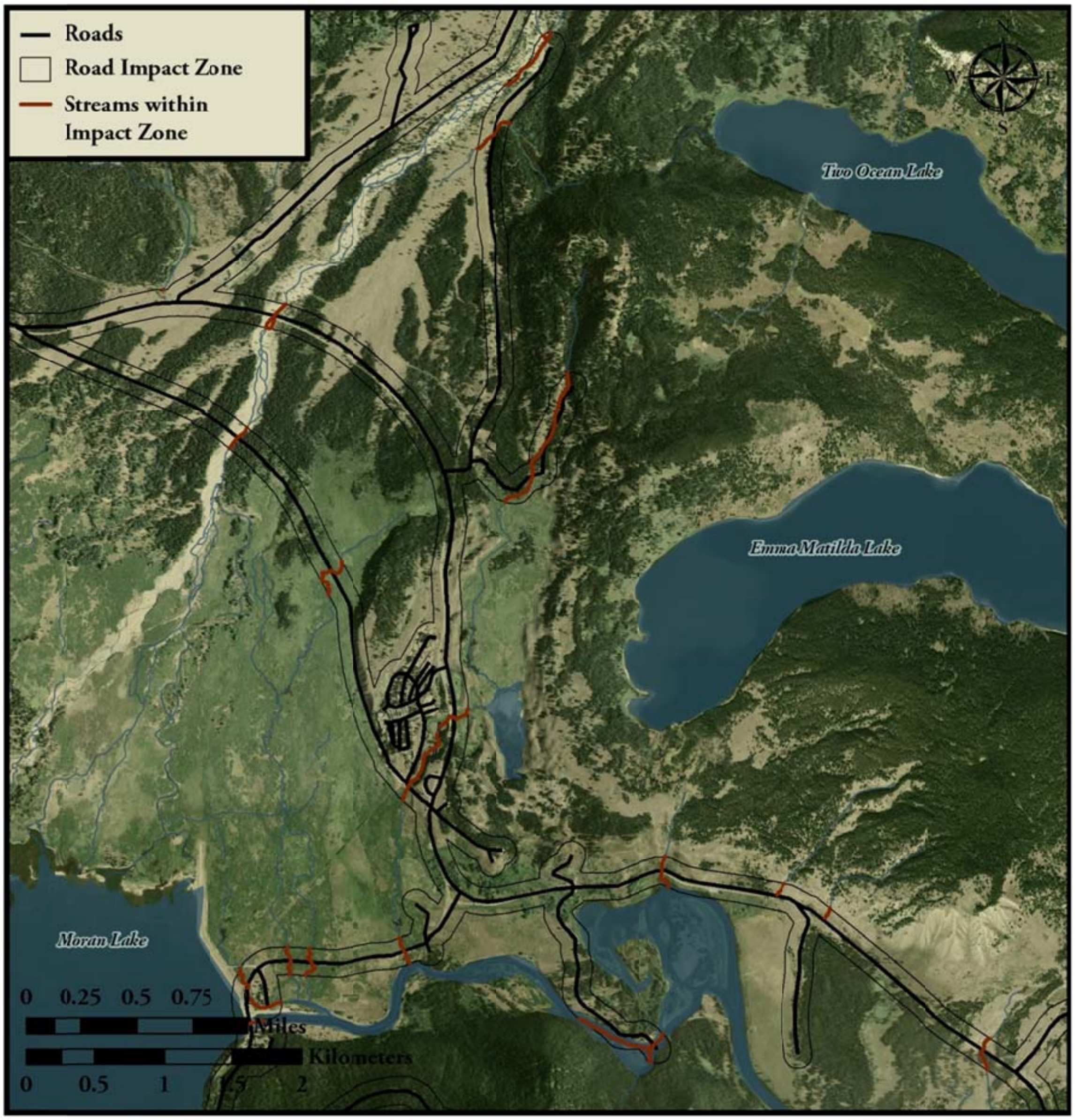

Figure 3.49. Example showing stream shoreline within impact zone.

Table 3.13. Assessment of undeveloped river and stream shoreline.

Watershed	Total (Miles)	Impacted (Miles)	Undeveloped (Miles)	Percent Undeveloped
Arizona Creek	7.91	0.85	7.06	89%
Bradley Lake	43.97	3.69	40.28	92%
Ditch Creek	73.55	11.28	62.26	85%
Gros Ventre River-Bierer Creek	23.37	4.28	19.09	82%
Jenny Lake	43.33	0.15	43.18	100%
Lake Creek-Fall Creek	83.41	6.21	77.21	93%
Lava Creek	1.04	0.07	0.97	93%
Leigh Lake	44.94	0.41	44.52	99%
Lower Buffalo Fork	30.98	3.22	27.76	90%
Lower Jackson Lake	49.94	4.38	45.56	91%
Lower Pacific Creek	52.28	4.13	48.15	92%
Moose Creek	82.15	0.00	82.15	100%
Moran Bay	85.20	0.00	85.20	100%
Owl Creek	65.92	0.00	65.92	100%
Polecat Creek	9.57	0.00	9.57	100%
Snake River- Baseline Flat	57.72	2.99	54.73	95%
Snake River- Pilgrim Creek	17.32	1.11	16.21	94%
Snake River-Sheffield Creek	69.00	4.30	64.70	94%
Snake River-Spread Creek	157.55	18.83	138.72	88%
Snake River-Spring Creek	1.10	0.20	0.91	82%
Snake River-Stewart Draw	66.20	5.50	60.70	92%
Upper Jackson Lake	87.11	2.61	84.49	97%
TOTAL	**1153.54**	**74.21**	**1079.34**	

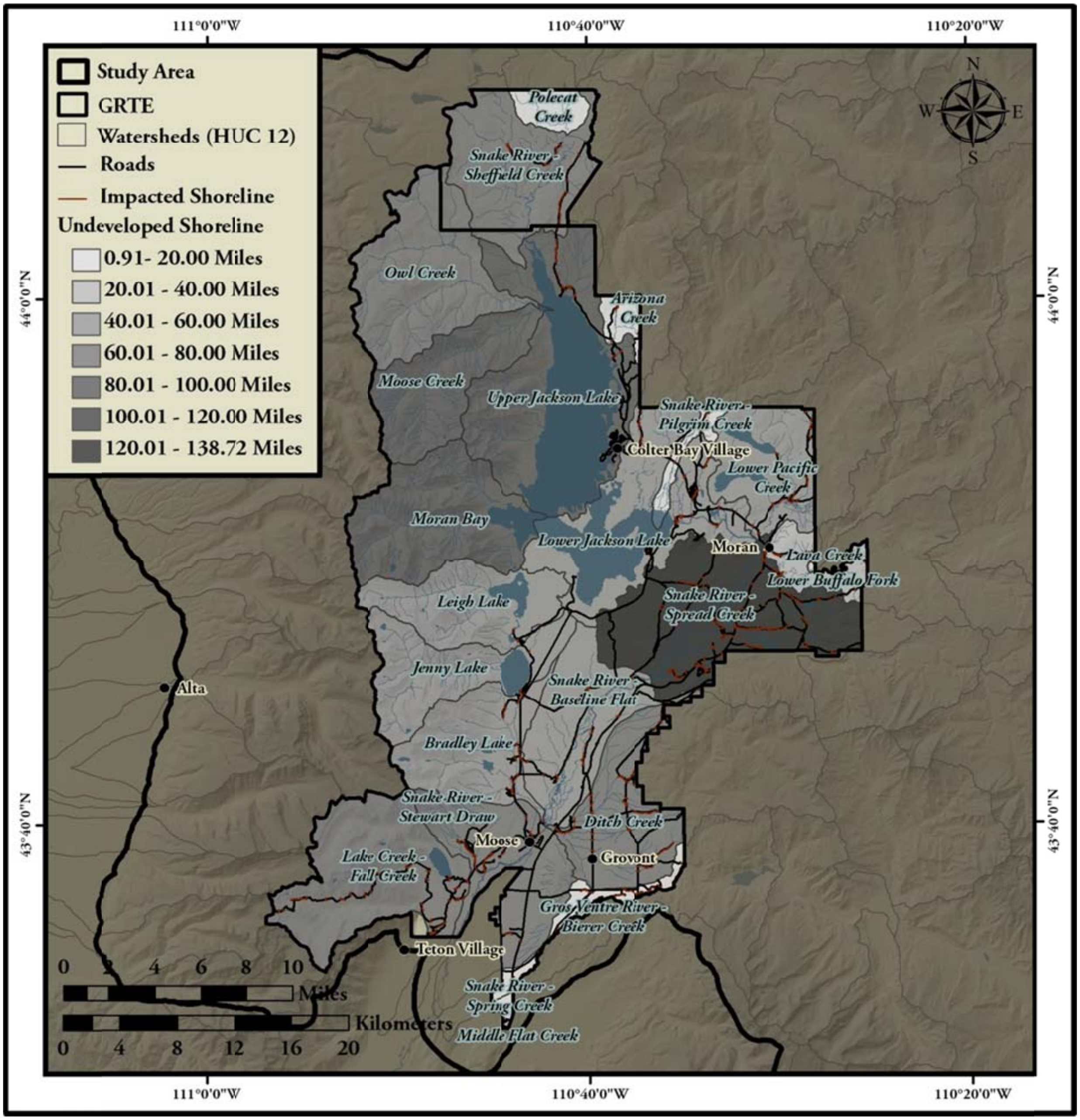

Figure 3.50. Relative condition of watersheds measured by miles of undeveloped shoreline.

shoreline. Figure 3.51 presents a summary of the condition of undeveloped shoreline, but as a proportion of river and stream length not impacted by development.

It can be noted that several watersheds on the western side of the park are not impacted by road development and associated human activities. The Snake River-Spread Creek watershed has both a high number of miles of undeveloped shoreline and a relatively low percentage of undeveloped shoreline. While this seems contradictory, it can be explained by the fact that this watershed has numerous rivers and streams.

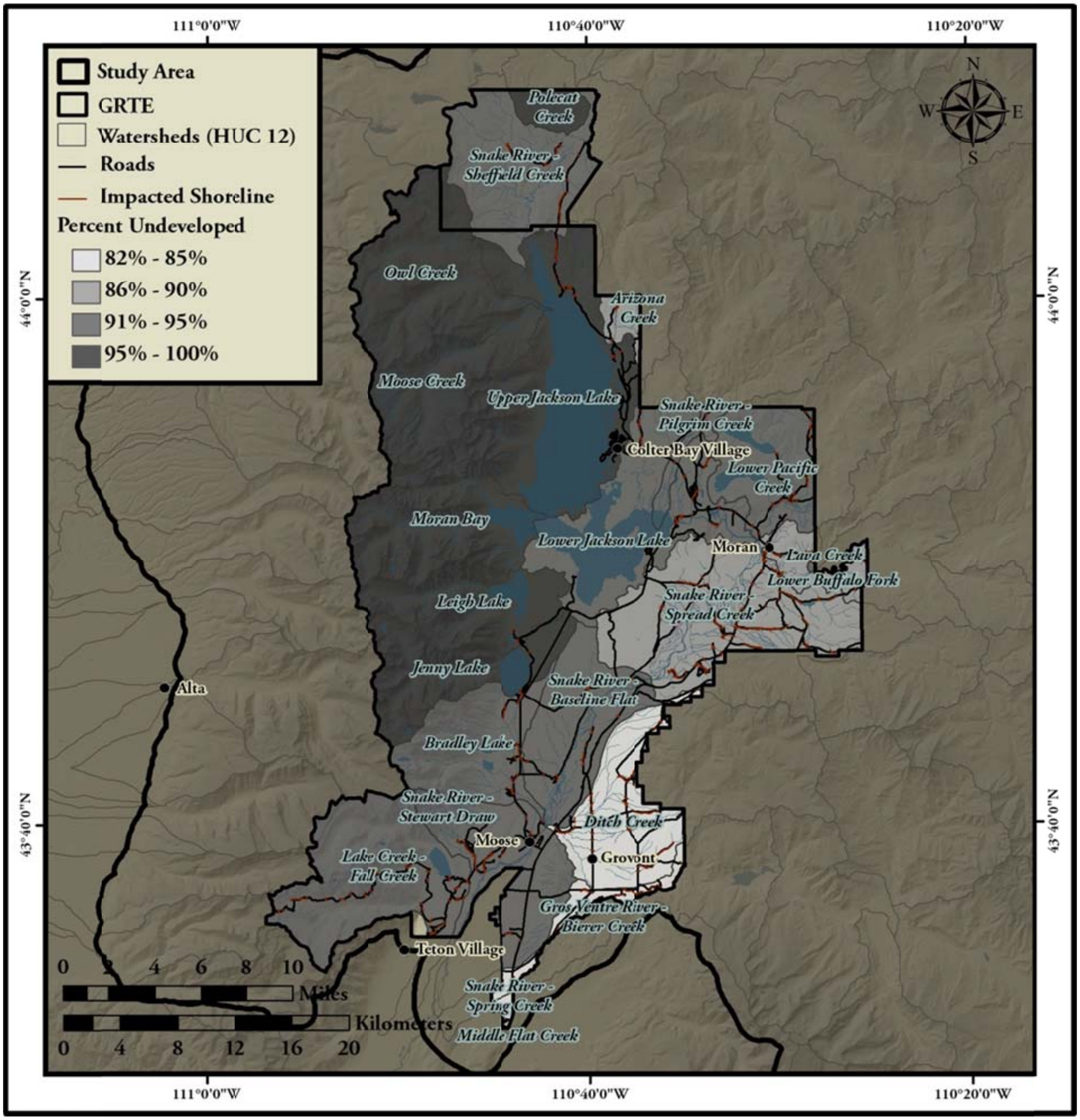

Figure 3.51. Relative condition of watersheds measured by proportion of river and stream length not impacted by road development.

<u>Summary and Conclusions</u>

This evaluation presents a simple GIS analysis that provides a quick synopsis of the condition of rivers and streams and their proximity to human activity. It provides a broad assessment of the relative impact of human activity across watersheds, as defined by the terms of the study. This assessment could be refined by focusing on only high impact roads or redefining the impact zone by varying the buffer distance.

Forest Health

Forest Patch Size by Watershed

It is important to understand the interactions that exist between spatial patterns and ecological processes and functions. This process of understanding generally involves deriving landscape indices or metrics, such as patch size or number of patches, and measuring a response variable, such as presence or absence of an exotic species, on the ecosystem. Subsequently, the metric or metrics may be related to the response variable using statistical methods to describe the relationship or to make predictions where data have not been collected. Presented are the methods applied to derive a suite of metrics that may subsequently be related to other ecological processes of interest in GRTE at different scales.

Methods

FRAGSTATS (McGarigal et al., 2002), a computer software program designed to compute a wide variety of landscape metrics, was used to derive forest patch size and other metrics of interest at a watershed HUC (Hydrologic Unit Code) Level 12. In addition to the patch area, the number of patches, patch density, patch cohesion, and clumpiness was generated. It is important to mention that FRAGSTATS is able to generate many metrics, not only the ones mentioned. The user can decide which metrics to derive or to generate all. However, many of these metrics are highly correlated, and care must be observed as to not generate and present redundant information.

In this study, land cover information was available at two different scales. Data from the Northwest Gap Analysis Program and data from the vegetation map prepared by GRTE personnel were utilized for regional and local assessments, respectively. Therefore, metrics for both datasets were derived. Given that ecological processes may be measured at different scales (i.e. regional and local), it was determined that the staff at GRTE may benefit from having information at two different scales and spatial contexts for subsequent analyses.

For both datasets, the land cover classes were recoded into a binary response (FOREST/OTHER), and then the metrics were obtained only for the FOREST class. Table 3.14 shows which classes from the Northwest Gap dataset and from the GRTE vegetation map were utilized in this assessment.

Table 3.14. Forest land cover classes (from Northwest Gap dataset) collapsed into a new FOREST class.

CODE	CLASS
40	Rocky Mountain Aspen Forest and Woodland
67	Northern Rocky Mountain Mesic Montane Mixed Conifer Forest
69	Rocky Mountain Lodgepole Pine Forest
70	Southern Rocky Mountian Dry-Mesic Montane Mixed Conifer Forest and Woodland
73	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
74	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland
77	Middle Rocky Mountain Montane Douglas-fir Forest and Woodland
78	Rocky Mountain Poor Site Lodgepole Pine Forest
84	Inter-Mountain Basins Aspen Mixed Conifer Forest and Woodland

For the GRTE vegetation map, the field PHYSIO in the data attribute table was used to discriminate classes to be collapsed into the FOREST class. In this case, the following physiognomic classes were used: Coniferous Forest, Deciduous Forest, and Mixed Forest. None of the Woodland physiognomic classes were used in this study.

It was also considered important to generate metrics for each forested class. In this way, if the characteristics of a forest type, such as lodgepole pine, need to be assessed, then they are also available. For instance, for a specific hydrologic application, it may be desired to know if the aspen forest is more fragmented than the spruce-fir forest in a particular watershed. This type of assessment has been done using both land cover datasets.

Figures 3.52 and 3.53 show the spatial context of the study area in relation to the watersheds and GRTE limits. In Figure 3.52, notice that on the western side of GRTE, the spatial extent of the watersheds exceeds the extent of the study area originally defined. Since this analysis is focused on providing metrics by watershed, the watersheds to the west of GRTE outside of the study area were also included. There are 79 watersheds for which landscape metrics have been generated using the Northwest Gap dataset (Figure 3.52). Figure 3.53 shows the forest distribution in relation to the GRTE limits. For this extent, landscape metrics have been generated for 13 watersheds using the GRTE vegetation map, which is of a higher resolution, both spatially and thematically, than the Northwest Gap dataset.

<u>Results</u>

For each of the 79 and 13 watersheds, a database of the calculated metrics was prepared and joined to the watershed shapefile. Figure 3.54 illustrates two of the metrics generated: total area of forest and number of patches of forest per watershed. This figure is a simple example of what could be represented using the attributes of the watershed shapefiles. One can quickly interpret which watersheds have a higher degree of fragmentation. For instance, a given watershed may have a reasonable coverage of forest, but with a high number of patches, whereas other watersheds may have the same forest cover, but with fewer patches. Forest patchiness may influence the effectiveness of wildlife corridors amongst other ecological functions.

This analysis suggests that the most fragmented watersheds in the study area are Spread Creek, Teton Creek, and Upper Lewis River. These three watersheds respectively have 710, 677, and 593 patches of forests. The proximity of these watersheds to populated places and to major roads may be one of the causative factors. Conversely, DeLacy Creek, Elliot Creek, and Jackpine Creek are the least fragmented watersheds, with 5, 51, and 56 patches of forest. Here it seems that remoteness may be a factor that explains the degree of fragmentation found in these drainage areas.

Another metric that was considered of interest was a measure of forest proximity to roads (primary, secondary, and trails). This metric is important because it can be used as a surrogate measure to assess risks to wildlife. For instance, one would expect those watersheds with higher forest proximities to roads to pose a higher risk for animals, particularly in areas and seasons of high traffic.

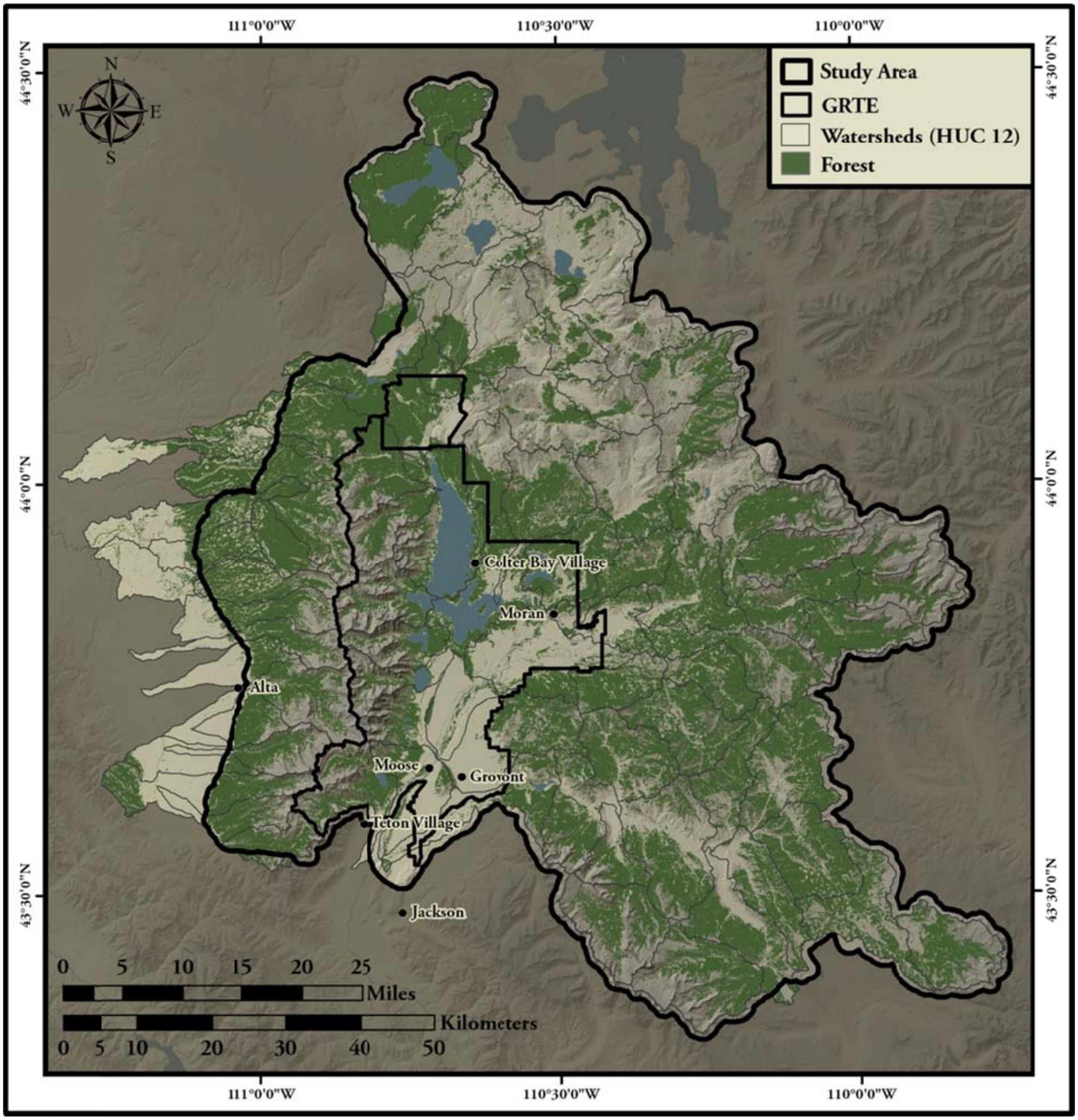

Figure 3.52. Spatial distribution of forest across the study area. Forest landcover data derived from the Northwest Gap dataset.

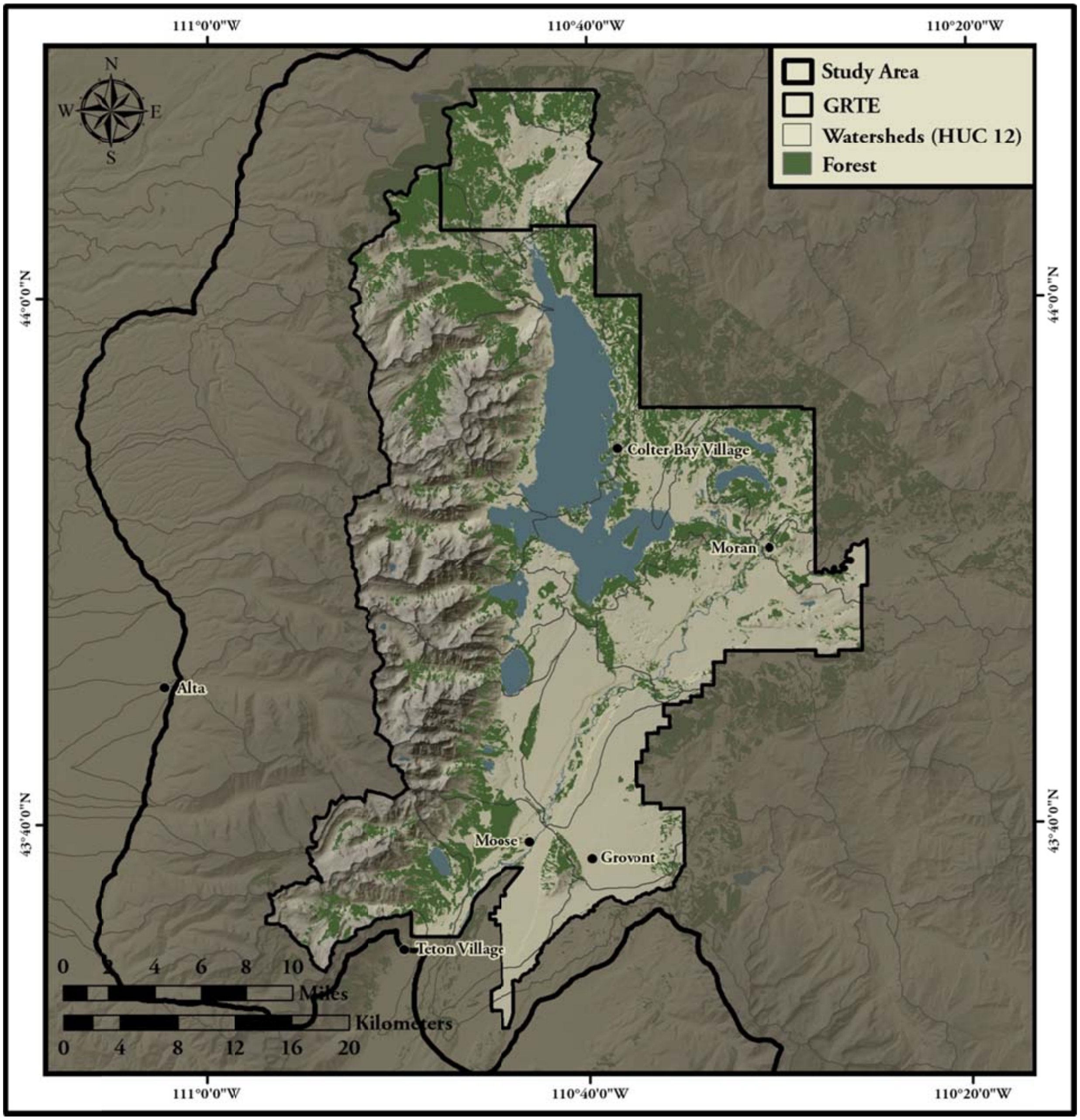

Figure 3.53. Spatial distribution of forests across Grand Teton National Park. Data provided by Grand Teton National Park.

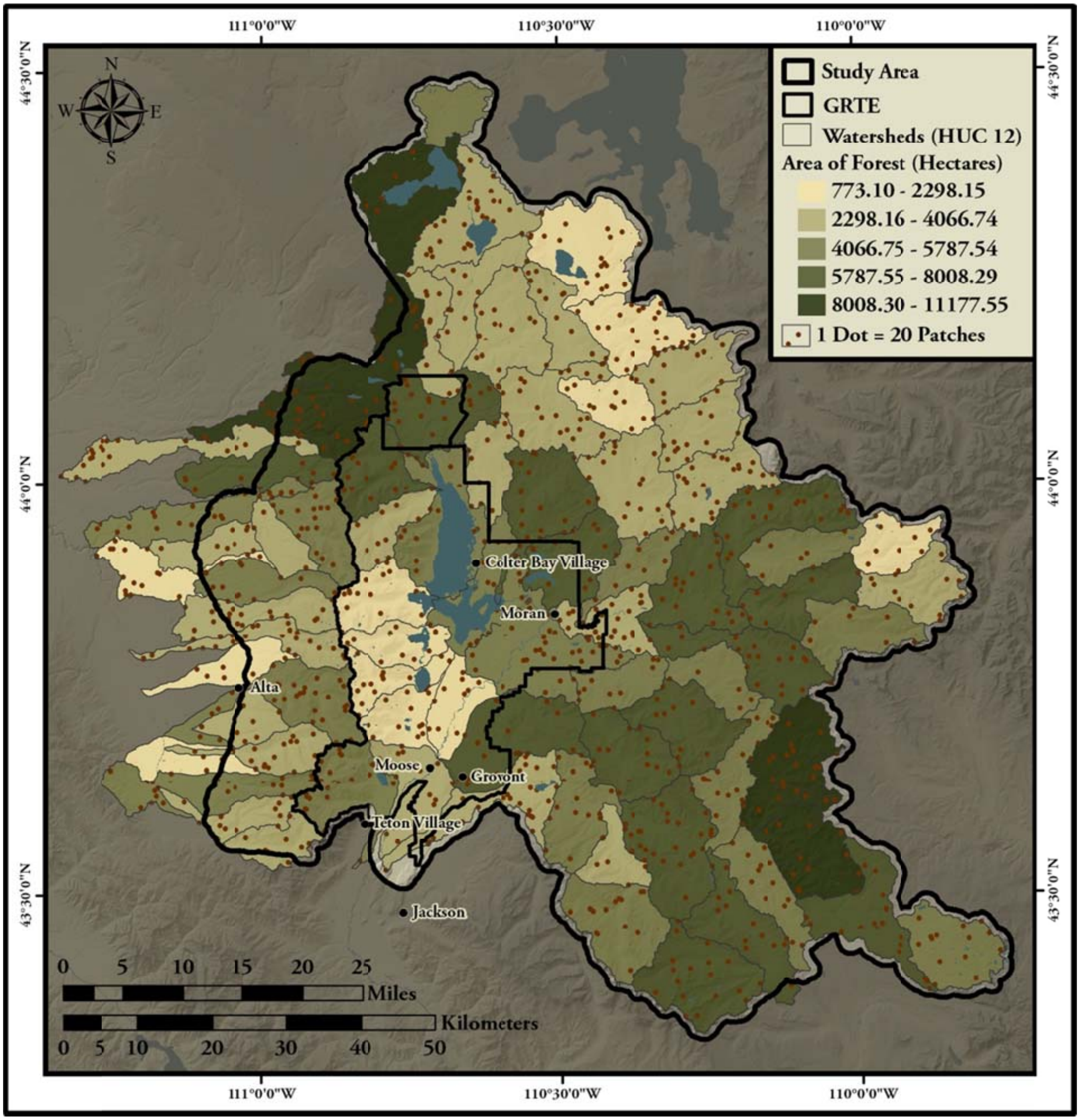

Figure 3.54. Total area of forest (hectares) and number of patches of forest per watershed.

For this metric, a 250-meter (820-foot) buffer on each side of roads and trails was generated. The buffer was intersected with the forested area per watershed. Subsequently, the area of forest within the buffer was calculated. Figure 3.55 displays this metric in terms of percentage. Watersheds with higher values have a larger portion of their forest within the buffer, and thus could potentially be more impacted by anthropogenic activities than those having low percent values.

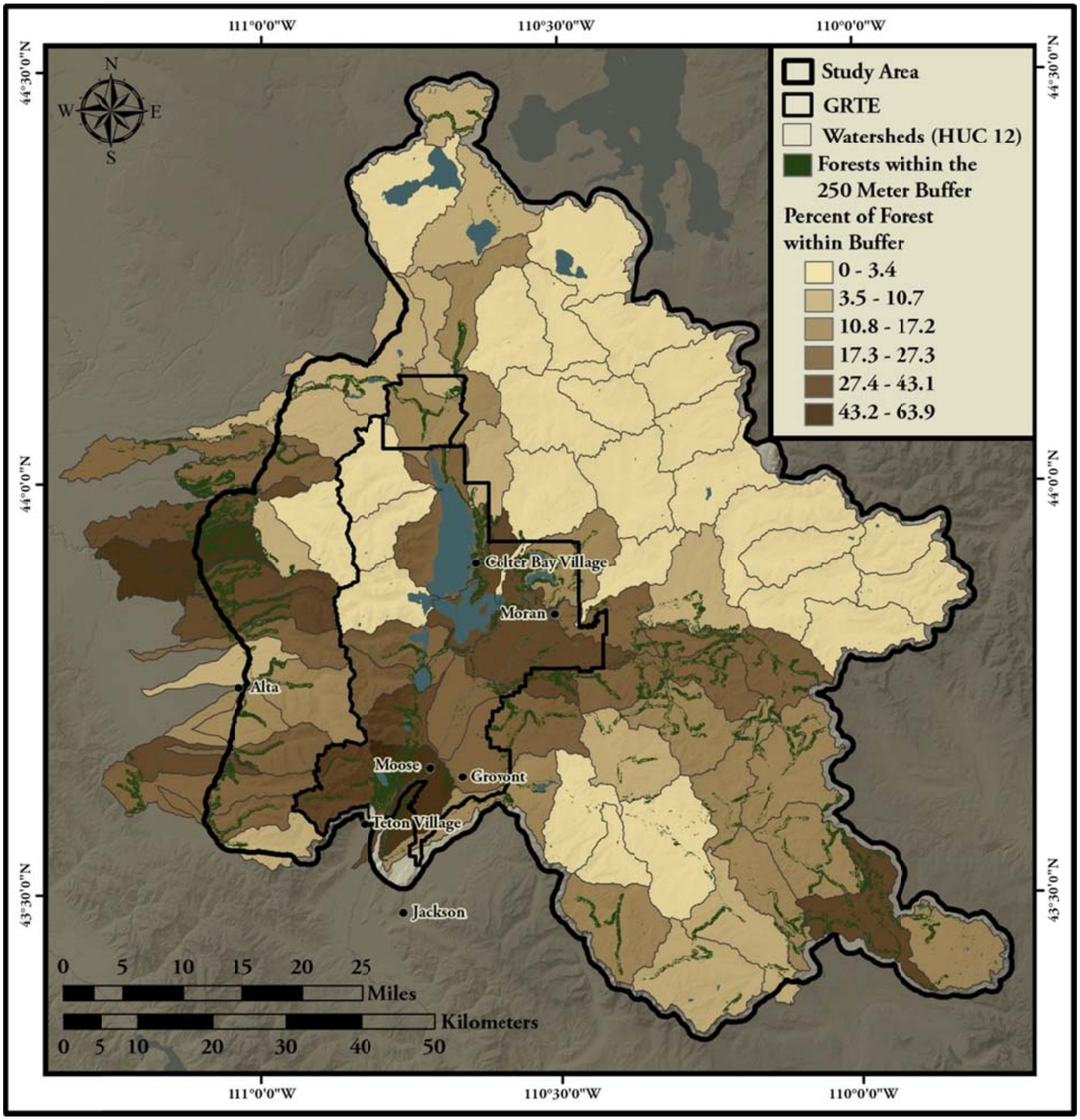

Figure 3.55. Forest proximity to roads. Percent of forested area by watershed that lies within a 250-meter buffer of roads and trails.

This analysis suggests that those watersheds located west of the Teton Range show the highest percentages of forest concentration within the buffer of roads. In this area, towns, such as Alta, are surrounded by a dense network of primary and secondary roads. Within the boundaries of GRTE, there are five watersheds that should be identified. Lower Jackson Lake, Spread Creek, Bradley Lake, Fall Creek, and Stewart Draw have 32, 34, 38, 43, and 51 percent of their forested area within the 250-meter (820-foot) buffer around roads.

Summary and Conclusions

A series of patch metrics were generated for all of the 79 watersheds following a binary approach (FOREST/OTHER) and also by type of forest. This was done using the Northwest Gap dataset and the higher resolution vegetation map prepared by GRTE. In addition, a surrogate measure of forest proximity to roads and trails was created.

Whitebark Pine Distribution and Regeneration

Whitebark pine (*Pinus albicaulis*) is a fundamental component of many high elevation ecosystems in the Greater Yellowstone Ecosystem (GYE). Although whitebark pine is not considered commercially important, this long-lived, slow-growing species is revered for its biologic and aesthetic value. Taxonomically, whitebark pine is a member of the genus *Pinus*, the subgenus *Strobus*, and the subsection *Cembrae*, one of five stone pines worldwide (Critchfield and Little 1966). The distribution of whitebark pine is limited to the high mountains of western North America, including a western portion extending from the coast ranges of British Columbia through the Cascades and Sierra Nevada ranges of Washington, Oregon, and California, and an eastern portion from the Rocky Mountains of British Columbia and Alberta south through Idaho, Montana, Wyoming, and Nevada (McCaughey and Schmidt, 2001). Whitebark pine is typically found in tree-lined environments occurring as high as 12,000 feet (3,660 meters) in the Sierra Nevada Range, 10,500 feet (3,200 meters) in western Wyoming, and 2,950 feet (900 meters) in British Columbia. At higher elevations, whitebark pine is often the dominant tree species, while in lower elevation stands within the GYE, it forms associations with the following species: lodgepole pine (*Pinus contorta* var. *latifolia*), Engelmann spruce (*Picea engelmanii*), subalpine fir (*Abies lasiocarpa*), limber pine (*Pinus flexilis*), and Douglas-fir (*Pseudotsuga menziesii*) (McCaughey and Schmidt, 2001). Whitebark pine is associated with cold, moist environments, often on steep, wind-swept slopes with poor soils. The majority of soils under which whitebark pine establishes are classified as cryochrepts, which tend to be younger, less developed, and leached (acidic) (Weaver, 2001). The climatic zone for whitebark pine is characterized by short, cool summers and long, cold winters with significant snowfall accumulation (Arno and Hoff, 1990).

The tenacity of whitebark pine and its ability to mitigate the harshness of these high elevation environments, create opportunities for other species. Its presence increases the biodiversity of both plant and animal communities throughout the ecosystem (Tomback and Kendall, 2001). The multi-stemmed and open growth form of whitebark pine provides hydrologic integrity by regulating runoff and reducing soil erosion (Farnes, 1990). While whitebark pine is considered a climax species on more rugged, droughty sites, it also functions as an early seral species in moist, sheltered areas by serving as a nurse plant for its shade-tolerant competitors (Arno and Hoff, 1990). The large, nutritious seeds of whitebark pine are a major food source for a wide array of wildlife including the Clark's nutcracker (*Nucifraga columbiana*), red squirrels (*Tamiasciurus hudsonicusto*), and grizzly bear (*Ursus arctos*). Whitebark pine communities are designated as critical habitat for grizzly bear, where after a productive cone crop, the bears tend to forage almost exclusively on whitebark pine seeds (Kendall, 1983; Mattson and Reinhart, 1997). In addition, whitebark pine provides a high quality food supply for bears just prior to hibernation (Mattson et al., 1992). These important functions are why whitebark pine is regarded as a keystone species of the upper subalpine zone in the GYE.

Whitebark pine populations are declining throughout their range from a combination of infestations by a native insect, mountain pine beetle (*Dendroctonus ponderosae*), an introduced fungal disease, white pine blister rust (*Cronartium ribicola*), and altered climate conditions. Western Regional Climate Center data indicate mean annual temperatures for the 11 western states have increased by 0.9 degrees Fahrenheit (0.5 degrees Celsius) since the mid-1970's (Logan et al., 2010). The warmer summers and milder winters have promoted temperature-driven shifts in mountain pine beetle phenology, allowing the beetles to complete their life cycles in a single year. The shortened regeneration time of the beetles has contributed to more severe outbreaks within their historic range and unprecedented mortality in whitebark pine forests (Logan and Powell, 2001; Bentz and Schen-Langenheim, 2007; Bockino and McCloskey, 2010). Without a co-evolved defense mechanism as seen in lodgepole, the primary host, attacks in whitebark pine forests are now faster, more intense, and more widely distributed. White pine blister rust is yet another challenge that can cause rapid declines due to mortality and decreased recruitment from extensive damage to cone bearing branches, seedlings and saplings (Tomback et al., 1995). The weakening of rust-infected trees not only increases the susceptibility to other pathogens, it has also been shown at some GYE sites, whitebark pine is preferentially selected for by mountain pine beetle over lodgepole (Bockino, 2008; Six and Adams, 2006). Hence, the status of whitebark pine forests within GRTE is of great concern.

Methods

To assess the current distribution and status of whitebark pine stands within the study area, two primary sources were examined: (1) the Greater Yellowstone Whitebark Pine Distribution Map and Condition Assessment organized by the Greater Yellowstone Coordinating Committee, Whitebark Pine Subcommittee (GYCCWBPSC, 2010), and (2) a recent technical report provided by GRTE on whitebark pine monitoring within the park (Bockino and McCloskey, 2010).

The Greater Yellowstone Whitebark Pine Distribution Map and Condition Assessment is a complex dataset integrating several distinct data sources including: (1) USFS/NPS vegetation data-derived GYE-wide Whitebark Pine Distribution Map polygons, (2) Remote Sensing Application Center (RSAC) Landsat Thematic Mapper imagery-derived relative conifer canopy change from 2000 to 2007, (3) LANDFIRE canopy cover data for 2007, (4) Burned Area Emergency Rehabilitation/Monitoring Trends in Burn Severity (BAER/MTBS) fire perimeter data for all mapped fires for 2007 and prior, (5) USFS/NPS Whitebark Pine Condition Assessment, and (6) Landscape Assessment System (LAS) mortality data caused by cumulative mountain pine beetle attacks in whitebark pine stands.

In 2007, GRTE initiated a monitoring program for whitebark pine, augmenting an existing GYE-wide monitoring and restoration project, with 26 additional study locations to assess stand condition and regeneration within GRTE specifically. Objectives of GRTE's monitoring program are to track the condition of whitebark pine through the: (1) installation of permanent monitoring transects throughout the whitebark zone (read annually) to detect temporal change; (2) quantification of the spatial distribution of blister rust and beetles; (3) quantification of the severity of blister rust and MPB; (5) identification of areas of low beetle activity or rust infection; (4) description any relationships between edaphic factors and disturbance severity; and (6) quantification of the spatial distribution and abundance of regeneration (Bockino and McCloskey, 2010).

Results

The total distribution of whitebark pine accounts for 266,908 acres (108,014 hectares) within the study area. Within GRTE specifically, whitebark pine covers 26,619 acres (10,772 hectares). In approximately one-third of the stands within GRTE (9,272 acres/3,752 hectares), whitebark pine is considered the dominant species where it occupies 60 percent (or greater) of the relative canopy cover (Table 3.15 and Figure 3.56).

Results from GRTE whitebark pine monitoring transects (Figure 3.57) provide insight to the overall condition of whitebark pine, by identifying the temporal and spatial patterns of whitebark pine mortality, cone production, and regeneration, along with the spread of mountain pine beetle activity and blister rust infection observed between 2007 and 2010 (Bockino and McCloskey, 2010). Table 3.16 summarizes whitebark pine monitoring data at both transect- (i.e. the proportion of transects sampled) and tree- (i.e. the proportion of individual trees sampled) levels. Although the intensity varies spatially, whitebark pine experienced increased mortality, mountain pine beetle activity, and blister rust severity during the study period (Table 3.16 and Figure 3.58). Between 2007 and 2010, the mortality rate of whitebark pine increased from 17 percent to 31 percent, with beetle activity as the primary culprit. The presence of mountain pine beetles in whitebark pine increased from 14 percent to 21 percent. Based on 2007 data alone, results suggest that mountain pine beetle activity increased in more severely rust-infected whitebark pine, beetle activity was greater on the east slope of the range, and occurred at rates higher than expected at lower elevations (less than 9,500 feet/2,896 meters) and on south-facing aspects. Results from an additional aerial survey covering the entire GYE in 2009 (Macfarlane et al., 2010), identified beetle activity in the visible tree canopy in 90 percent of all watersheds containing whitebark pine.

Blister rust was evident on 100 percent of transects. At the tree-level, incidence of rust decreased from 55 percent to 43 percent between 2007 and 2010 (Table 3.16). As beetles or rust induced mortality, the trees were removed from the sample population, affecting the total number of whitebark pine with rust. In contrast, the severity of blister rust (i.e. mean number of cankers per live whitebark pine) increased from 11.7 percent to 22.7 percent between 2007 and 2010 (Table 3.16). The range of mean number of cankers per live whitebark pine across all transects increased from 0.4 percent to 22.2 percent in 2007, to 1.3 percent to 45.5 percent in 2010 (Table 3.17). Data from 2007 suggest blister rust severity was positively correlated with lower elevations (less than 9,500 feet/2,896 meters), south-facing aspects, and larger diameter whitebark pine.

With one exception (i.e. Twenty-five Short), whitebark pine regeneration was evident on all transects over time, but the abundance varied. Table 3.18 provides understory data for all transects, including regeneration abundance of whitebark pine (less than 4.6 feet/1.4 meters in height) and relative proportions that were rust-free. In 2010, whitebark pine regeneration ranged from zero to 2,280 seedlings per hectare (Table 3.18). Ninty-six percent of the regeneration in 2010 was rust-free, of which 59 percent were less than 15.7 inches (40 centimeters) in height (Table 3.19).

Table 3.15. Whitebark pine distribution within GRTE and the study area.

Whitebark Pine Distribution	Total Acres of Whitebark Pine	Acres of Whitebark Pine Dominant Stands	Acres of Mixed Stands
GRTE	26,619	9,272	17,347
Study Area	266,908	140,574	126,334

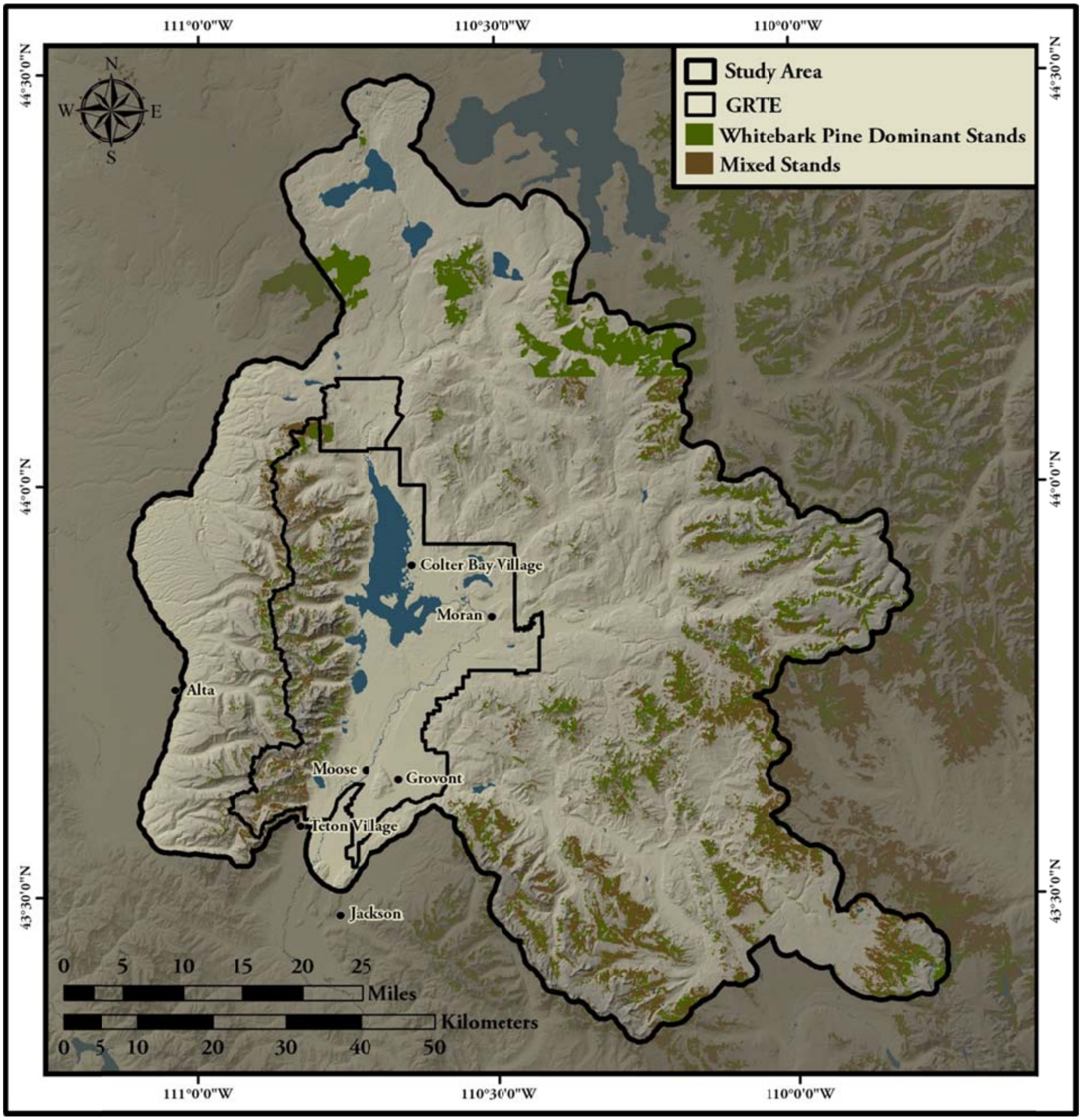

Figure 3.56. Distribution of whitebark pine within the study area.

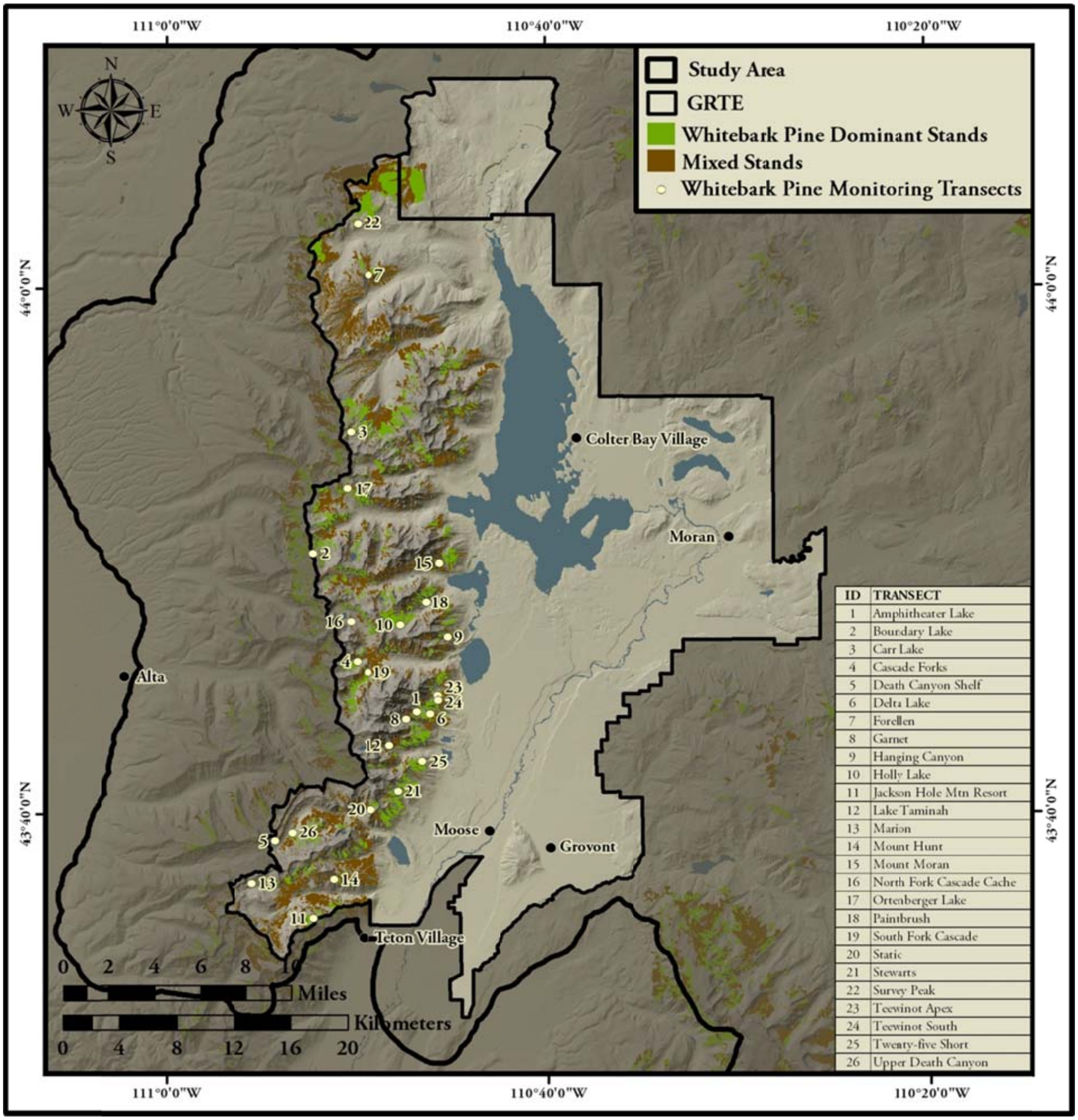

Figure 3.57. Whitebark pine monitoring transects in Grand Teton National Park.

Table 3.16. Whitebark pine (PIAL) conditions in Grand Teton National Park, 2007-2010.

Samples	Total Number Transects Sampled				Total Number Individual Whitebark Pine Sampled			
	2007	2008	2009	2010	2007	2008	2009	2010
	24	22	9	21	452	400	172	405
Variables	**Proportion of Transects Sampled (%)**				**Proportion of Individual Whitebark Pine Sampled (%)**			
	2007	**2008**	**2009**	**2010**	**2007**	**2008**	**2009**	**2010**
Dead PIAL	63	77	78	81	17	28	22	31
Mountain pine beetle	50	68	56	71	14	24	7	21
Blister rust (live PIAL only)	100	100	100	100	55	60	50	43
Mean # Cankers/PIAL (live only)[1]					11.7	11.1	7.84	22.7
Evidence of Cones (live PIAL only)[2]	100	68	67	66	30	21	19	29
Regeneration Present	100	95	100	95				

[1]Not a proportion – the mean number of cankers on live whitebark pine that are infected with blister rust.
[2]Live PIAL that have evidence of cone production (cones or cone skeletons).

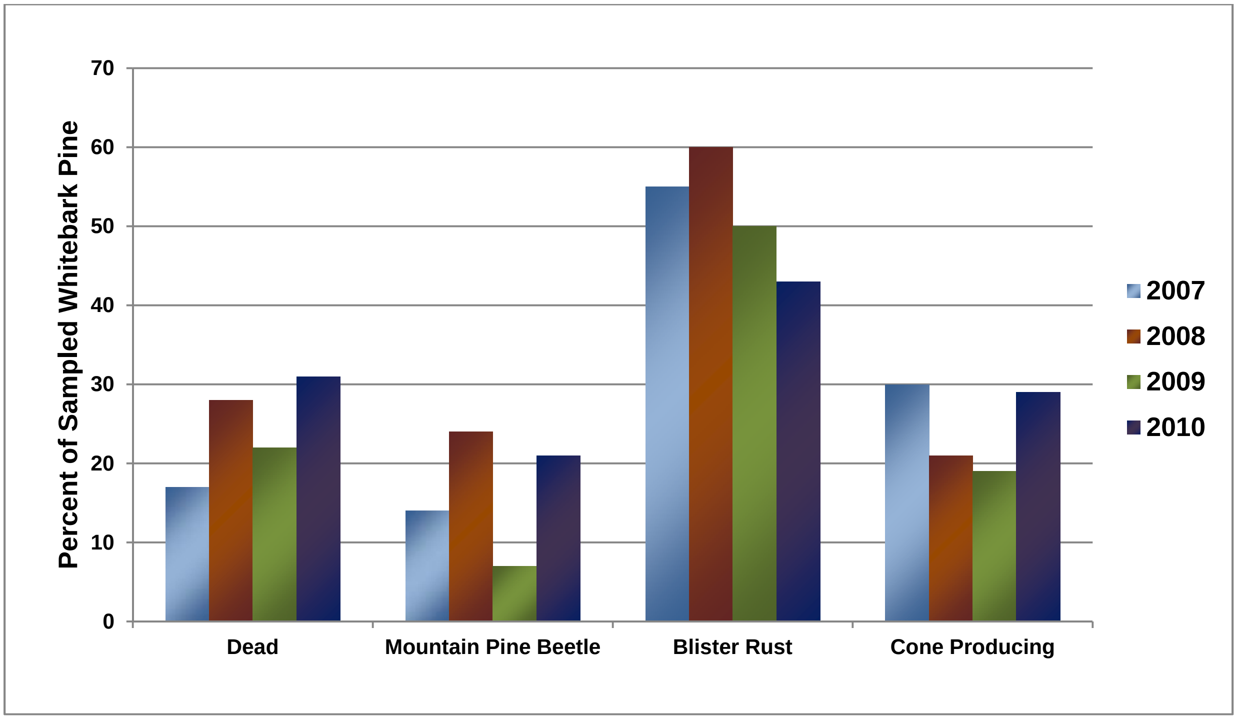

Figure 3.58. Proportion of individual whitebark pine sampled in Grand Teton National Park that are dead, have been attacked by mountain pine beetle, are infected with blister rust, and those that are cone producing.

Table 3.17. Overstory tree data for whitebark pine (PIAL) by monitoring transect in Grand Teton National Park, 2007-2010. Blank cells indicate years in which transects were not visited.

Transect	Percent PIAL Dead				Percent PIAL with Mountain Pine Beetle				Percent PIAL with Evidence of Cones				Percent Live PIAL with Rust				Mean Number Cankers / Live PIAL			
	2007	2008	2009	2010	2007	2008	2009	2010	2007	2008	2009	2010	2007	2008	2009	2010	2007	2008	2009	2010
Amphitheater Lake	0	0	0	0	8	0	0	0	40	24	36	16	44	48	56	60	3.4	5.7	13.3	19.3
Boundary Lake	0		4		0		0		4		4		33		33		0.9		1.5	
Carr Lake	8		8		8		8		27		25		46		46		1.4		4.5	
Cascade Canyon	20	20		50	0	10		50		38		50	63	88		50	6.1	18.6		6.5
Death Canyon Shelf	0	0		0	0	3		0	35	35		52	45	48		61	8.5	14.5		21.4
Delta Lake	0	40		40	0	40		40	50	0		50	80	67		67	11.6	16.3		26
Forellen	32	33		33	0	2		2	62	38		49	28	45		66	1.5	4.7		10.7
Garnet	0	0			0	0			33	20			60	53			3.3	7.4		
Hanging Canyon	47	63		68	47	68		68	10	14		16	90	86		83	19.4	33.6		26.7
Holly Lake	0	0		0	0	0		0	60	60		60	80	80		80	10.8	26.6		25
Jackson Hole Mtn Resort	9	9		14	0	0		0	5	15		16	65	55		61	6.9	13		12
Lake Taminah	7	7	14	32	0	0	21	21	4	0	4	0	54	62	67	58	3.2	6	8.9	10.4
Marion	63	63		63	63	63		63	100	33		33	66	66		66	7.7	14.7		23.7
Mount Hunt	13	13		13	0	38		0	57	42		43	86	100		100	11.2	20.3		21.6
Mount Moran	8		17		0		0				0		26		30		0.4		0.7	
North Fork Cascade Cache	0	0	0	0	0	0	0	0	30	30	20	10	30	40	50	60	1.5	3.4	7.3	10.7
Ortenberger Lake	2		29		21		21		64		70		82		90		7		17.7	
Paintbrush Canyon		22		28		22		22		0		7		43		46		1.2		1.3
South Fork Cascade	0	11		11	0	0		0	70	38		22	78	75		75	5	13.3		24.8
Static	33	78	78	78	67	78	78	78	58	25	0	0	92	100	100	100	17.2	20.8	30	30.8
Stewarts	0	65	75	100	24	94	94	100	18	17	0	0	88	83	NA	NA	22.2	27.5	NA	NA
Survey Peak	3	3		6	3	13		3	3	0		18	58	65		64	6.8	12.1		15.5
Teewinot Apex	50	57		86	50	50		71	29	17		0	71	100		100	8.9	22.7		45.5
Teewinot South	63	79		89	79	79		95	14	0		0	100	100		100	18.9	28.3		28
Twenty-five Short		80		80		100		80		0		0		100		100		11		14
Upper Death Canyon	22	22		50	44	33		50	14	0		0	29	57		75	5.4	5.4		3.8

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Table 3.18. Understory tree data for whitebark pine by monitoring transect in Grand Teton National Park, 2007-2010. Blank cells indicate years in which transects were not visited.

Transect	Total Number Seedlings/Hectare				Percent Seedlings Rust-Free			
	2007	2008	2009	2010	2007	2008	2009	2010
Amphitheater Lake	1,240	1,680	1,800	1,520	100	100	100	99
Boundary Lake	700		1,740		100		100	
Carr Lake	240		240		100		100	
Cascade Canyon	60	40		120	67	100		100
Death Canyon Shelf	620	460		400	94	83		90
Delta Lake	740	760		980	100	100		98
Forellen	840	1,300		2,080	100	100		100
Garnet	420	640			100	100		
Hanging Canyon	1,080	860		1,060	100	98		98
Holly Lake	320	200		420	100	100		100
Jackson Hole Mtn Resort	940	1,740		1,200	100	99		92
Lake Taminah	740	1,220	1,140	2,060	97	100	93	89
Marion	20	20		40	0	0		100
Mount Hunt	280	100		120	100	100		100
Mount Moran	320		480		100		79	
North Fork Cascade Cache	320	700	660	640	100	100	97	100
Ortenberger Lake	160		660		88		94	
Paintbrush Canyon		20		20		100		100
South Fork Cascade	180	180		160	100	67		75
Static	220	2,640	2,080	880	91	100	100	100
Stewarts	1,580	2,460	2,720	2,280	99	100	99	98
Survey Peak	900	1,200		1,160	84	92		88
Teewinot Apex	120	80		100	83	50		80
Teewinot South	280	440		580	100	100		100
Twenty-five Short		0		0		NA		NA
Upper Death Canyon	100	60		60	80	100		100

Table 3.19. Whitebark pine regeneration abundance by size class in Grand Teton National Park, 2010.

Percent Whitebark Pine WITH Rust				Percent Whitebark Pine NO Rust			
New Emergents	Seedlings (<40 cm)	Saplings (40-100 cm)	Poles (101-139 cm)	New Emergents	Seedlings (<40 cm)	Saplings (40-100 cm)	Poles (101-139 cm)
0	0.4	1.8	2	7.3	58.6	20.9	9.1

As part of the Whitebark Pine Strategy for the Greater Yellowstone, the Whitebark Pine Subcommittee developed a Whitebark Pine Strategy Ranking System (GYCCWBPSC, 2010). The ranking system includes a composite score relative to canopy damage and to cone potential. Canopy damage was ranked from very low canopy damage with a very low-to-no current activity by mountain pine beetle to very high canopy damage with a very high level of beetle activity. Cone potential was assessed based on stand type (whitebark pine-dominant stand versus a mixed stand), degree of canopy damage, and canopy cover. Stands where whitebark pine was dominant (greater than or equal to 60 percent relative canopy cover) and where canopy closure was greater than 20 percent were considered more important. Table 3.20 shows the overall stand condition ranking system and the two scales used to identify stands needing protection, and conversely, restoration. For stands needing protection, 46 percent of all whitebark pine in GRTE (12,209 acres/4,941 hectares) and 33 percent of all whitebark pine in the study area (87,679 acres/35,482 hectares) fell within the top three protection ranks (7 to 9) (Table 3.21 and Figure 3.59). For stands needing restoration, two percent of all whitebark pine in the GRTE (545 acres/221 hectares) and 19 percent of all whitebark pine in the study area (50,164 acres/20,301 hectares) were classified in the top three restoration ranks (Table 3.22 and Figure 3.60).

Summary and Conclusions

The status and condition of whitebark pine forests in GRTE and throughout its range are changing dramatically and rapidly. With predictions of continued increases in temperatures and prolonged drought, many of the challenges whitebark pine forests currently face are likely to persist. The future distribution and abundance of whitebark pine in GRTE is unknown and will reflect the biology and ecology of whitebark, combined with the effects of the current blister rust and beetle disturbance. Limited propagule availability due to losses caused by mountain pine beetle and blister rust impacts may decrease future colonization rates (Bockino and McCloskey, 2010; and references therein). Bockino and McCloskey (2010) suggest that in mixed conifer stands, where whitebark is seral, beetle-caused mortality may release suppressed whitebark and promote increased growth rates. Current disturbances may promote this response in the GYE, as many stands contain several understory cohorts of whitebark (Bockino and McCloskey, 2010; and references therein).

GRTE is collaborating with a number of other federal and state agencies, universities, and private entities in an effort to promote (1) accurate knowledge of tree physiology, (2) updated spatial and temporal distributions of tree mortality and damage, and (3) timely investigations of current and potential whitebark pine recruitment (Bockino and McCloskey, 2010). Such efforts are contributing to a GYE-wide whitebark pine strategy to support the development of accurate and successful preservation and restoration activities.

Table 3.20. Whitebark Pine Strategy Ranking System.

Whitebark Pine Stand-Level Condition Assessment	Protect	Restore
Canopy Damage (Integration Landscape Assessment 2009, RSAC Landsat Imagery Canopy Change 2000-2007, Condition Assessment 2009)		
Very Low Canopy Damage; Current Mountain pine beetle (MPB) activity None to Very Low	5	0
Low Canopy Damage; Current MPB activity Low	4	0
Moderate Canopy Damage; Current MPB Activity Moderate	3	2
High Canopy Damage; Current MPB Activity Low	3	4
High Canopy Damage; Current MPB Activity Very High	2	4
Canopy Loss to Fire	1	4
Very High Canopy Damage; Current MPB Activity Very Low	1	5
Cone Potential (Stand type, Canopy damage, & canopy cover)		
Whitebark pine-dominant stand and closed/moderate canopy cover	4	4
Whitebark pine-dominant stand and open canopy cover	3	3
Whitebark pine mixed stand and closed/moderate canopy cover	2	2
Whitebark pine mixed stand and open canopy cover	1	1
Burned stands	0	0
Overall Stand Condition Score (Canopy Damage + Cone Potential)	**1 - 9**	**0 - 9**

Source: Bockino and MacFarlane, 2010

Table 3.21. Stand condition protection rankings for whitebark pine stands within Grand Teton National Park and the study area.

Whitebark Pine Stands Needing Restoration	Total Acres of Whitebark Pine	Stand Condition Rank 7	Stand Condition Rank 8	Stand Condition Rank 9	Stand Condition Rank 7-9	Percent of Whitebark Pine
GRTE	26,619	5,898	4,497	1,814	12,209	46%
Study Area	266,908	60,872	21,610	5,197	87,679	33%

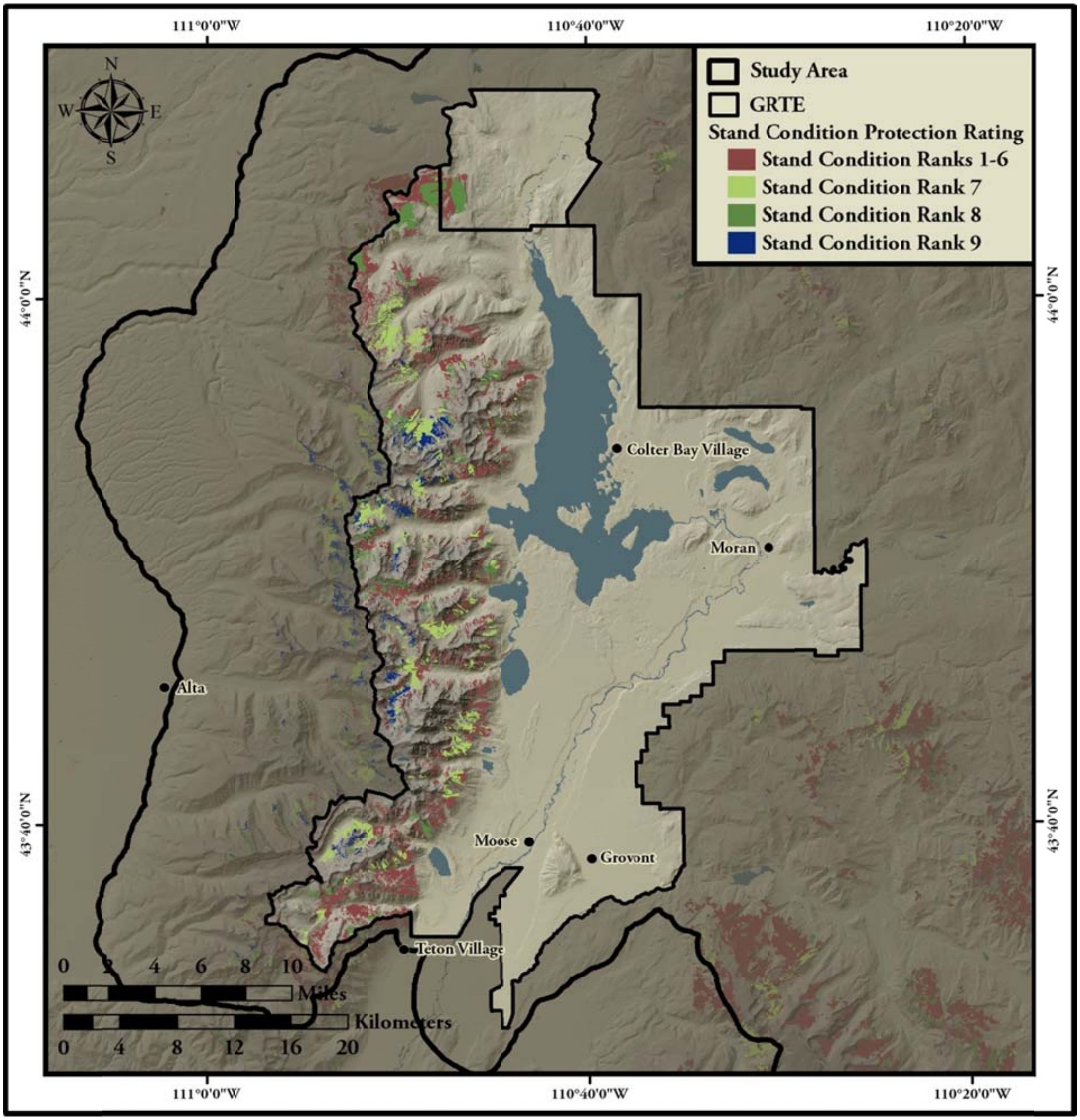

Figure 3.59. Distribution of protection ranking for whitebark pine stands within Grand Teton National Park.

Table 3.22. Stand condition restoration rankings for whitebark pine stands within Grand Teton National Park and the study area.

Whitebark Pine Stands Needing Restoration	Total Acres of Whitebark Pine	Stand Condition Rank 7	Stand Condition Rank 8	Stand Condition Rank 9	Stand Condition Rank 7-9	Percent of Whitebark Pine
GRTE	26,619	109	436	0	545	2%
Study Area	266,908	6,231	42,124	1,808	50,164	19%

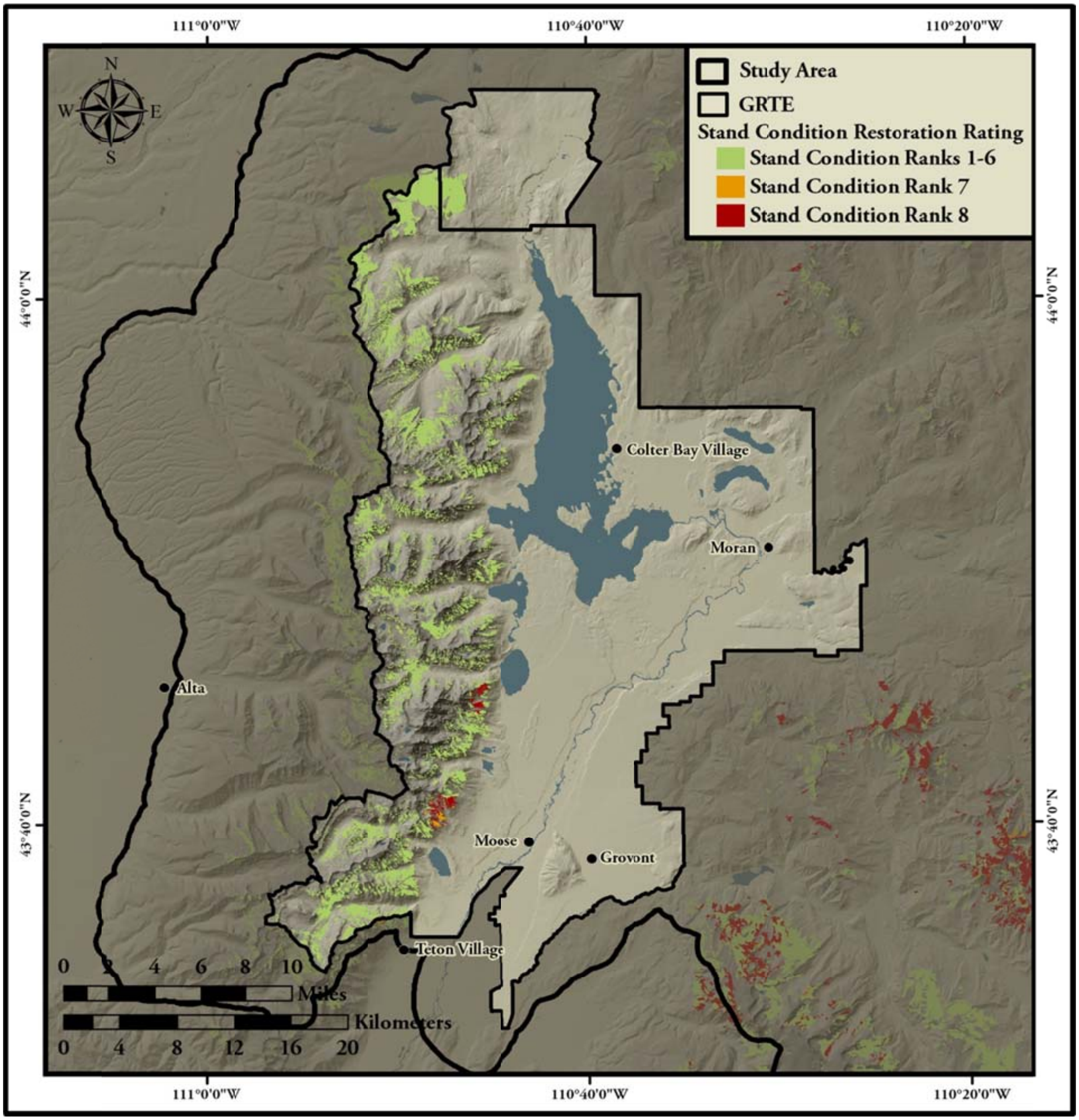

Figure 3.60. Distribution of restoration ranking for whitebark pine stands within Grand Teton National Park.

Insects and Disease

Mountain Pine Beetle

Since 1990, native bark beetles have killed millions of trees across millions of hectares of forest from Alaska to Mexico's northern Baja California. Although bark beetle infestations are a regular force of natural change in forested ecosystems, current outbreaks however, occurring simultaneously across western North America, are larger, more severe, and extending into ecosystems not previously affected (Bentz et al., 2009; Logan et al., 2010; Gibson et al., 2008).

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins, a bark beetle native to western North American forests and a member of a relatively small family of aggressive insects (*Curculionidae*, subfamily *Scolytinae*) (Bentz et al., 2009), is currently responsible for killing more pines (*Pinus* spp.) throughout its range than all other insect pests combined (Gibson et al., 2008). The current mountain pine beetle-caused mortality within the Greater Yellowstone Ecosystem (GYE) particularly in higher elevation whitebark pine (*Pinus albicaulis*) forests is unprecedented (Logan et al., 2010; NPS, 2008b; Bockino, 2008). Mountain pine beetles infest and reproduce within the phloem of most *Pinus* species, whose feeding activity which can girdle and kill successfully attacked trees (Logan and Powell, 2001; and references therein). In addition to mountain pine beetle activity, a blue staining fungus, carried by mountain pine beetles, is introduced as a secondary pathogen, which causes further damage to the tree by clogging the sapwood of living trees and preventing water and nutrient transport (Amman et al., 1989). Most host trees have evolved effective resin response mechanisms to defend themselves against bark beetle attacks; however, only those with a rapid and sustained response survive. But, if the timing of peak adult emergence from brood trees is synchronous, a new host tree's natural defense may not be sufficient to withstand a mass attack. Like other ectotherms, life-cycle timing and emergence synchrony in mountain pine beetle is strongly influenced by temperature (Powell and Bentz et al., 2009; and references therein).

Changing climatic conditions, specifically rising temperatures and decreasing precipitation, is one of the primary drivers behind the current outbreaks of mountain pine beetle throughout its range (Bentz et al., 2009; Logan et al., 2010; and references therein). Since the mid-1970s, Western Regional Climate Center data indicate mean annual temperatures for the 11 western states have increased by 0.9 degrees Fahrenheit (0.5 degrees Celsius) (Logan et al., 2010). Longer summers have extended mountain pine beetle reproduction and growth periods, followed by milder fall, winter, and spring temperatures permitting increased overwinter survival (Bentz et al., 2009) and a proliferation of populations in areas previously unaffected. Bentz and Schen-Langenheim (2007) found in several GYE high elevation sites a reduction in mountain pine beetle phenology, where beetles were completing their life cycle in three years (1970s), to two years (through 2002), to one year (2003 to 2006). The shortened generation time of the beetles has contributed to more severe outbreaks within their historic range and unprecedented mortality in whitebark pine forests (Logan et al., 2010). Without a co-evolved defense mechanism as seen in lodgepole pine, the primary host, coupled with prolonged water stress, attacks in whitebark pine forests are now faster, more intense, and more widely distributed. Assuming other inputs to the system remain constant, the decrease in mountain pine beetle generation time translates to a doubling in the rate of population growth (Bentz, 2008).

Forest history, as it relates to current forest structure, is another factor responsible for bark beetle outbreaks. Aggressive bark beetles favor mature trees. Many areas that have experienced major disturbances, such as stand-replacing fires or timber harvest, followed by fire suppression, are left with trees of similar age and size, a more vulnerable condition to bark beetle attack than younger, more diverse stands (Bentz et al., 2009).

Methods

The trends and extent of bark beetle activity within GRTE and the study area were determined by evaluating a combination of recently published literature and two distinct sources of spatial data: (1) a series of files acquired from the U.S. Forest Service's Forest Health Protection program's on-line data repository of annual aerial insect and disease detection surveys, and (2) a spatially integrated dataset provided by GRTE, depicting the distribution and condition of whitebark pine within the GYE (GYCCWBPSC, 2010), used to identify the impact by mountain pine beetle to whitebark pine within GRTE and the study area specifically.

The Forest Health Protection program conducts annual aerial insect and disease detection surveys in partnership with several western states to identify and map insect damage and mortality within and around National Forest lands. GIS data from the Bridger-Teton National Forest surveys conducted in 2006, 2008, and 2009 were used to determine the damage-causing agents and extent of activity within GRTE (USFS, 2006; USFS, 2008; USFS, 2009). Mapping was incomplete for GRTE in 2007. Because mortality by bark beetle is not typically symptomatic for nearly a year following an attack, the number of beetle-killed trees documented for a particular year are reflections of the prior year's mortality.

The whitebark pine dataset for the GYE incorporates a "Landscape Assessment System" which rates the degree of mortality from recently compiled field observations of canopy damage associated with mountain pine beetle activity. The assessment includes a mortality ranking system that accounts for mountain pine beetle-induced mortality in whitebark pine over time.

Results

The current tree mortality and trends caused by native bark beetles, and specifically mountain pine beetle, within GRTE, mirrors the epidemic levels reported throughout much of western North America. According to the aerial insect and disease detection surveys, mountain pine beetle is responsible for the majority of the damage in the years 2006, 2008, and 2009 (Table 3.23). Evidence of mortality caused by Douglas-fir beetle (*D. pseudotsugae*) and spruce beetle (*D. rufipennis*) was also apparent, but the declining and relatively low numbers reflect the lack of living host trees as a consequence of previous years' outbreaks. The causal agent for subalpine fir mortality was not identified in the detection surveys; however, the western balsam bark beetle (*Dryocoetes confuses*) is a common pathogen of subalpine fir and is responsible for some mortality in YELL (NPS, 2008b).

Table 3.23. Acres of canopy damage identified during annual aerial insect and disease detection surveys within Grand Teton National Park. Mapping was incomplete in 2007.

Damage-causing Agent	2006	2008	2009
Mountain pine beetle (*Dendroctonus ponderosae*)	1,797	23,268	20,733
Douglas-fir beetle (*Dendroctonus pseudotsugae*)	445	80	23
Spruce beetle (*Dendroctonus rufipennis*)	2		5
Subalpine fir mortality	869	665	470
Total Acres	**3,114**	**24,014**	**21,230**

Throughout its range, the primary host of mountain pine beetle is lodgepole pine (*Pinus contorta*), with only occasional outbreaks in whitebark pine. Within GRTE, lodgepole pine and whitebark pine are likewise the two primary species affected by mountain pine beetle (Table 3.24). What is concerning, however, are the dramatic increases in recent years of mountain pine beetle in lodgepole pine, particularly at lower-elevations, and throughout whitebark pine. Mountain pine beetle outbreaks are responsible for approximately 20 to 30 percent of mortality in the lodgepole pine forests in GRTE (K. McCloskey, GRTE, pers. comm.), and 95 percent of the cone-bearing whitebark pine (those greater than 5.0 inches/12.7 centimeters at breast height) throughout the GYE (Gibson et al., 2008). As was mentioned in the previous section on whitebark pine, GRTE whitebark pine monitoring transects revealed that between 2007 and 2010, the mortality rate of whitebark pine increased from 17 percent to 31 percent, with beetle activity as the primary cause. The presence of mountain pine beetles in whitebark pine increased from 14 percent to 21 percent (Bockino and McCloskey, 2010) (see section on Whitebark Pine Distribution and Regeneration, Table 3.24).

According to the GYE distribution and condition assessment of whitebark pine within GRTE, 30 percent of the stands where whitebark pine is dominant, and 36 percent of those that are mixed, appear to be free of mountain pine beetle activity (Table 3.25 and Figure 3.61). Sixty-nine percent of the whitebark pine-dominant and 64 percent of the mixed stands show some level of current mountain pine beetle activity (i.e. spot outbreaks, coalescing outbreaks, increasing coalescence) within GRTE. There are no stands within GRTE with complete die off (i.e. residual, gray canopy). However, within the extent of the study area, only 15 percent of the whitebark pine-dominant and 14 percent of the mixed stands appear to be free of mountain pine beetle activity (Table 3.26). Evidence of current mountain pine beetle activity within the study area amounts to 78 percent of the whitebark pine-dominant stands and 84 percent of the mixed stands. Both stand types, whitebark pine and mixed, have experienced some die off (four percent and two percent, respectively).

Summary and Conclusions

As was predicted by simulation models of bark beetle response to temperature, current warming trends have directly contributed to current mountain pine beetle outbreaks by exceeding critical limits, resulting in fundamental regime shifts in bark beetle phenology (Logan et al., 2010; and references therein). Bark beetle researchers believe that continued warming will fuel beetle attacks in areas where beetle activity was previously constrained by climate, such as in the northern latitudes and high

Table 3.24. Acres of mountain pine beetle-caused canopy damage to host tree identified during annual aerial insect and disease detection surveys within Grand Teton National Park.

Mountain Pine Beetle-caused Damage by Host	2006	2008	2009
Whitebark pine	129	763	1,022
Lodgepole pine	1,660	22,469	19,655

Table 3.25. Cumulative mountain pine beetle-induced mortality in whitebark pine within Grand Teton National Park.

	Grand Teton National Park					
Landscape Assessment System's Mortality Rating	**Acres all Whitebark Pine**	**Percent of all Whitebark Pine**	**Acres Whitebark Pine Dominant**	**Percent of Whitebark Pine Dominant**	**Acres Mixed Stand**	**Percent of Mixed Stands**
0.0 - 1.0 (no unusual mortality)	9,086	34%	2,800	30%	6,286	36%
1.1 - 2.0 (multiple spot outbreaks)	11,595	44%	3,788	41%	7,807	45%
2.1 - 3.0 (coalescing outbreaks)	5,105	19%	2,106	23%	2,999	17%
3.1 - 4.0 (increasing coalescence)	756	3%	545	6%	211	1%
4.1 - 6.0 (residual, gray canopy)	0	0%	0	0%	0	0%
Burned	77	0.3%	34	0.4%	43	0.2%
Total Acres	**26,619**		**9,272**		**17,347**	

Source: GYCCWBPSC, 2010

elevation forests of the western United States (Bentz et al., 2009).

Although bark beetles are a natural part of forest regeneration, the current rates of tree mortality in some forest ecosystems, particularly those where the dominant tree species require hundreds of years to reach maturity, as is the case for whitebark pine, the ability to recover and regenerate may be interrupted, or worse, threaten local extinction (Bentz et al., 2009). Hence, the status of the whitebark pine in GRTE, considering the combined threat of mountain pine beetle coupled with current infection rates by white pine blister rust (*Cronartium ribicola*) (see following section), is of great concern.

The ecological consequences associated with massive tree mortality may include declines in local wildlife populations, impacts to water quality and quantity, increased fire hazard, and fluxes in carbon exchange (Bentz et al., 2009). Such concerns are what brought a team of entomologists together from U.S. Forest Service, Research and Development western research stations, U.S. Forest Service, State and Private Forestry, and Forest Health Protection, to identify current bark beetle research priorities. The categories of research priorities include the following: vegetation management; ecological, economic, and social consequences of outbreaks; fire and bark beetle interactions; effects of climate change on bark beetle populations; and chemical ecology (Negron et al., 2008), which are described in more detail in Table 3.27.

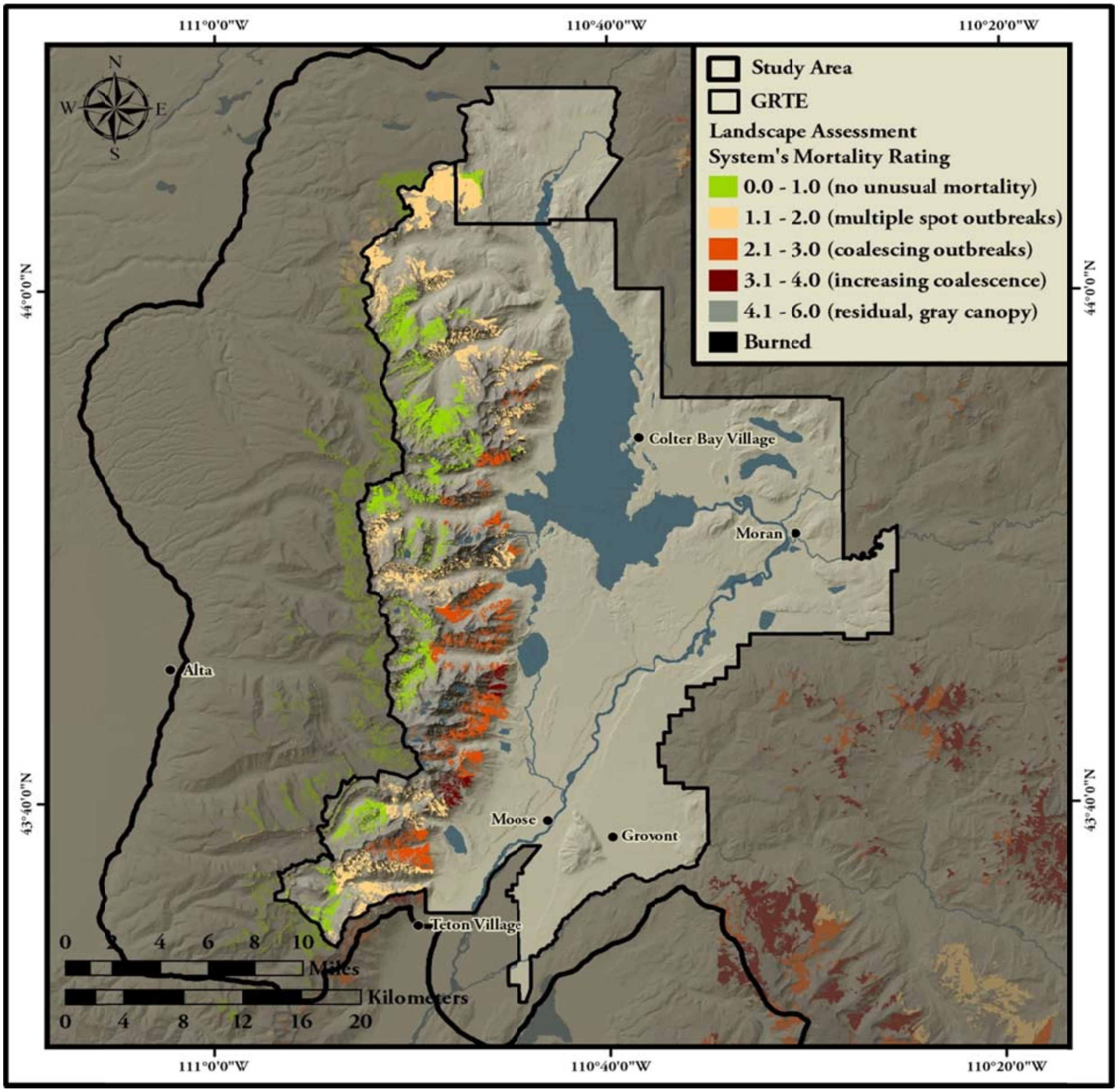

Figure 3.61. Cumulative mountain pine beetle-induced mortality in whitebark pine within Grand Teton National Park (GYCCWBPSC, 2010).

Table 3.26. Cumulative mountain pine beetle-induced mortality in whitebark pine within the study area.

	Study Area					
Landscape Assessment System's Mortality Rating	**Acres All Whitebark Pine**	**Percent of All Whitebark Pine**	**Acres of Whitebark Pine Dominant**	**Percent of Whitebark Pine Dominant**	**Acres Mixed Stand**	**Percent of Mixed Stands**
0.0 - 1.0 (no unusual mortality)	38,796	15%	21,226	15%	17,571	14%
1.1 - 2.0 (multiple spot outbreaks)	48,913	18%	29,237	21%	19,676	16%
2.1 - 3.0 (coalescing outbreaks)	70,250	26%	36,451	26%	33,799	27%
3.1 - 4.0 (increasing coalescence)	96,743	36%	44,236	31%	52,506	42%
4.1 - 6.0 (residual, gray canopy)	7,382	3%	5,399	4%	1,983	2%
Burned	4,825	2%	4,025	3%	800	1%
Total Acres	**266,909**		**140,574**		**126,334**	

Source: GYCCWBPSC, 2010

Table 3.27. Summary of research needs for bark beetles in the western United States.

Vegetation management
• Examining vegetation management strategies in forest types lacking information such as Douglas-fir and spruce forests. • Transferring vegetation management information on bark beetle susceptibility to large landscapes, longer time frames, and uneven-aged stands. • Determine the impact of microclimate change on bark beetle populations and the role of landscape patchiness on the efficacy of vegetation management. • Exploring the mechanisms by which thinning and other disturbance agents such as drought, disease, and defoliation influence tree physiology and susceptibility to bark beetles. • Assessing the effect of mechanical fuel reduction treatments on residual tree susceptibility to bark beetles.
Ecological, economic, and social consequences of bark beetle outbreaks
• Examining the role of bark beetles on forest stand structure, biogeochemical and hydrological cycling, net primary production, and species diversity. • Using spatial metrics and multiple variables to characterize nontimber impacts of bark beetles on the landscape. • Quantifying and modeling of nontimber outcomes of bark beetle activity.
Fire and bark beetle interactions
• Characterizing insect-caused tree mortality after fires. • Examining the fate of fuels after bark beetle outbreaks. • Defining the conditions, if any, where bark beetle outbreaks may influence fire occurrence, behavior, or severity.
Climate change
• Developing regional models that will lead to adequate predictions about west-wide climate change effects on bark beetles. • Studying the effect of climate change on bark beetle population dynamics and on defensive mechanisms of trees against bark beetles. • Developing phenology models for many bark beetle species. • Discerning the effects of climate change on the relationship between trees and associated bark beetles.
Chemical ecology
• Developing and refining semiochemical-based management strategies for mitigating insect-caused tree mortality in high value areas. • Clarifying and refining the scientific foundation for use of behavioral chemicals for mitigating bark beetle-caused mortality in reactive forest environments under climate change and air quality degradation. • Examining the biosynthesis of bark beetle communication chemicals, bioproduction of large quantities of highly pure semiochemicals, and biochemical interactions between bark beetles and their host conifers.

Source: Negron et al., 2008

Blister Rust

White pine blister rust is a non-native, invasive fungal pathogen that infects five-needled (white) pines (genus *Pinus,* subgenus *Strobus*). *Cronartium ribicola*, the fungus that causes white pine blister rust, initially enters through needle stomata, grows into the phloem tissue in branches and stems, and erupts as spore-producing cankers that cause death of the branches, top-kill, or death of the tree (Tomback et al., 2001). Depending on the level of infection, mature trees with blister rust can live for several years; however, saplings generally die within three years (NPS, 2007j; and references therein). Since its accidental introduction to western North America in 1910, blister rust has spread through all forested ecosystems where white pines are important components (McDonald and Hoff, 2001).

To complete its life cycle, blister rust requires an alternate host, gooseberries and currants, in the genus *Ribes*, and possibly species of *Pedicularis* and *Castilleja* (Burns et al, 2008; and references therein). The disease cycle involves partial development on the underside of the *Ribes* leaves which occurs during summer months during cool, wet periods (100 percent relative humidity). In late summer to early fall, as temperatures drop and relative humidity is high, basidiospores are released from the *Ribes* host and are windborne (typically less than 984 feet/300 meters, but up to 1.9 to 2.5 miles/3.0 to 4.0 kilometers) to the needles of the pine host, where the fungus continues to grow and reside into subsequent years (McDonald and Hoff, 2001). Blister rust lasts for only a single growing season in *Ribes* because the leaves are shed in the fall, but survives as a perennial disease in infected pines, with the potential to re-infect *Ribes* in subsequent years. The frequency of favorable conditions for spore production and transmission has enabled the fungus to spread rapidly throughout the Pacific Northwest and Intermountain West in both the United States and Canada (Kendall and Keane, 2001; McDonald and Hoff, 2001).

Although blister rust has spread through nearly the entire range of whitebark pine, mortality from the fungus is greatest in the northern Rocky Mountains (northwestern Montana, northern Idaho, and the southern Canadian Rockies), where infection levels are variable, but levels of over 70 percent are common (Kendall and Keane, 2001; Burns et al., 2008; and references therein). Perhaps due to drier conditions, incidence of blister rust in whitebark pine in the Greater Yellowstone Ecosystem (GYE) is lower compared to the northern Rockies, but is increasing. Surveys completed in 2006 estimated nearly 25 percent of the GYE has been affected by blister rust (Burns et al., 2008; and references therein). Blister rust is only compounding the problem between whitebark pine and the current mountain pine beetle outbreaks as was described in the previous section. Six and Adams (2007) found a preference of mountain pine beetle to rust-infected whitebark pine. Severe blister rust infection can interact with the moisture content within the sapwood, thereby weakening the tree’s response to other pathogens. Therefore, the current outbreak of mountain pine beetle in whitebark pine, may in part, be fueled by the spread of blister rust into these systems.

Blister rust is a continuous source of disturbance, as opposed to the cyclical outbreaks of the mountain pine beetle, and is considered one of the greatest threats to whitebark pine. Blister rust directly reduces recruitment potential by killing cone-bearing branches (and trees) and causes a high incidence of seedling and sapling mortality (Bockino, 2008; and references therein). Furthermore, reduction in cone (and seed) production is disrupting a co-evolved relationship between the whitebark pine and the Clark's nutcracker (*Nucifraga columbiana*), the primary dispersal agent for this large-seeded pine. The nutcracker, a facultative mutualist, although attracted to the high-energy value of whitebark pine seed, will opt for other food sources, emigrating between subalpine forests during periods of cone shortages (Tomback, 2001). Without the key dispersal mechanism, regeneration potential of whitebark pine is therefore in jeopardy (Tomback, 2001; McKinney, et al., 2009). Fortunately, with recent findings of resistance to blister rust in some individual whitebark pine trees, it is hoped that a genetic breeding program administered by the U.S. Forest Service (Mahalovich and Dickerson, 2004), will help offset current mortality trends by testing, propagating, and out-planting rust-resistant whitebark pine in restoration efforts.

Methods

To assess the extent of blister rust within GRTE, two recent reports, a 2009 Annual Report on the whitebark pine monitoring and restoration project within the GYE (GYWPMWG, 2010), and a 2010 GRTE resource brief on whitebark pine (Bockino, 2010), supplemented by other literature, were examined.

Between 2004 and 2007, the Greater Yellowstone Whitebark Pine Monitoring Working Group (GYWPMWG), consisting of representatives from the U.S. Forest Service, National Park Service, U.S. Geological Survey, and Montana State University, established 176 permanent (10 meter by 50 meter) transects, involving 150 whitebark pine stands throughout the GYE, to monitor changes in blister rust infection, and survival rates and regeneration in whitebark pine over time (GYWPMWG, 2010). Additional data, including, diameter at breast height, tree height class, and evidence of mountain pine beetle activity, were also collected at each site. By 2008 and 2009, half of all permanent transects were resurveyed, providing the first estimates of rates of change in blister rust infection and associated mortality in whitebark pine. The GYWPMWG anticipates by 2011, all transects will have been resurveyed at least once.

The GYWPMWG monitoring program however, only established two transects within the bounds of GRTE. In 2007, GRTE initiated a complementary study to the GYWPMWG monitoring program, including 27 additional study locations, to improve detection of infection rate and trends of blister rust in whitebark pine within GRTE specifically. Objectives of the monitoring program in GRTE are to track the spatial distribution of blister rust and beetles, the severity of blister rust and beetle caused mortality, and to identify areas of low beetle activity or rust infection through time (Bockino and McCloskey, 2010).

Results

From baseline accounts, of the 4,774 individual live whitebark pine trees (greater than 4.6 feet/1.4 meters tall) sampled between 2004 and 2007, the proportion of live trees with blister rust in the GYE was 20 percent (GYWPMWG, 2010; and references therein). Although the surveys completed in 2008 and 2009 included only a sub-sample of all permanent transects, the proportion of trees infected increased to 24.9 percent and 39.8 percent, respectively. The total number of trees infected by blister rust over time increased in some transects, while in others it decreased. Increases, as expected, were due to a greater number of trees showing signs of infection. Transects with reduced infection rates were due to death of a previously rust-infected tree by fire or mountain pine beetle.

Results from the GYWPMWG monitoring program on estimates of whitebark recruitment revealed that 24 percent of the live trees greater than 4.6 feet (1.4 meters) tall were mature enough to have produced cones at least once. The density of small live trees in the understory (less than 4.6 feet tall) was highly variable, ranging from zero to 12,500 per hectare. Also, between 2007 and subsequent resurveys in 2008 and 2009, a total of 145 trees grew up beyond the 4.6 foot-threshold, which were then marked for resurvey and incorporated into the existing live tree database.

As was mentioned in the previous section on whitebark pine, blister rust was evident on 100 percent of whitebark pine monitoring transects in GRTE (Bockino and McCloskey, 2010). The incidence of rust decreased between 2007 and 2010 from 55 percent to 43 percent (see section on Whitebark Pine Distribution and Regeneration, Table 3.28). However, due to the mortality caused by mountain pine beetles or rust, dead trees were removed from sample population, therefore affecting the total number of whitebark pine with rust. What is more concerning was the increase in blister rust severity (i.e. mean number of cankers per live whitebark pine), which increased from 11.7 percent to 22.7 percent between 2007 and 2010. Compounding the problem, data suggest that mountain pine beetle activity intensified in trees with higher severity blister rust (Bockino and McCloskey, 2010).

Additional detail on the interaction between mountain pine beetle and blister rust in whitebark pine ecosystems within the GYE was provided by Bockino (2008). With data from four study sites, one of which included the Teewinot area in GRTE, results showed that 52 percent of the whitebark pine sampled were dead, 70 percent were attacked by mountain pine beetle, 85 percent were infected with blister rust, and 61 percent were afflicted with both. Compared to the other three sites, mortality within pure whitebark pine stands at the GRTE site was lowest (33 percent), perhaps due to selection for and mortality of whitebark pine by mountain pine beetle being somewhat lower than at other sites (Table 3.28). However, the GRTE site (Teewinot) did have the highest incidence of blister rust in whitebark pine in both the pure (86 percent) and mixed stands (92 percent), and of those trees sampled, symptoms of blister rust were more prevalent in the crown (Table 3.28). Testing for relationships between blister rust severity and cone production across all sites, Bockino (2008) found a significant and negative relationship between blister rust severity and cone presence. Only one-third of the trees with heavy rust were cone-producing, whereas of those trees with little to no rust, 75 percent had cones. As was mentioned above, the reduction in cone production due to blister rust damage will negatively impact recruitment rates, seed availability for dispersal by the Clark's nutcracker, and subalpine forest and treeline structure and dynamics (Bockino, 2008; McKinney, et al., 2009; Tomback and Resler, 2007). Bockino (2008) also found that as blister rust severity increased, the probability of greater mountain pine beetle activity also increased, and under these high rust conditions, whitebark pine were the preferred host over lodgepole pine.

<u>Summary and Conclusions</u>

Results from the GYWPMWG and GRTE monitoring surveys and work by Bockino (2008) indicate that blister rust is well established throughout the GYE and GRTE. Infection by blister rust has reduced cone production, and the current interaction with mountain pine beetle has accelerated the mortality and decline of whitebark pine ecosystems in many areas. The trees that are able to outlive the current mountain pine beetle outbreaks will continue to face the on-going threat of blister rust. The impacts are still comparably less in the GYE than research sites in the Northern and Central Rocky Mountains in terms of cone production and nutcracker occurrence (McKinney et al., 2009). However, the ability to detect and respond to blister rust infection quickly after a new infection event is limited by the time it takes for fungal signs to appear at the surface of the tree and the schedule for resurveying transects (GYWPMWG, 2010).

Table 3.28. Site conditions during June-August 2006 field season for study sites in the Greater Yellowstone Ecosystem. White pine blister rust totals (symptoms, crown, or bole) exclude Sylvan Pass 'host species' site, due to negligible rust in whitebark pine in mature overstory. LP = lodgepole pine (not a host to blister rust), WB = whitebark pine, and X = non-applicable field. Values in bold are means. Table reproduced from Bockino (2008). Teewinot site is located within Grand Teton National Park; Breccia Peak and Mount Leidy sites are located east of Grand Teton National Park in Bridger-Teton National Forest; and Sylvan Pass site is located in northeastern Yellowstone National Park.

Stand Type (by Site)	Number Trees Sampled	Proportion of Trees						
		Dead	Blister Rust Symptomatic	Crown Rust Present	Bole Rust Present	Selected by MPB	MPB and Rust	Cones Present
Sylvan Pass								
LP	149	50	X	X	X	65	X	93
WB	164	79	0	0	0	84	X	24
Breccia Peak								
PURE	293	39	76	74	29	82	67	68
NHMIX	226	65	89	87	58	77	75	55
Teewinot								
PURE	392	33	86	85	45	50	47	65
NHMIX	204	62	92	89	73	66	64	38
Mount Leidy								
PURE	385	45	79	76	51	74	63	42
NHMIX	287	41	79	77	52	61	57	31
All WB-Rust Sites	**1,787**	**45**	**83**	**81**	**49**	**67**	**62**	**49**
Mean All WB	**1,947**	**52**	**X**	**X**	**X**	**69**	**56**	**56**

Invasive Species

Distribution and Extent of Cheatgrass

Cheatgrass (*Bromus tectorum*) is an annual exotic grass that has invaded vast expanses of land in the Intermountain West of the United States. Cheatgrass has been known to have traits that allow it to outcompete native species. For instance, by germinating earlier in the late winter or early spring, cheatgrass takes advantage of the initial available moisture that would otherwise be used by natural plant communities. Additionally, cheatgrass senesces before the majority of native plants. This characteristic, coupled with its high flammability, has allowed cheatgrass to modify the return interval of fires (from approximately 60 to 100 years to five to 10 years). This suite of ecological alterations negatively affect natural communities by reducing ecosystem diversity, which may ultimately produce cheatgrass monocultures.

Although cheatgrass occurs more frequently in lower, warmer locations, it has been reported in GRTE and surrounding vicinities. Therefore, it is necessary to assess the distribution and extent of cheatgrass in the study area so that a better understanding of affected natural communities may be obtained. The development of a remote sensing protocol to map cheatgrass extent and the probability of occurrence in the study area is reported.

A preceding effort to assess cheatgrass distribution in GRTE was prepared by Barnett and McCloskey (2008). This approach differs from that reported by Barnett and McCloskey in several aspects. Multi-temporal (within one year) satellite imagery was used in order to capture seasonal differences in cheatgrass phenology. Cheatgrass has a conspicuous phenological signature, characterized by earlier germination and senescence prior to native species. The modeling approach also differs as described below.

The objectives of this study were to (1) model the spatial distribution of cheatgrass in the study area based on multi-temporal vegetation indices and topographic geospatial layers, and (2) model the likelihood of occurrence of cheatgrass in the study area based on vegetation indices and topographic and climatic geospatial layers.

<u>Methods – Spatial Distribution of Cheatgrass</u>

One hundred eighty-nine field points were obtained for this study from different GRTE sources. These points were collected from 2001 to 2008. The dataset describes at which points a cheatgrass presence or absence was recorded. In addition, an estimate of cheatgrass percent cover is also available in the training dataset. Figure 3.62 shows the spatial distribution of these field points in the context of the three major watersheds (HUC 8).

Landsat Thematic Mapper (TM) imagery was acquired from the USGS Global Spectrogram Viewer (GLOVIS). Due to the spatial distribution of the field points, it was necessary to collect imagery from two WRS2 paths/rows, including P38 R29 and P38 R30 (Figure 3.62). The best available scenes (minimum cloud cover) from the middle of May until the beginning of October of 2008 were collected.

The imagery was standardized using the COST atmospheric collection algorithm, which is available from the Remote Sensing/GIS Laboratory at Utah State University. Once standardized, the normalized difference vegetation index (NDVI) was calculated for each scene. The NDVI may be used as a surrogate measure of greenness or vegetation health. By having a multi-temporal series of NDVI, the cheatgrass phenological changes can be followed throughout the year.

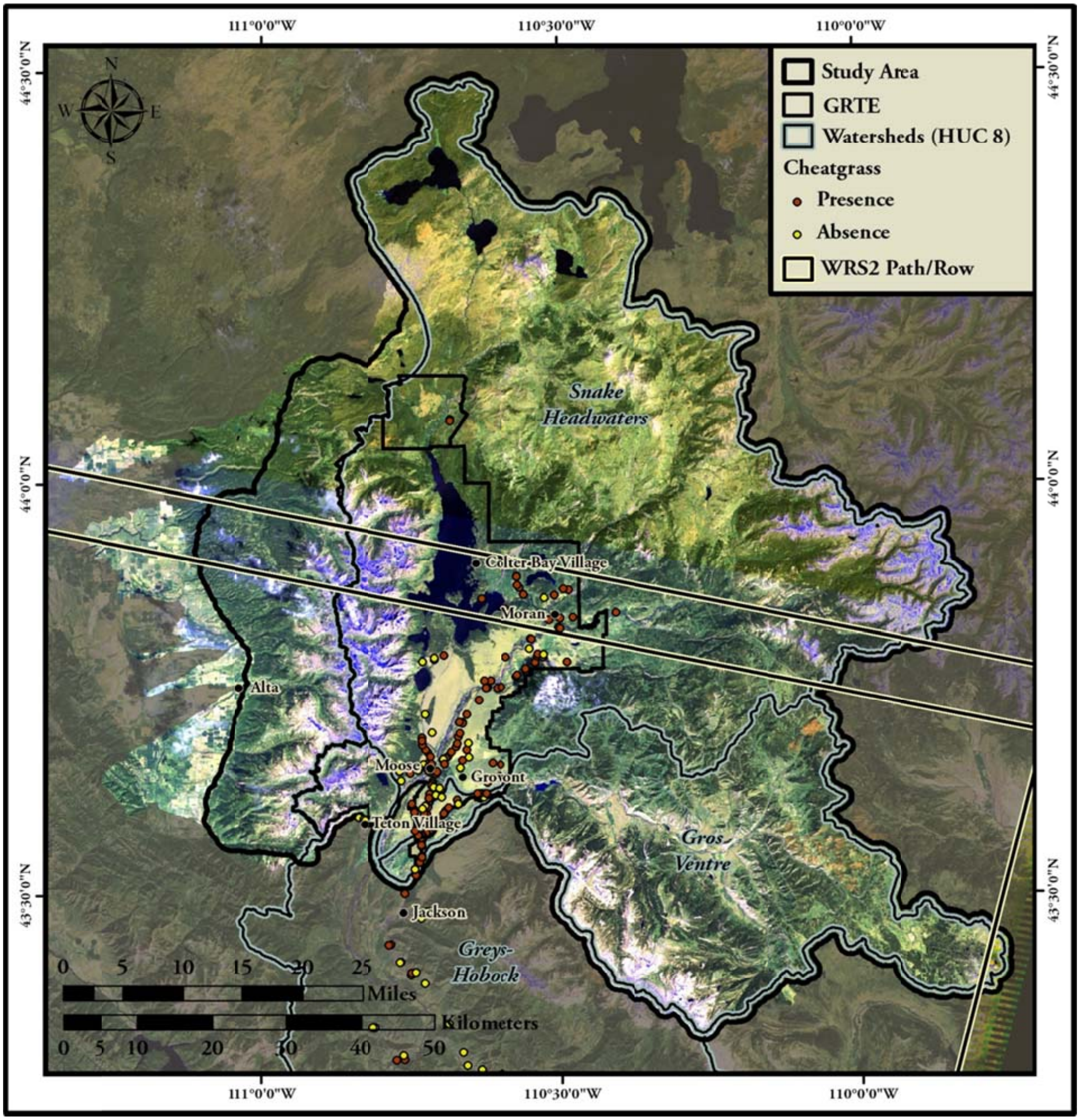

Figure 3.62. Cheatgrass presence and absence over a false-color Landsat Thematic Mapper (TM) imagery mosaic.

A 30-meter resolution digital elevation model (DEM) was acquired, and derivatives of the DEM, including slope and aspect, were generated. These variables can be used to enhance the understanding of cheatgrass spatial variation across the study area. Climatic information (precipitation, temperature, radiation, and humidity) were also collected from DAYMET and resampled to conform to the spatial resolution of the Landsat TM imagery.

The greenness (NDVI) values were extracted from the cheatgrass field points for all the available dates. These values were then plotted to identify a pair of dates that best discriminates the early germination and growth (upward pattern in greenness) of cheatgrass throughout the growing season.

Although there is some noise in the data, the dates of 10 May 2008, and 29 July 2008 were chosen for modeling. The greenness values for cheatgrass presences are slightly higher than the absences during May and the greenness presences are conspicuously lower than the absences in July because the cheatgrass has senesced by then (Figure 3.63).

In regard to the independent variable selection for modeling purposes, the concept of variable importance was used. The concept of variable importance is embedded in the Random Forest statistical algorithm. The concept suggests that a variable should be included in the classification model if when it is scrambled (replaced with random values), it has a big impact that decreases the overall accuracy. Once variable importance is determined, the most important variables are plotted to check for high correlation issues. If two variables that had been determined to be important during the Random Forest evaluation showed collinearity problems, then only one variable was kept. The advantage of utilizing this approach should be clear. An original dataset that contains more than 30 variables can yield a subset of 10 variables. Such a reduced dataset makes the classification and modeling process simpler and easier.

Support vector machines (SVM) were used to conduct the classification. SVM have their roots in the statistical learning theory and recently have acquired a good reputation because they are robust and accurate, even when using a small training dataset.

Twenty percent of the training points were withheld from the model for the purpose of model validation. This is helpful in assessing model accuracy. All statistical analyses were carried out using R Project for Statistical Computing (R Development Core Team, 2010).

<u>Results – Spatial Distribution of Cheatgrass</u>

Figure 3.64 shows the distribution and extent of modeled cheatgrass presence for the Snake River Headwaters watershed. The analysis was solely conducted on this watershed, as the majority of the field sampling points was concentrated in this area.

An accuracy assessment was conducted using both the training data points and the withheld points. As expected, the accuracy using the training points was higher (83 percent) than that of the validation (67 percent). It is important to explain what the classification results illustrated in Figure 3.64 indicate. If a pixel was classified as cheatgrass, it does not mean that the complete extent of the pixel (900 square meters: 30 meters by 30 meters) is fully occupied by cheatgrass. Rather, it means that the spectral signature of the pixel corresponds well with the ecological expectation (high values of greenness in May and low values of greenness in July) or typical phenological response of cheatgrass in the study area.

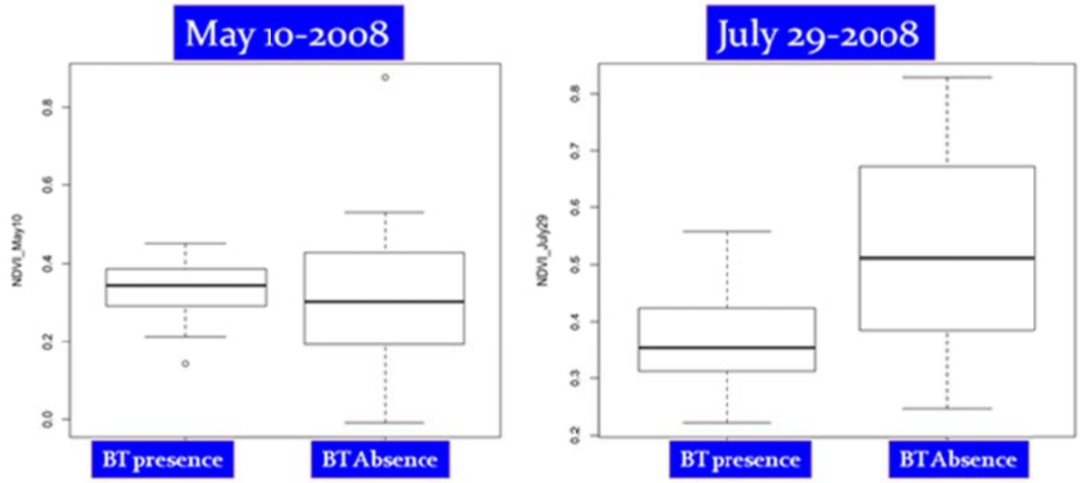

Figure 3.63. Box plots for cheatgrass presence and absence for the two dates that best discriminate phenological fluctuations.

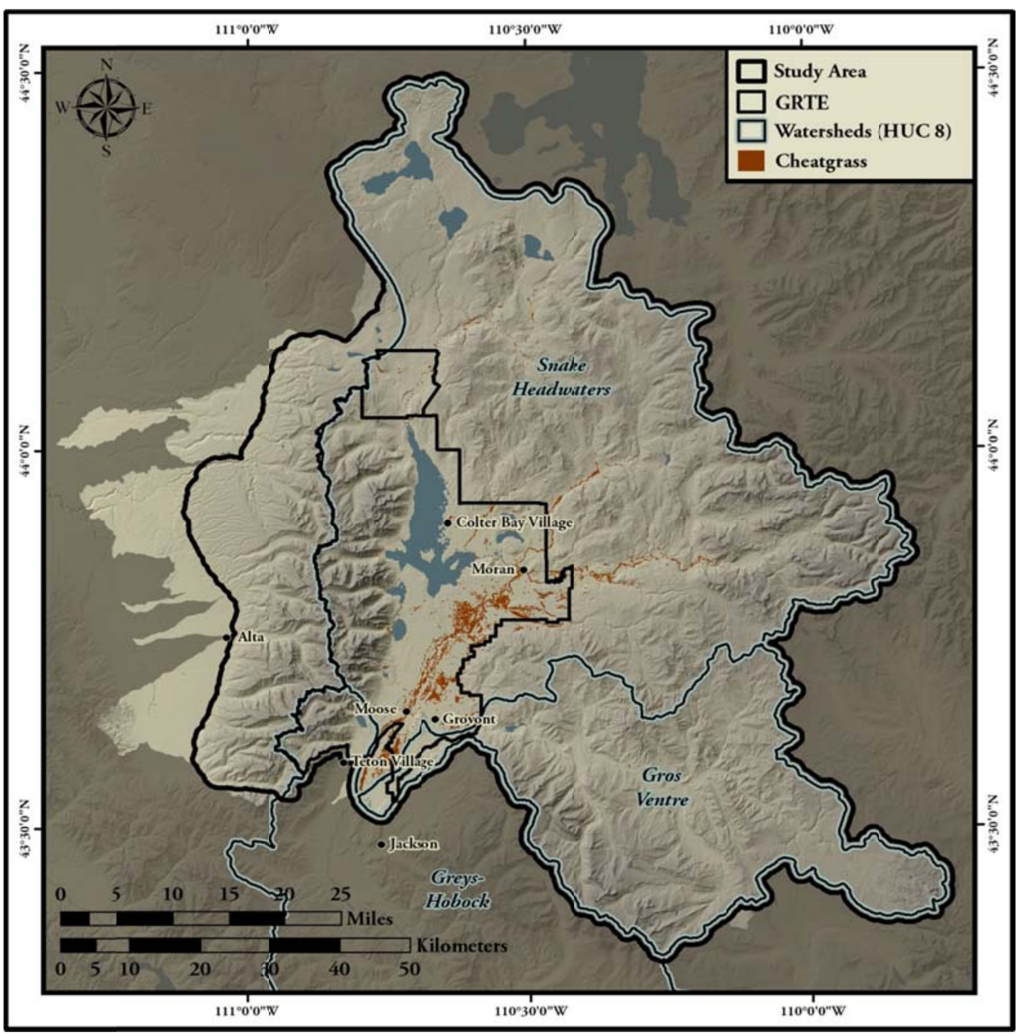

Figure 3.64. Current distribution of cheatgrass in the Snake River Headwaters watershed.

Methods – Likelihood of Occurrence

In addition to modeling the distribution and extent of cheatgrass, the probability of occurrence of cheatgrass in a given pixel was modeled. A map of probability can be used to assess which areas are more likely to be invaded by cheatgrass even though its occurrence in that location has not yet been reported. A high probability value may indicate that cheatgrass is likely to be found at a particular location. It may also indicate that the environmental conditions are particularly favorable for cheatgrass establishment and proliferation, even though it has not been reported.

The same field datasets that were used for the spatial distribution model were used for the probability model. However, only 60 of the 189 points were used. The 60 points selected for analysis were most recently collected (2006 through 2008) and seemed to provide a sensible spatial response during the modeling process.

Multi-temporal NDVI grids derived from MODIS (Moderate Resolution Imaging Spectroradiometer) imagery were used. A temporal series (bi-weekly composites) of NDVI was collected for this purpose. The series was comprised of information from April to November of 2008. The spatial resolution of this product is 231 meters (758 feet).

A digital elevation model (DEM) with the same spatial resolution as the MODIS NDVI was prepared, and derivatives of the DEM, including slope and aspect, were generated. A topographic relative moisture index (TRMI) was derived to see if it could provide predictive ability. Climatic information, including mean annual precipitation, temperature, radiation, humidity, growing degree days, and number of frost days, was collected from DAYMET (Thornton et al., 1997). The climatic data were resampled to conform to the spatial resolution of the MODIS NDVI product.

A logistic regression approach to model the likelihood of occurrence of cheatgrass was used. The logistic regression is part of the family of generalized linear models. With logistic regression, one begins with a dataset of presences and absences, and then linearly fits a logit function. Once the logit function has been fitted, the probability of a success can be obtained by a simple conversion.

A comprehensive process to assess which variables to include during modeling was conducted. Datasets were explored for collinearity. A stepwise logistic regression (both directions: forward and backward) that checked for influential measurements was conducted. This was performed 50 times and different models were sorted for importance (a balance between accuracy assessment and model simplicity). After a series of attempts using this procedure and also taking into account the ecological theory, it was determined to only use the topographic variables and climatic datasets. It seemed that the greenness information (multi-temporal NDVI) caused the model to overestimate the probabilities across the landscape. For example, whenever greenness was used, high probabilities of occurrence would be predicted in high terrain, such as that in the Teton Range. Since the objective was to model the probability of occurrence of an event at any given time, it seems appropriate to only use the topographic and climatic drivers of this occurrence.

Results – Likelihood of Occurrence

Figure 3.65 presents the results of the logistic regression model. An accuracy assessment of this model was conducted using X-fold cross-validation. This approach was used because the dataset is relatively small (60 events). Table 3.29 presents the confusion matrix and main metrics estimated for the accuracy assessment.

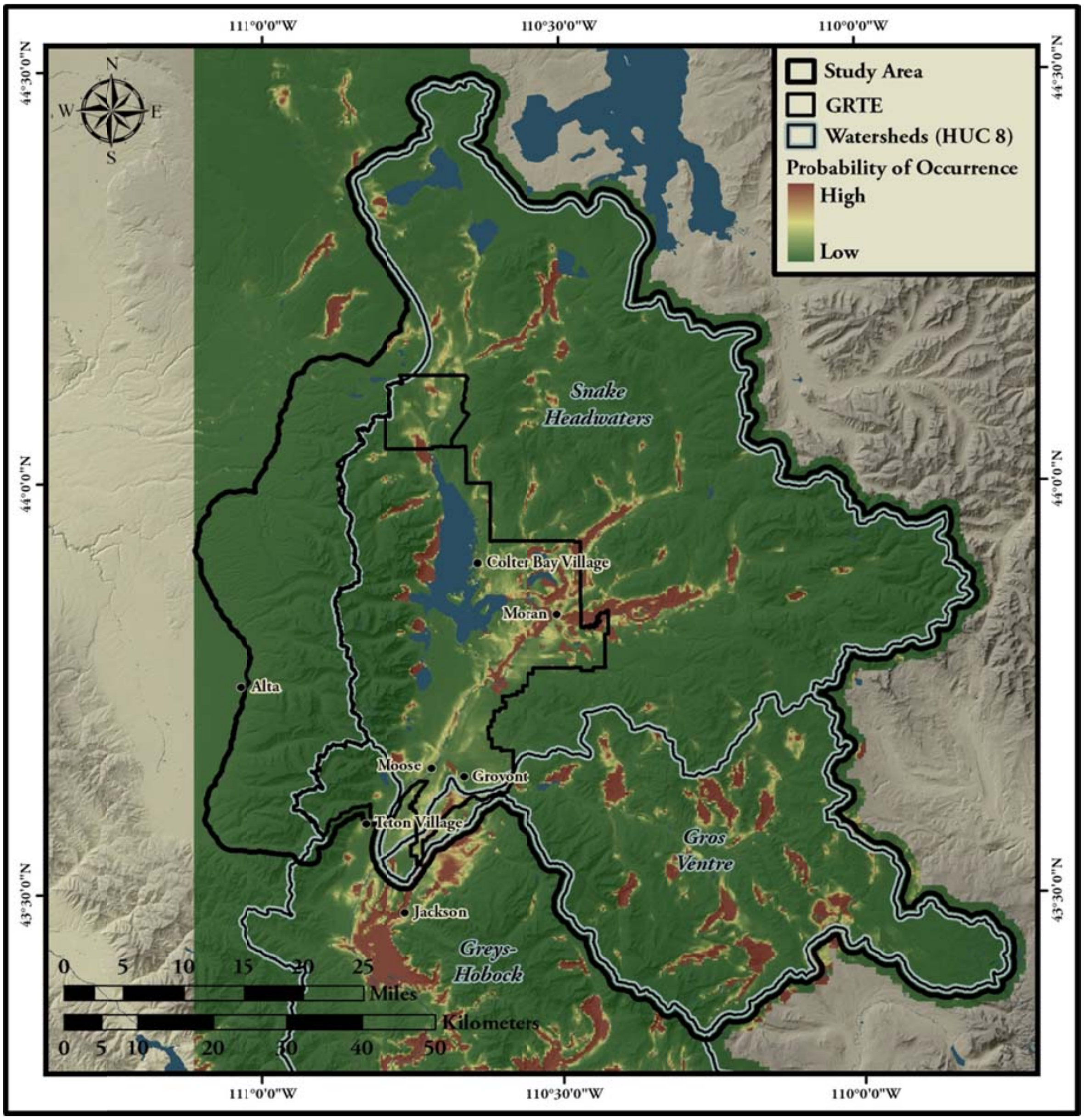

Figure 3.65. Likelihood of occurrence of cheatgrass in the study area.

Table 3.29. Confusion matrix and accuracy metrics for the logistic regression.

		OBSERVED	
		1 (Presence)	**0 (Absence)**
PREDICTED	**1 (Presence)**	**13**	5
	0 (Absence)	**3**	39
METRIC			
Percent Correctly Classified		0.866	
Sensitivity		0.812	
Specificity		0.888	
Kappa		0.672	

Summary and Conclusions

The modeling of cheatgrass distribution and extent was completed for the Snake River Headwaters watershed, which was the drainage unit that contained the majority of field sampling points. Further work needs to be done to model the distribution in the remaining watersheds within the study area (Gros Ventre and Greys-Hobock watersheds). In regard to the modeling of likelihood of occurrence, a simple and sensible model has been executed using coarser spatial resolution datasets.

Terrestrial Invasive and Exotic Plants by Watershed

It is important to know the distribution of invasive species in a system of prime ecological importance, such as GRTE. Therefore, two metrics for terrestrial invasive and exotic plants, including (1) number of sites with invasive events, and (2) richness of exotics, are summarized in the context of watersheds (HUC 12).

Methods

Grand Teton National Park prepared a comprehensive geodatabase of exotic plants that have been documented in the park and the surrounding areas. The distribution of the field points where exotics have been documented are displayed in Figure 3.66. The geodatabase contains the specific species that were found during the field surveys.

The data from the geodatabase were spatially joined to the watershed shapefile. A cross-tabulated query was obtained in order to summarize how many exotic locations were found in each watershed. This permitted species specific tabulation (and how many events per species) for each watershed. Table 3.30 provides an example of this tabulation (displaying seven of the 38 species) and Figure 3.67 depicts the number of events per watershed. While Figure 3.67 depicts the number of events per watershed, it is evident that there are many watersheds with zero events. Some of these watersheds may not have invasive or exotic plants, but it may be more likely that these watersheds were not visited during the field surveys.

It may also be valuable to evaluate the number of invasive and exotic species by watershed (Figure 3.68). An assessment of these two maps may provide useful information to managers. Perhaps those watersheds that have multiple events but few species should be treated differently than those watersheds with multiple events and numerous species.

Summary and Conclusions

The GRTE geodatabase of invasive and exotic plants has been reviewed, queried, summarized, and joined to the watershed shapefile. Therefore, the number of events, number of species, and which individual species occur by watershed can be evaluated.

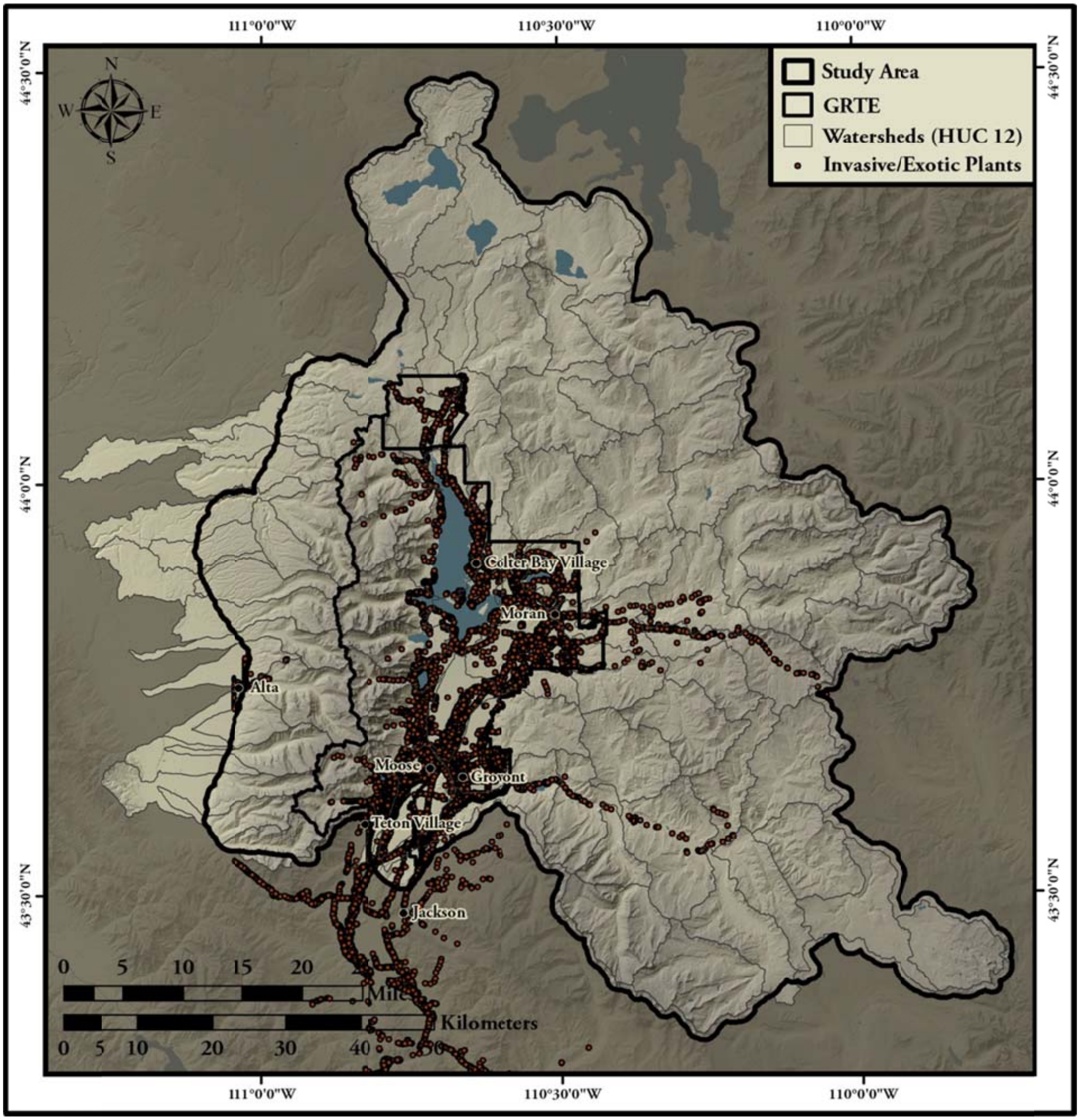

Figure 3.66. Distribution of field samples identifying terrestrial invasive and exotic plants.

Table 3.30. Example of tabulation depicting terrestrial invasive and exotic plants by watershed.

WATERSHED HUC-12 CODE	TOTAL EVENTS	NUMBER OF SPECIES	ACRE3	AGCR	AMT03	ANAR6	ARAB3	ARMI2	CANU4
170401010301	384	22		5		3			5
170401010302	76	14							1
170401010303	1039	30		3		2			65
170401010304	61	6							1
170401010305	28	5							2
170401010306	46	7							
170401010307	119	8							10
170401010308	1741	27		11		7			245
170401010309	56	10		1					12
170401010404	436	18		2					79
170401010501	1560	30		18		16			389
170401010503	2	2							1
170401010504	11	3							8
170401010505	779	29		26		9			166
170401010506	162	12							19
170401010507	273	23				6			32
170401010508	894	27		1		2			106
170401010509	1159	31	1	23	2	20		2	326
170401010510	2423	38	5	47		32			453
170401010607	57	11	1			1			28
170401010608	239	17	12			12			53
170401010609	287	24	1	8		3			79
170401010610	19	11	1	1					3
170401020203	21	3							17
170401020204	32	8	1			5			17
170401020302	32	7	4						22
170401020304	2	2	1						1
170401020305	1387	33	1	41		12			286
170401030102	1841	31		6		23	1		393
170402030203	1	1							
170402030204	1	1							
170402040201	132	12				6			67
170402040202	12	5							5
170402040204	125	11				12			62

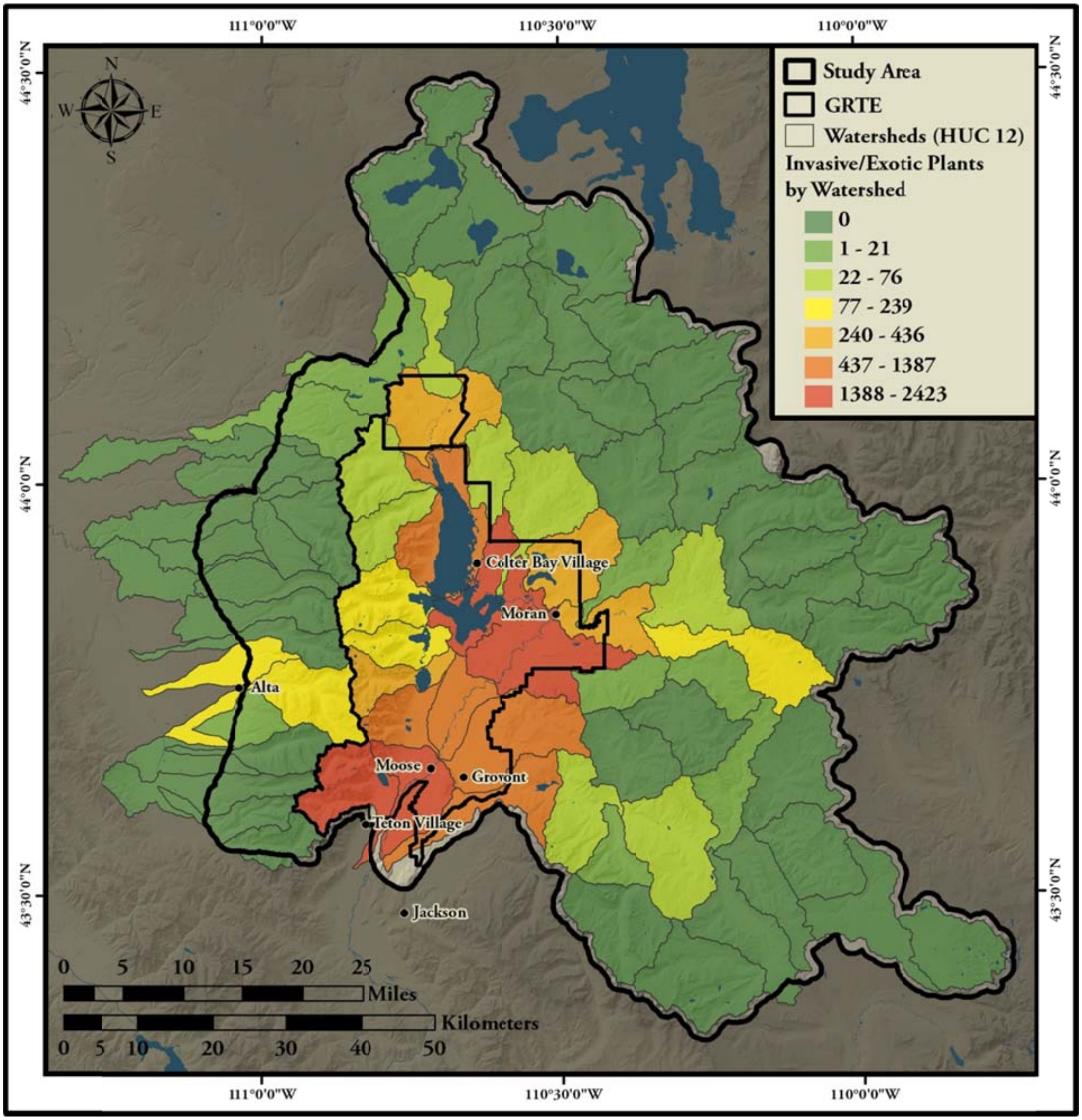

Figure 3.67. Number of field samples (events) with invasive and exotic terrestrial plants by watershed.

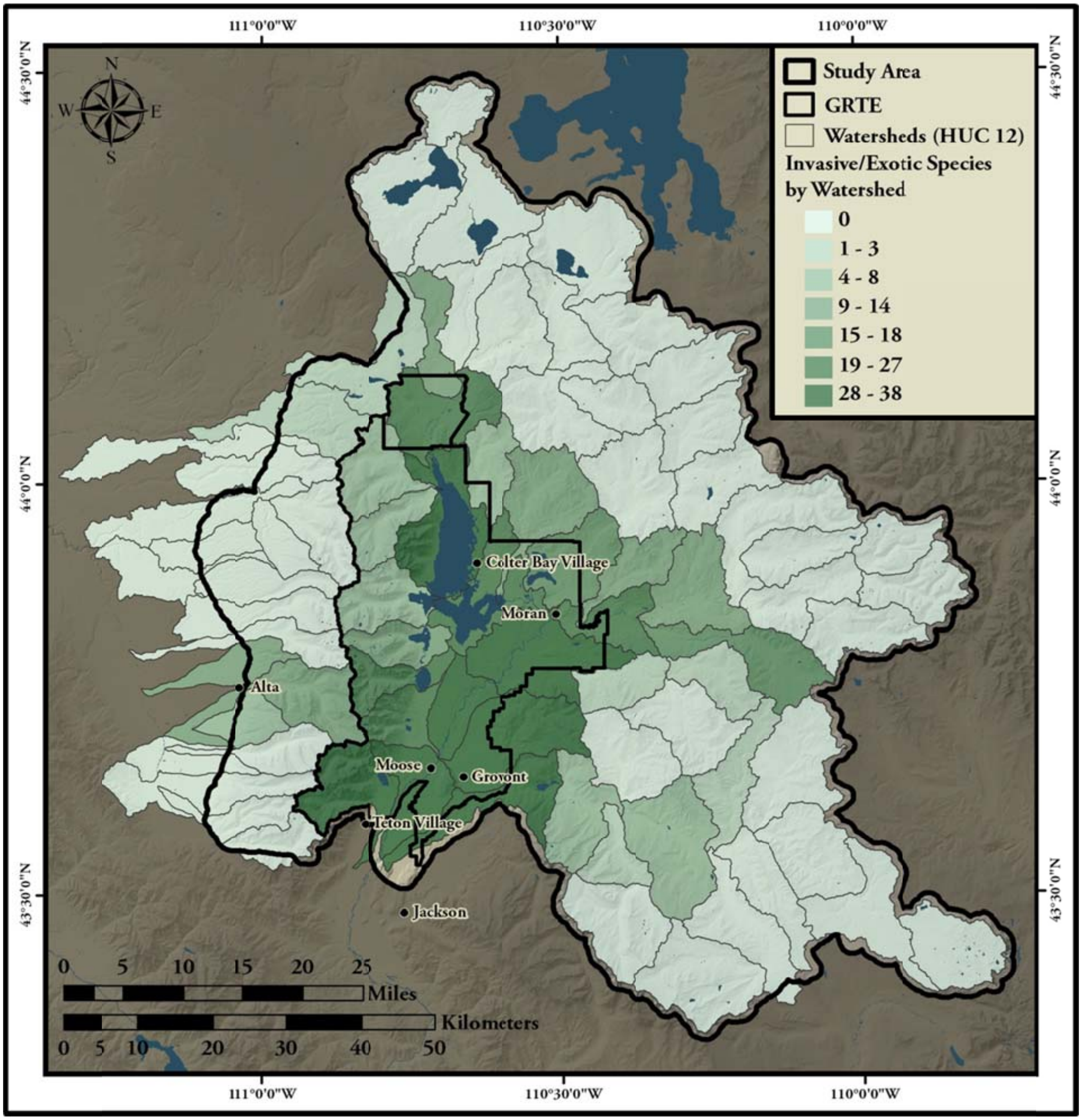

Figure 3.67. Number of invasive and exotic terrestrial plant species by watershed.

Land Cover and Land Use

Land Cover and Land Use Change

Landscapes are subject to change from human influences, natural disturbances, or both. It is important to be able to detect changes of land cover and land use that may negatively impact a pristine area. Remote sensing science provides a unique opportunity to monitor changes across large landscapes so that preventive or corrective measures may be planned.

Methods

To assess land cover and land use change, the 1992-2001 Retrofit Land Cover Change Product from the National Land Cover Dataset was used. In this geospatial product, there are two fundamental types of information: (1) unchanged pixels between the two dates, and (2) changed pixels or transitions between land cover and land use classes which are labeled with a "from-to" land cover change value.

Results

During the period of analysis, the land cover conditions in the study area remained largely unchanged. Table 3.31 presents the land cover and land use changes from 1992 to 2001 in the study area. Nearly 98 percent of the land showed no change between the two years. Although there we minimal change between the two years, transitions from forest, ice/snow, and barren to grassland, in addition to grassland to forest, represent the majority of the shifts in the land cover for this area. The vast majority of the transitions occurred on the highlands of the Teton Range and in the southeast (Upper Gros Ventre River watershed) (Figure 3.69).

Figure 3.70 shows the dynamics of land cover for GRTE. The seven most significant transitions are represented, including (1) barren to forest, (2) barren to grassland/shrub, (3) forest to grassland/shrub, (4) forest to wetlands, (5) grassland/shrub to forest, (6) ice/snow to barren, and (7) ice/snow to grassland/shrub.

Summary and Conclusions

The dynamics of land cover and land use in the study area have been evaluated and summarized. Based on the National Land Cover Dataset 1992-2001 Retrofit Land Cover Change Product, the land cover conditions in the study area remained largely unchanged. Approximately 2.3 percent of the land cover transitioned between 1992 and 2001.

Table 3.31. Retrofit land cover and land use transitions, 1992-2001.

Transition	Area (Hectares)	Percent
Forest - No Change	**370559.4**	**48.675**
Grassland/Shrub - No Change	**319300.1**	**41.942**
Wetlands - No Change	**21127**	**2.775**
Open Water - No Change	**19208.3**	**2.523**
Barren - No Change	**8269.5**	**1.086**
Forest to Grassland/Shrub	4459.9	0.586
Ice/Snow to Grassland/Shrub	3152.7	0.414
Barren to Grassland/Shrub	3149.1	0.414
Grassland/Shrub to Forest	3133.8	0.412
Agriculture - No Change	**2549.3**	**0.335**
Urban - No Change	**2105.5**	**0.277**
Ice/Snow - No Change	**853.7**	**0.112**
Forest to Wetlands	761.4	0.100
Barren to Forest	592.5	0.078
Ice/Snow to Barren	446.1	0.059
Open Water to Grassland/Shrub	278.3	0.037
Grassland/Shrub to Wetlands	223.7	0.029
Forest to Agriculture	179	0.024
Ice/Snow to Forest	132.3	0.017
Wetlands to Grassland/Shrub	122.9	0.016
Open Water to Forest	113.2	0.015
Agriculture to Grassland/Shrub	105.3	0.014
Wetlands to Open Water	95.5	0.013
Urban to Open Water	71.9	0.009
Grassland/Shrub to Agriculture	56.3	0.007
Grassland/Shrub to Open Water	45.5	0.006
Forest to Open Water	38	0.005
Open Water to Wetlands	32.4	0.004
Wetlands to Agriculture	31	0.004
Forest to Urban	16.9	0.002
Forest to Barren	15.6	0.002
Ice/Snow to Open Water	9.8	0.001
Open Water to Barren	9.3	0.001
Urban to Grassland/Shrub	6.9	0.001
Agriculture to Open Water	6.9	0.001
Agriculture to Urban	6.8	0.001
Grassland/Shrub to Urban	6.1	0.001
Grassland/Shrub to Barren	4.2	0.001
Grassland/Shrub to Ice/Snow	4.2	0.001
Urban to Barren	3.4	0.000
Agriculture to Wetlands	3.4	0.000
Open Water to Agriculture	2.2	0.000
Wetlands to Barren	1.8	0.000
Open Water to Urban	1.2	0.000

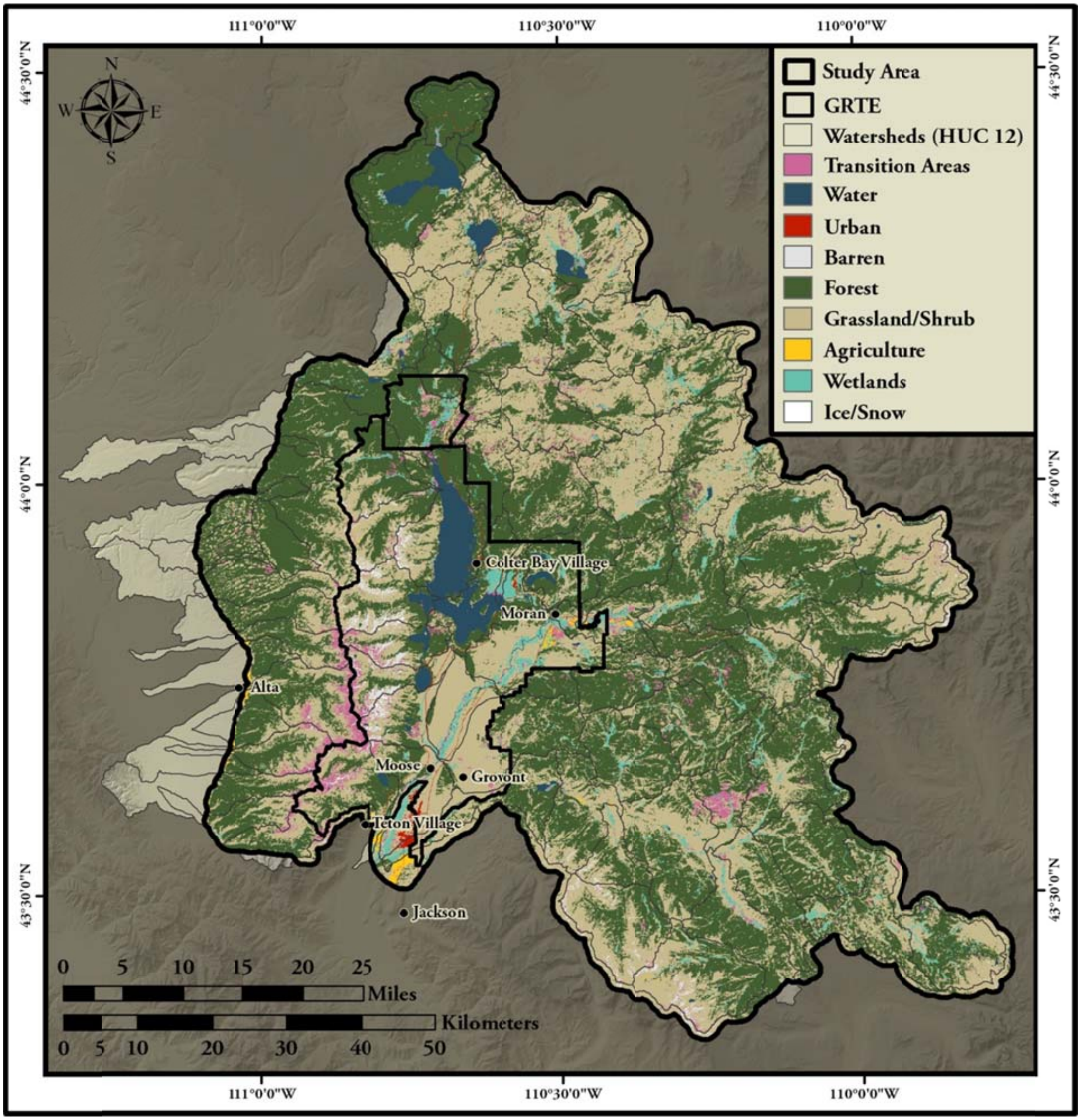

Figure 3.69. National Land Cover Database Retrofit Land Cover Change Product (1992-2001).

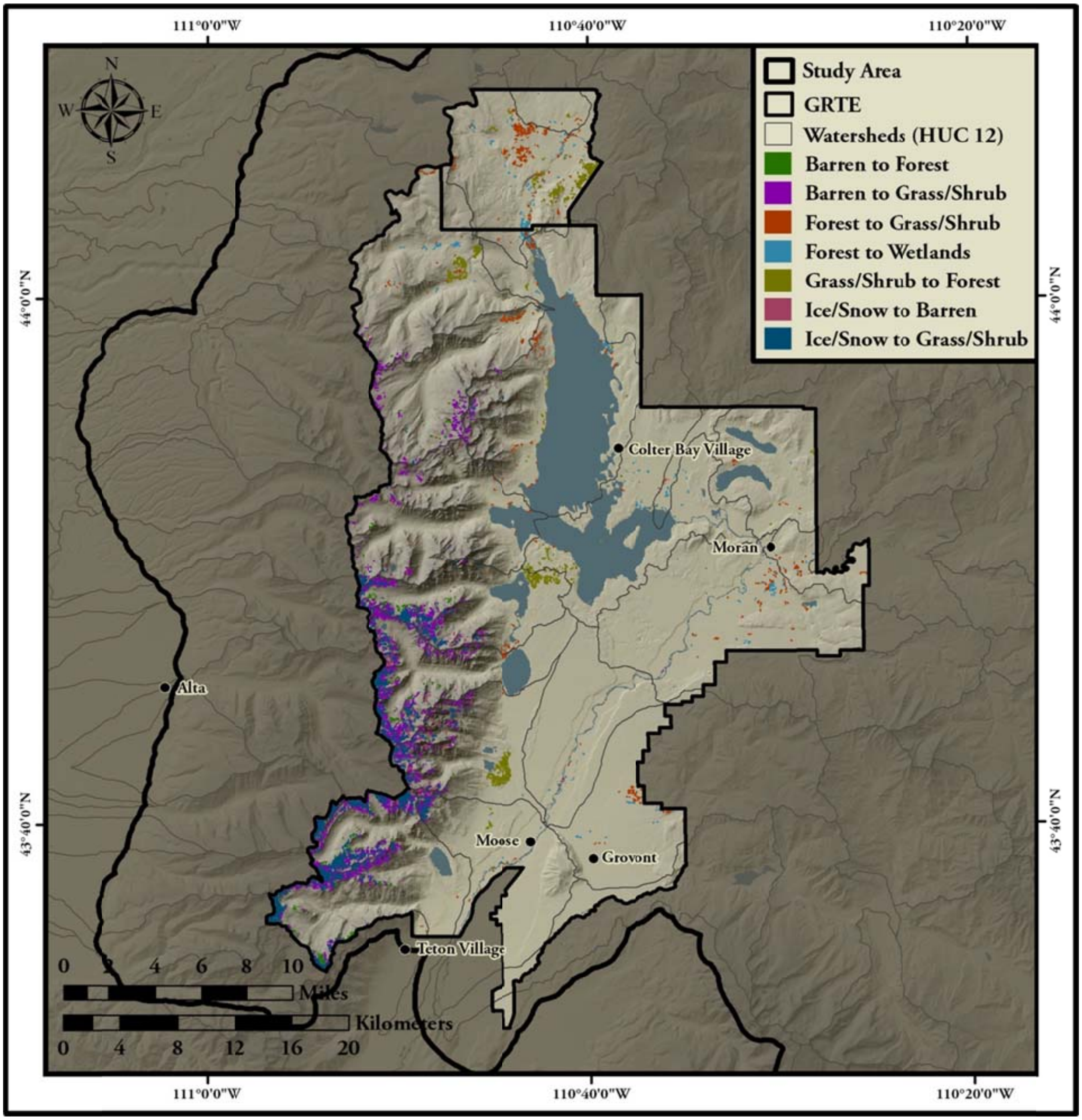

Figure 3.70. The most significant land cover transitions occurring within Grand Teton National Park.

Anthropogenic Land Use by Watershed

The degree of human pressure on the resources of GRTE and surrounding areas is a complex multidimensional variable. Anthropogenic land uses by watershed are summarized in order to determine which drainage areas seem to be more impacted by such land uses.

Methods

Vegetation datasets from the Northwest Gap Analysis Program and GRTE were used to extract anthropogenic land use classes. The Northwest Gap dataset was used to summarize information for the 79 HUC 12 watersheds within the study areas. The higher-resolution vegetation dataset provided by GRTE was used for the 13 HUC 12 watersheds within GRTE. The following classes were extracted: developed, pasture, and cultivated cropland.

Results

Table 3.32 contains the percentage of land occupied by different anthropogenic land use classes for the 13 watersheds within GRTE. Within GRTE, the Snake River-Stewart Draw watershed has the greatest percentage of urban area, and Moose Creek, Moran Bay, and Owl Creek have the least or no amount of urban area. Anthropogenic land use information, derived from the Northwest Gap vegetation data, is presented for all 79 watersheds within the study area in Figure 3.71. Within the study area, the Snake River-Stewart Draw, Elliot Creek-Teton River, and Lower Trail Creek watersheds have the highest percentages of developed area.

Summary and Conclusions

The proportional and absolute coverage of anthropogenic land use classes were extracted from both datasets (Northwest Gap and GRTE). Developed area and area of pasture and agriculture were calculated for each watershed within the two different study areas using the two datasets.

Table 3.32. Anthropogenic land uses for the watersheds within Grand Teton National Park.

Watershed	Huc 12 Code	Percent Urban	Transportation, Communication, and Utilities	Pasture and Crops	Water
Bradley Lake	170401010508	0.45	0.39	0.00	1.84
Jenny Lake	170401010507	0.05	0.28	0.00	8.62
Lake Creek-Fall Creek	170401030102	0.30	0.22	4.79	1.96
Leigh Lake	170401010506	0.07	0.09	0.00	7.62
Lower Jackson Lake	170401010308	0.60	0.41	0.00	27.47
Moose Creek	170401010305	0.00	0.00	0.00	0.74
Moran Bay	170401010307	0.00	0.00	0.00	7.34
Owl Creek	170401010304	0.00	0.00	0.00	0.09
Snake River-Baseline Flat	170401010505	0.11	0.34	0.00	0.03
Snake River-Sheffield Creek	170401010301	0.20	0.32	0.00	0.33
Snake River-Spread Creek	170401010501	0.26	0.34	0.12	0.36
Snake River-Stewart Draw	170401010510	4.16	1.14	2.15	0.13
Upper Jackson Lake	170401010303	0.56	0.26	0.00	40.28

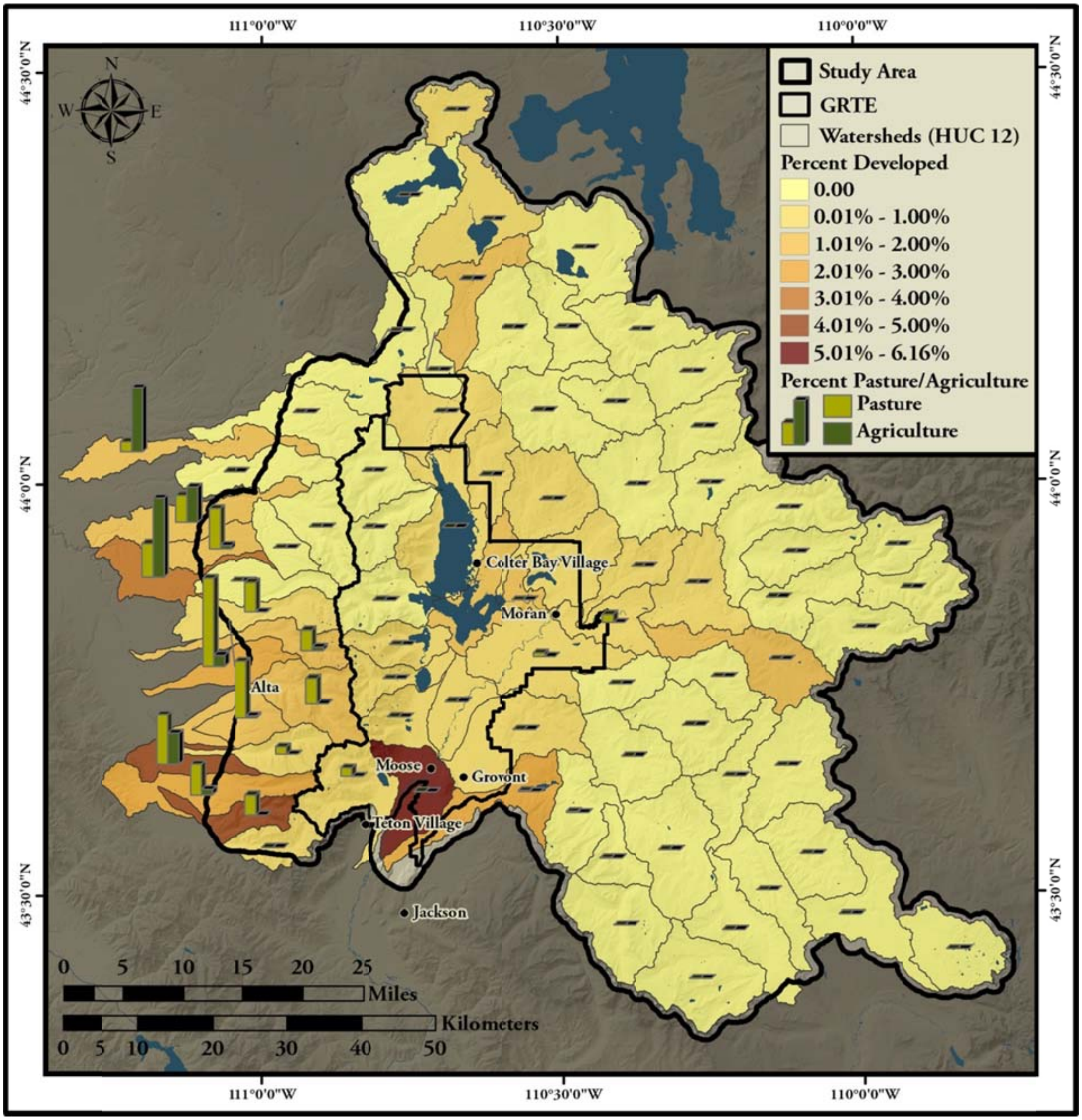

Figure 3.71. Anthropogenic land cover and land use by watershed.

Soundscapes

Natural soundscapes are the collective of all naturally-produced sounds, or silence, when any human-caused sounds are non-existent. Natural sounds occur within and beyond the perceptible limits of humans, transmittable through air, water, or solid materials (Ambrose and Burson, 2004). Many species of wildlife depend on their ability to perceive and produce sounds to attract mates, detect predators, find prey, and defend territories; all of which may be essential to an individual's reproductive success and survival. In addition to biological sounds, the physical sounds of flowing water, wind through vegetation, thunder, and lake ice expansion and contraction are part of the natural soundscape (Burson, 2008). Acoustically, the array of natural sounds within a given area may be masked by non-natural sounds, including those associated with certain human activities, such as road traffic, aircraft, and snowmobiles. These and other non-natural sources of sound often impact the natural soundscape and are an important management concern at GRTE. Natural soundscapes are a protected resource under National Park Service policies that are to be preserved or restored to the greatest extent possible (NPS, 2006f).

Two important physical characteristics of sound are: (1) "amplitude," which is the relative strength of pressure produced by a sound wave (measured in decibels, or dB), and (2) "frequency," defined as the number of times per second that a sound wave repeats itself (recorded in hertz, or Hz) (Ambrose and Burson, 2004). The range of normal human hearing is between 20 Hz (low frequency) and 20,000 Hz (high frequency), and includes sounds as low as 0 dB at 1,000 Hz (middle frequency). Levels of sound pressure are measured logarithmically, whereby an increase of 10 decibels, will have the perceived effect of doubling the sound's loudness. Because humans do not hear well at very low or very high frequencies, a weighting factor can be applied to sound data, a process called "A-weighting" (dBA), which adjusts the amplitude (dB) to more closely represent the sensitivity of the human ear (or other animal of interest) to different frequency ranges (Ambrose and Burson, 2004).

Park soundscapes are inherently and wildly variable depending on time and space (S. Burson, GRTE, pers. comm.). Within the park, there are areas where certain human-caused sounds are expected (e.g. visitor centers or travel corridors), contrasting with remote back-country areas where human-caused sounds are typically absent or minimal. What constitutes a disturbance or impact depends on a person's (or animal's) ability to hear a given sound (i.e. what is audible), and the relative sound pressure level (SPL) and duration of the intruding sound within the context of existing ambient sounds. Therefore, acoustical data collection involves selecting measurement locations, determining adequate measurement periods, and identifying what acoustic data to collect (Ambrose and Burson, 2004). The primary objective of the sound program at GRTE is to develop a database and conduct analyses to help understand the park's natural soundscape and to assess the various impacts from non-natural sound sources (Burson, 2008).

Methods

The draft report, *The Natural Soundscapes of Grand Teton National Park October 2002 – June 2008* (Burson, 2008), provided the primary source of information to assess soundscapes in GRTE. This report describes the extensive acoustical data that were collected at twenty-two sites in GRTE from October 2002 to April 2008. The purpose of the report was to "summarize the natural soundscape of the park and to quantify the impacts of non-natural sounds on the natural soundscape," which included "comparing the current acoustic conditions to the standards and thresholds outlined in the Yellowstone and Grand Teton National Parks and the John D. Rockefeller, Jr. Memorial Parkway's Winter Use Plans and the Jackson Hole Airport Use Agreement Extension Environmental Impact Statement" (Burson, 2008). The acoustic work completed in GRTE follows NPS guidelines outlined by Ambrose and Burson (2004).

The geographic coverage of sound monitors installed throughout the park involved the consideration of "acoustic zones" and the seasonal variety of activities and logistical constraints that occur within GRTE. Acoustic zones are defined by similar vegetation types (i.e. habitats), which are assumed to provide acoustic consistency relative to the biotic (e.g. mammals, birds, and insects) and physical (e.g. structure and form of the vegetation, presence of running water, topography, and micro-climate) components. The acoustic zones were subsequently overlaid by management zones to incorporate the human-caused noise potential by categorizing areas into developed, travel corridors, or back-country. Sound monitors collected data specifically during summer or winter months, or throughout all seasons to identify how both the natural soundscape and potential non-natural sounds change through time. Finally, depending on location, the duration (i.e. percent time audible) and sound levels of recognized sound events were compared to agreed-upon thresholds relative to existing ambient sound levels.

The majority of data were collected using automated acoustical monitors, which supported the following forms of acoustic analyses. For all data collection periods, high wind that created turbulence around the microphone, and thus artificially introduced high sound levels, and visits to the monitoring sites were removed from subsequent analyses.

<u>Audibility (Percent of Time Audible)</u>
High-quality digital recordings were analyzed to identify specific sound sources (e.g. snowmobile, animal, aircraft, and wind), duration and timing (i.e. daily or seasonal), and spatial distribution for all audible sounds. A systematic sampling scheme of regular, frequent intervals, typically 10 seconds every four minutes were recorded daily (n=360 recordings), for a total of 60 minutes per day. After the data were collected, the recordings were calibrated and replayed by investigators in the lab. The entire 24-hour period was analyzed, but specific time periods, such as 8:00 a.m. to 4:00 p.m., provides a summary of sound conditions audible during peak visiting hours, for example. The percent time audible for each sound source was calculated using the combined 10-second samples as approximations of all periods of the day. For example, if a particular sound source was audible for half of the samples (e.g. 180 of 360 samples), its percent time audible was calculated as 50 percent. Although a sampling scheme may miss an infrequent sound, prior tests using attended logging, other sampling schemes, and continuous recordings, have demonstrated that analyses using a 10 second per four minute sampling scheme closely approximate actual percent time audible of frequent non-natural sound sources (e.g. aircraft, wheeled vehicles, and oversnow vehicles) (Burson, 2008).

Audibility depends on the sound level of and distance from the sound source as well the presence of masking sounds, and on non-sound source variables such as atmospheric conditions, wind speed and direction, topography, snow cover, and vegetative cover (Burson, 2008). Factors such as these can influence the daily audibility at any given location. Therefore, a hierarchal classification system starting with the most to the least specific identification was used when logging the sound source (e.g. motorcycle, wheeled vehicle, motorized sound, non-natural sound, or unknown). Also, because some sounds masked those of others, the percent time audible statistics should be considered minimum values (Burson, 2008).

Loud Sound Events

An "event" refers to the loudest sources of sound at each monitoring site. Sampling for loud sound events involved 20-second digital recordings which when replayed, were tallied by each specific sound source. A sound event was logged if the sound level (decibel) and duration (seconds) exceeded a user-defined threshold. Two event thresholds were typically set, 70 dBA (A-weighted sound level) over one second (i.e. a fast sound level threshold) and 50 dBA over 10 seconds (i.e. a slow sound level threshold). Thresholds were adjusted depending on location and wind exposure. For example, slow sound level thresholds were increased in areas with frequent high winds to avoid recording thousands of wind events (Burson, 2008).

Measurements of loud sound events relative to the ambient sound environment, provides a context for determining potential impacts and supporting adaptive management. These data are used to address management concerns of sound impacts from oversnow vehicles (e.g. snowmobiles and snowcoaches) relative to the winter use plans defined acoustical standards and thresholds, and when developing future soundscape management plans, such as the Air Tour Management Plan for GRTE (Burson, 2008).

Sound Levels

Sounds can be quiet or loud depending on the magnitude of the initial disturbance. Ambient sound levels (i.e. frequency and amplitude) were measured using continuous one-second sound pressure levels (SPL) (A-weighted decibel) data. Four acoustic summary metrics were calculated, which include and are defined as the following:

- *maximum sound level* (L_{max}) = the maximum weighted sound pressure level (i.e. the logarithmic form of sound pressure, in dcibels), obtained by frequency weighting, or "A-weighting" decibel data.

- *energy level equivalent* (or "energy average") (L_{eq}) = the level (in decibels) of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.

- *50% sound level exceedance* (L_{50}) = the sound level exceeded 50 percent of the time during the measurement period. L50 is the same as the median, where half of the sound levels are above and half below.

- *90% sound level exceedance* (L_{90}) = the sound level exceeded 90 percent of the time during the measurement period.

The energy level equivalent (L_{eq}) is useful because its magnitude depends heavily on the loudest periods of a time-varying sound. However, L_{eq} must be used carefully because occasional loud sound levels (e.g. gusts of wind, birds, or thunder) may heavily influence (increase) its value, when typical sound levels are lower.

The 50 percent sound level exceedence (L_{50}) is used to describe the median sound level in an area. And, when other measures are unavailable, the 90 percent sound level exceedence (L_{90}), is the NPS (and other organizations) standard for use as an analog to the natural ambient in locations other than those most heavily impacted by non-natural sounds (Burson, 2008). There are many areas in GRTE where human-caused sounds are likely to affect the measured sound levels for less than 50 percent of the time, and almost certainly for less than 90 percent of the time.

Daily One-Second 1/3 Octave Band Frequency Spectrograms

Daily profiles of sound levels were created using one-second 1/3 octave band frequency data (i.e. 33 bands from 12.5 to 20,000 Hz). Sound levels (dBA), representing the one-second Leq of each 1/3 octave band frequency, were plotted for the 86,400 seconds of each day. These spectrograms show visually, how different sounds and associated sound levels are distributed through time (Burson, 2008).

Results

Between October 2002 and April 2008, a total of 43,534 hours of sound data were collected from the 22 recording sites distributed throughout GRTE. A summary of sound station information including management area, vegetation type, dates and hours of acoustical data collection are provided in Table 3.33. Figures 3.72 and 3.73 show the geographic coverage of sound stations depicting management area and season of recording, respectively. To account for expected differences in human-caused noises, the recording sites were distributed among three management zones, which included: seven sites in developed areas, five sites in travel corridors, and 10 sites in backcountry areas. The length of time that acoustical measurements were taken varied, ranging from three days to over one year. The majority of data came from four stations that had year-long continuous recordings (i.e. White Grass Ranch, Teton Road Lagoon, Headquarters Office, and Jackson Lake Cow Island) and four other stations with winter-only data (i.e. Flagg Ranch Ranger Station, Jackson Lake Colter Bay Picnic Area, Jackson Lake Catholic Bay, and Grassy Lake Road). The remaining sites provided insight into the acoustical conditions at additional locations for briefer time periods.

Because no one acoustical measure provides a complete picture of soundscape condition, the results from the various analyses should be viewed as complementary.

Table 3.33. Overview of sound recording stations installed in Grand Teton National Park.

Code	Site	Management Area	Vegetation Class	Season	Time Period	Hours
15	Jackson Lake Cow Island	Backcountry	Mixed Conifer Forest	multiple	15 Feb 2005 –27 Jul 2006	9,011
21	Timbered Island	Backcountry	Sagebrush Dry Shrubland	multiple	2 Oct 2002 –23 Jul 2003	3,473
22	White Grass Ranch	Backcountry	Mixed Grassland Herbaceous	multiple	2 Feb 2004 –7 Feb 2005	5,777
3	Beaver Creek2	Backcountry	Mixed Conifer Forest	summer	24 Aug 2007 – 9 Aug 2007	104
6	Cascade Canyon North Fork	Backcountry	Subalpine Fir-Englemann Spruce Forest	summer	1 Aug 2005 – 8 Aug 2005	161
4	Blacktail Butte	Backcountry	Cottonwood Riparian Forest	winter	8 Feb 2003 – 10 Feb 2003	49
16	Jackson Lake South Landing	Backcountry	Mixed Conifer Forest	winter	9 Feb 2003 – 19 Feb 2003	179
18	Pemble Trail	Backcountry	Mixed Conifer Forest	winter	17 Feb 2007 – 23 Feb 2007	135
1	Bar BC Ranch	Backcountry – Snake River	Sagebrush Dry Shrubland	summer	31 Aug 2005 – 6 Sep 2005	141
19	Snake River Spread North	Backcountry – Snake R iver	Cottonwood Riparian Forest	summer	7 Jul 2006 – 13 Sep 2006	1,120
13	Headquarters Office	Developed	Residential and Facilities	multiple	8 May 2007 – 16 Apr 2008	7,344
8	Colter Bay Picnic Area	Developed	Mixed Grassland Herbaceous	multiple	9 Feb 2005 – 13 May 2005	2,233
7	Colter Bay Landing	Developed	Mixed Grassland Herbaceous	winter	18 Mar 2004 – 27 Mar 2004	214
9	Colter Bay Picnic Loop	Developed	Douglas Fir Forest	winter	1 Jan 2003 – 5 Jan 2003; 9 Feb 2003 – 14 Feb 2003	198
10	Flagg Ranch Ranger Station	Developed	Lodgepole Pine Forest	winter	10 Feb 2003 – 20 Feb 2003; 4 Dec 2003 – 29 Mar 2004	2,477
14	Jackson Hole Airport Lek	Developed	Residential and Facilities	multiple	30 Mar 2006 – 20 Jun 2006	1,284
2	Beaver Creek	Developed	Residential and Facilities	winter	7Mar 2006 – 29 Mar 2006	518
5	Catholic Bay	Travel Corridor	Aspen Forest	multiple	28 Jan 2005 – 19 May 2005	2,858
12	Grassy Lake Road	Travel Corridor	Flooded Wet Meadow Herbaceous	multiple	4 Jan 2005 – 10 Jun 2005	2,749
20	Teton Road Lagoon	Travel Corridor	Lodgepole Pine Forest	multiple	14 Jan 2004 – 11 Feb 2005	8,289
11	Flagg Ranch South	Travel Corridor	Mixed Conifer Forest	winter	2 Jan 2003 – 6 Jan 2003	92
17	Pacific Creek Road	Travel Corridor	Lodgepole Pine Forest	winter	2 Jan 2003 – 5 Jan 2003; 8 Feb 2003 – 20 Feb 2003	328
			TOTAL			**43,534**

Source: Burson, 2008.

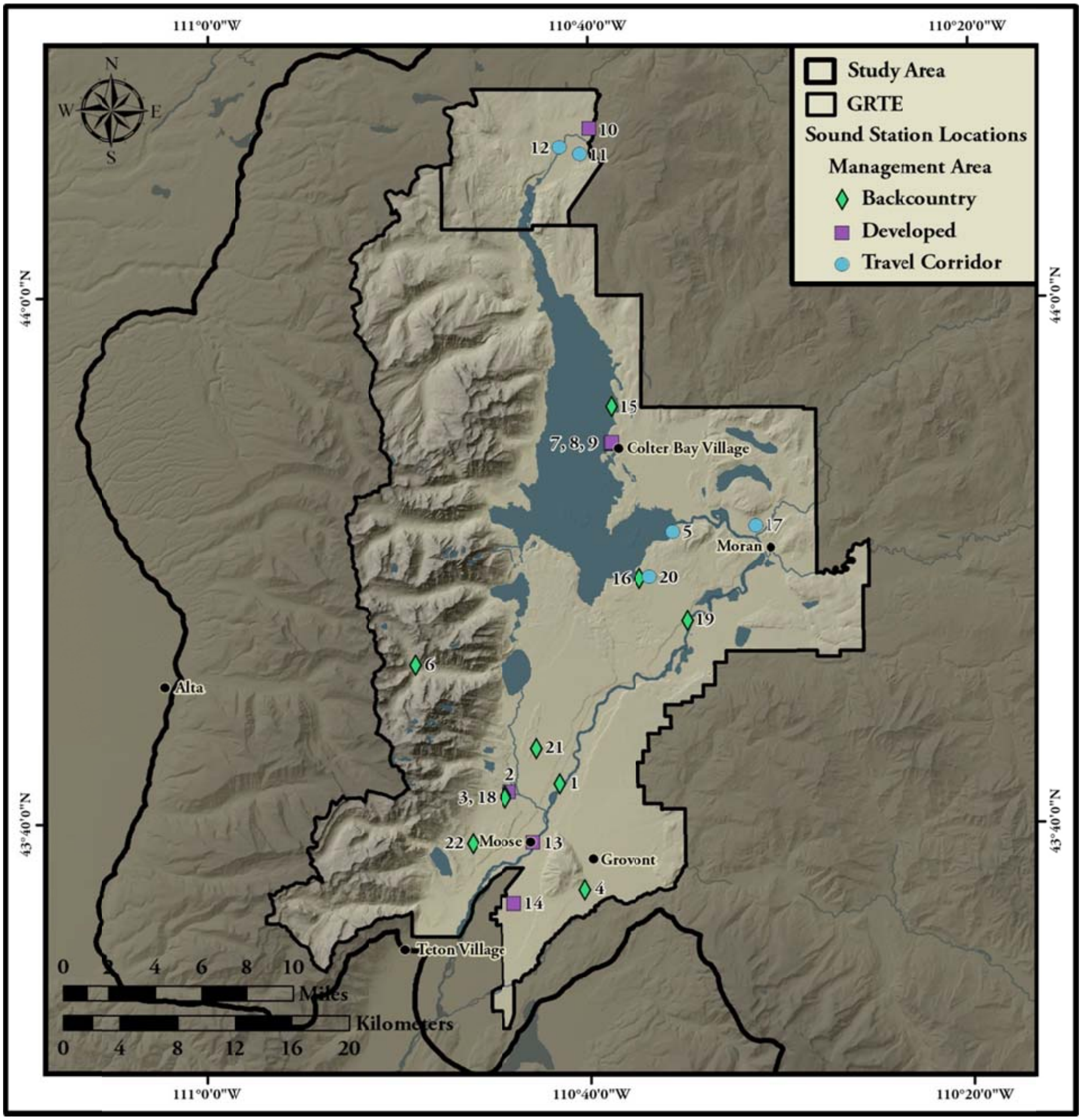

Figure 3.72. Sound stations in Grand Teton National Park as defined by management area.

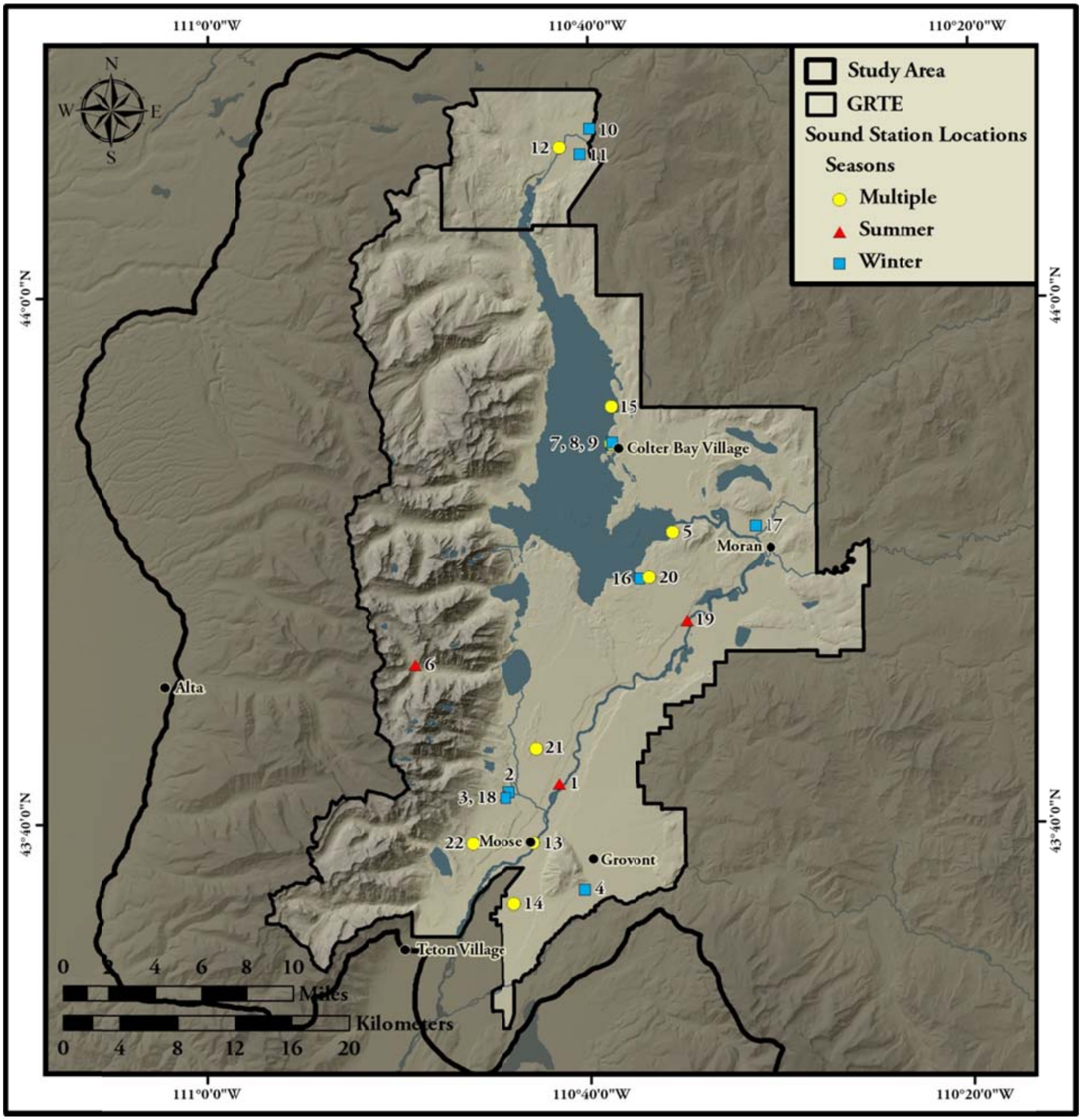

Figure 3.73. Sound stations in Grand Teton National Park as defined by season of recording.

Audibility

The results of audibility analyses are generally organized into non-natural and natural sound sources of interest, by season, date, or time of day. Figure 3.74 presents an overview of the most common sounds audible at all GRTE monitoring sites during summer and winter months. Sounds of summer consist primarily of running water (44 percent), bird vocalizations (42 percent), vehicles and other motors (36 percent), and wind (17 percent). During winter, silence prevails in GRTE (35 percent), with occasional wind (19 percent), followed by motorized vehicles (18 percent).

Excluding the recording sites located near buildings and utilities the majority of non-natural sounds are associated with motorized vehicles, including aircraft (10 percent of all 10-second sample recordings), wheeled vehicles on roadways within the park (10 percent), watercraft on Jackson and Jenny Lakes, and oversnow vehicles during the winter use season (Table 3.34).

Sounds associated with aircraft and oversnow vehicles are two primary management concerns at GRTE. In addition to the high altitude commercial overflights that can be heard throughout the park, GRTE is the only national park with a commercial jetport located within its boundary. Aircraft sounds are a widespread non-natural sound source in GRTE. The loudest sounds from the Jackson Hole Airport are created from aircraft starting up, taxiing, taking-off, and landing. There can be over 200 operations per day during the peak summer season (current annual average of about 90 per day). Figure 3.75 shows the percent time audible of aircraft during winter at multiple sites in GRTE. Within the area bound by aircraft audibility, many birds and smaller mammals live and breed, including an active spring and early summer sage grouse lek at the north end of the runway. Moose, elk, pronghorn antelope, and coyotes are also frequent visitors near the area most affected by airport-related sounds.

Oversnow vehicle use within GRTE has decreased both in permissible locations of use and numbers of vehicles in recent years. Mitigation efforts associated with a series of Winter Use Plans Environmental Impact Statements in 2002, 2003, and 2007 for YELL, GRTE, and JODR, have dictated appropriate sound level thresholds from oversnow vehicles to reduce impacts on the natural soundscape and other resources (see *Sound Levels* results for more information on current thresholds). Other than near Flagg Ranch, where most oversnow vehicle use occurs, monitoring data suggest that oversnow vehicles are audible on average less than 10 percent of the time in developed areas and travel corridors, and much less than 10 percent of the time in most backcountry areas.

Motorized traffic on park roadways is also a pervasive non-natural sound that affects large areas of the park. Road traffic varies by hour and season, but is nearly constant on the main roads during the summer days. Trucks, buses, and loud motorcycles cause a disproportionate impact on the natural soundscape.

Motorized boats are allowed on two large lakes in GRTE. Frequent shuttle boats deliver summer visitors to and from Inspiration Point across Jenny Lake. Jackson Lake has a larger diversity of motorized boats ranging from small rental skiffs to large ski-boats. Near the marinas at Colter Bay, Leek's, and Signal Mountain, motorized boats are especially audible and at high sound levels.

The natural soundscape of GRTE includes a diverse array of sounds attributed to both physical processes such as wind, running water, tumbling rocks, and thunder, as well as the biological activity from birds, mammals, insects, and amphibians (Table

3.35). The number and type of natural sounds present depend on the season and location. Year-round, bird sounds make up approximately 25 percent of all recording samples, followed by wind (22 percent), and the absence of any sound (18 percent). Winter months in GRTE are often characterized by the silence, yet, blasts from wind, creaking trees, and birds calling are also common. Stormy weather, vocalizations from birds and amphibians are typical sounds in spring. Bird songs in the mornings and buzzing insects in the afternoon are heard during summer months. While, rustling leaves, bugling elk, and grunts from bison are commonly heard in fall.

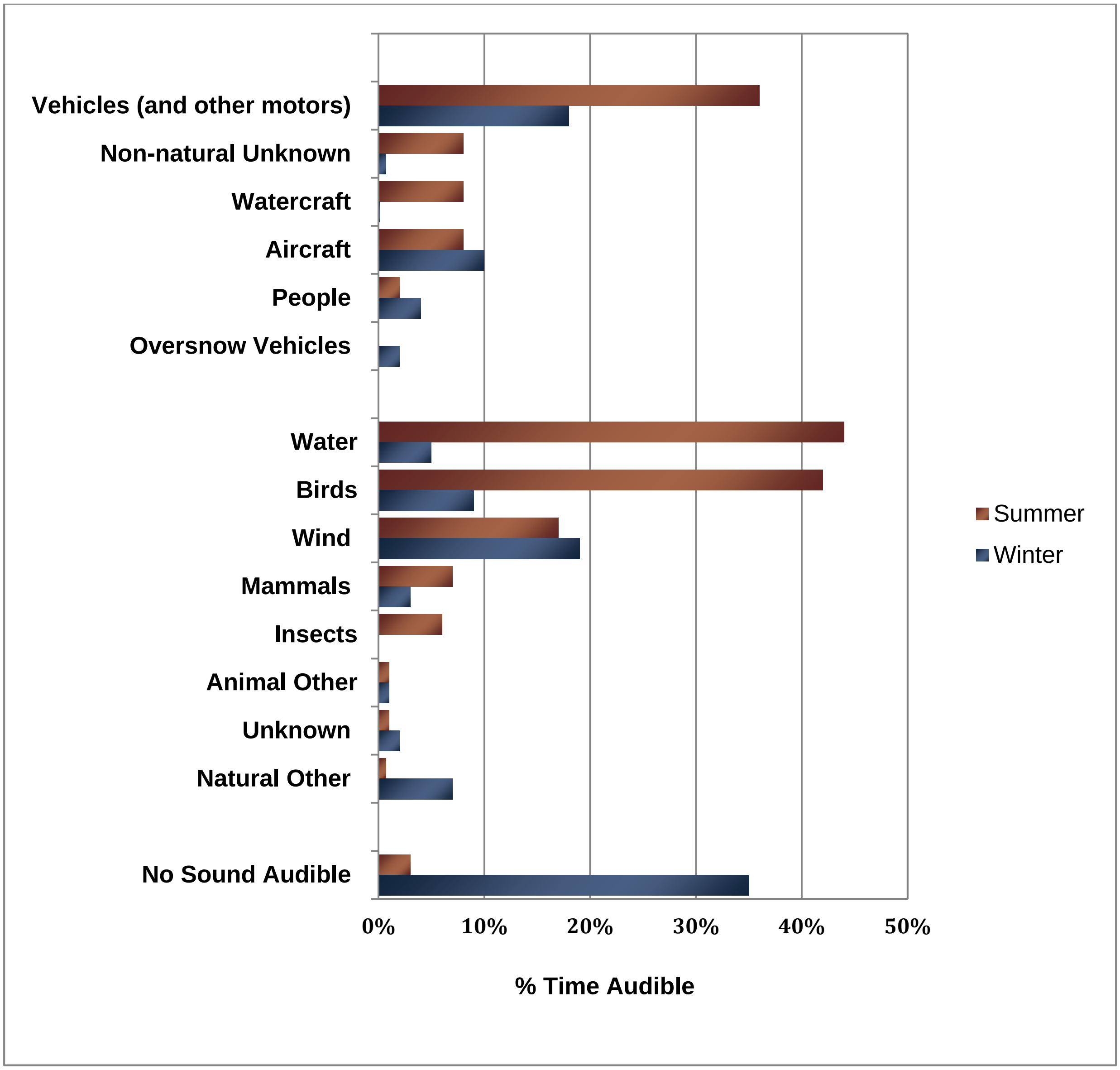

Figure 3.74. Summary of common sounds in Grand Teton National Park and percent of time audible from digital recordings completed in summer and winter months between 2002 and 2006 (Burson, 2008; Table 1).

Table 3.34. Number and percent of all samples of non-natural sounds identified from 10-second recording samples at monitoring sites in Grand Teton National Park, 2003-2006. No sound is tallied more than once (N=150,823 10-second samples; 420 cumulative hours).

Sound Source	Number of Occurrences	Percent of All Samples	Sound Source	Number of Occurrences	Percent of All Samples
Aircraft			**People**		
Jet	8,041	5.3%	Voices	3,019	2.0%
Propeller	5,664	3.8%	Skiing	124	0.1%
Helicopter	363	0.2%	Radios	86	<0.1%
Unidentified	692	0.5%	Walking	51	<0.1%
Total	**14,460**	**9.6%**	Gunshots	15	<0.1%
Road Vehicle			Unidentified	516	0.3%
Automobile	5,840	3.9%	**Other**		
Truck	1,067	0.7%	Rotary snowplow	1,169	0.8%
Motorcycle	182[1]	0.1%	Other snowplow	57	<0.1%
Unidentified	7,995	5.3%	Heavy Equipment	258	0.2%
Total	**15,084**	**10.0%**	Pump[2]	3,532	2.3%
Oversnow Vehicles			Ice Auger	169	0.1%
Snowmobile	999	0.7%	Construction	30	<0.1%
Groomer	218	0.1%	Buildings	39	<0.1%
Snowcoach	53	<0.1%	Alarm/Horn	255	0.2%
Either	7	<0.1%	Dog	431	0.3%
Unidentified	2	<0.1%	Horse	1	<0.1%
Total	**1,279**	**0.8%**	**Motor**		
Watercraft			Unidentified	24,446	16.2%
Motorized	4,670	3.1%	Other non-natural	1,058	0.7%
Non-motorized	1	<0.1%	Unidentified	2,897	1.9%
Boat wake	490	0.3%	**Total Non-Natural**	**72,040**	**47.8%**

Source: Burson, 2008; Table 2.
[1]Many other motorcycles were audible, but not tallied as such.
[2]Aeration pump on Signal Mountain sewage treatment ponds.

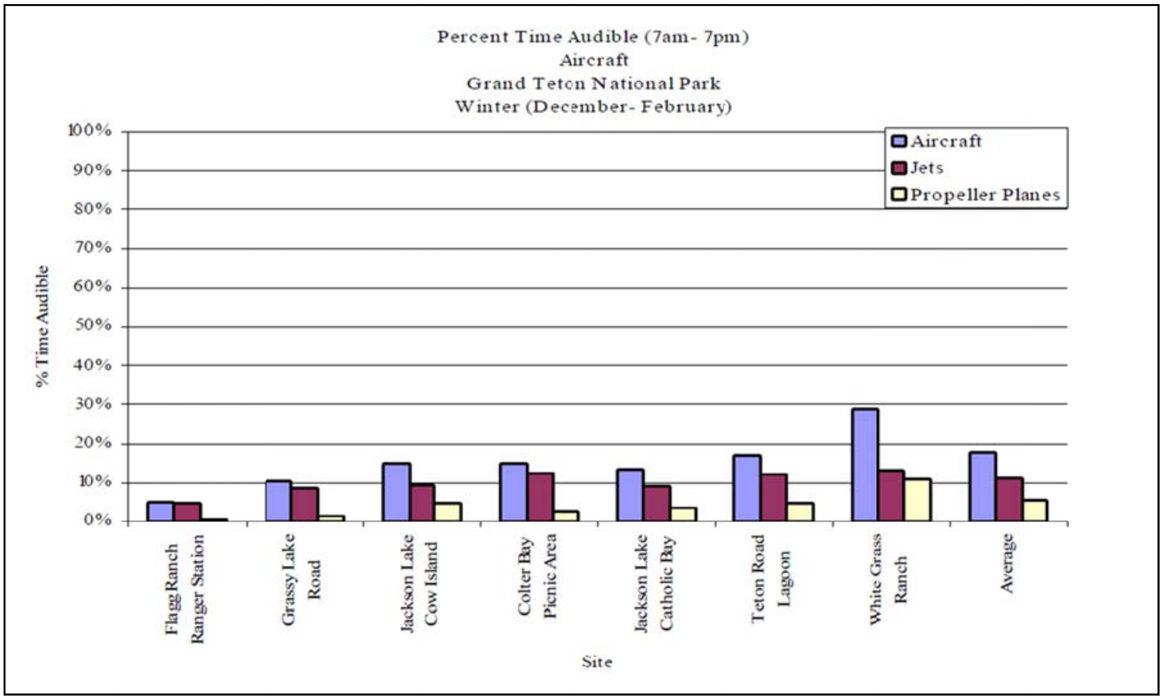

Figure 3.75. Percent time audible (7:00 a.m. to 7:00 p.m.) of aircraft during winter at multiple sites in Grand Teton National Park, 2003-2005. Sites ordered left to right by most distant to closest to Jackson Hole Airport. Audible aircraft included all aircraft not just those associated with Jackson Hole Airport (N = 101 days) (Burson, 2008; Figure 6).

Table 3.35. Number and percent of all samples of natural sound sources identified from 10-second recording samples at monitoring sites in Grand Teton National Park, 2003-2006. No sound is tallied more than once (N=150,823 10-second samples; 420 cumulative hours).

Sound Source	Number of Occurrences	Percent of All Samples	Sound Source	Number of Occurrences	Percent of All Samples
Physical Sounds			**Biological Sounds – Birds**		
Wind	33,547	22.2%	Raven	5,150	3.4%
Flowing Water	17,547	11.6%	Canada Goose	353	0.2%
Waves	13,733	9.1%	Chickadee	275	0.2%
Rain	2,250	1.5%	Black-Billed Magpie	260	0.2%
Snow	726	0.5%	Duck	113	0.1%
Water	349	0.2%	Gray Jay	61	<0.1%
Thunder	311	0.2%	Unidentified Bird	31,404	20.8%
Biological Sounds – Mammals			**Total Bird**	**37,616**	**24.9%**
Elk	5,342	3.5%	**Biological Sounds – Amphibians**		
Red Squirrel	2,324	1.5%	Amphibian	544	0.4%
Coyote	630	0.4%	**Biological Sounds – Unidentified**		
Chipmunk	610	0.1%	Unidentified Animal	1,966	1.3%
Wolf	60	<0.1%	**Silence**		
Unidentified Mammal	1,873	1.2%	No audible sounds	27,223	18.0%
Total Mammal	**10,839**	**7.2%**	Other natural	854	0.8%
Biological Sounds – Insects			Unidentified	2,897	1.9%
Insect	4,275	2.8%	**Total Natural**	**137,549**	**91.2%**

Source: Burson, 2008; Table 5.

When parsed out by management area, non-natural sounds often predominate within and near developed areas. Natural sounds were audible in developed areas during the day when human activities were quiet, but were more common at night and in the early morning. Each developed area has specific sounds associated with its function. Acoustical data were collected at the following developed areas: GRTE Headquarters in Moose, Jackson Hole Airport, Beaver Creek employee housing area, and (during winter months) at the oversnow vehicle staging areas at Flagg Ranch Ranger Station and Colter Bay. Figure 3.76 shows the percent time audible of oversnow vehicles at Flagg Ranch Ranger Station in winter. The microphones at Flagg Ranch Ranger Station were located 20 feet (6.1 meters) northeast of the ranger station, 120 feet (36.6 meters) from the plowed John D. Rockefeller, Jr. Memorial Parkway road, and 95 feet (28.9 meters) from the plowed entrance road to Flagg Ranch. All non-natural sounds collectively were audible for approximately 75 percent of the time between 8:00 a.m. to 4:00 p.m., with snowmobiles accounting for about 28 percent of those sounds. The percent of time audible of snowmobiles peaked at 9:00 a.m. and 4:00 p.m., when audibility was greater than 50 percent of the time during those hours.

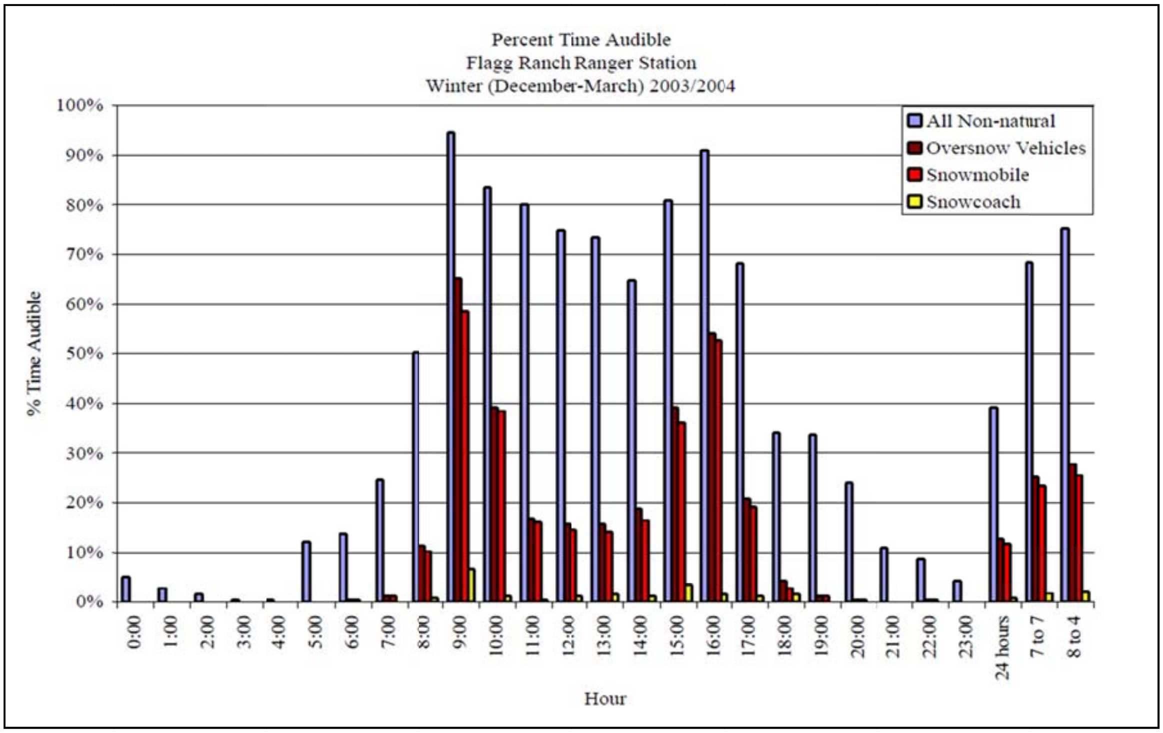

Figure 3.76. The percent time oversnow vehicles were audible by hour during winter 2003-2004 at Flagg Ranch Ranger Station, Grand Teton National Park (Burson, 2008; Figure E-41).

The soundscape of travel corridors varies by location and season. The main north-south highway (Highway 89) is busy year-round, but as is seen throughout the park, the level of traffic increases in summer months. Wheeled vehicles are often audible for 100 percent of the entire day during mid-summer days adjacent to both Highway 89 and Teton Park Road near Signal Mountain. Teton Park Road between Taggart Lake and Signal Mountain transforms to a much quieter place during winter with only occasional non-natural sounds from snow groomers, wheeled vehicles on the main highway (over four miles distant), and aircraft. Oversnow vehicles (i.e. snowcoaches and snowmobiles) travel between Flagg Ranch and Yellowstone's south entrance during the winter. Figure 3.77 shows the percent time audible of non-natural sounds, including aircraft, snowmobiles, and wheeled vehicles, recorded along Grassy Lake Road during winter. Grassy Lake Road is groomed during the winter allowing for snowmobile access between the Targhee National Forest and Flagg Ranch. The monitoring station on Grassy Lake Road was installed in an area characterized by flooded wet meadow herbaceous vegetation with patches of open conifers. The microphones were located 150 feet (45.7 meters) from the road. All non-natural sounds collectively were audible for approximately 42 percent of the time between 8:00 a.m. to 4:00 p.m., with snowmobiles accounting for about five percent of those sounds.

Sixty-five percent of the backcountry in GRTE, and 78 percent of the entire park, is within two miles (3.2 kilometers) of roads or developed areas (not including flight zones of planes). As such, the majority of backcountry soundscapes in GRTE include distant sounds from motorized vehicles. However, many backcountry trails in the Teton Mountain range are near fast flowing streams and rivers that tend to mask all but the loudest aircraft sounds. In areas away from flowing water, other natural sounds predominate, the sources of which depend on the season. Figure 3.78 shows the percent time audible of non-natural sounds, including aircraft, snowmobiles, and wheeled vehicles, recorded at Jackson Lake Cow Island during winter.

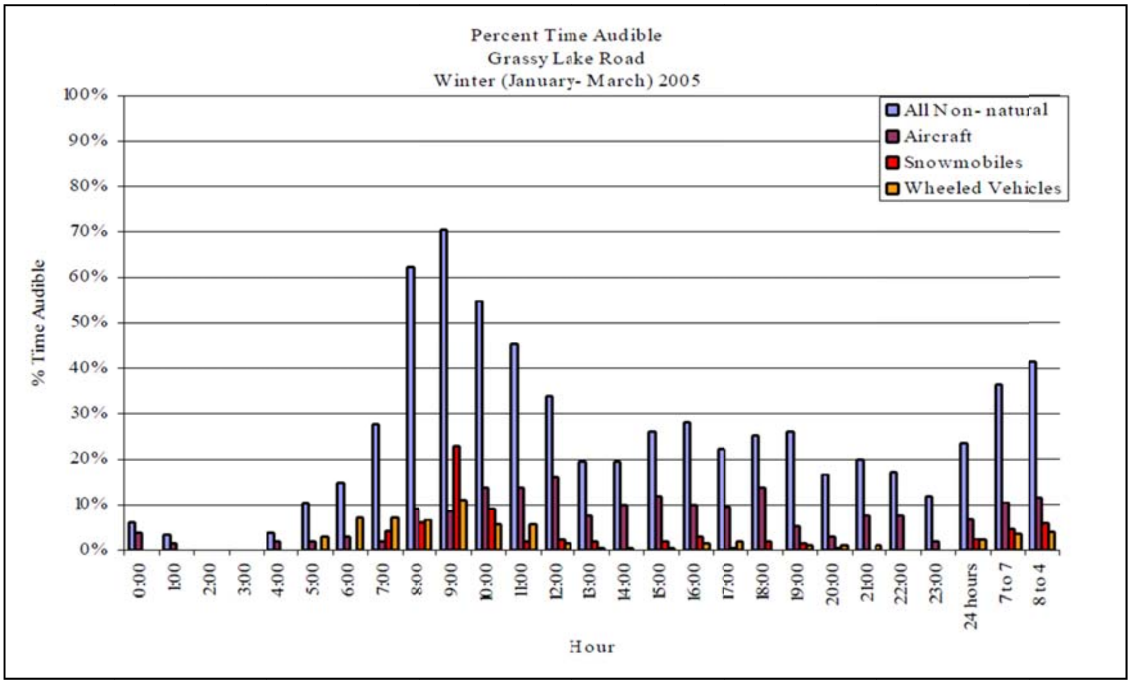

Figure 3.77. The percent of time non-natural sounds were audible by hour during winter 2005 at Grassy Lake Road, Grand Teton National Park (Burson, 2008; Figure E-45).

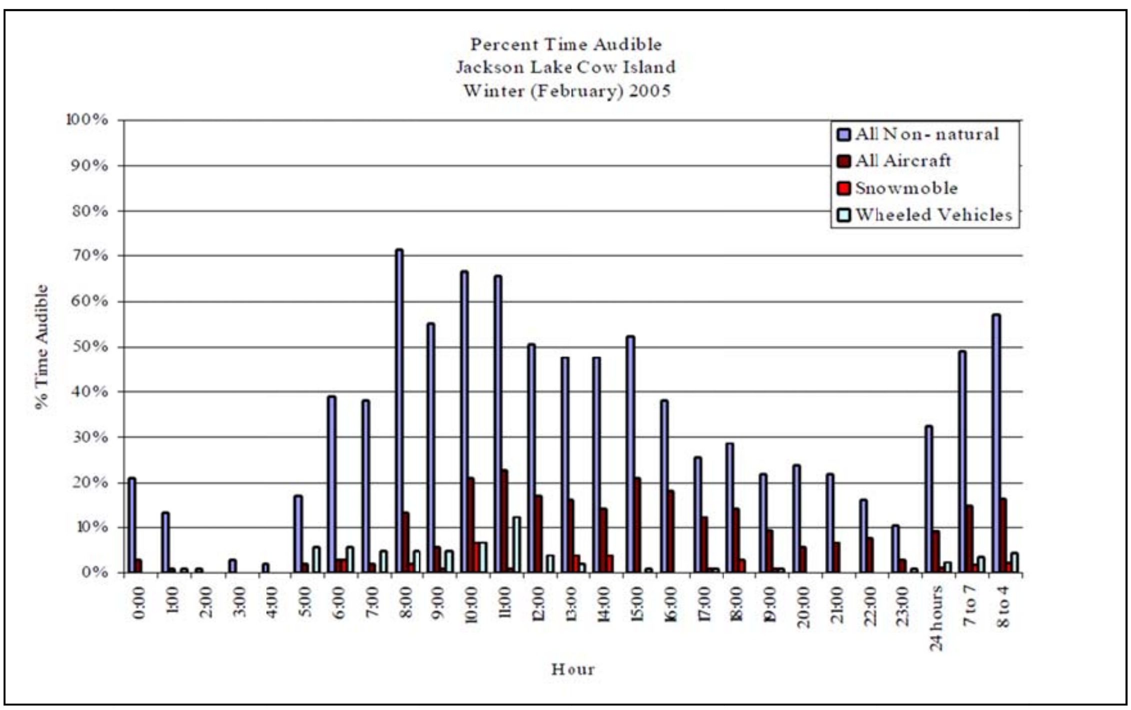

Figure 3.78. The percent of time non-natural sounds were audible by hour during winter 2005 at Jackson Lake's Cow Island, Grand Teton National Park (Burson, 2008; Figure 18).

Jackson Lake Cow Island is a backcountry site located on the west side of a small, forested island, 4,000 feet (1,219 meters) from Highway 89, 2,000 feet (609 meters) from the parking area at Leeks Marina, and approximately 1.5 miles (2.4 kilometers) north of Colter Bay. All non-natural sounds collectively were audible for approximately 57 percent of the time between 8:00 a.m. to 4:00 p.m., where snowmobiles were audible for only two percent of that time. However, sounds from aircraft were audible approximately 17 percent of the time. Figure 3.79 shows the percent time audible of natural sounds, primarily from wind and animals, recorded at Jackson Lake's Cow Island in winter and summer on a daily and hourly basis. Natural sounds, on average, nearly doubled in the summer on a daily basis (Figure 3.79a and 3.79c), which was largely due to the increase in sounds attributed to animals. The hourly distribution of animal sounds also increased in summer as daylight lengthened (Figure 3.79b and 3.79d).

Specific sound sources can be identified and their geographic distribution and timing can be used for inventorying and monitoring physical and biological sounds. The bugling of elk within GRTE is typically heard during fall months. Figure 3.80 shows the hourly cycle of elk bugling at White Grass Ranch, a backcountry site about 4,700 feet (1,433 meters) from the Moose-Wilson Road, between August 4, 2004 and November 10, 2004. Elk bugling is least common while aircraft sounds are most common during the day (Figure 3.81). The number of samples of elk bugling drops off considerably (about 9:00 a.m.), just as the percent time audible of aircraft activity peaks (greater than 30 percent of the time between 8:00 a.m. and 4:00 p.m.). Conversely, the elk sounds pick back up in the evening (about 7:00 p.m.) as sounds from aircraft diminish.

Loud Sound Events

Of the 34,000 loud sound events recorded at sound stations within GRTE, wind, road vehicles, and aircraft were the most common sources. Throughout the park, impacts from aircraft and motorized vehicles are the most wide-ranging non-natural sounds in the park. Table 3.36 provides examples of the number and percent of the loudest sound events recorded at four sound stations in GRTE. The locations are ordered from left to right on the table corresponding to north to south. The total number of events at any location depended both on the adjustable minimum sound level threshold (generally around 50 or 60 dBA) and the number of sounds occurring above that threshold. Wind was the most common event at the monitor adjacent to Grassy Lake Road, although both aircraft and oversnow vehicles were represented. The Teton Road Lagoon monitor, located approximately 100 feet (30.5 meters) from Teton Park Road, is groomed for skiing during winter and open for vehicular traffic during the rest of the year. The prevalence of loud motorcycles, especially during August, is consistent with other data collected in the park. The monitor at Bar BC Ranch is near the Snake River away from roads, but under the northern flight path of the Jackson Hole Airport. During the elk rut, elk vocalizations were the most common event at the White Grass Ranch monitor. However, the close proximity of White Grass Ranch to the Jackson Hole Airport is evident by the number of aircraft events, particularly in winter. Aircraft were often audible more frequently and louder during winter because of atmospheric conditions and the absence of other sound sources that mask aircraft sounds during different times of the year.

Figure 3.79. The percent of time natural sounds were audible at Jackson Lake's Cow Island, Grand Teton National Park, in winter by date (a) and hour (b), and in summer by date (c) and hour (d) (Burson, 2008; Figures 20, 24, 22, 26)

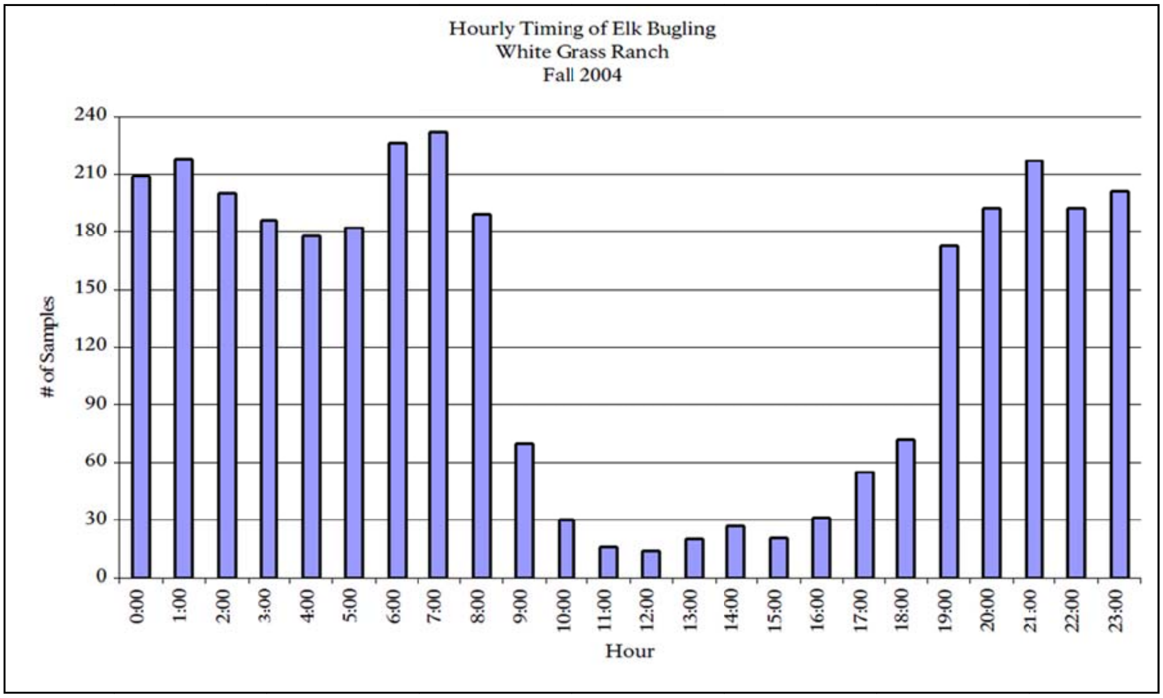

Figure 3.80. Number of 10-second recording samples with elk audible during fall 2004 by hour at White Grass Ranch, Grand Teton National Park (Burson, 2008; Figure 30).

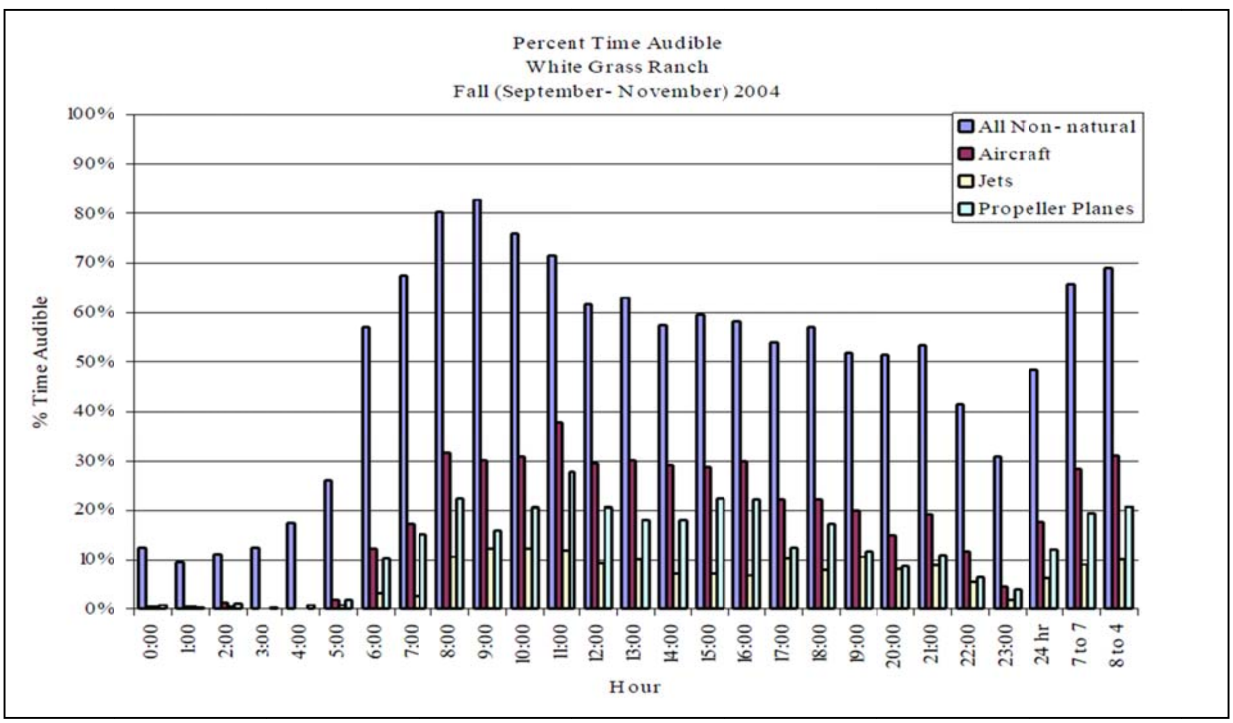

Figure 3.81. Percent time audible of non-natural sounds during fall 2004 by hour at White Grass Ranch, Grand Teton National Park (Burson, 2008; Figure E-7).

Table 3.36. Number and percent of loudest soumd events recorded at four sound monitoring stations in Grand Teton National Park.

Sound Events	Grassy Lake Road	Teton Road Lagoon		Bar Bc Ranch	White Grass Ranch	
	WINTER	WINTER	AUGUST	AUGUST	WINTER	AUGUST
NON-NATURAL						
Aircraft						
Jet	3 (3%)	22 (11%)	17 (3%)	82 (54%)	61 (50%)	13 (8%)
Propeller	1 (1%)	5 (2%)	11 (2%)	40 (26%)	3 (2%)	3 (2%)
Helicopter	4 (3%)		5 (1%)			3 (2%)
Unidentified Aircraft				4 (3%)		
Total	8 (7%)	27 (13%)	33 (5%)	122 (80%)	64 (52%)	19 (12%)
Road Vehicles						
Groomer	3 (3%)	53 (25%)				
Snowmobile	9 (8%)					
Road Vehicle			163 (25%)			
Truck			8 (1%)			
Motorcycle			186 (28%)			
Total	12 (10%)	53 (25%)	357 (55%)			
People						
Voices			1 (0.2%)		7 (6%)	4 (2%)
NATURAL						
Physical						
Wind	96 (82%)	114 (55%)	244 (37%)	27 (18%)	51 (41%)	45 (28%)
Thunder			19 (3%)	2 (1%)		
Biological						
Red Squirrel		3 (1%)				
Coyote		1 (0.5%)		1 (1%)	1 (1%)	4 (2%)
Elk						90 (56%)
Raven	1 (1%)	7 (3%)				
Unidentified		3 (1%)				
TOTAL EVENTS	**117**	**208**	**654**	**152**	**123**	**162**

Sound Levels

Sound level thresholds are used to identify the percent of time that a particular sound exceeds a threshold. The available oversnow vehicle limits for sound levels (dBA) and duration (percent of time audible) by management zone identified in the 2007 Winter Use Plan, the current plan, are presented in Table 3.37. Winter Use Plan thresholds apply only to sounds from 8:00 a.m. to 4:00 p.m.

The plotting of daily sound levels (dBA) for specific time periods and locations are useful for identifying exceedances of the prescribed thresholds. Figure 3.82 shows daily sound levels recorded at Teton Park Road Lagoon for one year from January 2004 to February 2005. Results of four acoustic summary metrics are presented including: maximum sound level (L_{max}), energy equivalent (L_{eq}), and the sound level exceedance metrics for 50 percent (L_{50}) and 90 percent (L_{90}) of the recording period. Each metric follows the same pattern where sound levels begin to rise in spring and drop off at the end of October, corresponding to the increase in both non-natural (e.g. wheeled vehicles) and natural (e.g. birds) sounds during that time of year. Although the L_{max} was consistently around 70 dBA, neither the percent time audible nor sound level of oversnow vehicles exceeded the soundscape thresholds identified for travel corridors in the 2007 Winter Use Plan (Table 3.37) at this sound monitoring sites.

Figure 3.83 provides a comparison of hourly sound levels (dBA) recorded in winter and summer at Teton Road Lagoon, a travel corridor, and White Grass Ranch, a backcountry site. Sound levels recorded in winter remained relatively low at both sites in terms of the 50 percent and 90 percent sound level exceedance (Figures 3.83a and 3.83c). The energy average (L_{eq}) did fluctuate, but in both cases may be the result of the loud sound events from wind, snow groomers, and/or jets (Table 3.36).

At Teton Road Lagoon in summer, sound levels were greater than 25 dBA 90 percent of the time (L_{90}), and the energy average (L_{eq}) was greater than 50 dBA between the hours of 9:00 a.m. and 6:00 p.m. (Figure 3.83b). White Grass Ranch was generally quieter in summer than at Teton Road Lagoon. The L_{eq} for White Grass Ranch stayed under 40 dBA throughout the day (Figure 3.83d). These differences were the result of closer and more frequent motorized vehicles on the road near Teton Road Lagoon.

Table 3.37. Management zones and soundscape thresholds in 2007 Winter Use Plan. Measured period is during daytime hours of park operations 8:00 a.m. to 4:00 p.m.

Management Zone	Percent Time Audible[1]	Sound Level Threshold
Developed Area[2]	NTE[3] 75%	NTE 70 dBA
Travel Corridor[2]	NTE 50%	NTE 70 dBA
Transition Zone	NTE 25%	NTE 65 dBA
Backcountry	NTE 10%	NTE natural ambient sound level[4]

Source: Burson, 2008; Table 4

[1]Audibility = The ability of a person with normal hearing to hear a given sound.

[2]Acoustic data measured at 100 feet from main travel areas

[3]NTE = Not to exceed

[4]The natural sound conditions found in a given area, including only sounds of nature.

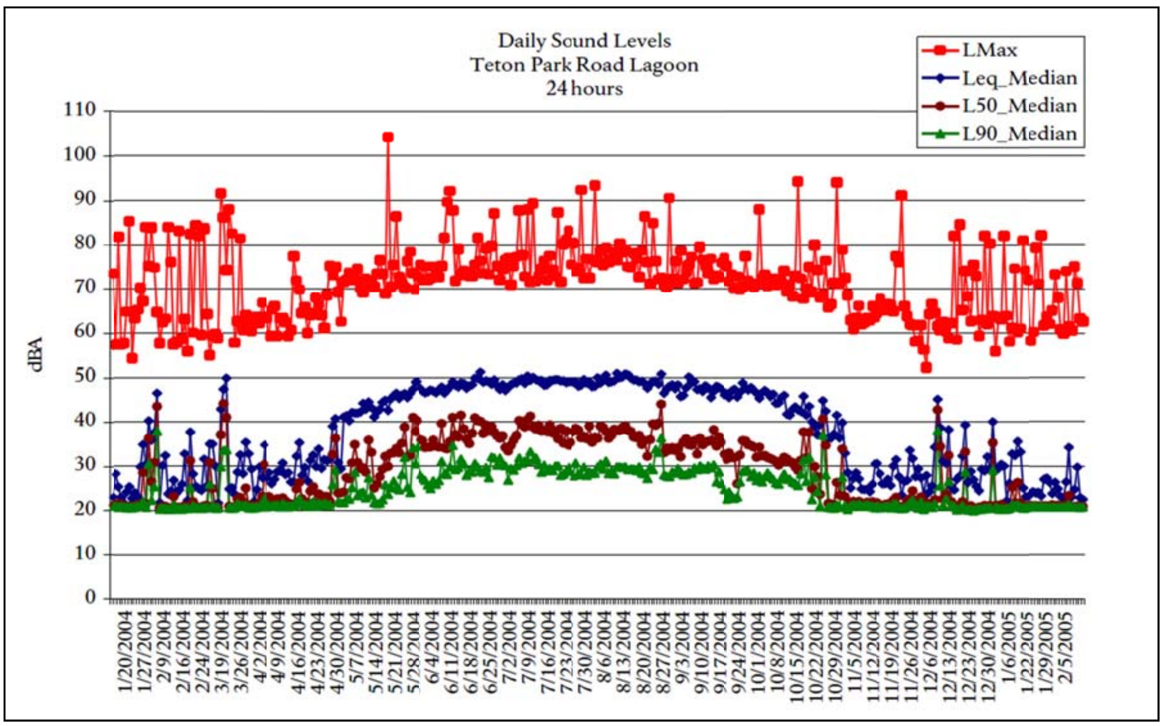

Figure 3.82. Daily sound levels between January 2004 and February 2005 at Teton Road Lagoon, Grand Teton National Park (n= 355 days; 8,153 hours) (Burson, 2008; Figure F-15).

Figure 3.83. Hourly sound levels at Teton Road Lagoon, Grand Teton National Park, in winter (a) and summer (b), and at White Grass Ranch, GRTE, in winter (c) and summer (d). (Burson, 2008; Figures F-16, F-22, F-13, and F-7).

Daily One-Second 1/3 Octave Band Frequency Spectrograms

The NPS Natural Sound Program in Fort Collins, Colorado, developed a technique for plotting each of the 33 one-third octave band frequency decibel levels for each second of the day (Figure 3.84). The major sources of sound at each monitoring site can be seen in these spectrograms. Each figure is one day, 24 hours, from midnight to midnight. Each row contains two hours starting with the first hour of the day, labeled with white two-digit numbers. The site and date is referenced in the title at the top of the graphic. The frequency is plotted on a logarithmic scale as indicated in the left margin. The right margin contains the decibel range and associated colors. Brighter colors indicate higher sound levels; deep blue is the quietest. Many of the common sound sources are identified by their characteristic shape and pattern on these spectrograms. On some figures, wind speed is indicated by a pink line. A wind line at the topmost portion of each row would indicate a maximum wind speed value of 11 miles per hour (five meters per second). Figure 3.84 through Figure 3.87 are spectrograms from representative sound stations at GRTE.

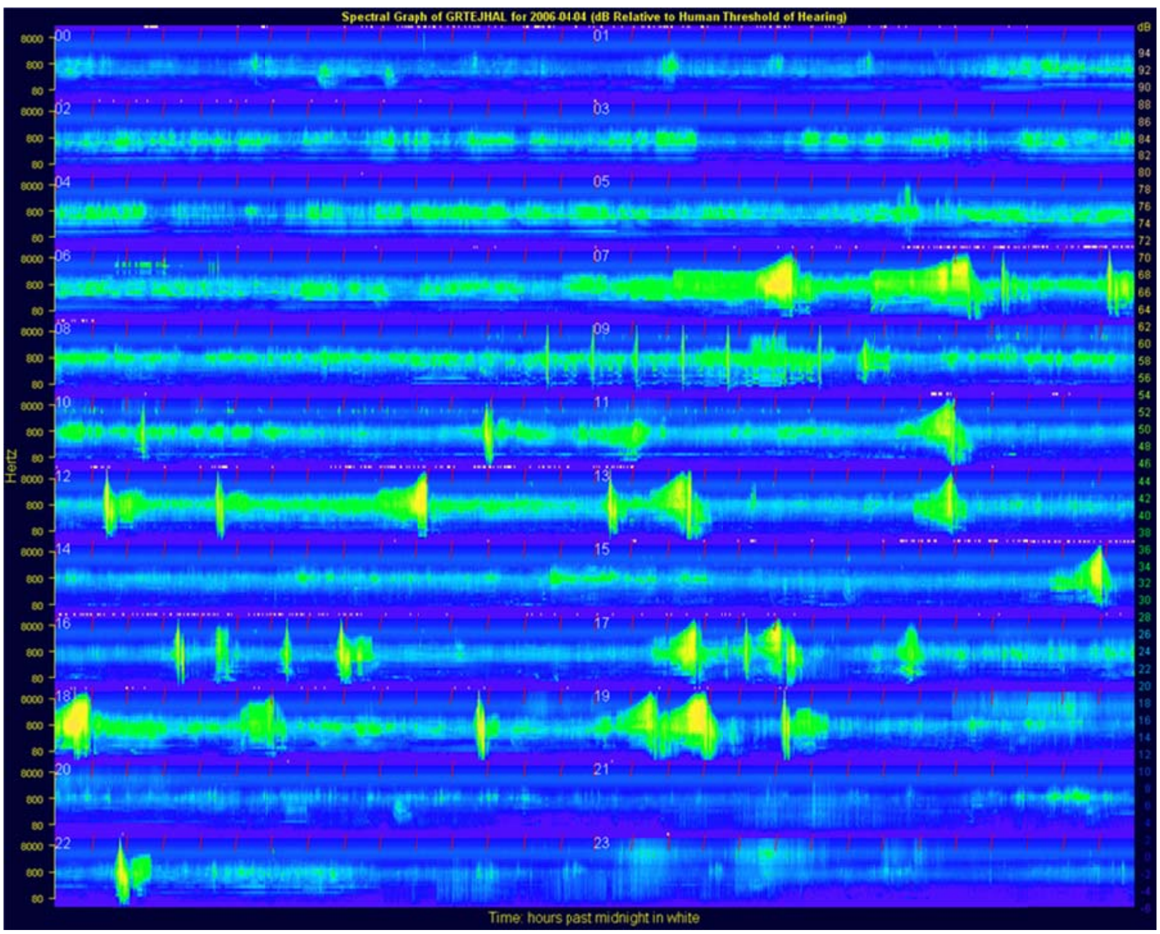

Figure 3.84. Sound level visualization of Jackson Hole Airport Lek in spring (April 4, 2006). The bright yellow blotches are aircraft taxiing, landing, and taking off (Burson, 2008; Figure G-1).

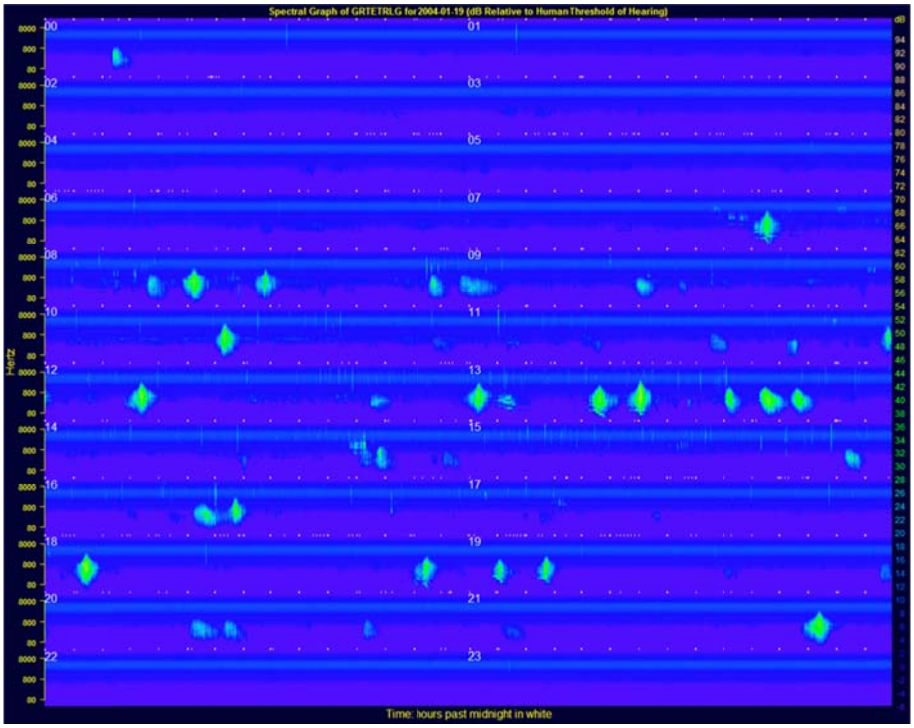

Figure 3.85. Sound level spectrogram of Teton Park Road Lagoon in winter (January 19, 2004). The adjacent road was groomed for skiing during the winter (Burson, 2008; Figure G-7).

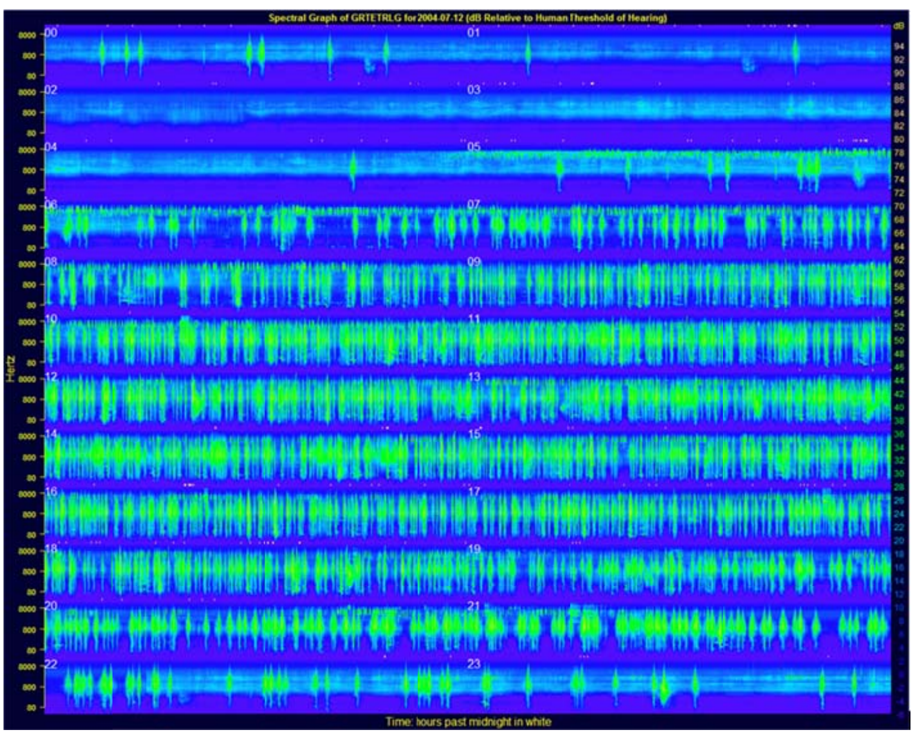

Figure 3.86. Sound level spectrogram of Teton Park Road Lagoon in summer (July 12, 2004), when the increase in wheeled vehicle traffic is evident nearly every hour of the day (Burson, 2008; Figure G-10).

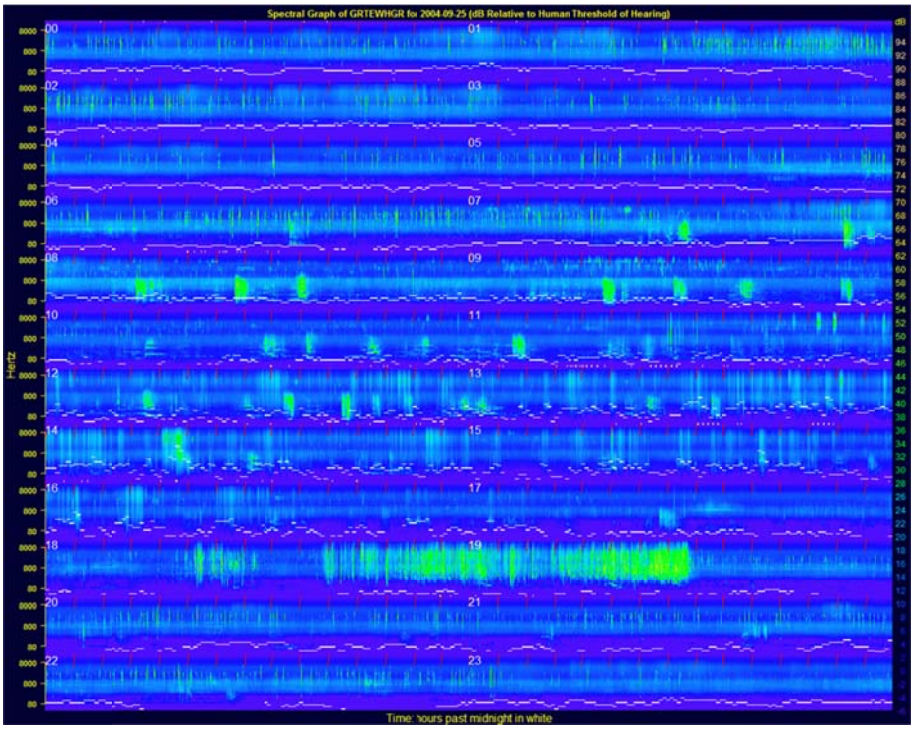

Figure 3.87. Sound level spectrogram of White Grass Ranch in fall (September 25, 2004). The numerous vertical sounds during the night are elk bugling (Burson, 2008; Figure G-11).

<u>Summary and Conclusions</u>

Grand Teton National Park is one of several national parks that have initiated acoustical studies in recent years. Some of the quietest sound levels ever recorded (near zero dBA) were recorded during winter months by sound stations located in the backcountry in GRTE and YELL. However, ambient sound levels vary considerably throughout the park, depending on location and time of year and time of day. The jets at Jackson Hole Airport bring the sound levels above 100 dBA under their flight path near the airport (Burson, 2008). The acoustical data collected at GRTE between 2002 and 2008 provide a standardized and scientifically credible approach to measuring and describing soundscapes. These data are being used to develop a comprehensive soundscape management program that will help protect and restore the natural soundscape of GRTE.

Water Quality

The term water quality is used to describe the condition of water, including its chemical, physical, and biological characteristics and its general composition (Diersing, 2009). Water quality is an important indicator of overall ecosystem health, and maintenance of unimpaired waters is vital for wildlife, habitat, human consumption and recreation, and agriculture (NPS, 2009h). Preserving water resources in national parks for future generations is a fundamental purpose of the National Park Service (NPS, 2010h).

Water quality varies from place to place, with the seasons, with climate, and with geology. Water may dissolve minerals in rocks and soil, percolate through organic material such as roots and leaves, and react with algae, bacteria, and other microscopic organisms. Flowing water may carry plant debris and stir up sand, silt, and clay, which may therefore contribute to higher turbidity. Although natural processes are a driving force in determining water quality, anthropogenic activities have had a significant detrimental impact. Pollutants from urban and industrial development, agriculture, mining, and combustion of fossil fuels have contributed to impaired water quality. Excess nutrients, such as nitrogen and phosphorus, have encouraged algal growth, caused low oxygen levels, and posed risks to fish populations. Chemicals, such as pharmaceutical drugs, dry cleaning solvents, gasoline, pesticides, and herbicides are widespread in streams and ground water and pose risks to human health, aquatic life, and fish-consuming wildlife (Cordy, 2001).

Water quality in GRTE is threatened by oil and gas development, nitrogen deposition, changes in hydrologic regimes, and invasive species introduction. High elevation watersheds are thought to be highly impacted by atmospheric deposition, primarily due to their underlying thin soils and resistant bedrock that limit acid neutralizing capacity. Other forms of pollution, including trace elements, mercury, and pesticides, may also threaten water quality and aquatic resources in GRTE. Changes in hydrologic regimes can result from climate change, diversions, and damming, which may therefore lead to flow alteration, changes in water temperature, and shifts in community composition.

Water quality is typically determined by quantifying several parameters, such as temperature, acidity (pH), dissolved mineral content, dissolved oxygen, and electrical conductance (Cordy, 2001). Levels of fecal coliform bacteria from human and animal wastes, concentrations of nitrogen and phosphorus, amount of particulate matter suspended in the water (turbidity), and the amount of salt (salinity) are also determined (Diersing, 2009). These characteristics are then compared to numeric standards and guidelines that are defined by federal and state agencies to determine the condition of the water and to decide if it is suitable for a particular use (Cordy, 2001; EPA, 2010f).

Methods

To evaluate the condition of water quality in GRTE, a review of literature, scientific studies, and a water quality monitoring reports was conducted. The U.S. Geological Survey, in conjunction with the National Park Service, has conducted water quality studies on the Snake River and its tributaries within and around GRTE. Two of these studies, *Water-Quality Characteristics of the Snake River and Five Tributaries in the Upper Snake River Basin, Grand Teton National Park, Wyoming, 1998-2002* (Clark et al., 2004) and *Water-Quality Characteristics of Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park,* *Wyoming, 2006* (Clark et al., 2007), provided an extensive amount of information to assess the quality of water resources in GRTE.

Studies conducted by Dustin and Miller (2001), Tippets et al. (2001), and Corbin and Woods (2004) provided additional information. Dustin and Miller (2001) evaluated the tropic state of selected lakes in GRTE; Tippets et al. (2001) evaluated backcountry water quality in GRTE; and Corbin and Woods (2004) evaluated the effects of atmospheric deposition on the water quality of 12 high alpine lakes in GRTE. Supplemental information was also provided by the report *Greater Yellowstone Network Water Quality Monitoring Annual Report: January 2007-December 2008.*

Results

Trophic States of Selected Lakes

In 1995, a study was initiated by Dustin and Miller (2001) to perform a benchmark trophic state survey for selected lakes in GRTE and to identify possible areas of concern. Six alpine lakes, six moraine lakes, three valley lakes, and two Colter Bay lakes were evaluated, totaling 17 of the most visited lakes (excluding Jackson Lake) in GRTE (Table 3.38). Alpine lakes included Amphitheatre Lake, Lake of the Crags, Delta Lake, Holly Lake, Lake Solitude, and Surprise Lake. Moraine lakes included Bradley Lake, Jenny Lake, Leigh Lake, Phelps Lake, String Lake, and Taggart Lake. The Colter Bay lakes evaluated for the study included Swan Lake and Cygnet Pond. Valley lakes included Christian Pond, Emma Matilda Lake, and Two Ocean Lake. All lakes were sampled for total phosphorus, chlorophyll-a, and transparency at various times from 1995 to 1997 during the summer season (Dustin and Miller, 2001).

Two models were used to determine the trophic state of each lake. The first model, the Vollenweider Model, was based on phosphorus utilization, while the second model, the Carlson Model, took into account transparency, in-lake phosphorus, and chlorophyll-a concentrations. Lakes were classified as either, oligotrophic, mesotrophic, or eutrophic (Dustin and Miller, 2001). Oligotrophic waters are those that are low in nutrients; they are unproductive, rich in oxygen, and low in turbidity. Eutrophic waters are those that are high in nutrients (e.g. nitrogen and phosphorus); they are productive and often exhibit low levels of dissolved oxygen. Mesotrophic lakes are those that are in between oligotrophic and eutrophic states (EPA, 2010g).

In 1995, the alpine lakes were found to be in very good condition (Table 3.39), and therefore, subsequent sampling was discontinued during the following years. The moraine lakes were found to be in very good condition with water quality comparable to that of alpine lakes (Table 3.39). However, the moraine lakes are more accessible than the alpine lakes and could be more impacted by visitors as potentially indicated by the trophic states. Jenny Lake was found to be slightly oligotrophic despite the heavy use it receives. The Colter Bay lakes were generally classified as strongly mesotrophic (Table 3.39). These two lakes were sampled to determine if sewage lagoons were leaking into Swan Lake. Additionally, Cygnet Pond and Swan Lake are located in an area that receives heavy use from wildlife, particularly waterfowl, and day hikers. Cygnet Pond was found to be consistently mesotrophic to slightly eutrophic, and it generally followed a pattern of increasing eutrophication as the summer progressed. The trophic states of the valley lakes varied considerably. Christian Pond was classified as mesotrophic and Emma Matilda Lake was classified as slightly oligotrophic. The trophic state of Two Oceans Lake was deemed inconclusive because model results were highly variable between samples and years (Table 3.39) (Dustin and Miller, 2001).

Overall, the water quality, as measured by trophic state, is very good in GRTE. None of the lakes revealed signs of accelerated eutrophication, although the results for Two Ocean Lakes were inconclusive. Trophic states in alpine and moraine lakes on the west side of GRTE ranged from oligotrophic to slightly mesotrophic. On the east side, where the watershed is more productive, trophic states ranged from slightly mesotrophic to eutrophic (Dustin and Miller, 2001).

Table 3.38. Characteristics of sampled lakes in Grand Teton National Park (Dustin and Miller, 2001).

Lake	Location	Elevation, in meters (feet)	Capacity, in 1000 m^3 (acre-feet)	Surface Area, in 1000 m^2 (acres)	Average Depth, in meters (feet)
Amphitheater Lake	Alpine	2,990 (9,800)	185 (150)	24 (6)	7.6 (25)
Lake of the Crags	Alpine	2,950 (9,700)	370 (300)	40 (10)	9 (30)
Delta Lake	Alpine	2,740 (9,000)	148 (120)	32 (8)	4.6 (15)
Holly Lake	Alpine	2,860 (9,400)	247 (200)	32 (8)	7.6 (25)
Lake Solitude	Alpine	2,750 (9,035)	1,110 (900)	120 (30)	9 (30)
Surprise Lake	Alpine	2,910 (9,540)	74 (60)	12 (3)	6 (20)
Bradley Lake	Moraine	2,140 (7,022)	6,900 (5,600)	280 (70)	24 (80)
Jenny Lake	Moraine	2,067 (6,783)	338,000 (274,000)	4,820 (1,190)	70 (230)
Leigh Lake	Moraine	2,096 (6,877)	329,000 (267,000)	4,330 (1,070)	76 (250)
Phelps Lake	Moraine	2,020 (6,633)	108,500 (88,000)	1,780 (440)	61 (200)
String Lake	Moraine	2,080 (6,830)	560 (450)	300 (75)	1.8 (6)
Taggart Lake	Moraine	2,104 (6,902)	10,800 (8,800)	445 (110)	24 (80)
Cygnet Pond	Colter Bay	2,090 (6,850)	100 (80)	80 (20)	1.2 (4)
Swan Lake	Colter Bay	2,070 (6,800)	220 (180)	150 (37)	1.5 (5)
Christian Pond	Valley	2,100 (6,890)	250 (200)	130 (32)	1.8 (6)
Emma Matilda Lake	Valley	2,095 (6,873)	16,650 (6,873)	3,640 (900)	4.6 (15)
Two Ocean Lake	Valley	2,100 (6,896)	11,220 (9,100)	2,630 (650)	4.3 (14)

Table 3.39. Trophic states of sampled lakes in Grand Teton National Park (Dustin and Miller, 2001).

Lake	Year	Carlson Model Trophic State	Vollenweider Model Trophic State	Average Trophic State
Amphitheater Lake	1995	Slightly Oligotrophic	Slightly Oligotrophic	Slightly Oligotrophic
Lake of the Crags	1995	Oligotrophic	Mesotrophic	Slightly Oligotrophic
Delta Lake	1995	Slightly Mesotrophic	Mesotrophic	Slightly Mesotrophic
Holly Lake	1995	Slightly Oligotrophic	Mesotrophic	Slightly Mesotrophic
Lake Solitude	1995	Strongly Oligotrophic	Slightly Oligotrophic	Slightly Oligotrophic
Surprise Lake	1995	Slightly Mesotrophic	Slightly Mesotrophic	Slightly Mesotrophic
Bradley Lake	1995	Mesotrophic	Slightly Mesotrophic	Slightly Mesotrophic
Jenny Lake	1995	Slightly Oligotrophic	Oligotrophic	Slightly Oligotrophic
Leigh Lake	1995	Oligotrophic	Strongly Oligotrophic	Oligotrophic
Phelps Lake	1995	Oligotrophic	Eutrophic	Inconclusive
	1996	Oligotrophic	Oligotrophic	Oligotrophic
String Lake	1995	Slightly Oligotrophic	Oligotrophic	Slightly Oligotrophic
Taggart Lake	1995	Slightly Oligotrophic	Mesotrophic	Slightly Mesotrophic
Cygnet Pond	1995	Mesotrophic	Mesotrophic	Mesotrophic
	1996	Strongly Mesotrophic	Strongly Mesotrophic	Strongly Mesotrophic
Swan Lake	1995	Mesotrophic	Slightly Mesotrophic	Mesotrophic
	1996	Strongly Mesotrophic	Strongly Mesotrophic	Strongly Mesotrophic
	1997	Strongly Mesotrophic	Strongly Eutrophic	Eutrophic
Christian Pond	1995	Slightly Mesotrophic	Mesotrophic	Mesotrophic
Emma Matilda Lake	1995	Slightly Mesotrophic	Oligotrophic	Slightly Oligotrophic
Two Ocean Lake	1995	Strongly Mesotrophic	Inconclusive	Inconclusive
	1996	Mesotrophic	Inconclusive	Inconclusive
	1997	Slightly Eutrophic	Eutrophic	Eutrophic

Backcountry Water Quality

In 1996, a study on the effects of human use on backcountry water quality was initiated as a cooperative effort between the U.S. Geological Survey and GRTE. The purpose of the study was: (1) to acquire baseline data on the current conditions of backcountry waters of GRTE and to use this baseline data as a means of measuring future changes, and (2) to evaluate the effects of concentrated recreational use on the water quality of backcountry waters in GRTE.

Backcountry sites were sampled during the summers from 1996 to 2005. Evidence of fecal coliform (i.e. *Escherichia coli*) was found at all sample sites. Through DNA analysis, or source tracking, it was possible to identify whether the contamination was of wildlife or human in origin. Source tracking of DNA in fecal coliform involves the comparison of analyzed fecal coliform DNA patterns with those in a known library to determine the origin of the coliform.

During the summers of 1996 and 1997, water samples were collected in Avalanche, Garnet, and Cascade Canyons and evaluated for fecal coliforms. Fecal coliforms were found in two of the three canyons investigated. In 1998, human fecal coliforms were found in Paintbrush, Cascade, Bradley, and Avalanche Canyons. In 1999, as the study expanded, human fecal coliforms were found in Avalanche, Leigh, Upper and Lower Death, Lower Granite, and Hanging Canyons, at Guide's Wall and Hidden Falls, in Glacier Gulch, at Taggart Lake, and again in Cascade Canyon. In 2000, human fecal coliforms were detected in Cascade Canyon, and an increase in coliforms was identified in Granite, Death, and Open Canyons (Tippets et al., 2001). During the sampling period (1995 to 2005), human fecal coliforms were found at a majority of sample sites. With increased visitation to the park, the percentage of human coliforms is expected to increase.

Water Quality of the Snake River and Five Eastern Tributaries in the Upper Snake River Basin

During the water years of 1998 to 2002, the U.S. Geological Survey, in conjunction with the National Park Service, conducted water quality sampling at an upstream and downstream site on the Snake River to characterize water quality conditions through GRTE. In 2002, a synoptic study was conducted to establish baseline water quality conditions of five of its eastern tributaries. Samples from the Snake River and the five tributaries were collected at 12 sites (Table 3.40) and analyzed for field measurements, major ions, dissolved solids, nutrients, selected trace metals, pesticides, and suspended sediments. The five eastern tributaries were also sampled for fecal-indicator bacteria (Clark et al., 2004).

Water quality samples were routinely collected from the Snake River above Jackson Lake at Flagg Ranch, Wyoming, and from the Snake River at Moose, Wyoming, during water years 1998 to 2002.

Monitoring data from the routine monitoring at sites on the Snake River in GRTE indicated that stream water quality was generally of good quality during water years 1998 to 2002. Differences in water quality were primarily attributed to natural differences in geology and variations in precipitation. Streamflow ranged from above normal to below normal, and water types ranged from sodium bicarbonate at the upstream site at Flagg Ranch to calcium carbonate at the downstream site near Moose (Clark et al., 2004).

Dissolved solid concentrations for samples collected from the Snake River above Jackson Lake at Flagg Ranch ranged from 62 to 240 milligrams per liter (mg/L). Dissolved solid concentrations for samples collected from the Snake River at Moose were significantly lower and ranged from 77 to 141 mg/L. Dissolved solid concentrations at Flagg Ranch were possibly higher due to inputs of geothermal waters from YELL. Suspended sediment concentrations for samples collected from the Snake River at Flagg Ranch and Moose ranged from 1.0 mg/L to 604 mg/L and 1.0 mg/L to 648 mg/L, respectively (Clark et al., 2004).

Table 3.40. Sampling sites in the upper Snake River Basin, Grand Teton National Park (Clark et al., 2004).

Site Number	Site Name	USGS Survey Station Number	Sampling Period
1	Snake River above Jackson Lake at Flagg Ranch	13010065	1998 to 2002
2	Pilgrim Creek below NPS boundary near Moran	435529110335101	2002
3	Pilgrim Creek near Moran	13010450	2002
4	Pacific Creek above NPS boundary near Moran	435459110275401	2002
5	Pacific Creek at Moran	13011500	2002
6	Buffalo Fork above Lava Creek near Moran	13011900	2002
7	Buffalo Fork near Moran	13012000	2002
8	Spread Creek at diversion dam near Moran	13012490	2002
9	Spread Creek near Moran	13012500	2002
10	Ditch Creek below South Fork near Kelly	13013530	2002
11	Ditch Creek near Moose	13013600	2002
12	Snake River at Moose	13013650	1998 to 2002

Concentrations of nitrogen and phosphorus were generally low in samples from the Snake River at Flagg Ranch and Moose. All samples of dissolved ammonia and nitrate were less than the water quality criteria for surface waters in Wyoming. The median dissolved nitrate concentrations at both sites were less than the reporting level of 0.05 mg/L, which is less than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States. Median concentrations of total nitrogen of 0.11 mg/L were less than the median total nitrogen concentration of 0.26 mg/L determined for undeveloped streams in the United States. In over 75 percent of the samples, dissolved orthophosphate concentrations were less than the reporting level of 0.02 mg/L, and total phosphorus concentrations were less than the reporting level of 0.06 mg/L (Clark et al., 2004).

Dissolved iron and manganese were the only trace metals analyzed in samples collected from the Snake River. The maximum dissolved iron concentration from Flagg Ranch was 38 micrograms per liter (µg/L), and the maximum iron concentration at Moose was 27 µg/L. The concentrations are considerably less than the Secondary Maximum Contaminant Level (SMCL) of 300 µg/L established by the Environmental Protection Agency (EPA). The maximum dissolved manganese concentration at Flagg Ranch was 9.3 µg/L, and the maximum manganese concentration at Moose was 7.0 µg/L. These concentrations are less than the SMCL of 50 µg/L established by the EPA (Clark et al., 2004).

Pesticide samples were also collected from the Snake River at Flagg Ranch and Moose. Concentrations of all pesticide compounds were less than the reporting levels, but in five samples from the Snake River, detectable concentrations of atrazine, EPTC, dieldrin, and tebuthiuron were found. The estimated concentration of dieldrin (0.003 µg/L), an organochlorine insecticide, was higher than the State of Wyoming drinking water standard for human health (0.00014 µg/L). Nonetheless, the rate of pesticide detection in samples from the Snake River was low compared to pesticide detections in samples from nationwide streams (Clark et al., 2004).

Water quality sampling sites for the synoptic study were located on Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek. Samples were collected at two sites (i.e. upstream and downstream locations) on each tributary during four sampling events in June, July, September, and November 2002. Samples were collected to include high-flow conditions (June), the period during and following high visitor use (July and September), and low-flow conditions (November) (Clark et al., 2004).

Data from the synoptic study indicated that the stream water of five eastern tributaries to the Snake River were generally of good quality in 2002. The water type of Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek was calcium bicarbonate. Concentrations of dissolved solids range from 75 mg/L in a sample from Pilgrim Creek to 235 mg/L in a sample from Ditch Creek. Differences in concentrations of dissolved solids between sites have been attributed to geology of the basins (Clark et al., 2004).

Concentrations of dissolved ammonia, nitrite, and nitrate in samples from the five eastern tributaries were less than the water quality criteria for surface waters in Wyoming. Concentrations of nitrate were less than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States. Total nitrogen and phosphorus concentrations in some samples exceeded the ambient criteria of 0.34 mg/L and 0.015 mg/L, respectively, that are recommended for forested mountain streams in the Middle Rockies ecoregion by the EPA. Sources of nitrogen and phosphorus are most likely natural because little development and cultivation is present in the five tributary basins (Clark et al., 2004).

Concentrations of trace metals and pesticides were low. The maximum dissolved iron concentration for all tributaries was 45 µg/L. This value is considerably less than the SMCL of 300 µg/L. The maximum dissolved manganese concentration for all tributaries was 12.8 µg/L. This value is less than the SMCL of 50 µg/L. Concentrations of dissolved arsenic, cadmium, chromium, copper, nickel, selenium, and zinc were less than the aquatic criteria established for surface waters in Wyoming. Of the 47 pesticides that were analyzed in 10 samples, only metolachlor was detected in one sample from Buffalo Fork at a concentration of 0.008 µg/L (Clark et al., 2004).

Suspended sediment concentrations ranged from 1.0 mg/L for samples collected at Pilgrim Creek, Pacific Creek, Spread Creek, and Ditch Creek to 286 mg/L for a sample collected from Buffalo Fork. Suspended sediment concentrations were generally highest in samples collected during late spring and lowest in samples collected during the fall (Clark et al., 2004).

Concentrations of fecal coliform ranged from one colony per 100 milliliters in a sample collected from Spread Creek to greater than 200 colonies per 100 milliliters in a sample collected from Ditch Creek. DNA source tracking revealed that avian coliform bacteria were dominant in Pilgrim Creek (32 percent of isolates), Buffalo Fork (31 percent of isolates), and Ditch Creek (35 percent of isolates); bovine coliform bacteria were dominant in Pacific Creek (24 percent of isolates); and deer and elk coliform bacteria were dominant in Spread Creek (25 percent of isolates). Human coliform bacteria accounted for six percent or less (Clark et al., 2004).

Water Quality of the Snake River and Four Western Tributaries in the Upper Snake River Basin

In 2006, the U.S. Geological Survey, in conjunction with the National Park Service, conducted a second synoptic study of water-quality in the Upper Snake River Basin. Samplings sites were located on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek. Two samplings sites were selected on each of the streams (Table 3.41). An upstream site was established to describe water quality in the upper part of the drainage basin, generally upstream from roads and recreational use. A second site was established downstream near roads and other areas that have high visitor use. Sampling events in June, July, August, and October were selected to characterize different hydrologic conditions and different recreational use periods. Samples were collected and analyzed for field measurements, major ions, dissolved solids, nutrients, selected trace metals, pesticides, and suspended sediments (Clark et al., 2007).

Water types of Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek were calcium bicarbonate. Dissolved solid concentrations were dilute in Cottonwood Creek and Taggart Creek, ranging from 11 to 31 mg/L. Dissolved solid concentrations ranged from 55 to 130 mg/L for samples collected from Lake Creek and Granite Creek. Alkalinity concentrations were small in Cottonwood Creek and Taggart Creek, ranging from 8 to 22 mg/L; thus indicating a potential sensitivity to acidification (Clark et al., 2007).

Nutrient concentrations were generally small in samples collected from Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek. Dissolved nitrate concentrations were the largest in Taggart Creek. Total nitrogen concentrations in samples collected at both sites on Taggart Creek were sometimes near, but were still less than the median concentration of 0.26 mg/L determined for undeveloped streams in the United States and less than the ambient total nitrogen criteria of 0.34 mg/L for forested mountain streams in the Middle Rockies ecoregions recommended by the EPA to address cultural eutrophication. Taggart Creek drainage is largely composed of talus and related material, and therefore, subsurface water may contribute to dissolved nitrate concentrations in Taggart Creek. Because of the small buffering capacity of Taggart Creek, the drainage basin may be the most sensitive to future increases in atmospheric deposition of nitrogen and subsequent eutrophication and acidification (Clark et al., 2007).

Dissolved iron and manganese concentrations were small in Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek. For all samples collected from the four western streams, the maximum dissolved iron concentration was 19 µg/L and the maximum dissolved manganese concentration was 2.8 µg/L. Both maximum iron and manganese samples were collected at the TC2 site on Taggart Creek (Clark et al., 2007).

Pesticide concentrations were less than laboratory reporting levels for all samples. Metolachlor was detected in a sample from Cottonwood Creek with an estimated concentration of 0.0002 µg/L. Trace element concentrations were small than aquatic life criteria for all samples. Suspended sediment concentrations were generally small for all samples, but the largest suspended sediment concentrations occurred during snowmelt runoff (Clark et al., 2007).

Water quality characteristics of streams in the western portion of the Snake River headwaters were compared to the water quality characteristics of streams sampled during 2002 in the eastern part of the Snake River headwaters. The median dissolved solids concentration (55 mg/L) for samples collected from western streams was smaller than the median dissolved solids concentrations (125 mg/L) from eastern streams. The median total nitrogen concentration (0.17 mg/L) in samples collected from streams in the western part of the Snake River headwaters area was larger the median concentration (0.10 mg/L) for samples collected from streams in the eastern part of the headwaters area. In contrast, total phosphorus concentrations generally were larger for samples collected from eastern streams. Total phosphorus concentrations in the eastern streams were associated with large suspended-sediment concentrations. Overall, concentrations of water-quality constituents for both the eastern and western tributaries of the Upper Snake River Basin were small compared to other Wyoming streams (Clark et al., 2007).

Table 3.41. Sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek in Grand Teton National Park, Wyoming (Clark et al., 2007).

Site Number	Site Name	USGS Survey Station Number
CC1	Cottonwood Creek at outlet of Jenny Lake near Moose	13012800
CC2	Cottonwood Creek near Moose	13013000
TC1	Taggart Creek near inlet to Taggart Lake near Moose	434222110454601
TC2	Taggart Creek near Moose	130112900
LC1	Lake Creek near inlet to Phelps Lake near Moose	433908110482201
LC2	Lake Creek at Moose-Wilson Road near Moose	433738110465301
GC1	Granite Creek near mouth of Granite Canyon near Moose	433655110494101
GC2	Granite Creek above Granite Creek supplemental near Moose	130116305

Effects of Atmospheric Deposition of Water Quality

In 2002, a study was initiated by Corbin and Woods (2004) to evaluate the effects of atmospheric deposition on water quality. Twelve high alpine lakes in GRTE (Alaska Basin, Amphitheater, Bradley, Delta, Granite Basin, Holly, Mica, Snowdrift, Solitude, Sunset, Surprise, and Trapper) were sampled. Sampling parameters included acid neutralizing capacity, pH, conductivity, anions and cations, dissolved organic carbon, nitrogen, and phosphorus (Table 3.42).

Corbin and Woods (2004) concluded that many of the high elevation lakes in GRTE are sensitive to acidification, with half of the lakes having lower acid neutralizing capacity concentrations (<100 micro-equivalents per liter (μeq/L)). Surprise Lake, Amphitheater Lake, Delta Lake, and Lake Solitude had acid neutralizing capacity concentrations below 50 μeq/L. Lakes in basins with granitic and/or metamorphic bedrock, such as Lake Solitude and Mica Lake, are the most sensitive to acidification, particularly when the basin contains a high proportion of young debris. Additionally, seasonal melt from glaciers may increase sensitivity to acidification by increasing the nitrogen flux in late summer. Lakes with basins that are at least primarily underlain by limestone bedrock, such as Alaska Basin Lake, Snowdrift Lake, and Sunset Lake, are the least sensitive to acidification.

Table 3.42. Major cations, major anions, pH, ANC, and conductivity of sampled lakes in Grand Teton National Park. Values are the mean of all samples collected. Units are in μeq/L, except for conductivity, which is measured in μS/cm. Adapted from Corbin and Woods, 2004.

Water Body	pH	ANC	Cond	Ca	Mg	Na	K	NH_4	F	Cl	NO_3	SO_4
Alaska Basin Lake	7.1	110.3	14.0	68.5	47.8	17.8	6.8	2.3	0.0	2.5	0.4	13.7
Amphitheatre Lake	6.6	49.3	7.4	38.6	12.6	14.1	5.6	1.2	0.0	3.4	5.2	7.7
Bradley Lake	7.2	148.9	19.4	88.6	38.1	28.5	15.7	3.0	2.1	5.8	9.7	17.4
Delta Lake	6.6	42.5	9.2	50.9	16.4	12.1	13.0	0.0	0.0	5.2	20.1	12.3
Granite Basin Lake	6.7	87.7	8.7	55.2	18.5	15.1	3.1	0.0	3.6	1.7	0.1	12.8
Holly Lake	7.0	96.7	13.3	79.4	26.5	26.7	11.1	0.8	3.9	2.9	0.1	26.8
Lake Solitude	7.1	37.9	8.4	93.2	30.1	8.9	5.8	1.2	4.5	2.1	12.2	17.1
Mica Lake	6.9	77.9	10.8	74.2	27.6	10.5	8.1	1.7	0.0	1.8	10.0	13.7
Snowdrift Lake	7.8	676.2	75.4	514.5	206.0	15.3	16.9	0.0	2.1	3.1	13.8	54.9
Sunset Lake	8.3	1488.3	182.5	1274.3	654.7	36.6	26.1	1.6	1.7	5.0	10.5	424.8
Surprise Lake	6.6	43.0	6.8	34.5	12.0	14.5	6.0	0.9	0.0	3.8	4.4	8.2
Trapper Lake	7.3	219.6	26.7	155.1	47.7	38.8	26.1	0.0	2.7	8.2	7.9	23.6

Greater Yellowstone Network Water Quality Monitoring

In 2003, the Greater Yellowstone Inventory and Monitoring Network conducted a study of water quality in GRTE. The review was an analysis and evaluation of existing water quality data collected from water bodies in GRTE and surrounding areas. Much of these data are stored in the EPA STORET database. The objectives of the study were to: (1) catalog the existing water quality data for GRTE from the EPA STORET database; (2) supplement these data with additional data as it became available; (3) review all the data for their utility in determining the status and trends in park water quality; (4) determine the status and trends and the range of variability in water quality in GRTE; and (5) identify and prioritize water quality monitoring needs in accordance with the goals of the vital signs monitoring program. The review concluded that water quality in GRTE is very high overall (when compared to state and EPA standards), with limited impacts from human activity in the park and in upstream watersheds (Woods and Corbin, 2003).

In 2006, parks within the Greater Yellowstone Network began monitoring water chemistry at fixed monitoring sites as part of the vital signs monitoring program. In 2007, water quality monitoring was further expanded to include high alpine lakes in GRTE due to their sensitivity to atmospheric deposition (O'Ney et al., 2009).

In 2007, water samples were collected at two sites on the Gros Ventre River and Sheffield Creek; at two sites on Pilgrim Creek and Spread Creek; and at two sites on the Snake River. In 2008, samples were collected at two sites on Lake Creek, Spread Creek, Pilgrim Creek, and Cottonwood Creek; at two sites on Ditch Creek and the Snake River; and at two sites on Pacific Creek. Water samples were analyzed for dissolved anions, dissolved cations, nutrients, dissolved metals, and total metals (O'Ney et al., 2009).

Since 2007, water samples have been collected at sensitive alpine lakes in GRTE: Amphitheatre Lake, Surprise Lake, and Delta Lake. Samples have been analyzed for pH, acid neutralizing capacity, conductivity, sodium, ammonium, potassium, magnesium, calcium, fluoride, chloride, nitrate, phosphate, and sulfate (O'Ney et al., 2009).

Greater Yellowstone Network water quality monitoring of the Snake River and its tributaries confirms results of previous studies, indicating that chemical constituents tend to vary in concentration based on underlying geology. Analysis of water samples from the Snake River and its tributaries revealed that six locations did not meet state and/or federal standards: Sheffield Creek at the Forest Service boundary (dissolved copper); both sites at Spread Creek (total iron); and Amphitheatre Lake, Surprise Lake, and Delta Lake (pH) (Table 3.43). The high metal concentrations at Sheffield Creek are presumably related to the geology of the area. The source of total iron at Spread Creek is also likely to be related to geology and geomorphology of the site. Field pH at Amphitheatre Lake, Surprise Lake, and Delta Lakes was identified as being below that acceptable range (acidic) for naturally occurring waters in Wyoming; however, the acid neutralizing capacity of the three high-risk lakes is still considered within natural ranges and does not show any immediate effects of nitrogen or sulfur deposition (O'Ney et al., 2009).

Summary and Conclusions

Synoptic studies and surface water monitoring suggest that water quality is generally good in and adjacent to GRTE. The water quality, as measured by trophic state, is very good, and none of the alpine, moraine, Colter Bay, or valley lakes sampled from 1995 to 1997 revealed signs of accelerated eutrophication. Trophic lakes in alpine and moraine lakes on the west side of GRTE ranged from oligotrophic to slightly mesotrophic, whereas trophic states on the east side of GRTE ranged from slightly mesotrophic to eutrophic (Dustin and Miller, 2001).

Data from routine monitoring at sites on the Snake River in GRTE during water years 1998 to 2002 and data from the 2002 synoptic study of stream water quality in five eastern tributaries of the Upper Snake River indicated that stream water quality was generally good. Differences were primarily attributed to natural differences in geology and geomorphology. Data from the 2006 study of stream water quality in four eastern tributaries of the Upper Snake River also suggested the stream water quality was generally good. Concentrations of water-quality constituents for both the eastern and western tributaries of the Upper Snake River Basin were small compared to other Wyoming streams (Clark et al., 2004; Clark et al.; 2007). Additionally, a 2003 review of historical water quality data based on EPA STORET data concluded that water quality in GRTE is very high overall (when compared to state and EPA standards), with limited impacts from human activity in the park and in upstream watersheds.

Although water quality in GRTE is generally in good condition, there are concerns about declining water quality in backcountry areas. Fecal coliforms have been founds in Paintbrush Canyon, Cascade Canyon, Bradley Canyon, Avalanche Canyon, Leigh Canyon, Upper and Lower Death Canyons, Lower Granite Canyon, Hanging Canyon, at Guide's Wall and Hidden Falls in Glacier Gulch, and at Taggart Lake. Many of these waters in GRTE are identified as Class I areas under the Clean Water Act of 1977, and therefore, further water quality degradation is prohibited. On a few occasions, some of these waters exceeded the limit of 126 *E.*

coli per 100 milliliters of water; however, on average, they were well below that level. Nonetheless, based on those results, resource managers in GRTE have recommended that an evaporation-style toilet facility be installed at the base of Cascade Canyon. This site has sustained intense use and is visited by an estimated 90,000 people per summer (Tippets et al., 2001).

In addition to declining water quality from fecal coliforms, many of the high elevation lakes in GRTE are sensitive to acidification from atmospheric deposition. Half of the lakes sampled in 2002 had relatively low acid neutralizing concentrations. Lakes in basins with granitic and/or metamorphic bedrock, such as Lake Solitude and Mica Lake, are the most sensitive to acidification, particularly when the basin contains a high proportion of young debris (Corbin and Woods, 2004).

Table 3.43. Locations in Grand Teton National Park where constituent concentrations did not meet applicable standards, 2007-2008. Adapted from O'Ney et al., 2009.

Site	Parameter	Year	Standard	Sampled Value(s)
Sheffield Creek (Forest Service boundary)	Dissolved Copper	2007	13 µg/L	17 µg/L
Spread Creek (Forest Service above dam)	Total Iron	2008	300 µg/L	1,770 µg/L
Spread Creek (at Highway 89)	Total Iron	2008	300 µg/L	1,620 µg/L
Surprise Lake	pH	2008	6.5 – 9.0	6.33 – 6.38
Amphitheatre Lake	pH	2008	6.5 – 9.0	5.76 – 6.33
Delta Lake	pH	2008	6.5 – 9.0	6.20 – 6.68

Wildlife

Amphibians

The word amphibian comes from the Greek words *amphi*, meaning double, and *bios*, meaning life, and refers to the larval, aquatic stage and the adult, terrestrial stage of the amphibian life cycle. This two-stage life cycle places amphibians in a unique and important role in ecosystem processes, functioning as a link between rich aquatic environments and terrestrial ecosystems. Because amphibian eggs, like fish eggs, lack an external shell and require water or a damp substrate for development, all amphibian species in the Greater Yellowstone Ecosystem (GYE) rely on shallow water bodies for egg deposition and larval development (Koch and Peterson, 1995). Thus, factors affecting the location and size of wetlands (drought or climate change, land use, and beavers) are likely to substantially affect the distribution and number of amphibian breeding populations.

Amphibian species have suffered rapid population declines in disparate areas of the world, including protected areas, since probably the beginning of the twentieth century (Houlahan et al., 2000; Alford et al., 2001). The causes for these declines are poorly understood and are likely to involve multiple complex factors. The six leading hypotheses for declines in amphibian populations are: (1) land use changes causing habitat loss and degradation; (2) infectious disease; (3) global change (climate warming and increased ultraviolet radiation); (4) toxic chemicals (e.g. pesticides); (5) invasive species; and (6) over exploitation of wild amphibians for food or the pet trade (Patla and Jean, 2010). Within the boundaries of GRTE and YELL, three of these hypotheses are unlikely to be of concern: land use changes, toxic chemicals, and commercial exploitation. However, land use changes in the GYE regional context may be of concern to regional amphibian populations, because YELL and GRTE have a relatively depauperate amphibian fauna compared to forested ecosystems at lower elevations and in more temperate regions (Patla and Jean, 2010). In the GYE, these lower-elevation regions are largely privately owned, primarily in valley bottoms and floodplains containing alluvial soils that are high in nutrients and water-holding capacity (Hansen and Rotella, 2002; Gude et al., 2006). Thus, while only one third of the GYE is privately owned, private lands play an important role in the viability of its amphibian populations.

Amphibian species in the GRTE include salamanders, frogs, and toads. Three amphibian species are apparently widespread and locally common to abundant in GRTE and YELL: tiger salamander (*Ambystoma mavortium,* formerly *Ambystoma tigrinum*), boreal chorus frog (*Pseudacris maculata*), and Columbia spotted frog (*Rana luteiventris*) (amphibian nomenclature follows Crother, 2008). Boreal toads (*Anaxyrus boreas boreas*, formerly *Bufo boreas boreas*) are apparently now less widespread and less common than in the 1950s (Koch and Peterson, 1995). Northern leopard frogs (*Lithobates* pipiens, formerly *Rana pipiens*) have vanished from GRTE. One non-native species, the American bullfrog (*Lithobates catesbeianus*, formerly *Rana catesbeiana*), occurs in GRTE at Kelly Warm Springs (Patla and Jean, 2010). Basic descriptions of amphibian species present in GRTE are presented below.

<u>Tiger Salamander</u>

The tiger salamander is the largest terrestrial salamander in the world. It can reach lengths of 13 inches (33 centimeters), and adults typically grow nine inches (23 centimeters) in overall length. They are identified by their stocky build, broad head, and small eyes. A key characteristic is the tubercles on the sole of each foot. The costal grooves (a set of parallel, vertical grooves on the sides of some salamanders, newts, and their larvae) are prominent and usually number 12 to 13, but can range from 11 to 14. Coloration is highly variable, but tiger-like markings are usually present on the back and sides (Figure 3.88) (USFS, 2010a).

The tiger salamander occupies a wide range of habitats. It can be found in almost any area, from deserts to mountains, that has a suitable water body for breeding and a friable substrate for burrowing. The adults are predominantly subterranean except during the breeding season and either excavate their own burrows or use those made by rodents. The species range is from mid-Alberta to Mexico and from the central California coast to the Missouri River (USFS, 2010a).

Tiger salamanders are early breeders and may begin migrating to ponds before the ice melts. They usually migrate at night during or shortly after rains. Breeding areas are usually devoid of predatory fish, but otherwise, these salamanders are not very niche specific. Eggs can be found either attached to submerged objects or on the bottom. In the colder areas where the species is found, the larvae may over winter and can become neotenic (the attainment of sexual maturity by an organism still in its larval stage) (USFS, 2010a).

Figure 3.88. Tiger salamander. Photo sources: National Park Service.

Boreal Chorus Frog

The boreal chorus frog is quite small, 0.75 to 1.5 inches (1.9 to 3.8 centimeters) in length. It has long toes but rather small toe pads with little webbing. A dark stripe extends from the eye to the groin. There are usually three rows of stripes or spots on the dorsal surface. The snout is pointed. It is distinguished from the western chorus frog by the shorter femur and darker stripes or spots on the back (Figure 3.89) (USFS, 2010b).

Figure 3.89. Boreal chorus frog. Photo sources: United States Forest Service (USFS) Region 4 and USGS Survey Amphibian Research and Monitoring Initiative.

The boreal chorus frog, a subspecies of the western chorus frog, is found in western Wyoming, southern Idaho, and most higher elevations in Utah. This frog can be found in marshes, ponds, and small lakes up to subalpine zones. It has been found up to 12,000 feet (3,658 meters) in the Uinta Mountains of Utah. The species is one of the earliest amphibians to emerge and is usually out before snow and ice are completely gone. The boreal chorus frog breeds from late winter to summer. It rarely migrates more than 300 feet (91 meters) from breeding areas (USFS, 2010b).

The boreal chorus frog deposits its eggs in clear water bodies lacking current, such as rain pools, marshes, lakes, and reservoirs. The pigmented eggs are laid in clusters of 30 to 75 and attached to submerged vegetation. Single females can lay up to 1,500 eggs. The voice of the boreal chorus frog is a loud vibrating chirping sound that sounds like a finger running across the teeth of a comb. It is similar to the voice of the western chorus frog, but it is longer and has a slower pulse rate. Calls last one-half to one second, and are made during the night. However, at the height of breeding season, the calls can be heard during the day (USFS, 2010b).

Columbia Spotted Frog

The Columbia spotted frog was previously classified as *Rana pretiosa,* but in 1997, the U.S. Fish and Wildlife Service changed the common and scientific names of the Wasatch Front population, West Desert (Utah) population, and the Great Basin population (Idaho, Nevada, and Oregon) to the Columbia spotted frog (*Rana luteiventris*). The Columbia spotted frog can be identified by the diffuse edged black spots on the back, the light colored strip on the upper jaw, complete webbing on the hind feet, pointed snout and upturned eyes. Their skin is not completely smooth, and adults have yellow or reddish tinted ventral surfaces on the legs and lower abdomen. Adults can grow to 3.5 inches (8.9 centimeters) in length. Males are smaller than females and have swollen thumbs (Figure 3.90) (USFS, 2010c).

Figure 3.90. Columbia spotted frog. Photo sources: National Park Service and Patla and Keinath, 2005 (Matthew Chatfield).

The Columbia spotted frog resides in mountainous areas in or near cold, slow moving streams, springs or marshes, ponds and small lakes where emergent vegetation is not extensive. It is diurnal and may cross land areas in the spring and summer after breeding. It can be found in habitats ranging from sagebrush benches to subalpine forests at elevations up to about 10,000 feet (3,048 meters) (USFS, 2010c).

The Columbia spotted frog is an early breeder, beginning as soon as snow and ice melt permits, which ranges from February to July depending on location. The pigmented eggs are deposited in softball clumps of 150 to 2,000 eggs that float on the surface. Several females may use the same site for egg deposition and each female may lay up to 3,000 eggs. The call of the Columbia spotted frog is a series of four to 50 faint, low pitched clicks that increase in intensity and last up to 10 seconds. Calls are given mostly during the day and occasionally underwater. It can be imitated by clicking the tongue against the top of the mouth (USFS, 2010c).

Boreal Toad

The boreal toad is usually green or brown with a light stripe down the back. Like all toads, it has a dry, warty skin. The warts may be reddish brown and are surrounded by black marks. Unlike other toads, it has no cranial crests, although it does have oval parotoid glands (large swollen areas behind the eye that can secrete a sticky white poison used to paralyze or kill a predator). The belly is pale with dark mottling. Adults reach up to five inches (12.7 centimeters) in size (Figure 3.91) (CARCNET, 2010a).

This species can be found in boreal forest, sub-alpine, and alpine environments up to an elevation of 10,000 feet (3,048 meters). It is usually found near ponds, streams, rivers, and lakes, but it often shelters in loose, moist soil or rodent burrows. Boreal toads are usually nocturnal except at high elevations. Their diet includes worms, slugs, and insects. Unlike most toads, boreal toads walk rather than hop. When disturbed they may exhibit a defensive posture by rising on their legs and puffing up with air. This makes it harder for predators to swallow them. They take two to three years to mature and can live up to 35 years in captivity (CARCNET, 2010a).

Breeding typically occurs in small shallow ponds and pools, often with a sandy bottom, and it takes place from April to June. Long strings of up to 16,500 eggs are laid and entwined around submerged vegetation. These hatch in three to 12 days. Larvae transform in six to eight weeks. The breeding call is a subtle peeping sound, like that of little chicks (CARCNET, 2010a).

Figure 3.91. Boreal toad. Photo sources: National Park Service.

American Bullfrog

The American bullfrog is the largest frog found in North America; tadpoles also grow larger than other species. Although native to North America, the American bullfrog is non-native in GRTE and west of the Rocky Mountains (Kupferberg, 1997). Their color varies from pale green to dark greenish/brown above and is creamy white below with variable dark mottling on the back or underside. It is distinguished by its very large tympanum which is always larger than the eye, especially in males, and by the lack of dorsolateral ridges. Adult males have pale to bright yellow chins during the breeding season. Adults may reach up to seven inches (17.8 centimeters) long (Figure 3.92). Sub-adult bullfrogs can sometimes be confused with northern green frogs; however, northern green frogs have two dorsolateral ridges that run partway down the back. An adult male northern green frog also has a large tympanum and yellow breeding colors, but is much smaller than an adult male bullfrog (CARCNET, 2010a).

Male bullfrogs reach maturity about three years after transforming, while females may take five or more years to mature. In the wild, they are known to live up to nine years after transforming. Bullfrogs are known for their voracious appetite. Smaller frogs make up an important part of their diet, along with insects, small mammals, and even occasionally small birds. In the winter, bullfrogs hibernate in large deep ponds, lakes, and rivers (CARCNET, 2010a).

Figure 3.92. American bullfrog. Photo sources: USGS Amphibian Research and Monitoring Initiative and CaliforniaHerps.com.

Although bullfrogs are usually found in water along a well vegetated shoreline, they require large permanent water bodies to breed. Breeding occurs later than in most other frogs and usually occurs from mid-June to late July on warm, humid, or rainy nights. Egg masses may contain up to 20,000 eggs spread out over the surface of the water. Tadpoles grow for up to three years before transforming into frogs. The call of the bullfrog is deep and resonant, often described as a bass, growly "jug-o-rum." A full chorus can be heard from a third of a mile away (CARCNET, 2010a).

American bullfrogs have been implicated in the decline of native amphibian species because they are voracious predators. They can also exert differential effects on native frogs and change community structure. In areas where they have been introduced, they can ultimately affect amphibian communities, predation rates, and survival rates (Kupferberg, 1997).

Methods

To assess the current condition of amphibian populations in GRTE, the National Park Service's (NPS) Greater Yellowstone Network (GRYN) amphibian monitoring program (AMP) project reports for years 2007 and 2008-2009 were examined (Patla and Gould, 2009; Patla and Jean, 2010). The GRYN AMP performs amphibian monitoring at 40 randomly selected small watersheds, called catchments, in the parks, with eight located in GRTE and 32 in YELL. The goal of this program is to estimate occupancy rates for the reproductive component of native amphibian species, incorporating the dynamics of wetland sites that provide potential breeding habitat.

The GYRN AMP selected catchments for long-term amphibian monitoring based on a stratified random sampling scheme to ensure the selection of catchments with suitable habitat, adequate spatial representation across major watersheds, and accessibility of sites (Figure 3.93). The sampling was designed so that the analyses performed would have inference to all shallow wetlands of GRTE and YELL. Monitoring was performed by field crews performing visual detection surveys.

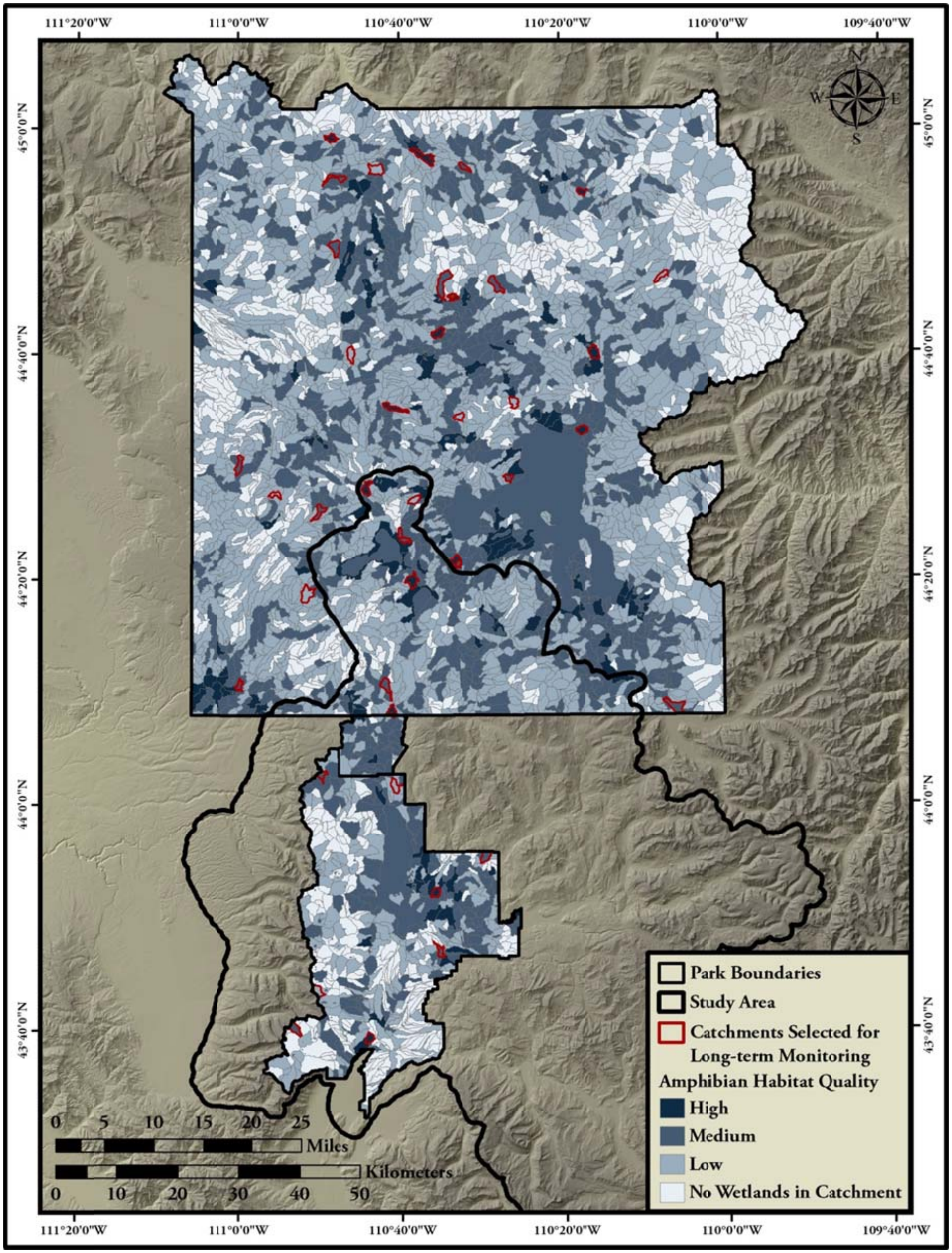

Figure 3.93. Catchments in Yellowstone National Park, John D. Rockefeller, Jr. Parkway, and Grand Teton National Park by amphibian habitat suitability. Catchments selected for long-term amphibian monitoring in Grand Teton and Yellowstone are bounded in red. All potential amphibian breeding sites within these 40 catchments were targeted for surveyal by the GRYN AMP; 32 catchments in Yellowstone, eight in Grand Teton.

Results

Because the GRYN AMP monitoring protocol has only recently been finalized, few years of data are available on which to perform analyses with respect to trends in amphibian populations in GRTE and YELL. Scientists are also in the process of developing a methodology that can allow an interpretation of amphibian trends over time that takes into account the species' sensitivity to changes in precipitation and wetlands.

The GRYN AMP performed proportion of area occupied (PAO) statistical analyses to estimate amphibian occupancy rates at the catchment level for GRTE and YELL for years 2007, 2008, and 2009. The PAO analyses adjusted for the probability that amphibian species may have been present in monitored catchments but were not detected by the field crews. The estimated occupancy rates of GRTE and YELL catchments by amphibian species for 2007, 2008, and 2009 are 0.49, 0.49, and 0.47 for boreal chorus frogs; 0.23, 0.45, and 0.42 for Columbia spotted frogs; 0.16, 0.16, and 0.09 for tiger salamanders; and 0.06 and 0.05 (2008 and 2009 only) for boreal toads (Figure 3.94) (Patla and Gould, 2009; Patla and Jean, 2010). The PAO statistics for 2008 and 2009 were produced by the amphibian monitoring program using one of the best supported models from the 2007 data analysis, and the provisional nature of the results is emphasized by its producers (Patla and Jean, 2010).

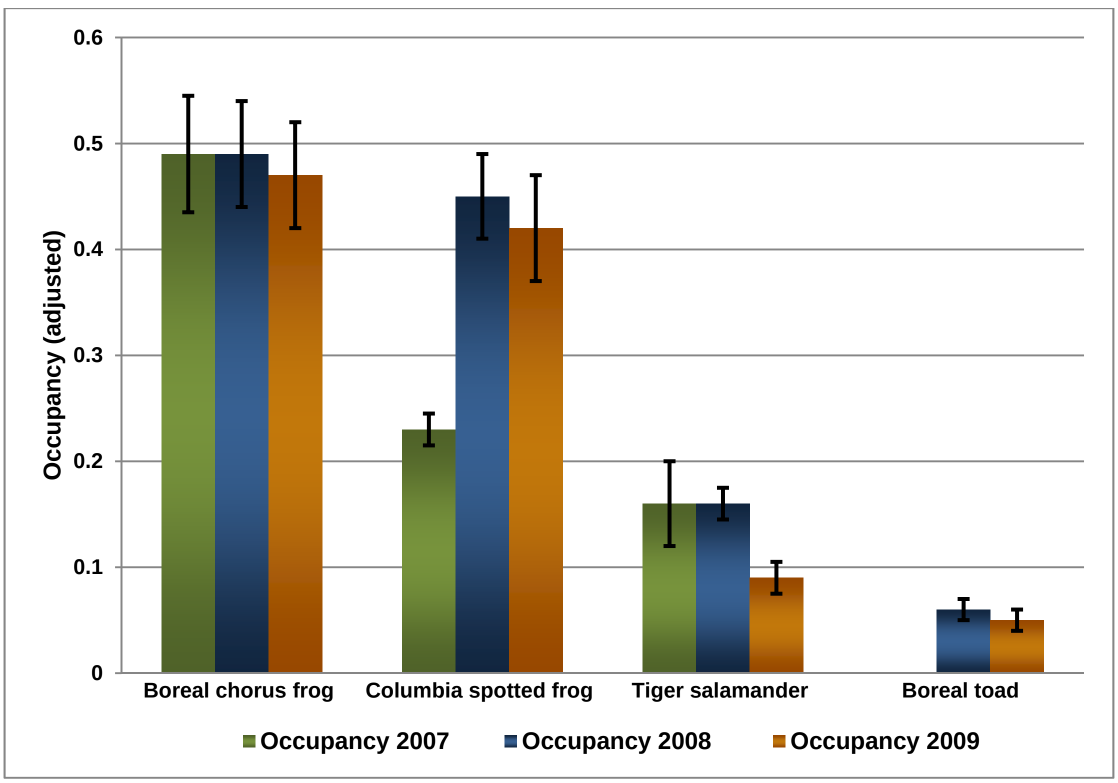

Figure 3.94. Amphibian occupancy estimates, with standard error bars, for Grand Teton National Park and Yellowstone National Park based on data collected at 40 catchments in 2007, 2008, and 2009. Occupancy refers to the proportion of catchments occupied by each breeding species, adjusted for the probability that the species may be present but not detected. Data on boreal toad breeding was too sparse in 2007 for modeling.

Breeding amphibian occupancy rates by species for 2006 to 2009 for GRTE catchments selected for long-term monitoring by the amphibian monitoring program were acquired from the amphibian monitoring program and are shown in Figure 3.95. For all years, the boreal chorus frog was the most widely detected amphibian in GRTE catchments, and the boreal toad was the most rarely detected. No leopard frogs or bullfrogs were found in the 2008 and 2009 field seasons in either GRTE or YELL (Patla and Jean, 2010).

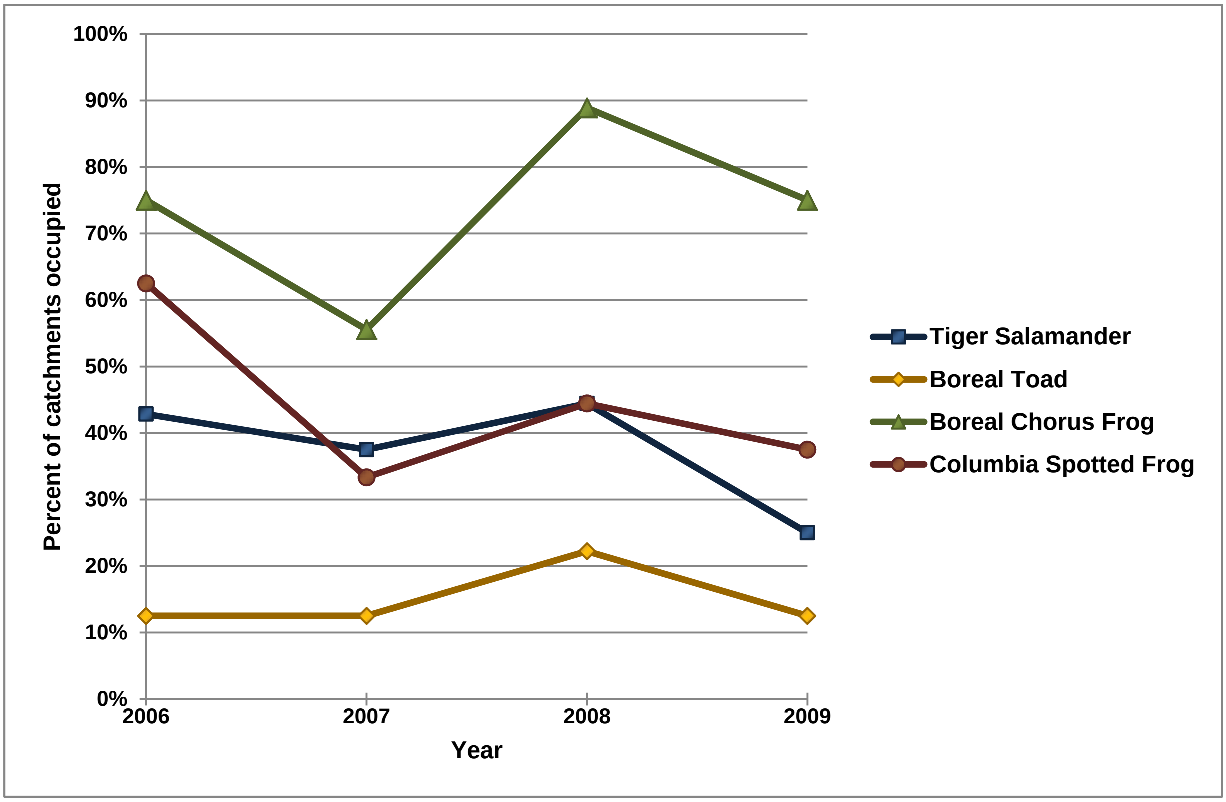

Figure 3.95. Percent of monitored catchments in Grand Teton National Park occupied by breeding amphibian species, 2006-2009.

<u>Summary and Conclusions</u>

Previous work has stated that three amphibian species (Columbia spotted frogs, boreal chorus frogs, and tiger salamanders) are considered common and widespread in YELL and GRTE. Based on more sampling across different quality habitat, their occurrence is better stated as widespread throughout the two parks, but in limited and unevenly distributed suitable wetland breeding habitat. The increase in amphibian breeding sites between 2007 and 2008 demonstrates the ability of native amphibians to respond to improved moisture conditions with increased breeding efforts, as 2008 was a wet year. However, it also suggests their vulnerability if climate change results in extended periods of unrelieved drought, shrinking wetlands, and larger proportions of available water diverted for human uses.

An amphibian disease database has been compiled for the GYE by the Yellowstone National Park Amphibian Disease Surveillance Program, including observed amphibian mortality over the past decade and diagnostic records for approximately 200 specimens that were submitted for analysis. The database and further investigation of disease has the potential to inform the amphibian monitoring program. Preliminary assessment of the database indicates that viral disease (ranavirus) may be widespread in the GYE, with confirmed or presumptive outbreaks of this disease detected in all four species (Patla and Jean, 2010). Ranaviruses are a large complex of related viruses that infect reptiles, amphibians, and fish. Different strains have coevolved with amphibian host populations and typically attack stressed individuals. Ranavirus infections are also more likely to occur when hosts are in dense aggregations (Corn, 2007). In addition to ranaviruses, chytrids (Chytridiomycota) may affect amphibian populations. Chytrids are an ancient group of saprophytic fungi that cause a variety of plant diseases and blights; however, it has been documented that the chytrid *Batrachochytrium dendrobatidis* is responsible for chytridiomycosis in amphibians. Both *Batrachochytrium dendrobatidis* and chytridiomycosis have been recorded at several locations in the GYE (Corn, 2007).

Landbirds

Landbirds represent a diverse group of bird species that occupy terrestrial habitats for most of their life cycles. Landbirds generally include bird species that are not primarily adapted to live continuously where aquatic conditions predominate (Sawyer et al., 1926). In GRTE, landbird species include sparrows, finches, swallows, woodpeckers, nuthatches, flycatchers, warblers, vireos, hawks, eagles, falcons, and others. Many GRTE landbird species are migratory, spending only three to six months in the park each year, and are also very closely tied to specific habitat types. For species such as these, although population numbers vary over time, relative abundances among broadly defined vegetation cover types or habitats typically do not (Ostermann-Kelm et al., 2010; and references therein). Because the loss of a particular habitat type will likely impact species that are relatively restricted to it, habitat-obligate bird species can function as useful indictors of habitat quality and quantity (Jansen and Robertson, 2001; Bock and Jones, 2004).

The Greater Yellowstone Inventory and Monitoring Network (GRYN) identified landbirds as a vital sign indicator of ecosystem health in their 2005 *Vital Signs Monitoring Plan for the Greater Yellowstone Network* (Jean et al., 2005). A pilot landbird monitoring program was subsequently developed by GRYN in cooperation with GRTE, and data collection was performed from 2005 to 2008. The principal design concept of the monitoring program was a focus on landbirds tied to specific habitat types (NPS, 2010i; Ostermann-Kelm et al., 2010). The pilot program focused on five habitats of concern: alpine, aspen, riparian cottonwood, riparian willow, and sage-steppe.

Methods used in the pilot program were draft and intended to evaluate the GRYN draft protocol (NPS, 2010i) to determine the feasibility of expanding the methods to other parks (B. Bingham, GRYN, pers. comm). Reports analyzing the methods used and the results obtained are incomplete and have not been peer reviewed. All data generated by the 2005-2008 landbird monitoring program are therefore provisional and should not be interpreted to assess the status of landbirds in GRTE (B. Bingham, GRYN, pers. comm). Nonetheless, data from the pilot program are the only data available related to the current status of landbirds in GRTE, and their inclusion in this NRCA document is accompanied by a categorical acknowledgement of their provisional nature.

Several major threats and concerns regarding landbirds in GRTE have also been identified by GRYN as vital sign indicators of ecosystem health (Jean et al., 2005). The relationships between landbirds and these other vital signs–climate, invasive plants, land use, fire, vertebrate disease, and visitor use–are briefly described in the following paragraphs.

Climate

The most directly observable effects of climate change on landbirds in GRTE are likely to occur in alpine habitat. Increases in temperature in alpine habitat can lead to increased snowmelt rates and changes in vegetation. These changes can cause earlier laying dates in some alpine bird species (Brown et al., 1999). Although earlier laying dates may lead to favorable changes in reproduction for some species (i.e. higher probability of second clutches, increased egg volume and associated increases in hatchability), it can also lead to resource limitation (e.g. decreased availability of alpine vegetation and arthropods) late in the breeding season. The magnitude of this threat is probably greatest for obligate ground-nesting species (Hendricks, 2003; Morton, 1994).

In aspen habitat, changes in moisture regimes could lead to a decline or death of current aspen clones. Alternatively, increases in temperature and droughty conditions could lead to more fires, which may help aspen establishment (NPS, 2010i).

Invasive Plants

Shrub-steppe habitats are particularly vulnerable to invasion by non-native plant species. Sagebrush communities are declining throughout the western United States, largely due to the influx of non-native species such as cheatgrass (Mack, 1989). Such species invade sagebrush habitats quickly, causing changes in habitat quality and fire regimes which lead to the establishment of a competitive advantage of invasive species over native species (Aguirre and Johnson, 1991; Knapp, 1996). As a result of these vegetation changes, bird community composition can shift from sage-steppe obligates to generalists and/or grassland obligates (NPS, 2010i).

While restricted within the boundaries of GRTE, conversion of habitat to agricultural uses can also decrease the resiliency of an area to invasions by non-native species. In a regional context, such changes can have significant effects on migratory species, including many landbirds that are of interest for monitoring (NPS, 2010i).

Land Use

Land use changes can lead to habitat fragmentation, which can decrease overall habitat quality and quantity, and potentially lead to increased invasion by non-native species. Land use changes may also impact landbird migratory routes and schedules.

In riparian habitats, changes in vegetation structure and surrounding landscape attributes can have a significant effect on bird diversity and abundance (Sanders and Edge, 1998). Loss of riparian habitat is generally the result of changes in basic fluvial geomorphic processes, the extent and connectivity of these habitats, and/or grazing (NPS, 2010i). The loss of riparian habitats has been suggested as the most important cause of population decline among landbird species in western North America (Dobkin et al., 1998).

In aspen habitats, overbrowsing of aspen suckers and saplings can lead to a lack of recruitment of suckers and an overall reduction in aspen numbers (Kay and Bartos, 2000). The resulting simplified stand structure can lead to reduced insect habitat, thus reducing food availability for insectivorous birds (Bailey and Whitman, 2002; Bailey and Whitman, 2003). Fire suppression can also lead to decreases in aspen stands. Fire suppression in aspen stands may allow conifer species to invade, which can lead to the death of the aspen clone (NPS, 2010i).

Disease

Some landbird species can be affected by the West Nile virus, which has begun to spread throughout the Intermountain West in recent years (Zuckerman, 2003; Phalen and Dahlhausen, 2004). Birds are the primary vertebrate host for West Nile virus, and mosquitoes are the primary vector. Transmission of West Nile virus to humans occurs through mosquitoes that feed on both birds and mammals. Crows, magpies, house sparrows, house finches, and other passerines appear to develop the highest concentrations of the virus in their blood (Phalen and Dahlhausen, 2004).

A second disease-like impact on GRTE landbirds is the impact of blackfly infestations on red-tailed hawks. The reproductive success of red-tailed hawks in GRTE has been shown to be significantly impacted by blackfly infestations and associated transmission of the parasitic blood protozoan *Leucocytozoon* to nestlings. Because blackfly infestations and associated nestling mortality may go undetected in standard raptor surveys, studies should be designed so that the presence and effects of blackflies can be documented properly (Smith et al., 1998).

Visitor Use

Landbirds are directly and indirectly impacted by visitor use within and around national parks. Visitors can directly disturb birds through activities, such as hiking, driving, and skiing. For example, it has been suggested that backcountry skiing may adversely affect alpine and subalpine bird species by packing powder used for snow burrows and disturbing bird feeding behavior (Martin, 2001). While visitor-induced disturbances can cause immediate effects on individual animal behavior and in areas of high use, long-term changes in bird communities due to visitor use are unlikely (NPS, 2010i).

Methods

Two assessments of the condition of GRTE landbirds are presented. The first is an estimation of all of the landbird species within the park. It was derived by comparing a National Park Service list of all bird species in GRTE (NPS, 2006g) against two sources of landbird classifications: Harshman (2008), which lists landbirds by order, and Rich et al. (2004), which lists landbirds by family. Any GRTE bird species from the National Park Service list also within lists of either Harshman (2008) and/or Rich et al. (2004) was identified as a GRTE landbird species.

The second GRTE landbird condition assessment was performed by examining the provisional results of the 2005-2008 GRTE landbird monitoring pilot study, conducted by the GRYN in cooperation with GRTE (NPS, 2010; Ostermann-Kelm et al., 2010). The monitoring project included a survey of landbird species during the breeding season in five habitats of concern: alpine, aspen, riparian willow, riparian cottonwood, and sage-steppe (Ostermann-Kelm et al., 2010). The methods used in the monitoring project can be summarized as thus: from multiple points on a series of transects, trained observers recorded all birds seen and heard during a five-minute period and measured their distance from the observer with a rangefinder (Figure 3.96). Observers documented the location of each bird (i.e. inside the habitat type of interest, outside, or flying over), number of individuals, sex, and detection type (i.e. singing, calling, or observed) (Wolff, 2008a).

Peer review and final reporting of the 2005-2008 landbird monitoring pilot study are ongoing; the provisional status of the results reported here is emphasized. Results related to two objectives of the GRTE landbird monitoring program are included here: (1) estimations of the density of 20 habitat-obligate species in habitats of concern, and (2) estimations of species richness of bird communities in the five habitats of concern. Distance-sampling based detection probabilities were incorporated in the estimation of parameters related to both objectives (Ostermann-Kelm et al., 2010).

Results

Landbird Species within GRTE

Through a comparison of Harshman (2008) and Rich et al. (2004), 136 landbird species were identified from the National Park Service (2006g) list of 195 bird species in GRTE (Table 3.44).

Species Density and Richness

Analysis of the landbird monitoring pilot project survey focused on 33 habitat-obligate landbird species. Data were suitable for estimating densities in 19 of these species (Ostermann-Kelm et al., 2010) (Table 3.45).

Based on the provisional results of the 2005-2008 landbird monitoring pilot project, Figures 3.97 through 3.101 show estimated species densities in habitats of concern, and Figure 3.102 shows estimated species richness across the habitats of concern (Ostermann-Kelm et al., 2010). Methods used in the monitoring project are draft and project reports are incomplete and have not been peer reviewed; therefore, the provisional nature of the results presented here is emphasized, and no interpretation of these data should be performed to assess the status of landbirds at GRTE or elsewhere (B. Bingham, GRYN, pers. comm).

Summary and Conclusions

Landbirds are bird species not primarily and anatomically adapted to live continuously where aquatic conditions predominate (Sawyer et al., 1926). Of 195 bird species found in GRTE, 136 can be considered landbirds by comparison with two assessments of landbird orders (Harshman, 2008) and families (Rich et al., 2004). Many landbird species are migratory, spending only part of the year in GRTE. Landbird species are also often highly dependent on specific habitat types, making landbirds useful as an indicator of overall habitat quality and quantity (Hutto, 1998).

Knowledge on the status of landbirds in GRTE with respect to species densities and richness is limited. In cooperation with GRTE, a GRYN landbird monitoring pilot program collected data on landbird species across five habitats of concern within GRTE from 2005 to 2008. A primary purpose of the pilot program was to evaluate the draft GRYN vital signs monitoring protocol for landbirds (NPS, 2010i) with respect to the feasibility of expanding the methods to other parks in the GRYN network (B. Bingham, GRYN, pers. comm). The pilot project was designed to measure metrics, such as species density and richness, in five habitats of concern: alpine, aspen, riparian cottonwood, riparian willow, and sage-steppe. Data analyses and reports from the landbird monitoring pilot project are incomplete and have not been peer reviewed; therefore, all data from the monitoring project presented in this section are provisional. GRYN has made no determination regarding whether or how to proceed with landbird monitoring in GRTE or elsewhere (B. Bingham, GRYN, pers. comm).

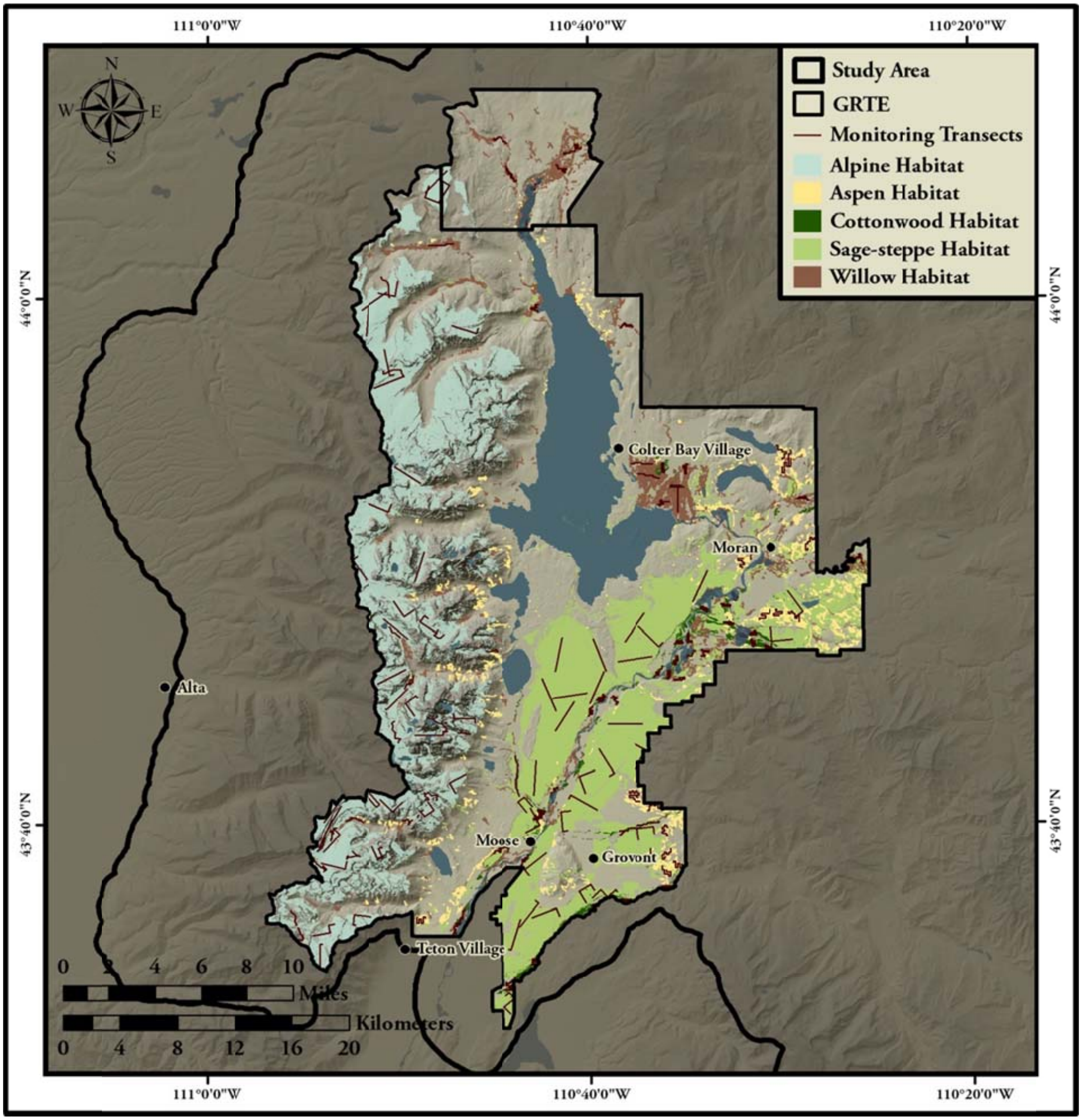

Figure 3.96. Location of the five habitats of concern used in the 2005-2008 landbird monitoring pilot project. Monitoring transects are shown as dark red lines; not all transects were used in all years.

Table 3.44. Landbirds in Grand Teton National Park. List compiled by comparing the National Park Service (2006g) list of 195 bird species in Grand Teton with landbird orders and families in Harshman (2008) and Rich et al. (2004), respectively. The comparison identified 136 landbird species in Grand Teton. Table attributes, names, and Taxonomic Serial Numbers (TSN) were obtained from the National Park Service (2006g).

TAXONOMIC SERIAL NUMBER	SCIENTIFIC NAME	COMMON NAME
Order: Apodiformes - Family: Trochilidae[2]		
178038	*Selasphorus platycercus*	Broad-tailed hummingbird
178040	*Selasphorus rufus*	Rufous hummingbird
178048	*Stellula calliope*	Calliope hummingbird
Order: Columbiformes - Family: Columbidae[2]		
177071	*Columba livia*	Rock dove
177125	*Zenaida macroura*	Mourning dove
Order: Ciconiiformes - Family: Accipitridae[2]		
175300	*Accipiter gentilis*	Northern goshawk
175304	*Accipiter striatus*	Sharp-shinned hawk
175309	*Accipiter cooperii*	Cooper's hawk
175350	*Buteo jamaicensis*	Red-tailed hawk
175367	*Buteo swainsoni*	Swainson's hawk
175373	*Buteo lagopus*	Rough-legged hawk
175377	*Buteo regalis*	Ferruginous hawk
175407	*Aquila chrysaetos*	Golden eagle
175420	*Haliaeetus leucocephalus*	Bald eagle
175430	*Circus cyaneus*	Northern harrier
175590	*Pandion haliaetus*	Osprey
Order: Ciconiiformes - Family: Falconidae[2]		
175603	*Falco mexicanus*	Prairie falcon
175604	*Falco peregrinus*	Peregrine falcon
175613	*Falco columbarius*	Merlin
175622	*Falco sparverius*	American kestrel
Order: Ciconiiformes - Family: Ciconiidae****		
175265	*Cathartes aura***	Turkey vulture**
Order: Galliformes - Family: Phasianidae[2]		
175790	*Bonasa umbellus*	Ruffed grouse
175855	*Centrocercus urophasianus*	Greater sage grouse, sage grouse
175860	*Dendragapus obscurus*	Blue grouse
Order: Passeriformes[1] - Family: Alaudidae[2]		
554256	*Eremophila alpestris*	Horned lark
Order: Passeriformes[1] - Family: Bombycillidae[2]		
178529	*Bombycilla garrulus*	Bohemian waxwing
178532	*Bombycilla cedrorum*	Cedar waxwing

Table 3.44. Landbirds in Grand Teton National Park (continued).

TAXONOMIC SERIAL NUMBER	SCIENTIFIC NAME	COMMON NAME
Order: Passeriformes[1] - Family: Certhiidae[2]		
178541	*Troglodytes aedon*	House wren
178547	*Troglodytes troglodytes*	Winter wren
178608	*Cistothorus palustris*	Marsh wren
178614	*Salpinctes obsoletus*	Rock wren
178803	*Certhia americana*	Brown creeper
Order: Passeriformes[1] - Family: Cinclidae[2]		
178536	*Cinclus mexicanus*	American dipper
Order: Passeriformes[1] - Family: Corvidae[2]		
501550	*Pica hudsonia*	American magpie, black-billed magpie
179667	*Perisoreus canadensis*	Gray jay
179685	*Cyanocitta stelleri*	Steller's jay
179725	*Corvus corax*	Common raven
179731	*Corvus brachyrhynchos*	American crow
179750	*Nucifraga columbiana*	Clark's nutcracker
Order: Passeriformes[1] - Family: Fringillidae[2]		
178856	*Vermivora celata*	Orange-crowned warbler
178878	*Dendroica petechia*	Yellow warbler
178891	*Dendroica coronata*	Yellow-rumped warbler
178897	*Dendroica townsendi*	Townsend's warbler
178931	*Seiurus noveboracensis*	Northern waterthrush
178940	*Oporornis tolmiei*	Macgillivray's warbler
178944	*Geothlypis trichas*	Common yellowthroat
178973	*Wilsonia pusilla*	Wilson's warbler
179032	*Dolichonyx oryzivorus*	Bobolink
179039	*Sturnella neglecta*	Western meadowlark
179043	*Xanthocephalus xanthocephalus*	Yellow-headed blackbird
179045	*Agelaius phoeniceus*	Red-winged blackbird
179094	*Euphagus cyanocephalus*	Brewer's blackbird
179104	*Quiscalus quiscula*	Common grackle
179112	*Molothrus ater*	Brown-headed cowbird
179140	*Pheucticus melanocephalus*	Black-headed grosbeak
179151	*Passerina amoena*	Lazuli bunting
179173	*Coccothraustes vespertinus*	Evening grosbeak
179190	*Carpodacus cassinii*	Cassin's finch
179191	*Carpodacus mexicanus*	House finch
179205	*Pinicola enucleator*	Pine grosbeak
179215	*Leucosticte tephrocotis*	Gray-crowned rosy-finch
179222	*Leucosticte atrata*	Black rosy-finch
179233	*Carduelis pinus*	Pine siskin
179236	*Carduelis tristis*	American goldfinch
179259	*Loxia curvirostra*	Red crossbill

Table 3.44. Landbirds in Grand Teton National Park (continued).

TAXONOMIC SERIAL NUMBER	SCIENTIFIC NAME	COMMON NAME
Order: Passeriformes[1] - Family: Fringillidae[2] (continued)		
179268	*Loxia leucoptera*	White-winged crossbill
179310	*Pipilo chlorurus*	Green-tailed towhee
179314	*Passerculus sandwichensis*	Savannah sparrow
179366	*Pooecetes gramineus*	Vesper sparrow
179371	*Chondestes grammacus*	Lark sparrow
179410	*Junco hyemalis*	Dark-eyed junco
179435	*Spizella passerina*	Chipping sparrow
179440	*Spizella breweri*	Brewer's sparrow
179455	*Zonotrichia leucophrys*	White-crowned sparrow
179464	*Passerella iliaca*	Fox sparrow
179484	*Melospiza lincolnii*	Lincoln's sparrow
179492	*Melospiza melodia*	Song sparrow
179532	*Plectrophenax nivalis*	Snow bunting
179882	*Piranga ludoviciana*	Western tanager
554267	*Icterus bullockii*	Bullock's oriole
Order: Passeriformes[1] - Family: Hirundinidae[2]		
178427	*Tachycineta thalassina*	Violet-green swallow
178431	*Tachycineta bicolor*	Tree swallow
178436	*Riparia riparia*	Bank swallow
178443	*Stelgidopteryx serripenni*	Northern rough-winged swallow
178448	*Hirundo rustica*	Barn swallow
178455	*Petrochelidon pyrrhonota*	Cliff swallow
Order: Passeriformes[1] - Family: Laniidae[2]		
178511	*Lanius excubitor*	Northern shrike
178515	*Lanius ludovicianus*	Loggerhead shrike
Order: Passeriformes[1] - Family: Muscicapidae		
179759	*Turdus migratorius*	American robin
179779	*Catharus guttatus*	Hermit thrush
179788	*Catharus ustulatus*	Swainson's thrush
179811	*Sialia currucoides*	Mountain bluebird
179824	*Myadestes townsendi*	Townsend's solitaire
Order: Passeriformes[1] - Family: Paridae[2]		
554382	*Poecile atricapillus*	Black-capped chickadee
554385	*Poecile gambeli*	Mountain chickadee
Order: Passeriformes[1] - Family: Passeridae		
554127	*Anthus rubescens*	American pipit
Order: Passeriformes[1] - Family: Regulidae[2]		
179865	*Regulus satrapa*	Golden-crowned kinglet
179870	*Regulus calendula*	Ruby-crowned kinglet

Table 3.44. Landbirds in Grand Teton National Park (continued).

TAXONOMIC SERIAL NUMBER	SCIENTIFIC NAME	COMMON NAME
Order: Passeriformes[1] - Family: Sittidae[2]		
178775	*Sitta carolinensis*	White-breasted nuthatch
178784	*Sitta canadensis*	Red-breasted nuthatch
178788	*Sitta pygmaea*	Pygmy nuthatch
Order: Passeriformes[1] - Family: Sturnidae[2]		
178625	*Dumetella carolinensis*	Gray catbird
178654	*Oreoscoptes montanus*	Sage thrasher
179637	*Sturnus vulgaris*	European starling
Order: Passeriformes[1] - Family: Turdidae[2]		
179773	Ixoreus naevius	Varied thrush
Order: Passeriformes[1] - Family: Tyrannidae[2]		
178279	*Tyrannus tyrannus*	Eastern kingbird
178287	*Tyrannus verticalis*	Western kingbird
178341	*Empidonax traillii*	Willow flycatcher
178345	*Empidonax hammondi*	Hammond's flycatcher
178346	*Empidonax oberholseri*	Dusky flycatcher
178360	*Contopus sordidulus*	Western wood-pewee
554221	*Contopus cooperi*	Olive-sided flycatcher
554255	*Empidonax occidentalis*	Cordilleran flycatcher
Order: Passeriformes[1] - Family: Vireonidae[2]		
179023	*Vireo gilvus*	Warbling vireo
554477	*Vireo plumbeus*	Plumbeous vireo
Order: Piciformes[1] - Family: Picidae[2]		
505769	*Picoides dorsalis*	American three-toed woodpecker
178154	*Colaptes auratus*	Northern flicker
178196	*Melanerpes lewis*	Lewis' woodpecker
178208	*Sphyrapicus thyroideus*	Williamson's sapsucker
178211	*Sphyrapicus nuchalis*	Red-naped sapsucker
178250	*Picoides arcticus*	Black-backed woodpecker
178259	*Picoides pubescens*	Downy woodpecker
178262	*Picoides villosus*	Hairy woodpecker
Order: Strigiformes[1] - Family: Caprimulgidae[2]		
177979	*Chordeiles minor*	Common nighthawk
Order: Strigiformes[1] - Family: Strigidae[2]		
177880	*Otus kennicotti*	Western screech-owl
177884	*Bubo virginianus*	Great horned owl
177902	*Glaucidium gnoma*	Northern pygmy-owl
177921	*Strix varia*	Barred owl
177929	*Strix nebulosa*	Great gray owl
177932	*Asio otus*	Long-eared owl
177935	*Asio flammeus*	Short-eared owl
177938	*Aegolius funereus*	Boreal owl

Table 3.44. Landbirds in Grand Teton National Park (continued).

TAXONOMIC SERIAL NUMBER	SCIENTIFIC NAME	COMMON NAME
Order: Strigiformes[1] - Family: Strigidae[2] (continued)		
177942	*Aegolius acadicus*	Northern saw-whet owl
177946	*Athene cunicularia*	Burrowing owl
Order: Strigiformes[1] - Family: Tytonidae[2]		
177851	*Tyto alba*	Barn owl

*Taxonomic Serial Numbers (TSN) are unique, persistent, non-intelligent identifiers for scientific names in the context of the Integrated Taxonomic Information System (ITIS). Standard taxonomic information is available for positive TSN values from the ITIS web site (http://www.itis.gov/). Negative TSN values represent records in NPS species that are pending reconciliation with ITIS.
**Although the turkey vulture is listed by NPS (2006g) as belonging to the Ciconiiformes order and the Ciconiidae family, neither of which are listed as landbird groups in Harshman (2008) nor Rich et al. (2004), the species is categorized by some authorities as belonging to the Falconiformes order and the Cathartidae family (Sibley and Ahlquist, 1991), which are listed in both Harshman (2008) and Rich et al. (2004), respectively, as landbird groups.
[1]Bird orders classified by Harshman (2008) as landbirds.
[2]Bird families classified by Rich et al. (2004) as landbirds.

Table 3.45. Results from the 2005-2008 landbird monitoring pilot project, displaying bird species present in five habitats of concern. The project targeted 33 habitat-obligate bird species; data were suitable for estimating density for 19 of these species (denoted in bold).

HABITAT TYPE	SCIENTIFIC NAME	COMMON NAME
Riparian willow	*Passerella iliaca*	**Fox sparrow**
	Melospiza lincolnii	**Lincoln's sparrow**
	Oporornis tolmiei	MacGillivray's warbler
	Oporornis tolmiei	**Song sparrow**
	Empidonax traillii	**Willow flycatcher**
	Wilsonia pusilla	**Wilson's warbler**
Riparian cottonwood	*Spizella passerina*	**Chipping sparrow**
	Empidonax oberholseri	**Dusky flycatcher**
	Troglodytes aedon	**House wren**
	Vireo gilvus	**Warbling vireo**
	Contopus sordidulus	Western wood-pewee
	Dendroica petechia	**Yellow warbler**
Aspen	*Molothrus ater*	Brown-headed cowbird
	Spizella passerina	Chipping sparrow
	Empidonax oberholseri	**Dusky flycatcher**
	Sialia currucoides	**Mountain bluebird**
	Vireo gilvus	**Warbling vireo**
	Contopus sordidulus	Western wood-pewee
Sage-steppe	*Spizella breweri*	**Brewer's sparrow**
	Pipilo chlorurus	**Green-tailed towhee**
	Eremophila alpestris	Horned lark
	Oreoscoptes montanus	Sage thrasher
	Passerculus sandwichensis	Savannah sparrow
	Pooecetes gramineus	**Vesper sparrow**
	Sturnella neglecta	Western meadowlark
Alpine	*Anthus rubescens*	**American pipit**
	Leucosticte atrata	**Black rosy-finch**
	Spizella breweri	Brewer's sparrow
	Nucifraga columbiana	Clark's nutcracker
	Salpinctes obsoletus	Rock wren
	Selasphorus rufus	Rufous hummingbird
	Zonotrichia leucophrys	**White-crowned sparrow**
	*Aeronautes saxatalis**	White-throated swift*

*Although the white-throated swift (*Aeronautes saxatalis*) is identified as a landbird species by Ostermann-Kelm et al. (2010) and Rich et al. (2004), it was not listed in the comprehensive list of 136 landbird species in Table 3.44 because it was not identified as a bird species in the October 2006 list of birds in GRTE.

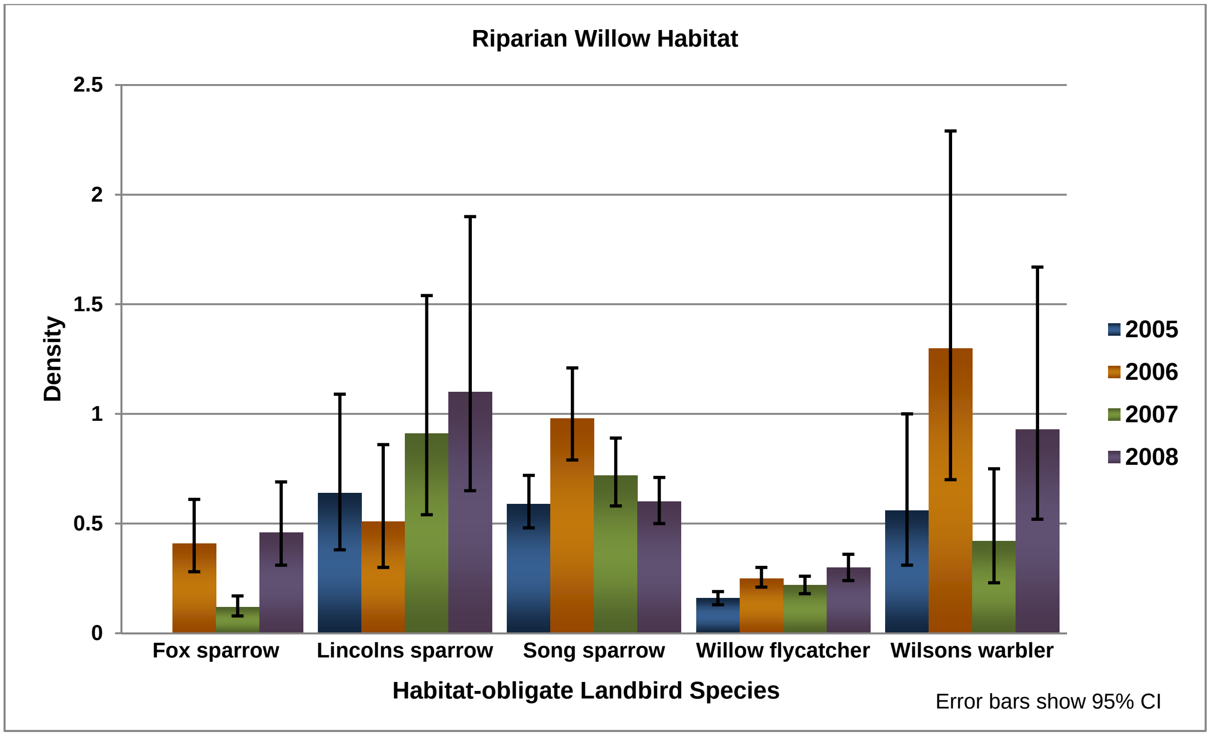

Figure 3.97. Species density of select habitat-obligate species in riparian willow habitat (Ostermann-Kelm et al., 2010). All data are provisional.

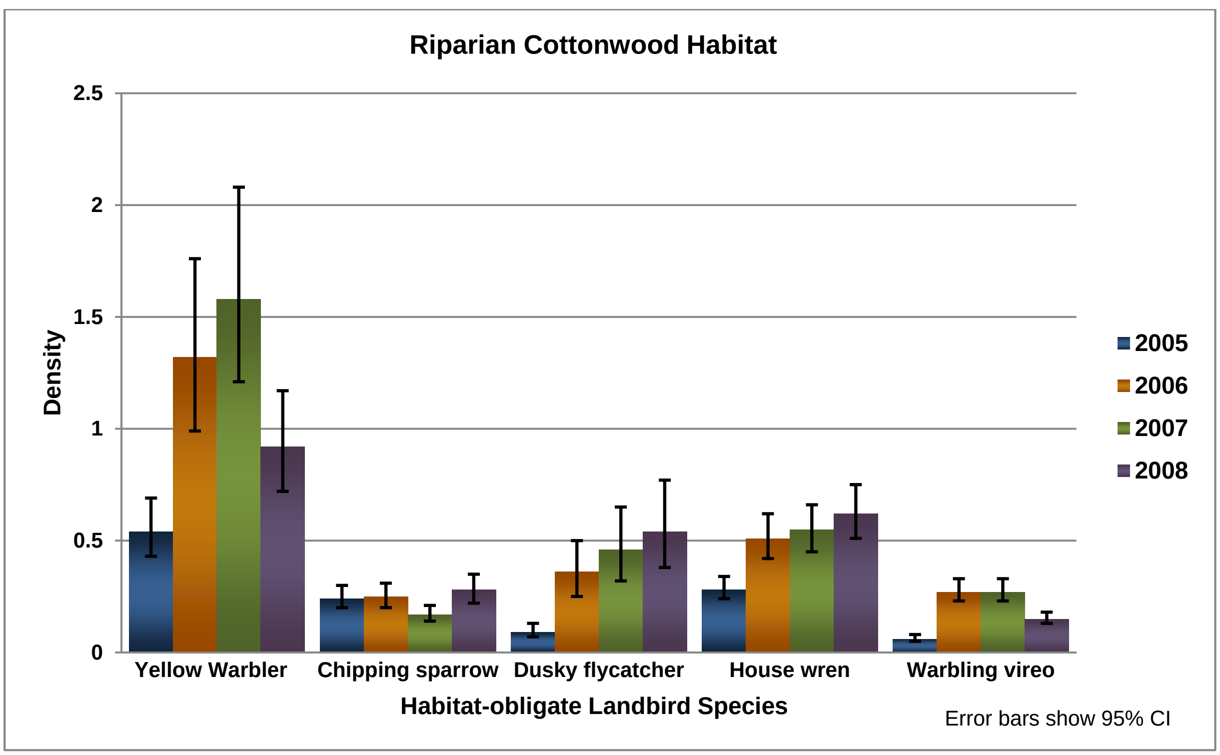

Figure 3.98. Species density of select habitat-obligate species in riparian cottonwood habitat (Ostermann-Kelm et al., 2010). All data are provisional.

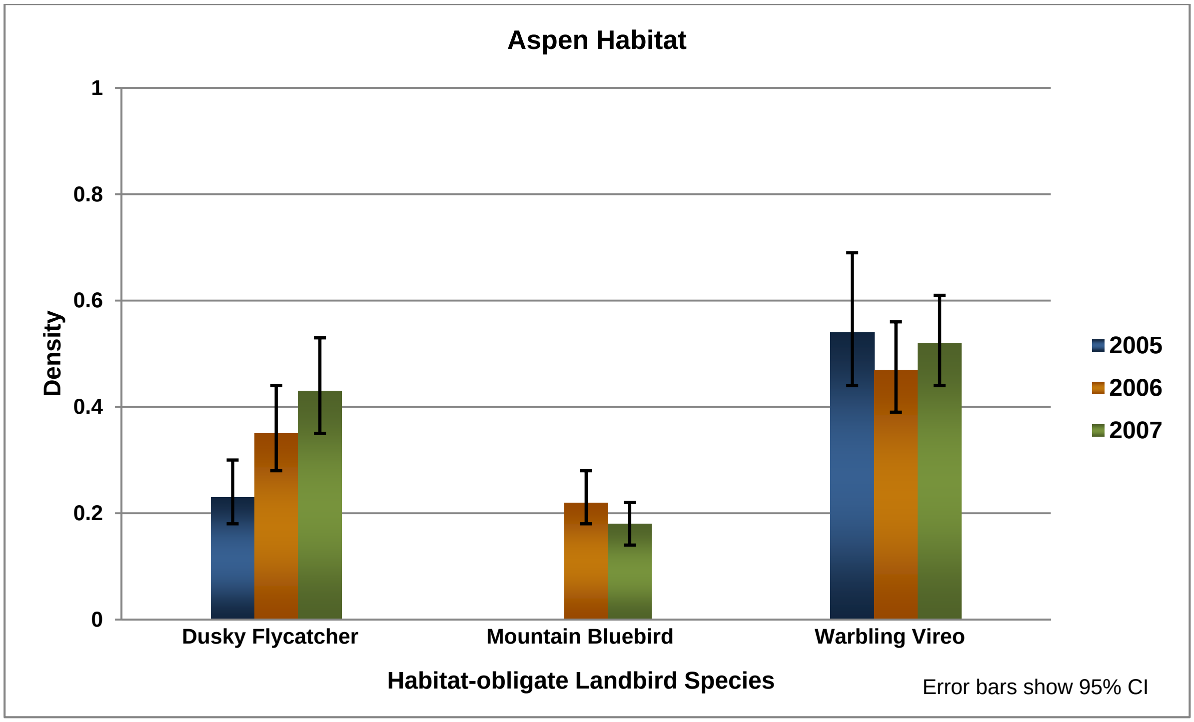

Figure 3.99. Species density of select habitat-obligate species in aspen habitat (Ostermann-Kelm et al., 2010). All data are provisional.

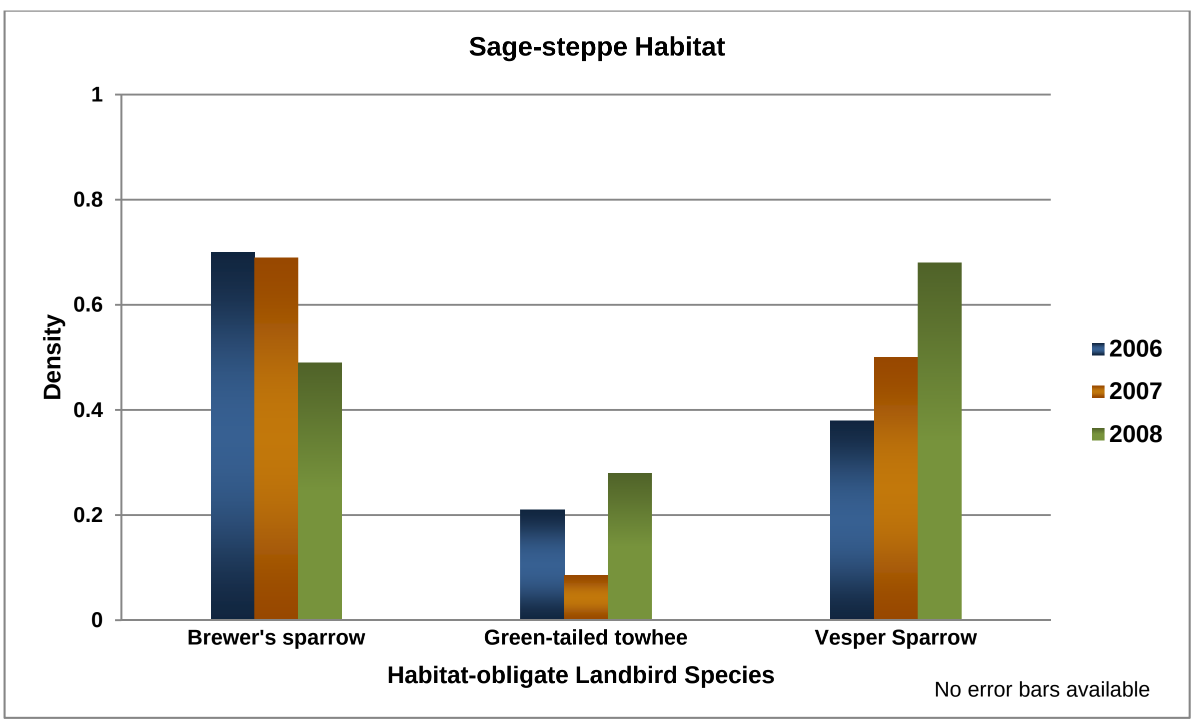

Figure 3.100. Species density of select habitat-obligate species in sage-steppe habitat (Ostermann-Kelm et al., 2010). All data are provisional.

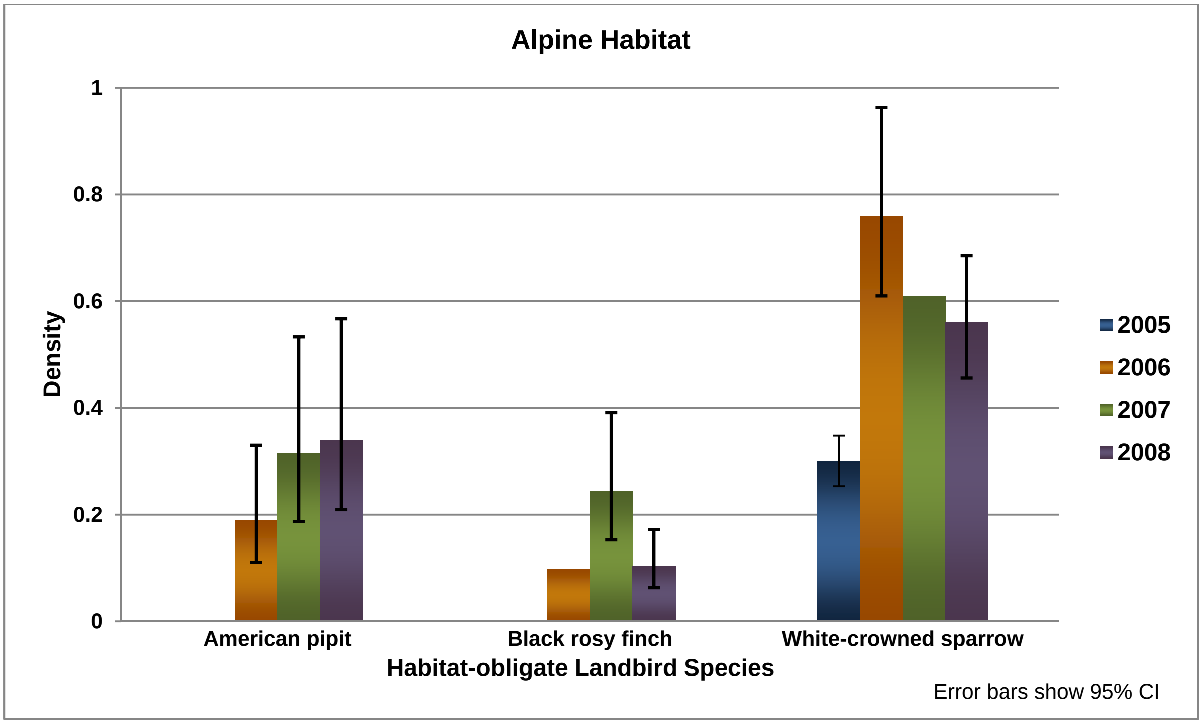

Figure 3.101. Species density of select habitat-obligate species in alpine habitat (Ostermann-Kelm et al., 2010). All data are provisional.

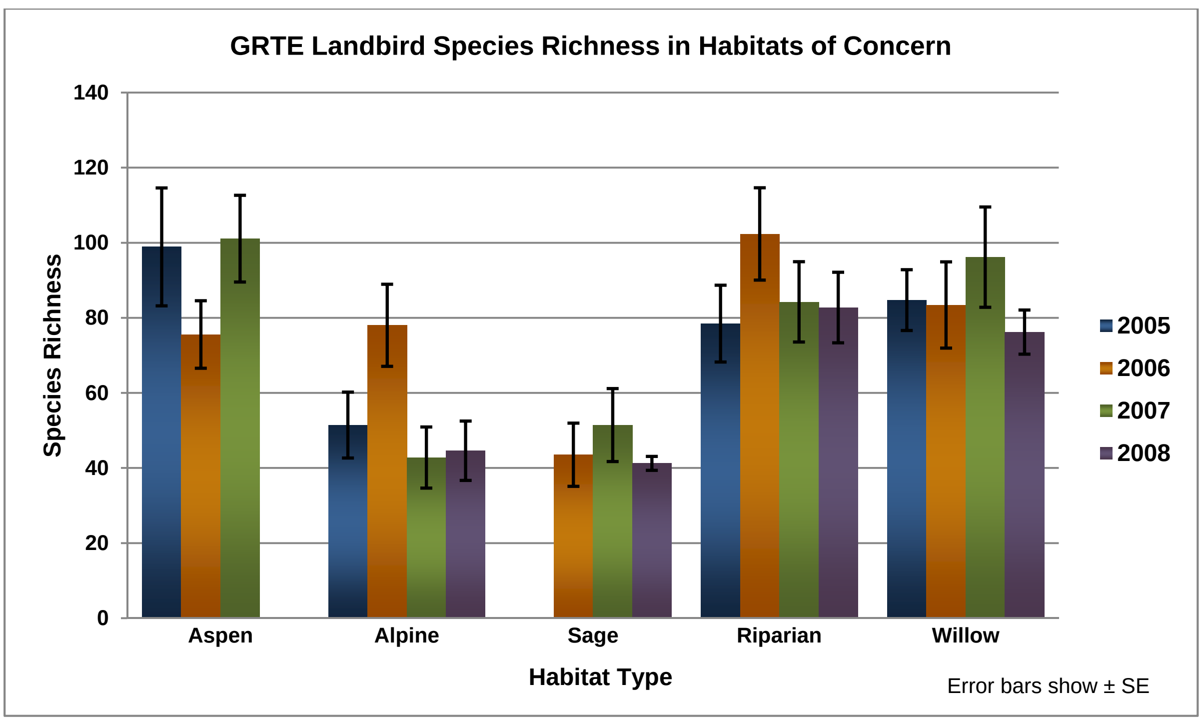

Figure 3.3.102. Landbird species richness across habitats of concern in Grand Teton National Park. (Ostermann-Kelm et al., 2010). All data are provisional.

Birds of Concern

Bald Eagle

Bald eagles (*Haliaeetus leucocephalus*) are large brown bodied raptors with a pure white head and tail, including an unfeathered tarsi and a massive yellow beak (Figure 3.10). Translation of the scientific name means white-headed sea eagle. During the first four years as an immature bird, the plumage is mottled brown and white. Both the head and tail are dark during these years. Adult plumage is usually obtained by the sixth year of life. Plumage is similar for males and females; however, females are larger than males. A large female may be 38 inches (96.5 centimeters) long and weigh 14 pounds (6.4 kilograms), while a small male may only be 28 inches (71 centimeters) long and weigh 6.5 pounds (2.9 kilograms). The wingspan of bald eagles typically averages seven feet (2.1 meters) (NAS, 2010a). In flight, the bald eagle often soars or glides with the wings held at a right angle to the body (USFWS, 2010b). The bald eagle is endemic to North America, and it is a well-known symbol of the United States of America. In 1782, Congress named the bald eagle the national symbol of the United States (NPS, 2010j).

Habitat

Today, bald eagles occur across the continent of North America and into northern Mexico. They are found near open water and range over great distances; however, they typically return to nest in the vicinity where they fledged (NPS, 2010j). Bald eagle habitat, movements, and food habits change throughout the year; however, they primarily occupy territories near major rivers and lakes in the GYE where they opportunistically feed on fish, small mammals, birds, and carrion. Harmata et al. (1999) radio-tagged bald eagles in the GYE and found that the bird locations were associated with seasonal concentrations of prey and carrion. In the spring, bald eagles were primarily found along water bodies where cutthroat trout were spawning, but they were also found in areas where ground squirrels were concentrated. In the autumn, they were found where whitefish were spawning or in areas where ungulate viscera piles were left by hunters (Harmata et al., 1999).

Figure 3.103. Bald eagle. Photo sources: National Biological Information Infrastructure and U.S. Fish and Wildlife Service.

Bald eagle migration patterns vary based on life stage and resources. If they possess access to open water, they can remain at a particular nesting site year-round (Gerrard and Bortolotti, 1984). While some adult bald eagle pairs spend the entire winter in close proximity to their nesting territory in the GYE, other pairs migrate to lower elevations, such as the area around Gardiner, Montana, to secure food. Migration to ungulate winter ranges and watercourses free of ice is common. While adult pairs remain at a particular nesting site year-round or migrate to lower elevations, most juvenile bald eagles migrate to the Pacific Northwest or other warmer climates for the winter. By spring, eagle pairs and juveniles return to their nesting territory in the GYE or neighboring regions (Harmata et al., 1999; Swenson et al., 1986; NPS, 2008c).

Bald eagles usually mate for life and may reuse the same nest year after year. Bald eagle pairs typically produce two eggs once a year, although the number of eaglets that successfully fledge depends partly on weather (NPS, 2010j). Bald eagles are highly adaptable with respect to breeding habitat; however, the presence of a reliable and available food source early in the nesting season is mandatory (Swenson et al., 1986). Swenson et al. (1986) studied bald eagles in three regions, or units, of the GYE from 1972 to 1982. In the Snake River unit, which encompassed most of GRTE and other areas along the Snake River in Wyoming and Idaho, bald eagle nests were primarily found in riparian zones. Riparian tree species were the most common used for nesting, but Douglas-fir trees were often used when bald eagles nested along lakes and reservoirs. Bald eagles seemed to choose trees that were as large or larger than surrounding trees for nesting. In addition, nearly all bald eagle nests were located near important spawning stream for spring spawning fish species, such as cutthroat trout (*Oncorhynchus clarkii*) and Utah suckers (*Catostomus ardens*). The proximity of peripheral spawning streams to bald eagle nesting habitat is important because peripheral streams remain relatively clear during the spring as compared to the Snake River, which often becomes laden with silt from snowmelt and runoff (Swenson et al., 1986).

Trends

During the middle of the twentieth century, bald eagles were nearly extinct. In 1963, there were only 417 nesting pairs in the lower 48 states. Loss of habitat, shooting, and poisoning by the pesticide dichloro-diphenyl-trichloroethene (DDT) were the primary causes of population declines. Increased legal protection, including placement on the Endangered Species List, and banning the use of DDT, have contributed the remarkable recovery of bald eagles (NAS, 2010a). Bald eagles were placed on the Endangered Species List in Idaho, Wyoming, Montana, and 40 other states in 1978. As population numbers increased throughout their range, the U.S. Fish and Wildlife Service upgraded that status of bald eagles to a threatened species in 1995. In 2007, the bald eagle was delisted from the Threatened and Endangered Species List (Wolff, 2009a). According to the National Audubon Society, there are currently at least 7,066 nesting pairs in the lower 48 states (NAS, 2010a).

Grand Teton National Park has been actively monitoring bald eagles within its borders since the 1970s (Wolff, 2003). Nest surveys take place from mid-April through July or August, until young fledge or leave the nest. A nesting territory is considered occupied if a pair of birds is observed in association with the nest or there was evidence of recent nest maintenance (Wolff, 2009a). Data collected since 1987 indicates that there is an expanding population of bald eagle pairs in both GRTE and YELL (Figure 3.104). In 2007, mild spring temperatures contributed to record bald eagle productivity in GRTE, with 16 fledglings produced by 14 nesting pairs (NPS, 2010j).

Because bald eagles are sensitive to human presence, GRTE enforces a one-half mile closure from February 15 to August 15 around all bald eagle nests (NPS, 2010j). In 2009, there were 15 known nesting territories in GRTE, predominantly located along the Snake River, Buffalo River, and Jackson Lake (Wolff, 2009a). All productivity parameters for 2009 exceeded the 1987 to 2009 mean with the exception of young per productive nest (Figure 3.105). Nesting success was the same in 2009 compared to the long-term average of 63 percent (Wolff, 2009a).

There has been a dramatic recovery in bald eagle populations since the 1970s, with increases in geographic distribution and the number of occupied territories within the park. However, the number of young per occupied territory has not changed appreciably (Figure 3.106). State management objectives have been exceeded since 1987 (Wolff, 2009a). Although it is estimated that the number of nesting pairs will continue to increase throughout Wyoming, human activity and development, both residential and recreational, near rivers and lakes continues to degrade nesting habitat. Bald eagles are also sensitive to organochlorines, high levels of heavy metals, organophosphates, and carbamate pesticides. These contaminants could affect production and survival (WGFD, 2005a).

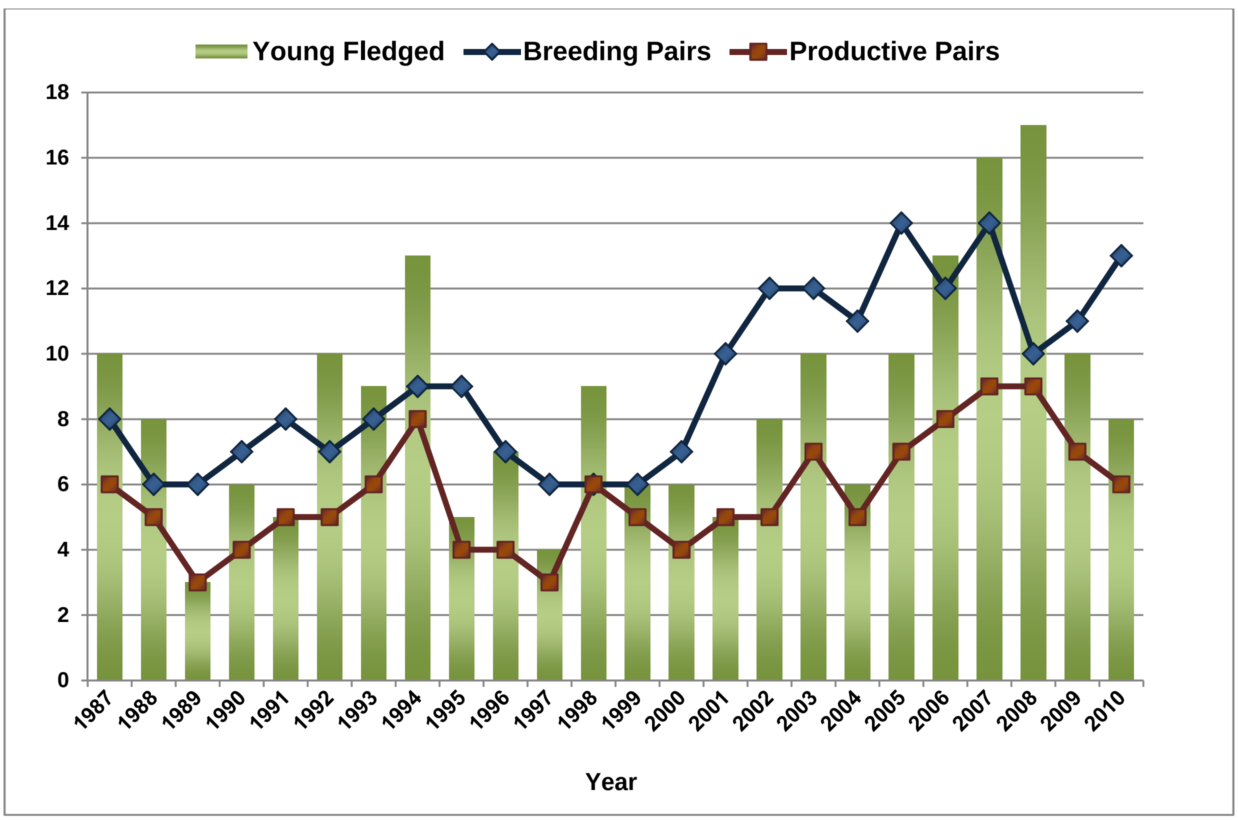

Figure 3.104. Bald eagle breeding and productive pairs and young fledged counted in Grand Teton National Park, 1987-2010. Data source: Grand Teton National Park (Sue Wolff).

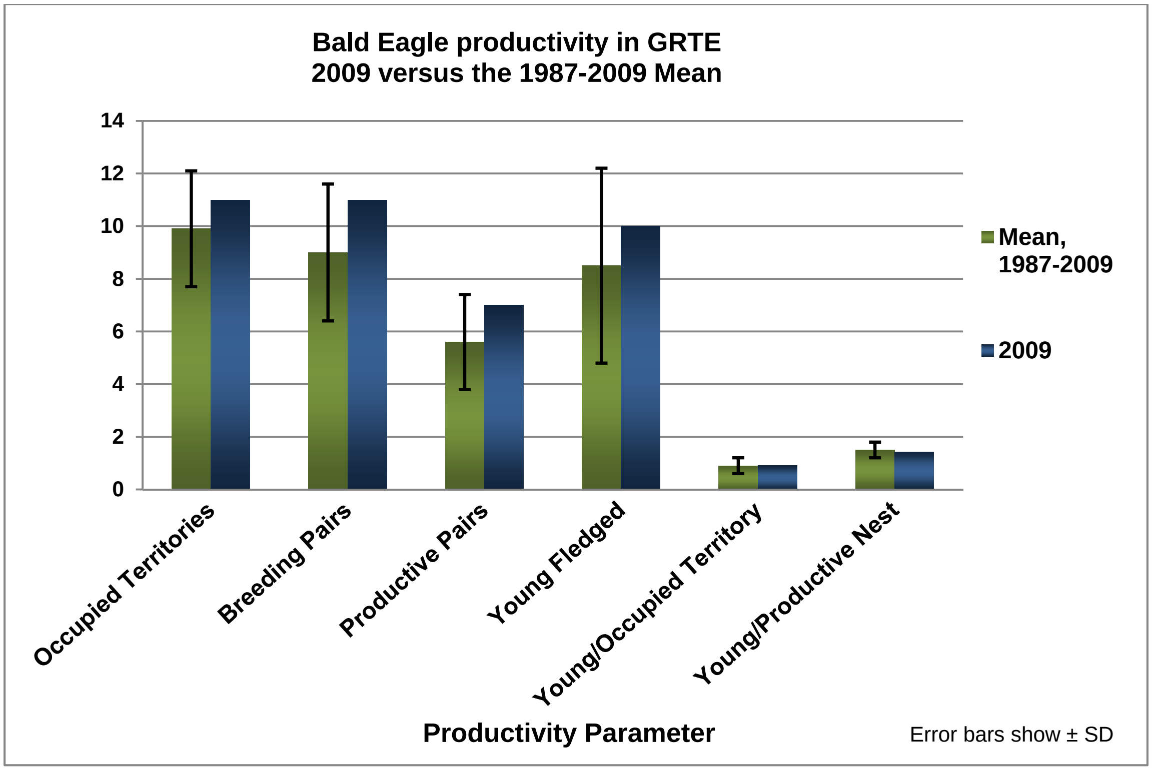

Figure 3.105. Bald eagle productivity in Grand Teton National Park, comparing 2009 and the 1987-2009 mean. Source: Wolff, 2009a.

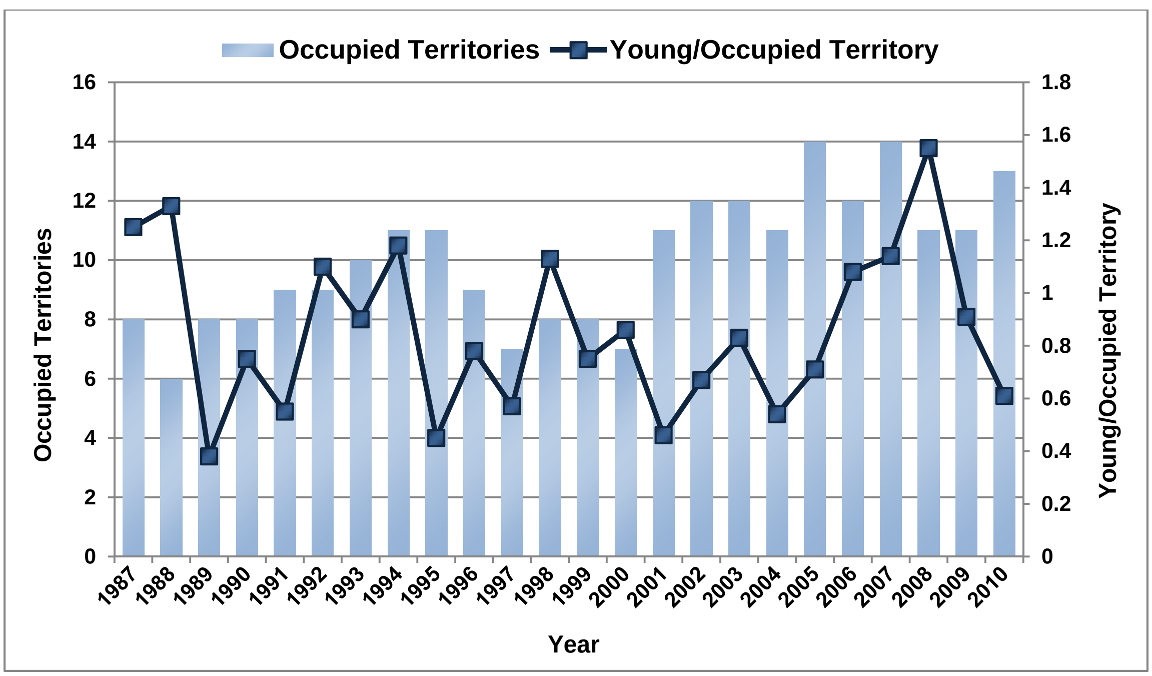

Figure 3.106. Occupied bald eagle territories in Grand Teton National Park and young per occupied site, 1987-2010. Data source: Grand Teton National Park (Sue Wolff).

Great Blue Heron

The great blue heron (*Ardea herodias*) is a large, colonial-nesting wading waterbird (Butler, 1992). On average, great blue herons weigh 4.6 to 7.3 pounds (2.1 to 3.3 kilograms), and have a height of 3.2 to 4.5 feet (1.0 to 1.4 meters) and a wingspan of 5.5 to 6.6 feet (1.7 to 2.0 meters). Great blue herons are slate gray, with a blue tinge, have black shoulder patches, a white face, and a white crown that is underscored by black eye stripes ending in slender plumes. Long plumes also extend from the slender, elongated body at the neck, breast, and back. The bird has a thick yellow bill and long, stilt-like brownish legs (Figure 3.107) (NAS, 2010b).

Habitat

Great blue herons are widespread across North America. They thrive year-round in both freshwater and saltwater habitats from southern Alaska to Central America, and into the Caribbean Islands. During the breeding season, they extend their northern range into central Canada and eastward into Nova Scotia. Great blue herons can be found in a wide variety of aquatic habitats, ranging from wetlands, riverbanks, marshes, and swamps, to tidal flats and shores. Although they primarily feed on fish, they have a varied diet that includes invertebrates, amphibians, reptiles, birds, insects, and small mammals (NAS, 2010b).

Great blue herons form pair-bonds, usually in March and April, soon after reaching their nesting grounds. Most great blue herons breed in localized colonies, sometimes up to several hundred pair. Heron colonies, often termed heronries, are typically located in treetops, bushes located in swamps, islands, peninsulas, shorelines, and less frequently, on the ground or artificial structures. Nest sites are preferentially located near foraging areas and in isolated locations that are difficult for humans and terrestrial predators to reach (Butler, 1992; NAS, 2010b). Nests constructed of sticks are lined with reeds, mosses, and grasses to support a clutch of two to six eggs. Eggs are incubated by both parents for 25 to 30 days. Both parents care for the chicks, which are fed by regurgitation. Chicks can survive on their own when they are about two months old, but they often return to the nest to be fed by the adults for another few weeks (USFWS, 2009a; NAS, 2010b).

Trends

Early in the twentieth century, great blue heron populations suffered from unrestricted hunting; however, they were much less impacted by plume hunters and pesticides than other heron species. With legal protection and greater awareness about conservation, great blue herons are among the most abundant wading birds in North America and their numbers have remained strong over a broad range. Their population in North America is estimated at 124,500 (NAS, 2010).

While they are one of the most widespread wading birds in North America, colony size is relatively small in GRTE and Wyoming (Oakleaf et al., 1996; Butler, 1992). The great blue heron is classified as a Species of Special Concern in GRTE and the state of Wyoming because of its restricted and vulnerable habitat and its sensitivity to human disturbance. Great blue herons have been monitored in GRTE since 1987. The highest reported number of active nests in GRTE was in 1992 where there were less than 60 nests. Occupancy in the park has varied widely, with overall productivity declining and many rookeries becoming inactive over time (Wolff, 2009b). Approximately 209 rookeries have been located in Wyoming, but usually less than 25 percent are active in any one year (WGFD, 2005b).

Figure 3.107. Great blue heron. Photo sources: National Park Service (Will Elder) and U.S. Fish and Wildlife Service (Gary Kramer).

Monitoring of great blue herons in GRTE in 2009 consisted of visits to seven historic heronries: North Steamboat Mountain, Oxbow, Buffalo Fork 1, Buffalo Fork 2, Bar BC, Blacktail Ponds, and Witty's. Occupancy, nesting status, and productivity were assessed through the use of spotting scopes and binoculars. Nests were classified as occupied if one or more adults were seen on or near a nest. Nests were classified as productive if young survived to within 80 percent of fledging age. Monitoring efforts in 2009 found only one active rookery, Buffalo Fork 2, in GRTE. Twelve nests were occupied at this heronry and 10 nests successfully produced 15 young (Figure 3.108). The number of nests and young fledged was slightly lower than the 10-year average. The 2009 mean was 12.7 and the 10-year average was 13.7 (Wolff, 2009b).

Although herons can become habituated to repeated non-threatening human activities, unexpected human disturbances, such as those caused by tourists or recreationists, can cause herons to be flushed from nests at distances of up to 650 feet (200 meters) (Vos et al., 1985; Carney and Sydeman, 1999). Human intrusions on heronries can influence heron occupancy, displace herons to areas of lower prey availability, disrupt nesting behaviors, increase predation, and lead to rookery abandonment (Wolff, 2009b). Therefore, most studies recommend a minimum buffer zone of 985 feet (300 meters) from the periphery of colonies during courtship and nesting season in which no human activity should take place (Butler, 1991). In addition to direct human disturbance, the availability of large, contiguous stands of cottonwood-riparian habitat required for heronries in Wyoming is restricted and vulnerable to disturbance, development, and changing land use practices (WGFD, 2005b).

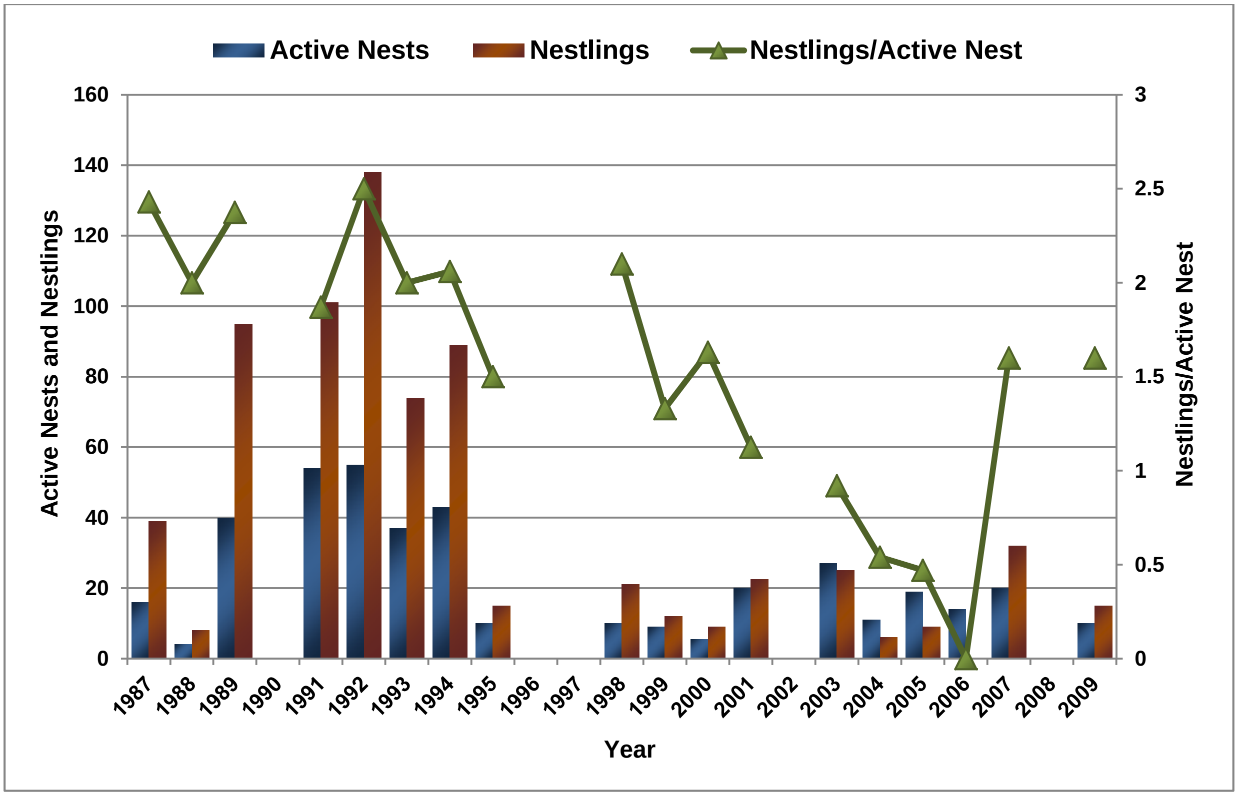

Figure 3.108. Great blue heron productivity in Grand Teton National Park, 1987-2009. Source: Grand Teton National Park (Sue Wolff).

<u>Osprey</u>

Ospreys (*Pandion haliaetus*) are large raptors, weighing 3.1 to 4.4 pounds (1.4 to 2.0 kilograms), with a dark brown back, dark brown upper wings, a mostly white breast and belly, a white crown and forehead, and a dark line through the eye (Figure 3.109). They range from 21 to 24 inches (53 to 61 centimeters) in length and have a wingspan of 4.6 to 6.0 feet (1.4 to 1.8 meters). They are about the size of a large gull, and are often mistaken for bald eagles, although the latter is larger and has an all-white head and tail. When in flight, the wings of the osprey have an obvious bend at the wrist (USGS, 2003a).

Ospreys are commonly referred to as fish hawks because they are the only raptor to almost exclusively feed on fish (Poole et al., 2002). An average adult osprey consumes approximately one pound (0.5 kilogram) of fish per day (Follett, 1987). Studies of GRTE and YELL ospreys in 1979 and 1980 found that their diets were composed of Utah sucker (*Catostomus ardens*), cutthroat trout *(Oncorhynchus clarkii*), carp and minnows (Cyprinidae), longnose sucker (*Catostomus catostomus*), and salmon (Salmonidae) (Swenson, 1979; Alt, 1980).

Figure 3.109. Osprey. Photo sources: Poole et al., 2002 (Fred Truslow) and U.S. Fish and Wildlife Service (Ferrell Clayton).

Habitat
Ospreys are found in a wide variety of habitats throughout the world, but they are primarily found near marine environments. Large inland rivers, lakes, and reservoirs also provide suitable habitat. Ospreys are found in GRTE during the summer months when they breed. They are adaptable in their choice of nesting habitat, but they require some basic conditions. Ospreys dive for fish feet first and can access only the top meter of water; therefore, they require nesting sites with nearby access to shallow waters with abundant fish populations. They also require open, generally elevated sites that are free from predators, and an ice-free season sufficient to allow fledging of young (Poole et al., 2002). In GRTE, ospreys commonly use streamside trees and dead snags in cottonwood-willow and riparian habitat as nesting sites (Marston et al., 2005; Follett, 1987). Other potential nesting sites include rocky cliffs and promontories. Although artificial nesting sites, such as utility or nesting poles, are not widely found in GRTE, ospreys will readily use such structures where they are available (Poole et al., 2002). In GRTE, osprey nests are generally found at Jackson Lake and other low elevation lakes in the park, and along the Snake River, the Gros Ventre River, the Buffalo Fork River, and their tributaries (Follett, 1987; Wolff, 2009a).

Ospreys reach sexual maturity in three years. At this time, they find a mate and generally pair for life. Males select the nesting site, and the pair returns to the same nesting site year after year. A clutch of three to four eggs are laid, which is incubated mostly by the female. While males occasionally assist the female, they primarily search for and provide food to the female during the 38-day incubation period. Offspring fledge when they are about 50 to 55 days old, but depend on their parents for nourishment for another eight weeks (USFWS, 2009b; NAS, 2010c).

Trends
Ospreys suffered from population declines due to the widespread use of DDT and other pesticides. In the United States, declines were most severe along the North Atlantic coast and in the Great Lakes region.

Following bans on the use of such chemicals in the 1970s, osprey populations have rebounded. According to the National Audubon Society, by the year 2000, most North American populations had rebounded to near-historical abundance levels, with birds reoccupying former habitats and moving into new areas. Some states, however, have not experienced such successful turnarounds, and still list the species as sensitive, threatened, or endangered (NAS, 2010c).

The osprey is considered a Species of Special Concern in GRTE due to its ecological importance as an indicator species and its population status in some parts of the country (Wolff, 2009a). Yellowstone National Park also considers the osprey to be a Species of Special Concern because of the serious downward trend of its population, which is partly attributed to the decline in cutthroat trout populations in Yellowstone Lake (NPS, 2008c). Currently available information indicates that the osprey is not a Species of Special Concern in Wyoming (WGFD, 2005b), Montana (MTFWP, 2004), or Idaho (IDFG, 2004), but as of 2000, the osprey was considered a sensitive species in at least 29 states (Mitchell and Wolters, 2000).

Osprey nest monitoring in GRTE began as early as 1972, but standardized productivity surveys have been conducted since 1990. Nest surveys take place from mid-April through July or August, until young fledge or leave the nest. A nesting territory is considered occupied if monitors observe a pair of birds in association with the nest or evidence of recent nest maintenance (Wolff, 2009a). In 2009, 10 of 19 occupied osprey nests produced 14 young, an increase from numbers seen in 2008. Compared to the 19-year average (1990-2009), the number of occupied territories and productive pairs in 2009 were higher, the number of breeding pairs and young fledged were lower, and the number of young per occupied territory and young per productive nest were slightly lower (Figures 3.110 and 3.111). Nest success was comparable to past years (83 percent compared to 65 percent, respectively). Trends over the last few decades show that the number of osprey territories has slightly declined, whereas the number of young per occupied nest has increased (Figure 3.112) (Wolff, 2009a).

Threats to osprey populations continue to be posed in countries where pesticides are not regulated. The birds are also vulnerable to the destruction of nest sites by logging; the conversion of habitat into farmland; declines in water quality and fish populations, such as the decline of cutthroat trout populations in Yellowstone Lake; shooting; and electrocution by power transmission lines and transformers (NAS, 2010c). Human activity near nesting sites may have an adverse impact on breeding success (Follett, 1987); however, if not harassed, they are reasonably tolerant of human presence, and they are not as sensitive to human presence as bald eagles or peregrine falcons (Wolff, 2009a). In many areas, ospreys have benefitted from active management, including the erection of artificial nesting platforms, and the reintroduction of birds into areas where the species had been decimated (NAS, 2010c).

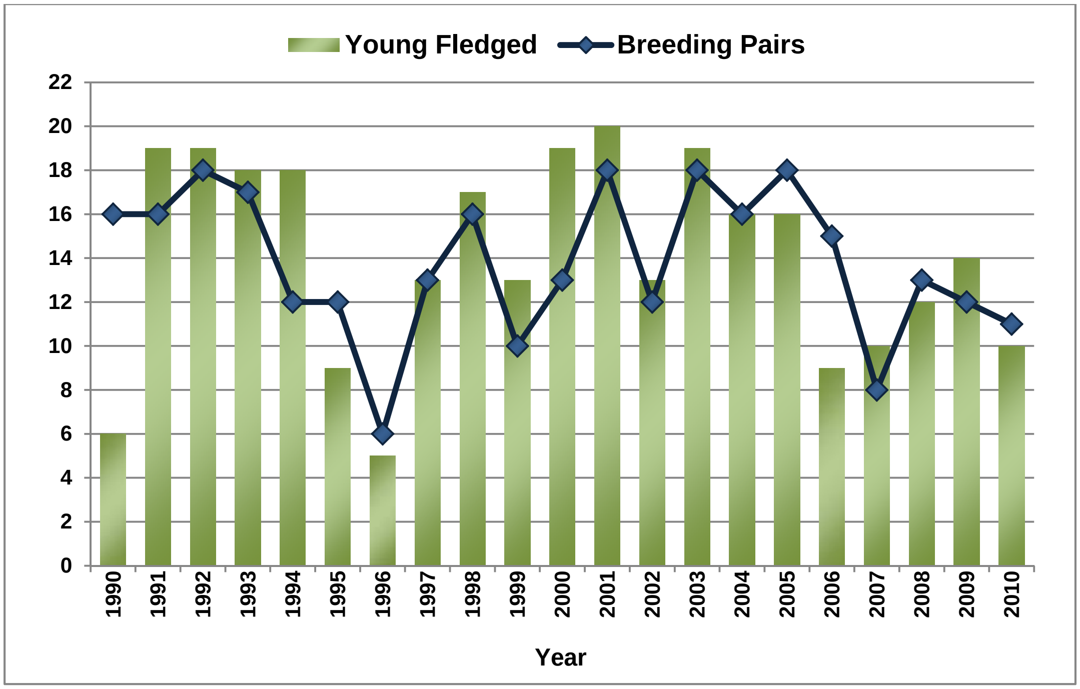

Figure 3.110. Osprey breeding pairs and young fledged counted in Grand Teton National Park, 1990-2010. Data source: Grand Teton National Park (Sue Wolff).

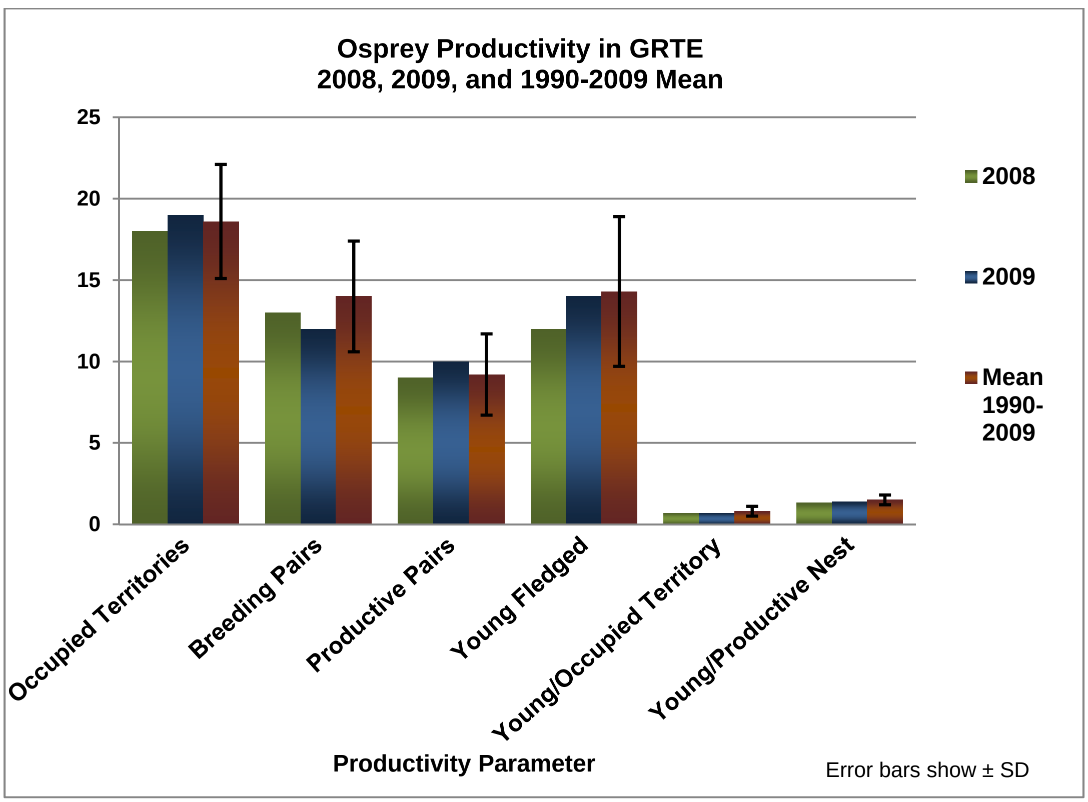

Figure 3.111. Osprey productivity in Grand Teton National Park, comparing 2008, 2009, and the 1990-2009 mean. Source: Wolff, 2009a.

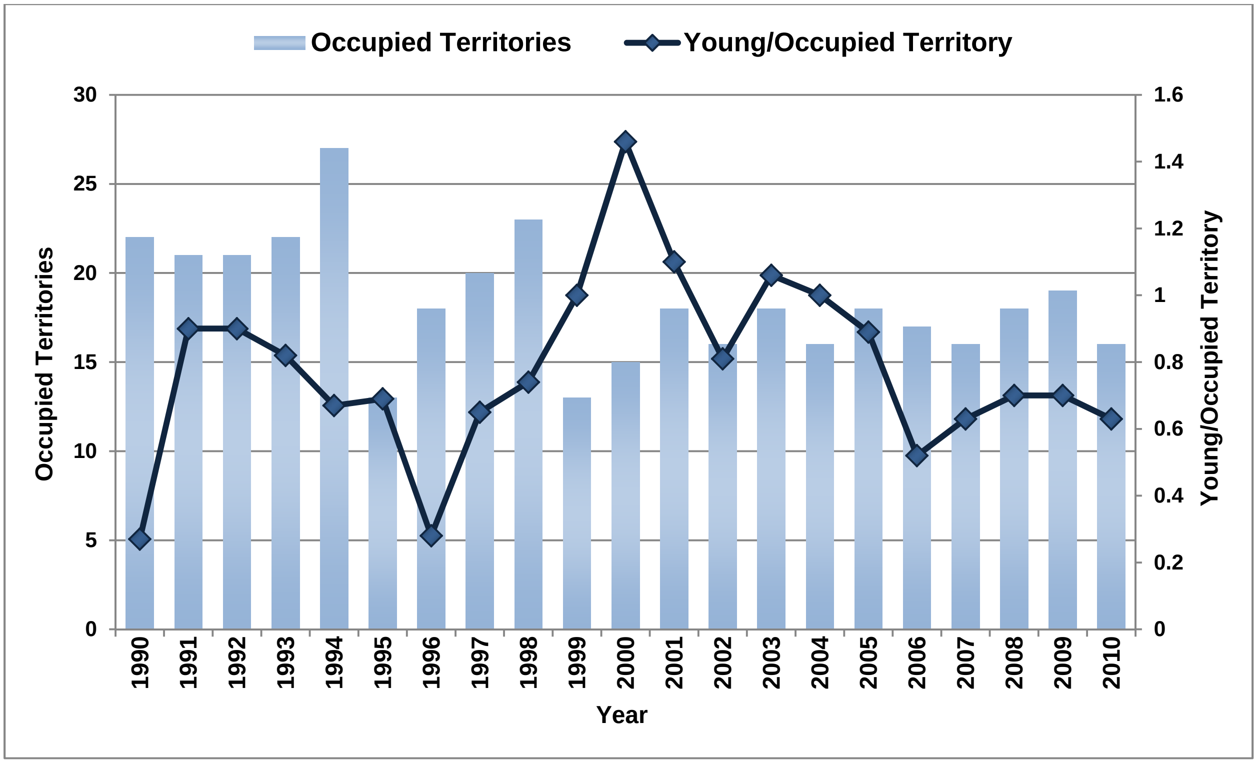

Figure 3.112. Occupied osprey territories in GRTE and young per occupied site, 1990-2010. Data source: Grand Teton National Park (Sue Wolff).

<u>Peregrine Falcon</u>

The peregrine falcon (*Falco peregrines*) is a medium-sized raptor that is slightly larger than the American crow (*Corvus brachyrhynchos*). They are characterized by a black crown and nape and a black wedge extending below the eye forming a distinctive helmet. Plumage varies, but the long, pointed wings are typically slate colored on the crown, back, and upper surface. The throat is white and the under parts are white to buff, with blackish brown bars on the sides, thighs, abdomen, underwings, and lower breast area (USGS, 2003b) (Figure 3.113). Peregrine falcons, with a wingspan of about 40 inches (102 centimeters), are celebrated as one of the fastest birds on earth. The average flight speed of peregrine falcons is 40 to 55 miles per hour (64 to 89 kilometers per hour), but they are capable of reaching speeds of 200 miles per hour (322 kilometers per hour) in controlled dives, called stoops, when striking avian prey in mid-air. They primarily hunt small and medium sized birds, especially ducks and waterfowl. For this reason, peregrine falcons have been called duck hawks. However, they are also well adapted to kill a variety of birds, including warblers, gulls, blackbirds, swallows, terns, pheasants, and even herons (McEneaney et al., 1998; Sibley, 2001; and NPS, 2008d).

Figure 3.113. Peregrine Falcon. Photo sources: National Park Service (Gary Hartley) and U.S. Fish and Wildlife Service (Steve Maslowski).

Habitat

Peregrine falcons have one of the broadest global distributions of all birds on earth, with habitat on every continent except Antarctica. One of the three North American subspecies, the American peregrine falcon (*Falco peregrines anatum*), is found in the Greater Yellowstone Ecosystem (GYE). American peregrine falcons use this area as breeding habitat from late March or early April to October. During the late fall season, GYE peregrine falcons migrate south to western Mexico and northern Central America (McEneaney et al., 1998). In the GYE, they typically nest in protected enclaves on high cliffs, greater than 150 feet (46 meters), that provide commanding views of meadows, rivers, or valleys where prey is abundant. However, they prey on smaller birds and forages in a variety of other open habitats, from open woodlands and forests to shrub-steppe, grasslands, and marshes (NPS, 2008d; WGFD, 2005a).

Peregrine falcon pairs are territorial and generally will not tolerate another peregrine falcon nest, or eyrie, within a few miles. Territory size varies depending on prey abundance and nest site availability (NPS, 2008d). Nests are selected by females and are generally founded on cliff ledges with vegetation and under an overhang. Sites with a southerly exposure are preferred. Females scrape a shallow hollow, usually in the loose soil, sand, gravel, or dead vegetation, in which to lay their eggs. Peregrine falcon eyries in the GYE have been found at elevations as high as 10,220 feet (3,115 meters) on Colter Peak in the Absaroka Range (McEneaney et al., 1998).

Peregrine falcons breed in the GYE from early April to early May, and females typically lay three to four eggs about two weeks after breeding (McEneaney et al., 1998; Ratcliffe, 1993). Factors affecting annual productivity include egg and chick mortality from cold, wet, and late spring weather, and prey availability (NPS, 2008d). On average, only one or two nestlings live long enough to fledge from the nest. Both parents care for the young, though females are present on the eggs for most of the incubation period, which may last from 28 to 37 days. Peregrine falcon nestlings, or eyasses, spend five to six weeks in the nest after hatching. Eyasses typically fledge in August, but may remain dependent upon their parents for an additional six to 15 weeks (NPS, 2008d).

Trends

Peregrine falcon populations in the United States were severely affected by the widespread use of DDT and other pesticides. DDT was sprayed in and around the GYE in the 1950s to combat spruce budworm infestations. Raptors, such as peregrine falcons, became contaminated by consuming prey that had eaten grain or insects treated with pesticides, thereby being exposed to much higher levels than were found in the air or water. Heavily contaminated female raptors failed to produce eggs, laid thin-shelled eggs that broke before hatching, or passed organochlorines to the egg, which caused the embryo to die. By the 1960s, peregrine falcons were considered extirpated from the GYE (Wolff, 2009a). In 1970, the U.S. Fish and Wildlife Service listed the peregrine falcon as an endangered species under the Endangered Species Conservation Act of 1969, a precursor of the Endangered Species Act of 1973. The banning of DDT in 1972 and protections afforded by the Endangered Species Act led to the recovery of the peregrine falcon throughout most of its range in the United States. In 1999, the U.S. Fish and Wildlife Service de-listed the species (Green et al., 2006).

Surveys conducted in the late 1970s concluded that no peregrine falcon nests were occupied in Idaho, Montana, or Wyoming. Subsequently, peregrine falcon reintroduction programs were initiated in the GYE. In 1980, 11 juveniles at three sites in Jackson Hole were released; in 1981, four juveniles in Centennial Valley, Montana, were released; in 1982, the state of Idaho released eight juveniles at two sites on the western edge of the GYE; and in 1983, the Wyoming Game and Fish Department released four juveniles in YELL. By 1986, 52 peregrine falcons had been released in GRTE, and by 1988, 36 had been released in YELL (NPS, 2008d; Wolff, 2009a). The first verified nesting attempt in GRTE occurred in 1987 and the first successful breeding in GRTE occurred in 1988.

Despite an abundance of potential nest sites within GRTE, peregrine falcon populations in the park have remained relatively small. Annual surveys conducted since 1990 have identified four eyries in GRTE located at Garnet Canyon, Webb Canyon, and by Glade Creek. Nest surveys take place from May through July or August. A nesting territory is considered occupied if a pair of birds is observed in association with the nest or there is evidence of recent nest maintenance (Wolff, 2009a). Eyries at Garnet Canyon, Webb Canyon, and by Glade Creek were occupied by nesting pairs from 2005 to 2008, producing three fledglings in 2005, none in 2006, one in 2007, and none in 2008 (NPS, 2008d; NPS, 2010k). In 2009, eyries at Webb Canyon and Glade Creek each produced two chicks. No eyrie was located at Garnet Canyon (Wolff, 2009a). In 2010, an eyrie was found at the mouth of Cascade Canyon. Peregrine falcons have also been reported in Death Canyon and Hanging Canyon and west of String Lake, but no eyries have been found in these territories (Wolff, 2009a).

Peregrine falcon productivity in GRTE has been low but relatively stable over the last 15 years. During the last decade, between one and three eyries have been occupied in GRTE each year. Nest success has varied and the number of young per productive pair in the park (0.67) has been lower than that reported in the state of Wyoming (1.6) (Wolff, 2009a). The low productivity rate and small number of peregrine falcon territories in GRTE may be due to the short breeding season, harsh spring weather, or other unknown factors (NPS, 2010k).

Peregrine falcons have been perhaps more successful in the GYE when compared to GRTE. Significant gains have been made in the states of Wyoming, Idaho, and Montana (McEneaney et al., 1998), and in YELL, which boasts one of the highest concentrations of nesting peregrine falcons in the northern Rocky Mountains (NPS, 2008d). The number of nesting pairs in YELL has increased steadily since reintroduction efforts began in 1983. In 2007, there were 32 known nesting pairs in YELL that produced 47 fledglings, the largest number of nesting pairs recorded in YELL (NPS, 2010k).

Although peregrine falcons have few natural threats, they continue to face anthropogenic threats. Threats to peregrine falcons include environmental contamination by certain flame retardant chemicals, particularly polybrominated diphenyl ethers (PBDEs), which are used in electronic equipment, textiles, paints, and many other products. PBDEs easily leach into the environment and can concentrate in birds of prey, impairing their reproductive biology (NPS, 2010k). Although nest success rates and productivity in the GYE remains relatively high, long-term monitoring could include sampling of eggshell fragments to determine toxin concentrations. In addition to environmental contamination, peregrine falcons are also highly sensitive to human disturbance. The impact of rock climbers following routes that support peregrine falcon forage, roosting, and nest sites can be particularly severe in remote areas where they are not habituated to human presence (NPS, 2008d).

Greater Sage-Grouse

The greater sage-grouse (*Centrocerus urophasianus*) is the largest species of grouse in North America, standing 22 to 30 inches (56 to 76 centimeters) tall and weighing up to seven pounds (3.2 kilograms). The adult male has a dark gray back, black throat, white breast, and black belly. In full display, a yellow air sac is inflated from underneath the white breast feathers, the tail is fanned, and feather plumes are erected on the head. The female is smaller than the male, with a brown throat and breast, a black belly, and lacks the ornate head plumes and yellow air sac (Figure 3.114) (NAS, 2010d; Knick and Schuler, 2009a; USFWS, 2010c).

Habitat

Greater sage-grouse are strongly tied to the sagebrush habitats of western North America. They depend on relatively large expanses of sagebrush-dominated habitat intermixed with an understory of native grasses and forbs. Three subspecies of big sagebrush, two species of low sagebrush, and silver sagebrush are most important for greater sage-grouse (Knick and Schuler, 2009b). Greater sage-grouse have large annual ranges that can exceed 1,000 square miles (2,590 square kilometers) (Knick and Schuler, 2009b). Lek sites, which are gathering sites for display and courtship, tend to occur in less vegetated areas; nesting sites are found in areas dominated by various sagebrush species (NAS, 2010d); and wintering sites typically occur at lower elevations on south- to west-facing slopes where sagebrush is most available (Holloran and Anderson, 2004).

Figure 3.114. Greater sage-grouse. Photo sources: Idaho Department of Fish and Game (Brian Currie) and USDA Natural Resource Conservation Service.

Greater sage-grouse have been the subject of research because of their elaborate courtship displays. Large numbers of males, ranging from 14 to 70 birds, gather in the spring at leks to conduct elaborate courtship displays for groups of females. Males fan their pointed tail feathers, erect their head plumes, strut forward, and produce a series of “wing swishes,” “air sac plops”, and a whistle. If a female is interested in a particular displaying male, she will solicit a copulation from him. As is typical with a lek mating system, male greater sage-grouse do not provide females with any resources after mating, and do not provide any type of parental care (NAS, 2010d; Knick and Schuler, 2009a).

In late spring, after courtship, females move into nesting habitat, usually some distance from the lek site, with increased sagebrush canopy cover and height, residual grass cover, and a diversity of forbs (Holloran and Anderson, 2004). Females build ground nests, usually in association with some vertical structure, such as overhanging sagebrush, and lay an average of six to nine eggs. Eggs are incubated for 25 to 29 days before they hatch. The chicks are precocial, meaning that they are capable of leaving the nest shortly after hatching. While they receive some parental care from the female, they are capable of feeding on their own (NAS, 2010d; Knick and Schuler, 2009a). The diet of greater sage-grouse primarily consists of sagebrush species leaves; however, grasshoppers, beetles, and ants are important food sources for young and occasionally for adults during summer months (NAS, 2010d).

Trends

Once widespread over much of western North American, the range of greater sage-grouse has been greatly reduced during the past 200 years. The historic range of greater sage-grouse included portions of 16 states and three Canadian provinces. Presently, greater sage-grouse are found in 11 states: Washington, Oregon, Idaho, Montana, North Dakota, eastern California, Nevada, Utah, western Colorado, South Dakota, Wyoming; and two Canadian provinces: Alberta and Saskatchewan (Figure 3.115). It has been estimated that they occupy only 56 percent of their historical range (USDA, 2009a; USFWS, 2010c).

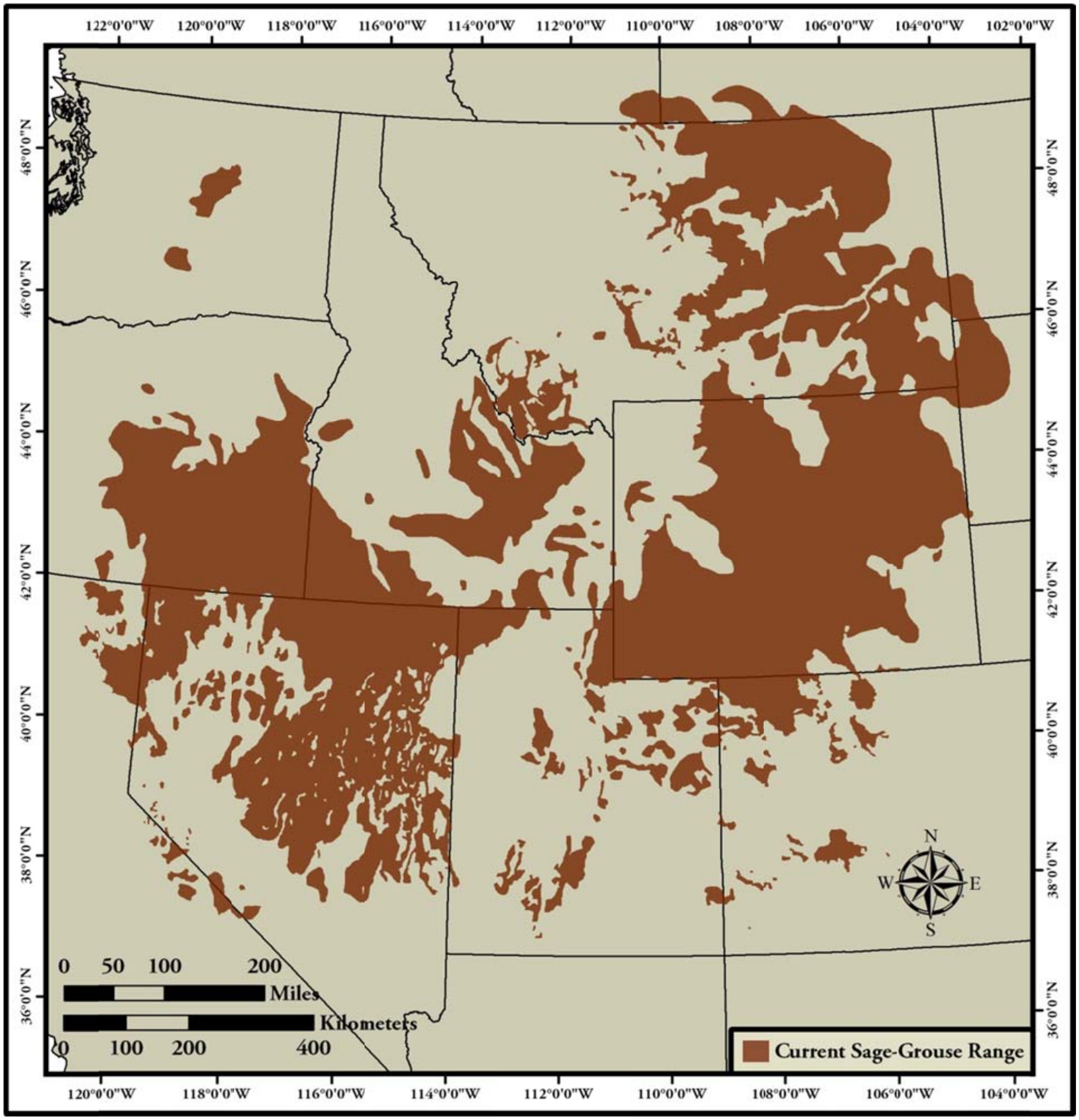

Figure 3.115. Current greater sage-grouse range. Data source: Wyoming Game and Fish Department.

Despite their broad distribution, greater sage-grouse numbers have declined in many areas as a result of multiple factors. Habitat fragmentation, degradation, and loss caused by altered fire regimes, invasion by exotic annuals (e.g. cheatgrass), residential development, conversion to agriculture, oil and gas development, and improper livestock grazing have contributed to declines (NPS, 2009i; Knick and Schuler, 2009b). Over the past decade, the U.S. Fish and Wildlife Service (USFWS) received numerous petitions to list the greater sage-grouse under the Endangered Species Act. In response to the most recent petition, in March 2010, the USFWS proposed not to list greater sage-grouse, deeming them "warranted, but precluded by higher priority listing actions" (USDI, 2010). Although the species has not been federally listed, greater sage-grouse are considered a Species of Special Concern in Wyoming (WGFD, 2005b), Idaho (IDFG, 2004), and Montana (MTFWP, 2004).

Greater sage-grouse were common in the Jackson Hole region in the late 1800s, but sage-grouse numbers have also declined in this area even though most of the land is federally administered and protected from development. The present distribution of the Jackson Hole population covers the southern portion of Teton County, Wyoming, with several of the currently occupied and historic leks occurring within the boundary of GRTE. The Jackson Hole greater sage-grouse population is non-migratory, as all of their seasonal needs are met within local habitats (NPS, 2009i).

Biologists from GRTE, the Wyoming Game and Fish Department, and other collaborators have conducted annual lek counts of greater sage-grouse in the Jackson Hole area since the 1940s (NPS, 2009i). Between early March and mid-May, historic leks are visited to assess grouse occupancy. Once sage-grouse are present at leks, bi-weekly visits are conducted to count male and female attendance and to document behavior, number of copulations, and predator activity (Wolff, 2008b).

There are approximately 15 documented lek sites in and around GRTE (Figure 3.116). Four of these leks were consistently occupied during the 2008 breeding season: Airport, Moulton East, Timbered Island, and RKO. Three other leks, Airport Pit, Bark Corral, and Spread Creek, were occupied inconsistently by few birds. Four historically occupied leks, Antelope Flats, Beacon, McBride, and Circle EW, were inactive and possibly abandoned (Wolff, 2008b).

During the last decade of monitoring, helicopter surveys for new leks have been conducted in conjunction with traditional ground-based surveys. Three new leks have been located within or relatively near GRTE, including one each in GRTE, the National Elk Refuge, and the Gros Ventre drainage (NPS, 2009i). Holloran and Anderson (2004) have suggested that the Gros Ventre sage-grouse population occupying the upper Green River and Gros Ventre River drainages may be a potential source of immigration into GRTE.

Even with decades of monitoring data, it has been difficult to substantiate a population trend for greater sage-grouse because of variations in survey efforts. However, based on the data, a few assumptions can be made. Between 1949 and 2003, a precipitous decline in greater sage-grouse counts, both within GRTE and throughout Jackson Hole, was observed. During this period of time, the Jackson Hole population declined 73 percent, from approximately 500 birds to less than 182 birds (Holloran and Anderson, 2004). Within GRTE specifically, attendance at known leks dropped by 75 percent. However, between 1950 and 2001, GRTE monitoring surveys did not involve searching for new leks within the park. Therefore, sage-grouse counts in GRTE during these years may have been underestimated. Nonetheless, biologists have been concerned because sage-grouse numbers declined despite the high proportion of public lands and protected habitat. These lands had also not experienced the impacts commonly associated with greater sage-grouse declines (Wolff, 2003).

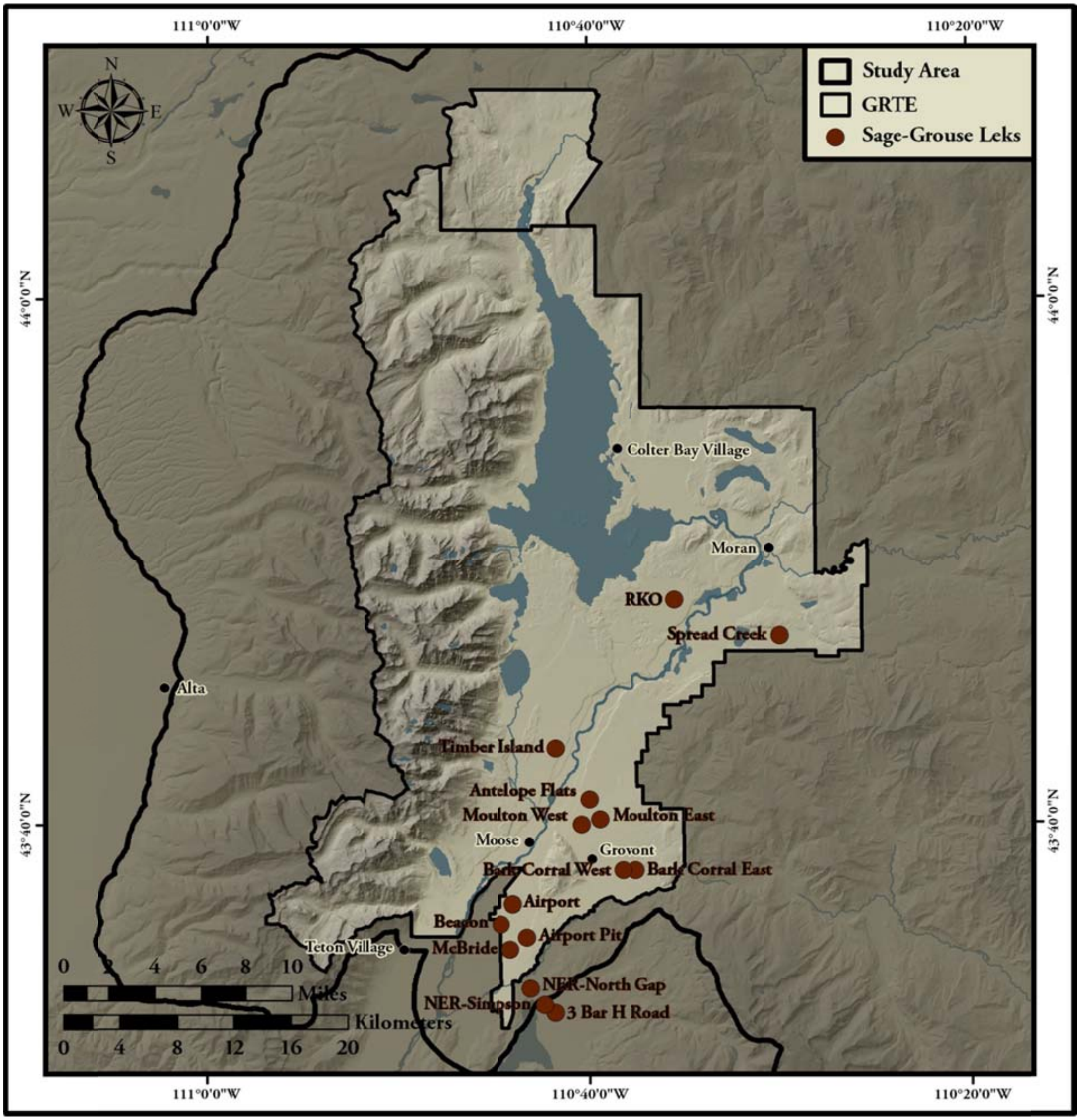

Figure 3.116. Location of greater sage-grouse leks in and around Grand Teton National Park. Data source: Wyoming Game and Fish Department.

Although sage-grouse populations are well below historic averages and have showed a decreasing trend since surveys were initiated, annual counts for sage-grouse in GRTE have been showing a slight increasing trend since 1999, but since 2005, population counts have been variable (Figure 3.117). In 2008, the maximum number of males counted in GRTE was 103. The female count increased from 28 in 2005 to 72 in 2008 (NPS, 2009i). The maximum count of males in 2008 at nine leks in GRTE was near or above the 11-year average (1998 to 2008) (Figure 3.118). Of the four leks occupied, Moulton East had the highest male count (n=38), followed by Timbered

Island (n=26), Airport (n=16), and RKO (n-12). Male counts at Moulton East, Timbered Island, and Bark Corral were above average, but the Airport lek was below the 11-year mean. Female grouse counts were highest at Airport (n=25), followed by Moulton East (n=24), Timbered Island (n=18), and RKO (n=5) (Wolff, 2008b).

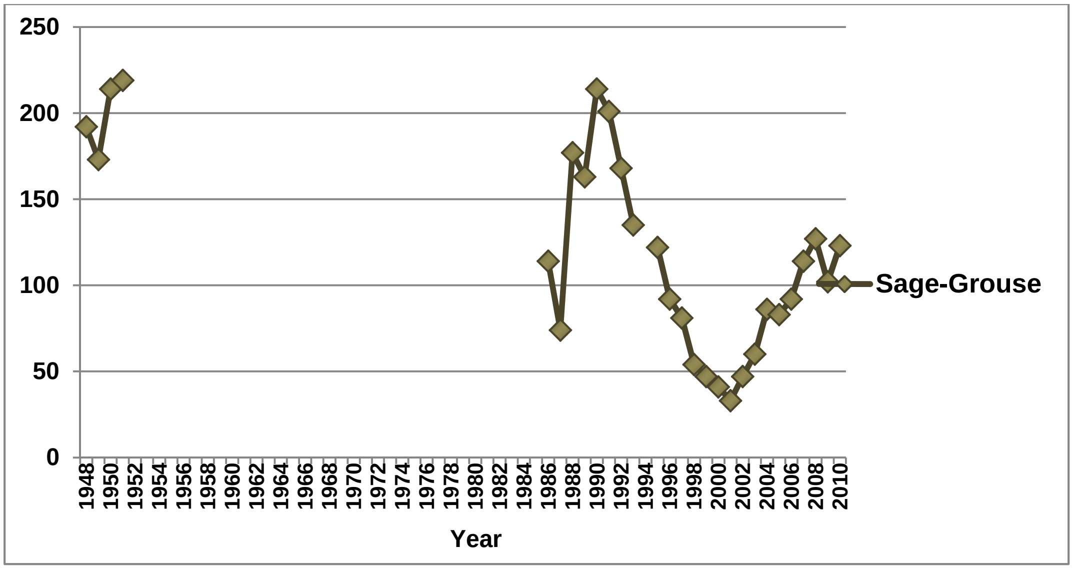

Figure 3.117. Maximum counts of male greater sage-grouse at area leks, 1948-1951 and 1987-2010. Data source: Grand Teton National Park (Sue Wolff).

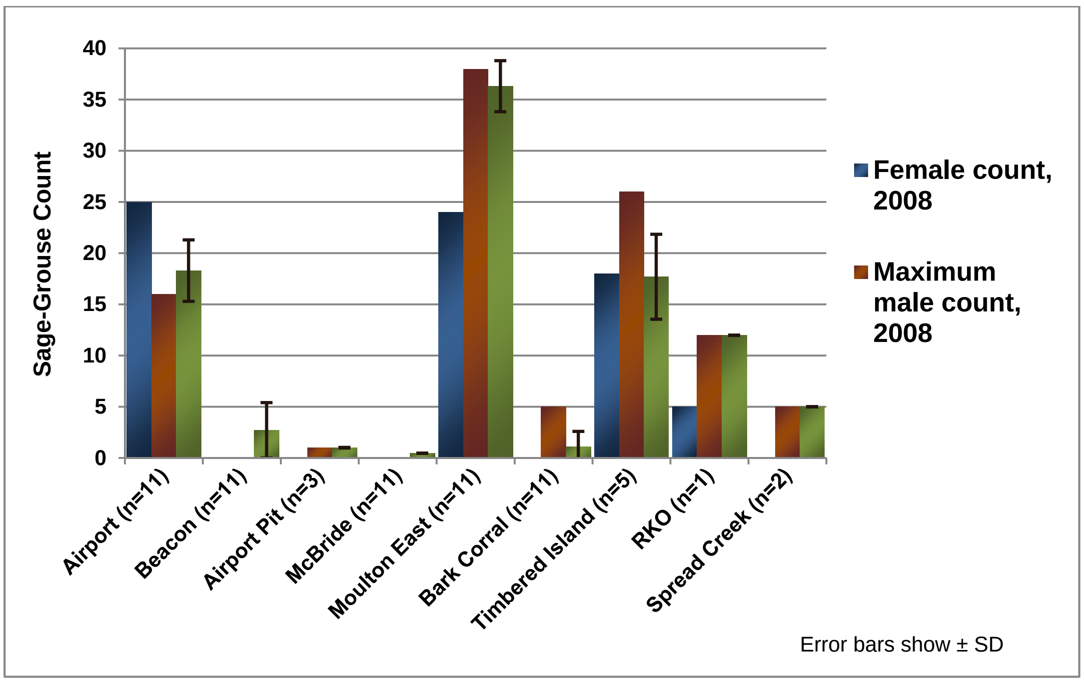

Figure 3.118. Maximum counts for male and female sage-grouse at leks in Grand Teton National Park in 2008. The x-axis denotes the lek site and number of years observed between 1998 and 2008. Female counts were not available for all lek sites. Source: Wolff, 2008b.

In GRTE, sage-grouse declines have been correlated with predation and with habitat loss and fragmentation that has resulted from fire, livestock grazing, and land development. Additionally, depending on snow levels and the availability of sage-brush, winter habitat may be a limiting factor on population growth in the Jackson Hole area (Holloran and Anderson, 2004). These factors, when combined with the relative isolation and small numbers of greater sage-grouse in the Jackson Hole area, may threaten population viability. Consequently, biologists and land managers have recommended limiting prescribed fires and enforcing seasonal closures around active leks. Current research is being conducted to determine the impacts of predators, such as the common raven, on sage-grouse productivity and brood survival. Additional research is needed to identify ways to protect the remaining population (NPS, 2009i).

<u>Trumpeter Swan</u>

The trumpeter swan (*Cygnus buccinator*) is the largest species of waterfowl in North America, weighing up to 30 pounds (13.6 kilograms) and having a wingspan of seven to eight feet (2.1 to 2.4 meters). They stand four feet (1.2 meters) tall, measuring up to five feet (1.5 meters) from bill to tail. Trumpeter swans are distinctive for their trumpet-like call and all-white plumage (Figure 3.119). Young birds are gray to brownish, with mottled pink and gray bills, but they attain the all-white adult plumage after the first year (NAS, 2010e).

Habitat

Previous to European settlement, the distribution of trumpeter swans was widespread throughout North America (Alison, 1975), but overharvest and habitat destruction caused significant reduction in numbers and range (Banko, 1960). By the early 1930s, trumpeter swans were nearly extirpated from the lower 48 states except for a population in the GYE (NPS, 2010l). The current trumpeter swan population is largely based in Alaska and the western Canadian provinces; however, the birds also breed locally in many areas across the Rockies and western plains (NAS, 2010e).

The distribution of trumpeter swans is divided into three North American populations: the Pacific Coast Population, the Interior Population, and the Rocky Mountain Population (Figure 3.120) (Proffitt et al., 2009). The Rocky Mountain Population is composed of several subpopulations that breed in different locations: the GYE, the Grand Prairie-Peace River region of Alberta, and the eastern portions of British Columbia and the Yukon Territory. The two Canadian subpopulations are large (approximately 5,000) and growing, whereas the GYE subpopulation is comparatively small (400 to 500) (Oyler-McCance et al., 2007) and has remained stable over the past 40 years (Proffitt et al., 2009). In winter, all of these subpopulations nest in the GYE, where the trumpeter swans use waters kept ice free by springs, geo-thermal activity, and outflow from dams (NPS, 2010l).

Trumpeter swans breed on shallow bodies of water with plenty of vegetation, including freshwater marshes, ponds, lakes, and slow moving rivers. In the GYE, they nest in habitats with some or all of the following features: open, slow moving, shallow water with highly irregular shorelines (Mitchell and Eichholz, 2010; YELL, 2010a); sufficient room for take-off (greater than 328 feet or 100 meters); banks with little or no shrub cover; abundant, diverse, and accessible aquatic vegetation; greater than 75 percent open water in winter, with freezes occurring only intermittently and for less than two consecutive days; and little or no human disturbance (Lockman et al., 1987).

Figure 3.119. Trumpeter swans. Photo sources: U.S. Fish and Wildlife Service.

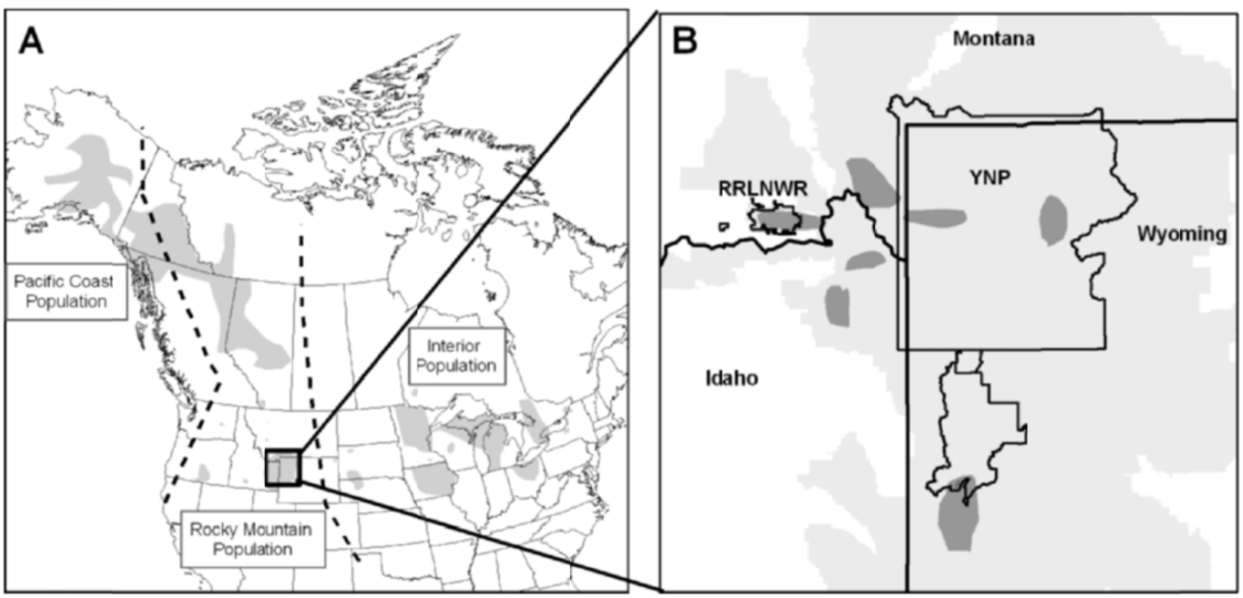

Figure 3.120. Approximate ranges (light grey) of the Pacific Coast, Rocky Mountain, and Interior trumpeter swan populations (a), 1967-2007. Detail of the Greater Yellowstone Ecosystem subpopulation range (b). Red Rocks Lake National Wildlife Refuge (RRLNWR), an important winter range area (dark grey), is to the west of Yellowstone National Park (labeled YNP in this figure) and Grand Teton National Park. Source: Proffitt et al., 2009.

Compared to birds with shorter life spans, trumpeter swans are slow to breed. While birds may pair off in their second year of life, they may not breed until their seventh year. Trumpeter swans remain paired for life and both parents build a large nest, often on a raised mound, island, or even a beaver lodge. Once completed, females typically lay four to six eggs in June. When cygnets emerge, they are brooded by the female for another 24 to 48 hours before being led to feeding grounds. While cygnets can feed themselves, the parents often assist by treading in shallow water to rouse invertebrates. Young trumpeter swans cannot fly until they are 100 to 120 days old, and although they fledge in September or October, a family group usually remains together throughout the first winter (NPS, 2010l; NAS, 2010e).

Like many other species of waterfowl, trumpeter swans primarily feed at night (Squires and Anderson, 1995). They are primarily herbivorous; they forage in shallow water to reach submerged aquatic vegetation, fish, or small invertebrates. They also graze on land, particularly in winter, picking up grasses, seeds and grains, and occasionally digging for roots and tubers (NAS, 2010e). In the GYE, trumpeter swans feed on *Chara* species, Canadian waterweed (*Elodea canadensis*), and the tubers of sago pondweed (*Potamogeton pectinatus*). Such leafy aquatic vegetation is low-quality forage which is quickly passes through the digestive tract at the expense of digestive efficiency; therefore, trumpeter swans wintering in the GYE spend more than half of their time foraging (Squires and Anderson, 1995).

Trends

By the early 1930s, it was estimated that only 69 trumpeter swans remained south of the United States-Canada border. Since 1940, the species has been recovering slowly. Federal protection under the Migratory Bird Act of 1918 and numerous conservation efforts have been successful in increasing populations and reintroducing birds into areas that have not been occupied in decades. According to the National Audubon Society, the current global population is estimated at 34,803 (NAS, 2010e).

In the GYE, GRTE is located in the GYE subpopulation's Snake River Core Area (Snake River Basin) and provides important habitat for nesting trumpeter swans. During the past decade, nesting pairs in GRTE comprised of 30 to 40 percent of the total number of occupied sites in the Snake River Core Area, or 23 percent of all occupied sites in western Wyoming outside of YELL (Figure 3.121). Over the same period, nesting pairs in GRTE have fledged an average of 5.6 cygnets per year, accounting for 16 percent of production in western Wyoming. Although the number of nest territories has varied, and a few new nest sites have been established, swan pairs have disappeared from some traditional sites that had been occupied for decades. Reasons for these changes may include drought, human activities, and increased predation by recovering populations of predators (Wolff, 2008c).

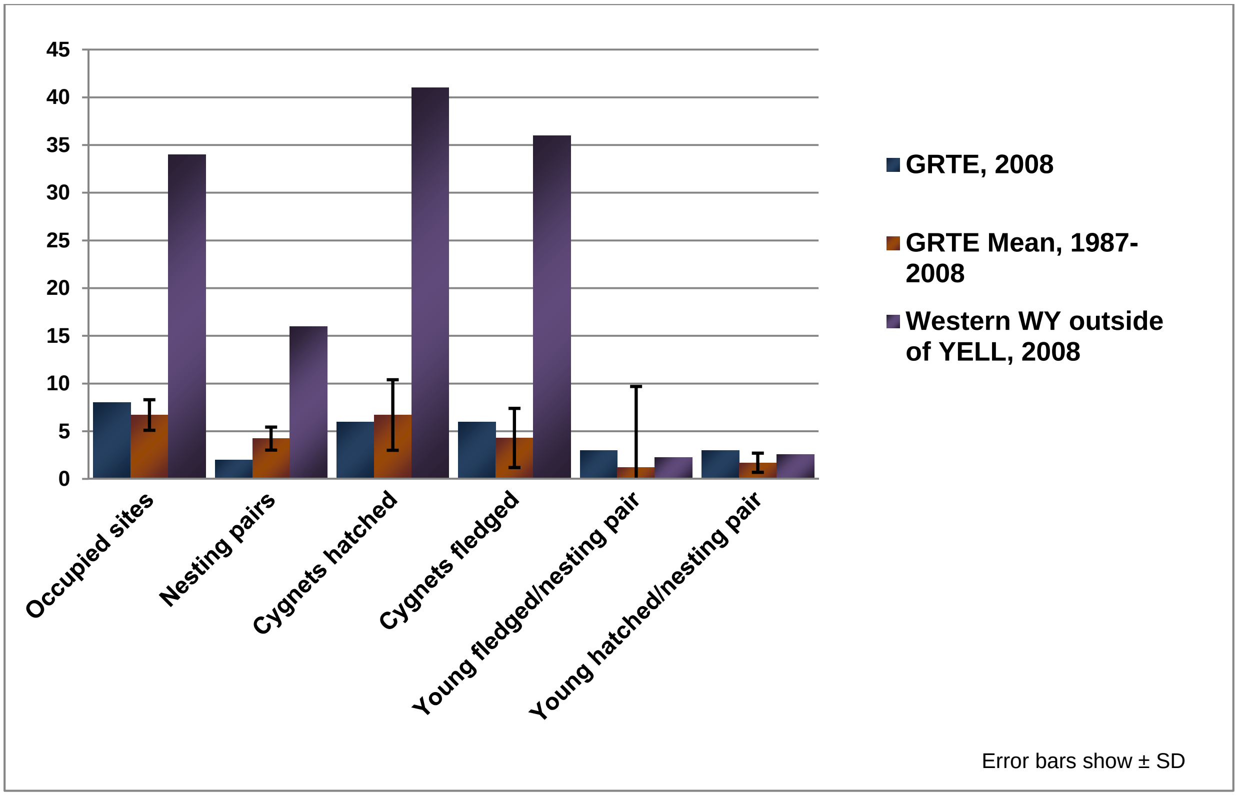

Figure 3.121. Trumpeter swan productivity in Grand Teton National Park and western Wyoming outside of Yellowstone National Park in 2008. Source: Wolff, 2008c.

While the size of the GYE subpopulation has remained relatively stable over the last 40 years, trumpeter swans are nonetheless considered a Species of Special Concern in Wyoming (WGFD, 2005b), Idaho (IDFG, 2004), and Montana (MTFWP, 2004). Additionally, trumpeter swan numbers in some areas of the GYE have experienced declines. For instance, only four resident adult trumpeter swans were recorded in YELL in 2009, the lowest on record since 1931 (NPS, 2010l). Reasons for slow growth rates in the GYE subpopulation likely have several contributing factors. First, certain characteristics of trumpeter swan breeding biology have contributed to re-establishment difficulties. Since the species is long lived, reaching over 30 years of age, trumpeter swans are slow to breed. Second, recent drought in the GYE has reduced wetland area; consequently, this reduction may be a limiting factor within YELL and GRTE. Third, resident swans may also be unable to successfully compete with migratory flocks for habitat, and marginal winter habitat in the GYE may not provide enough aquatic vegetation for current numbers of wintering swans, Canadian geese, and ducks (NPS, 2010l).

In GRTE, biologists have monitored annual territory occupancy, nesting status, and cygnet survival since 1987. In 2008, 13 trumpeter swan breeding territories were monitored. Swan pairs occupied eight territories and nested at two sites: Pinto Ponds and Swan Lake. Four cygnets fledged from Pinto Ponds, a site that has historically had high rates of nest success and cygnet survival. The pair at the Swan Lake territory relocated its nest to a nearby area with less human disturbance than the former nest site. This site successfully fledged two cygnets in 2008, the first time this site produced young since 2004 (Wolff, 2008c).

While the number of occupied trumpeter swan sites in GRTE has slowly increased over the last 10 years, the number of nesting pairs has not increased commensurately (Figure 3.122). Meanwhile, rates of nest success (percentage of nests that successfully produce young) and cygnet survival have trended upward over the last 20 years (Wolff, 2008c).

Proffitt et al. (2009) found that YELL acts as a sink for swans dispersing from more productive areas within the GYE, and recommended that the National Park Service pursue a management agenda integrated with agencies controlling more productive areas within the GYE. Such a management recommendation would be applicable to GRTE insofar as analogous dynamics describe the function of the park in the context of trumpeter swan behavior and habitat use in the GYE.

Management objectives should also integrate mitigation strategies for continuing threats. Trumpeter swans are particularly sensitive to human presence and activity, and human disturbance can prove fatal to chicks on breeding grounds and weakened adults in winter. The species is also highly susceptible to lead poisoning. Research has demonstrated that hundreds of trumpeter swans die each winter from the effects of ingested lead shot. Although lead shotgun pellets are illegal for waterfowl hunting, they remain legal for other purposes. A disproportionate number of trumpeter swans acquire lead poisoning on hunting grounds when feeding (NAS, 2010e).

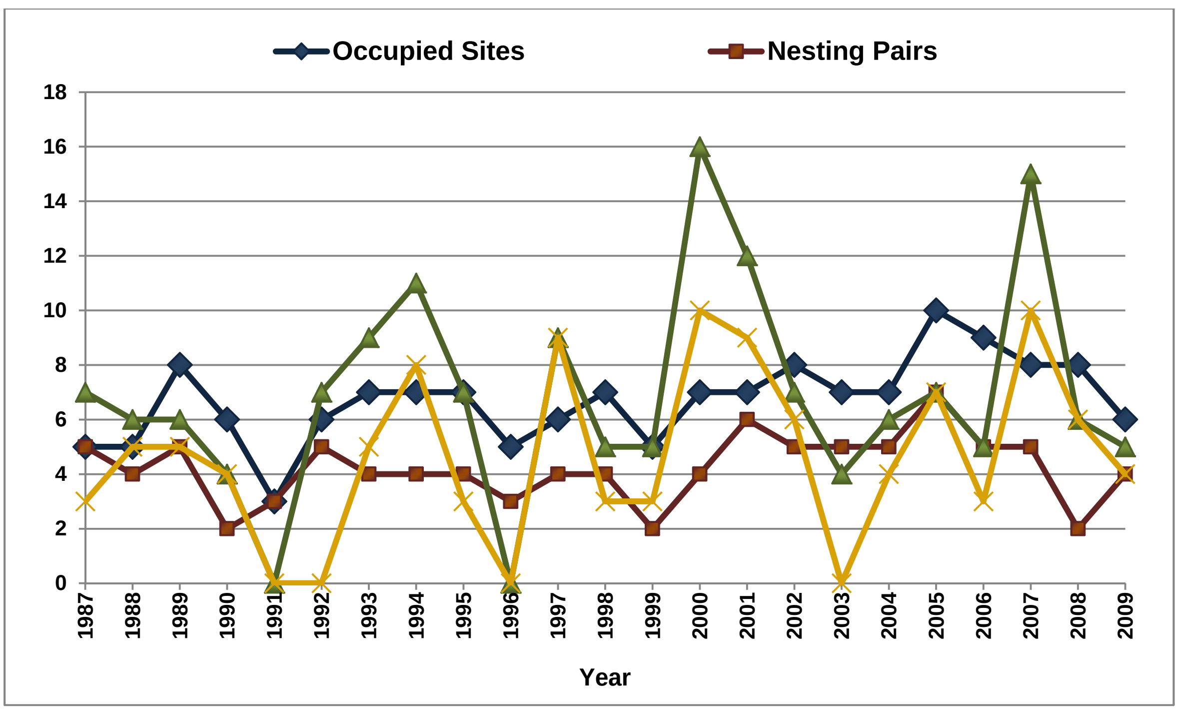

Figure 3.122. Trumpeter swan productivity in Grand Teton National Park, 1987-2008. Source: Wolff, 2008c.

Fishes

Fish assemblages, which are groups of species that co-occur in the same area, are structured by local, regional, and historical processes operating at various spatial and temporal scales (Maret, 1999). Environmental conditions, such as elevational gradients and thermal characteristics, also have a substantial influence on the occurrence of species (Quist et al., 2004). Lotic systems in the Rocky Mountain region of North America differ from those in the east with regard to processes and environmental conditions, and therefore differ in fish assemblage complexity. Fish assemblages are comparably depauperate in the western United States (Quist et al., 2004; Maret, 1999) and are assumed to be shaped by broadscale factors such as selective extinctions during the late Pleistocene; recolonization pattern; long-term zoogeographic barriers, such as waterfalls and mountain ranges; broad climatic conditions; intermediate or stream scale climatic and geomorphological factors such as stream gradients; and site scale features such as adequate resting refugia (Mebane, 2002).

Fish assemblages in GRTE are typical of intermountain cold waters and consist of relatively few species (Mott, 1998). They consist of members from the Salmonidae family; the Cyprinidae or minnow family; the Catostomidae or sucker family; and the Cottidae or sculpin family. The Salmonidae family includes trout, salmon, char, and whitefishes and is confined to the cooler waters of the northern hemisphere. Salmonids evolved from living in cold, nutrient-poor waters of glaciated areas and have subsequently colonized many coastal and headwater streams and coldwater lakes in North America and Eurasia. The Cyprinidae or minnow family is one of the most abundant and widely distributed groups of freshwater fishes. In North America, there are approximately 300 species, many of which are important ecologically and economically. They provide the link in the aquatic food chain from algae or aquatic invertebrates to larger fish species that are sought after for food and recreation (NVDCNR, 2010).

The Catostomidae or sucker family is restricted to North America, with the exception of one species in China. Catostomids are close relatives of minnows, apparently having evolved from cyprinid ancestors. Many species of suckers, especially in the arid western United States are long-lived, with some living more than 50 years. The Cottidae or sculpin family contains both marine and freshwater fish species, with all adapted to living at the bottom of water bodies. Sculpins are scaleless, but some have sharp prickles over most of their body. Sculpins are typically only a few inches in length, have a large flattened head, large eyes, and fan-like pectoral fins. They have large mouths with small teeth and are voracious feeders on aquatic invertebrates. They are inactive during daylight hours and feed at night (NVDCNR, 2010).

It is estimated that there are 13 native fish species and five non-native fish species in GRTE (Mott, 1998; Novak et al., 2005; WGFD, 2010a). The native fish fauna includes: Snake River cutthroat trout (*Oncorhynchus clarkii* spp. or *Oncorhynchus clarkii behnkei*), Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*), longnose dace (*Rhinichthys cataractae*), speckled dace (*Rhinichthys osculus*), mottled sculpin (*Cottus bairdii*), Paiute sculpin (*Cottus beldingii*), bluehead sucker (*Catostomus discobolus*), mountain sucker (*Catostomus platyrhynchus*), Utah sucker (*Catostomus ardens*), mountain whitefish (*Prosopium williamsoni*), redside shiner (*Richardsonius balteatus*), northern leatherside chub (*Lepidomeda copei*), and Utah chub (*Gila atraria*) (Table 3.45). The Snake River cutthroat trout is often grouped with the Yellowstone cutthroat trout because the two subspecies cannot be genetically distinguished (Gresswell, 2009). However, recent studies have suggested that the Snake River cutthroat trout is a morphologically divergent ecotype of the more broadly distributed Yellowstone cutthroat trout. Behnke (1992) also contended that the Snake River cutthroat trout constituted a separated subspecies because of its distinctive and abundant tiny spots and its characteristic life history (NPS, 2006h).

The non-native fish fauna in GRTE includes: rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinus fontinalis*), lake trout (*Salvelinus namaycush*), brown trout (*Salmo trutta*), and Arctic grayling (*Thymallus arcticus*) (Table 3.46). In western Wyoming, non-native fish species, as well as some native fish species, such as Utah suckers, Utah chubs, redside shiners, and speckled dace, are expanding in range. The introduction and expansion of non-native fish populations have probably resulted in reduced native fish populations. Non-native species may suppress native fish populations through competition, hybridization, and/or predation. Additionally, introduced piscivorous (fish-feeding) game fish, such as brown trout, may detrimentally affect cyprinid (minnow) populations (WGFD, 2005a).

Table 3.45. Native fish species in Grand Teton National Park.

COMMON NAME	FAMILY	SCIENTIFIC NAME	NATIVE DRAINAGE IN WYOMING**
Bluehead Sucker*	Catostomidae	*Catostomus discobolus*	1, 4, 7
Longnose Dace	Cyprinidae	*Rhinichthys cataractae*	1, 2, 3, 5, 6, 8
Mottled Sculpin	Cottidae	*Cottus bairdii*	1, 4, 7, 9
Mountain Sucker	Catostomidae	*Catostomus platyrhynchus*	1, 2, 4, 7, 8, 9
Mountain Whitefish*	Salmonidae	*Prosopium williamsoni*	1, 2, 3, 4, 7, 8, 9
Northern Leatherside Chub*	Cyprinidae	*Lepidomeda copei*	1, 9
Paiute Sculpin	Cottidae	*Cottus beldingii*	1, 9
Redside Shiner	Cyprinidae	*Richardsonius balteatus*	1, 9
Snake River Cutthroat Trout*	Salmonidae	*Oncorhynchus clarkia behnkei*	1
Speckled Dace	Cyprinidae	*Rhinichthys osculus*	1, 4, 7, 9
Utah Chub	Cyprinidae	*Gila atraria*	1, 9
Utah Sucker	Catostomidae	*Catostomus ardens*	1, 9
Yellowstone Cutthroat Trout*	Salmonidae	*Oncorhynchus clarkii bouvieri*	1, 2, 3, 8

*Species of Greatest Conservation Need (SGCN) as defined by the Wyoming Game and Fish Department. SGCN designation is intended to identify species whose conservation status warrants increased management attention and funding, as well as consideration in conservation, land use, and development planning in Wyoming.
**Drainage code: 1-Snake River; 2-Big Horn River, Shoshone River, Wind River; 3-Powder River; 4-Green River; 5-North Platte River; 6-Little Missouri River, Cheyenne River, Niobrara River, Belle Fouche River, South Platte River; 7-Little Snake River; 8-Yellowstone River; 9-Bear River.

Table 3.46. Non-native fish species in Grand Teton National Park.

COMMON NAME	FAMILY	SCIENTIFIC NAME
Arctic Grayling	Salmonidae	*Thymallus arcticus*
Brook Trout	Salmonidae	*Salvelinus fontinalis*
Brown Trout	Salmonidae	*Salmo trutta*
Lake Trout	Salmonidae	*Salvelinus namaycush*
Rainbow Trout	Salmonidae	*Oncorhynchus mykiss*

Native Fish Species

Snake River Cutthroat Trout

The Snake River cutthroat trout (*Oncorhynchus clarkii spp.* or *O. clarkii behnkei*) is a member of the Salmonidae family. It is also known as the fine-spotted cutthroat trout and is distinguished from other subspecies by its profuse fine spotting. It has a brownish yellowish body with dull silvery, green, or bronze tints. The fine spots cover nearly every part of its body with the exception of its white belly (Figure 3.123). As the name implies, cutthroat trout have a red or orange slash under each side of the lower jaw (WGFD, 2010a; WGFD, 2005a).

The native range of the Snake River cutthroat trout is principally in the western portion of Wyoming and southeastern Idaho, specifically the upper Snake River, Greys River, and the Salt River above Palisades Reservoir. Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), Snake River cutthroat trout were present in the Buffalo, Greys, Gros Ventre, Hoback, Salt, and Snake River drainages. In the Gros Ventre River drainage, Snake River cutthroat trout were abundant (seven or more individuals) in Bar BC Spring Creek; in the Snake River drainage, they were abundant in Blue Crane Creek, Cody Creek, Crescent H Spring, Fish Creek, Flat Creek, and Spring Creek.

This subspecies of cutthroat trout thrives in lakes, reservoirs, and large rivers with good overhead cover. Larger Snake River cutthroat trout, which can grow to greater than 20 inches (51 centimeters), feed on other fish, insects, annelids, snails, and small rodents, while smaller fish primarily feed on insects. Spawning begins in late March and continues until June or July, and fry (juvenile fish) emerge about 50 days later (WGFD, 2005a).

Alteration of habitat and the introduction of non-native species may be responsible for population declines. Habitat alterations include: manipulation of the hydrograph by Jackson Lake Dam; loss of connectivity due to the construction of Jackson Lake Dam and dewatered stretches caused by irrigation diversions; construction of levee systems; and modification of land use, which has increased bank erosion, siltation, and water salinity, and resulted in nutrient loading and pollution. In localized areas, non-native species have affected populations through direct predation or competition of food and spawning resources (WGFD, 2005a).

Conservation actions proposed for Snake River cutthroat trout by the Wyoming Game and Fish Department (WGFD) include: conducting surveys to provide baseline data and to monitor distribution and population trends; determining if the genetic integrity of native populations have been altered by introduced species; and evaluating the potential for restoring habitat within suitable portions of historic range that are currently uninhabited or where competing or hybridizing species can be removed (WGFD, 2005a).

Figure 3.123. Snake River cutthroat trout. Image source: College of Idaho Orma J. Smith Museum (Illustration by Joseph Tomelleri).

Yellowstone Cutthroat Trout

The Yellowstone cutthroat trout (*Oncorhynchus clarkia bouvieri*) is a member of the Salmonidae family. It is also known as the large-spotted cutthroat trout and is visually distinguished from other cutthroat trout by the large black spots that are particularly concentrated in the caudal peduncle (trunk of the tail fin). It is yellowish brown, silvery, or brassy bronze with paler colors toward the belly (Figure 3.124). It has two prominent red slashes on the lower jaw, and the gill plate is crimson blush (WGFD, 2005a; WGFD, 2010a).

The Yellowstone cutthroat trout is native to the Yellowstone River drainage downstream to the Tongue River, including the Big Horn and Clarks Fork River drainages. It is also found in Pacific Creek and other Snake River tributaries. Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), Yellowstone cutthroat trout were present in the Buffalo, Greys, Gros Ventre, Hoback, Salt, Snake, and Yellowstone River drainages.

A survey conducted from 2002 to 2004 evaluated 252 miles (405 kilometers) of Snake River headwaters, including 156 miles (251 kilometers) in GRTE for presence of fish species. The survey revealed that native and non-native trout were present in 73 percent of the stream length. Cutthroat trout were present in 88 percent of the occupied length, with 21 percent occupied by Yellowstone cutthroat trout, 21 percent occupied by Snake River cutthroat trout, and six percent by both species. Thirty-nine percent of the occupied length was present by cutthroat trout that could not be identified by morphotype/subspecies. Non-native brook trout (*Salvelinus fontinalis*), which were present in approximately 17 percent of the occupied stream length, may have displaced cutthroat trout from three small streams within GRTE (NPS, 2008e).

Figure 3.124. Yellowstone cutthroat trout. Image source: College of Idaho Orma J. Smith Museum (Illustration by Joseph Tomelleri).

Yellowstone cutthroat trout are found in clear, cool streams and rivers, but they are also found in lakes and ponds. Yellowstone cutthroat trout feed on zooplankton, freshwater shrimp, a wide variety of insects, mollusks, and other trout. In Yellowstone Lake, this subspecies migrates to inflowing streams to spawn from May to July. In later summer or early fall, the fry emerge from gravel (WGFD, 2005a).

Within the historical range of Yellowstone cutthroat trout, this subspecies, as well as the Snake River cutthroat trout, is considered a species of special concern by many state and federal agencies and organizations (Young, 2010). In the GYE, native cutthroat trout species, including both Yellowstone and Snake River, are considered keystone species, upon which many other species depend. They spawn in shallow water where they become an important food source for other wildlife, including grizzly bears (YELL, 2010b).

The primary threat to Yellowstone cutthroat trout existence since European colonization is the introduction of hybridizing and competing trout species. The presence of the highly piscivorous lake trout (*Salvelinus namaycush*) in Yellowstone Lake is a particular concern (NPS, 2006h). Loss of habitat from human development is also a contributing factor and extensive dam construction has limited movement of the species to major spawning headwater tributaries (WGFD, 2005a). Although not detected in GRTE, whirling disease has infected and reduced populations of cutthroat trout in YELL. Whirling disease is caused by the parasite *Myxobolus cerebralis* and attacks the developing cartilage of young fish, resulting in skeletal deformities and whirling behavior (YELL, 2010c).

Since threats to native cutthroat trout in the GYE are numerous, the present management strategy is to protect, enhance, and restore cutthroat populations and habitats where possible (WGFD, 2005a). Long-term population monitoring conducted by the NPS and WGFD includes: cutthroat trout spawning migration traps, cutthroat trout fall netting assessment, cutthroat trout spawning visual surveys, and angler report card information (NPS, 2006h). The WGFD also indicates that conservation actions proposed for Yellowstone cutthroat trout include: conducting surveys to provide baseline data and to monitor distribution and population trends; determining if the genetic integrity of native populations have been altered by introduced species; and evaluating the potential for restoring habitat within suitable portions of historic range that are currently uninhabited or where competing or hybridizing species can be removed (WGFD, 2005a).

Longnose Dace

The longnose dace (*Rhinichthys cataractae*) is a minnow in the Cyprinidae family. This subspecies of dace has a dark olive-colored body with reddish dorsal and tail fins (Figure 3.125). Longnose dace have an elongated, robust body, a forked tail fin, and a long snout that overhangs the mouth (Helfrich et al., 2005). Adults are usually about 2.5 to 3.5 inches (6.3 to 8.8 centimeters) in length (Edwards et al., 1983).

Figure 3.125. Longnose dace. Image source: Cornell University Department of Natural Resources (Kraft et al., 2006).

Longnose dace are widely distributed, naturally occurring throughout much of North America, from northern Canada to northern Mexico (UDWR, 2010a). In the western United States, they extend along the Rocky Mountains and throughout the Pacific slope from Oregon north through British Columbia (Edwards et al., 1983). Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), longnose dace were present in the Buffalo, Greys, Gros Ventre, Hoback, Salt, and Snake River drainages. In the Buffalo River drainage, longnose dace were common (four to six individuals) in Buffalo Fork; in the Gros Ventre River drainage, they were common in Soda Creek; in the Hoback River drainage, they were common in Coyote Gulch; and in the Snake River drainage, they were common in Cody Creek, Coulter Creek, Ditch Creek, Heart River, and Wolverine Creek.

Longnose dace are primarily benthic feeders, eating insect larvae, insects, algae, and plant matter. They inhabit the region directly above the substrate. They are most abundant in swift flowing, steep gradient, headwater streams of larger river systems. They prefer riffle areas in streams with gravel and rock beds, but they will occupy quiet shallower water pools in the absence of competing species. The species spawns during the spring and summer over gravel substrate. Eggs hatch in about one week, and young stay in slow water areas until they are six weeks of age (Edwards et al., 1983).

Although longnose dace are abundant and relatively common in the western United States, and they are found in all major drainages within GRTE, specific trend or population information is not available for the state of Wyoming or GRTE.

Speckled Dace

The speckled dace (*Rhinichthys osculus*) is a small minnow in the Cyprinidae family. The backs and sides of this subspecies of dace are dusky yellow or olive in color and are covered with dark speckles or splotches (Figure 3.126). During spawning season, the bases of fins turn red in both sexes, and males often get a red snout and lips. Speckled dace are generally 3.1 to 4.3 (8.0 to 11.0 centimeters) in length (UCCE, 2003).

Speckled dace are native to the western United States, as well as to parts of southwestern Canada and northern Mexico (UDWR, 2010a). Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), speckled dace were present in the Gros Ventre, Hoback, Salt, and Snake River drainages. In the Snake River drainage, speckled dace were abundant (seven or more individuals) in Blue Crane Creek, Cody Creek, Fish Creek, Spring Creek, and Third Creek.

Figure 3.126. Speckled dace. Image source: New York State Museum (Illustration by Emily Damstra).

Speckled dace have adapted to many different habitat types, ranging from cold swift-flowing mountain headwaters to warm intermittent desert streams and springs (UDWR, 2010a); however, they are rarely found in lakes (Page and Burr, 1991). They prefer clear, oxygenated water, with movement due to a current. They are benthic feeders that primarily eat insect larvae and other invertebrates, although algae and fish eggs are also consumed. This species spawns during the spring and summer over gravel areas that have been cleaned by territorial males (UDWR, 2010a). Embryos hatch in six days, and the larvae remain in gravel for seven to eight days. The fry spend the early part of their lives in shallow areas of streams (UCCE, 2003).

The speckled dace is both widely distributed and morphologically available. It was once thought to be 12 species, but it is now considered a complex of subspecies whose distributional limits and morphological variation are poorly known (Page and Burr, 1991). Although widely distributed in the western United States, specific trend or population information for the speckled dace is not available for the state of Wyoming or GRTE.

Mottled Sculpin

The mottled sculpin (*Cottus bairdii*) is a member of the Cottidae family. This subspecies of sculpin is generally less than six inches (15 centimeters) in total length, and has a large, flattened head, a slender tapered body, and a very large mouth with fleshy lips. The pectoral fins are very large and the caudal fin is rounded. The mottled sculpin, as the name implies has blotches of tan, brown, yellow, and black covering its body (Figure 3.127) (Brown, 1982; WGFD, 2005a).

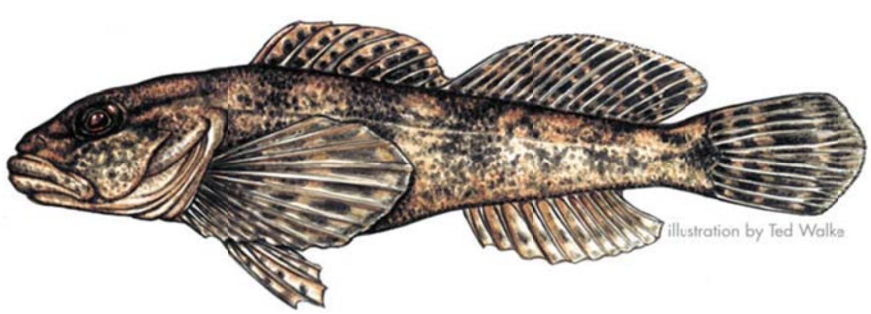

Figure 3.127. Mottled sculpin. Image source: Pennsylvania Fish and Boat Commission (Illustration by Ted Walke).

Mottled sculpins have a wide but discontinuous distribution. They range from northern Georgia and Alabama to Canada in eastern North America, and throughout the Rockies to the west. Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), mottled sculpins were present in the Buffalo, Greys, Gros Ventre, Hoback, Salt, and Snake River drainages. In the Gros Ventre River drainage, mottled sculpin were abundant (seven or more individuals) in Carmichael Fork and Soda Creek; in the Hoback River drainage, they were abundant in Jenny Creek; and in the Snake River drainage, they were abundant in Blue Crane Creek, Cody Creek, Fish Creek, Plateau Creek, Spring Creek, and Wolverine Creek.

Mottled sculpins are bottom dwellers and are most often associated with headwater streams having sand, gravel, and rubble substrates. They prefer cold water and are not found in temperatures exceeding 70 degrees Fahrenheit (21 degrees Celsius). They prefer clear water, but they can be found in somewhat turbid water. They actively feed at night and primarily consume freshwater shrimp, mayfly, and caddis fly nymphs; however, they also eat leeches and plant material. Mottled sculpins spawn from February to June when males establish a nest cavity of rocks or vegetation. The eggs are fertilized and adhered to the roof of the cavity (WGFD, 2005a). After about three weeks of development, the eggs hatch and the fry drop to the bottom of the nest. Males continue to defend their offspring until the fry disperse from the nest (Brown, 1982).

Mottled sculpin are the most abundant sculpin in the United States. In Wyoming, the existence of the mottled sculpin appears to be stable or expanding and habitat conditions also appear to be stable. Although they are the most abundant sculpin in the United States, proposed conservation actions by the WGFD include: developing a better understanding of habitat and flow requirements in order to assess the impacts of water and land use activities; developing new methods to restore habitat at a watershed level; developing and implementing monitoring protocols; conducting surveys to provide baseline data; and continuing to reestablish entire native fish assemblages in streams rehabilitated to remove non-native trout species (WGFD, 2005a).

Paiute Sculpin

The Paiute sculpin (*Cottus beldingii*) is a member of the Cottidae family. The coloration of Paiute sculpins is variable, ranging from shades of green, brown, gray, and blue. There are usually four to five vertical bands on the sides, and the fins are mottle or barred. The pectoral fins are very large, the caudal fin is rounded, the dorsal fins are separated, and the pelvic fins may extend past the vent. Paiute sculpins are usually 2.4 to 4.0 inches (6.1 to 10.2 centimeters) in length, but they can reach lengths of 5.0 inches (12.7 centimeters) (UCCE, 2003). Paiute and mottled sculpins can be difficult to distinguish from each other because they have similar traits. However, mottled sculpins have a small row of teeth on the roof of their mouth, whereas Paiute sculpins do not. Additionally, mottled sculpins have two spines along the edge of the gill cover, whereas Paiute sculpins have only one spine along the edge of the gill cover (WGFD, 2006).

Paiute sculpins are native to parts of Utah, Idaho, Wyoming, Colorado, Nevada, California, Oregon, and Washington (UDWR, 2010a). They have a limited distribution in Wyoming, but they are commonly found in the headwaters of the Snake River in Teton, Lincoln, and Sublette counties. More broadly, they are found in the Columbia River drainage from Idaho, western Wyoming, and northeast Nevada to western Washington and Oregon, and in endorheic basins, such as Lake Tahoe (WGFD, 2005a; Page and Burr, 1991).

Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), Paiute sculpins were present in the Buffalo, Greys, Gros Ventre, Hoback, Salt, and Snake River drainages. In the Buffalo River drainage, Paiute sculpins were abundant (seven or more individuals) in Lava Creek and Split Rock Creek; in the Greys River drainage, they were abundant in Blind Trail Creek, Crow Creek, South Fork of the Little Greys River, and Three Forks Creek; in the Gros Ventre drainage, they were abundant in Cottonwood Creek, Maverick Creek, North Fork of Fish Creek, Red Creek, Sohare Creek, and Steep Creek; in the Hoback River drainage, they were abundant in Boulder Creek and Mumford Creek; in the Salt River drainage, they were abundant in Spring Creek; and in the Snake River drainage, they were abundant in Coburn Creek, Enos Creek, North Fork of Spread Creek, Nowlin Creek, and Pilgrim Creek.

Paiute sculpins are nocturnal benthic feeders that are commonly found in rubble and gravel riffles of cold creeks, streams, and rivers. As with mottled sculpins, the flattened heads and slender tapered bodies of Paiute sculpins allow them to inhabit complex cracks and crevices among and between rocks (WGFD, 2006). Paiute sculpins primarily consume the nymphs of stoneflies, mayflies, and caddisflies, but they are also known to feed on snails, beetles, algae, and detritus (WGFD, 2005a; UDWR, 2010a). Spawning primarily occurs in May and June in areas where there is adequate rocky or gravelly substrate to hide nests. When the fry hatch, they remain within the nest for another one to two weeks (UCCE, 2003).

In Wyoming, the existence of the Paiute sculpin appears to be stable and habitat conditions also appear to be stable. Although populations and habitat conditions appear stable, proposed conservation actions by the WGFD include: developing a better understanding of habitat and flow requirements in order to assess the impacts of water and land use activities; developing and implementing monitoring protocols; and conducting surveys to provide baseline data (WGFD, 2005a).

Bluehead Sucker

The bluehead sucker (*Catostomus discobolus*) is a member of the Catostomidae family. The coloration of adults varies according to habitat and ranges from gray-blue to tan to yellowish. As the name implies, the head often has a blue cast (Figure 3.128). During spawning season, the fins of both males and females become orange, and males develop tubercles on the anal and caudal fins (Carman, 2007). Bluehead suckers have an elongated body with a narrow caudal peduncle, a bulbous snout, and a large mouth (CDOW, 2010). The mouth has well-developed cartilaginous edges for scraping algae off rocks. Adult bluehead suckers are typically six to 10 inches (15 to 25 centimeters) in length, but can attain lengths of 18 inches (46 centimeters) (WGFD, 2005a).

Bluehead suckers are native to parts of Utah, Idaho, Arizona, New Mexico, and Wyoming. Specifically, the species occurs in the upper Colorado River system, the Lake Bonneville basin, and the Snake River system (UDWR, 2010a). The Snake River population is thought to range from Jackson Lake Dam to Palisades Reservoir. Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), bluehead suckers were present in the Gros Ventre and Snake River drainages.

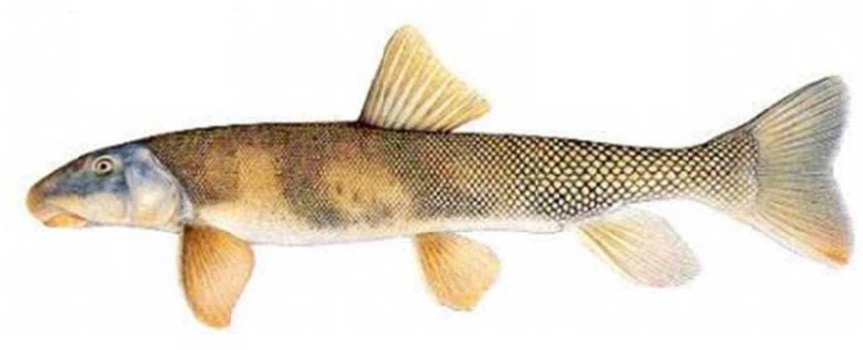

Figure 3.128. Bluehead sucker. Image source: Ute Tribe Fish and Wildlife Department (Illustration by Joseph Tomelleri).

Bluehead suckers are found in a wide variety of areas from headwater streams to large rivers. They are absent in areas of standing water. Their streamlined body and narrow caudal peduncle indicate an adaptation to living in strong currents of large rivers. They also prefer turbid to muddy, alkaline streams that have a rocky substrate (WGFD, 2005a; CDOW, 2010). Bluehead suckers are benthic feeders that primarily consume algae, but their diet may also include small bottom-dwelling invertebrates. Spawning occurs from April to June, preferably in clean gravel or cobble beds (Carman, 2007).

Bluehead suckers are considered a species of special concern in Wyoming, Idaho, Utah, Colorado, Arizona, and New Mexico because their distribution has dramatically declined at site, stream, sub-drainage, and drainage scales. Flow alteration, habitat alteration and loss, and the introduction of non-native fish species have contributed to their decline (WGFD, 2005a). In Wyoming, they are greatly restricted in numbers and distribution and extirpation is possible. The species is also declining in genetic purity over the majority of its range in Wyoming due to introgression with non-native sucker species (WGFD, 2010b).

Conservation actions proposed by the WGFD include: developing refugia for bluehead suckers in the form of pond habitats; developing a better understanding of basic biology, life history, and ecology; developing and implementing monitoring protocols; conducting surveys to provide baseline data; and evaluating the potential for restoring habitat within suitable portions of historic range (WGFD, 2005a).

Mountain Sucker

The mountain sucker (*Catostomus platyrhynchus*) is a member of the Catostomidae family. Adult mountain suckers are dark brown or tan and fade to white on the belly (Figure 3.129). Dark mottles, in the shapes of saddles, may be present on the backs of some specimens (CDOW, 2010). Mountain suckers have a slender, cylindrical body. They are quite small, rarely exceeding six inches (15 centimeters) in length. They have a deep caudal pendunce, a short head, and a deep cartilaginous plate or ridge on the lower lip, presumably for scraping algae and invertebrates from rocky stream substrates (WGFD, 2005a; Belica et al., 2006).

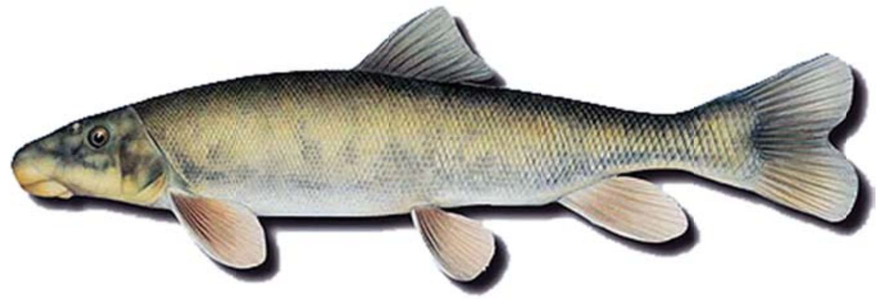

Figure 3.129. Mountain sucker. Image source: United States Forest Service, Rocky Mountain Region (Belica et al., 2006).

Mountain suckers occur in much of the intermountain western United States north of Arizona and in parts of western Canada (UDWR, 2010a). In Wyoming, mountain suckers are common in all drainages west of the Continental Divide. East of the Continental Divide, they are common in northern and northwestern counties (WGFD, 2005a). Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), mountain suckers were present in the Buffalo, Greys, Gros Ventre, Hoback, Salt, and Snake River drainages. In the Gros Ventre River drainage, mountain suckers were common (four to six individuals) in Trail Creek; and in the Snake River drainage, they were common in Quarter Creek.

Mountain suckers primarily occur in lotic waters, from small montane streams to large rivers. They are most commonly found in smaller headwater streams, but they have been collected from several rivers throughout their range. They have also been found in lentic habitats including lakes and reservoirs. They are reported to occur in some alpine lakes in Wyoming. In streams, they are most common in low gradient segments that consist of riffles, pools, and runs (Belica et al., 2006). Mountain suckers are primarily benthic feeders, browsing on stream bottoms for algae, small invertebrates, and organic matter. During the spawning period, which occurs during spring and summer months, mountain suckers are found in abundance in riffle habitats (WGFD, 2005a; Belica et al., 2006).

In Wyoming, the mountain sucker population is believed to be stable, but there are concerns that habitat is declining. Potential threats to the long-term persistence of mountain suckers include land and water management activities that result in habitat degradation, loss, or fragmentation, and fisheries management activities, such as species introduction and control programs (Belica et al., 2006).

Conservation actions proposed by the WGFD include: developing a better understanding of habitat and flow requirements for the species; developing new methods to restore habitat at a watershed level; developing and implementing monitoring protocols; conducting surveys to provide baseline data; and continuing to reestablish entire native fish assemblages in rehabilitated streams (WGFD, 2005a).

Utah Sucker

The Utah sucker (*Catostomus ardens*) is a member of the Catostomidae family. The coloration of Utah suckers varies from dark olive to copper with a white belly (Figure 3.130). They have dusky fins and a subterminal mouth (UDWR, 2010b). Utah suckers typically range in length from 15 to 20 inches (38 to 51 centimeters), but lengths of 25.5 inches (65 centimeters) have been recorded (IDAFS, 2010; Page and Burr, 1991). The appearance of Utah suckers can be similar to bluehead suckers; however, Utah suckers lack the deep cartilaginous plate or ridge on the lower lip (WGFD, 2010c).

Utah suckers are native to the Bonneville Basin of Utah, Idaho, Nevada, and Wyoming. In addition to their native range, they have been introduced to and become established in the Colorado River system (UDWR, 2010a). Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), Utah suckers were present in the Buffalo, Greys, Gros Ventre, Hoback, and Snake River drainages.

Utah suckers are highly adaptable and have been found in habitats ranging from shallow, fast, high-gradient alpine streams to slow, deep, low-elevation meandering rivers. They have also been found in lacustrine environments, such as Jackson Lake in Wyoming and Utah Lake in Utah (Cardall, 2008). Utah suckers are benthic feeders, consuming both plant and animal matter, with algae being the most common food item. They are often found in streams and lakes with silt, sand, gravel, or rock substrates. The species spawns during the late spring either in streams or along lake shores. Eggs are broadcast into water and deposited over gravel and sand. The male stirs the substrate with tail movements to partially bury the eggs (IDAFS, 2010); however, no parental care is given to eggs or young (UDWR, 2010a).

Utah suckers are found in the Snake River system above Shoshone Falls in Wyoming. Although Utah suckers are thought to be common and relatively abundant within their range, specific trend or population information is not available for the state of Wyoming or GRTE.

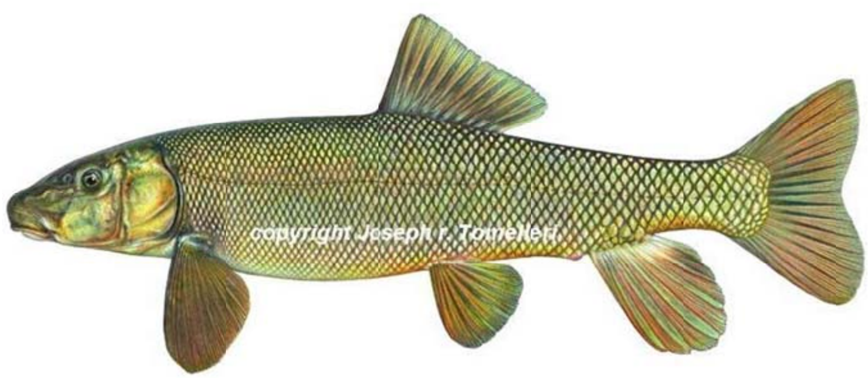

Figure 3.130. Utah sucker. Image source: www.americanfishes.com (Illustration by Joseph Tomelleri).

Mountain Whitefish

The mountain whitefish (*Prosopium williamsoni*) is a member of the Salmonidae family. Mountain whitefish have rounded and elongated bodies, and adults are typically 10 to 16 inches (25 to 41 centimeters) in length. They have an adipose fin and their caudal fin is deeply forked. Coloration of mountain whitefish is gray-bronze on the back and fades to silver on the sides (Figure 3.131). They have a small mouth overhung by the upper jaw, giving them a sucker-like appearance. However, they can be distinguished from suckers by the presence of the adipose fin. They can also be distinguished from trout by their larger scales and from graylings by their small pointed mouth and smaller dorsal fin (WGFD, 2010a; IDAFS, 2010).

Mountain whitefish are native to lakes and streams in the western United States and western Canada (UDWR, 2010a). They are specifically found from the Canadian Rockies south to Colorado and Nevada. They are common in drainages west of the Continental Divide, such as the Snake, Green, and Bear rivers, and they reside in the Madison, Yellowstone, Big Horn-Wind, and Tongue rivers east of the Divide (WGFD, 2010a). Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), mountain whitefish were in the Buffalo, Greys, Gros Ventre, Hoback, and Snake River drainages. In the Snake River drainage, mountain whitefish were abundant (seven or more individuals) in Fish Creek; they were common (four to six individuals) in Crescent H Spring, Price Spring Creek, and the Snake River.

Mountain whitefish are typically found in deep, fast-flowing rivers that are large, clear, and cold; however, they are sometimes abundant in lakes. Mountain whitefish eat insects and insect larvae, specifically caddis fly and midge larvae, and stonefly and mayfly nymphs. They also eat fish eggs and small fish. However, in lakes, their primary food source is plankton. The species is most active during the night and winter. Mountain whitefish spawn from late fall to early winter, usually in stream riffles with gravel substrates. No nests are made, but eggs are adhesive, and they stick to the bottom. Eggs develop over the winter and hatch in the early spring (UDWR, 2010a).

In Wyoming, population size and distribution of mountain whitefish appear to be declining, but extirpation is not imminent. Habitat is vulnerable, but it is currently not restricted. Water management and impoundments alter spawning, rearing, feeding, and overwintering habitats and can reduce populations (WGFD, 2010b). There may also be some competition between mountain whitefish and native trout, but no evidence of detrimental effects has been documented (WGFD, 2005a). Proposed conservation actions by the WGFD include: developing a baseline assessment of mountain whitefish distribution and population structures in order define potential actions, and developing monitoring protocols and sites (WGFD, 2005a; WGFD, 2010b).

Figure 3.131. Mountain whitefish. Image source: www.PinedaleOnline.com (Illustration by Michelle LaGory).

Redside Shiner

The redside shiner (*Richardsonius balteatus*) is a small minnow in the Cyprinidae family. Shiner species are discerned from other minnows by their scales, which reflect light and make the fish shine. Redside shiners are named for the coloration of males during spawning. During the spawning season, males turn crimson and bright yellow on the sides and belly. Redside shiners are also darker than most shiner species. They have a dark olive back and a dark mid-side band and a parallel light stripe above the band from the snout to the tail fin (Figure 3.132). They are flat-sided, thin fish with a clearly forked tail, and a setback dorsal fin. They average four inches (10 centimeters) in length (MTFWP, 2006).

Redside shiners are native to southwestern Canada and the western, especially the northwestern, United States (UDWR, 2010a). They are found throughout the Columbia River drainage and the Bonneville basin in ponds, lakes, ditches, springs, sloughs, and rivers where the current is slow or absent (IDAFS, 2010). Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), redside shiners were present in the Buffalo, Salt, and Snake River drainages. In the Snake River drainage, redside shiners were abundant (seven or more individuals) in Cody Creek, Fish Creek, and Third Creek; they were common (four to six individuals) in Christian Creek.

Redside shiners prefer heavily vegetated areas of slow-moving water with a sandy or muddy substrate. They are opportunistic feeders, eating insects, mollusks, zooplankton, small fishes, fish eggs, and algae (UDWR, 2010a). The species spawns during the spring and early summer over a gravel substrate or submerged vegetation. Females produce and broadcast 800 to 3,600 eggs, which are fertilized and adhered to plants, rocks, detritus or the substrate. Eggs hatch after two weeks (UDWR, 2010a; IDAFS, 2010).

Although redside shiners are found in all major river systems throughout the Bonneville basin, specific trend or population information is not available for the state of Wyoming or GRTE.

Figure 3.132. Redside shiner. Image source: Montana Department of Fish, Wildlife, and Parks (Illustration by Joseph Tomelleri).

Northern Leatherside Chub

The northern leatherside chub is a minnow in the Cyprinidae family. It is one of two taxa formerly known as the leatherside chub (*Gila copei* and *Snyderichthys copei*) that was recently split into two species: the northern leatherside chub (*Lepidomeda copei*) and the southern leatherside chub (*Lepidomeda aliciae*) (WGFD, 2010b). The coloration of leatherside chub species is bluish above and silvery below (Figure 3.133). The males have bright orange-red coloration on the axils of the paired fins. The skin has a leathery texture with small scales, and the anal and dorsal fins have eight fin rays. Leatherside chub species live up to eight years, and adults reach a maximum length of six inches (15 centimeters) (UDWR, 2010a).

Leatherside chub are native to the Bonneville and upper Snake River basins of Utah, Idaho, and Wyoming, and the Wood River system of Idaho (IDAFS, 2010). The species may have been introduced into the upper Snake River Basin because it was unknown there until 1934 (NVDCNR, 2010). In 1998, it was recognized that a population of leatherside chub existed in the Snake River drainage near the mouth of the Buffalo Fork River (Mott, 1998); however, electrofishing and hook-n-line surveys conducted by Novak et al. (2005) indicated that the species was present in Pacific Creek.

The habitat requirements of leatherside chub are poorly understood; however, they typically occupy deep pools in medium sized streams with cool water temperatures. They are often found in habitats with some form of cover (vegetation, woody debris, and/or lateral banks), and they require flowing water. They generally do not persist in lakes or reservoirs (WGFD, 2010b). Little is also know about the biology of the species; however, it is believed to have a prolonged spawning period from April through August (WGFD, 2005a).

Leatherside chub were once common throughout their native range, but they have declined in abundance. They are considered a sensitive species throughout their range and are considered a species of special concern in Utah, Idaho, and Nevada. In Wyoming, leatherside chub are rare and of special concern. Habitat alterations and the introduction of non-native species are believed to be responsible for their decline. Specific habitat alterations include: manipulation of flood regimes that cause the degradation or loss of spawning habitat; cold water discharges from dams that limit spawning and contribute to fish mortality; and land-use practices that dewater stretches of streams, increase bank erosion, siltation, and water salinity, and result in nutrient loading and pollution (WGFD, 2005a).

Figure 3.133. Leatherside chub. Image source: www.americanfishes.com (Illustration by Joseph Tomelleri).

Conservation actions proposed by WGFD include: developing new methods to restore habitat at a watershed level; developing a better understanding of the basic biology, life history, and ecology of the species; developing monitoring protocols; conducting surveys to provide baseline data and to monitor distribution and population trends; and evaluating the potential for restoring habitat within suitable portions of the historic range that are currently uninhabited or where competing or hybridizing species can be removed (WGFD, 2005a).

Utah Chub

The Utah chub (*Gila atraria*) is a minnow in the Cyprinidae family. The coloration of Utah chubs is olive brown to black, and occasionally bluish, on their backs, and brassy or silvery on their sides. Their underside is whitish or silver (Figure 3.134). Utah chubs typically reach a size of seven to 10 inches (18 to 25 centimeters) in length (IDAFS, 2010).

The Utah chub is native to the Bonneville basin of Utah, Idaho, Wyoming, and Nevada, and to the Snake River drainage above Shoshone Falls and the lower Wood River system. Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), Utah chub were present in the Snake River drainage. They were abundant (seven or more individuals) in Third Creek.

Utah chub can adapt to a myriad of environmental conditions. They occur in lakes, reservoirs, and rivers, and they are often associated with dense vegetation. Utah chubs are omnivorous, feeding on aquatic plants, zooplankton, insects, and crustaceans (UDWR, 2010a). Spawning occurs in late spring and early summer and eggs are scattered over various substrates in shallow waters. Each female produces approximately 40,000 eggs (IDAFS, 2010). No parental care is given to the eggs, which hatch in approximately one week (UDWR, 2010a).

Although the species is native to the Bonneville basin and the Snake River drainage, they are often considered to be an undesirable fish species. In some reservoirs, they have become very abundant and may reduce sport fish populations through intense competition for food and space (UDWR, 2010a). In some areas, attempts have been made to eradicate the species from important trout waters, but populations often quickly rebound (IDAFS, 2010).

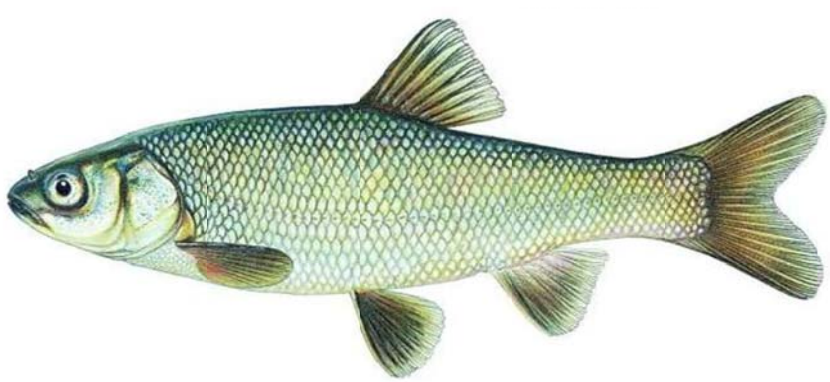

Figure 3.134. Utah chub. Image source: www.americanfishes.com (Illustration by Joseph Tomelleri).

Non-Native Fish Species

Rainbow Trout

Rainbow trout (*Oncorhynchus mykiss*) are members of the Salmonidae family. Coloration of rainbow trout varies with size and habitat; however, their backs are generally bluish to greenish, their sides are silvery with a pink or reddish band, and the tips of their fins are white. They have black spots on their backs and sides and may have a faint red or orange slash on their lower jaw (Figure 3.135). They can grow up to 45 inches (114 centimeters) in length (Page and Burr, 1991).

The historic range of rainbow trout extends from Alaska to Mexico and includes British Columbia, Washington, Oregon, California, Idaho, and Nevada (NRCS, 2000). Although the species is native to western North America, it has been widely introduced into cold and cool waters in Wyoming (WGFD, 2010a). Rainbow trout have been successfully domesticated and are widely utilized by fishery management agencies to supplement sport fisheries (IDAFS, 2010).

Rainbow trout are an adaptable species that have been widely transplanted. They are now found in lakes, large rivers, and small streams throughout the world (IDAFS, 2010). Prime rainbow trout waters are clear, clean, and cold, and good stream habitat consists of an array of riffles, pools, submerged wood, boulders, undercut banks, and aquatic vegetation (NRCS, 2000). Rainbow trout primarily eat invertebrates, including insects, worms, zooplankton, and insect larvae. Some larger rainbow trout become piscivorous and eat other fish (UDWR, 2010a).

Rainbow trout spawn in streams over gravel substrates during the spring. Eggs hatch in about one month, and fry emerge from the gravel about two the three weeks after hatching. Since rainbow trout and cutthroat trout are relatives and they often occupy the same habitat, similarities in spawning time and location often lead to rainbow-cutthroat trout hybrids (UDWR, 2010a; WGFD, 2010a). Rainbow-cutthroat trout hybrids have been found in the Gros Ventre, Hoback, and Snake River drainages (Novak et al., 2005).

Hybridization between species is the primary cause of decreased genetic purity in native cutthroat trout populations. In Wyoming, rainbow trout are no longer stocked in waters containing native populations of cutthroat trout (WGFD, 2010a). As of 1998, the few remaining populations of rainbow trout in GRTE were found in Jenny Lake and in sections of the Gros Ventre River (Mott, 1998).

Figure 3.135. Rainbow trout. Image source: Cornell University Department of Natural Resources (Kraft et al., 2006).

Brook Trout

Brook trout (*Salvelinus fontinalis*) are members of the Salmonidae family. Coloration of brook trout varies from olive, blue-gray, or black above with a silvery white belly and worm-like markings (vermiculations) along the back (Figure 3.136). Brook trout have red spots on their sides, and they are sometimes surrounded by bluish halos. The lower fins are reddish orange, but have a white front edge with black (MIDNR, 2010). Brook trout can grow up to 27.5 inches (70 centimeters) in length (Page and Burr, 1991).

Brook trout are native to the eastern United States and Canada, where they historically occupied habitat from Newfoundland and the Hudson Bay south to the Great Lakes and northern Georgia (Page and Burr, 1991). The species was widely introduced in the western United States from the late 1800s until around 1940. It has become well established in many western mountainous regions (WGFD, 2010b). Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), brook trout were present in the Buffalo, Greys, Gros Ventre, Hoback, Salt, and Snake River drainages.

Brook trout are common in cold, clear headwater streams. Like most salmonid fishes, brook trout thrive in waters with low temperatures and high oxygen content (Kraft et al., 2006). They are found throughout the upper Snake River drainage in streams and beaver ponds (Mott, 1998). Brook trout have been described as voracious feeders with the potential to consume large numbers of zooplankton, crustaceans, worms, fish, and insects (MIDNR, 2010). Brook trout spawn in the fall over sand and gravel substrates. As spawning season approaches, the colors of brook trout are intensified, especially in males whose flanks are belly become orange-red with a black stripe along each side. Aggregations of spawning brook trout are often found in small tributaries and along lakes shorelines, with solitary females seen digging shallow nests (Kraft et al., 2006). Fertilized eggs hatch in approximately two months (UDWR, 2010a).

Successful reproduction of brook trout can often lead to overcrowding. Overcrowding can eliminate other trout species and cause brook trout to remain stunted in growth (UDWR, 2010a). Brook trout are a significant threat to native cutthroat trout populations because of their highly aggressive nature, prolific reproduction, and slightly larger size as fry (IDAFS, 2010).

Figure 3.136. Brook trout. Image source: Michigan Department of Natural Resources and Environment.

Lake Trout

Lake trout (*Salvelinus namaycush*) are members of the Salmonidae family. Coloration of the body is light green, gray, dark green, brown, or almost black. The underside is lighter in color and the body has lighter colored spots (Figure 3.137) (WGFD, 2010a). Lake trout are large and typically range in length from 15 to 20 inches (38 to 51 centimeters). They weigh an average of 10 pounds (4.5 kilograms), but they can exceed 50 pounds (23 kilograms) (MNDNR, 2010; IDAFS, 2010).

Lake trout are native to Canada, Alaska, the Great Lakes, and New England; however, they have been introduced into several cold-water lakes in the western United States. They were stock in the upper Snake River drainage as early as 1890, and they now inhabit many of the lake in the drainage, including Jackson Lake (Mott, 1998). In 1994, their presence was confirmed in Yellowstone Lake, where they were apparently illegally introduced at least 20 years prior (YELL, 2010d).

Lake trout are slow growing, long-lived species that may not mature for 10 years; they can live more than 30 years (IDAFS, 2010). They inhabit large, deep, cold lakes, and they generally feed on other fish. They are strongly influenced by annual temperature events within lakes. During the winter, lake trout can range throughout a lake and prey upon fish and bottom insects, and in late April or early May, they actively feed upon minnows and abundant insect larvae (Kraft et al., 2006). Lake trout spawn in the fall over areas covered in rocks and gravel. Fertilized eggs settle within rocky crevices where they remain until they hatch four to six months later (UDWR, 2010a; Kraft et al., 2006).

Unlike most trout species, which require streams and rivers for spawning and early rearing, lake trout generally carry out their entire life cycle in a lake. For this reason, they have been able to outcompete native trout species (IDAFS, 2010). Impacts of lake trout in GRTE are not fully understood, but stocking of lake trout in Jackson Lake was discontinued in 2007 by the WGFD. In YELL, lake trout have had a significant ecological impact. Despite major efforts to remove lake trout by gillnetting, they are consuming and competing with native cutthroat trout populations. The reduction of native cutthroat trout populations has affected grizzly bear, osprey, and bald eagle populations because native cutthroat trout are an important food source for those species (NPS, 2008e; YELL, 2010d).

Figure 3.137. Lake trout. Image source: National Park Service Greater Yellowstone Science Learning Center.

Brown Trout
Brown trout (*Salmo trutta*) are members of the Salmonidae family. They have a light brown streamlined body with dark spots that are surrounded by light colored halos (Figure 3.138). They have small scales, a broad square tongue with 11 to 12 large teeth, a square tail, two dorsal fins including one adipose fin, light pectoral fins, and nine to 10 rays in the anal fin (WGFD, 2010a; MIDNR, 2010). The typical size of an adult brown trout is 13 to 16 inches (33 to 41 centimeters) in length, but they can grow up to 40.5 inches (103 centimeters). Weight tends to be limited to about five pounds (2.3 kilograms) in streams, but weights greater than 25 pounds (11.3 kilograms) have been recorded (MIDNR, 2010; IDAFS, 2010).

Brown trout are native to Europe, western Asia, and northern Africa. They were introduced into North America as a sport fish in 1883. They are now widely stocked throughout much of the United States and southern Canada (Page and Burr, 1991). Brown trout are now widely distributed in lakes and streams throughout Wyoming. In GRTE, they are mostly confined to the Snake River and Jackson Lake (Mott, 1998). Based on electrofishing and hook-n-line surveys conducted by Novak et al. (2005), brown trout were present in the Hoback, Salt, and Snake River drainages.

Brown trout inhabit cool, high gradient streams and cold lakes. In streams, adults live in pools and young occupy pools and riffles (Page and Burr, 1991). They prefer dense cover, particularly overhead cover from undercut banks and vegetation (WGFD, 2010a). Brown trout are piscivorous, but they also consume amphibians, rodents, and invertebrates, including insects, snails, and crayfish. They spawn in mid- to late-fall in rivers and streams. Females dig areas called redds in the gravel substrates of stream riffles. Female and male fish then pass over the redd, laying and fertilizing eggs. The eggs, which hatch in one to two months, are then covered with gravel (UDWR, 2010a).

Due to the piscivorous nature of brown trout, they can often have a detrimental effect on populations of both native fishes and non-native sport fishes (UDWR, 2010a). Brown trout reflect a dilemma in managing fish communities and fisheries. While brown trout may represent an important species to anglers, they have impacted native fish species that are unable to compete for resources (Kraft et al., 2006).

Figure 3.138. Brown trout. Image source: Cornell University Department of Natural Resources (Kraft et al., 2006).

Arctic Grayling

Arctic grayling (*Thymallus arcticus*) are members of the Salmonidae family. They are distinguished from other salmonids by an extremely large sail-like dorsal fin. They are gray and bluish in color and have iridescent gray scales (Figure 3.139). They have varying numbers of black spots scattered along the anterior portion of both sides. The dorsal fin of breeding males is strikingly colored with blue or violet spots. The adipose, caudal, pectoral, and anal fins are gray, and the pelvic fins are often marked with pink to orange stripes (AKDFG, 2010). They can reach 10 to 15 inches (25 to 28 centimeters) in length and can live as long as 11 or 12 years (IDAFS, 2010). Different sizes and ages of Arctic grayling may be found throughout a river system. There is often a discernable pattern of grayling size from river mouth to the headwaters, with the older, larger adults being more prevalent in the upper reaches of the river and stream system (AKDFG, 2010).

The Arctic grayling is holarctic in distribution, which means that the species occurs in the northern parts of North America, Europe, and Asia. In North America, Arctic grayling are native to northern Canada and Alaska, extending south to Michigan, Montana, and extreme northwestern Wyoming. They have been introduced into a number of locations in Wyoming, the western United States, and Eurasia (WGFD, 2005a).

Arctic grayling naturally inhabit both lakes and streams. They prefer clear, large rivers, creeks, and mountain lakes (WGFD, 2005a). They are generalists in their food habits, but drifting aquatic insects, especially mayflies, stone flies, and caddis flies are their primary food items (AKDFG, 2010). Arctic grayling spawn in streams during the early spring. Immediately after spawning, adult grayling begin their migration to summer feeding areas. Depending on where they spawned, the distance traveled can be up to 100 miles (161 kilometers). Grayling fry hatch about two to three weeks after the spawning period, and they tend to occupy quieter waters near where they were spawned (AKDFG, 2010).

Arctic grayling are rare in Wyoming. Within their native range, they are still present, but the introduction of competing non-native fish species, such as brown trout and brook trout, and the fragmentation of migratory pathways caused by the construction of Hebgen Dam have impacted fluvial grayling populations (NPS, 2008f). Consequently, they have been listed as a candidate species under the Endangered Species Act, primarily due to their much reduced range in Montana. Outside of their native range (e.g. GRTE), Arctic grayling have been introduced to provide a unique fishing opportunity. Although there is a concern for the sustainability of native grayling populations in the northern Rocky Mountains, within Wyoming, management actions are focused on providing a healthy, sport fishery (WGFD, 2005a).

Figure 3.139. Arctic grayling. Image source: National Park Service Greater Yellowstone Science Learning Center.

Fisheries Management

The WGFD has historically managed fisheries in GRTE. Fisheries management in GRTE differs from the situation in YELL. Since YELL was designated a national park prior to Wyoming becoming a state in 1890, Wyoming "could not lay claim to any of the wildlife in Yellowstone" (O'Ney and Gipson, 2006). While fisheries resources in YELL are federally managed under the jurisdiction of the NPS, fisheries resources in GRTE are managed by the state under the jurisdiction of the WGFD.

In the decades following the formation of GRTE in 1929 and the expansion in 1950, the NPS and the WGFD postured for control of fisheries in the park. The WGFD claimed sole jurisdiction over fish management and resisted attempts by the NPS to influence fisheries programs. This resulted in numerous disputes, most of which were resolved in favor of the WGFD (Mott, 1998). The level of animosity has diminished in recent years, and since 2001, the two agencies have developed and maintained an excellent working relationship. Although the WGFD continues to have jurisdiction over fisheries management in the park, fisheries are jointly managed by the WGFD and NPS (O'Ney and Gipson, 2006).

Fisheries management in GRTE is further complicated by the operation of Jackson Lake Dam, which has been administered by the Bureau of Reclamation (BOR) since 1906. The reservoir release schedules set by the BOR affect floodplain vegetation, biodiversity, and river morphology, all of which affect fish and wildlife populations along the Snake River and its tributaries (Marston et al., 2005). Consequently, GRTE and the WGFD have been working with the BOR to develop reservoir release schedules that would be more representative of natural flows of the Snake River (O'Ney and Gipson, 2006).

Prior to the formation of GRTE, non-native trout species were introduced via fish stocking efforts of the WGFD and the now-defunct United States Fish Commission. In the 1950s, nearly all park waters were stocked with a variety of fish species. In 1966, stocking was limited to native cutthroat trout, with the exception of the Jackson Lake lake trout stocking program. In 1969, the NPS recommended phasing out fish stocking programs in GRTE. As cooperation between the WGFD and NPS increased through the 1980s and 1990s, fish stocking programs were gradually eliminated. In 2007, the WGFD phased out a 70-year-old lake trout stocking program for Jackson Lake after finding that the stocking program had little effect on overall lake trout harvest (O'Ney and Gipson, 2006; NPS, 2008e). Cutthroat trout stocking in Trapper Lake and Bearpaw Lake was discontinued in recent years primarily due to increased communication and cooperation between the WGFD and GRTE. Presently, current fish stocking in the park is limited to hatchery-reared cutthroat trout in Two Ocean Lake (Mott, 1998; NPS, 2008e; O'Ney and Gipson, 2006).

In addition to discontinuing fish stocking programs within GRTE, attempts to restore fisheries have been made. In 2004, an inventory of the distribution of cutthroat trout and non-native trout in the Snake River and its tributaries was completed. The inventory rendered valuable information on the location of fish species both within and near GRTE and identified areas for management concern, such as the location of anthropogenic barriers to fish passage and other habitat improvement opportunities (O'Ney and Gipson, 2006). Irrigation diversions within GRTE, mostly in the eastern and southern portions of the park, have heavily impacted some cutthroat trout spawning streams (Mott, 1998). They remain a concern for the park because they may serve as conduits for pollution and divert cutthroat trout into irrigation ditches. As of 2008, the NPS was seeking funds for a system of fish screens to redirect cutthroat trout back into the Snake River (NPS, 2008e). In 2010, Spread Creek Dam, a dam managed by GRTE located just outside the park in the Bridger-Teton National Forest, was demolished in order to restore 50 miles (80 kilometers) of Snake River cutthroat trout habitat in Spread Creek and its tributaries. The dam removal project was funded and administered by Trout Unlimited, in cooperation with GRTE and other stakeholders (Hatch, 2010; Scholfield, 2010).

Mammals

Bighorn Sheep

Bighorn sheep (*Ovis canadensis*) are members of the Bovidae family, which includes bison, antelope, and wild and domestic cattle, sheep, and water buffalo. They range in color from light brown to grayish brown, with a white-cream rump patch, muzzle, and lining on the back of all four legs

Bighorn sheep are named for the large, curved horns borne by the males, or rams (Figure 3.140). The horns of rams are the largest of any ruminant in proportion to body size and they can comprise of eight to 12 percent of total body weight. Ram horn size, age, and body size serve as visual indicators of dominance and rank within a herd. Rams of equal size establish dominance through head butting contests. Ram skulls have two layers of bone above the brain that function as shock absorbers during these collisions. Female bighorn sheep, or ewes, also have horns, but they are short with only a slight curvature. Rams weigh from 174 to 319 pounds (79 to 145 kilograms) and stand 2.7 to 3.7 feet (81 to 112 centimeters) at the shoulder. Ewes are smaller, weighing up to 130 pounds (59 kilograms) and standing 2.5 to 3.0 feet (76 to 91 centimeters) (NPS, 2006i).

Habitat

Bighorn sheep are found in portions of the Sierra Nevada and Cascade mountain ranges and throughout the Rocky Mountains, from Peace River in British Columbia south to Mexico. The Rocky Mountain bighorn sheep (*O. c. canadensis*) found in the GYE is one of several currently recognized species. Other subspecies include the desert bighorn sheep (*O. c. californiana*), Dall sheep (*O. dalli*), and Stone sheep (*O. d. stonei*). In Wyoming, approximately 90 percent of Rocky Mountain bighorn sheep occur in eight core native herds in the northwest portion of the state, in the Absoroka, Teton, Gros Ventre, and Wind River ranges (WGFD, 2010b).

Rocky mountain bighorn sheep are habitat specialists that prefer steep, rocky areas with horizontal visibility and escape terrain. Areas with slopes greater than 27 degrees with occasional rock outcroppings, which provide protection from predators and disturbances, are preferred. Core habitat is likely to be composed of land within 980 feet (300 meters) of escape terrain or within 3,280 feet (1,000 meters) if bordered by escape terrain on at least two sides. Other features for suitable habitat include: aspect, distance to perennial water sources, natural and manmade barriers to migration, and distance from human activities and domestic animals. Bighorn sheep prefer areas that have open vegetation, where they can visually detect predators and maintain contact with members of their herd, and that are within 2.0 miles (3.2 kilometers) of perennial water sources. Habitats that restrict movement by natural barriers (i.e. rivers, lakes, or dense vegetation) or manmade barriers (i.e. roads, canals, or residential development) are considered less suitable (NPS, 2006i).

Figure 3.140. Bighorn sheep. Photo sources: U.S. Geological Survey and National Park Service.

Bighorn sheep herds in northwest Wyoming primarily use alpine tundra and associated rocky cover during the summer. In the winter, they use lower-elevation open, grassy benches and southerly slopes, with some herds wintering on wind-swept ridges at high elevations (WGFD, 2010b). The current population of bighorn sheep in GRTE resides year-round at high elevations. Rather than moving to lower elevations in the winter, they persist in windblown areas above 9,500 feet (2,900 meters) in two areas at the north and south ends of the Teton Range in steep canyons on the east and west slopes (Figure 3.141). The Teton herd is considered the smallest and potentially most isolated native sheep herd in Wyoming (NPS, 2007k; Dewey and Stephenson, 2008a).

Trends

Bighorn sheep once numbered in the millions in the western United States. Prior to European settlement, they were widespread in nearly all steep habitats in the mountains, foothills, river breaks, and prairie badlands. However, catastrophic declines occurred in the late 1800s and early 1900s. These declines were due to a combination of overgrazing of habitat by domestic livestock, unregulated market hunting, human developments on bighorn sheep habitat, and die-offs from diseases that were acquired from domestic livestock. The decline was so extensive that all populations of the Rocky Mountain subspecies were extirpated from Nevada, New Mexico, Utah, Washington, and nearly all of Oregon. Remaining populations existed as small, isolated groups in a highly fragmented distribution (Singer and Gudorf, 1999).

Historically, the herd in the Teton Range was part of a complex of several native herds that inhabited nearby mountain ranges. However, several of the native herds became extirpated, and development in Jackson Hole has cut off routes to wintering areas where populations mingled (Singer and Gudorf, 1999). The bighorn sheep population in the Teton Range persists as a small herd despite severe winter conditions, habitat loss due to low elevation development, fire suppression, and potential negative effects from intense year-round recreational use (NPS, 2007k). Population dynamics are strongly affected by year-to-year variations in lamb and yearling survival, primarily because adult survival in not greatly influenced by changes in population density (NPS, 2006i).

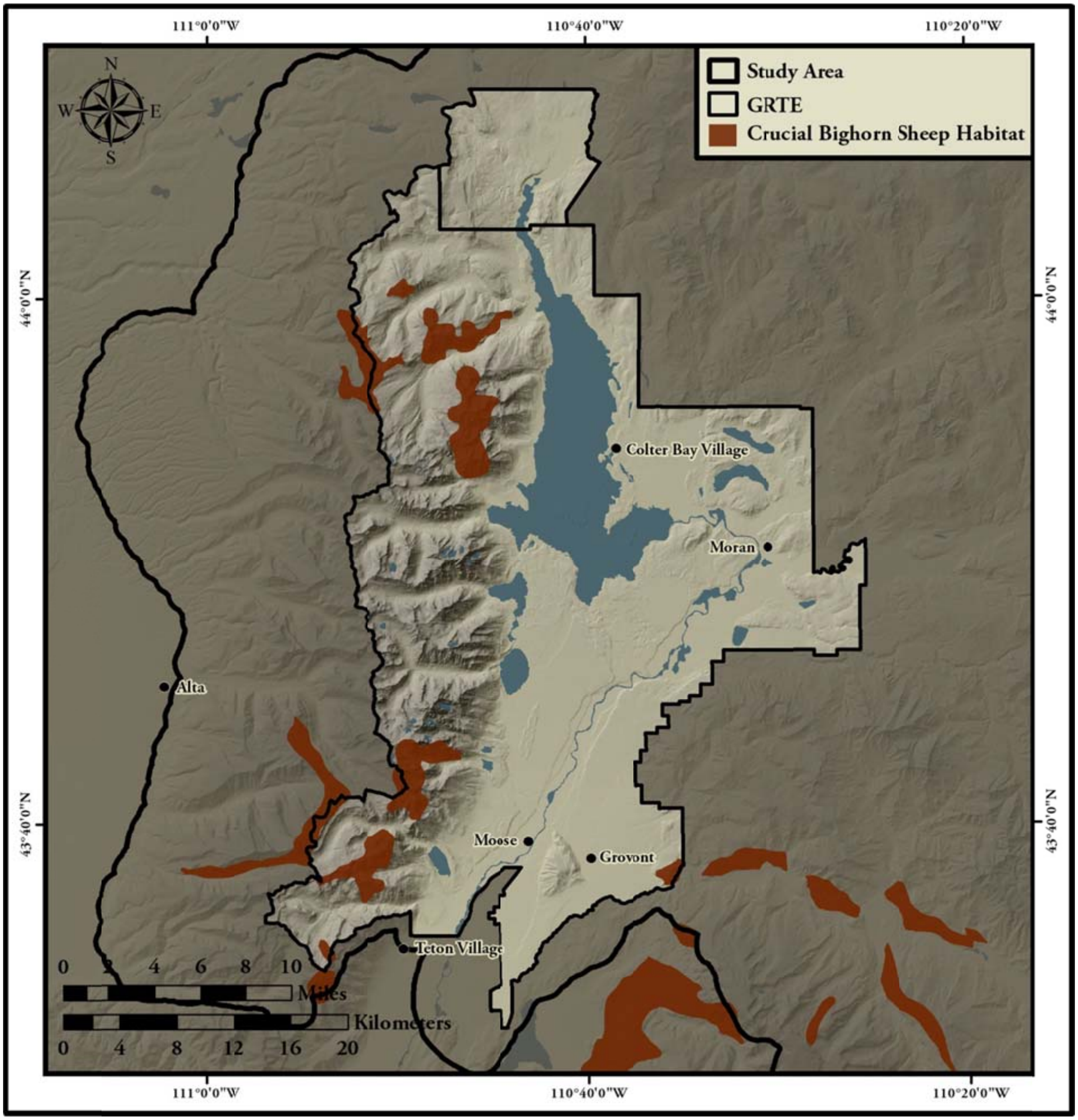

Figure 3.141. Bighorn sheep crucial habitat. Data source: Wyoming Game and Fish Department.

The population in the Teton Range was estimated at 100 to 150 individuals in 2007 based on helicopter classification flights (NPS, 2007k). However, estimates of the Teton Range herd are typically based on annual land-based surveys conducted by GRTE personnel. In 2008, population composition and trend estimates were generated using three survey methods: ground-based surveys, helicopter surveys, and during a genetics study. Ground-based surveys have been used since 1990, and they are conducted in late summer by backcountry crews using binoculars and spotting scopes to scan upper elevation areas for bighorn sheep. The helicopter survey was conducted in mid-March, and the genetics study was carried out during the summer (Dewey and Stephenson, 2008a).

The 2008 ground-based survey observed four groups containing a total of 15 ewes and four lambs, which was below the 12-year average of 32 ± 4.5 animals for roughly the same survey area. The groups were observed at Colter Canyon, Fossil Mountain, Owl Peak, and Webb Canyon (Table 3.47). Annual counts from the ground-based survey have been variable, ranging from a low of 10 bighorn sheep in 1995 to a high of 58 in 1993. The helicopter classification flight in March 2008 counted 51 ewes, 22 rams, eight yearling rams, and 15 lambs, thus totaling 96 animals. The genetics survey observed 22 groups totaling 91 sheep, which included duplicate observations of some animals. The genetics study observed ratios of 42 lambs, 14 yearlings, and 22 rams per 100 ewes (Dewey and Stephenson, 2008a).

Of the three survey methods, the helicopter survey possibly gave the most accurate estimate for the composition of the bighorn sheep herd in the Teton Range with a ratio of 43 rams to 100 ewes. The total count of 96 animals is also more consistent with the 2007 population estimate of 100 to 125 animals. When compared to the helicopter survey, the other survey methods are highly subject to bias. Ground-based surveys are subject to visibility bias, and a variety of factors can influence detectability, including group size, composition, behavior, light conditions, and observer experience. The ground-based survey also counted zero rams which obviously underestimated the proportion of rams in the herd. The survey conducted during the genetics study had a high potential for bias because observers targeted collared females that were almost exclusively found in ewe-lamb groups (Dewey and Stephenson, 2008a).

Since helicopter surveys presumably gave the most accurate estimates, management in GRTE has recommended that mid-winter helicopter flights be conducted when feasible to obtain reliable herd-wide population and classification ratio estimates. Alternatively, ground surveys can offer a cost-effective means of gauging general trends of herd composition (Dewey and Stephenson, 2008a).

Table 3.47. Location of bighorn sheep observed during 2008 ground-based surveys in Grand Teton National Park (Dewey and Stephenson, 2008a).

DATE	**8/20/2008**	**8/20/2008**	**8/21/2008**	**8/21/2008**
LOCATION	**COLTER CANYON**	**FOSSIL MOUNTAIN**	**OWL PEAK**	**WEBB CANYON**
Rams	0	0	0	0
Ewes	3	4	4	4
Lambs	2	0	1	1
TOTAL	5	4	5	5

Threats

Continued threats to bighorn sheep populations are habitat loss and disease. Sheep populations in the GYE are small and isolated, increasing the vulnerability of a population to inbreeding and disease. Habitat fragmentation and loss have prevented the use of historical migration routes. Limited winter range in high-elevation, avalanche-prone areas will likely have the greatest impact on the long-term survival of the herd in the Teton Range. Therefore, providing secure winter range and minimizing human disturbance by enforcing closures may be essential for the sustainability of the herd in GRTE. As of 2007, managers from GRTE, Bridger-Teton National Forest, and the WGFD have been re-evaluating bighorn sheep seasonal range designations to secure and restore habitat and reduce human disturbances (NPS, 2007k).

Vegetation encroachment caused by fire suppression has reduced horizontal visibility and sheep habitat. Singer and Gudorf (1999) suggested that the U.S. Forest Service conduct controlled burns on former low-elevation winter ranges on the west side of the Teton Range because they would help restore historic habitat. Diseases, such as those caused by *Pasteurella* bacteria, contracted from domesticated animals can cause major die-offs in bighorn sheep populations. Buffer zones, ranging from 10.6 to 18 miles (17 to 29 kilometers), would prove beneficial in separating bighorn sheep habitat from sheep grazing allotments (Schoenecker, 2004). In 2004, members of the Teton Range Bighorn Sheep Working Group succeeded in retiring the last domestic sheep grazing allotment in the Teton Range (NPS, 2007k).

Elk

Elk (*Cervus elaphus)* are members of the Cervidae family, which also includes deer, moose, caribou, and other ruminants in which the males have branching antlers that are shed each year (Figure 142; NPS, 2010m). They are the same species as European red deer, even though visually they are quite different. North American elk are also commonly called wapiti, the Shawnee name for elk meaning "white rump" or "white deer." Four subspecies of elk live in North America today with Rocky Mountain elk (*C. e. nelsoni*) occurring within the Rocky Mountains and Intermountain West (UDWR, 2010c). The Rocky Mountain elk is the most plentiful of the four elk subspecies, with an estimated 800,000 to 900,000 individuals (NRCS, 1999).

Figure 3.142. Elk in the Greater Yellowstone Ecosystem. Photo sources: U.S. Geological Survey (Vicki Patrek and Kim Keating).

Elk males, females, and young are known as bulls, cows, and calves, respectively. Bulls stand about five feet (1.5 meters) high at the shoulder and weigh approximately 700 pounds (318 kilograms). Cows are slightly shorter and weigh approximately 500 pounds (227 kilograms). Bulls and cows are tannish brown in color above and darker in color below. A small whitish tail is surrounded by a yellowish white rump patch that is bordered by darker hairs. Bulls have a dark shaggy mane that covers their necks. Calves, generally born as singles (twins are extremely rare) in May and June, weigh 30 pounds (14 kilograms) at birth. Calves are brown with white spots, providing them with good camouflage from predators (YELL, 2010d).

Bulls begin growing their first set of antlers when they are one year old. Older bulls begin to grow antlers as soon as the old antlers are shed in early spring (UDWR, 2010c). The antler growing period is shortest for yearling bulls (about 90 days) and longest for healthy mature bulls (about 140 days). The antlers of a typical healthy mature bull are 55 to 60 inches (140 to 152 centimeters) long, slightly less than six feet (1.8 meters) wide, and weigh about 30 pounds (14 kilograms) per pair (YELL, 2010d).

Elk are gregarious animals, and often gather into large nursery bands of cows and calves in early summer. During this time, it is common to see groups of several hundred elk. Nursery bands eventually disperse into smaller groups across summer range. Bulls generally live apart from cows and calves during the summer while their antlers grow and often band together during this time. The velvet that covers and provides nourishment to the growing antlers begins to shed in early August. The rut, or breeding season, begins in early September and lasts through October. Bulls begin to bugle, and cows gather into harems of approximately 10 to 20 females. The bulls in prime condition, usually ranging from six to eight years of age, are most likely to succeed in gathering a harem and fending off challengers. After the rut, bulls leave the cows and calves and either become reclusive or band together with other bulls. It is quite common to see large groups of bulls in the late fall and winter (UDWR, 2010c; NPS, 2010m).

Habitat

Elk are versatile generalists that use a mixture of habitat types in all seasons. They have a varied diet that consists of grasses, forbs, and shrubs. They feed on grasslands and open areas, use coniferous forests for shelter, and browse in the fall and winter when snow covers the ground. Most of their winter diet consists of grasses and shrubs; the consumption of forbs increases during spring. Ecotones between open and dense cover are also important to elk because they use the tall herbaceous vegetation to hide newborn calves (NPS, 2010m).

In areas that experience high snowfall and severe winter conditions, such as those in the GYE, elk migrate from higher-elevation summer ranges to lower-elevation winter ranges with less snowpack and more accessible forage. Elk winter in lower-elevation wooded areas that provide hiding and security cover. Densely wooded lowlands and north/northeast-facing slopes provide valuable hiding cover, and drier, open south/southwest-facing slopes can provide available forage. When migrating between summer and winter ranges, elk use transitional range. Transitional range commonly consists of Douglas-fir, aspen, pine, and other woodland communities intermixed with open pasture. These transitional range habitats provide forage required by elk to build fat reserves in the fall and to support calving in the spring.

Since winter range forage quality is typically poor, transitional range can be extremely important in sustaining elk populations (NRCS, 1999).

Grand Teton National Park supports a migratory Rocky Mountain elk population that is part of the larger Jackson elk herd. Each spring, thousands of elk migrate from the National Elk Refuge and the Gros Ventre River drainage to higher elevation areas of GRTE, YELL, and the Bridger-Teton National Forest. The Jackson elk herd has been the largest elk herd in North America for most of the last century, numbering 13,000 since 2001. Approximately 2,500 elk from the Jackson elk herd spend the summer in GRTE. Although elk are found throughout the park, they occur at relatively high densities in low elevation open sagebrush habitats and forested areas at the base of the Teton Range. Most elk that summer within the park migrate to winter range on the National Elk Refuge near Jackson; however, a small number of elk spend the winter in the eastern portion of the park (Figure 3.143) (Dewey, 2008a).

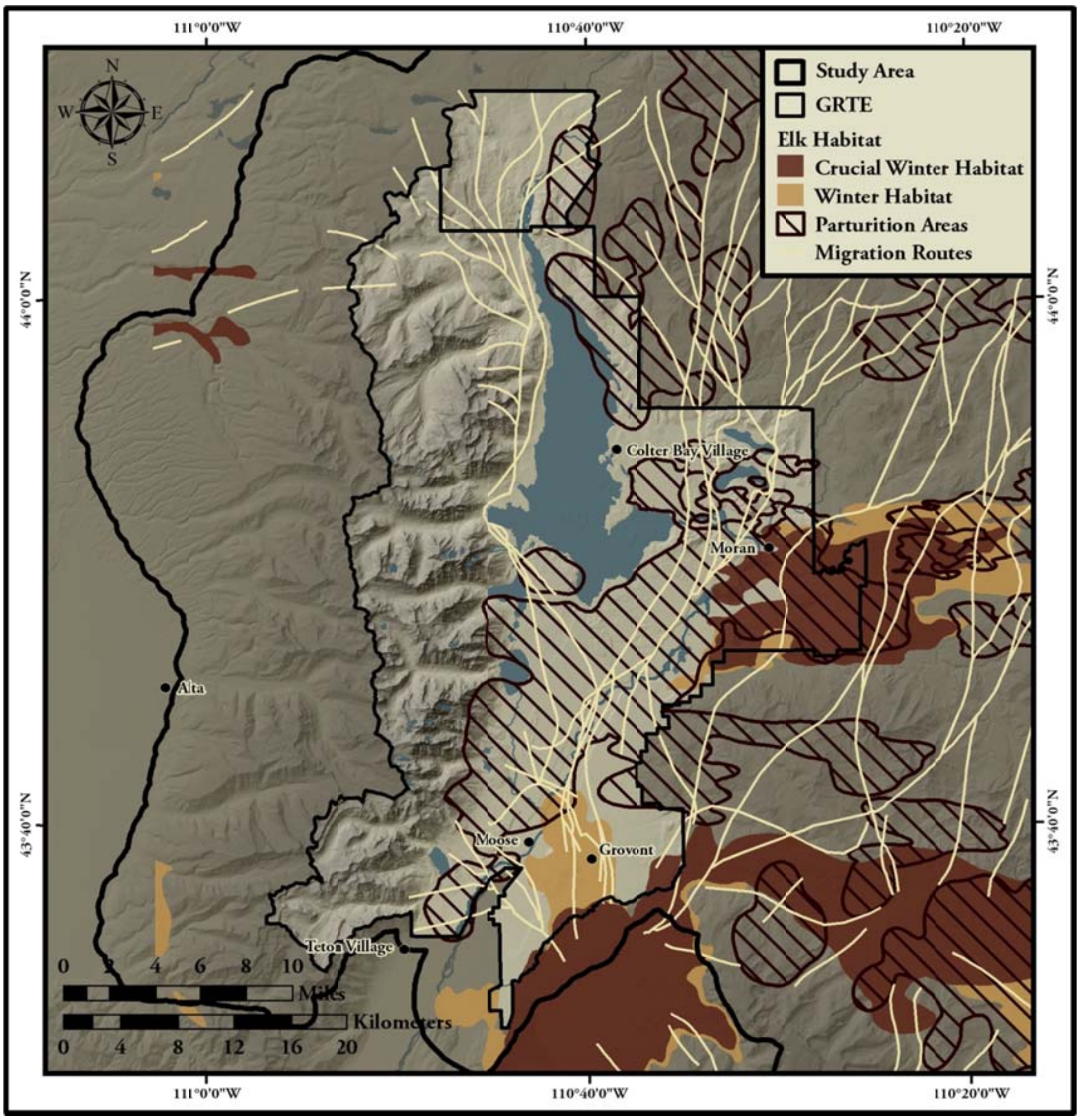

Figure 3.143. Elk habitat and migration routes. Data source: Wyoming Game and Fish Department.

Trends

Prior to European settlement, elk range extended across most of temperate North America. However, uncontrolled harvests, market hunting, habitat destruction, and westward settlement decreased elk populations and distribution. By 1900, elk had disappeared from more than 90 percent of their original range and the remaining populations occupied western mountains (USFWS, 2010d). Various conservation efforts aimed at protecting and reintroducing elk populations, regulating hunting, and restoring habitat were successful. Consequently, elk populations have been restored to most suitable ranges in western North America (NPS, 2010m).

When settlers arrived in Jackson Hole in the late 1800s, there may have been as many as 25,000 elk in the entire valley. Development in the town of Jackson and the establishment of ranches and farms in Jackson Hole valley significantly reduced elk habitat. These factors, when combined with severe winters in the early 1900s, precipitated a severe reduction in the Jackson elk herd population. To conserve the herd, local citizens, in conjunction with state and federal officials, began feeding the elk in the winter of 1910. In 1912, Congress set aside land adjacent to the town of Jackson that would eventually become known as the National Elk Refuge. Currently, the refuge consists of nearly 25,000 acres. As of 2007, approximately half of the Jackson elk herd (5,600 to 7,500 elk) spends the winter there (USDI, 2007; USFWS, 2010d).

Annual summer classification counts of elk in GRTE have been conducted via helicopter surveys since 1990. The standard survey area includes the central valley portion of the park, the Elk Ranch/Uhl Hill area, and the Willow Flats area. The central valley is an area of high elk density and open habitats where the probability of sighting elk is high. Based on replicate surveys, the precision of these surveys with respect to classification and elk numbers is relatively good (Dewey, 2008a).

A total of 1,383 elk was observed and classified within the survey area in 2008 (Table 3.48). The 2008 total exceeded the 2007 survey by 433, and is slightly higher than the five-year running average from 2003 to 2007 of 1,090 elk. However, the trend in population since 1990 suggests that the sampled population has remained stable (Dewey, 2008a).

Herd ratios and composition for the 1,383 elk classified by helicopter were calculated (Figure 3.144). Mature bull ratios increased, but spike bull ratios slightly decreased. Calf ratios declined to the lowest level documented to date (16 calves per 100 cows in the standard survey area; Table 3.49). Most of this decline has been attributed to lower calf ratios observed at the Willow Flats area (14 calves per 100 cows). Calf ratios in the other survey areas were variable, ranging from 12 to 40 calves per 100 cows.

Table 3.48. Grand Teton National Park mid-summer (August 7-8, 2008) elk classification standard survey area results (Dewey, 2008a).

SURVEY AREA	MATURE BULLS	SPIKE BULLS	COWS	CALVES	TOTAL
Central Valley	64	30	569	105	768
Elk Ranch/Uhl Hill	19	1	1	0	21
Willow Flats	33	24	471	66	594
TOTAL	116	55	1041	171	1383

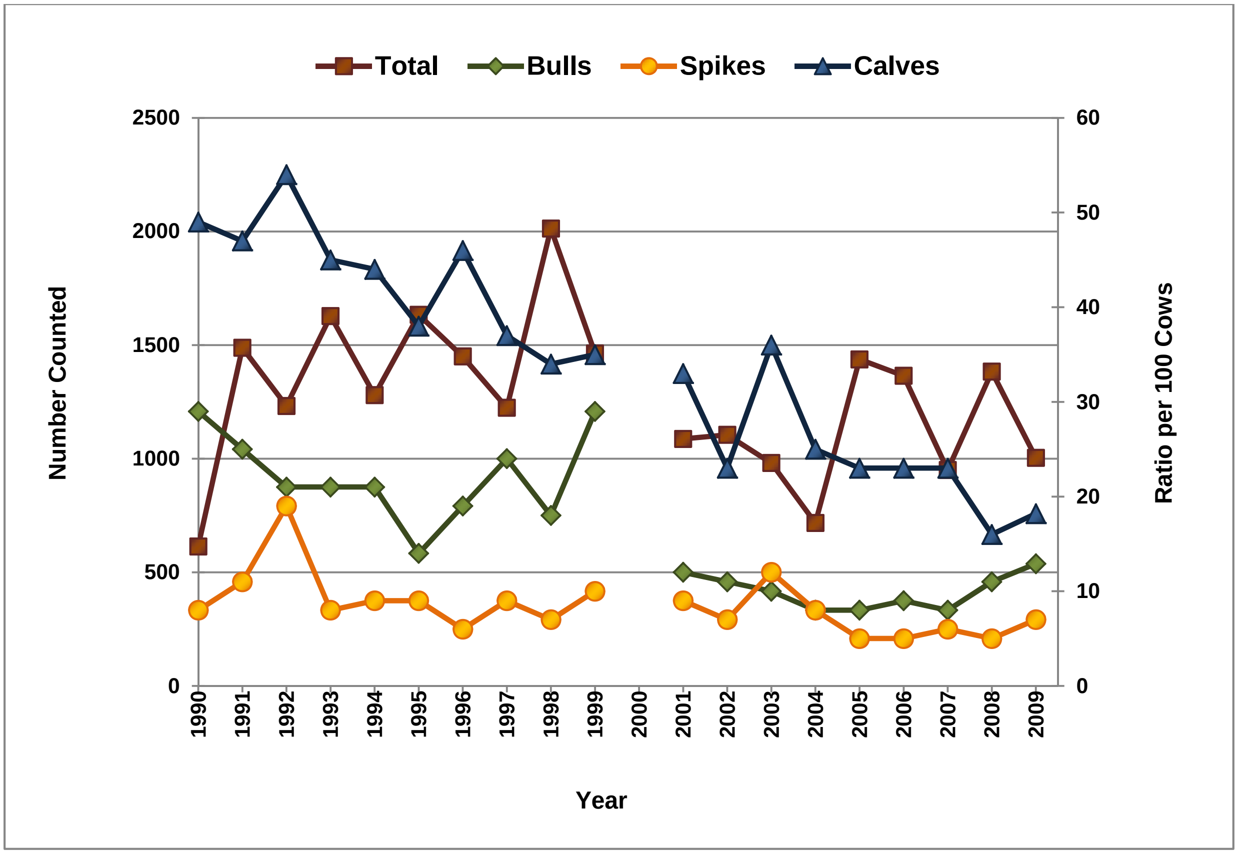

Figure 3.144. Number of elk counted and sex ratios for elk observed in Grand Teton National Park, mid-summer classification counts, 1990-2009. Data source: Grand Teton National Park (Sarah Dewey).

Table 3.49. Sex ratios and population percentages for elk in Grand Teton National Park observed during mid-summer (August 7-8, 2008) classification (Dewey, 2008a).

AGE CLASS	HERD RATIOS (AGE CLASS/100 COWS)	POPULATION PERCENT
Mature Bulls	11	8
Spike Bulls	5	4
Cows	-	75
Calves	16	12

Elk distribution has remained similar to past years. The number of elk in the central valley of GRTE was higher by 271 in 2007, but was within the range counted during the previous five years. Numbers counted at the Elk Ranch/Uhl Hill area were lower than the number counted in 2007, but consistent with numbers counted in the area since 1999. The number of elk counted at the Willow Flats area was the highest since counts were initiated in 1999 (Dewey, 2008a).

In addition to the standard survey area, several additional areas were surveyed in 2008. These areas include: Mystic Isle burn, the west side of Teton Park Road between

Jenny Lake and Murie Ridge, and the Snake River corridor south of Moose (Table 3.50). The Snake River corridor south of Moose was surveyed for the first time. Calf ratios were approximately 40 calves per 100 cows in this surveyed area (Dewey, 2008a).

Threats

Although supplemental feeding at the National Elk Refuge has helped the Jackson elk herd population recover, it has also caused some problems. The high concentration of animals at the refuge has contributed to high levels of brucellosis, a contagious bacterial disease that often causes infected cows to abort their first calves, in the herd. Feeding has also allowed for an unusually low winter mortality rate. Non-harvest mortality has averaged a low one to two percent of the herd, compared with 12 percent of 85 non-fed, adult female elk studied from 2000 to 2004 in northern YELL. The low mortality rate has impacted willow, cottonwood, and aspen habitats (NPS, 2007l). Since 1980, a growing number of bison have wintered at the refuge, capitalizing on feeding programs initially intended for elk. Since discovering the supplemental food source, the bison herd has grown at an annual rate of 13 percent, numbering 1,100 animals in 2007 (USDI, 2007).

To address the complex and potentially controversial issues surrounding elk resources, GRTE has adopted a long-term management plan in coordination with the National Elk Refuge and other agencies. Under the plan, the Jackson elk and bison herds will be managed with an emphasis on improving winter, summer, and transitional range in the park and on the refuge. The plan calls for the park to work in close partnership with the WGFD to implement a "dynamic framework for decreasing the need for supplemental food on the refuge" based upon knowledge of existing conditions, trends, new research findings, and other changing circumstances (USDI, 2007).

The management plan is designed to achieve several desired conditions over 15 years. These objectives include maintaining the population of the Jackson elk herd at 11,000, a reduction from 13,000, with 5,000 expected to winter at the refuge. The targeted summer elk population in GRTE is 1,600 under the plan, a reduction from 2,500 (USDI, 2007). According to the plan, "when necessary, to achieve elk population objectives," targeted elk hunting in GRTE will be permitted as per the enabling legislation of the park. Most permits issued in reduction efforts within the park are for antlerless (mostly female) elk. Total annual harvest averaged 20 percent of the Jackson elk herd from 1982 to 2001, of which five percent was a reduction in GRTE (NPS, 2007l).

Table 3.50. Grand Teton National Park mid-summer (August 7-8, 2008) elk classification additional survey area results (Dewey, 2008a).

SURVEY AREA	MATURE BULLS	SPIKE BULLS	COWS	CALVES	TOTAL
Mystic Isle Burn	6	0	23	8	37
West Side of Teton Park Road	4	0	10	4	18
Snake River (south of Moose)	1	8	120	48	177
TOTAL	11	8	153	60	232

Gray Wolf

Gray wolves are the largest wild members of the Canidae family, which also includes coyotes and domesticated dogs. All wolves are considered members of the same species (*Canis lupus*), except for those native to the southeastern United States, which are commonly referred to as the red wolf (*Canus rufus*). Recent research suggests that North America has five extant subspecies of *Canis lupus*, although distinctions between them are generally not significant. The subspecies present in the GYE is the Rocky Mountain wolf (*Canis lupus occidentalis*). The Rocky Mountain wolf is native to Alaska and the northern Rocky Mountains of Canada and the United States (NPS, 2006j).

Despite their common name, gray wolves range in color, having various combinations and shades of white, brown, gray, and black (Figure 3.145). Adult males weigh up to 130 pounds (59 kilograms), but on average, they weigh 110 to 115 pounds (50 to 52 kilograms). They are typically 5.0 to 6.5 feet (1.5 to 2.0 meters) long from nose to tail tip. Adult females weigh up to 115 pounds (52 kilograms), but on average, they weigh 90 to 95 pounds (41 to 43 kilograms). They are typically 4.5 to 6.0 feet (1.4 to 1.8 meters) in length. Most adult wolves stand 26 to 32 inches (66 to 81 centimeters) tall at the shoulder. They have long legs and a deep, narrow chest and large feet that enable them to travel long distances in snow (NPS, 2006j).

Gray wolves are highly social, territorial pack animals that hunt and live in groups. Their basic social unit is the pack, and central to the pack are the dominant (breeding) male and female. The remaining pack members are usually related to the dominant pair and express their subordinate status through postures and expressions. A simple pack is made up of a breeding pair with pups, whereas a complex pack has a breeding pair with several generations of offspring. Pack size is related to the size of available prey. The larger the prey, the greater the food supply and the number of wolves needed to bring the prey down. Packs that feed on deer usually have five to seven wolves, whereas those that prey on moose, elk, and bison have more than 15 wolves. The social organization of wolf packs is hierarchical, with breeding reserved for a dominant male and female pair. The dominant pair also determines the direction and routes of travel (NPS, 2006j).

Figure 3.145. Gray wolves. Photo sources: U.S. Fish and Wildlife Service.

Wolves reach sexual maturity at two years, but usually only the dominant male and alpha female within a pack mate. However, when conditions permit, a pack may produce multiple litters. Wolves typically breed from late January through April, with wolves at higher latitudes generally breeding later. Wolves in the GYE breed in February. Wolves who become pregnant prepare dens three weeks prior to the birth of their pups. Most wolf dens are burrows in the ground, but wolves may also den in hollow logs, rock caves, or abandoned beaver lodges. The gestation period for wolves is approximately 63 days, and pups are born from late March through April. With an established denning area, pack movements center around the den. When pups are six to 10 weeks old (late May to early July), the pack begins moving to a series of rendezvous sites, with each site approximately one to four miles from the previous site. This movement continues until the pups are mature enough to travel with the adults, which is usually in September or early October (NPS, 2006j).

Habitat
Gray wolves are true habitat generalists. Their presence depends on the availability of suitable prey rather than geophysical features or plant communities. Historically, wolves occupied a vast American range, which included all habitat types except tropical rainforests, true deserts, and the southeastern United States. The adaptability of wolves allowed them to at one point in time have the broadest distribution of any land mammal (Fritts et al., 1994). The size of wolf territories is highly variable and depends on pack size, food availability, and season. Territories are typically larger in the winter than in the summer (NPS, 2006j).

Wolves are carnivorous, with ungulates accounting for more than 90 percent of their diet in most regions. In addition to preying on ungulates, wolves prey on beaver where populations are abundant and they obtain meat by scavenging the carcasses of animals that died from other causes. The winter diet of wolves monitored near Jackson from 2000 to 2006 consisted of elk (greater than 90 percent), with 47 percent of kills being elk calves (NPS, 2008g). Sometimes, wolves prey on bison and moose, especially in the winter when these animals are in their weakest condition; however, these large animals are often difficult and dangerous to kill. In the summer, approximately 25 percent of the diet of YELL wolves is mule deer (NPS, 2006j).

Social and Legal Context
In most western societies, wolves have long been considered a devilish predator; consequently, they have been the target of systematic extermination campaigns by governments and private individuals (Lopez, 1978). In the United States, wolf extermination began in the 1630s and spread westward with Euro-American settlement. Western state and local governments and livestock associations offered bounties on wolves in the nineteenth and twentieth centuries. Wolves were nearly universally despised by Euro-Americans in the United States, and even the celebrated conservationist Teddy Roosevelt condemned the wolf as the "beast of waste and desolation" (Fritts et al., 1994). Managers of national parks also regarded wolves as vicious predators, and with congressional support, wolves were routinely killed in YELL in order to protect the well being of more desirable animals such as elk and deer (NPS, 2006j). By the 1930s, the species had been nearly extirpated from the lower 48 states except for isolated populations in remote areas of northern Minnesota. After the advent of more ecologically-based wildlife management programs in the 1920s, the National Park Service adopted a policy in 1931 that focused on the prohibition of predator control. The policy prohibited

predator control except "when they are actually found making serious inroads upon herds of game or other animals needing special protection" (Albright, 1931). However, by this time, wolves were absent in YELL (NPS, 2006j).

By 1978, all *Canis lupus* subspecies were federally listed under the Endangered Species Act in the lower 48 states, with the exception of Minnesota (NPS, 2006j). Following an extensive environmental impact analysis in the late 1980s and early 1990s, the U.S. Fish and Wildlife Service (USFWS) began a wolf recovery program in YELL and other locations in the western United States. In collaboration with Canadian wildlife biologists, the USFWS captured and transported a total of 33 wolves from the provinces of Alberta and British Columbia to YELL in 1995 and 1996. The YELL population has since become established and has spread to surrounding regions, including GRTE.

With wolf reintroduction efforts appearing successful, the USFWS delisted the gray wolf in Wyoming, Montana, and Idaho on March 28, 2008, shifting management authority to the respective states (USDI, 2008). The Wyoming Game and Fish Commission subsequently adopted a regulation whereby wolves could be hunted (WGFC, 2008). However, the USFWS delisting decision was challenged by a number of environmental groups, resulting in a federal court injunction on July 18, 2008 that suspended the delisting of the species in the northern Rocky Mountains and returned management to the federal government (Keszler, 2008). On August 5, 2010, a federal court ruling reinstated the legal protections of the Endangered Species Act for the gray wolf in the northern Rocky Mountains outside of "experimental populations" in southern Montana, Idaho south of Interstate 90, and all of Wyoming (USFWS, 2010e).

Under the ruling, states and tribes with USFWS-approved wolf management plans are afforded maximum legal flexibility over their management of wolves. Montana, Idaho, and the Wind River Tribal Lands in Wyoming currently have wolf management plans, but as of November 2010, the state of Wyoming outside of the Wind River Tribal Lands did not have a USFWS-approved wolf management plan. Therefore, the USFWS continues to be the lead management agency for wolves in nearly all of Wyoming (USFWS, 2010e). The state has requested that the USFWS accept its wolf management plan, and a legal decision from Judge Allen Johnson is pending (USFWS, 2010f). Regardless of future management plan decisions or status of wolves in Wyoming, wolf hunting will not be permitted in GRTE (NPS, 2008g). However, the state could request permission to hunt wolves within JODR.

Trends

Gray wolves were reintroduced into YELL in 1995 and 1996. The first YELL wolves were observed in GRTE in 1997, but they later returned to their home range in YELL. In 1998, two groups of wolves, known as the Jackson Trio and the Teton Duo, were found in GRTE. The Jackson Trio was renamed the Gros Ventre Pack after they denned in a remote area in the Gros Ventre drainage on the Bridger-Teton National Forest. The Teton Duo remained in GRTE and was renamed the Teton Pack. The Teton Pack produced a litter of pups in 1999, the first litter of wolf pups in GRTE in over 70 years. Since then, wolves have continued to expand and reproduce within GRTE and Jackson Hole (Dewey et al., 2009).

In GRTE, NPS and USFWS biologists cooperatively monitor wolves in the park, focusing on denning activity, pup production, mortalities, movements, and dispersal. Wolf monitoring is conducted via aerial surveys and radio collars. Radio collar monitoring employs both traditional VHS radio collars as well as GPS collars with ARGOS satellite uplinks, which send a sample of data points via satellite to scientists. This technology allows the scientists to readily relocate wolves that move great distances outside the park. Radio collars were deployed on 24 wolves from five packs in late winter and spring of 2009. Of the 67 wolves in the area, 25 (37 percent) were radio collared at the end of 2009 (Dewey et al., 2009).

The Jackson area wolf population grew from 11 to 76 between 1999 and 2009, at which time six packs were resident in the area. The six packs resident to the area in 2009 were the Phantom Springs Pack, Pacific Creek Pack, Buffalo Pack, Antelope Pack, Huckleberry Pack, and Pinnacle Pack. This was the greatest number of wolves known to exist in the area since wolves recolonized Jackson Hole in 1998 (Figures 3.146 and 3.147). The increase was attributed to increases in the Buffalo Pack, which probably produced multiple litters in 2009 (Dewey et al., 2009).

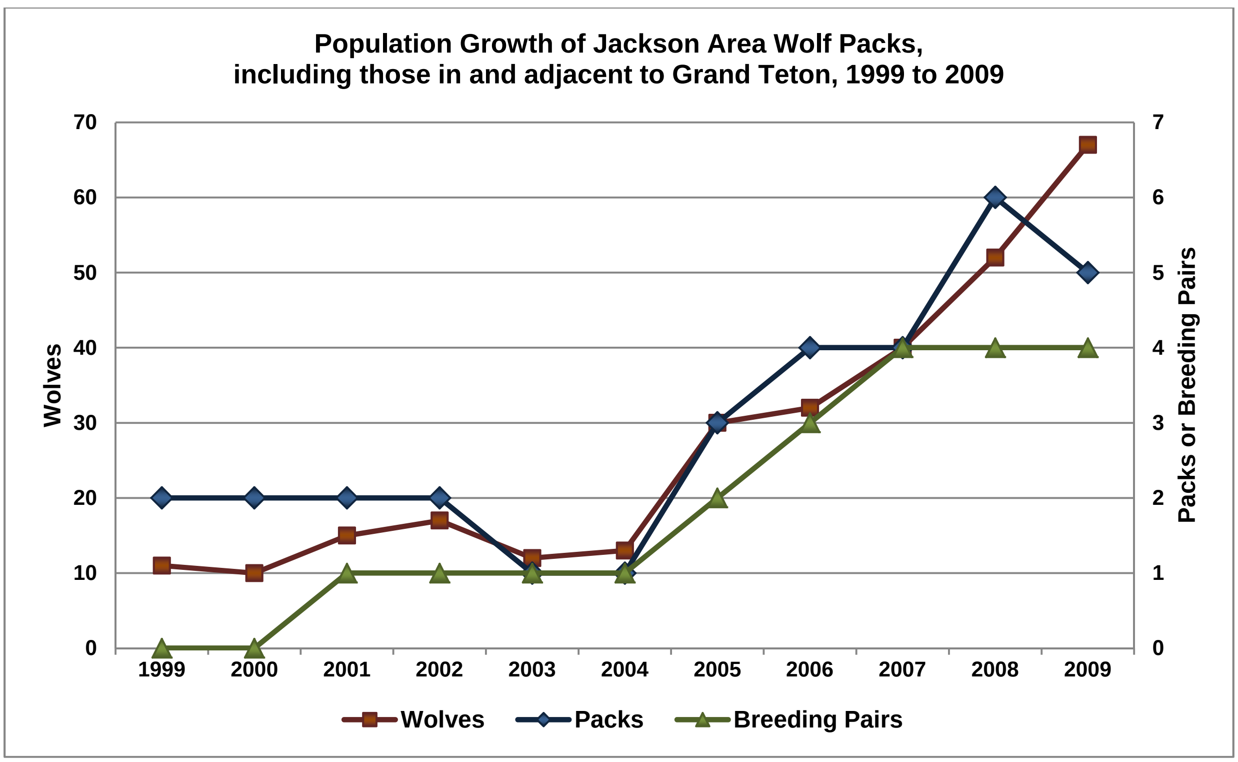

Figure 3.146. Population growth of Jackson area wolf packs, including those in and adjacent to Grand Teton National Park, 1999-2009 (Dewey et al., 2009).

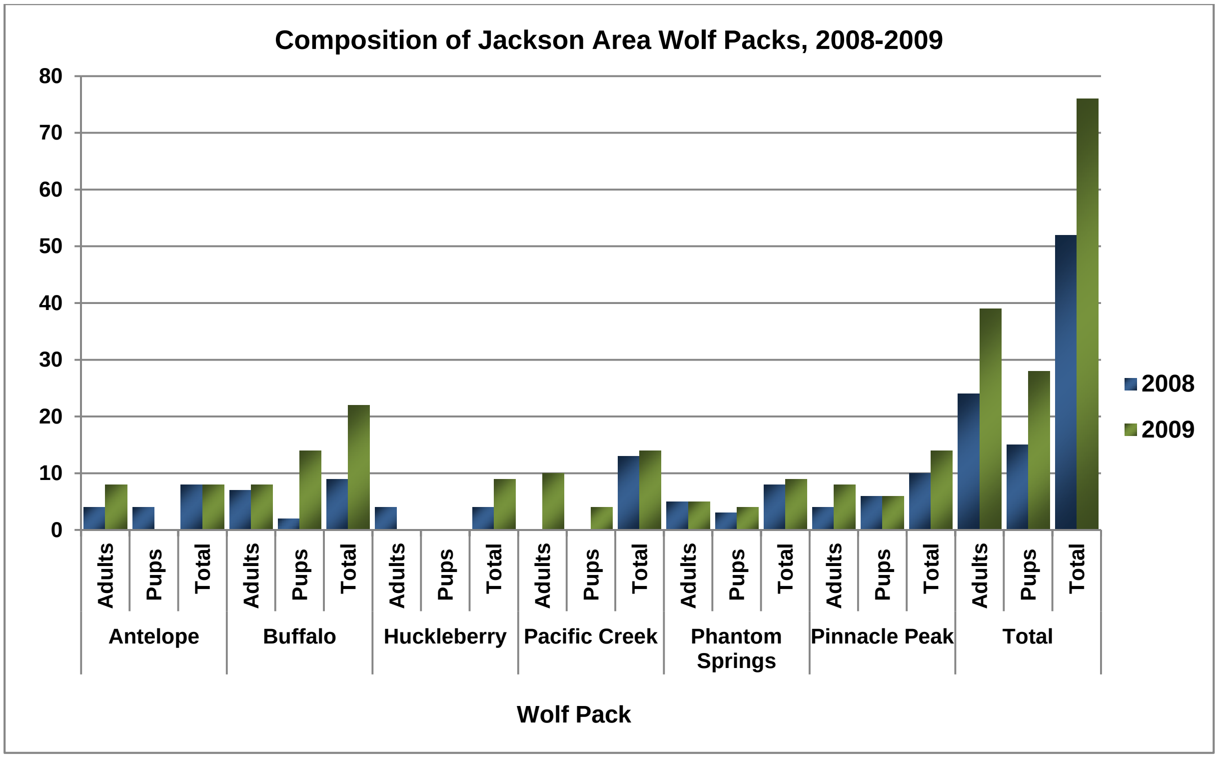

Figure 3.147. Composition of Jackson area wolf packs, 2008-2009. Number of adults and pups for the Pacific Creek Pack in 2008 and number of adults and pups in the Huckleberry Pack in 2009 are unknown and appear as zeros in this chart (Dewey and Stephenson, 2008b; Dewey et al., 2009).

In GRTE and Jackson Hole, pack size ranged from eight to 22, with an average of 13 wolves. Four of the packs were documented with pups in 2009 and were counted as breeding pairs. The breeding pairs produced a total of 28 pups that survived to the end of the year (Figure 3.147). The average number of pups per breeding pair surviving to late fall was 5.6. The Antelope Pack denned and produced pups, but it appeared that all pups had died by the end of 2009. This pack was not counted as a breeding pair. The status of the Huckleberry Pack was not certain in 2009, as there were no radio-collared wolves in the pack. However, nine wolves were documented at the end of 2009 (Dewey et al., 2009).

One radio-collared wolf (723M) of the Phantom Springs Pack dispersed during spring 2009. This wolf was collared in early April and dispersed within a week of capture. He was subsequently located with another wolf more than 50 miles southeast of the park. This wolf is now considered to be a member of the Rim Pack. Another radio marked wolf from the Phantom Springs Pack died in 2009. The cause of death for this wolf was under investigation at the end of 2009. Wolf 596F of the Buffalo Pack was last located with the pack in late November 2008. Since monitoring flights resumed in January 2009, 596F has not been located and her location is unknown. Wolf 599F of the Huckleberry Pack was last found with the pack in late November 2008. The departure of this wolf left no other radio-collared members in the pack, and radio contact with this pack was lost. The pack did not use their traditional denning site in 2009, but sightings throughout their territory suggest that the pack or individuals still exist (Dewey et al., 2009).

All five members of the Antelope Pack handled by biologists during winter captures were infected with sarcoptic mange. Sarcoptic mange is caused by the mite *Sarcoptes scabei*, which is a common ectoparasite of wolves and other canids. The mite burrows into the skin of infected animals, which leads to scratching, rubbing, and hair loss. Without the insulating qualities of the hair, fitness may be reduced, and in severe cases, infected animals may succumb to exposure or other secondary infections. Young wolves are often more severely affected than adults. Two pups from the Antelope Pack were observed at a rendezvous site in mid-summer with severe cases of sarcoptic mange (Dewey et al., 2009).

Threats

In the GYE outside of national parks, the primary causes of wolf mortality are human related. Where conflicts with humans are less likely to occur, most wolves die of natural causes, but where human conflicts are likely to occur, wolves die from vehicular accidents, illegal killings, and management removals due to predation on domestic animals. This is reflected in the mean annual survival rates of wolves within YELL and within the GYE outside of protected areas. In YELL, survival rates are 80 to 85 percent, whereas survival rates in the GYE outside of protected areas are 55 percent. These survival rates highlight the importance of protected areas for sustaining wolf populations. Research from the USFWS indicates that with an adequate prey base in protected areas, an established wolf population can reproduce at a rate sufficient to offset human-caused mortality rates of 28 to 35 percent (NPS, 2006j). In GRTE, management has implemented closures around the denning sites to minimize human disturbance. Closures begin when denning is confirmed and are lifted when pups begin traveling with the rest of the pack (Dewey et al., 2009).

<u>Grizzly Bear</u>

The grizzly bear (*Ursus arctos horribilis*) is a subspecies of brown bear (*Ursus* arctos), and it is one of two bear species found in the GYE. Compared to the black bear (*Ursus americanus*), grizzly bears are larger, more aggressive, and not as widely distributed across the continent. In addition to their size and aggression, grizzly bears differ from black bears in that they have a large muscle mass above their shoulder; they have a concave, rather than a straight or convex, facial profile; and they have long, relatively straight claws (NPS, 2010n; NPS, 2010o; Schwartz et al., 2003).

The coloration of grizzly bears varies from blond to black. The coat often has pale-tipped hairs that give the animal a grizzled appearance. Additionally, many grizzly bears in the GYE have a light brown girth band (Figure 3.148). Unlike many of the other physical features, the coloration of grizzly and black bears is so variable that it is not a reliable means of telling the two species apart, particularly when bears are not fully grown (NPS, 2010n; NPS, 2010o).

An adult grizzly bear stands approximately 3.5 feet (1.1 meters) at the shoulder. Males weigh 300 to 700 pounds (140 to 320 kilograms) and females (sows) weigh 200 to 400 pounds (90 to 180 kilograms). Despite their size, grizzly bears can run up to 40 miles per hour (65 kilometers per hour) (Blanchard and Knight, 1991; NPS, 2010n). They are also capable of swimming, and contrary to common belief, they are capable of climbing up trees, particularly when they are small (NPS, 2010n).

Figure 3.148. Grizzly bears. Photo sources: National Park Service (R. Robinson and Jim Peaco).

Grizzly bears reproduce relatively slowly compared to other terrestrial mammals. Females rarely breed before the age of four, and they typically become pregnant once every three years. Grizzly bears breed from May to July, and sows give birth to cubs in winter dens during late January or early February. Litter size is usually one or two cubs, sometimes three, and rarely four. Cubs usually spend two-and-a-half years, and sometimes three-and-a-half years, with their mother before she or a suitor chases them away so she can mate again. Young females frequently establish their home range within the vicinity of their mother, but young males disperse farther. The size of home ranges for female grizzly bears varies from 309 to 537 square miles (800 to 1,390 square kilometers), whereas the size of home ranges for males varies from 813 to 2,075 square miles (2,100 to 5,370 square kilometers) (NPS, 2010n; NPS, 2010o).

Habitat

Grizzly bears are omnivorous generalists who utilize a variety of habitats over large areas of terrain. They make extensive use of forested areas and substantial use of non-forested meadows and valleys. Habitat use is affected by social hierarchy and the availability of seasonal food sources.

Adult males generally dominate the best habitats and food sources, followed by mature females with cubs, and then by other single adult bears. Sub-adult bears, which are just learning to live on their own away from their mother, are lowest on the social ladder and are likely to be living in poor-quality habitat (NPS, 2010n).

Until mid-May, grizzly bears depend mostly on ungulates for food. They scavenge on winter-killed elk and bison carcasses and prey on newborn elk calves throughout late spring and early summer. From early May through mid-August, grizzly bears feed on cutthroat trout. These fish provide a valuable food sources, especially in June and July, when streams become shallower and the fatigued post-spawning cutthroat are easier to catch. Later in the summer, grizzly bears will often move to high talus slopes to feed on aggregations of army cutworm moths, which migrate from warmer climates in the Great Plains to the Rocky Mountains. From July through September, the bears excavate the moths from the talus and consume them by the thousands (NPS, 2010n).

From September to October, in years when they are available, whitebark pine nuts are the most important food source for grizzly bears in the GYE. Research indicates that the annual abundance of these nuts is a predictor of grizzly bear survival and reproduction rates (Mattson et al., 1992; NPS, 2010n). Meat from ungulates becomes more important to grizzly bears in years of poor whitebark pine nut production. Grizzly bears will prey on rut-weakened and rut-killed elk, bison, and moose. However, they also consume a variety of other plants and insects in the fall, including pond weed root, sweet cicely root, grasses and sedges, bistort, yampa, strawberry, globe huckleberry, grouse whortleberry, buffaloberry, clover, horsetail, dandelion, false truffles, and ants (NPS, 2010n).

Beginning in July, grizzly bears enter a period of hyperphagia (i.e. increased consumption of food), during which they may put on more than three pounds of weight per day until they enter their dens for the winter (Blanchard and Knight, 1991). Grizzly bears hibernate in dens which they dig over the course of a few days. Dens are usually excavated in sandy loam, clay loam, or rocky silt soils located on the mid to upper one-third of 30 to 60 degree slopes at 8,200 to 8,860 feet (2,500 to 2,700 meters) in elevation. The den includes an entrance, a short tunnel, and a chamber. To minimize heat loss, the den entrance is usually just large enough for the bear to squeeze through. After excavation is complete, the bear covers the chamber floor with bedding material such as spruce boughs or duff and buries the entrance with snow (NPS, 2010n).

During hibernation, grizzly bears live off a layer of fat that was built up during the prior summer and fall. The small surface area to mass ratio of grizzly bears means they lose heat much more slowly than do smaller hibernators. They are therefore able to cut their metabolic rate by 50 to 60 percent during hibernation. Their respiration slows from six to ten breaths per minute to one breath every 45 seconds, and their heart rate drops from 40 to 50 beats per minute to 8 to 19 beats per minute. Grizzly bears can break down the urea produced from fat metabolism, and the resulting nitrogen is used to build protein that allows the bear to maintain muscle mass and organ tissue. When grizzly bears emerge from hibernation in the spring, they will have lost 15 to 30 percent of their body weight and increased their lean body mass (NPS, 2010n).

Trends

Prior to Euro-American settlement, the grizzly bear occupied most of western North America, from the Great Plains to the Pacific Ocean and from Mexico to northern Alaska. However, by 1975, hunting, trapping, poisoning, habitat loss, and the depletion of important food sources, such as salmon, bison, and elk, led to the extirpation of grizzly bears from Mexico and all but two percent of their historic range in the lower 48 states (Mattson et al., 1995). The grizzly bear remains in a few isolated locations in the lower 48 states, with the GYE and northwestern Montana being the only areas south of Canada in which significant populations remain (NPS, 2010n).

In 1974, the grizzly bear population in the GYE was estimated at 136. In 1975, grizzly bears in the GYE were listed as a threatened species under the Endangered Species Act due to the frequency of human-caused grizzly bear mortalities, loss of habitat, and geographic isolation from other grizzly bear populations. Subsequently, a grizzly bear recovery area was established, which encompassed about 9,500 square miles (25,000 square kilometers), including YELL, GRTE, JODR, and significant portions of surrounding lands (NPS, 2010n).

In 1982, the U.S. Fish and Wildlife Service (USFWS) completed the first Grizzly Bear Recovery Plan, and in 1983, the Interagency Grizzly Bear Committee was established to improve communication and cooperation among federal and state administrators. The Interagency Grizzly Bear Committee set forth several regulations designed to reduce human-caused grizzly bear mortality on federal lands. These regulations, in combinations with favorable environmental conditions, helped the grizzly bear population in the GYE to rebound in the late 1980s and 1990s. By 1998, the grizzly bear population was estimated at 344 (NPS, 2010n).

From 1998 to 2003, the grizzly bear population in the GYE grew at an annual rate of four to seven percent, and the range of the population expanded by nearly 50 percent. In 2004, the minimum population was estimated at 431 bears. In 2005, the USFWS determined that the grizzly bear population in the GYE constituted a distinct population segment that was highly likely to persist over large areas into the foreseeable future. On April 30, 2007, the USFWS removed grizzly bears in the GYE from threatened species status; however, a lawsuit and court ruling in September 2009 forced the USFWS to restore the threatened species status. As of August 2010, the USFWS was considering whether to appeal the decision (NPS, 2010n).

Grizzly bears in the GYE are monitored by the U.S. Geological Survey (USGS) Interagency Grizzly Bear Study Team (IGBST). Grand Teton National Park personnel collaborate with the IGBST by gathering and submitting a variety of demographic information from grizzly bears in the park (Cain and Schwartz, 2008). The status of grizzly bears in the GYE is reported annually by the IGBST.

The IGBST estimates the population of GYE grizzly bears each year based on the number of unduplicated females with cubs-of-the-year (COY) observed via aerial and ground surveys. In 2009, 42 unduplicated sows with COY were observed, rendering an estimate of 582 bears in the GYE. This total is slightly less than the 596 bears estimated in 2008, but it is more than twice the number of bears recorded 20 years ago (Cain and Schwartz, 2008; Haroldson, 2009). Statistical models suggest that in 2009 the population was growing at an annual rate of approximately 4.2 percent (Haroldson, 2009). On October 29, 2010, the IGBST estimated that the 2010 population of grizzly bears in the GYE was at least 603. This would be the highest level in decades and more than three times the size of the population in 1975 (Brown, 2010).

The IGBST monitors grizzly bear mortality each year to determine whether mortality levels are within sustainable limits. While mortality was unusually high in 2008 (Cain and Schwartz, 2008), estimates of total mortality of independent females and males in 2009 were within sustainable limits, as were human-caused mortalities of dependent young. The IGBST documented 31 known grizzly bear mortalities in the GYE during 2009, 24 of which were attributable to human causes (Haroldson and Frey, 2009). In 2010, preliminary estimates indicate that at least 62 grizzly bears in the GYE were killed or removed from the wild (Brown, 2010).

Grizzly bear-human conflicts in the GYE are inversely associated with the abundance of natural bear foods (Gunther et al., 2004). In

2009, the availability of high-quality, concentrated bear foods were above average during the spring, average during the summer, and above average during the fall. During the summer, many grizzly bears were observed at high elevation army cutworm moth aggregations sites, and abundant berry crops attracted bears in GRTE. Autumnal whitebark pine seed production was considered good to excellent throughout most of the ecosystem (Gunther et al., 2009).

The number of incidents in which habituated grizzly bears frequented roadside meadows and the outskirts of developments in GRTE continued to increase in 2009. Park staff managed visitors and bears at 129 roadside grizzly bear-traffic jams. A significant amount of staff time was spent managing habituated bears and the visitors viewing and photographing them. There were 148 grizzly bear-human conflicts reported in the GYE in 2009; none of these conflicts occurred in GRTE (Gunther et al., 2009). During the summer of 2010, two people were killed by grizzly bears in the GYE, the first fatalities since 1986. Both incidents occurred on national forest land, and both of the bears involved were euthanized (NPS, 2010n).

Threats
Greater than 80 percent of grizzly bear mortalities in the GYE result from human causes. These include collisions with vehicles, self-defense kills, and illegal shootings. Additionally, grizzly bears are often removed because they have caused property damage. Human activity also poses a threat to grizzly bear populations insofar that it diminishes suitable habitat and food sources. Diminishing habitat and food sources are likely to bring grizzly bears into greater conflict with people as bears attempt to access human food, garbage, and livestock (NPS, 2010n).

Two important food sources of grizzly bears in the GYE have also been threatened. First, the population of cutthroat trout has been reduced in some areas of the GYE, notably Yellowstone Lake and its tributaries, as a result of the illegal introduction of non-native lake trout (*Salvelinus namaycush*) and whirling disease, which is caused by the parasite *Myxobolus cerebralis*. Secondly, whitebark pine stands have deteriorated in the GYE due to a fungus (*Cronartium ribicola*) that causes white pine blister rust, and more alarmingly, due to mountain pine beetle (*Dendroctonus ponderosae*) outbreaks. Mountain pine beetle activity has caused widespread mortality in trees throughout the GYE, killing 72.6 percent of whitebark pine trees on transects monitored by the IGBST from 2002 to 2010 (Haroldson and Podruzny, 2010). The diminished stock of whitebark pine trees may enhance the likelihood of grizzly bear-human conflicts, which tends to increase in years of low food availability (Gunther et al., 2004).

The long-term impact of diminished access to cutthroat trout and whitebark pine nuts on the grizzly bear population in the GYE may be difficult to predict. However, bears are highly adaptable mammals that currently make use of several high-quality and widely-distributed foods sources. In northwest Montana, where whitebark pine stands have been significantly depleted by extensive infections of white pine blister rust, grizzly bears have appeared to successfully adapt to significant depletions of whitebark pine nuts by switching to other foods (NPS, 2010n).

Moose

Moose (*Alces alces*) are the largest member in the Cervidae family. Four subspecies of moose are recognized in North America, including Shiras moose (*A. a. shirasi*), eastern moose (*A. a. americana*), northwestern moose (*A. a. andersoni*), and Alaskan moose (*A. a. gigas*). The Shiras moose, the smallest of the four subspecies, is the subspecies found in the GYE. Mature Shiras moose bulls weigh considerably less than other moose subspecies, but can still weigh up to 1,000 pounds (454 kilograms) and stand more than seven feet (2.1 meters) at the shoulder. Female moose (cows) can weigh up to 900 pounds (408 kilograms). Both sexes are dark brown, often with tan legs and a muzzle (Figure 3.149). Their long legs enable them to wade into rivers and through deep snow, to swim, and to run fast. Bulls can be distinguished from cows by their large palmate antlers, which can span five feet (1.5 meters) from tip to tip (YELL, 2010e; NPS, 2010p; UDWR, 2009).

Moose are solitary animals for most of the year, except during the mating season or rut. During the rut, which begins in September, both bulls and cows are vocal and are very aggressive. Bulls use their antlers in dominance displays and challenges. Bulls may challenge one another by clashing antlers. The bull on the offensive tries to knock its opponent sideways, and if such a move is successful, the challenger follows through with another thrust. These fights rarely result in serious damage; however, occasional mortal injuries can result. Following the rut, in late November, bulls typically shed their antlers; however, some young bulls may retain their antlers as late as March. Shedding heavy antlers conserves energy and promotes winter survival. In April or May, bulls begin to grow new antlers. While yearlings grow six to eight inch (20 centimeter) spikes, prime adults grow the largest antlers (YELL, 2010e).

Cows are pregnant through the winter, and gestation is approximately eight months. Calving peaks in late May or early June. When a cow is ready to give birth, she drives off any previous offspring that may have wintered with her and seeks out a thicket. Cows usually give birth to one or two young, with each weighing 25 to 35 pounds (11 to 16 kilograms). A calf walks within a few hours after birth. They grow rapidly and achieve sufficient size by five months of age to endure deep snow and cold weather. Although they grow rapidly, they often become prey for bears, wolves, cougars, and coyotes (YELL, 2010e).

Habitat

Moose are found in forested areas and willows flats from southeastern British Columbia to northern Colorado. They are herbivorous browsers that primarily eat shrubs and trees. The twigs and foliage on shrubs and trees are high in cell-soluble sugars and readily ferment in the rumen (Tyers, 2003). In the GYE, the principal staples of moose diet are the leaves and twigs of willows, followed by other woody browse species, such as gooseberry and buffaloberry. In the summer, moose also eat aquatic plants, such as water lilies, duckweek, and burweed. An adult moose consumes approximately 10 to 12 pounds (4.5 to 5.5 kilograms) of food per day in the winter and 22 to 26 pounds (10 to 12 kilograms) of food per day in the summer (YELL, 2010e).

Figure 3.149. Shiras moose. Photo sources: Ralph Haberfeld (Younkin et al., 2008) and National Park Service (Jeff Foott).

Since moose require large quantities of food, they are constrained by the time required to locate and process these resources. Moose density is therefore largely determined by the quantity of available forage. Research indicates that moose may maximize feeding efficiency by seeking concentrations or patches of vegetation where they can spend relatively long periods of time foraging, especially during the winter. Accordingly, moose home ranges have been described as series of high use areas connected by travel routes. Such home areas may be comprised of closely related feeding sites of a few acres or less, each of which can be used for several days or weeks (Tyers, 2003). In the GYE, moose migrate in winter to lower elevations where willows remain exposed above the snow; however, some move to higher elevations to winter in mature stands of subalpine fir, Douglas-fir, and Engelmann spruce. Moose can easily move and feed in these thick stands of conifers because the branches prevent snow from accumulating on the ground (YELL, 2010e). In late March to mid-April, or after a snow crust forms or snow depths decrease, moose leave winter ranges and move to spring ranges (Younkin et al., 2008).

The moose in GRTE belong to the Jackson herd unit, which is one of the 13 herd units defined by the Wyoming Game and Fish Department (WGFD). The Jackson herd unit is comprised of individuals in approximately 2,000 square miles (5,200 square kilometers) of habitat in western Wyoming. The Jackson herd is partially migratory, moving between distinct but overlapping summer and winter ranges (Dewey, 2009a). The herd spends the spring, summer, and fall in mid- to upper-elevations both within and outside of GRTE. The herd often uses the sagebrush flats north of Jackson during these seasons. Most of the winter range occurs in river drainages within GRTE (Figure 3.150). These winter riparian habitats are dominated by narrowleaf cottonwood and willow (Younkin et al., 2008; Anderson et al., 2008; Dewey, 2009a).

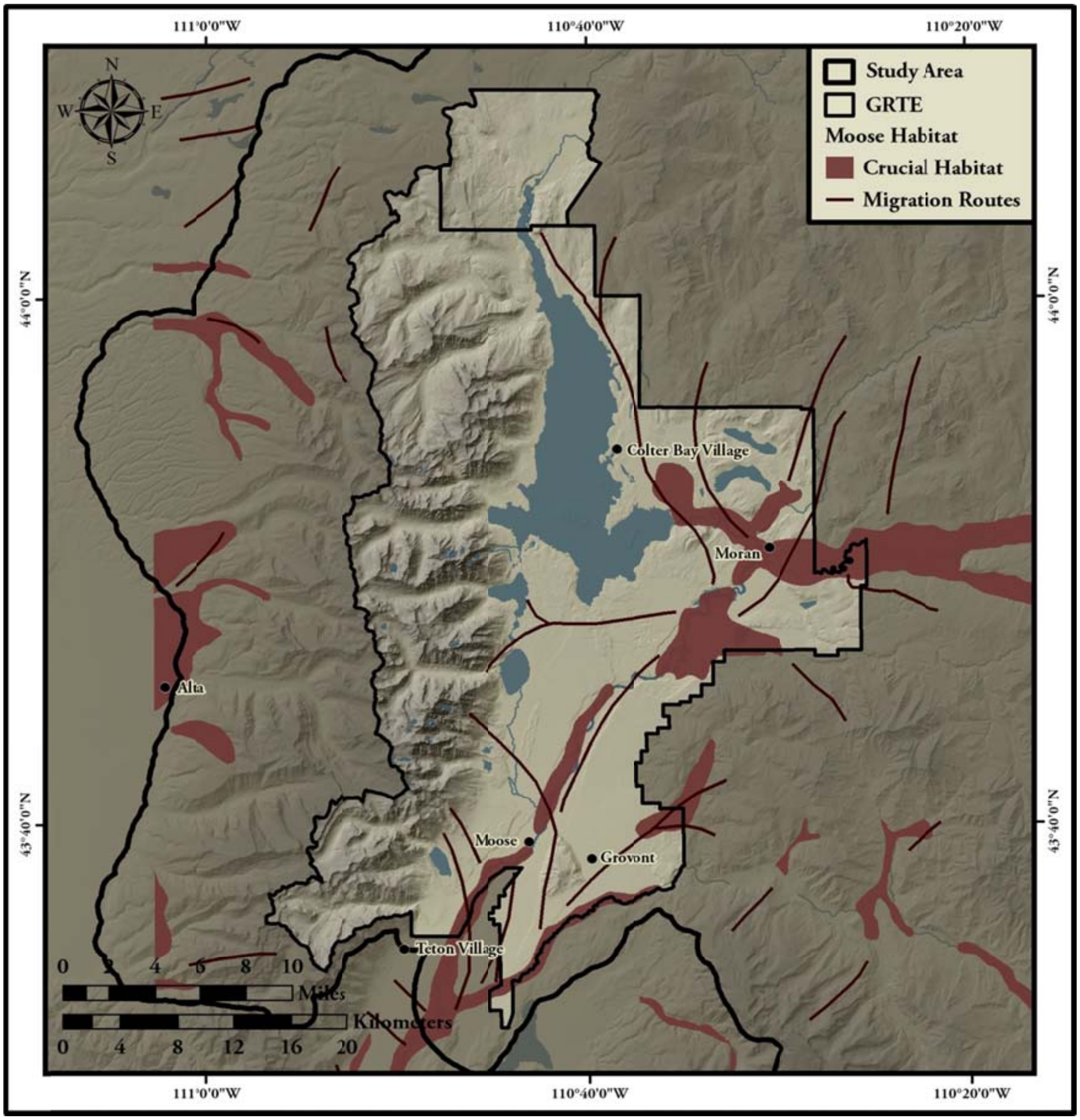

Figure 3.150. Crucial moose habitat and migration routes. Data source: Wyoming Game and Fish Department.

Trends

Moose are a relatively new species in the GYE. It is believed that they entered Wyoming from Montana and Idaho within the past 150 years. Moose appear to have been scarce in YELL until the latter half of the nineteenth century and in Jackson Hole until early in the twentieth century. Forest fire suppression, restrictions on moose hunting, and moose transplantation has contributed to their broadened distribution and increased population. Long-term studies suggest that North American moose populations tend to erupt, crash, and then stabilize at a density level that depends on current ecological conditions and hunting pressure. While moose populations in many areas of the Rocky Mountains have continued to grow into new habitat, those in YELL and Jackson Hole have declined since the 1980s (Figure 3.151) (NPS, 2010p).

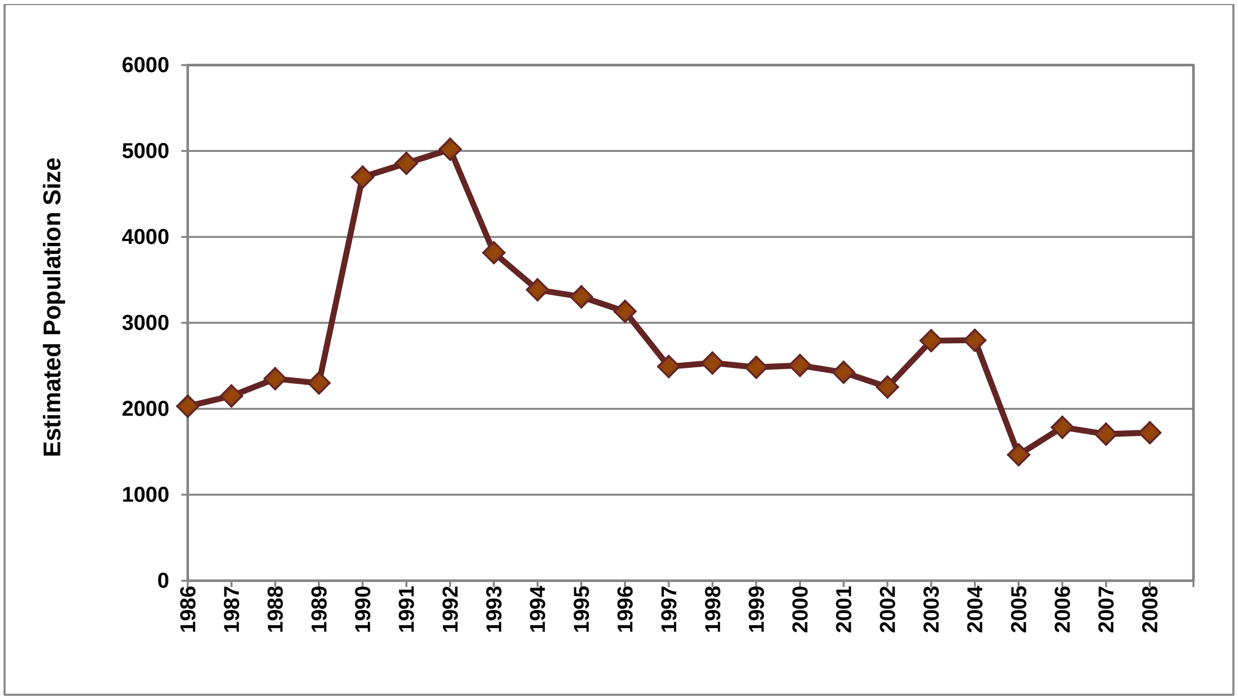

Figure 3.151. Estimated population size of the Jackson moose herd, 1986-2008 (Dewey, 2009a; data compiled from WGFD Job Completion reports).

The Jackson moose herd is monitored by the WGFD. The WGFD conducts annual aerial surveys of riparian and upland winter range by helicopter, usually in mid-February. Surveys focus on core moose winter ranges and include the low elevation and upland habitats adjacent to the Snake River, Pacific Creek, Buffalo Fork, Spread Creek, Ditch Creek, and the Gros Ventre River. Open sagebrush and bitterbrush habitats are also surveyed (Dewey, 2009a). Since moose are usually found alone or in small family groups and use habitat in which they are often well concealed, accurate estimates of population size and distribution are difficult to obtain (NPS, 2010p).

During the 1960s, it was estimated that approximately 35 percent of the Jackson moose herd counted during winter surveys in GRTE maintained a home range exclusively within the park. Between 2001 and 2005, an average of 32 percent of the moose observed during aerial surveys was observed in GRTE (Figure 3.152). Assuming that these numbers remain valid for current conditions, this would indicate that approximately one-ninth of the Jackson moose herd may maintain a home range exclusively within GRTE. However, the current size of the population in GRTE in summer is unknown (Dewey, 2009a). Using counts from winter surveys, the WGFD estimates the total population of the Jackson moose herd. The 2009 aerial survey counted 362 moose, and the WGFD estimated total herd population at 970 animals. Thirty-three percent of the moose observed were bulls. Estimated 2009 ratios for the Jackson moose herd were 15 calves and 57 bulls per 100 cows (Figure 3.153). Within GRTE, 83 moose were observed during the 2009 survey flights, which was slightly higher than the 59 observed in 2008. Seventy-seven percent of the cows observed in the park were without calves, 23 percent had one calf, and no twins were observed (Dewey, 2009a). Mid-winter counts suggest that the current trend of wintering moose is downward (Figure 3.152).

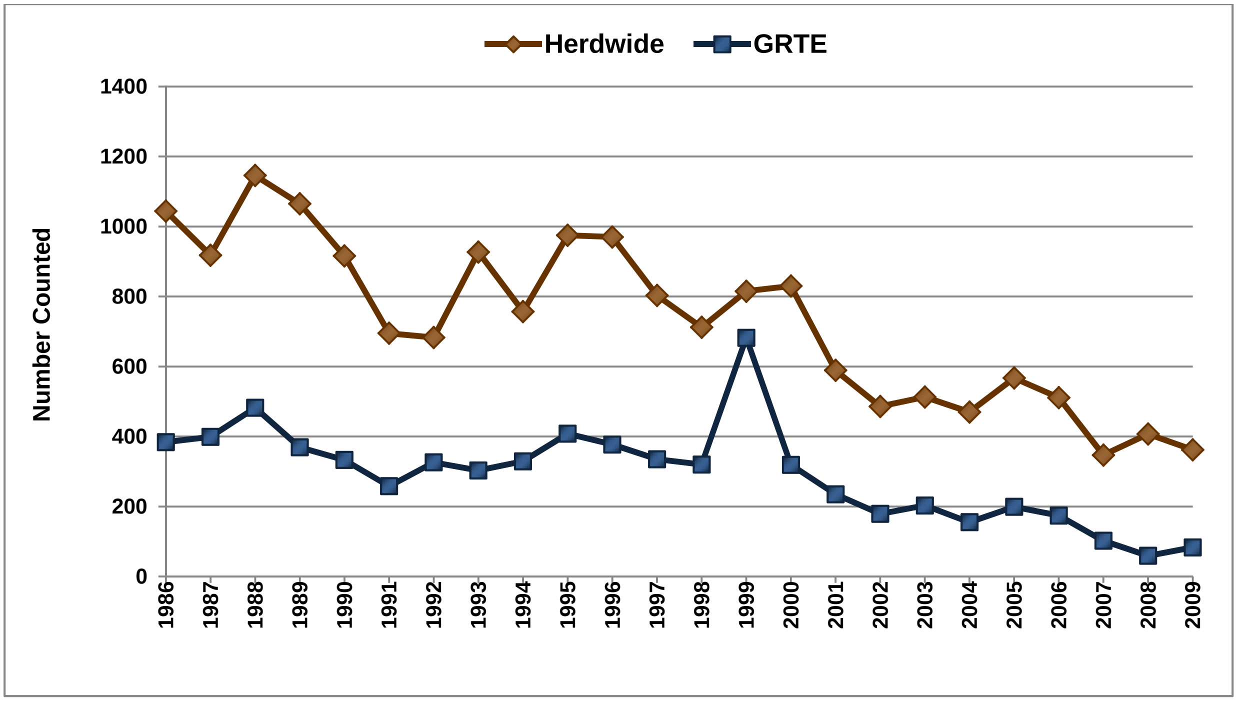

Figure 3.152. Mid-winter counts of the Jackson moose herd, 1986-2009 (Dewey, 2009a; data compiled from WGFD Job Completion reports).

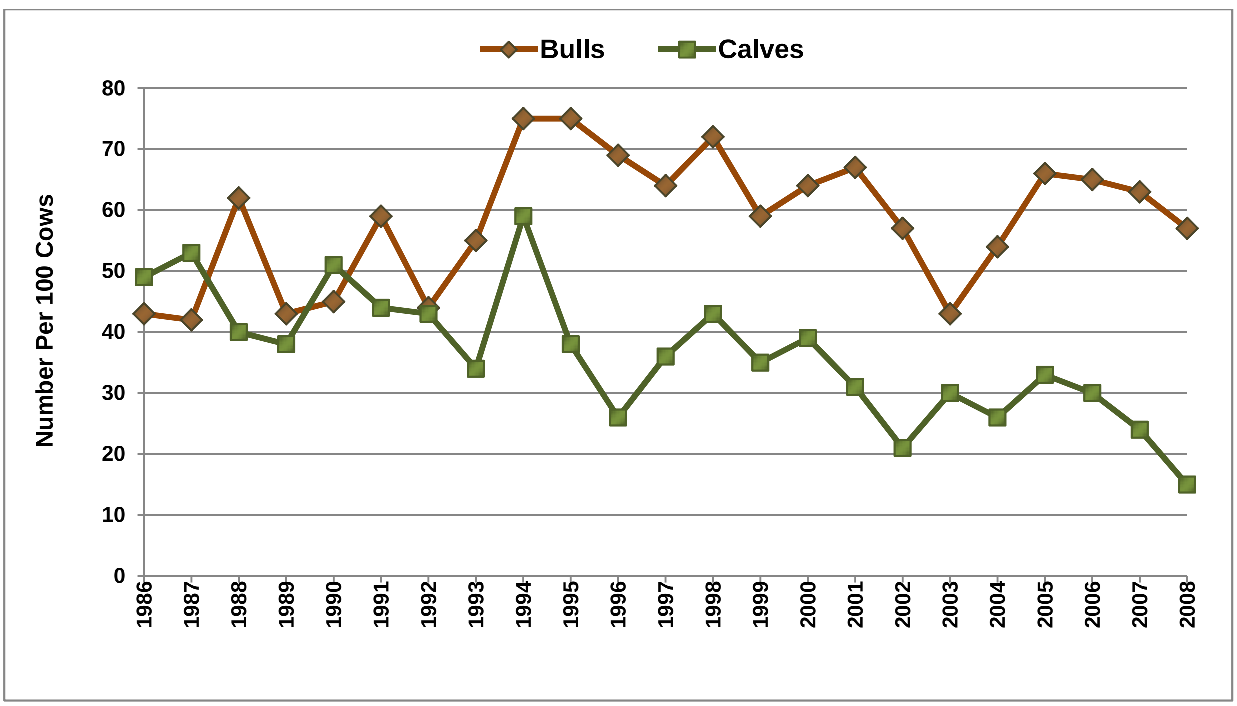

Figure 3.153. Estimated ratios of bulls and calves per 100 cows for the Jackson moose herd, 1986-2008 (Dewey, 2009a).

Threats

The population of the Jackson moose herd has declined over the last several decades for unknown reasons. The present ecological landscape is different than it was at the turn of the twentieth century when the moose population was expanding. State biologists and researchers are concerned about the factors responsible for the decline. Several studies have suggested that moose are nutritionally limited. More specifically, studies conducted by Wigglesworth and Wachob (2004), Berger (2004), and Becker (2008) suggest that a population increase of moose as a result of a lack of natural predators and human hunting may be the cause of habitat degradation in the Jackson winter range where moose may have exceeded their carrying capacity (Younkin et al., 2008).

To assess the quality and quantity of moose habitat for the Jackson moose herd and to develop management recommendations for enhancing and conserving moose habitat, the WGFD contracted with the Teton Science Schools to conduct a habitat assessment study. The results were released in 2008 (Younkin et al., 2008). The report provided a systematic and comprehensive review of important habitat for the Jackson moose herd across WGFD-defined focus areas, exclusive of privately owned lands. The habitat vegetation condition for 105,574 acres (42,724 hectares) was identified (Figure 3.154), and specific management recommendations of high, medium, and low priorities for enhancing and conserving moose habitat for 91,488 acres (37,023 hectares) was provided (Figure 3.155). These management recommendations reflect priorities and objectives of the WGFD and Teton Science Schools, but may not necessarily reflect priorities and objectives of GRTE.

Presently, the management goal for moose in GRTE is “to maintain the moose population and the ecosystems on which they rely.” In 2009, crucial moose winter ranges along the Snake River south of Moran Junction were closed to human entry to provide secure winter habitats for moose and other ungulates. Closures were in effect from December 15 to April 15 (Dewey, 2009a).

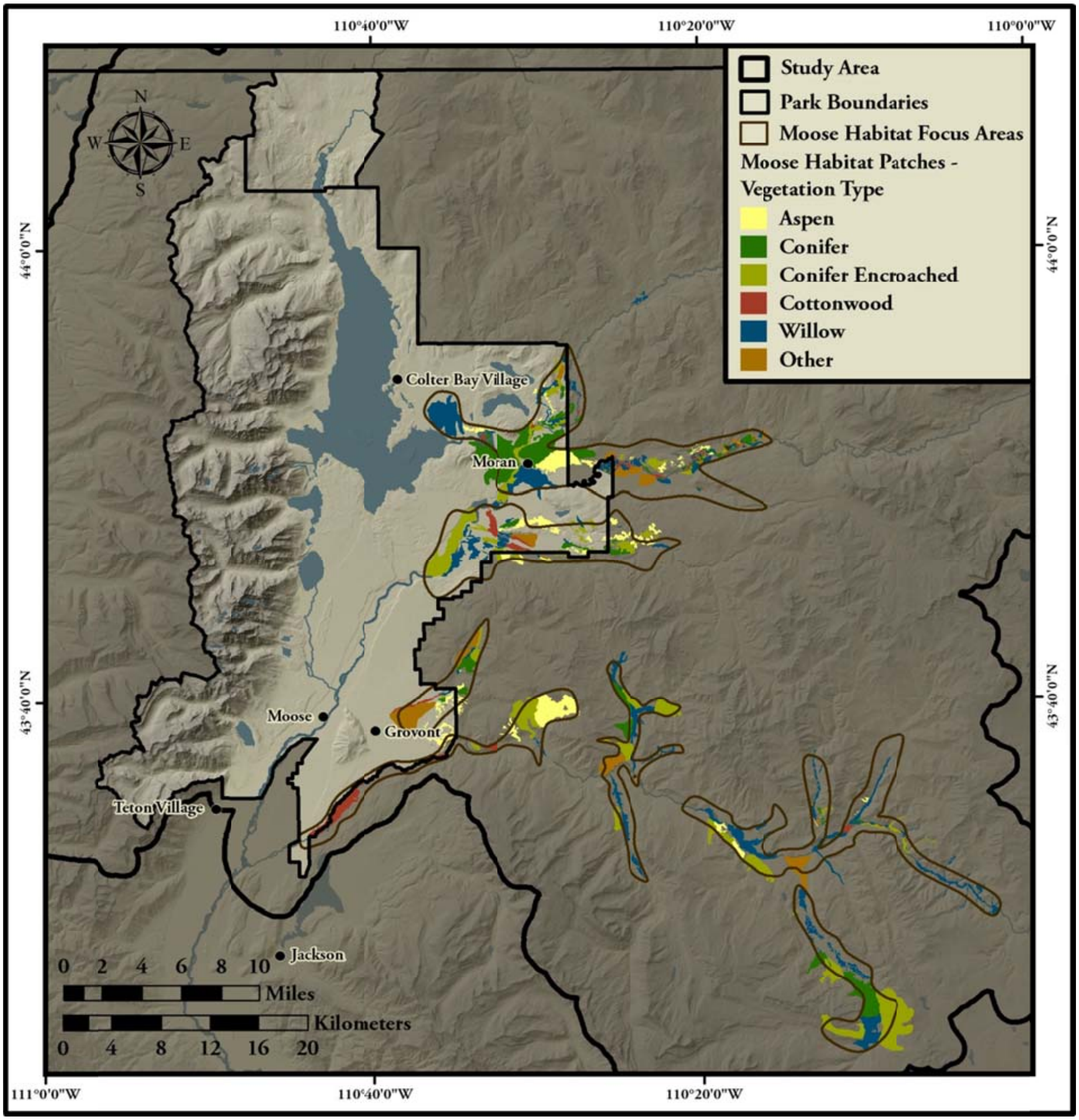

Figure 3.154. Moose habitat vegetation as defined by the Wyoming Game and Fish Department moose habitat assessment (Younkin et al., 2008).

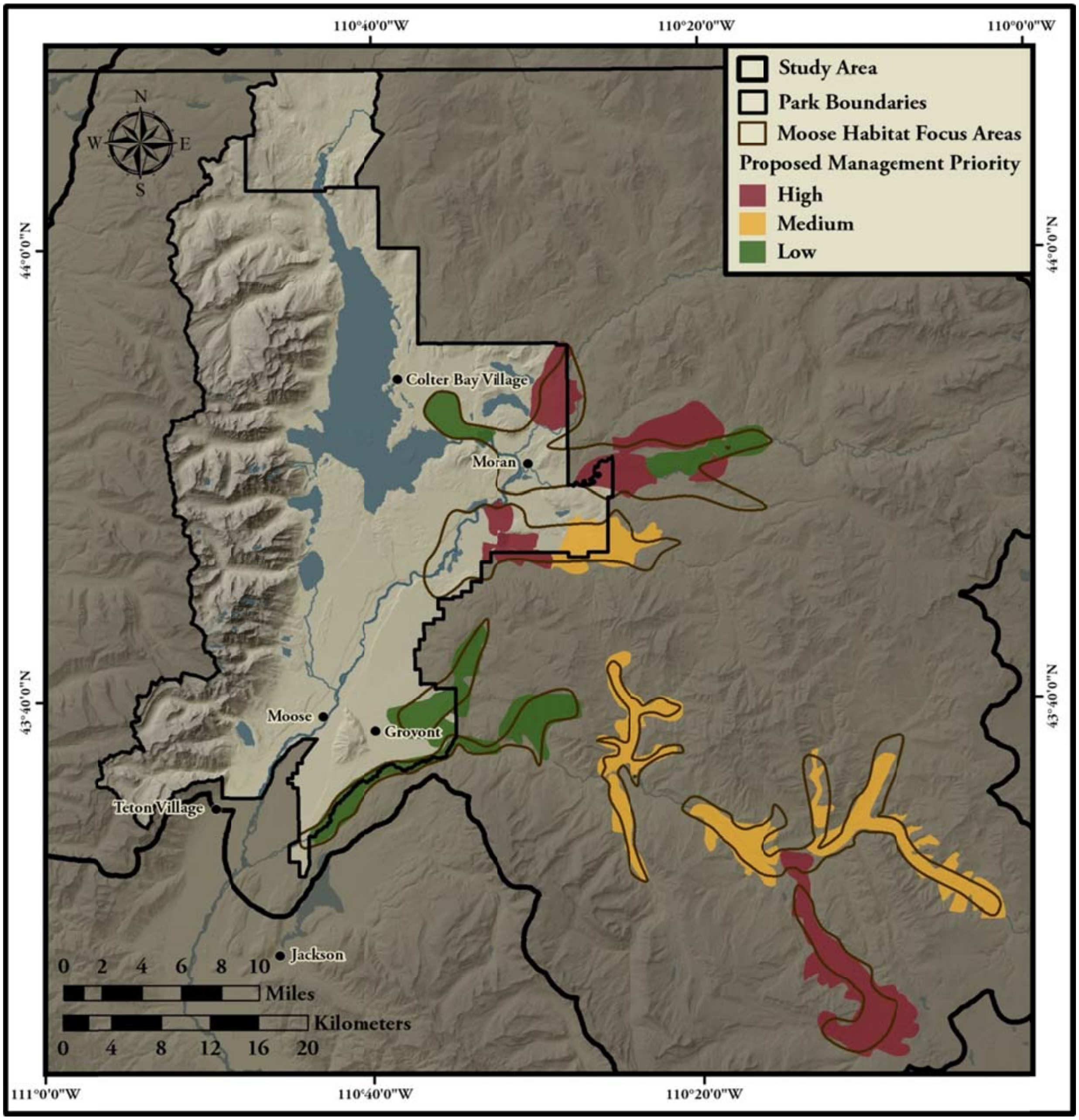

Figure 3.155. Proposed management priority of moose habitat as defined by the Wyoming Game and Fish Department moose habitat assessment (Younkin et al., 2008).

Pronghorn

Pronghorn (*Antilocapra americana*) are the fastest land mammal in North America, and they are the only species of extant ungulate that are endemic to the continent. They are also the only remaining members of the Antilocapridae family. While pronghorn are often referred to as antelope, true antelope belong to the Bovidae family, which are native to Africa and Asia. Five pronghorn subspecies have been recognized, but anatomical differences used to distinguish them are slight. Greater than 90 percent of all pronghorn, including those in the GYE, belong to the subspecies *A. a. americana* (NPS, 2010q).

Compared to other North American deer, pronghorn are relatively small. Their weight seldom exceeds 125 pounds (57 kilograms). They are mostly white and rusty brown to tan, with black and dark brown markings on their head and neck (Figure 3.156). Bucks have broad, black cheek patches; does have less black on their head. Marking on both males and females are similar, but they are variable enough to distinguish the sex. Pronghorn have horns that grow over a bony core protruding from the skull. Males have uniquely forked horns, and approximately 70 percent of females have horns, but they are not forked and are usually only a few inches in length (NPS, 2010q).

Unlike other ungulates in the GYE, the body of the pronghorn is built for both speed and endurance. It has a relatively small stomach and large heart, lungs, liver, and kidneys. These adaptations help the pronghorn reach sprinting speeds of over 60 miles per hour (96 kilometers per hour), and maintain speeds of 45 miles per hour (72 kilometers per hour) over several miles. Pronghorn evolved on plains where speed was necessary to evade predators, but the ability to jump was not necessary (NPS, 2010q). Therefore, despite being able to cover nearly eight yards (7.3 meters) per stride when running, pronghorn are generally unable to jump fences, and will instead squeeze under fences where possible (Hawes, 2001; NPS, 2010q).

Both male and female pronghorn may breed for the first time when they are 16 months old, but females often wait until the following year. Pronghorn bucks begin defending groups of does from other bucks in mid-summer in preparation for the rutting season, which typically lasts for two to three weeks in September (NPS, 2010q; Caslick, 1998). After a gestation period of approximately 250 days, fawns are born from late May through June. The first pregnancy of a doe typically results in one fawn, but subsequent births are usually twins (NPS, 2010q).

Pronghorn fawns are frequently preyed upon by coyotes, and less frequently, by other predators, including bears, bobcats, cougars, red fox, golden eagles, and wolves. Research from YELL dating back to the 1950s indicates that only 25 percent of pronghorn fawns survive their first summer (Caslick, 1998). Most fawns taken by coyotes are killed within the first three weeks of life. By the time they are seven weeks old, healthy pronghorn fawns can outrun predators, including wolves. Healthy adult pronghorns are rarely taken by predators, as they are skittish animals that can easily outrun pursuers (NPS, 2010q).

Habitat

Historically, tens of millions of pronghorns occupied a range that extended from the south-central grasslands of Canada to the high plains of central Mexico, and from the Mississippi River to the Pacific Ocean. While pronghorn can still be found throughout the extent of their historic range, their numbers have been severely reduced (Hawes, 2001; NPS, 2010q).

Figure 3.156. Pronghorn. Photo sources: Blank et al. (2006) and National Park Service (Jim Peaco).

The pronghorn found in GRTE use flat grasslands and sagebrush-steppe communities extending from Moran, Wyoming, south to the National Elk Refuge during the summer. In the fall, they migrate 125 miles (200 kilometers) to less snowy winter range in the upper Green River basin. This migration is the longest migration in the lower 48 states; the migration corridor navigates high elevation passes in the Gros Ventre Mountains and averages 1.2 miles (2 kilometers) wide, although topographical bottlenecks narrow the corridor to as little as 397 feet (121 meters) in some locations (NPS, 2010q; Sawyer and Lindzey, 2000). Archaeological evidence indicates that pronghorn have used the narrow pass at Trappers' Point west of Pinedale, Wyoming, in this migration for over 6,000 years (Miller and Saunders, 2000). While the majority of pronghorn migrate to winter habitat, small groups of pronghorn were reported in the Jackson Hole area beginning in the winter of 1992-1993. Except during the mildest winters, survival rates have been generally low, and all of the pronghorn wintering in the Jackson Hole valley perished during the 1997-1998 winter. Over time, the selection process has appeared to favor pronghorn that migrate (Sawyer and Lindzey, 2000; NPS, 2010q).

Because their primary means of defense is the ability to flee from danger, sometimes over long distances, pronghorn depend on widely distributed suitable forage in both winter and summer ranges. Due to their small stomachs, pronghorn require succulent vegetation high in protein and other nutrients. Pronghorn eat new grass in the spring and may preferentially select forbs when available, but sagebrush makes up the primary portion of their diet, as it is high in protein compared to other winter forage. Research has estimated that the winter diet of GYE pronghorn is sagebrush, rabbitbrush, and greasewood (NPS, 2010q).

Trends

During the nineteenth century, pronghorn populations were severely reduced due to hunting, habitat loss, and fencing. The pronghorn population was estimated to have reached a low of around 13,000 animals in the 1910s before conservation programs began to reverse the trend. As of 2000, the continental population was estimated to be around 800,000, of which 400,000 were found in Wyoming. Wyoming has the highest densities and by far the largest number of pronghorn of any state, followed by Montana (NPS, 2010q; Hawes, 2001).

The WGFD has conducted informal ground surveys of summer range in GRTE and the Gros Ventre River drainage since 1970. They arrived at counts that ranged from a high of 423 pronghorn in 1990 to a low of 162 in 1996. Surveys conducted between 1992 and 2002 estimated counts between 150 and 300 pronghorn (NPS, 2010q). The current summer pronghorn population in the Jackson Hole valley and the Gros Ventre drainage is estimated at 300 and has remained relatively stable in recent years (Figure 3.157). However, fawn to doe ratios have been less than 40 to 100, suggesting that fawn mortality in GRTE is usually high or that many of the does arriving on GRTE summer ranges are barren. Barren does may have a better likelihood of surviving the long annual migration, whereas pregnant does may have a better likelihood of surviving by remaining in the Green River drainage after delivering their fawns (NPS, 2010q).

Since 2004, GRTE has performed summer aerial transect surveys in an attempt to better estimate the population of pronghorn in the Jackson Hole area. This monitoring technique provides a population estimate with associated confidence intervals. In 2009, GRTE park personnel conducted aerial transect surveys to count pronghorn in the Gros Ventre River drainage and the central valley of Jackson Hole in mid-June. North-south transects spaced at 0.5 miles (0.8 kilometer) apart were flown at 300 feet (91 meters) above ground level, beginning at Beacon Ridge in the Gros Ventre and working west to the base of the Teton Range. Pronghorn were assigned to one of five distance bands marked on the wing struts of the plane as the aircraft passed perpendicular to the group. Alternate sides of the plane were observed on each transect (Dewey, 2009b).

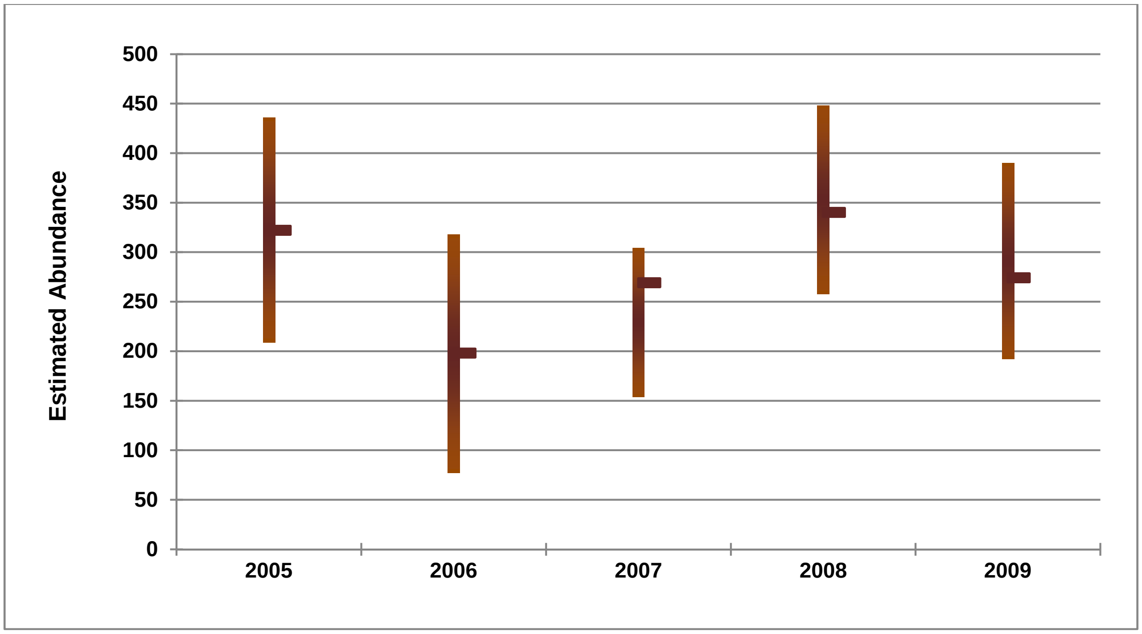

Figure 3.157. Preliminary abundance estimates and 95 percent confidence intervals for Jackson area pronghorn, 2005-2009. The 2006 estimate is for central valley pronghorn only. Data source: Grand Teton National Park (Dewey, 2009b).

One hundred fifty-six pronghorn in 93 groups, with a mean group size of 1.67, were observed within distance bands during the 2009 surveys. Of these, 24 pronghorn in 19 groups were seen in the Gros Ventre River drainage. These values are similar to the number of individuals and groups of pronghorn seen in 2007 when single observer flights were initiated. The other 132 pronghorn in 74 groups were observed in the Jackson Hole valley. The number of groups counted was sufficient to perform abundance estimates. While the total number of pronghorn seen was less than the high of 169 in 2008, the preliminary abundance estimates and associated confidence intervals for 2009 suggest that the 2008 and 2009 estimates are not statistically different (Figure 3.157). One hundred thirty-eight additional pronghorn in 67 groups were counted during the 2009 GRTE survey flights, but these animals were beyond distance bands or on the opposite side of the aircraft and were not used in distance sampling estimates (Dewey, 2009b).

In addition to aerial transect surveys, the WGFD conducted a pronghorn survey from roads during late summer in 2009. Of the 256 total pronghorn counted by the WGFD, 55 percent were does, 26 percent were bucks, and 23 percent were fawns. Ratios were estimated at 41 fawns and 35 bucks per 100 does (Dewey, 2009b).

Threats

Concerns about the long-term viability of the GRTE pronghorn herd exist because their migration corridor traverses an area of rapidly expanding development. Pronghorn are particularly vulnerable to habitat loss and fragmentation along their migration route. The migration corridor is already somewhat impeded, as it requires pronghorn to navigate at least 35 fences (Sawyer and Lindzey, 2000). Rapid development and fence construction in the area near Pinedale, Wyoming, has also crossed the migratory bottleneck near Trappers' Point (NPS, 2009j). Excessive development in critical portions of the migration route could lead to the extirpation of the species from GRTE (Berger, 2003). Accordingly, a movement to modify 500 miles of fence along the migration corridor to be more conducive to wildlife movement is underway (NPS, 2010q).

Other threats to the pronghorn population in the GYE include vehicular accidents. The annual road kill data in YELL typically includes one or two pronghorn; however, more collisions likely go unreported and undetected. In January 2007, a collision with a truck on an unfenced service road in a gas field south of Pinedale, Wyoming, resulted in the death of 21 pronghorn. The tendency of pronghorn groups to run in unison as a means of outpacing and confusing predators has suggested that pronghorn are vulnerable to mass casualties. Since 2003, at least four other similar accidents have occurred in southwest Wyoming, including a train accident that killed 41 pronghorn (NPS, 2010q).

Since wolves were reintroduced into the GYE in 1995, the number of documented pronghorn kills by wolves has been few. Interestingly, pronghorn may be beneficiaries of wolf reintroduction in the GYE because wolves have a negative impact on coyote populations. There is evidence that the reintroduction of wolves has precipitated a species-level trophic cascade in which a negative correlation between coyote and wolf densities has facilitated four-fold higher pronghorn fawn survival rates in areas used by wolves in and near GRTE (Berger et al., 2008).

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