JACKSON HOLE CONSERVATION ALLIANCE

STATE OF WILDLIFE IN JACKSON HOLE

2018

State of Wildlife in the Jackson Hole Area

Authors: Frances H. Clark & Corinna Riginos

Table of Contents

List of Abbreviations

BTNF — Bridger-Teton National Forest
GTNP — Grand Teton National Park
GYA — Greater Yellowstone Area
GYE — Greater Yellowstone Ecosystem
JH — Jackson Hole
NER — National Elk Refuge
NRTAB — Natural Resources Technical Advisory Board
SGCN — Species of Greatest Conservation Need
SWAP — State Wildlife Action Plan
WGFD — Wyoming Game and Fish Department
YNP — Yellowstone National Park

Acknowledgements

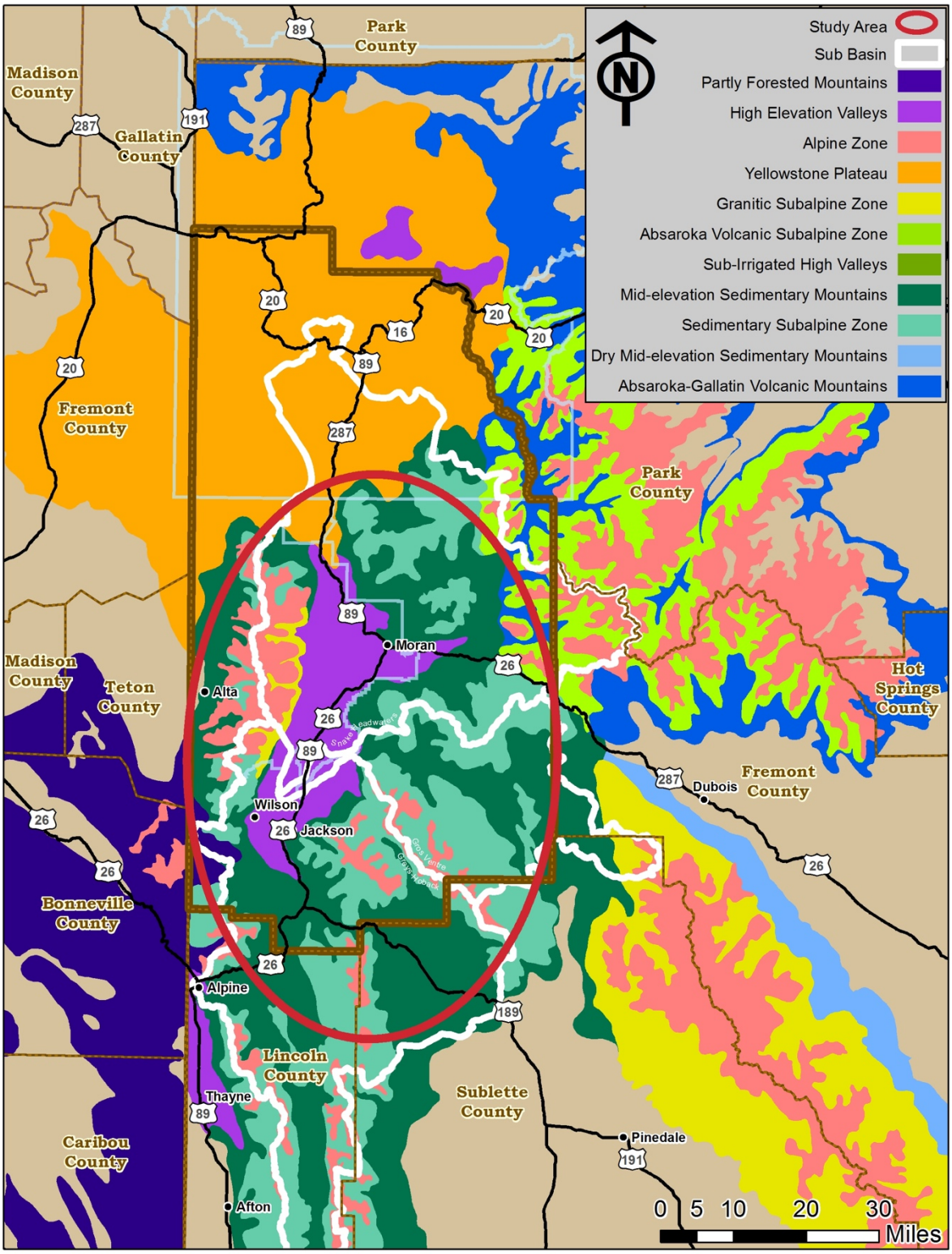
All maps were created by Chauncey Smith. Melia DeVivo contributed to the process of identifying our study area and selecting conservation targets. Siva Sundaresan served as the liaison from the Jackson Hole Conservation Alliance.

This report draws on the expertise of numerous biologists. The following people contributed in important ways, from meetings and conversations to reviewing drafts of sections of this report:

Diane Abendroth — Teton Interagency Fire
Bryan Bedrosian — Teton Raptor Center
Steve Cain — Grand Teton National Parks Foundation
Eric Cole — National Elk Refuge, U.S. Fish and Wildlife Service
Alyson Courtemanch — Wyoming Game and Fish Department
Ross Crandall — Craighead Beringia South
Mark Daluge — Teton Weed and Pest
Mark Elbroch — Panthera
Gary Fralick — Wyoming Game and Fish Department
Rob Gibson — Wyoming Game and Fish Department
Carlin Girard — Teton Conservation District
Morgan Graham — Teton Conservation District
Kathleen Gura — Teton Raptor Center
Dave Gustine — Grand Teton National Park, National Park Service
Matt Kauffman — Wyoming Migration Initiative, Cooperative Fish and Wildlife Research Unit
Kevin Krasnow — Teton Science Schools
Mary Lohuis — Citizen
Susan Marsh — Naturalist, author
Kelly McCloskey — Grand Teton National Park, National Park Service
Mike Merigliano — Plant ecologist
Diana Miller — Wyoming Game and Fish Department
Kerry Murphy — Bridger-Teton National Forest, U.S. Forest Service
Deb Patla — Northern Rockies Conservation Cooperative
Susan Patla — Wyoming Game and Fish Department
Drew Read — Trumpeter Swan Association
Dan Reinhart — Grand Teton National Park, National Park Service
Anna Senecal — Wyoming Game and Fish Department
John Stephenson — Grand Teton National Park, National Park Service
Tracy Stevenson — Wyoming Game and Fish Department
Amy Williams — Teton County Weed and Pest
Jason Wilmot — Bridger-Teton National Forest, U.S. Forest Service
Ben Wise — Wyoming Game and Fish Department

Images courtesy of Frances H. Clarke
Maps courtesy of Corinna Riginos and Chauncey Smith

The report was commissioned by the Jackson Hole Conservation Alliance, a local grassroots conservation organization dedicated to protecting the wildlife, wild places, and community character of Jackson Hole by advocating for conservation policy based on the best available facts and data.



Jackson Hole area (study area) in relation to sub-basins of the Upper Snake River and sub-regions of the Middle Rockies ecoregion

Introduction and Summary

The Purpose of this Report

The purpose of this report is to identify and highlight key conservation "targets" and the threats to those targets in the Jackson Hole area. In doing so, we aim to promote efficient and effective conservation efforts backed by sound science. The report was commissioned by the Jackson Hole Conservation Alliance in support of these ends.

We have defined a geographic area that is a distinct and important part of the Greater Yellowstone Ecosystem — one of the most ecologically intact and beloved regions of the world. We have chosen ten targets that together encompass the biological diversity of the Jackson Hole area most in need of conservation attention. For each of these targets, we have researched the current status and trends relative to historic benchmarks and identified the major threats to them over the next 50 years. Through this process, and with the input of numerous biologists and managers, we have gathered the best and most up-to-date scientific knowledge about each of our conservation targets in the Jackson Hole area.

Our intent is to motivate and focus conservation efforts. We compile this report for the Jackson Hole community at large to encourage people to work together on the difficult task of conserving these targets. This document is an assessment of the status and threats to wildlife, not a prescription for how to manage or how to solve the complex conservation challenges that lie ahead. It is meant to highlight and complement the many exemplary efforts already underway by various land and resource management agencies, NGOs and local government leaders. Our purpose is to provide a reference that cuts across jurisdictional lines and synthesizes a large amount of existing knowledge in one place.

Selection of Geographic Extent — The Jackson Hole Area

Jackson Hole lies within the Greater Yellowstone Ecosystem (GYE) — a large, complex, and iconic part of the United States. The GYE is considered by many to be the most ecologically intact temperate ecosystem in the world. It is home to the headwaters of three major river systems, abundant wildlife, and diverse and unique geology. It is defined by two National Parks, five National Forests, two national wildlife refuges, and other surrounding private, state, and federal lands.

Within this context, our goal was to define an ecologically and socio-politically meaningful piece of the GYE that could broadly be considered the "Jackson Hole area." Our intent was that this extent should capture the defining features of the area, while acknowledging that it is connected to the much larger ecosystem. We defined our geographic extent by identifying key ecological and social-political factors and seeking input from diverse experts and stakeholders. Although we gave more weight to ecological factors than political boundaries, in some cases political boundaries did define edges to our geographic extent. For example, we decided to limit the scope to Wyoming, although we acknowledge many important ecological connections that cross borders into neighboring states.

The ecological factors we used as a basis for defining the Jackson Hole area were (a) the main watershed or drainage sub-basins of the Upper Snake River basin, and (b) the main ecoregions around Jackson Hole. Watersheds are defined by topography and represent natural barriers to many animals' movements, especially aquatic species. Ecoregions are defined using a combination of information on underlying rocks and soils, climate, topography, and plant cover; they represent broad groupings of ecologically similar units at a coarse scale [1]. The sub-basins and sub-ecoregions together suggested a core area, mostly in Teton County. While we determined a core area for this study, we recognize that this core area is ecologically connected to other, nearby areas such as the Yellowstone Plateau, the Salt River basin, and the Upper Green River basin.

The area we have defined through this process is ecologically distinct within the Greater Yellowstone Ecosystem — particularly because it includes significant areas of high elevation sagebrush valleys, sedimentary mountains, and alpine areas. At the same time, this area lies more or less at the heart of the GYE and is a crucial piece of the ecosystem in terms of habitat connectivity for many wildlife species.

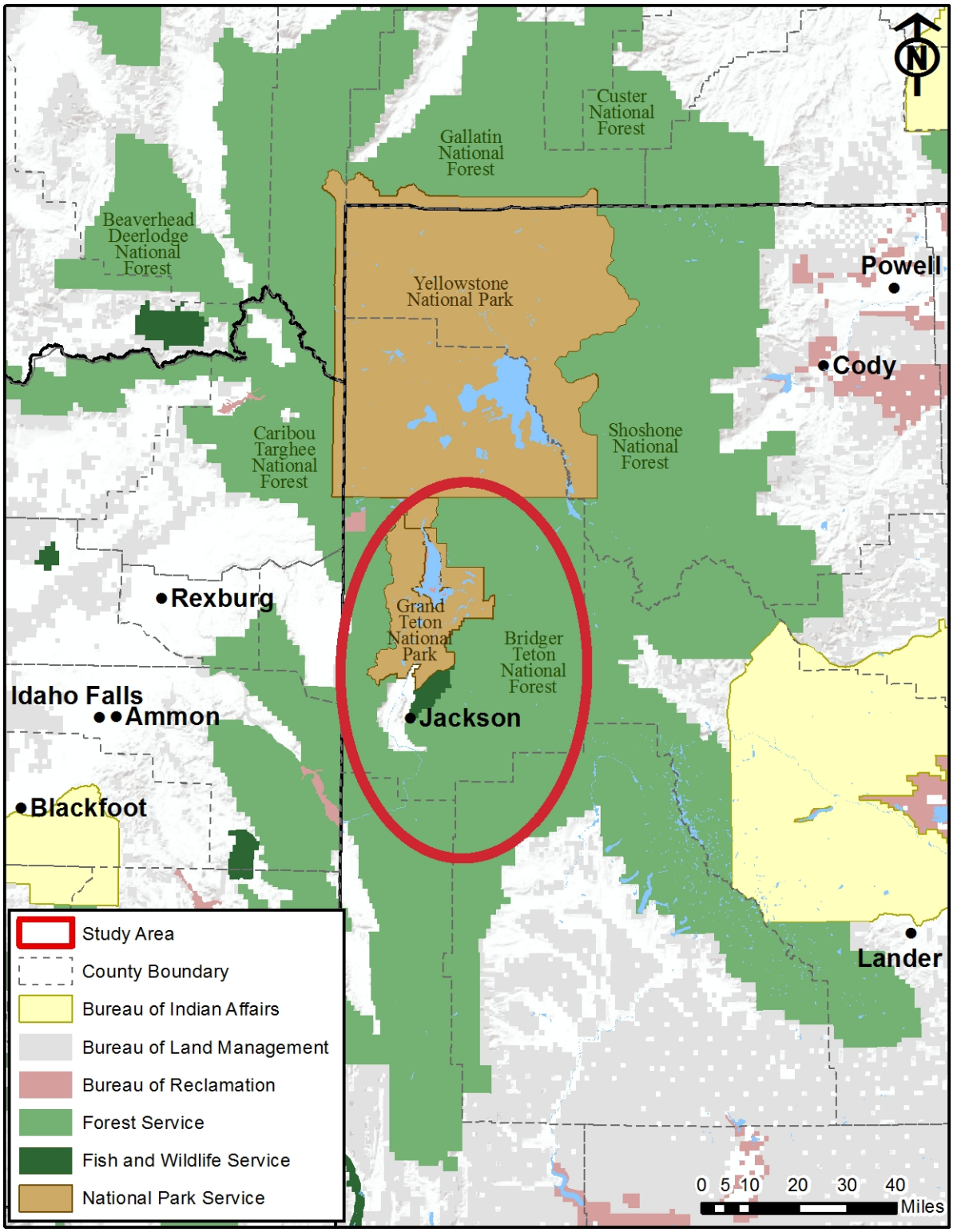
Selection of Conservation Targets

We selected a set of conservation targets based on a methodology developed by the Conservation Measures Partnership, a consortium of national and international conservation organizations and foundations. A target can be a species, a habitat, or a process. This approach emphasizes concentrating on a few targets to focus conservation actions in a way that conserves much of the ecological integrity of the area effectively and efficiently [2, 3]. The process of selection involves local stakeholders and is informed by experts and research. It allows for some flexibility in criteria.

We reviewed lists of rare, endangered, or vulnerable species on a federal, state, and county level. We looked at the type and distribution of habitats throughout the state and region, and considered significant natural processes such as fire, hydrological dynamics, disease, and migration. We reviewed agency and county management plans and discussed potential targets with numerous scientists and managers. We deliberately sifted through, selected, and connected together what we propose here as a practical set of conservation targets that encompass the majority of the natural diversity of the Jackson Hole area.

Key questions we asked:

1. Is the target vulnerable e.g. declining or under significant threat?
2. How feasible is it to track the target's status over time to determine whether management actions are effectively conserving it?
3. Can sound local management and policies have an impact on sustaining or recovering the target?
4. Is the target a regionally important population or habitat of a more widespread species or habitat type that we do not want to lose?
5. How will conserving this target influence other elements in the ecosystem? Does this target serve as a useful umbrella for other potential targets?
6. How do all the targets fit together as a set to capture most of the natural diversity of the Jackson Hole area?
7. Are we leaving anything out?



Jackson Hole area within the Greater Yellowstone Ecosystem.

Assessment of Status, Trends and Threats

For each target, we evaluated its status and trend relative to the best available data from the past. Historic data were variable; in some cases we compared current status of the target population, habitat, or process relative to 40-50 years ago, but in several cases these targets have only been given significant attention in the last couple of decades. We also evaluated the main threats facing each target over the next 50 years. We gave each threat an overall rating of “low,” “medium,” or “high” based on its severity, extent, irreversibility, and probability of occurring. Severity is defined as the level of damage to the conservation target; extent is the geographic area expected to be affected within the study area; irreversibility describes the degree to which the effects of a threat can be undone or restored; and probability is defined as the likelihood of the threat occurring if it is not present yet [2].

We emphasize that all threat ratings could change over time as conditions change or as more information becomes available. We also emphasize that a “low” threat rating does not mean the threat is less important to address than a “medium” or “high” rating. Some threats are more easily addressed than others, and every threat that can be alleviated will help to ensure the persistence of the target species, habitats, and vital processes in the Jackson Hole area.

Overview of Targets, Status, and Threats

Through the selection process, we settled on ten main targets, four of which group together. The main body of this report details each target’s ecological importance, its current status and trends relative to the past several decades, and the threats facing that target, as well as any information gaps around that target. Here, we provide a short overview for each target.

Snake River and Wetlands Complex

The headwaters of the Snake River and its associated lakes, streams, wetlands, and tributaries flow through the heart of the Jackson Hole area and create a rich habitat mosaic that supports much of the area’s biological diversity. Within this broad target, we highlight four more specific targets; however, we urge that the whole river and wetlands complex should be considered critical and deserving of conservation attention.

Hydrologic Processes

- *Importance:* Hydrological processes are fundamental to riverine and wetland systems. The depth and flow rate of water, the deposition and stability of sediments, and magnitude and frequency of flooding events define the diverse habitat mosaic that is essential for supporting plants and animals.
- *Status and Trend*: For decades, the Jackson Lake Dam and levees between Moose and Hog Island have altered river flows, reducing flooding and channel meanders along the Snake River and affecting spring creek flows, with significant impacts for fish and wildlife habitat.
- *Greatest Threats*:
    - *Residential development and agriculture cause water withdrawals and nutrient additions*: Water withdrawals alter water tables and stream flows. Runoff brings added nutrient to water bodies, compromising water quality and promoting algae blooms and aquatic plants that can clog channels.
    - *Invasive and problematic species*: Invasive plants such as spotted knapweed and perennial pepperweed are readily spread by equipment and flowing waters,

displacing native species. If the few New Zealand mud snails occurrences expand and if Zebra mussels are transported here by watercraft, these prolific invertebrates can disrupt the first and essential links in the aquatic food chain, changing food availability and water quality for many other species.
    - *Dams and levees*: Jackson Lake Dam and the levees continue to alter hydrological dynamics.

Beaver

- *Importance:* Beaver are ecosystem engineers that create willow habitat and stable ponds that provide habitat for numerous other species of amphibians, plants, insects, fish, and birds.
- *Status and Trend*: Beaver abundance in GTNP declined by 80% over the past 40 years. Beaver are trapped outside of the park, and the impact of trapping on their population is not known. Several agencies are considering restoring beaver to watersheds to enhance these habitats and ecological services. Beaver are considered a conservation opportunity.
- *Greatest Threats*:
    - *Residential development*: The expansion of development leads to more trapping as “nuisance” animals are removed.
    - *Unknown*: The cause of beaver declines in GTNP is unknown but may relate to hydrological changes. Levees, water diversions, and other hydrological changes are all likely threats.

Cottonwood Galleries

- *Importance:* Narrowleaf cottonwood galleries provide vital and unique habitat for a variety of birds and bats. They are essential habitat corridors for many larger terrestrial species and are an excellent indicator of riverine ecosystem integrity.
- *Status and Trend*: Jackson Lake Dam and levees limit flooding, which is essential for new cottonwoods to germinate and establish. Trees are long-lived but an estimated 30% of this forest type has been degraded since the 1950s between the dam and Moose; this figure is likely greater for the leveed areas south of the Park.
- *Greatest Threats*:
    - *Dams and levees*: Jackson Lake Dam and the levees continue to limit flooding and cottonwood establishment.
    - *Climate change*: Changes in precipitation and hydrologic processes may lower the water table, favoring spruce over cottonwoods.
    - *Invasive and problematic species*: Invasive plants can crowd out native plants in the cottonwood galleries, reducing habitat quality for wildlife.
    - *Residential and recreational development*: Remaining cottonwood galleries are being degraded by the construction of homes, golf courses, and boat launches.

Snake River Cutthroat Trout

- *Importance:* This subspecies of cutthroat trout is a popular sport fish and an indicator of a healthy riverine and wetland ecosystem that supports many other species.
- *Status and Trend*: Currently considered common throughout the watershed.
- *Greatest Threats*:

    - *Disease*: Cutthroat trout are vulnerable to whirling disease, an introduced parasite that is spreading.
    - *Changes in temperature due to climate change*: Warming waters are expected to reduce trout reproduction, resistance to disease, and ability to compete with non-native trout.
    - *Changes in hydrological processes due to climate change*: Changes in hydrological processes and water diversions compound the effects of warming waters.

Sagebrush and Sage-Dependent Species

- *Importance*: The sagebrush plains and grassy buttes of the Jackson Hole valley support a diversity of species not found in other habitats, including the vulnerable Greater Sage-Grouse. The high elevation and precipitation make the sagebrush steppe in this area different from other parts of the West.
- *Status and Trends*: Many areas of sagebrush are protected within Grand Teton National Park, but many other areas have been converted to other land-uses. It is estimated that 45% of historic sage-grouse habitat has been lost. Sage-grouse numbers have declined by 50-75% since the 1950s.
- *Greatest threats*:
    - *More frequent fire*: Sagebrush is adapted to infrequent fires (>100 years between fires) and it takes many years for the shrub to recover. Fires are expected to become much more frequent as the climate warms. Human activity in sagebrush areas also increases the risk of accidental fire.
    - *Invasive and problematic species*: Invasive species, especially cheatgrass, promote fire and outcompete native plants. A warming climate is expected to hasten the spread of cheatgrass, which has devastated sagebrush systems elsewhere.
    - *Air and vehicle traffic, roads and airports*: Cars, trucks, airplanes, and airport management to push birds away from the runway disturb the highly sensitive sage-grouse, threatening their ability to reproduce.

Ungulate Migration as a process

- *Importance*: Ungulate migration routes, such as the designated Path of the Pronghorn, crisscross the Jackson Hole area. The number, length, and relative intactness of migrations found in the Jackson Hole area are rare on a global scale. Migration is an essential process for maintaining the large herds of ungulates that are a vital part of the GYE.
- *Status and Trends*: Most migration routes have been altered to some extent by human presence. The historic bighorn sheep migration from the top of the Tetons to the valleys has been completely severed. Elk migrations are much shorter than they were pre-settlement. Deer and pronghorn have to navigate many obstacles as they migrate.
- *Greatest threats*:
    - *Roads*: Vehicle traffic makes it hard for ungulates to cross roads that cut through their migration routes and winter ranges.
    - *Fences*: Fences can be difficult or even impossible for animals to cross.
    - *Residential and energy development*: Development in the private lands of Jackson Hole makes it difficult for ungulates to move freely through the landscape. Energy development in deer and pronghorn winter ranges in Sublette County threaten some of the herds that migrate into the Jackson Hole area for the summer.

- *Disease:* Chronic wasting disease is expected to arrive in the Jackson Hole area in the coming years; this disease is expected to significantly reduce the populations of migratory elk and deer.

Moose

- *Importance*: Moose are one of the most beloved species of wildlife in Jackson Hole. Moose roam among local wetland and stream habitats and up drainages throughout the valley — relying on habitat connectivity across the valley. This sub-species of moose, the Shiras moose, is found only in the northern Rockies and many of its populations are undergoing precipitous declines.
- *Status and Trends*: Moose numbers have plummeted from around 3,000 or more in the early 1990s to about 500 today. Their reproductive success continues to be low and there is no sign of a population rebound occurring.

Greatest threats:

- *Climate change*: Climate change is the greatest overall threat to moose, as it threatens to increase direct thermal stress to these temperature-sensitive animals and contributes to several indirect threats.
- *Disease*: Carotid artery worm can severely alter moose cognition and vision, directly or indirectly contributing to mortalities. A warming climate is hastening the spread of this fly-borne pathogen.
- *Roads*: Rising traffic volumes are making roads more and more difficult for moose to cross and access different parts of their habitat.
- *Residential development*: Some of the most in-demand and valuable real estate in the private lands of Jackson Hole sits in moose habitat. Development reduces habitat available to moose and introduces new stresses to animals that must live in increasing proximity with humans.

Goshawk and the Mature Forest Mosaic

- *Importance*: The Northern Goshawk is a good indicator of large blocks of unfragmented, older-aged conifer forest. This connected forest mosaic is vital habitat for many other species including a variety of owls, songbirds, and small mammals.
- *Status and Trends*: Methods for counting goshawk are evolving and time consuming, making it difficult to determine trends; however, surveys suggest declines in nesting presence or success in disturbed habitats.
- *Greatest threats*:
  - *Fire*: The frequency and severity of forest fires are expected to increase as the climate warms over the next several decades, threatening the mosaic of mature conifers.

- *Recreation*: Hikers, mountain bikers, backcountry skiers and other recreationalists use mid-elevation (6,300-7,800 foot) conifer forests extensively. Trails can fragment the forest, and increased human and dog presence disturbs raptors and their prey, reducing the quality and connectivity of their habitat.
- *Invasive and problematic species*: Invasive plants displace native species, reduce the food available for herbivores that may be prey for goshawk and other raptors, and can contribute to more frequent fires.

Whitebark Pine

- *Importance*: Whitebark pine trees grow where most other trees cannot and play a unique ecological role by supplying an abundance of nutritious pine "nuts" for red squirrels, grizzly bears, and Clark's Nutcrackers. Clark's Nutcrackers and whitebark pine have a rare mutualism where a plant depends upon a bird. Whitebark pine stands protect the snowpack in the subalpine zone that feeds streams throughout the growing season.
- *Status and Trends*: Whitebark pine populations have declined between 40%-90% in the GYE and across its range in the last two decades, mostly due to blister rust and mountain pine beetle infestations. Although these trees are highly threatened, the Jackson Hole area includes some trees and remnant stands that may contain the genetic keys to the future survival of these populations.
- *Greatest threats*:
  - *Invasive and problematic species: White pine blister rust* is an introduced fungal disease that kills whitebark pine trees of all ages. Outbreaks of another problem species mountain pine beetle have become more frequent and severe due to warming temperatures. These two pests combined give little opportunity for old or young trees to survive.
  - *Climate change:* Warming temperatures will enable Subalpine fir and Engelmann spruce to grow at higher elevations, crowding out whitebark pine.
  - *Fire*: Climate change is expected to cause more frequent and extensive forest fires, leaving insufficient time for trees to reach reproductive age between fires.

Watch List

In addition to the above targets, we identified a number of species and habitats to keep an eye on as possible future targets. These include some vital players in the Jackson Hole area's ecology, such as grizzly bears, wolves, aspen stands, and amphibians. These and others did not make our top-tier target list because we determined that (1) They were already receiving ongoing and sufficient attention, funding and expertise, often on a regional or national scale; (2) They did not currently meet our criteria; and/or (3) We did not have sufficient information about them. We applaud the work being accomplished on these species and habitats and recommend that we watch how they are doing over time to see if they merit target status in the future.

Cross-Cutting Threats

The threats summary table provides a quick, visual overview of the major threats to each target. A more detailed version of this table, with explanations of each threat, is included in the full report. From these tables, it is clear that there are many threats that are shared across targets. In fact, most of the

threats to wildlife in the Jackson Hole area are inter-related, synergistic, and cumulative. Some of the common threats shared by multiple targets are:

- Altered hydrologic dynamics of our rivers, streams, wetlands, and lakes
- Development of rural areas in the private lands of the JH area
- Roads and traffic
- Increases in the amount and number of types of recreation
- Invasive and problematic species and diseases, often exacerbated by climate change
- Expected changes in the frequency and severity of fires, primarily due to climate change
- Rising temperatures and changes in precipitation and hydrological processes due to climate change

Contributing Factors

A number of other factors contribute indirectly to the direct threats we have outlined for each target. It is important to recognize these indirect threats, because in many cases they are the ultimate drivers of direct threats. Key indirect threats include:

- *Climate change*: Climate change is itself a direct threat (e.g. warming temperatures physically stress many species) as well as an indirect threat that aggravates many other direct threats. It threatens to facilitate invasions of exotic species and pathogens, change fire regimes, and reduce species' abilities to cope with diseases or competitors. Conserving landscape connectivity and viable populations enable species to adapt to climate change. Continuing to understand the impacts of climate change as they unfold will also be vital in enabling managers to respond in a timely manner.
- *Human population growth*: The GYE lies within one of the fastest growing rural areas in the country. Currently there are 400,000 residents in the GYE region. Human population growth is the ultimate cause of expanding residential and commercial development, increased recreational activity, and increased number of vehicles on our roads.
- *Laws, policies, and funding:* Different agencies and elected officials — federal, state, and county — are responsible for determining the legal parameters, management plans, budgets, and day-to-day operations that affect both public and private lands and the wildlife that live on these lands. Policies and laws can shape the extent to which a direct threat manifests itself or not. For example, land-use regulations determine what forms of development can happen and where. Funding for cooperative efforts across agencies and jurisdictions is essential for controlling certain threats such as the spread of invasive species and enabling multi-partner strategies to conserve whitebark pine. Some current and upcoming plans and policies that could play a considerable role in contributing to or mitigating direct threats to our targets include: the Bridger-Teton National Forest management plan, Teton County natural resource land development regulations, and forest fuels reductions plans.

Additional Thoughts

As we have compiled this status and threats assessment and sifted through numerous reports, management plans, and research papers, several additional lessons have become apparent. These include:

1. Of all ecosystems in the lower 48 states, the GYE has the *greatest possibility of maintaining its essential functions and species diversity despite climate change*. The varied elevations, north-south trending mountains, large area, and intact landscape with viable populations of species are key to resilience to climate change.

2. A wide variety of biologists and managers have contributed significantly to our collective scientific understanding of the local region. Their research is thorough and often cutting-edge. It is also clear that *local study of species and habitats is essential* for future decision-making. Animals and habitats respond differently to the conditions found in northwest Wyoming compared to other regions. Especially as the climate changes, we need to continue improving our understanding of local wildlife ecology.
3. *The residents of Jackson Hole have a strategic role in assuring the future of the GYE*. The Jackson Hole area includes habitats, species, and connections that are vital to the GYE as a whole. Even though the Jackson Hole area is only a piece of the GYE, the central location and unique features of this area (for example, high altitude sagebrush valleys) make this area regionally important to conservation in the entire GYE.

We have written this report to be scientifically rigorous and thorough, yet accessible to the general public. Although we do not make management recommendations here, we wish to note that the keys to conservation of the targets we have identified are (1) cooperation across multiple management entities, from town and county government to the federal level, and (2) an engaged and concerned citizenship to support these efforts. There is a long legacy of conservation leadership in the GYE and in Jackson Hole; we hope that by focusing attention on a few, key conservation targets and their individual and cross-cutting threats, we can help rally the community as a whole to tackle the conservation challenges that lie ahead.

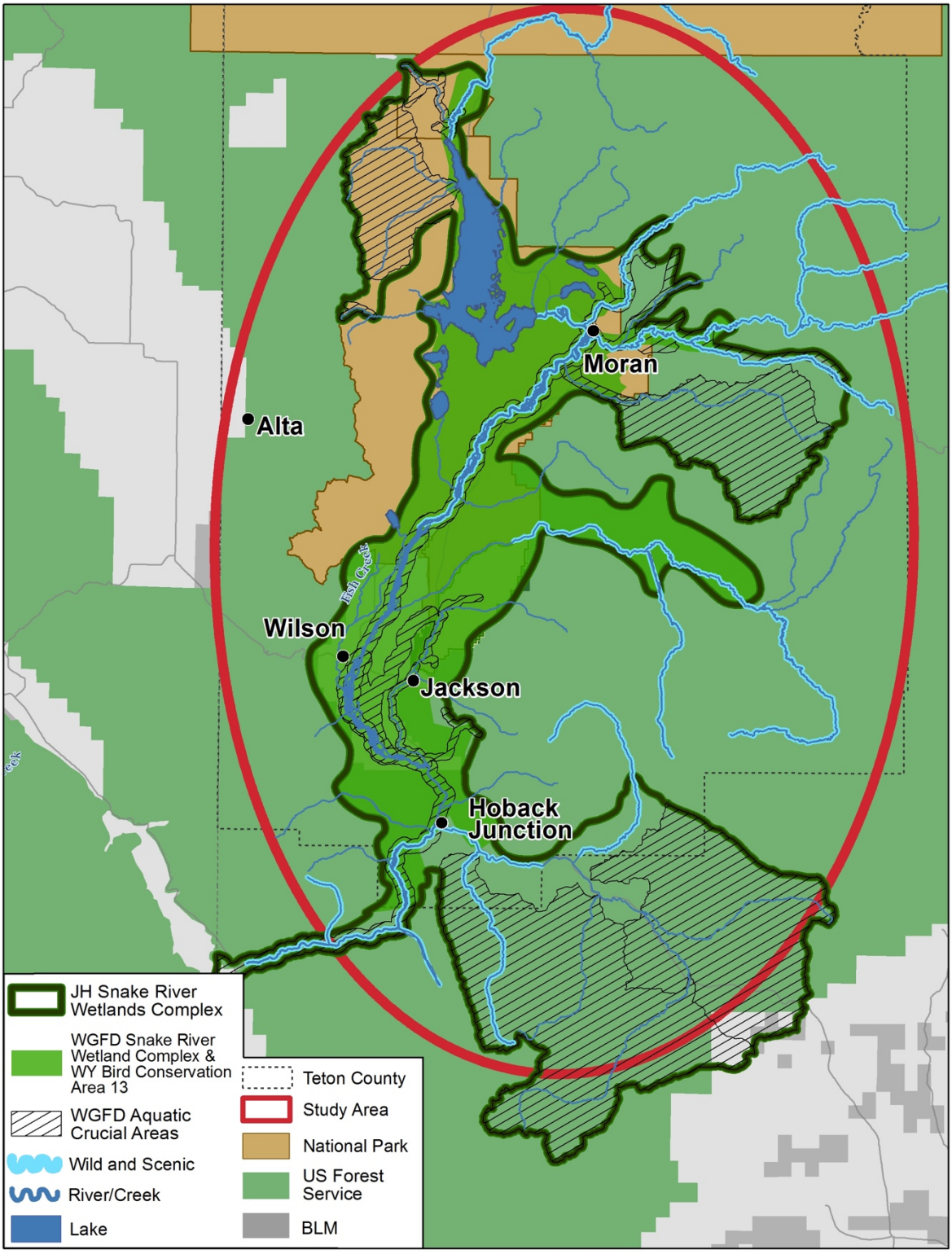
[Summary by Corinna Riginos and Frances H. Clark]

Threats and Threat Rating

This table provides a synthesis and brief explanation of the threats for each of our chosen targets. The threats are explained in greater detail in the separate chapters on each target. The purpose of this table is to provide an easy and centralized reference for each threat and its overall rating. We have followed the Conservation Measures Partnership's threats classification scheme [4] for grouping threats into overarching themes.

Category	Sub-Category	Hydrology	Beaver	Cottonwood Galleries	Cutthroat Trout	Sagebrush & Sage-grouse	Ungulate Migration	Moose	Goshawk & Mature Forest Mosaic	Whitebark Pine
Residential and Commercial Development	Residential Development	Moderate	Minor	Minor		Moderate	Major	Moderate	Minor	
Residential and Commercial Development	Tourism and recreation areas	Minor					Minor	Minor	Moderate	
Agriculture	Livestock farming and ranching: grazing and haying	Minor		Minor	Moderate		Major			
Agriculture	Livestock farming and ranching: fences						Major	Minor		
Energy Production and Mining	Oil and gas drilling						Minor			
Transportation and Service Corridors	Roads and paved pathways	Minor			Minor	Moderate	Major	Moderate		
Transportation and Service Corridors	Flight paths and airports	Minor				Moderate				
Human Intrusions and Disturbance	Recreation: mountain biking							Minor	Moderate	
Human Intrusions and Disturbance	Recreation: hiking						Minor	Minor	Minor	
Human Intrusions and Disturbance	Recreation: backcountry skiing						Moderate			
Human Intrusions and Disturbance	Recreation: water craft			Minor						
Natural Systems Modification	Dams, levees, and water management	Moderate	Unknown	Major	Moderate		Moderate			
Natural Systems Modification	Fire: increase in frequency, extent, severity					Major		Moderate	Moderate	Moderate
Natural Systems Modification	Fire: fuels management								Minor	
Natural Systems Modification	Supplemental food for ungulates						Moderate	Minor	Minor	
Invasive and Problematic Species and Pathogens	Invasive species: animals	Major			Moderate					
Invasive and Problematic Species and Pathogens	Invasive species: plants	Moderate		Moderate		Major	Moderate		Minor	
Invasive and Problematic Species and Pathogens	Pathogens and microbes				Major		Moderate	Moderate		Major
Pollution	Household and commercial sewage and waste water	Major								
Climate Change	Changes in temperature regimes				Major		Minor	Major		Major
Climate Change	Changes in precipitation and hydrological regimes		Unknown	Major	Major		Minor	Minor		

KEY Minor Threat Moderate Threat Major Threat Unknown



Snake River wetland complex area within the Jackson Hole area.

Snake River Wetlands Complex

Critical water for life in Jackson Hole

Overview

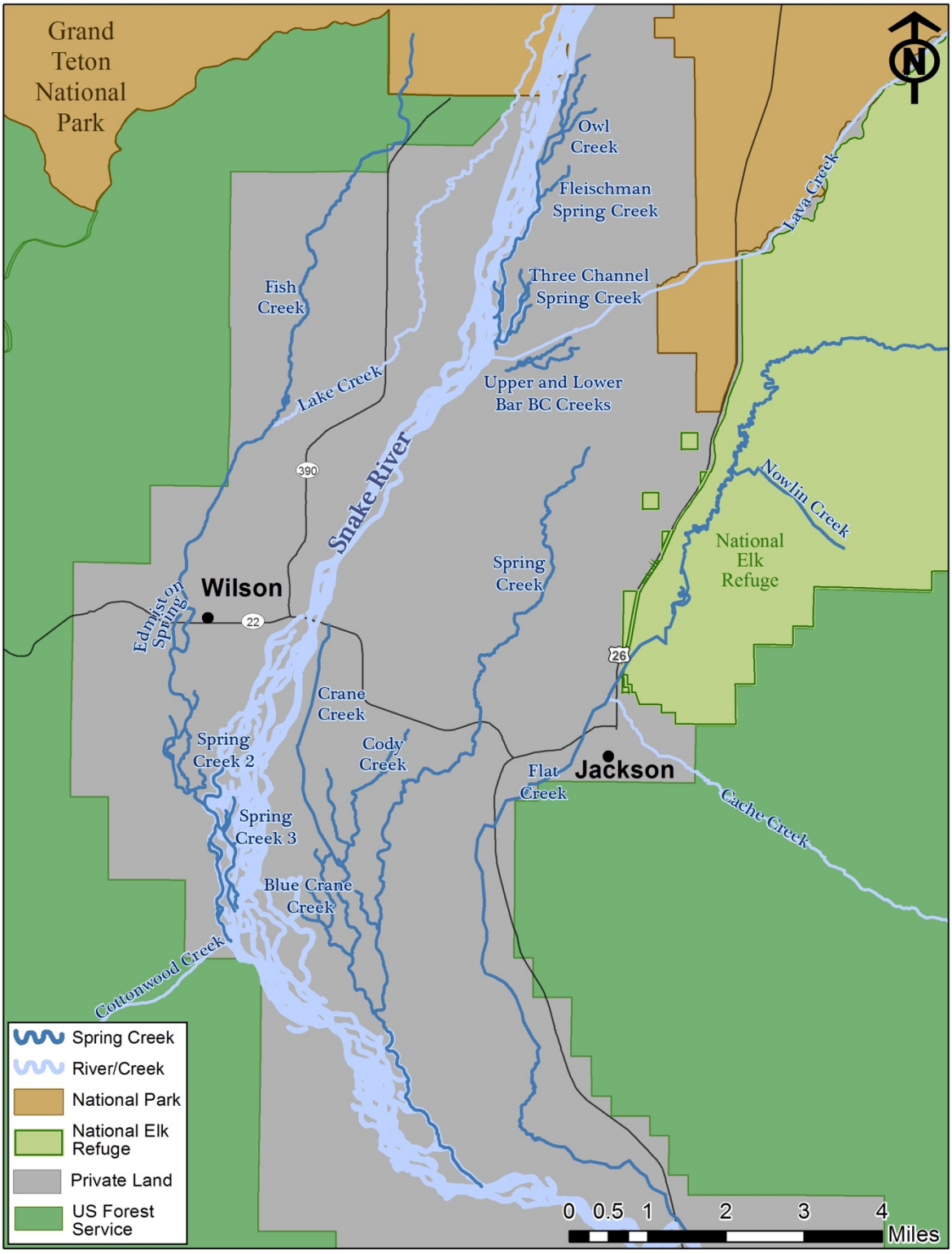
Below the towering Tetons, the signature landmark of Jackson Hole, lies an equally impressive and perhaps more significant scene: the Snake River. Spied from almost all points of the valley, the glistening river wends its way south through forested moraines, sage-clad river benches, and past dikes and housing developments, then spreads wide between ancient sedimentary hills before bending west and channeling through the Snake River Canyon. At the Idaho border, it pools behind the Palisades Dam. The beginnings of the Snake River and its many sources of water are central to the ecological and social well being of Jackson Hole. We chose it as a “conservation target” because of its ecological necessity and the many threats that require cooperative attention.

Description

Riverine habitats and associated wetlands form a life-sustaining mosaic throughout the Jackson Hole area (JH area). Creeks and streams arise in the mountains, flow down through the glacially sculpted valley to feed lakes, and foster willow-alder shrub-swamps, cattail marshes, and grassy wet meadows. These waters meet to form the main stem of the Snake River, which is joined by the Gros Ventre and Hoback Rivers. Augmented by snowmelt or heavy rains, these larger streams and rivers flood extensive lowlands, altering streambeds, braiding together channels, and supporting galleries of cottonwoods. Both streams and wetlands contribute to the vital aquifer that lies beneath the valley floor. Spring creeks, also fed by snowmelt and connected to channels above and the water table below, form their own wetland mosaics. Each of these types of water features and wetlands independently and collectively supports a unique array of plants and animals that interact in biological communities.

Ecological Importance

Wetlands are one of the most important ecosystems on Earth [5]. In Wyoming, wetlands and riparian areas combined support 18 species of greatest conservation need (SGCN) yet cover only 2% of the land, indicating the disproportionate importance of wetlands [6, 7]. Within Teton County, wetland and riparian areas provide crucial habitat for 80% of migratory birds, including 76 species in nesting season, with 23 species relatively abundant in the southern GYE [8]. The upper Snake River is said to serve as the ecological nexus for biodiversity at all levels from invertebrates to large mammals [9] and is ranked the largest, best preserved, least vulnerable wetland systems in the state, except for private lands within its center which are deemed at high risk [10]. This system’s integrity, size, and location within the GYE signify that the upper Snake River is integral to the largest preserved ecosystem in the contiguous United States.



Spring creeks within the core private lands of the Jackson Hole area.

Target: Hydrological Processes

We have chosen the upper Snake River and associated wetlands as an overall conservation target for its high ecological value and significant threats, and also because there is strong potential for cooperation among many agencies and groups to address these threats. Within this target we also emphasize four associated targets: hydrological processes, cottonwood galleries, beaver, and Snake River Cutthroat Trout. WGFD calls this system the Upper Snake River Basin Wetland Complex and has developed an exemplary plan [11] along with an Aquatic Habitat Priority Areas Plan [12]. We merge much of these two areas, along with two state designated bird conservation areas, and call the target Snake River Wetlands Complex. By choosing this combination of habitats, our intention is to support and focus the work already in process.

Hydrological processes determine the formation and dynamic of riverine and wetland ecosystems. These processes include the amount and timing of precipitation; flow amount, velocity, and duration; water penetration below ground as well as flows above ground; evaporation and transpiration rates, and the like. These processes are fundamentally affected by climate, geology, topography, and soils. The upper Snake River is categorized in part as a gravel-bed river system, which is found in glacially sculpted valleys in the Rocky Mountains from the GYE to Yukon (C. Girard, personal communication, [9]). Surrounded by mountains and shaped by glaciers, these deep, broad valleys concentrate nutrients, flows, and wildlife, creating a unique opportunity for biodiversity.

In all watersheds, water drains downslope and through soils to collect in streams and wetlands. Abiotic forces of hydrology (amount, timing, quality of water), hydraulics (energetic movement and forces), and geomorphology (sorting and arrangement of various sediments) ultimately support and, in turn, are affected by the overlying biological network. Biological players include both small and large organisms, from algae and invertebrates to trees and ungulates. The integrated dynamic of abiotic and biological elements occurs both above and below ground. While these essential elements are similar across watersheds, each system is unique due to the variety and complexity of influences [13, 14].

The JH area lies within the wettest region of the state (range from 14-40 inches of precipitation) with the vast majority of precipitation falling as snow [6]. Moisture from the Pacific Ocean is carried inland across the western United States during the winter months by a variety of means, including storms that form in the Gulf of Alaska which are then directed towards western Wyoming by the jet stream. When that moisture is forced against the Teton Range, it is lifted upward, and that lifting over the mountains produces additional snowfall at the higher elevations. Approximately five times more snow falls annually at the upper elevations in the Tetons than at valley floor (J. Woodmency, personal communication). Consequently, a deep snowpack builds up in the mountains and a lesser amount in the valley below.

Come spring, the valley floor begins to thaw and the overlying snow melts. Melt water percolates through the deep gravel layers of glacial outwash and more recent alluvial deposits and seeps into stream and river channels. As temperatures increase in the mountain summits, melting snow begins to rush downslope, feeding rising creeks. Pacific, Buffalo Fork, Spread, and Fish Creeks and Gros Ventre and Hoback Rivers swell the Snake River. Peak flood season typically starts in May and runs into June [15].

Melt waters flow underground as well as through established stream and river channels. The water table is the area below the soil surface that is fully saturated with water. The amount and depth of water stored and the flow rate within this underground reservoir depends in large part on the type and distribution of deposits, as well as the tilt of the land. Combined valley and mountain runoff can raise water tables 8-15 feet (2.4-4.5 m) in Jackson Hole during flood months [16]. Hydraulic pressure can push cool water (as well as micro-organisms) underground through the “hyporheic” zones into adjoining streams, such as between Fish Creek and the Snake River. These buried, moving waters can give rise to spring creeks that form at the base of the mountains or along former river channels (C. Girard, personal communication). As they are fed by underground water, spring creeks feature cool temperatures, consistent flow, and hyporheic nutrient regimes and create their own wetland mosaics important to

wildlife, including vital fish spawning areas. Examples of spring creeks include Flat, Fish, and Bar BC Creeks, as well as the aptly named Spring Creek. In sum, in this glacial-valley ecosystem, streams are fed by ongoing snowmelt and water table reserves.

Spring floods are essential to the dynamic of the riverine and wetland systems. Snow melt provides the energy and substance to carry sediments — from clays and sands to gravels and cobbles — downstream, scouring islands, accreting sand bars, undercutting banks, and realigning channels in the valley floor. This dynamic is easily seen in Ditch, Spread, and Pacific Creeks as well as the Gros Ventre and Snake Rivers.

Floods also determine the primary vegetative structure along floodplains. Windblown seeds of willows and cottonwoods, along with other pioneer plants, take root in the moist, exposed soils after floods. Depending on the amount of disturbance and available seed sources, over time herbs, shrubs, and trees provide both vertical and horizontal vegetative complexity. Roots draw up nutrients, and leaves convert these elements into new compounds, which ultimately change the chemistry of soil and water. Plant debris — fallen trees, clumps of branches and leaves — also alter channel flows and nutrient regimes. Boatmen and fishermen are tuned to these changes. Severe floods restart the successional process all over again. Flooding is the primary natural disturbance event in these systems.

Even minor changes in topography, soils, and the depth and duration of water can alter plant growth, causing the difference between wet meadows, shrub-swamps, and marshes. Temporary flooding in spring that dries up by mid summer supports sedges and specially adapted grasses. Areas with water at or just below the surface much of the spring and summer may be dominated by willows, while marshes have 1-2 feet (0.3-0.6 m) of water flowing throughout the growing season and are filled with emergent cattails, sedges and rushes as well as floating pondweeds.

The complex interactions among many species, nutrient cycles, and physical structures within floodplains and wetland communities provides for a disproportionate amount of diversity for the area covered.

Wildlife: Fish, Birds, Mammals, Amphibians and Reptiles, Invertebrates

An exceptional variety of species depend on this wetland complex, including state species of greatest conservation need (SGCN) and species that the Teton County Natural Resources Technical Advisory Board (NRTAB) has chosen as “focal” species. The summary below is elaborated upon later in this section.

At the smallest scale, tiny organisms may be flushed by water through different layers of deposits (hyporheic zones) to where springs upwell into spring creeks. These microorganisms, such as bacteria, fungi, and protozoa feed macroinvertebrates, such as insects, segmented worms, and nematodes, that in turn feed fish [17]. Many bird, amphibian, and reptile species rely on a combination of wetland types as well as adjacent uplands to complete their breeding cycles. Beaver enhance this diversity by building dams that expand ponded areas, support willow groves, and maintain stream flows. Several large mammals use the network of riparian corridors for key transportation routes seasonally or daily, including elk, deer, moose, bison, black and grizzly bears, and mountain lions. Bats roost, travel, and feed disproportionately in or near rivers, lakes, and wetlands. Fish move extensively to different parts of the stream system, including the Bluehead Sucker and Snake River Cutthroat Trout. River otters, which are very rare in Wyoming, need extensive territories of riparian habitat with fish and invertebrates. Streams and rivers together with the mosaic of wetlands accommodate a network of seasonal and daily movements throughout the region.

Status and Trends of Snake River Wetlands Complex

Both dams and levees have altered the geomorphological dynamic of the Snake River as well as the biological dynamic of the river systems. Formerly, the river was a complex of braided channels and wooded islands that provided a highly diverse and productive habitat of both aquatic and terrestrial species. Floods typically occurred every few years [18] and floodwaters reached well over and beyond the first banks, adding or depleting sediments and nutrients. Elevated water tables helped to nourish and flush spring creeks. In extreme flood years, roiling waters swept away towering cottonwoods and encroaching spruce trees, preparing the ground for a new generation of seeds.

Since the construction of the Jackson Lake Dam in 1906, natural hydrological cycles have been changed. Peak flows of the Snake River have been reduced in both frequency and magnitude and naturally very low flows are artificially augmented. One researcher determined that between 1945 and 1989, on the river stretch from the Jackson Lake Dam to Moose, 30% of cottonwood communities had changed to a mixed forest of cottonwood and blue spruce, with an increased dominance of blue spruce over time [18]. Willow and alder shrub-swamp, which contains more biodiversity than the evergreen spruce forest, declined significantly (27%).

The Jackson Lake Dam will remain and the hydrological processes will continue to be manipulated. By law, the Jackson Lake Dam will continue to store water belonging to the state of Idaho. Over the years, flows have been adjusted to accommodate recreational activities such as rafting to fishing by moderating the low and peak flows throughout the tourist season. Dam outflows are also carefully managed to prevent flooding downstream in high snow melt years, as occurred in 2017.

An even greater alteration to the river dynamic began with the construction of levees for 22 miles (35 km) from below Moose to Hog Island. The levee system was constructed in the 1950s to provide flood protection for ranch lands in the floodplain, and it continues to be maintained to protect new homes. The increased water velocity, instability of river islands and banks, and loss of overland flooding and channel

meanders have reduced natural habitat by an estimated 80-90% since 1956 or from 25,000 acres to just 2,500 acres beyond the reach of the dikes [19].

The levees have profoundly impacted fish and wildlife habitats along the river. Adult Bluehead Suckers are significantly fewer in this constrained stretch of river. [20]. The cottonwood forest no longer receives regular peak floods or even normal spring waters, reducing opportunities for seedlings to establish and threatening older tree survival. Where intensive grazing exists in the cottonwood riparian zone, both elk and cattle reduce vegetative structure and diversity. Furthermore, houses and other forms of development in the floodplain eliminate, degrade, and alter the more extensive wetland mosaic beyond. Maintenance of the dikes — including elimination of woody vegetation — disrupts nesting birds in summer (F. Clark, personal observation). In some areas, spring creeks are responsible for 40% of spawning Snake River Cutthroat Trout [21], and yet many spring creeks are no longer receiving regular flushing (A. Senecal, personal communication).

It is hard to imagine that these levees will ever be removed as they are essential to protecting private homes and ranch lands. However, opportunities exist for improvements [10]. The Teton Conservation District along with the Army Corps of Engineers (ACOE) are investigating mitigation opportunities. Overall, human alteration of the flooding dynamic by the dam and levees has significant, often permanent, impacts on the natural river system. Remarkably, despite the dam and levees, the upper Snake River remains a very rich and relatively undisturbed natural resource.

Threats to Snake River Wetlands Complex

The ongoing and future threats to the Snake River Wetlands Complex, including the hydrological processes, are several, inter-related, and synergistic. Pressures include increased development of private lands and increased recreation on lakes, ponds, streams, and rivers on public lands. The dam and levees continue to compromise natural river flows. Climate change adds a wildcard into the type, amount, and timing of precipitation and, therefore, the natural hydrological dynamics of even unaltered riverine and wetland systems. Combined, these threats pervade the Snake River Wetlands Complex.

Development — Moderate to high, locally

- **Dam and levees — Moderate** — These structural constraints and flow manipulations will continue to affect spring creek flows, river morphology, and vegetation, particularly cottonwood galleries. Lower peak flows and lack of flooding reduce the water table throughout the valley and affect water flows throughout the season, including spring creeks that spawn fish and nurture amphibians. Furthermore, these property protections continue to encourage development within the floodplain, including cottonwood galleries — adding to reduction and fragmentation of key wildlife corridors and habitat.
- **Development within the core of the JH area on private lands — High, local** — Several state plans target private lands in the core of the valley as the most vulnerable area in the region [10, 22]. Outright loss and degradation of habitat along with fragmentation and human disturbance irreplaceably alters plant communities and the wildlife that depend on them. Creation of pastures and hay fields with their associated grazing, irrigation ditches, and diversions have all degraded natural wetlands, but not irreparably. However, many of these properties are now being sold and developed for new homes, which will cause irreplaceable wetland loss and leave fewer options for mitigating the effects of the levees.
- **Water use, diversion, obstruction — Unknown, local** — Public water demand will grow with increased development within the JH area. Already, diversions for new development including golf courses and lawns, as well as traditional agriculture, have caused stretches of the Gros

Ventre to dry up in late summer. Interruption of water flows fragments the river with implications both down and up stream, particularly for fish.

- **Nutrient additions (from lawn fertilizers, livestock waste, and septic systems) — High, local** — Natural systems utilize certain levels of nitrogen and phosphorus to function; however, when human inputs become excessive, they can cause an increase in algae blooms and aquatic plants, which in turn reduce oxygen in the water and clog the natural flushing of channels. Many of these inputs filter through soils or are injected below ground into the groundwater. Spring creeks are particularly affected. Fish Creek is experiencing these phenomena [23]. Water quality in Flat Creek has also been compromised. And as new areas south of Jackson are developed, a further network of spring creeks and tributaries could be compromised.
- **Transportation routes — Low, local** — Widening of Rt. 22 and other highways has the potential to reduce wetlands and obstruct both overland and groundwater flows. If not designed adequately, road construction and drainage systems can impede wildlife movements and aquatic species passage along wetland corridors. Runoff from winter road treatments can affect water quality. Finally, the Jackson Hole Airport lies over the Jackson Hole aquifer that supplies 95% of the water for Jackson Hole residents. Chemical contaminants are being closely monitored [16].

Invasive and Problematic Species — Moderate, potentially extensive

Non-native species are degrading aquatic ecosystems, plant communities, and wildlife populations, with new intruders likely to come. Each species can have different impacts depending on its reproductive cycle and response to its novel environment. It is hard to predict how an alien will respond to the specific conditions of the JH area; however, those listed below are of most concern to wildlife managers of aquatic, riparian, and wetland environments.

Fish: Introduced fish species are affecting the genetic strains and viability of native populations.

- Fall spawning trout and char species, such as Brown, Brook and Lake Trout, reach maturation earlier in the season as compared to cutthroat trout, which spawn in the spring. Superior body size and weight give these introduced species an advantage when competing for limited resources and also make cutthroat trout vulnerable to piscivory. When large, the main food of these introduced trout is small fish, including native cutthroat trout (Anna Senecal, personal communication).
- The prospect of invasion by Silver Carp (H*ypophthalmichthys molitrix*), which is currently found in the Mississippi watershed but not yet in our region, is a concern among fisheries managers. Originally from Asia, this exotic was introduced into the U.S. for plankton control and as fish food. It can grow to 3 feet (1 m) and weigh 60 pounds (27 kg). While they mature between 4 and 8 years old in their native waters, in North America they can mature in as few as as 2 years [24]. If present in large numbers, Silver Carp has the potential to cause enormous damage to native species because it feeds on plankton required by native mussels and larval native fish.

Invertebrates:

- New Zealand mudsnails (*Potamopyrgus antipodarum*) were discovered in the Snake River in Idaho in 1987 and are now present above Jackson Lake Dam in Polecat Creek and the Snake River at the Flagg Ranch boat ramp [25]. In Yellowstone National Park, researchers have counted over 750,000 mudsnails per square meter. Originally from New Zealand, this one-eighth inch (3 cm) snail can adapt to a wide variety of temperatures, turbidity, velocity, stream productivity, substrates, and other variations of aquatic habitats. A single female mudsnail can result in a colony of 40 million snails in one year. Grazing at night, the snails consume plant and animal detritus, algae, sediments and diatoms. In some areas they outcompete other

macroinvertebrates and can outcompete or displace native snails, mussels, and aquatic insects that native fish species and other animals depend on for food. Although abundant, New Zealand mudsnails do not provide any food value for fish, ducks, or other waterfowl. They can also alter nutrient (nitrogen and carbon) cycles.

These snails are easily and invisibly introduced to new waters. Snails are transported on boats, fishing gear, and other equipment as well as muddy bodies of birds and mammals, and even travel through the guts of fish. They can seal themselves into their shells, enabling them to withstand several weeks in cool, damp conditions. It is easy to see how they have spread so readily from the Great Lakes into the watersheds of the West and Pacific Coast. [26–28].

- Quagga and zebra mussels (*Dreissena polymorpha, D. bugensis*) are closely related to each other, are both about a half inch (4 cm) long, and may even hybridize. They filter prodigious amounts of water, clearing the water column of phytoplankton, which includes single-celled algae, diatoms, and cyanobacteria that zooplankton depend upon. These microscopic organisms are the first links in the food chain that nourishes fish and waterfowl. Also, as the mussels remove phytoplankton, the water becomes more clear and light penetrates more deeply; this stimulates aquatic plant growth, altering the dominance and mix of species. The mussels' pseudofeces, or by-products of phytoplankton consumption, can reduce oxygen, increase acidity, and concentrate pollutants in the water. The pathways of change are still being researched, but it is apparent that these non-native mussels alter the natural ecology of aquatic systems.

  The highly adaptable mussels have spread by bilge water and fishing and boating equipment, leapfrogging across the country over the last couple of decades. While not in the GYE at this time, their spread is mostly invisible and unpredictable, and managers predict that they will eventually arrive in this area [22, 29, 30]. Once detected, they would be very difficult to remove. Infestation sites would be most likely Jackson Lake and Palisades Reservoir. Not only would they alter water quality, they could have significant impacts by encrusting pipes and other apparatus of the dams (M. Daluge, personal communication).

Plants: Invasive plant species typically produce an abundance of seeds that germinate readily on a variety of soils and light conditions. Seedlings grow and flower quickly and/or plants spread vegetatively by stem or root. Few indigenous insects or diseases are able to deter their spread. Consequently, these invasive exotics crowd out native plants, altering food and cover characteristics valuable to wildlife of all sizes and kinds. They can also infest nearby agricultural and other disturbed sites. In the JH area, weed control experts are concerned about spotted knapweed (*Centaurea maculosa*) and perennial pepperweed (*Lepdium latifolium*) which are already invading shores and islands of our rivers, along with tamarisk trees (*Tamarix* sp.) which are just beginning to show up from the south (M. Daluge, personal communication).

- Spotted knapweed (*Centaurea maculata*) is found throughout the region, primarily on upper terraces of major river courses, gravel bars, and relatively dry, disturbed sites. Early and deep root development, as well as colonization of roots by arbuscular mycorrhizal fungi, may contribute to its invasiveness by facilitating greater acquisition of nitrogen and phosphorus. Chemicals released from decaying plant leaves, stems, and roots may chemically interfere with the growth of other herbaceous species (allelopathy). The physical dominance of this exotic species can reduce the number and diversity of native plants that animal species depend upon. The county is also on the alert for other species of knapweed (*C. diffusa, C. repens).* [31–33].
- Perennial pepperweed (*Lepidium latifolium)*, a "Priority 1" noxious weed of Teton County — meaning it is highly invasive, poses the highest threat to native plant communities, and is known

to render land unfit for wildlife — is also colonizing the Snake River watershed. This Eurasian species belonging to the mustard family (Brassicaceae) can produce hundreds of small white flowers which together produce thousands of tiny seeds per plant. In sunny, moist sites in the JH area, plants can grow to 4-5 feet tall (1.2-1.5 m) and the roots from a single plant can extend 10 feet (3 m) in a year from which new plants can sprout. Pieces of roots spread by scouring waters also enable colonization. The density of plants degrades wildlife habitat as well as agricultural lands and lowers diversity of native flora and fauna. The weed can act as a salt pump, i.e. it draws salt ions from deep within the soil profile and increases salinity near the surface, which can be disadvantageous for plants intolerant to salt. It is known to interfere with colonization by cottonwoods. [34, 35]

- Several different species of tamarisk or saltcedar trees and shrubs have spread throughout the U.S. Tamarisk (*Tamarix* spp.), with its colorful pink flowers and semi-evergreen foliage, was planted as an ornamental and to prevent soil erosion. However, it escapes cultivation and has spread throughout much of the U.S. It can form monocultures that severely reduce biodiversity; its tiny seeds and foliage are not eaten by native animals, the leaves leave a salt residue on the top of soil, and it reduces nesting habitat for birds. Furthermore, it can change the moisture and chemistry of riparian soils; plants have the ability to transpire up to 200 gallons of water each day and negatively modify soil alkalinity by releasing salt. Thus, tamarisk is another invasive plant species that land managers are concerned about in wetland and riparian habitats. [33, 36]

Pathogens — Moderate

Introduced pathogens such as chytrid fungus and ranavirus, transferred by fishermen's and researchers' boots and gear, as well as waterfowl feet, can infect amphibian populations (see Amphibians section, below). Whirling disease can kill sensitive populations of cutthroat trout, especially as waters warm and drought occurs more frequently due to climate change (see Cutthroat Trout section, below).

Recreation — Moderate, potentially extensive

While we often consider wildlife safe in our national parks and forests and wild and scenic rivers, increasing numbers of people recreating in the front country and now backcountry has an impact on wildlife. While individual actions may seem to have little consequence, each adds up. Increasingly popular travel routes up canyons and to lakes affect habitats that many birds, mammals, and amphibians depend on absolutely, with no other alternatives. People and their dogs make noise and movement, pushing wildlife away, often without people ever seeing them. This occurs in places such as the dikes in Wilson and trails up Cache and Game Creeks. Boating along the mainstem of the river has intensified, particularly below the Wilson Bridge where a permit system was incorporated in May 2015. Expanded boat launches and parking areas intrude into cottonwood galleries and wildlife corridors. Proposed in-river structures to enhance whitewater experiences could reduce fisheries and impede fish passage especially for the Snake River's migratory fish populations, such as Snake River Cutthroat Trout and Bluehead Suckers (C. Girard, personal communication). Increased activity on the Snake River, particularly at dusk, dawn, and night could add a major source of interruption to mammals (S. Cain, personal communication).

Climate Change — Unknown, likely high and extensive

Changes in precipitation patterns, snowpack, runoff amount and timing, warming and drying up of streams and ponds, and flooding regimes all affect essential hydrological processes, invasive species success, and, therefore, habitat and species. For instance, across its range, Yellowstone Cutthroat Trout populations are projected to decline by 28% by the 2040s and 58% by the 2080s under high emissions

scenarios [37]. This is due in part to the direct negative effects of warming stream temperatures, but also because of competitive interactions with non-native Brook and Rainbow Trout, which are predicted to fare relatively better under warming conditions [37–39]. These same influences are also noted for the Snake River Cutthroat Trout [22]. Warming waters and eutrophication can encourage proliferation of zebra mussels and mudsnails. The greater the resilience —- size, health, and connectivity of populations of both plants and animals — the greater the opportunity for survival in the years to come.

Also, catch and release fly-fishing is a very large recreational industry in the Snake River that is expected to have an increasingly negative effect on fish with rising water temperatures. Trout have been shown to have increased mortality following catch and release as water temperatures rise (C. Girard, personal communication).

Indirect Threats or Contributing Factors

- **Land-use regulations** — Teton County land-use regulations are currently being revised. These will have significant impact on the future of private properties in the core of the JH area as regulations determine the location, type, and density of development and, consequently, the proximity to and connectivity of sensitive habitat. Regulations affect the amount of water withdrawn and number of roads built. Each allowed use has cumulative impacts on the whole area.
- **Unintended introductions** — Boating and fishing activities accidentally transport invertebrates such as New Zealand mudsnails and Zebra mussels into new waterways, lakes, and wetlands. Education programs and inspections reduce the chance of introductions.
- **Reduction in funds and personnel** — Local, county, state, and federal funds and personnel affect monitoring of water quantity and quality, management of levees and dams, control of invasive exotics, and restoration of stream channels for fish. Reduction of funds and cooperative programs can have significant negative effects on these projects.
- **Permits** — Trapping permits determine how many beaver are trapped out of an area which can affect the presence and density of beaver.

Opportunities and Collaboration

In the JH area, federal, state, and county agencies have jurisdiction over the different types of critical wetlands, both public and private. Independently, these public servants have acknowledged the critical nature of the Snake River wetlands complex and developed plans, policies, and regulations to conserve and restore plentiful clean water, flood control, and wildlife diversity. They cite ongoing threats of water withdrawals, diversions, and obstructions on private lands — within the core of the JH area — which alter the essential hydrological processes of the region. Parties are concerned also with pollutants and invasive non-native species of fish, diseases, and plants. With coordination and prioritization, as well as delegation of tasks and allocation of funding, over the long term there is ample opportunity to maintain the resiliency of the habitat for wildlife. (See list at the end of this chapter for agency jurisdictions and priorities).

Information Gaps

- Ongoing effect of levees and dam on plant communities — The last comparison was done in 2005. What are the trends on type of and extent of wetland habitat?

- Impacts of levee construction on hydrological dynamics — How does the aggrading (building up) and degrading (downcutting) of the Snake River bed affect the valley's water table, flood risk areas, and management of industries like gravel mining?
- What are the cumulative losses due to development?
- Future Land Development Regulations (LDRs) — How will the regulations affect the development of private lands and, therefore, the hydrological dynamics and habitats within and around them?
- Cumulative impacts of small diversions — What is the amount of water being withdrawn and diverted from natural channels by the many small irrigation ditches and other diversions, and what is the quality and quantity of the water being returned? The 12 USGS water gauges in the JH area monitor only the large-scale impacts.
- What is the specific extent and impact of recreation on wetland species? This subject is understudied.
- What will be the impacts of climate change on hydrological processes, invasive species, and wildlife populations in the future?

Highlighted Habitats and Associated Species

Below, we detail the variety of habitats and species found in the Snake River Wetlands Complex, their associated Trends/Status, and Threats specific to each. We emphasize the notable and interesting characteristics of each habitat or species to accentuate its importance and fascination. These descriptions are not intended to be comprehensive — we list sources for additional information on each.

We have chosen **cottonwood galleries, beaver**, and **Snake River Cutthroat Trout** as associated targets to help focus attention on a few ecological elements that, if conserved, will benefit the biodiversity overall. We also provide additional information on several "watch list" species: edge-of-range populations of Harlequin Ducks, Common Loons, and Trumpeter Swans and amphibians as a group. Of key importance is sustaining the underlying hydrological dynamics with broad floodplains.

The following watershed components are organized more or less as the water flows:

- headwater streams, ponds, and lakes
- willow shrub-swamps
- marshes
- large streams and mainstem rivers

Habitat: Mountain streams, ponds, and lakes

The upper reaches of the Snake River watershed features federally designated Wild and Scenic Rivers and other high quality waters. Many of these streams are protected within designated Wilderness Areas under U.S. Forest Service management. Some flow into several large glacial lakes, such as Jackson, Emma Matilda, Two Ocean, String, Leigh, Jenny, and Phelps.

Isolated or small populations of three SGCN birds — Harlequin Duck, Common Loon, and Trumpeter Swan — utilize these streams, lakes, and wetlands and illustrate the precarious nature of edge-of-range populations. Edge-of-range populations are notable because they offer opportunity for genetic adaptations, range expansions, and safety from stochastic (chance) events over the long term. We highlight them here because the JH area protects a significant portion of these populations and, therefore, has a heightened responsibility for preserving them to benefit the species overall and to retain the species in Wyoming and on our national public lands. We designate them as watch-list species: if the current inventories and management actions continue, the populations will likely remain relatively stable.

Edge-of-range bird populations — Watch List

Harlequin Ducks

The Wyoming Harlequin Duck population is found only in northwest Wyoming and is currently considered stable; however, recently pairs have not been documented on some historic nesting streams in the Teton Range [22]. The population is the southeastern-most breeding population in western North America with an estimated 70 pairs in Wyoming [40].

A small group of colorful, even clownish looking, ducks migrate to northwest Wyoming to breed, and then leave again to spend the rest of the year along the Pacific coast. Harlequins are found breeding only in Grand Teton and Yellowstone National Parks and in the Bridger-Teton and Shoshone National Forests. Pairs bond in the late fall on the coast and arrive in mountain streams by mid-May. Typically the species nests on islands or in dense shrubs adjacent to low-gradient, clear-water creeks in subalpine habitats. Pairs return to the same location over the years. Males depart in June to July, a strategy to prevent competition with their growing family for sparse resources. Females remain with the chicks until they fledge (are able to fly). Females and surviving juveniles migrate to the west coast in late fall. Females do not fully mature until 5 years old and their broods often do not survive, so long-term productivity in harlequins is relatively low [22].

Fitted with remote sensing tags, two male harlequins were tracked in 2016 flying 930 miles (1500 km) from GTNP to Vancouver Island within 12 and 20 days respectively. So far, Wyoming's Harlequin Ducks appear to concentrate in the Strait of Juan de Fuca (Puget Sound) in Washington state and British Columbia [41].

Trends/Status: WGFD conducts helicopter surveys every five years and additional surveys by air or land as funding is available. Based on results over the last 30 years — most recently in 2007, 2008, and 2012 — WGFD estimates a minimum of 70 breeding pairs and a stable population. A mid-May 2017 aerial survey spotted 53 harlequins, similar to the number counted in 2012 [42]. Biodiversity Research Institute is working with WGFD to improve survey techniques to find, track, and understand our local birds [40].

Threats: Breeding habitat along isolated, clear water streams is very limited. The main threat in our area is expanded recreational use by pack rafters, fishermen, and other recreationists in these vital and sensitive areas. Birds can easily be disturbed to abandon their nests or young. Forest fires or recreational use can cause erosion and siltation of streams. As harlequins exhibit strong site fidelity, if they are pushed off breeding streams, it is unknown whether they would continue to return to the Snake River drainage to attempt breeding. They are unlikely to try again or even return the following year. Too much disturbance along these critical streams could extirpate the population in Wyoming, following Colorado and California with the loss of these remarkable birds [22].

Common Loons

Common Loons (*Gavia immer*) are known for their haunting calls echoing across tranquil lakes on summer nights and fluffy chicks straddling glistening black-and-white backs of statuesque adults. While widespread across Canada and northern New England, only a few nesting loons are seen or heard in Wyoming. This isolated population of 40-60 birds resides 200 miles (322 km) south of the next nearest population in Montana and is distinctive in appearance and behavior. The JH area supports the most southern population of Common Loons in North America.

Loons are intriguing birds. With legs near the back of their streamlined bodies, they can dive up to 250 feet (76 m) for over 5 minutes in pursuit of their primary prey: fish. In addition to being extremely agile and quick under water, they can fly up to 60-70 mph (96-112 kph), making them a challenging sport bird. Yet, they are very awkward walking on land. As top predators, these piscivores are subject to

bioaccumulation of toxins including lead fishing tackle (V. Spagnuolo, personal communication 2017). Due to their longevity, food source, and site fidelity, they are well known to represent the integrity of aquatic habitats.

Loons live for up to 30 years, yet the likelihood of replacing themselves in their lifetime can be low. Undisturbed loon nesting habitat is becoming more limited. Common Loons breed on lakes usually greater than 25 acres (10 ha) with clear waters to 10-15 feet (3-4 m) to facilitate catching small-to mid-sized fish, their primary food. Fish need lakes greater than 6 feet (2 m) deep to overwinter under the ice. Other habitat parameters include particular structure and vegetation for nesting sites and four months of ice-free surface to provide chicks time to fledge. As their shallow nests are built within 4 feet of shoreline, changes in water levels of 6-12 inches (15-30 cm) are destructive. Also, adults return to a given territory year after year, dispersing at best only 8 miles (13 km). If their vital habitats are disturbed or are destroyed, they may not venture far enough to find a new location. Loss of habitat is one reason for the retraction of their range throughout North America. [43, 44]

Even provided habitat, loons do not breed until they are 4-6 years old and with limited success. A pair incubates only two eggs and typically only one chick survives to fledge after 12-13 weeks. This lone juvenile must migrate to and mature at sea for 2-3 years on its own before it returns to its natal area. One bird from a lake in Yellowstone migrated over 1500 miles (2415 km) to Baja California for the winter, indicating the perilous nature of their life cycle. [43, 44]

Researchers are discovering differences in the Wyoming population compared to others. The birds are smaller in size and utilize smaller and often fishless lakes. Atypical for the species, the two most productive pairs in the GYE have been on fishless lakes with a covering of lily pads. Perhaps these ponds without fish but with added plants contain more invertebrates that are the perfect size for chick food [44].

The Wyoming population of Common Loons is barely stable [6, 45]. Survey counts since the 1980s show a population decline starting in 2007 to only 17 territorial pairs and 15 nesting pairs of loons in 2015, with a recent rebound to 21 territorial pairs in 2016. Most nesting pairs are within YNP (13) with a few scattered elsewhere on U.S. Forest Service lands (5), and in Grand Teton National Park (1). There is potential for additional territorial pairs in historical and potential sites throughout the GYE including the Wind River Mountains. Currently, nesting productivity is 0.53 chicks per territorial pair per year just over the 0.48 threshold needed for population stability, that is they must produce one successful chick every two years. [44, 45]

One of the key threats to nesting loons in the JH area is human disturbance by adventurous boaters, paddle boarders, and hikers, as well as fishermen. Recreationists can cause adults to abandon nests and chicks. With so few isolated nesting habitats for these birds, Common Loons have a risky existence even within our national parks and wilderness areas. They are cited as Extremely Vulnerable by WGFD [22]. As many of their current and potential sites are within our JH area, we place them on our watch list.

Trumpeter Swans

With a wingspan of 7-8 feet (2.1-2.4 m) and a body that extends up to 6 feet (2 m) from beak to tail in in flight, Trumpeter Swans are the largest water birds in North America. Pure white all over except for their sloping black beaks and wide webbed feet, these graceful birds are a popular subject of wildlife paintings and photographs. They excite visitors and residents alike who see these glistening birds gliding on lakes or flying overhead, making a racket like an orchestra of out-of-tune trumpets.

Trumpeter Swans seen in the upper Snake River basin are direct descendants of the remnant U.S. population that survived through the species' population collapse of the early 1900s. After an era of extensive exploitation, particularly for powder puffs and fashionable women's hats, only a tiny population of 60-70 resident adult birds and an additional number of Canadian migrants that wintered in the Greater

Yellowstone was thought to remain in the world, safely isolated in the remote areas of the Greater Yellowstone area. Red Rocks Lake National Wildlife Refuge was created in 1932 for its protection, and these few birds increased to over 500 swans by the 1950s, protected from hunting and provided with supplemental food in the winter. Many offspring were the source for attempting to re-establish nesting Trumpeter Swans to Oregon, Nevada, and Wyoming. Several thousand swans were “discovered” in Alaska which winter along the west coast and are considered a separate breeding population. Thanks to conservation efforts, over 63,000 Trumpeter Swans now reside in North America. (S. Patla, personal communication). [46–48]

Ironically, the successful re-establishment of Trumpeter Swans throughout the U.S. and Canada may be imperiling our local population. In winter, Jackson Hole residents see hundreds of swans feeding in open waters of Flat and Fish Creeks and flying overhead between Jackson and the Snake River, and consequently think swans are common and secure. However, most of these birds are winter migrants from Canada. In 2015, the WGFD winter survey recorded 568 swans. The summer count of resident Teton County swans that year was 68. Winter migrants compete for scarce resources — ice-free waters and food sources—with our relatively few resident birds here in JH area. Indeed, overall, the JH area core population, which averaged 62 birds between 1999 and 2016 [49], is losing nesting sites and is of low productivity. Ongoing conservation efforts are essential to maintaining this isolated, historic flock [47].

As with Common Loons, Trumpeter Swans have specific behaviors and habitats that limit nesting success in the GYE. Typically, swans do not reproduce until 6-7 years old and pairs prefer to return to traditional sites. Their offspring also return to the same vicinity. Swans need both security and forage for nesting and survival [49]. For breeding, swans prefer stable, quiet, and shallow waters greater than 8-15 acres (3.2-6 ha) in size with at least 5 acres (2 ha) of shallow areas less than 4 feet (1.2 m) deep with

supporting vegetation. Fluctuating water levels can flood nests. These large birds also need nutrient-rich waters that provide aquatic vegetation and invertebrates to nurture their young, such as can be seen along Flat Creek. Nesting pairs will stay on territory to raise their chicks for 5-6 months. In winter, swans require 45 foot-wide (13 m) unfrozen stretches of river or lakes to feed and rest. Also, swans require long take-off and landing zones 300 feet (91 m) long that are not obstructed by fences or powerlines, a particular hazard in developed areas. [6, 22, 49]

Status/Trends: The JH area protects one of a very few breeding concentrations of Trumpeter Swans outside of Alaska, and these often isolated groups are small and vulnerable [50]. Numbers in the JH area have fluctuated over the last 30 years and continue to do so. Although the number of nesting pairs has increased since 2004 in the Green River basin, challenges remain for swans nesting in the GYE as a whole [22, 47]. WGFD has worked over the years with ranchers and other private property owners to increase nesting habitat with some success and continues to monitor birds annually. To maintain this population, continued conservation management is necessary.

Threats to Swans: Trumpeter Swans are easily disturbed off their nests by human activity from developments, tourism, and recreation. Isolated breeding territories are becoming more scarce as increasing number of recreationists and visitors access more remote sites. Other hazards include electrical wires, unmarked wire fences, mistaken identity by hunters, and Bald Eagles predating their young. Larger numbers provide for greater resilience. [22]

Habitat: Willow shrub-swamps

A mass of billowing green, willow shrub-swamps appear monotonous. Indeed, different willow species with their simple oblong leaves are hard even for botanists to distinguish. Yet within these dense thickets, bugs buzz, birds chirp, and large beasts munch away. There is much more diversity than first meets the eye.

Hydrological processes and soil types drive the establishment of shrub-swamps. Typically shrub-swamp habitats flood in spring, and as summer arrives, the water table drops below the surface. Unlike upland plants, wetland plant species can survive anaerobic, saturated soils for a few weeks during the growing season and, therefore, can dominate. Each of the nine different willow (*Salix* spp.) species in the JH area is specialized to slightly different conditions. Mountain alder (*Alnus incana var. tenuifolia*) is also able to live in nutrient poor soils and in anaerobic conditions and is frequently found with willows. Bacteria (actinomycetes) growing within root nodules of alder fix nitrogen and thereby enrich soils and affect successional processes [51]. Willow-alder shrub-swamps can intersperse with cottonwood riparian habitats or dominate on their own.

This shrub community provides various functions. Willows and alders help to stabilize flooded areas with their extensive root systems. Their multiple stems slow flows and cause fine sediments to settle out, building and enriching soils. Willows provide important browse for moose and elk, especially in winter. Richer soils and varied structure provide for invertebrates, thereby enhancing food for birds, amphibians, and fish. Willows have a large number of phytophagous (plant eating) insects, which add biodiversity in their own right, but also attract a variety of insect eaters including birds and bats. Both willows and alders re-sprout readily and offer dense cover for wildlife, including moose (which rely heavily on willows for the majority of their winter diet), elk, and deer. Taller willows support greater bird diversity [52]. Other wetland types can mix with shrub-swamps. For instance, lower elevations of just a foot or so can support primarily herbaceous vs. woody plants, forming pockets of cattails, sedges, and grasses. When interspersed with open water, these wetland mosaics are particularly productive for waterfowl.

As mentioned above, willows can support great bird diversity – mostly small to medium songbirds. Red-wing Blackbirds, Lincoln's and Song Sparrows, Yellow Warblers, and Common Yellowthroats are common to these shrubby, insect-rich wetlands. MacGillivray's Warbler, a fairly

common but often elusive, bright yellow bird with a black cap, has been selected as one of the Teton County NRTAB;s focal species. It is considered an obligate riparian bird that serves as a good indicator for species richness in this habitat. It requires dense shrub cover for nesting, including willow thickets intermixed with wetland herbaceous species. [53-55]

Surprisingly, several other seemingly common bird species are in decline throughout the country. Brewer's Blackbird, Wilson's Warbler, and Least Flycatcher are listed as "common birds in steep decline" throughout the U.S. according to Partners in Flight, a coalition of federal and non-profit groups [55]. Willow Flycatcher *(Empidonax traili*i*),* a nondescript bird with an easy to distinguish "fitz-bew" call, is also listed as vulnerable by several agencies and partnerships including Partners in Flight. Alder Flycatcher is found across Wyoming in appropriate habitat, but the highest breeding concentrations occur in portions of Grand Teton National Park around Jenny and Jackson Lakes [52]. They require willow stands of about 5 acres (2 ha) with dense shrubs, openings, and water nearby for nesting success.

Willow shrub-swamps with their dense thickets, insects, and variable micro-topography are important for a diversity of large ungulates and small birds. When adjacent to streams and rivers, they also sculpt stream morphology and create important habitat diversity for fish and other aquatic life (C. Girard, Personal communication).

Location: Extensive shrub-swamps are found around Flagg Ranch in the Rockefeller Parkway; Willow Flats near Jackson Lake; and along Pacific Creek, Buffalo Fork, and sections of the main stem of the Snake and upper Gros Ventre Rivers. Willow stands along the north end of Moose-Wilson Road are a prime place for viewing wildlife — particularly moose — associated with this habitat. Willow was common in the National Elk Refuge before the abundance of elk suppressed the community. Stands are also common along sections of Fall and Fish Creeks in and around Wilson.

Trends in willow habitat: Since the change in flood control at the Jackson Lake Dam in 1947, willow habitat along the Snake River from Jackson Lake dam to Moose has been reduced by 240 acres (97 ha) or 27% between 1945-1987, with an anticipated reduction of 40% by 2033 [18]. This calculation does not take into account any changes due to the dikes below Moose. Ninety-five percent of willow habitat in the National Elk Refuge has been heavily browsed by elk along the lower portion of Flat Creek [8]. Areas around the Gros Ventre and South Park Feed Grounds have also been over browsed. It is unknown what reductions of willow habitat have occurred elsewhere over the past decade or so, including the effect of historic grazing, irrigation regimes on agricultural fields, or development of houses such as along the West Bank and Wilson. On the other hand, with fewer elk and moose, some areas such as around Fish Creek in Wilson and in the Buffalo Valley may support more willow habitat now than in decades past.

Threats: Development of private lands along floodplains, streams, and spring creeks can destroy and fragment willow habitat. Furthermore, development can affect the underlying hydrological dynamics of water quantity and quality. Changes in irrigation methods from flooding ditches to overhead pivot systems could also affect these dynamics and, therefore, willow stands. An abundance of elk is a threat near feed grounds. Trapping of beaver also likely affects the extent of some willow communities. All these impacts on the willows themselves affect habitat for moose, beaver, elk, birds, amphibians, and fish.

Information gap: Whether there have been increases or decreases in willow habitat, including location, size, and nutritional quality.

Target Species: Beaver

This keystone species has declined significantly since 1977, including a 25% decline between 2006 and 2011 along the Snake River within Grand Teton National Park, and possibly other areas as well. With careful inventory and study, beaver may provide opportunities to alter hydrological processes and improve sites within the Snake River Wetland Complex for Trumpeter Swans, amphibians, waterfowl, songbirds, otter, and other species.

Beaver are strongly associated with willows along flowing water. These giant rodents with flat paddle-like tails and two big front teeth rely on willow for food and building materials for their dams and lodges. By building dams, beaver raise the water table and trap sediments; willow seeds land upon exposed, moist edges and germinate in spring, and the seedlings have sufficient moisture in late summer to survive, forming new colonies. Heavy browsing of established plants also stimulates vegetative reproduction. These additional willows enable beaver colonies to thrive. With this positive correlation of beaver and willow, beaver can live in a given stream system for years, slowing floods, maintaining water tables, and adding wildlife habitat. Beaver and willows are often considered mutualists. [56]

Beaver feed on aspen and willow bark and use these soft, woody materials to construct dams, which provide protective moats for their mounded, hollow lodges. Monogamous, beaver raise their kits in lodges and spend winters feeding on stores of willow branches stashed under the ice. If undisturbed and with sufficient habitat, beavers can quickly increase in number, which can become a “nuisance” in developed areas where they often chew on planted aspen trees. Trapping typically eliminates two-year old beavers that are looking for a new territory, thereby restricting their distribution. Trapping of adults can disrupt the colony’s social order and make the family more vulnerable. (Drew Reed, personal communication).

Note, not all beavers build dams and moated lodges. Instead, some create bank lodges along wider, faster rivers like the Snake where their dams are futile, or they form lodges on calm lakeshores. Individual beavers can switch their behavior from building dams to bank lodges.

Ecological Significance

Beaver are considered ecological engineers and a keystone species that disproportionately affects the surrounding ecosystem [57]. Beaver impacts depend on the position of their colonies in the watershed and on the structure of their dams [57]. In certain situations, beaver dams impound water, flooding out and often killing larger trees that then become roosts and breeding habitat for birds. By creating stable ponded waters, beaver create new habitat for aquatic plants and insects that, in turn, provide for various birds, including waterfowl [58, 59]. Fish utilize different depths and temperatures around these ponds, including overwintering in unfrozen recesses. Otters also frequent beaver ponds. The overall vegetative, structural, and hydrologic diversity provided by beaver ponds makes them particularly significant to ecology of aquatic environments.

Amphibians are attracted to beaver areas [60]; these areas can create unusual hotspots where four amphibian species reside [61]. Recent research indicates that amphibians colonized beaver-influenced wetlands at a 35% higher rate than wetlands without beaver [60]. Beaver wetlands often benefit these amphibians by increasing the diversity and connectivity of wetland habitat and buffering against drought [62]. The SGCN species of western (boreal) toads and Columbia spotted frogs were more than twice as abundant in beaver influenced wetlands. Other studies in North America and Europe support this positive association between beaver wetlands and amphibians. (See amphibian section below).

Not only do beaver often add wildlife value, beaver ponds are recognized for providing ecosystem services that benefit both wildlife and people. They control flooding and sediment runoff, elevate and/or restore groundwater, maintain stream flows in summer, and filter water, thereby improving water quality. Federal and state agencies promote beaver restoration into watersheds where they do not interfere with human developments.

Status and Trends

Beaver abundance in Grand Teton National Park declined by almost 50% between 1977 and 2004 [63, 64] and another 25% by 2011 [65], together totaling an 80% drop over the past 40 years. These surveys indicate that a large portion of beaver used to live along this section of the Snake River. It is unclear why beaver have declined to such a degree [65]. However, it may be that the side channels that often support beaver have been altered by changes in hydrological dynamics due to the Jackson Lake Dam.

Outside of the park, trapping likely keeps beaver populations lower than they would be otherwise. Harvest records within WFGD hunt management area 1, which includes the JH area, lists 426 beaver trapped in 2013-14, or 13% of the total hunted in the state. Hot spots include private lands from the south entrance of Grand Teton National Park through Wilson along the Snake River, and east of the Snake River to Kings Highway and the airport area. Beaver also occur south of Melody Ranch (D. Reed, personal communication). Private property owners often have beaver removed, as they chew expensive landscape trees — often aspen — around ornamental ponds. Such trapping for “nuisance” animals is common and legal. Under state regulations, beaver “causing damage or flooding can be removed at anytime by the landowner” [66]. Trapping in the national parks, National Elk Refuge, and some creeks, such as portions of Cache, Cliff, and Granite Creeks, is prohibited. Some other creeks have quotas (often 5 per trapper) and seasons. Elsewhere, trapping is unlimited. Reporting is voluntary, not required. It is unclear what the magnitude of the impact of trapping is on beaver populations.

Threats to Beaver - Mostly Unknown

- The reasons for the steep decline of beaver in the Grand Teton National Park portion of the Snake River are unknown. It could be due to changes in backwater channels and ponds, but the causes have not been studied in detail [65].
- Trapping on private lands and certain drainages could be limiting population expansion. However, lack of trapping records or reports is one factor that makes it impossible to know the extent or impacts.

Beaver as a Conservation Opportunity

WGFD has included beaver reintroduction and management in their priority habitat and restoration and enhancement strategies [6, 12]. Yellowstone National Park is actively researching methods to restore willow-alder shrub-swamps, beaver, and associated bird species. The U.S. Forest Service looks upon beaver as a benefit to habitat. Beaver are being used to enhance stream systems in Teton County, ID. The Trumpeter Swan Association is researching areas where beaver may enhance swan nesting habitat. Beaver restoration in the National Elk Refuge could enhance amphibian populations [67].

In summary, we consider beaver a target species for its ecological value and opportunit**y.** This keystone species has declined significantly since 1977, including a 25% decline between 2006 and 2011 within Grand Teton National Park and possibly other areas as well. With careful inventory and study,

beaver may provide opportunities to alter hydrological dynamics and improve sites within the Snake River Wetland Complex for trumpeter swans, amphibians, waterfowl, songbirds, otter, and other species.

Information Gaps

- Extent of beaver decline.
- Cause of beaver declines.
- The feasibility and benefits of enhancing the Wetland Complex by conserving and restoring beaver populations throughout the watershed.

Watch List: Amphibians

Amphibians are declining worldwide [68, 69], and there are indications that several of the seven species in the JH area may be in decline as well. Threats of development on private lands, as well as disease and climate change, could have serious impacts on populations in the future. Fortunately, there is a significant body of ongoing research on national lands to monitor their status, although significantly less research is available on private lands in the private core of the JH area. We want to make sure these small creatures, representative of intact wetlands and uplands, persist in our region.

All amphibian species in the JH area depend on wetlands for reproduction. Breeding adults deposit their eggs in stagnant, shallow water warmed by the sun in spring after snowmelt. These areas include various types of still water: seasonal and permanent ponds, lake margins, marshes, non-flowing ditches and channels, and oxbows or other backwaters of streams. Within about two weeks, larvae hatch out, sporting torpedo-shaped bodies with gills, long tails, and tiny eyes (also called tadpoles for frogs and toads). They metamorphose into tail-less creatures with four legs, lungs, and prominent eyes (except salamanders) between July and September of the same year. However, development rates are dependent on water temperature and other site characteristics. The persistence of water over this time is key to their initial survival.

Adults, which can live for 12 years or more, and juveniles, which take several years to reach reproductive age, spend most of their lives on land or underground rather than in the wetlands where they breed. Upland areas and stream corridors that connect breeding sites to summer and winter habitat are thus crucial for amphibians to complete their life cycle.

Amphibian Species in the JH Area

Three species are very rare or perhaps already extirpated. American bullfrog (*Lithobates catesbeianus*), found only in Kelly Warm Springs, is targeted for elimination by Grand Teton National Park as it is an introduced population. The northern leopard frog (*Lithobates pipiens)* has not been seen or recorded since 1995 and may well be extirpated from the county. The Great Basin spadefoot toad (*Spea Montana*) possibly occurs in a very limited area in the JH area. Spadefoot toads are eruptive — emerging after heavy rains to congregate in temporary puddles and pools within dry habitats of sagebrush and scrublands. The harsh nasal-sounding snores of males makes identification of breeding sites highly feasible if searches are conducted at the appropriate times and places. More information on Great Basin spadefoot toads would be helpful as the Wyoming State Habitat Priority report mentions it in several drainages for Jackson [12].

Four Relatively Common Amphibian Species that Deserve Monitoring

Western Tiger Salamander (*Abystroma mavortium*) often surprises people. The 6-8 inch-long (15-20 cm) crawling creatures with mottled skin and long tails can be found occasionally in basements, manure piles, water tanks, burrows and other moist places that prevent desiccation. In spring and summer, salamanders migrate to or away from breeding ponds, sometimes crossing roads, particularly on rainy nights. If lucky, one can see dozens basking on rocks around a mountain lake in summer (F. Clark, personal observation). Hatching from tiny eye-ball like eggs attached to underwater stems (singly or in rows), the larvae have greenish bodies with distinctive feathery gills. Legs appear while the larvae are still small. This species has amazing plasticity — while most larvae metamorphose in the same season, some may remain in the breeding ponds for multiple years before they eventually transform. Yet others become reproductively mature while still retaining their gills and dependence on water. A shape-shifting species! After breeding in water, adults spend most of the time underground in rodent burrows, natural cavities, or burrows they dig.

Breeding populations of western tiger salamanders have been found to persist best in relatively larger, deeper, more permanent water bodies [60, 70]. Stocking fish, which eat the larvae, into mountain lakes and ponds can contribute to their declines along with various viruses. Fragmentation of habitat in developed areas can prevent safe movement and alter water quality. Due to the lack of knowledge of populations and their threats, this species has become a SGCN since 2010 [6, 22].

Boreal chorus frog (Pseudacris maculata) is relatively common in the JH area and Wyoming. The species is considered a good “flagship species” to promote awareness of wetland habitats [71] and thus it was chosen by the Teton County NRTAB as a focal species. These thumbnail-sized to 1.5 inch-long (4 cm) frogs are often heard trilling in artificial ponds and irrigation ditches throughout the valley from very early spring into early summer. They attach their eggs — up to 200 tiny black dots within an elongate gelatinous mass — onto stems of sedges and rushes in shallow ponds with plenty of emergent vegetation. The larvae gain legs within 6-10 weeks and at only ½ inch (1.2 cm) long, the new froglets leap to terrestrial habitats. While it is impossible to gauge the numbers of frogs from their strident mating calls (D. Patla, personal communication), they are estimated to be numerous and wide ranging throughout the JH area and the state [22]. Reduction in their distinctive calls in neighborhoods could indicate a decline in the local population. The Nature Mapping Jackson Hole program encourages citizen scientists who hear these frogs to record their presence.

Columbia Spotted Frog (*Rana luteiventris)* inhabits mountains and valleys in northwest Wyoming. A disjunct and genetically distinct population is found in the Bighorn Mountains. Up to 3.5 inches (8 cm) long with warts and blotches rather than distinct spots, Columbia spotted frogs can be found in the JH area from the valley floor to the subalpine zone, breeding in a variety of ponded water bodies. After breeding, adults disperse and spend the summer in moist areas or along streams and lakes [72]. They overwinter aquatically or underground in springs, beaver dams, and spring-fed ponds where they can avoid freezing temperatures. While tadpoles metamorphose the first summer, juveniles require 2-5 years to mature (4-6 years at higher elevations), a precariously long time before they have an opportunity to replace themselves.

Western Toad (*Anaxyrus boreas)* is widespread but with substantially fewer known breeding sites than Columbia spotted frogs, boreal chorus frogs, and western tiger salamanders. Noticeably warty with a white stripe down their backs, western toads lay long, thin strings of eggs, averaging 5,200 eggs per fertile toad, and tadpoles typically metamorphose in 4 to 8 weeks. They breed in wetlands from the valley floor to the lower subalpine zones, 6,000-9,000 feet (1.830-2.745 m) in elevation in the JH area. There are two main populations: in mountains in northwestern-western Wyoming and a Southern Rockies population that includes southeastern Wyoming. The Southern Rockies population has declined severely and has probably been decimated by the disease chytridiomycosis (chytrid fungus disease). The U.S. Fish & Wildlife Service is currently deciding if western toads should be listed as a threatened or

endangered species. This process will include a review of genetic information that may determine whether the western toad population in the JH area is included in the listing.

Status and Trends of Amphibians

Five amphibian species in or potentially in the JH area are listed by WGFD as SGCN: Western tiger salamander, Columbia spotted frog, western toad, northern leopard frog, and Great Basin spadefoot toad. Teton County has selected two amphibians as Focal Species: western toad and the more common boreal chorus frog. The U.S. Fish and Wildlife Service is considering listing the southeast population of western toad in 2017 and may include the western toad population in northwestern Wyoming.

Worldwide, as a taxonomic group, amphibians are declining faster than any other vertebrate class [73]. In the GYE, survey results of amphibians vary. Statistical modeling of monitoring data collected from 2002-2011 in Grand Teton and Yellowstone National Parks indicated declines in breeding site occupancy [60]. Boreal chorus frog was the only species among the four widespread amphibian species that did not show declines in this time period. The importance of beaver impoundments for amphibians in our area was indicated by this publication (see beaver section above). Modeling analyses of monitoring results using shorter and more recent time frames (2006-2012) showed slight increases for three species. Western toad data were regarded as too sparse for analysis [61]. Additional analysis of annual monitoring data from Yellowstone and Grand Teton National Parks is in progress, using increasingly complex statistical modeling tools.

Inventory, monitoring, and research have been ongoing in the JH area and adjacent areas since the early 1990s, resulting in a substantial body of information. Most of the formal work has been conducted in Yellowstone and Grand Teton National Parks [74]. In addition, inventory and site-specific monitoring has been conducted on the National Elk Refuge since 1998 [67] and in the Bridger-Teton National Forest. Citizen scientists, as part of the Nature Mapping program, have provided vetted observations of amphibians to the state Wildlife Observation System (WOS) since 2009. WGFD's appointment of a state herpetologist within the aquatic division has also bolstered information. Unfortunately, little to no survey work has been conducted on private lands due to difficulties of access and study design. However, Teton Conservation District has begun amphibian monitoring in conjunction with WGFD on private land sites in 2017 (C. Girard, personal communication).

In sum, at this time, considerable information is available about amphibian populations on public lands in the JH area. Investigation of trends and population persistence is ongoing, leading to increased knowledge of the effects of habitat fragmentation, disease, and climate change on amphibians in the Yellowstone-Teton area and across the Western U.S. While there is scant information on the proportion of occurrences on private lands vs. protected lands, Nature Mapping records suggest that Columbia spotted frogs and western toads are considerably more rare on private lands than public lands. Due to the rapid development of private lands over the past several decades and likely into the future, amphibian populations could be imperiled. Both wetlands used for reproduction and uplands containing summer and winter habitat are necessary for amphibian survival.

Threats to Amphibians

- Loss of habitat by development can wipe out local populations permanently. Fragmentation and degradation of habitat by homes, landscaping, roads, and culverts can prevent amphibians from hopping or swimming to different parts of their year-round range or colonizing new sites. Cleaning up rough, woody debris and underground cavities can eliminate their moist havens. Also, amphibians are vulnerable to chemicals — including herbicides and pesticides — that can penetrate their permeable skin or kill their invertebrate prey. Widely scattered populations of

these small animals that creep and leap to their varied habitats are particularly vulnerable to fragmentation.

- Other threats much harder to mitigate include climate change and disease. Drought and unusual weather patterns can dry up breeding areas and can alter moisture levels in surrounding areas, thus decreasing reproduction and survival [60, 75]. Two diseases — one a virus, the other a fungus — are both widespread in this region. Ranavirus is known to cause sudden mass mortality [61]. Recent research indicates it can be spread between fish and amphibians [60]. Chytrid disease has been shown to slowly reduce population sizes of amphibians and is a global problem [76, 77].

[Deb Patla, herpetologist, contributed extensively to this section]

Target Habitat: Narrowleaf Cottonwood Galleries

We have selected narrowleaf cottonwood galleries as a target. Cottonwood galleries provide essential habitat for a range of species, particularly birds and bats,. They are also essential corridors for many larger species. Cottonwood galleries are particularly dependent on periodic flooding for survival. The impacts of dams, levees, water diversions, and development may not be seen for decades due to the trees' longevity. Over time, the presence of both aged and juvenile stands of narrowleaf cottonwood is a good indicator and flagship species for effective conservation.

Description

Green ribbons of cottonwood border the major rivers of the arid west, accentuating the life-giving source of water both human and animal communities depend upon. In the JH area, phalanxes of 60-foot (18m) tall narrow-leaved cottonwood (*Populus angustifolia*) border the Snake River from Moran Junction south to Hoback. Broad crowns are supported by trunks 2-3 feet (0.6-1 m) in diameter, clad in fissured bark. Silverberry, snowberry, red-stemmed dogwood, and chokecherries — all berry-producing species — may grow in the bright shade along with horsetails and grasses. Willows often crowd into openings nearby. These understory plants are nurtured by the cottonwoods' abundant deciduous leaves that decompose quickly, adding nutrients to the soil and flowing waters. Seedlings of evergreen Colorado spruce establish in shade and can grow up to out-compete the shade intolerant cottonwood seedlings and saplings.

Cottonwoods depend on particular hydrological dynamics to reproduce sexually, a necessity for their populations to endure and adapt over time. Cottonwoods seed abundantly each year; in mid-June, miniature seeds are carried on fine hairs high into the air on warm breezes — looking like snowflakes in a wayward snowstorm. Despite their abundance, the seeds literally have a one-in-a-million chance of germinating. Cottonwood depends on synchrony with seasonal dynamics e.g. peak flooding. A tiny, short-lived (1-2 week viability) seed has to land in a place with a particular set of conditions: moist, mineral soil in full sunlight. These conditions are most likely after severe flooding. Furthermore, flood waters must recede beneath the ground at the same rate as the root grows [78]. A cottonwood seed has a one-in-a-billion chance of reaching maturity from seed; it requires a decade to establish, grow, and become mature [13]. Over many years, pulses of floods create new habitat for seedlings which grow to form stands of different age classes along the river's sinuous path. Disrupting changes in flooding and the associated changes in geomorphology regimes is the single greatest impediment to riparian forest regeneration [13].

Ecological Significance

Cottonwood trees and their associated plants support myriad species of birds and small mammals: their soft wood enables woodpeckers, including rare Lewis' Woodpeckers, to form nesting holes for American Kestrels, Mountain Bluebirds, Tree Swallows, and other cavity nesting birds. Large trees provide roosts for bats, Bald Eagles, hawks, and Osprey. Grassy areas host shrews and mice that serve as prey to raptors, including Great Gray Owls. Continuous stretches of galleries provide habitat, cover, and travel routes for large mammals, such as deer, moose, elk, and black and grizzly bears, which need particularly large ranges. As movement corridors connecting habitat, galleries enable these large animals to mix with individuals from distant areas, sustaining genetic diversity and therefore resilience in wildlife populations [9]. Cottonwood galleries connect much of the JH area from north to south along the Snake River and east out the Buffalo Fork Valley, up Spread and Ditch Creeks, and along the Gros Ventre and Hoback Rivers. Cottonwoods contribute significant shade and large woody debris to the Snake River and its tributaries, adding habitat diversity and playing a role in forming the diverse interconnected patchwork of micro-habitats that so many species' life histories rely upon, including cutthroat trout. Cottonwood galleries form an essential artery for wildlife in the JH area and are an excellent indicator of ecosystem integrity [13].

Status and Trends

The Jackson Lake Dam and levees control essential flooding incidents, potentially decoupling the opportunity for cottonwood to germinate in time with receding floods. Fortunately, narrow-leaf cottonwoods can live for 200-300 years, provided they can reach sufficient moisture, so the existing trees may have time to regenerate sexually. Cottonwoods can also re-sprout from damaged trunks or reproduce vegetatively from fallen limbs, but these are often clones of ancient trees and are perhaps less adapted to climate change [78]. Over time, without flooding and associated scouring, the stands will die out. This can be seen along dried up riparian margins of the Snake River. Already, 30% of this forest type has been degraded since 1957 between Jackson Lake Dam and Moose [18]. There has not been a similar comparison for areas below the park boundary, although the Army Corps of Engineers states that 90% of wetland habitat in general has been affected by the dikes installed in the 1950s [19].

In other regions of the country such as in Arizona along the San Pedro River, changes in hydrological dynamics have killed off cottonwood trees (different species) to such an extent that communities are planting trees, an expensive and complex restoration effort; however, even these efforts are not successful without restoring the underlying hydrological dynamics [13]. Fortunately, our species of cottonwoods are longer-lived and therefore individual trees have time to contribute to new generations if hydrological conditions are sufficiently restored.

Without disturbance of flood or fire, the evergreen forest primarily of Colorado spruce (*Picea pungens*) and occasional hybrids, will likely expand, thereby changing the ecology of cottonwood galleries or even shading them out. These evergreen forests have less nutrition in their branches for browse, lower plant diversity growing in their dense shade, and fewer and different nutrients recycling regularly into the soil and water. On the other hand, the dense evergreen structure provides thermal cover in summer for ungulates and winter habitat for Great Gray Owls. Large trees afford nesting sites and perches for Bald

Eagles and Osprey, as well as roosts for bats. While both kinds of trees are valuable, in the Snake and Gros Ventre riparian corridors, narrow-leaf cottonwoods contribute distinctive diversity in the JH area.

Threats to Cottonwood Galleries

- **Development of homes, parks, golf courses, and boat launches — High, local.** Development continues to degrade remaining habitat on private land. Trees are cut down and artificial ponds and landscaping replace natural habitat and affect local hydrological dynamics. Associated human activities displace wildlife. These pressures are intensifying and causing irreparable harm to the cottonwood galleries connecting wildlife along the full reach of the Snake River.
- **Levees — High**. For decades the Jackson Lake Dam and levees have significantly altered hydrological processes and therefore the regeneration of these long-lived trees. This is a subtle degradation of habitat. There may be some opportunity to restore more natural hydrological regimes in some places (C. Girard, personal communication).
- **Grazing and browsing — Low, local**. In agricultural areas, cattle graze heavily in the understory. Elk in and near feed grounds can have the same effect of eliminating the complexity of the habitat and reducing bird life. This disturbance provides opportunity for invasive species such as spotted knapweed, Canada thistle, Dalmatian toadflax, and perennial pepperweed to further alter the understory vegetation.

Associated Species

Cottonwood riparian forests, along with a mixture of Colorado spruce and balsam poplar (*Populus balsamifera),* provide habitat for a variety of species. Here we emphasize several.

*Bald Eagles (*Haliaeetus leucocephalus*)*

The largest nesting population of Bald Eagles in Wyoming resides along the upper Snake River. Bald Eagles prefer a combination of open water and high river sinuosity away from human disturbance. They require trees large and strong enough — such as old cottonwoods — to hold up their giant nests, and birds prefer to be high above the surrounding landscape. They feed primarily on fish but will hunt waterfowl and small mammals as well as scavenge carrion.

Trends/status: Currently the Bald Eagle population along the Snake River drainage in the JH area appears to be stable. WGFD 2016 annual inventory reveals 42 of 50 (84%) surveyed territories were occupied and 28 of 39 (74%) nests surveyed were successful. The productivity data for Greater Yellowstone population collected from 1982-1995 and 2016 indicates the productivity or number of young per occupied site for 2015 is within the historic range. WGFD continues to monitor Bald Eagles annually, and partners are researching effects of development and toxins on their health and reproduction. Genetic studies are also being pursued. [22, 79]

Threats: The loss of large trees over time can affect the eagles' reproductive potential here in the JH area [22]. Nesting eagles are sensitive to disturbance by people, including those recreating in their breeding and foraging habitat, such as boaters along the Snake River. Housing developments in riverine zones, such as south of Grand Teton National Park, also fragment their habitat and disturb the birds.

*Osprey (*Pandion haliaetus*)*

Formerly called "fish hawks", Osprey are a common sight in the JH area where they have sufficient nesting trees or constructed platforms located near their essential food resource: fish. Starting in

October, these birds migrate as far as Cuba and Venezuela for the winter. With luck on their migration and wintering grounds, they return in early May, often to the same partner and nest.

Status and Trends: While not rare and while only a very small portion of the worldwide distribution is here, Osprey are an iconic species here in Jackson Hole. Their population is tracked in part by the Nature Mapping program of JH Wildlife Foundation, Grand Teton National Park, and Teton Raptor Center.

Threats: Low — Loss of nesting sites due to loss of large cottonwood trees as well as competition with Canada Geese affect reproduction. Some action is being taken to provide platforms designed to prevent geese from commandeering nesting sites in early spring. Electrocution from perching on wires is a source of direct death. Otherwise, the main concern is their survival on their wintering grounds in other countries where conservation efforts are rudimentary.

*Great Gray Owls (*Strix nebulosa*)*

Great Gray Owls are very rare in Wyoming and are near the southern point of their range in Wyoming. Recent research concludes that these owls concentrate in riparian forests south of Jackson in winter [80]. (For more on Great Gray Owls, see Goshawk chapter of this report).

Bats

Since 1998, the Wyoming Bat Working Group (WYBWG) has been concerned about the status, life histories, and survival of bats. Over the last decade, the WYBWG has been creating conservation plans, conducting surveys, and developing standards for assessment of these nocturnal flying mammals [81] in association with the Western Bat Working Group and federal agencies.

Approximately 10 species of bats — (seven SGCN)—use wetlands and riparian areas within the Upper Snake River and Wetland Complex [22]. Some are considered particularly rare, such as fringed myotis (*Myotis thysanodes)*, Yuma myotis (*M. yumanensis*), and Townsend's big-eared bat (*Corynorhinus townsendii*). Our more common species include little brown myotis (*M. lucifugus)*, silver-haired bat (*Lasionnycteris noctivagans*), hoary bat (*Lasiurus cinereus*), and big brown bat (*Eptesicus fuscus*) [22, 82]. More common species may well contribute a larger benefit to the ecosystem due to their numbers. While often persecuted by people who have misconceptions of their danger to humans, bats provide ecosystem services, including consuming many insects. While bats often feed in insect-rich areas such as wetlands, they often roost some distance (miles) away and, therefore, may play a significant role in nutrient transfer by acting as "pepper shakers," distributing nutrients throughout their home range [81]. Bats often feed or roost near water, as they require water to excrete toxic nitrogenous waste products accumulated by their high protein diet of insects. People often think of bats roosting in large numbers in caves, but several species roost in smaller number in trees, including cottonwoods, particularly in summer. Others use buildings.

Status and Trends: Unknown — Preliminary survey work was conducted in Grand Teton National Park in 2005 [82]. A combination of observations, mist netting, and acoustic detectors are typically used — but different species use a variety of different territories, have different calls, and fly at different altitudes and times of night. Grand Teton National Park, in cooperation with Boise State University, began research in 2016, coupling acoustic, light, and roost monitoring with radio telemetry to assess factors that influence bat use of historic properties in Grand Teton and how this affects the human-bat interface. Otherwise, extremely little is known about bats in this area (D. Gustine, personal communication).

Threats:

- **White-nose syndrome:** Along with habitat destruction, climate change, and in some locations, wind energy, one of the greatest threats to bats is white-nose syndrome

(WNS). WNS, a fungus disease, is moving west from the northeastern U.S., where it has had devastating impacts (up to 90-100% mortality) on some bat populations, primarily those that roost in colonies. To date, the nearest occurrence of WNS to Wyoming is in eastern Nebraska [83]. WNS has infected at least two of our common resident JH area species: big brown bat (*Eptesicus fuscus*) and little brown myotis (*Myotis lucifagus*). While not yet here, when it does arrive, WNS could have devastating effects on some populations.

- **Public perceptions and health:** In general, bat populations are highly susceptible to loss of any one of their habitat needs, but particularly maternity roosts and hibernation sites, including buildings. While public awareness of the ecological role of bats has improved, bats are often persecuted, particularly around developed areas. Evermore education is needed. In national parks, balancing public health concerns with maintenance of buildings, often historical sites, with bat roosts, is a management concern (D. Reinhart, personal communication). Of note: while bats are associated with rabies, very few reports of rabies from bats are reported nationally each year, with only one confirmed rabid bat in Teton County in at least 17 years [84]. Sixty-three deaths attributed to rabies in bats have been documented in the U.S. between 1951 and 2016 [85].

Information Gap: There is a scarcity of information on our bat populations and the vulnerability of bats in general to loss of habitat and white-nose syndrome in the JH area**.**

Habitat: Marsh

Marshes support an abundance of water and wildlife, adding significant diversity to the landscape. In Wyoming, the 5th driest state in the nation, marshes are rare. Only a few such lush habitats are found in the JH area; however, one is perhaps the most notable wetland in the valley: Flat Creek marsh on the National Elk Refuge.

Marshes are flooded to a greater depth and for longer periods than any other wetland type [7]. Abundant, slowly moving water flows across the land most of the year. Our Wyoming woody plant species cannot survive in the constant flow and anaerobic conditions. Instead, specially adapted herbaceous “emergent” plants such as cattails, sedges, and bulrushes dominate. Using starches stored in their roots and underground stems during the previous year, the plants grow new leaves through the water afresh each spring. As waters warm, last year’s dried leaves decompose and provide nutrients that make marshes one of the most productive habitats in the JH area. In open water, floating aquatic plants, such as Sago pondweed, duckweed, and pond lilies, thrive on the recycled nutrients and full sun. Nutrients and stands of dense vegetation interspersed with water support a range of micro- and macro- invertebrates.

Marshes provide habitat for amphibians, fish, waterfowl, and Trumpeter Swans. Taller plants provide shelter, nesting material, and food for muskrats and a variety of birds. Red-wing Blackbirds, Yellow-headed Blackbirds, Marsh Wrens, and Song Sparrows are noisy denizens of marshes. Ducks of all sorts utilize these areas during migration. Many ducks nest in the reeds, their young chicks swimming out, diving or dappling for food, and then rushing back into cover if threatened. Sora and American Bitterns, and more rarely Virginia Rails, skulk through the reeds, rarely seen. Muskrats, related to voles not rats, are the signature mammal of marshes and are adapted to eating all kinds of herbaceous vegetation but particularly cattails and pond lilies. They build “push ups” or high mounds of herbaceous material for dens, which are also used as perches by birds. The workings of muskrats add to the spatial and species diversity of the marsh. Marshes are extremely productive wildlife habitat.

Marshes provide several other important ecological services. Typically located in shallow basins, floodwaters can spread and slow before draining downstream, often recharging aquifers. The dense plant

structure and extensive roots impede water movement, reduce scouring and erosion, and cause sediments to settle out. Cattails have been proven to take up toxins into their roots, also improving water quality. Thus marshes enhance water quality and decrease storm damage, which benefits people as well as wildlife.

Location: The National Elk Refuge features the most visible extensive marsh in the JH area. It is easily seen from Highway 89 heading north out of Jackson. The total acreage is only 630 acres [8]. Surrounding wetlands are classified as wet meadows (see below). No other marsh wetlands are mapped in GTNP or the private lands of Teton County. However, the Grassy Lake Road area in the Rockefeller Parkway features patches of marshes interspersed with willow shrub-swamps and wet meadows. Lakes and ponds with relatively shallow shores can have narrow perimeters of marsh vegetation.

Threats: In general, marshes can be impacted by development with associated changes in hydrological processes and nutrient loads. Fortunately, most of the marshes in the JH area are protected as federal lands. Winter herds of elk in the NER can compact soils and add excessive nutrients, altering the natural vegetation along the Flat Creek marsh. In other locations, boaters can intrude upon marshy edges of lakes and ponds, upsetting wildlife.

Habitat: Wet Meadows and Fields

Wet meadows are one of the most overlooked wetland types of all as high water tables are temporary, and wet meadows are often camouflaged by tall upland grasses in agricultural fields or mountain meadows.

Wet meadows are dominated by native sedges and water-tolerant grasses. Wet meadows form in low-lying, flat terrain that is flooded by melting snow on frozen ground, from overflows from streams and ditches, and seasonally high water tables. They are often interspersed within pastures and hay fields. These very shallow wetlands provide important habitat for many species temporarily and seasonally. The relatively abundant water stimulates rich grass and sedge growth by mid-summer and fall that benefits ungulates in fall and winter.

Diversity within wet meadows shifts throughout the seasons. As soils thaw, invertebrates such as worms wriggle to the warm, soft surface within reach of probing bills of Wilson's Snipe, White-faced Ibis, and egrets. Amphibians may use this moist habitat for movement to deeper waters for breeding. Migrating ducks, sandpipers, dowagers, phalaropes, and avocets may stage here on their way north. Sandhill Cranes form nests out of mud in wetter depressions and feed on nearby vegetation or invertebrates. Long-billed Curlew use their 4-8 inch-long (10-20 cm) bills to probe and pick for invertebrates in May and June, and sage-grouse chicks glean insects in late summer. Elk and deer graze on grasses in fall. Bison prefer sedges for their winter diet. While temporary, these uses of wet, grassy habitats provide essential resources. Sites such as the Walden Ranch conservation easement north of Highway 22, the National Elk Refuge, Elk Ranch Flats and south of Willow Flats in Grand Teton National Park, as well as the less apparent meadows in the Rockefeller Memorial Parkway including Grassy Lake, provide viewing opportunities of this transitory wildlife.

Threats: Depending on the land development regulations, private unprotected agricultural lands are subject to intense development and therefore outright loss of habitat and fragmentation. Grazing by domestic stock as well as concentrated numbers of elk and bison can also impact these habitats. Changes in irrigation systems can also alter local water tables and therefore presence of wet meadows.

Target Species: Snake River Cutthroat Trout

Snake River Cutthroat Trout (*Onocorhyncus clarkia* spp.), a popular native sport fish, is an indicator of an intact riverine and wetland ecosystem throughout the JH area. It is considered a state SGCN and the Teton County NRTAB selected it as a Focal Species [86]. The Snake River Cutthroat

Trout thrives in the cool, clear waters of the upper Snake River and is not yet contaminated by hybridization with non-native Rainbow Trout. Focusing on its need for connectivity, water quality and quantity, and natural flow regimes will benefit many other species highlighted in this report, including the much more rare Bluehead Sucker. The Bluehead Sucker (*Catostomus discobolus*), a native non-game species and also SGCN, is documented in relatively few drainages. Recent research determined that Bluehead Sucker ranges from the north to south end of the Snake River annually [20]. We chose the relatively common Snake River Cutthroat Trout as a Target Species for its value as a flagship and umbrella species.

Ecological Significance

Snake River Cutthroat Trout is an unnamed subspecies [87] that is sometimes referred to as the fine-spotted cutthroat trout, as opposed to the large-spotted Yellowstone Cutthroat Trout (*Oncorhynchus clarkii bouvieri*). Cutthroat trout are the only native trout in Wyoming and includes several subspecies. The Snake River Cutthroat Trout is the native subspecies specifically in the Snake River and its tributaries between Jackson Lake and Palisades Reservoir. Historical and genetic evidence suggests that cutthroat trout have been inhabiting Wyoming's waters for over one-million years. Their distribution was the result of the recession of glaciers and the formation of ice dams creating huge lakes over vast areas of the landscape. When ice dams broke and waters receded, isolated populations of cutthroat trout were left in the different drainages of Wyoming. In this case, the watershed divide of Two Ocean Lake may have isolated the populations of our two local subspecies of Yellowstone Cutthroat and Snake River Cutthroat Trout [87, 88]. This more or less distinct subspecies is prized by anglers who are concerned about hybridization with the closely related Rainbow Trout (*Oncorhynchus mykiss)* that has been introduced throughout Wyoming.

Healthy, sustainable cutthroat trout populations require life-history variations related directly to diversity in the physical nature of the Snake River system [21, 86]. Recent research concludes that where there is a greater mix of habitat types, cutthroat trout have a greater expression of life histories. These include spawning strategies that make their populations more resilient to disturbances and other changes that inevitably occur over time [21]. Factors such as watershed connectivity, stream network topology and complexity, temperature and gradient, as well as physical structure of woody debris, all provide heterogeneity between and within tributaries and lakes. In large, intact river systems, as opposed to small streams, cutthroat trout utilize a much wider range of habitat variations and spatial patterns that enable them to diversify their life histories accordingly. Due to the extensive, relatively intact upper Snake River system, Snake River cutthroat trout have a greater resiliency over the longer term.

Status and Trends

WGFD conducts annual population estimates on the Snake, Gros Ventre, Hoback, and Salt Rivers. Currently it is considered common in the watershed [22]. Even so, WGFD has documented several declines in creeks. A 2008 survey of Flat Creek in the National Elk Refuge upstream from the fish hatchery revealed a decline in the Snake River Cutthroat Trout population and an increasing Brook Trout population. The survey showed Snake River Cutthroat Trout greater than five inches in length in this section had declined from 191 per mile in 2002 to 58 per mile. The number of non-native Brook Trout greater than five inches increased from 18 per mile in 2002 to 122 per mile in this trophy class fishery. Cutthroat populations downstream of the hatchery did not show the same decline [88]. Another survey documented a decline in native cutthroat biomass with a 27% reduction in estimated pounds per mile between 2004 and 2010 along 15 miles of Fish Creek. Estimates of numbers of cutthroat trout spawning also suggest the population is declining in this reach [22, 25].

Threats

- **Non-native species** — Medium. Potential hybridization by non-native Rainbow Trout travelling upstream from Idaho (currently blocked by the Palisades Dam) or from past or future introductions into the upper Snake River and lakes is a concern for preserving the purity of the subspecies. Also, Rainbow Trout are direct predators of and competitors to our native species [22]. Brook Trout is another non-native competitor. Brown Trout are abundant in Jackson Lake and in the Snake River above the lake and are a known predator and competitor to cutthroat trout. Also, Lake Trout are present in Jackson, Phelps, and Jenny Lakes and are known to predate heavily on cutthroat trout. These non-native species can have negative effects on our native trout no matter what the health of the ecosystem.
- **Disease** — High, potentially extensive. Cutthroat trout are sensitive to whirling disease (*Myxobolus cerebralis*), a microscopic parasite introduced from Europe in the early 1900s. The parasite was first detected in Wyoming in 1988, including at the Fish Creek Fish Hatchery in Jackson. It was found in Yellowstone Lake in 1998, where it has infected 20% of Yellowstone Cutthroat Trout. The disease is spreading through the Yellowstone Lake watershed. It is spread by fish-eating birds, such as Great Blue Herons; by anglers, boats, and equipment that is not thoroughly cleaned; and by transport of diseased fish. Relatively warm waters and drought associated with climate change increase incidence of whirling disease. There is no control of the disease in the wild. [89, 90]
- **Degradation, fragmentation, and destruction of habitat by development and agriculture** — Moderate, local. Private lands in Teton County are concentrated in the heart of the watershed. Agricultural irrigation systems — water diversions, channels, and dams — can block or alter fish movements and cause direct mortality by capturing fish in areas that are later dewatered. Cattle grazing can break down banks, affecting shorelines where fish can harbor. Residential and resort development can affect water quality and hydrological dynamics, as well as connectivity. Spring creeks, important spawning areas, are particularly vulnerable in areas that already suffer degradation, such as Fish and Flat Creeks. Artificial ponds, landscaping, lawns and associated nutrient and pesticide run-off can alter temperatures, oxygen levels, and chemistry in waters flowing into larger creeks and the river itself from above and below ground. Road culverts, irrigation dams, and other impediments like the proposed Snake River Wave Park can prevent fish from migrating to overwinter, spawn, and feed.
- **Decline of cottonwood galleries** — Low, local. Over the longer term, loss of cottonwood galleries could also affect cutthroat trout populations. Trees and shrubs provide shade that maintains cool water temperatures and habitat for terrestrial insects that serve as food for juveniles. Galleries add wood and organic matter to the stream. The wider and more structurally diverse the riparian area or buffer, the more value trees will have for cutthroat trout. [91]
- **Climate Change** — High, extensive. Warming of waters and alteration of hydrological cycles and flows are predicted effects of climate change that will severely affect cold-water fishes, including distribution, reproduction, and resistance to disease [38]. Also, it will increase competitive ability of non-native trout species such as Lake and Brown Trout.

Opportunities

Cutthroat trout and several other species are the subject of cooperative efforts. WGFD, Trout Unlimited, federal landowners, Teton Conservation District, and other partners are focused on improving impaired stream systems, with significant accomplishments in the last five years [22]. Local partnering agencies are spearheading strategies for preventing invasive non-native fish, invertebrates — such as New Zealand mudsnails and zebra mussels — diseases, and exotic plants, which will also conserve the

ecological values of the Snake River Wetlands Complex. While WGFD and other biologists are doing their share, it is important that planners, county leaders, and landowners support development regulations and projects to complement these efforts. Recreationists, such as boaters and anglers, have an important role in preventing spread by cleaning their crafts and gear.

Concerned Agencies: Opportunities for Cooperation

The following federal, state, and county agencies have jurisdiction over different parts of the Snake River Wetlands Complex. Many have developed plans, policies, and regulations that affect the future of the JH area.

- National Park Service — Yellowstone and Grand Teton National Parks, along with J.D. Rockefeller Jr. Memorial Parkway, protect the headwaters and main stem of the Snake River and its associated cottonwood gallery forests, willow shrub-swamps and the majority of lakes. Jackson Lake dam is within GTNP.
- Bridger-Teton National Forest — First- and second-order streams, many of them designated as Wild and Scenic Rivers, feed into larger streams and into the Gros Ventre, Snake, and Hoback Rivers. Caribou-Targhee and Bridger-Teton also protect rivers draining into Idaho to the west of the watershed divide. The Bridger-Teton National Forest Management Plan [92] states that the forest includes the “Best cold water fisheries anywhere in the world.”
- National Elk Refuge — NER has 2,676 acres (1,083 ha) of wetlands. These include several creeks, a marsh, and Gros Ventre riparian zones which cover 1,400 acres (566 ha) of riparian and willow habitat. Flat Creek marsh is one of the most extensive marshes in the JH area. NER wetlands are “some of the most diverse and important in Jackson Hole” [8].
- Wyoming Game and Fish Department — In the JH area, the state oversees two Wildlife Management Areas (WMA) which include portions of the Snake and Hoback Rivers, including created wetlands in South Park which benefit waterfowl and Trumpeter Swans. They also oversee fishing and trapping permits.
- Teton Conservation District — This partnering agency is statutorily obligated to conserve soil and water and monitor EPA impaired streams.
- Private landowners and managers — Private lands in Teton County lie within the core of the wetland system described. Ranchers control irrigation systems and grazing rotations. Homeowners along Fish, Flat, Cache Creeks and other spring creeks affect nutrient inputs and water withdrawals. Resort owners also manage pesticides, fertilizers, and water use. The Jackson Hole Airport lies above the aquifer that supplies 98% of water used for domestic and public supply in Teton County [16, 93]. All have a stake in the water quantity and quality that flows through or under their land.

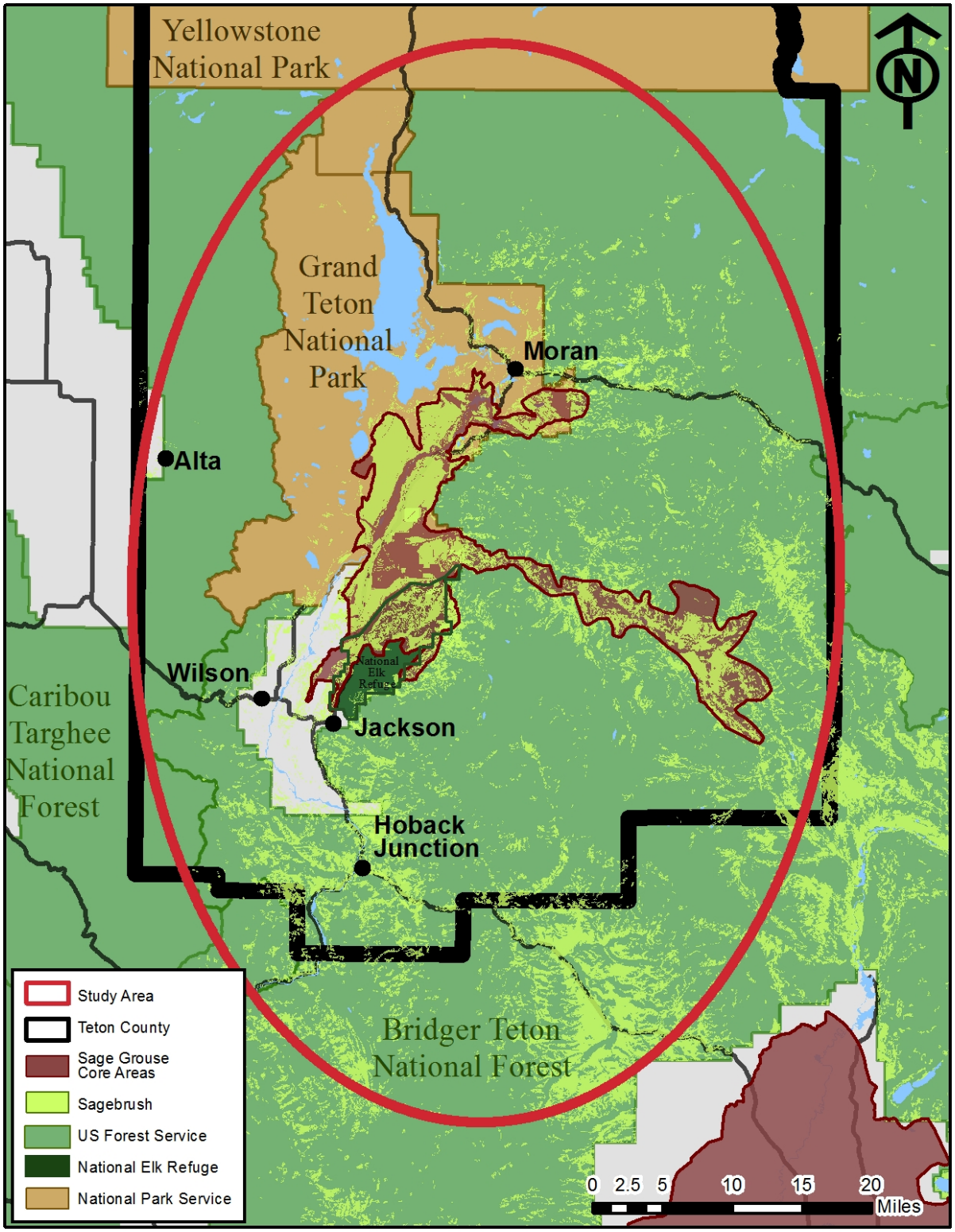
Federal, state and county agencies and associated conservation partnerships have highlighted the importance of wetlands over the years:

- WGFD — Snake River wetland conservation plan [11] highlights the importance of this system. In addition, the agency has designated several connected Aquatic Wildlife Conservation Areas [6, 12] in the JH area; one of only six Priority Wetland Habitats for the state, and two Bird Habitat Conservation Areas [11]. Furthermore, managers have outlined Crucial and Enhancement habitat, with accompanying plans for and investments in stream and fish restoration projects. Many other initiatives support wetland conservation and improvements.
- National Wild and Scenic River designation for over 407 miles (655 km) of stream mostly within BTNF but also within GTNP and YNP boundaries.

- National Wilderness Act protects extensive montane habitat in its most natural state, preventing exploitation of designated areas as well as providing restrictions on mechanical use and fire management options.
- Department of Environmental Quality (DEQ) assigns the top ranking of Class I waters to most of the streams in the region with the exception of Flat and Fish Creeks.
- Army Corps of Engineers (ACOE) built and now maintains the dam and the levees.
- Teton County Commissioners determine land use regulations, including type and density of development.
- Several NGOs also participate in water and wetland issues, including: Jackson Hole Conservation Alliance, Jackson Hole Wildlife Foundation, Snake River Fund, Trout Unlimited, Friends of Fish Creek, Wyoming Wetlands Association, Trumpeter Swan Association.

In sum, many agencies and partnerships have focused on different aspects of this complex system, indicating its high value ecologically and socially to the region, state, and nation.

[This chapter by Frances H. Clark]



Sagebrush cover and sage-grouse core areas within the Jackson Hole area.

Sagebrush and Sage-Dependent Species

Overview

The high-altitude sagebrush and grassland areas are one of the critical habitats in the Jackson Hole area. These shrublands define the Jackson Hole valley both in terms of its appearance — the open sea of sagebrush leading up to the surrounding mountains, the riot of wildflowers dotting hillsides and the valley floor in early summer — and its high abundance of wildlife. The sagebrush steppe habitat is dominated by mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) but includes many other species of shrubs, grasses, and forbs (non-grass herbs). It is valuable habitat for many species of birds and ungulates, including the vulnerable Greater Sage-Grouse (*Centrocercus urophasianus*; hereafter "sage-grouse"), and is a critical connector between other habitats. Because of its high altitude and relatively high precipitation, the sagebrush steppe ecosystem in our study area is ecologically distinct from sagebrush ecosystems in other parts of Wyoming, making it important both locally and regionally. We have chosen this habitat as a conservation target due to the combination of its ecological value and uniqueness and the various threats facing it and the species it supports.

Sagebrush and Sage-Grouse Across the West

Sagebrush ecosystems are widespread across the Western United States. There are several species of sagebrush, the most common being big sagebrush (*Artemisia tridentata*). Individual localities can be dominated by one of three different sub-species and can be quite different ecologically. This broad ecosystem that was once thought of as a vast wasteland is now recognized to be complex and biologically important.

Sagebrush ecosystems are critical habitat for a variety of wildlife species. Perhaps the most famous is the sage-grouse, which depends entirely on sagebrush ecosystems and is very sensitive to human disturbances. Sage-grouse are chicken-like birds that live primarily on the ground and are most known for their elaborate spring courtship displays on shared leks (display sites). In addition to sage-grouse, sagebrush ecosystems support many other bird species as well as iconic large mammals such as pronghorn and mule deer. These are but a few representative examples; all in all, more than 350 species rely on sagebrush ecosystems [94].

Although the "sagebrush sea" once covered some 204,000 mi^2 (529,000 km^2) across the West, sagebrush now exists in about 55% of its previous extent [95]. Various anthropogenic activities have greatly reduced the quantity and quality of sagebrush habitat. These include energy development, conversion to cropland, urban and exurban development, wildfires, invasion of exotic annual grasses, and conifer encroachment [96]. Dramatic increases in wildfire and the invasive cheatgrass (*Bromus tectorum*) are two processes that go hand-in-hand and together severely compromise the quality of sagebrush ecosystems as wildlife habitat. Cheatgrass aggressively out-competes native grasses and forbs early in the growing season, then dries out, becoming highly flammable and increasing the chance of wildfire [97]. Wildfires then burn sagebrush shrubs and native grasses, opening up more opportunity for cheatgrass to colonize [97]. Because these shrubs do not resprout, they can take anywhere from 20 to over 100 years to recover to pre-fire abundance [98]. Meantime the ongoing spread of cheatgrass means that the area is likely to burn again before the shrubs recover [99]. This process has converted millions of hectares of land from a sagebrush sea to a cheatgrass sea [100]. Eradicating cheatgrass once it has taken over is virtually impossible. Because few animals eat cheatgrass, the ability of the land to support wildlife and livestock is severely compromised once cheatgrass becomes abundant.

Multiple anthropogenic changes to sagebrush ecosystems over the last several decades have put sage-grouse under increasing threat [101]. Sage-grouse require large areas of land and a specific

combination of habitat features at specific spatial scales in order to successfully reproduce [102, 103], making them sensitive to any changes in their habitat. Sage-grouse have been considered for listing under the Endangered Species Act but are not currently listed; keeping them off the Endangered Species List is a high priority for many land managers around the West and has motivated widespread efforts to arrest the bird's population declines.

Sagebrush and Sage-grouse in the Jackson Hole Area

Geography

Most of the sagebrush in Jackson Hole is located in the valley bottoms of Grand Teton National Park, such as the extensive Antelope Flats. However, mixed shrub- and grassland areas can be found on the exposed (mostly south-facing) slopes of many of the hills and buttes around the valleys. On the valley floor, there are some pockets of intact native grassland — largely on the National Elk Refuge — and many areas that were converted to agricultural grasslands by settlers in the valley. Pasture grasses are mostly non-native smooth brome (*Bromus inermis*) and crested wheatgrass (*Agropyron cristatum*). Some of these pastures are used by livestock today, while others are within the National Elk Refuge and Grand Teton National Park and are not used by livestock. Other areas in the valley that were once sagebrush have been developed for residential and commercial use.

Ecological importance

The high-altitude, cold-weather mountain big sagebrush (a subspecies of sagebrush) habitat in Jackson Hole is one of only a few areas of its kind in the Western US [104]. Other sagebrush steppe systems in Wyoming and most of the West are found at lower elevations with a much more arid climate. The Jackson Hole area sagebrush includes both “foothill shrublands” and “sagebrush shrublands” habitat types, as designated by the State Wildlife Action Plan [6], which are two of the eight priority habitats in the state.

Because of its high elevation and precipitation, the sagebrush steppe in Jackson Hole can include patches of more montane shrub species such as antelope bitterbrush (*Purshia tridentata*) and snowberry (*Symphoricarpos oreophilus*). Areas to the west of the Snake River, such as Lupine Meadows in GTNP, can be dominated by low sagebrush (*Artemisia arbuscula*). In the spring and summer, many distinct flowers can be found blooming in the sagebrush ecosystem. These include popular species such as shooting stars, larkspur, fritillary, phlox, and buttercups, as well as the more visible arrowleaf balsamroot and lupine. These spring and summer blooms attract diverse pollinators including hummingbirds and bumblebees.

The sagebrush is important habitat for many birds, small mammals, ungulates, and carnivores in the Jackson Hole area. Relatively common bird species that rely on sagebrush and grasslands include Brewer’s, Vesper and Savannah Sparrows; Western Meadowlark, Mountain Bluebird, and Green-tailed Towhee, as well as raptors such as Northern Harriers, Short-eared owls, and Prairie Falcons. Uinta ground squirrels and least chipmunks provide abundant food for coyotes, Red-tailed Hawks, and other raptors. Several Species of Greatest Conservation Need use this area, including sage-grouse (see below), Brewer’s Sparrow and more rarely, Sage Thrasher. Long-billed Curlews also breed in the grassland areas, particularly on the National Elk Refuge and Kelly Hayfields in GTNP. Although this species is widespread in the western US, it has declined considerably, and maintaining existing populations of curlews has become a priority.

Ungulates that use this habitat include pronghorn, moose, bison, elk, and mule deer. Bison and elk make heavy use of the grassier areas, including old fields. Pronghorn summer in the sagebrush flats of GTNP and move more than 100 miles (161 km) south for winter in the famous Path of the Pronghorn migration. Moose rely heavily on antelope bitterbrush and other shrubs in the fall as they put on fat reserves for the winter. Mule deer depend on the mixed grass and shrub hillslopes ringing the valley for their winter habitat. Because these ungulates use the sagebrush and grassland areas heavily, predators such as wolves also use these areas.

The Jackson Hole area is home to a small but important population of sage-grouse. This population is genetically distinct from other sage-grouse populations in the region, probably because of its relative isolation and high-altitude habitat [105]. The majority of the population is found in GTNP, with some presence on the National Elk Refuge and two leks in the Gros Ventre River Valley [106]. Unlike grouse elsewhere in Wyoming, these grouse do not make long-distance migrations [107].

Current Status of Sagebrush and Sage-grouse in Jackson Hole

The human footprint in the Jackson Hole area has had a substantial impact on the sagebrush habitat. Most notably, many areas that were once sagebrush have been converted to residential, commercial, and agricultural land-uses. Historically, the majority of the valley, as far south as Melody Ranch and the Squaw Creek flats, as well the Jackson Hole airport and neighborhoods west of the airport, were covered in sagebrush and used by sage-grouse (B. Bedrosian, personal communication). It is estimated that greater than 45% of historic sage-grouse habitat has been lost (B. Bedrosian, personal communication).

While development is effectively irreversible, old agricultural fields can be restored to sagebrush habitat, albeit with a large amount of effort. For example, in the Kelly Hayfields area east of Blacktail Butte, GTNP is working extensively to restore a sagebrush community in former pastures. Restoration is a long and complex process since introduced pasture grasses and invasive plant species compete aggressively with slower-growing native grasses, forbs and shrubs; however, park ecologists anticipate that they will successfully bring a functioning sagebrush community back to the restored areas within the next 30 years (K. McCloskey, personal communication). In the summer of 2016, sage-grouse were seen using a site where restoration was initiated in 2008, lending significant optimism that restoration is on track to provide functional habitat for sagebrush-dependent species in the coming years. There are plans to extend sagebrush restoration efforts to several other areas within GTNP, and the same restoration methods could be applied to other areas in the valley in the future.

Fire is another factor that has effectively removed sagebrush habitat for sage-obligate species such as sage-grouse, at least temporarily. A fire in 2003 burned a significant portion of sage-grouse winter habitat around Blacktail Butte, and in total an estimated 13.5% of available sagebrush in the Upper Snake River Sage-Grouse Conservation Area has burned within the last 30 years [106]. Full recovery from fire can take anywhere from 20 to 100 years for sagebrush communities in general [98], but recovery may be on the faster end of the spectrum (15-30 years) in the Jackson Hole area (K. McCloskey, personal communication), which is more resilient to disturbances than many other sagebrush systems. Nevertheless, if significant areas are burned or fires occur frequently, they can effectively reduce sagebrush habitat for years to come.

Where sagebrush has not been impacted by development, agriculture, or fire, it is generally thought to be in fair to good condition, although formal habitat quality assessments have not been conducted. The relatively cool and wet climate of Jackson Hole has helped to limit many invasive plant species that thrive in warmer conditions, including cheatgrass [108]. However, invasive species do have some significant presence; the National Elk Refuge, for example, estimates that invasive plants cover 1,100 acres (445 ha) of the refuge (out of a total of 24,565 acres, or 9.941 ha)[8]. At present some of the most common designated noxious weeds are musk thistle (*Carduus nutans*) and spotted knapweed (*Centaurea maculosa*), but the pasture grass crested wheatgrass is also acting as an invasive species in some areas. Cheatgrass, once rare, expanded significantly on the NER during recent drought years and is now estimated to occupy 250 acres (101 ha) of the Refuge [8].

Conifer encroachment into sagebrush — a problem in many other high-elevation areas of the West — is only a problem in the area between the Upper Gros Ventre and Upper Green River (K. Murphy, personal communication). Conifer encroachment can dramatically reduce habitat quality for

sage-grouse and other sagebrush-dependent wildlife. However, it can be effectively dealt with by mechanically removing conifers, something the BTNF is considering doing in the affected area.

Various historic data sources indicate that sage-grouse used to be much more common in the Jackson Hole area than they are today; one source reports about 500 grouse in total, with 200 males on leks (courtship display sites where they can most easily be counted) every year between 1948-1951 [109]. This number is lower today, with total males on leks in the past two decades ranging from 47 to 165 [106]. There are some challenges to accurately estimating sage-grouse populations, and the most widely-accepted metric is mean males per lek. According to this metric, sage-grouse numbers declined substantially in the late 1990s and have remained somewhat reduced since then [106]. In general, local experts agree that this population of sage-grouse has declined and is at high risk of further decline in the future [106].

The cause of past declines in sage-grouse numbers is not known but is likely a combination of factors. Winter forage availability is a limiting factor for these birds, given the deep snow in Jackson Hole that typically buries all but the tallest shrubs, but it is not likely that snow itself has become any deeper over time. A more likely cause of sage-grouse decline is changes in the availability of high-quality habitat, which may put particular stress on the birds in the winter when food is limited. Increasing numbers of vehicles along roads within sage-grouse habitat and an increase in air traffic at the Jackson Hole Airport may also be impacting grouse, which are highly sensitive to noise [106]. Vehicles and airplanes can also hit birds — a source of direct mortality. All of these factors have likely combined to impact sage-grouse numbers.

Threats to sagebrush habitat, sage-grouse and sage-dependent species

The threats to the sagebrush habitat and sage-grouse are similar. The comprehensive Upper Snake River Basin Sage-Grouse Local Working Group Conservation Plan (2014) identified key threats to sage-grouse in their focal area; our list is adapted from theirs but tailored to the slightly different geography of this report.

- **Fire — High, extensive**: Fires in the GYE are expected to become more frequent over the next century as the climate warms, leaving fuels drier and more likely to burn [110]. Since sagebrush systems take many years to recover fully from fire, any increase in fire frequency could turn large areas into non-sagebrush cover for several decades. The impact of fire is reversible over time, if the area does not re-burn and if fire does not substantially advance the spread of cheatgrass or other invasive plants.
- **Invasive plants — High, extensive**: As the climate warms, future temperature regimes are expected to accelerate the invasion of cheatgrass and other invasive plants in this region [108, 111]. Cheatgrass poses a particular threat to the ecosystem because of its ability to promote fire and potential to dramatically transform entire landscapes from native shrub and grass dominance to cheatgrass dominance. Invasion by cheatgrass could effectively eliminate sagebrush habitat over large areas with little scope to reverse it.
- **Increased air and vehicle traffic — High, local** (for sage-grouse): The rising numbers of vehicles on roads and flights in and out of the Jackson Hole Airport will likely result in more birds being hit by vehicles and planes. The associated increase in noise and, potentially, active disturbance (to push birds out of airplane flight paths) may cause birds to abandon leks and breeding areas near the airport, which is in the core of remaining sage-grouse habitat. Although the Jackson Hole Airport has developed a Wildlife Hazard Management Plan to reduce the negative effects of the airport on grouse, it may be challenging to fully compensate for an increase in number of airplanes or potential expansion of the airport in the future.
- **Other infrastructure development — Moderate, local:** Other infrastructure development presents a high risk to sage-grouse but a moderate risk to the sagebrush ecosystem as a whole. Construction of new pathways, trails, or other infrastructure development in intact sagebrush provides opportunities for cheatgrass to establish and spread. For sage-grouse in particular, any increase in human presence or infrastructure can disturb nests and can cause an increase in predators such as foxes and ravens. Although each individual development may have a small footprint, these can add up to have substantial cumulative impacts on the habitat and its associated wildlife. For sage-grouse, these effects are generally difficult to mitigate or reverse.
- **Residential and commercial development — Moderate:** Although much of the sagebrush ecosystem is protected, patches of private land are at risk for development. Such direct habitat loss may be somewhat mitigated by restoration of sagebrush habitat (on site or elsewhere), but restoration is a long and costly process. Agricultural land that is dominated by pasture grasses but is, nevertheless, important habitat and movement corridors for many wildlife species, is at high risk of development.
- **Grazing — Moderate:** Livestock activity is limited to a few areas within our study area. A somewhat unique potential threat to this habitat type in the Jackson Hole area is the effects of large numbers of wild ungulates, particularly bison, on sagebrush and habitat quality for other species such as sage-grouse. Bison are primarily grazers and, similar to cattle, have the capacity to substantially reduce grass and forb cover, leading to a reduction in food (both plants and insects) and protective cover available to other species. However, managing bison numbers and movements is much more complicated than managing cattle numbers and pasture access. In

several years in the past when bison numbers in GTNP were well above the objectives for that herd, biologists observed very low grass cover in sage-grouse breeding habitat (B. Bedrosian, personal communication; K. McCloskey, personal communication). The bison herd has been at objective over the last several years and grazing impacts have reduced. Nevertheless, understanding and managing the tradeoffs among multiple conservation priorities (e.g. bison versus sage-grouse) is a challenge for this region.

- **Conifer encroachment — Low, local:** Conifer encroachment is currently a problem in a limited area and is not expected to become a more widespread problem.

Opportunities & Multi-Partner Cooperation

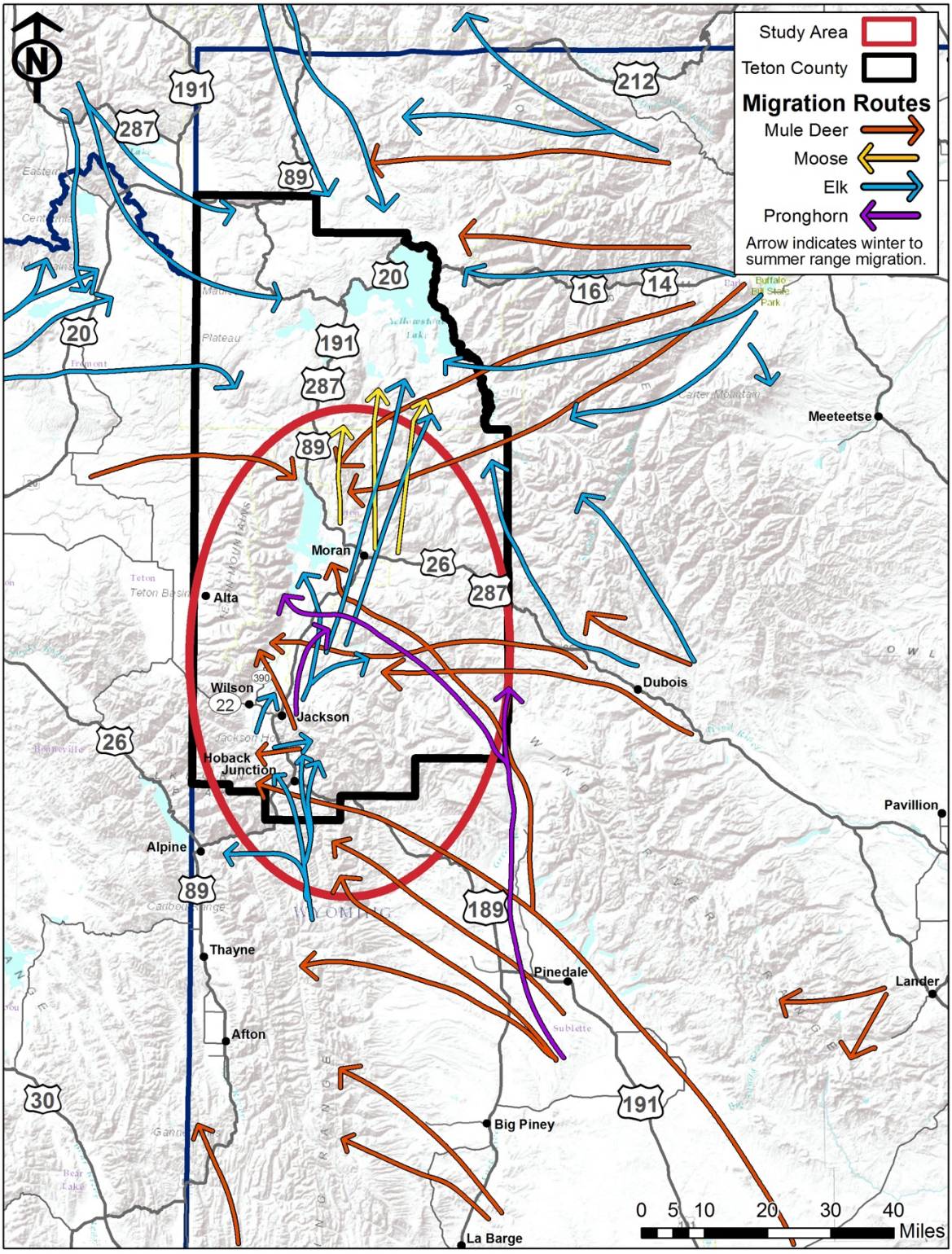
Although the threat of cheatgrass is a concern, the sagebrush community in the Jackson Hole area is considered to be one of the most cheatgrass-resistant in the entire western US; nevertheless, cheatgrass is present and increasing in the valley, and only with active management will it be possible to escape the cheatgrass-fire cycle. This underscores the importance of prioritizing management actions that keep the Jackson Hole sagebrush and grassland communities intact, including efforts to control cheatgrass and other invasive species and to restore habitat where possible.

For sage-grouse, the small size of the population makes it vulnerable. It is clear that thoughtful, forward-looking management will be necessary to ensure that this species remains in Jackson Hole. However, because this area is generally more protected and resilient to disturbances than sage-grouse habitat elsewhere in the West, there is good reason to be optimistic that Jackson Hole's unique population of sage-grouse can persist. The Upper Snake River Basin Sage-Grouse Local Working Group is an active group that includes members of the key agencies and NGOs and is doing much to improve knowledge and management of sage-grouse.

Information Gaps

- There is great need to identify more effective ways to control cheatgrass (for which research is ongoing at a national scale) and to test the effectiveness of different measures locally.
- There is need to continue studying and improving practices for restoring sagebrush, especially practices that can work over large scales.

[This chapter by Corinna Riginos]



Migration paths of deer, elk, moose and pronghorn antelope in and out of the Jackson Hole area.

Ungulate Migration

Overview

Large mammal migrations make up some of the most stunning and iconic images of wildlife in the world. The visage of large groups of ungulates struggling to travel great distances and facing numerous obstacles along the way captures the imagination of the general public and scientists alike. The Greater Yellowstone Ecosystem and the Jackson Hole area are home to some of the most intact large ungulate migrations in the world. Animals do not just migrate out of preference; migration is an essential part of their lives. We selected ungulate migrations as one of our conservation targets because the number, length, and relative intactness of migrations found in the Jackson Hole area are rare on a global scale; because they are important to sustaining populations of ungulates that are iconic and valuable in this area; and because migrations are highly vulnerable to anthropogenic habitat modifications.

Ungulate Migrations Around the World

Ungulate migrations were once a common phenomenon around the world. Some are very familiar popular images: the millions of bison that once moved across the Great Plains of North America or the hordes of wildebeest that still migrate in the Serengeti grasslands of East Africa. Ungulate migrations have historically occurred in many different places, on nearly every continent, and have involved many different species of antelope, deer, and even elephants [112]. The term “migration” indicates regular seasonal movements, and is different from “nomadism” in which animals move but in no fixed pattern. Migration routes are usually consistent from year to year in both space and time.

There are several reasons why ungulates migrate, and the process of migration is essential for keeping migratory herds as large as they are. Migration is thought to allow herds to be as much as ten times larger than they would be without migration [113]. The advantages of migration fall into two broad categories: (1) it helps ungulates to reduce their exposure to predators, and (2) it allows them to to move seasonally to where food is most abundant or nutritious for that season [112]. Many predators are tied to dens and territories which mean that predators cannot follow migratory herbivores all year; historically this has allowed some benefit to migratory ungulate populations over resident ones. More recently in the GYE, predation risk has dropped for non-migratory ungulates because they spend the whole year near human settlements, which predators avoid. While the role of predator-avoidance in driving migration is somewhat variable, the nutritional benefits of migration are more universal. Migratory animals reap the benefits of being able to move to where the best food is available. In tropical climates, ungulates typically follow the rains and green grass or migrate to permanent water sources in dry times. In cold climates, such as the GYE, migratory ungulates move down in elevation to escape the deep snow that covers their food in winter, then return to those high elevation areas to capitalize on the high quality food found there in summer.

In many places, ungulate migrations no longer occur, and ungulate numbers have declined substantially as a consequence. The main causes of their declines, globally, include overhunting, habitat loss, and anthropogenic habitat barriers (e.g. development, fences, roads) [114–116]. Large ungulate migration as a phenomenon is imperiled in most parts of the world [114–116].

Ungulate Migrations in the Jackson Hole Area

The GYE harbors one of the most significant remaining networks of ungulate migrations in the world, and the Jackson Hole area is a hub of migrations within the GYE. Species that migrate in and out of this area include mule deer, elk, moose, pronghorn, bison and bighorn sheep. These migratory

ungulate species depend on migration corridors that traverse many types of land ownership, including many private lands as well as public lands in Yellowstone and Grand Teton National Parks, National Forest lands, the National Elk Refuge (U.S. Fish and Wildlife Service), Bureau of Land Management lands, and State and Wyoming Game and Fish Commission lands.Two of the most remarkably long terrestrial migrations in the world — and longest known migrations for their respective species — start in the Jackson Hole area: the Path of the Pronghorn from the Green River Basin to Grand Teton National Park (up to 160 mi or 258 km) [117], and the Red Desert to Hoback mule deer migration from near Rock Springs to southern Teton County (150 mi or 241 km) [118]. Below we list the major migration corridors into and out of Teton County.

Mule deer:

- The deer that winter near Rock Springs travel all along the western flanks of the Wind River range to reach their summer range in the Hoback area [118].
- Deer that winter south of Pinedale migrate north into the Hoback area for summer. Some of these deer even travel as far as GTNP (data from Hall Sawyer).
- Deer that winter north of Evanston migrate into the Wyoming Range, Salt Range and tributaries of the Snake River near Alpine and the confluence of the Snake and Hoback Rivers (Gary Fralick, personal communication).
- Deer that summer in the Gros Ventre and GTNP areas are now being found to migrate east, through the Teton Wilderness, to Dubois and Cody as well as west into Idaho for the winter (Sarah Dewey, personal communication).
- Deer that summer in the southern part of GTNP (e.g. Moose, Granite Canyon) and the Munger Mountain area migrate into the southern Jackson Hole valley where they winter on the hills and drainages around Jackson and the Game Creek area.

Pronghorn:

- Pronghorn migrate from their summer range in the sagebrush flats of GTNP southeast through the Gros Ventre range and then south past Pinedale. A portion of this herd continues further south into the heart of the Green River Basin [117].

Elk:

- Elk that congregate on the National Elk Refuge and state feedgrounds in the Gros Ventre drainage during the winter migrate north to the Teton Wilderness, Yellowstone National Park, Grand Teton National Park, and the Gros Ventre Range for the summer [119]. Some of these animals make a much shorter migration to the areas between Wilson and Moose.
- Elk that winter on state feedgrounds south of Jackson migrate to the Snake River Range, Salt Range and Gros Ventre range for the summer [120].
- Elk that winter on feedgrounds south of the Hoback Junction migrate north to the Hoback Junction and Hoback and Snake River canyon areas during summer.

Bighorn sheep:

- Bighorn sheep used to migrate between the high-elevation zone of the Tetons and the surrounding valleys, but this migration route has been cut off for more than 70 years due to early residential development, ranches, fences, and roads in Jackson Hole [121]. The Teton bighorn sheep herd is an example of a local ungulate population that has lost its migration routes due to human development and now persists at very low numbers [122].
- The Jackson Bighorn Sheep Herd is larger, and remains migratory, moving between high elevation summer ranges in the Gros Ventre Mountain Range and low elevation winter ranges on the National Elk Refuge (Miller Butte), Gros Ventre drainage, lower Curtis Canyon, Flat Creek, and the Camp Creek area east of Hoback Junction.

Moose:

- Major moose winter ranges for the Jackson Moose Herd are located in the Buffalo Valley, along the Snake River, Gros Ventre drainage, and some smaller areas in and around the towns of Jackson and Wilson. Little is known about the seasonal movements of the moose that winter in the Gros Ventre drainage and around the towns of Wilson and Jackson. Farther north, moose that winter in the Buffalo Valley migrate north into the Teton Wilderness for the summer [123, 124].
- The Sublette Moose Herd is located to the south of Jackson. Moose in the northern portion of this herd spend the winter along the Snake River and smaller drainages such as Fall Creek.
- See Moose chapter of this report for more on the status and threats to moose in the Jackson Hole area.

Bison:

- The majority of the Jackson Bison Herd winters on the National Elk Refuge, although some animals spend the winter in Grand Teton National Park and areas around Spread Creek, Elk Ranch, and Shadow Mountain. Bison migrate to Grand Teton National Park for the summer.

Conserving ungulate migration routes is vital to ungulate populations for at least two reasons. First, they are critical paths connecting winter and summer habitat. Second, as new research on ungulate migrations in western Wyoming and the GYE is showing, migration routes are in fact important habitat themselves. Whereas ecologists used to think of migration routes as transportation corridors, they are now recognizing that migration routes serve a much broader ecological role.

Our emerging appreciation for the importance of migration routes as habitat features relates to two new concepts in migration ecology: green-wave surfing and stopover ecology. The idea of green-wave surfing is that ungulates move from lower elevation winter habitat to higher elevation summer habitat in pace with the timing of spring vegetation greenup across the landscape [125]. This, in theory, enables migrating ungulates to eat the most nutritious, fresh plant material as they migrate — hence they are “surfing the green wave.” There has been some debate about whether all migratory ungulate species and populations do or do not exhibit this behavior, but recent evidence shows that mule deer in western Wyoming do track the green wave relatively closely [126]. Other ungulates in Wyoming and elsewhere surf the green wave with varying success [127]. Surfing the green wave is likely vital for helping ungulates regain body fat as they move out of the lean winter and into the nutritionally demanding lactation phase that many females are entering.

The related concept of stopover ecology is that ungulates stop for several days to weeks at certain key locations along their migration routes. These stopover locations may have especially good foraging opportunities for animals following the spring greenup and are important habitat patches used only during migration [128, 129]. In fact, deer spend approximately 95% of their migration time in stopover areas [128, 129].

Conserving migration routes and habitat connectivity is also a critical component of maintaining ungulate populations’ resilience to other disturbances. Animals that can move and migrate — and even change their movement and migration patterns over time — stand a far better chance of surviving in the face of threats such as a warming climate, habitat degradation, energy development, and diseases such as chronic wasting disease (deer and elk) and pneumonia (bighorn sheep). There is little that can be done to stop the spread of chronic wasting disease, which has not yet been detected in the Jackson Hole area but is expected to impact ungulates in this area in the near future; however, enabling animals to move, to exchange genes that may confer resistance to disease, and continue to reap the benefits of a migratory lifestyle will help to buffer their populations against the worst impacts of this disease. Similarly, maintaining habitat connectivity will help animals to adapt to a warming climate, unpredictable weather events, and changes in their habitat quality.

Current Status of Ungulate Migrations in the Jackson Hole Area

In the Jackson Hole area, as in the rest of the world, migratory animals can face a variety of obstacles and habitat alterations that affect their ability to migrate. Anthropogenic changes to the landscape, such as housing and commercial development, gas fields, fences, and roads, can broadly be arrayed along a gradient of permeability to migrating ungulates [130]. At low to moderate levels of development, these changes may have little to no impact on animal migrations; as the level of these developments increases, ungulates may change their migration behavior, e.g. speeding up to move through developed areas more rapidly; and at very high level of development, animals may no longer be able to cross through developed areas. Roads and fences are a particular concern for migrating ungulates because they can present a substantial to complete barrier effect, depending on the traffic volume and type of fence, respectively [131]. Anthropogenic habitat modifications can also affect ungulate migrations in less obvious ways; for example, where humans deliberately or inadvertently provide food for ungulates, it can change their migration patterns.

One concern about impeded and altered migrations is that they may be difficult to restore. Knowledge of migration routes is passed from cow to calf or doe to fawn, and animals show a high fidelity to their learned migration routes throughout their lives. If a migration route were cut off by anthropogenic barriers and subsequently those barriers were removed, it is unclear whether, or over what time scale, animals would successfully rediscover their historic migration routes.

WGFD is embarking on a multi-year effort, with partners from the Wyoming Migration Initiative, GTNP, NER, and others, to designate high-use migration corridors and stopover areas as “vital habitat” for deer, elk, and moose in western Wyoming. This designation gives these areas similar priority as crucial winter ranges under state management. WGFD recommends no loss of habitat function within designated areas. Although this is a positive step for protecting migration routes, it is also important to recognize that it still leaves many migration areas (with lower, but still significant, use) with no official designation or protection.

Ungulate migration patterns and corridors in the Jackson Hole area range from completely impeded to relatively intact and vary substantially from species to species. Of course, it is difficult to know what migrations looked like before permanent human settlement in the area, and it is likely that what we today consider to be the more intact migration routes are substantially altered relative to pre-settlement times.

Bighorn Sheep

Migrations of bighorn sheep are some of the most altered in the Jackson Hole area. As recently as 70 years ago, bighorn sheep from the Teton Herd migrated from their summer range in the alpine zone of the Teton Range to the surrounding valleys, including Jackson Hole, in winter [121]. Beginning about 100 years ago, human settlement and agriculture in the valleys began to cut sheep off from their winter ranges. Fences, roads, residential development, and competition with domestic sheep all contributed to the collapse of this migration [121].

Remarkably, a population of bighorn sheep still lives in the Tetons as non-migratory animals, wintering in what was historically their summer range [122]. These tenacious animals eke out a living in the very high, wind-swept ridges of the Tetons through the winter. Then, remarkably, they trek down to the mid-elevation zone in the spring to follow the spring greenup back up the mountain — essentially catching the second half of what used to be their migration route. The adaptability of these animals is remarkable; however, it is very likely that this population would be larger and more resilient to disturbances if it could migrate to its historic winter range rather than endure the extremely harsh winter conditions of the Tetons [122]. Further, although this population of bighorn sheep lives entirely within GTNP, it is still impacted by human activities. Sheep avoid areas used by backcountry skiers and snowboarders, even when those areas are otherwise good habitat [132]. This has resulted in as much as

a 30% reduction in habitat that is effectively available to some of these sheep that are already living a marginal existence. GTNP is working to reduce some of these impacts of backcountry recreation by testing the effectiveness of winter closures in important bighorn sheep habitat.

In contrast, the neighboring Jackson Herd of bighorn sheep continues to migrate between low elevation winter ranges on Miller Butte on the National Elk Refuge and on Bridger-Teton National Forest at Curtis Canyon, Flat Creek, lower Gros Ventre drainage, and Camp Creek areas. This herd is much larger (approximately 400-500 sheep) and more resilient than the Teton Herd (80-100 sheep), likely due to its ability to migrate along various routes to different low elevation winter ranges (A. Courtemanch, personal communication).

Elk

Elk migrations in western Wyoming and the JH area have been truncated for over 100 years. For example, a variety of historical sources indicate that the Jackson elk herd that currently winters in the National Elk Refuge used to migrate much farther south, through the Gros Ventre drainage and Hoback Canyon and into the Green River Basin and possibly even the Red Desert [133]. Migrations such as these may have initially been truncated due to human settlement in elk winter range, conversion of winter ranges to hayfields, and unregulated commercial hunting, which caused migrations out of Jackson Hole to dwindle.

As these long-distance migrations became less possible, shorter distance migrants that wintered in Jackson Hole started to receive supplemental winter feeding, which began on today's National Elk Refuge in 1912 and was then duplicated at state-operated elk feedgrounds. This practice was established for several reasons. First, and foremost, winter feeding of elk helps to prevent elk from mixing with cattle, which are ranched in the valley bottoms that were once elk winter habitat; this practice is done primarily to prevent the spread of diseases such as brucellosis from elk to cattle, and to prevent elk from raiding stored hay for livestock. Secondarily, winter feeding helps prevent elk from starving during the winter, especially when they are no longer able to access their former winter range.

The establishment of winter elk feedgrounds has been effective at short-stopping elk migrations; fed elk currently migrate on average 12 miles (19.2 km) fewer than unfed elk [120], and it is likely that unfed elk once migrated even further. However, it seems that the act of feeding elk has altered their migration patterns in other fundamental ways. Fed elk are less responsive than unfed elk to typical spring migration cues such as greenup and more responsive to early fall migration cues such as cold temperatures [120]. In spring, this means that fed elk arrive on summer grounds later than their unfed counterparts and miss some of the nutritional benefits of the spring migration. In the fall, these same fed elk abandon the higher quality summer feeding grounds earlier than their unfed counterparts. These differences in behavior suggest that, should elk feeding be eliminated or reduced in the future, formerly fed elk may lack the cultural knowledge to take advantage of the nutritional benefits of the migration process.

More recent anthropogenic habitat changes appear to be further altering the migration patterns of the Jackson elk herd, as well as other elk herds in the GYE. Between 1978 and 2012, the proportion of "long-distance migrants" versus "short-distance migrants" in the Jackson herd decreased substantially, from an estimated 99% to 59% long-distance migrants [119]. Long-distance migrants follow migration routes from the National Elk Refuge, where they winter, to summer ranges in Yellowstone National Park, the Teton Wilderness, Grand Teton National Park, and the Gros Ventre mountains or Range. Short-distance migrants, in contrast, travel only 8-10 miles to summer on mostly private lands (largely agricultural and housing developments) between Moose and Wilson. The reason for this change is not entirely known but appears to be linked to higher reproductive success among the short-distance migrants [119]. This may be happening for several reasons, including (1) differences in predation pressure, (2) differences in food availability and quality, and (3) differences in elk vulnerability to harvest.

Short-distance migrants are exposed to fewer predators than long-distance migrants. Whereas wolf and grizzly numbers have increased significantly in the parks and wilderness areas in the GYE over the last several decades, these predators are relatively less abundant in areas of human habitation and agriculture, which they avoid. Thus, the combination of human development and an increase in carnivore abundance over the broader landscape may be driving changes in elk migration patterns. Additionally or alternatively, changing climate may be favoring resident and short-distance migrants over long-distance migrants. In the eastern GYE, declines in the reproductive success of long-distance migratory elk were tied to an increase in the rate of spring green-up [134]; faster spring green-up and shorter duration of spring may reduce the nutritional benefits of migration, favoring animals that do not migrate or migrate only a short distance. Furthermore, elk that spend the summer in and near irrigated agricultural fields and residential landscaping have a consistently higher quality food source, than long-distance migrants. Finally, short-distance migrants spend the majority of the summer and fall on private lands, making them less vulnerable to hunter harvest than elk on public lands. All of these factors have potentially combined to increase the productivity of short-distance migrants and have led to the recent decline in long-distance migrations in the Jackson Elk Herd.

Similar changes have likely occurred to some extent in the Fall Creek Elk Herd to the south of Jackson. However, elk that migrate long distances in the Fall Creek Elk Herd to the Snake River Range, Wyoming Range, and Gros Ventre Range are exposed to comparatively fewer large carnivores than elk from the Jackson Herd. Nevertheless, a trend toward more short-distance migrants that summer on private lands versus long-distance migrants is undoubtedly occurring in the Fall Creek Herd (A. Courtemanch, personal communication).

Because elk migrations stop short of historic winter range, elk have fewer major roads to cross than migrating deer and pronghorn. Nevertheless, roads do present an obstacle that elk face in parts of the Jackson Hole area. Elk must cross some of Wyoming's busiest two-lane roads as they move across Highway 22, as they cross Highway 89 north of Jackson on their way into and out of the NER, and on portions of Highways 89 and 191 south of Jackson and in the Hoback and Snake River canyons. Between 2011 and 2015, an average of 37 elk were hit each year on Teton County's roads outside of GTNP (C. Riginos and WYDOT, unpublished data), with more collisions inside GTNP.

Pronghorn

In contrast to elk and bighorn sheep migrations, the single major pronghorn migration in Teton County, the famous Path of the Pronghorn, is relatively intact. Archaeological evidence indicates that pronghorn have been migrating from their winter range south of Pinedale through the narrow Trapper's Point — a band of sagebrush sandwiched between a river and riparian area just West of Pinedale — for some ~6,000 years [115]. From there, these animals move north through another narrow band of sagebrush into the Gros Ventre Mountains, and northwest through several other narrow bottlenecks to reach GTNP [115, 117]. The portion of this migration corridor that is within GTNP and BTNF is officially protected and is the first migration corridor in the United States to gain federal protection. The remainder of the migration corridor passes through private and BLM land and is more imperiled.

Before 2012, the Trapper's Point area presented a significant bottleneck and problem to this group of migratory pronghorn. Trapper's Point is a natural habitat bottleneck along their migration corridor, but this bottleneck was made even narrower by housing developments, and even harder to traverse because it is bisected by the busy Highway 191 [117, 135]. In 2012, the Wyoming Department of Transportation completed construction of two highway overpasses and six highway underpasses, accompanied by 12.4 mi(20 km) of fencing, in the Trapper's Point area. This has provided a safe way for pronghorn and mule deer to cross Highway 191. Over the first three years since crossing structures were installed, more than 19,000 safe pronghorn crossings were observed (largely on overpasses) and collisions between vehicles and pronghorn dropped from an average of 12 per year to zero per year

[136]. The dramatically successful crossing structures at Trapper's Point have effectively removed the most significant barrier to the Path of the Pronghorn migration.

However, this migration still faces some serious challenges. Energy development in their winter range in the Pinedale Anticline region has substantially reduced the habitat available to this herd. Between 2005 and 2009, high-use pronghorn habitat in the Jonah and Pinedale Anticline Project Area gas fields south of Pinedale declined by 82% [137], which is likely to have a negative long-term impact on this pronghorn population. Future energy development in this area could further threaten the Path of the Pronghorn migration.

Fences pose another serious challenge for pronghorn. As of 2004, the pronghorn migrating from the Upper Green to GTNP had to traverse 105 different fences [115]. Pronghorn are reluctant to jump over fences so typically pass under the lowest wire [138]. When these wires are low and barbed, or if it is a woven-mesh (sheep) fence, it can be difficult or impossible for pronghorn to pass under the fence. Animals that attempt to jump over taller wire fences risk entanglement in wires and likely injury or death; this risk is particularly high for juvenile animals [138]. Replacing traditional fencing with "wildlife-friendlier fencing," which involves smooth top and bottom wires and specific guidelines about wire heights, can help alleviate the problem that fencing poses to migrating ungulates such as pronghorn [139]. However, private landowners cannot be mandated to change their fencing, and sheep ranchers prefer to use the woven-mesh fencing that is particularly challenging for pronghorn and deer. For a portion of the pronghorn that migrate from the Upper Green to GTNP, the ~20 m (~30 km) stretch of US 191 north of Farson that is lined with non-wildlife-friendly fencing appears to be a complete barrier, whereas pronghorn cross the same highway further north where the fencing changes to wildlife-friendlier fencing [135]. The challenge of unfriendly roadside fencing compounds the challenges that pronghorn already face in crossing this busy highway.

Mule Deer

There are multiple mule deer migrations into and out of the Jackson Hole area, and these face a variety of levels of impediment and threat. The major threats to these migration routes are various forms of development: roads, residential, and energy.

Deer that summer in the Teton Wilderness, northern GTNP, and the Gros Ventre, and winter to the east and northeast (e.g. near Cody and Dubois) face relatively few obstacles. Much of their summer and migration habitat is protected. These deer face some challenges as they move into their winter range, where there is more development. Agriculture around the towns of Cody and Dubois, for example, may already have altered deer winter habitat use and migration patterns. In the Dubois area, Highway 26 bisects deer winter range and is a significant source of mortality for migrating and wintering mule deer [140]. Where animals are frequently hit by vehicles on roads, it is typically a sign that these roads are challenging for animals to cross.

The portion of the Sublette Mule Deer Herd that winters in the Jackson Hole valley is significantly imperiled by development. These deer summer in protected areas in GTNP (e.g. Moose, Granite, and Death Canyon areas) and Munger Mountain, but their migration routes and winter habitats bring them into heavily developed areas around Jackson (e.g. the buttes in town and to the east of Highway 89 / 191 south) [141]. Although parts of their winter habitat are somewhat protected as Crucial Winter Range, other parts are not protected and are separated from the protected areas by major roadways. For example, deer cross Highway 89 frequently from East Gros Ventre Butte, High School Butte, and the hills east of Rafter J, likely to access riparian habitat and thermal cover. These same roads, as well as other obstacles, cut across these deer migration routes. New GPS collar data from GTNP show that another portion of deer that summer in Moose migrate across north Highway 89 (Cache Street) and along the southern edge of the NER to winter in the Cache Creek drainage (S. Dewey, personal communication). Along these routes, deer pass through residential and commercial

developments, over heavily-trafficked roads, and across a fast-moving river where their access is constrained by steep levees. More than 100 deer per year get hit by vehicles in a few concentrated areas along Highway 89/191 (Broadway/Cache), indicating that this road in particular is a major barrier to deer habitat connectivity.

Deer from the Sublette Herd that migrate into the southern Jackson Hole area from areas further south also face a variety of obstacles and threats. Deer that winter south of Pinedale live part of their year in an area that has experienced a great deal of oil and gas development over the last two decades. Deer have been shown to avoid using areas around well pads, especially those being actively drilled, resulting in habitat loss [142, 143]. Energy development can also be a partial barrier to deer migrating through these same areas [130]. Deer from this area used to face another partial barrier as they crossed Highways 191 and 189 west of Pinedale — both during migrations and all winter long — but they are now largely able to cross this road safely since the installation of the Trapper's Point underpasses and overpasses in 2012 [136]. These deer migrate to their summer range in the Hoback Basin at the southern end of Teton County and the Jackson Hole area..

Another portion of the Sublette Herd stretches farther south, all the way to winter ranges in the Red Desert, from their summer ranges in the Hoback Basin. In their long journey from the Red Desert (near Rock Springs), these animals' most difficult road crossing is on Highway 191/189 south of the Rim Station but north of the Trapper's Point crossing structures [140]. Interstate 80, at the far southern end of this herd's migration and winter range, creates a near-complete barrier for deer movements. The occasional deer is known to cross I-80; however, it is speculated that deer used to cross this road freely and continue their migration further south, especially during heavy snow winters [118]. Without the ability to do that anymore, these deer are likely experiencing greater winter mortality than they otherwise would.

Other bottlenecks and partial barriers along the migration route include several narrow passages between lakes at the base of the Wind River Range and human developments [118]. Recently a parcel of land at the south end of Fremont Lake was purchased and donated to the State of Wyoming to be managed as conservation land in perpetuity. This will help ensure that mule deer can continue to pass through the narrow bottleneck. However, two other similar bottlenecks, encroaching development and fencing, are still a challenge for this deer migration. Elk fencing around feed grounds are particularly challenging for deer; this highlights some of the challenges of managing for multiple species at the same time in a complex landscape of multiple human uses.

For all of these deer migrations, fences are a challenge. Although deer are able to jump many fences, any fence passage still carries a significant risk that the animal will get entangled [138]. Additionally, newborn fawns have a harder time navigating fences than adult deer. Fences can create a barrier to migration if they are too high or constructed of woven wire/mesh. As for pronghorn, minimizing fencing and making fences wildlife-friendlier helps to maintain a permeable landscape for migrating deer.

Other deer migration routes are still being discovered. A recent effort to collar deer in GTNP is beginning to show that animals move to at least six different winter locations in Idaho and Wyoming (S. Dewey, personal communication). As we learn more about deer movements, it will be important to incorporate new knowledge into land-use planning to understand and take action against any threats to these migrations.

Moose

The status and threats to moose populations in the Jackson Hole area are covered in a separate chapter of this report. In terms of migrations specifically, the status for moose differs from one area to another. Research on moose migrations in Jackson Hole have been limited to the animals that spend the winter in the Buffalo Valley/Spread Creek areas in northern Grand Teton National Park. These moose migrate into the Teton Wilderness, Togwotee Pass, and northern Teton Range areas for the summer. These migrations are relatively intact as they are almost exclusively within national park or designated

wilderness areas. The main threat to the continued existence of these migration routes may be the declining moose population itself. As fewer and fewer animals traverse the migration routes, some routes will likely disappear simply by attrition and loss of knowledge of historic migration routes.

Much less is known about the migration patterns of moose that winter farther south in the Gros Ventre drainage, near the towns of Jackson and Wilson, and in the southern Snake River corridor. Animals that winter near Jackson and Wilson likely experience some impediments to their movements and migrations due to development, roads, and fences. These are discussed in greater detail in the chapter on Moose.

Threats to Ungulate Migrations

We consider here the major threats to the ungulate migrations that move into or out of the Jackson Hole area. These threats may occur within the JH area or in portions of the migration corridor outside the JH area, or both.

1. **Roads — High, Local**. Rising traffic volumes in the Jackson Hole area and beyond mean that roads are likely to become more and more impermeable barriers for many ungulate migrations. Almost all of the ungulate migrations in and out of the Jackson Hole area are already impacted by roads, with roads presenting a partial to complete barrier. Wildlife-vehicle collisions are also a source of mortality for migrating ungulates; on average 2-4% of Wyoming's mule deer are hit on roads every year. Traffic volumes in the Jackson Hole area are already relatively high and continue to grow, especially as commercial and residential development expands and more

tourists visit the JH area. Once a migration route or other movement corridor is cut off by a road, it may be difficult or impossible to restore that migration corridor.

2. **Fences — Moderate, Extensive**. Like roads, certain types of fences are a considerable barrier to ungulate movements and migrations. Fences range widely in the degree to which they are permeable to wildlife, from completely impermeable to easily crossed. In the Jackson Hole area, organizations like the Jackson Hole Wildlife Foundation are working with public land agencies and willing private landowners to remove or convert less-permeable and hazardous fences and replace them with wildlife-friendlier fences. Teton County's Natural Resource Regulations also require that fences on non-agricultural lands meet wildlife-friendlier standards. In some places, fences put up to keep elk away from livestock impede the movements of other ungulate species (e.g. the fence along the west side of the NER). Identifying and removing or converting fences that exist within ungulate migration corridors should be a high priority in the future.
3. **Residential and commercial development — Moderate to High, Local.** Development in the private lands of the Jackson Hole area and beyond makes it increasingly difficult for ungulates to move freely through the landscape. Although each individual development has only a small impact, the cumulative impact of many developments can be large, and there may be thresholds of development beyond which animals are no longer able to move through an area. Furthermore, dense development within known migration routes and stopover sites can degrade important foraging areas. Development can also make it difficult to mitigate other threats, such as roads, on migrating ungulates. For example, it is difficult to provide safe wildlife crossings opportunities in an area that is heavily built-up. For some individual migration routes, the threat of development is high, whereas for others the threat is more moderate.
4. **Energy development — Moderate, Local.** Energy development, especially in southwestern Wyoming, is a threat to some of the migratory ungulates that move into and out of the Jackson Hole area. The threat is considerable for certain herds, but low to absent for other herds (e.g. those that migrate within Jackson Hole or through more protected lands around the JH area).
5. **Climate change — Low, Extensive.** Climate change is already impacting ungulate migrations and can be expected to impact them more in the future. Shorter, faster spring green-ups mean a shorter period of time for migratory ungulates to benefit from the highest quality, most nutritious grasses and forbs in the spring. With less of this high quality grass, animals can be expected to have lower body condition and lower pregnancy rates. It is not yet clear how well ungulates can adapt to these changing conditions or what the implications will be for their population sizes. A related threat from climate change is that it may contribute to animals switching from a migratory to resident strategy. If the nutritional benefits of migration wane due to climate change, resident strategies can become more dominant in the population. This could cause further competition between migrants and residents on limited winter ranges.
6. **Disease — Moderate, Extensive**. There are several significant diseases that pose a threat to migratory populations of ungulates. Chronic wasting disease (CWD) in cervids and pneumonia complex in bighorn sheep are just two important examples. Both diseases have contributed to population declines, and pneumonia has caused the elimination of several entire bighorn sheep herds in the state [144, 145]. Additionally, management strategies to curtail the spread of diseases, especially from wild animals to domestic livestock, poses a threat to migration. Elk migrations are short stopped at feedgrounds to prevent the commingling of elk and cattle, with the goal of preventing transmission of brucellosis. These management practices create an environment that increases exposure of wild elk to the brucellosis bacteria, causing a vicious cycle of greater prevalence among feedground elk [146]. While brucellosis is not a population-limiting disease among free-ranging elk [147], there is growing evidence that CWD is [144, 148]. By concentrating animals in one place, feedgrounds can increase the transmission of CWD in addition to brucellosis. Disease impacts are a pervasive threat to migratory populations, but

allowing animals to continue migrating may help diminish their exposure to disease and highly contaminated areas.

7. **Supplemental feeding — Moderate, Extensive.** Supplemental feeding includes elk that are fed at official feedgrounds and deer and moose that are fed at unofficial feed sites (usually places where private citizens put out food for animals). Supplemental feeding disrupts migration patterns by keeping animals near the supplemental food. It also contributes to disease risk and the associated threat to populations of migratory animals.

Opportunities and Cooperation

There are a number of things that can be done to reduce or manage the threats to ungulate migrations. The effects of roads can be mitigated by providing opportunities for wildlife to cross roads safely. These mitigations can range from public awareness campaigns to dedicated wildlife highway under- or over-passes. Highway under- and over-passes can be more than 80% effective at reducing wildlife-vehicle collisions and improving habitat connectivity for big game [136, 149]; however, they are not always feasible to install given costs, existing development along roadsides, and technical and social considerations. Currently, the Wyoming Department of Transportation is building six wildlife underpasses on Highway 89 between South Park Loop Road and Hoback Junction. Teton County has also commissioned a Wildlife Crossings Master Plan; this will provide recommendations for how to ensure safe wildlife crossings in priority areas in the rest of the county. Citizen groups and the Jackson Hole Wildlife Foundation have also been very active in promoting safe crossings along Highway 390, by installing fixed radar signs and dynamic message signs, working with WYDOT to reduce speed limits and raise public awareness about the presence of big game (especially moose) along this road.

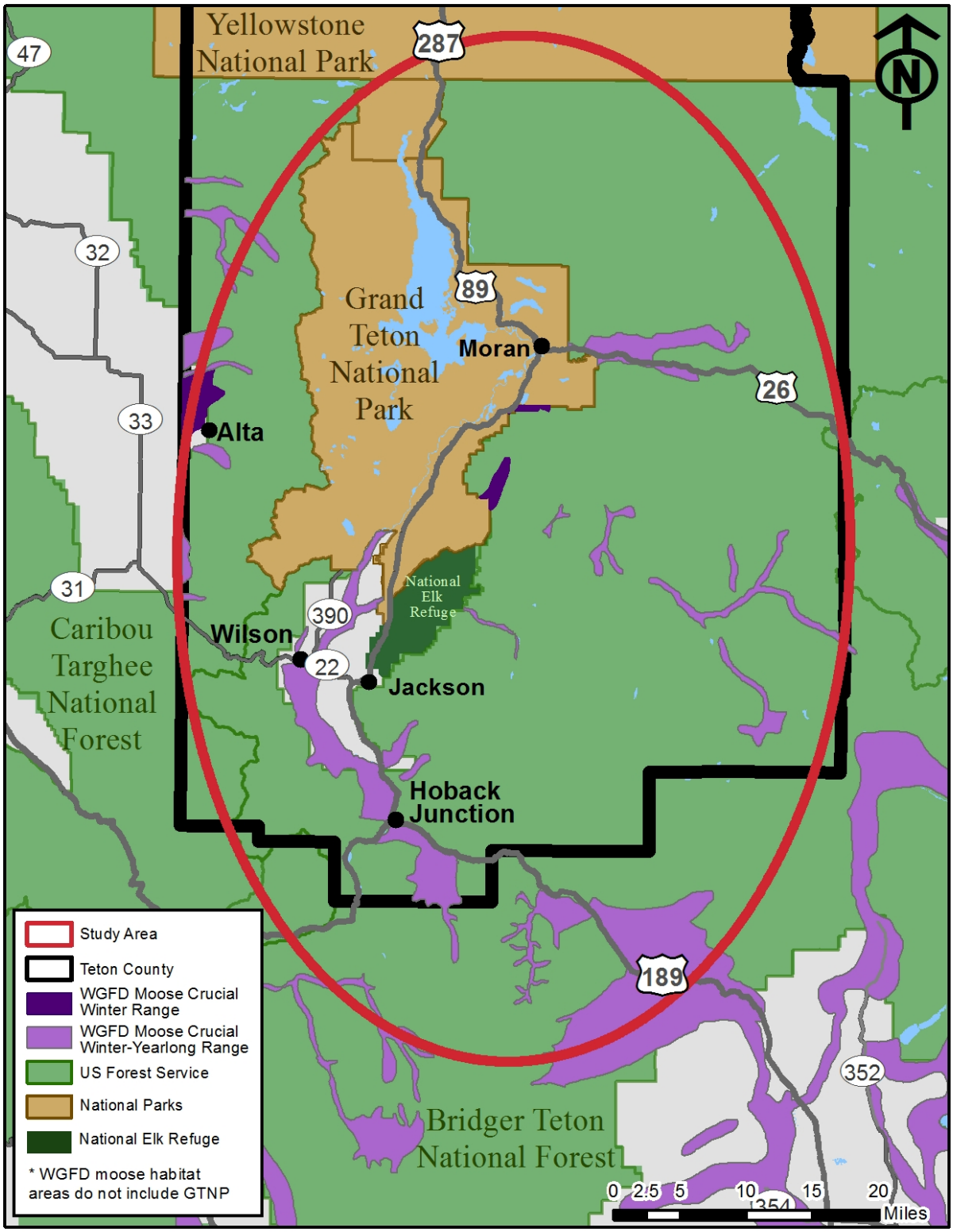
The effects of development can also be mitigated by protecting key migration corridors and habitat (especially winter habitat, which tends to be more developed). The Migration Assessment for Teton County, currently in development by the Wyoming Migration Initiative, and the recently completed Focal Species Habitat Mapping for Teton County, WY [150] can help to prioritize parcels of land for protection as conservation easements or limit development to minimize negative impacts on migratory wildlife.

Of course, conserving long-distance migrations that extend beyond the Jackson Hole area will require protections and partnerships beyond the Jackson Hole area. Although migrations are sensitive and easily disrupted, there has been a huge increase in public awareness and appreciation for ungulate migrations in Wyoming in recent years. This gives hope that diverse stakeholders will come together to conserve the Jackson Hole area's spectacular migrations for generations to come.

Information Gaps

- New migration routes are being discovered; documenting these routes is a key first step to conserving them.

[This chapter by Corinna Riginos]



Crucial moose habitat within the Jackson Hole area.

Moose

Overview

Moose is one of the most beloved and iconic species of wildlife in Jackson Hole. Traffic jams up when a moose is near a major road; tourist shops feature a huge range of t-shirts with moose on them; residents put up metal moose cut-outs to remind people to slow down for moose. Moose are very much a part of the cultural identity of Jackson Hole. And yet, their numbers have dropped dramatically in the last 25 years, and their future is far from secure.

Jackson Hole's moose are part of the Shiras moose sub-species, found only in the northern Rockies. Wyoming is home to nearly half of the world's Shiras moose. Although the sub-species is not currently considered threatened, many individual populations, including Jackson's, are undergoing precipitous declines. Protecting moose habitat may not be sufficient to conserve moose in Jackson Hole. We chose moose as a conservation target because of their recent declines, because their conservation needs are not fully met by our other targets, and because they are a culturally important species in this region.

Moose Ecology

Moose (*Alces alces*) is the largest member of the deer family. Moose are found in a belt that stretches around the northern hemisphere's boreal zone, including northern North America, northern Europe, and Russia; however, different areas are home to distinctly different sub-species of moose. Moose are thought to have arrived in North America via the Bering land bridge 10,000-14,000 years ago, and there are now four sub-species in North America. The sub-species found in the Rockies and Northwest, from Colorado to Alberta and British Columbia, is the Shiras moose (*A. alces shirasi*) — the southernmost in range and smallest in size in North America. Shiras moose weigh only about half as much as the Alaskan moose (*A. alces gigas*).

All sub-species of moose share some unique characteristics and adaptations. Most recognizable, of course, are the enormous paddle-like antlers that male moose sport for much of the year. Moose also have very long legs and two large, spreading front toes; these features help them to move efficiently on land and in water. Spreading toes help moose to distribute their weight so that they do not sink completely into deep snow. Long legs help them navigate through the deep snow in winter and over downed trees in the summer months. Long legs and spreading toes also allow moose to be extremely effective swimmers. Moose have unique nose flaps that shut underwater, enabling them to dive in shallow lakes and ponds, where they eat a variety of aquatic plants. They also have hollow hairs that are thicker at their ends than their bases; these features help provide insulation in the winter and give moose extra buoyancy in the water.

In general, moose prefer habitat near streams and ponds. Willows, found along streams, are a major part of their winter diet, and aquatic plants make up a significant portion of their summer diet. Moose also eat a variety of other trees (e.g. aspen), shrubs (e.g. antelope bitterbrush), and forbs. In the Jackson Hole area, they winter in low elevation riparian, shrub, and aspen habitats, and summer in higher elevation riparian corridors, montane meadows, and aspen habitats, with regular migration routes between winter and summer ranges. They may seek out conifer or aspen cover for shade in summer and shallower snow in winter.

Moose are very sensitive to temperature. They experience heat stress at temperatures above about 57° F (14° C) in summer and 23° F (-5° C) in winter [151], and exposure to heat stress has been linked to decreased body condition [152]. This may be one of the reasons that moose have declined substantially in recent decades in areas near the southern edge of their range, e.g. in Minnesota and

across the range of the Shiras moose in the Rockies [153, 154]. As discussed below, moose are being impacted by a variety of factors related to climate change.

History and Current Status of Moose in the Jackson Hole Area

Although moose are today an iconic feature of the Jackson Hole landscape, they were not always found here. There is no fossil evidence of moose living in this area, and early trappers and traders traveling through the Jackson Hole area in the 1830s-1860s did not observe any moose in the area [155]. All evidence indicates that moose began to appear in the Yellowstone and Jackson Hole areas in the late 19th century through a natural process of range expansion, possibly concurrent with human settlement, the rise of livestock production in the region, and predator reduction campaigns to protect livestock.

By 1912, there was a self-sustaining population of moose in Jackson Hole [156]. By 1950 there were about 600 moose in the area, by the early 1980s there were about 2,000, and by the early 1990s this number had exploded to somewhere between 3,000 and 5,000 moose in the Jackson Hole herd [156]. It is hard to imagine that moose were once reported to number as many as 50 per square mile in the Buffalo Valley and Spread Creek [155]!

Historically, as at present, the highest numbers of moose have been reported in the Buffalo Valley along the Buffalo Fork River, in the Pacific Creek drainage, along the Snake River, and along the Gros Ventre River and tributaries. The riparian vegetation, especially willows, provides essential food and habitat for moose. Moose that winter in the Buffalo Valley and the Pacific Creek drainage migrate north to higher elevation areas in the Teton Wilderness .

From a peak population estimate of 3,000-5,000 in 1990-1992, moose numbers have since plummeted at an alarming and persistent rate. Today, there are estimated to be about 500 moose in the Jackson herd [157]. Our study area also includes the Targhee moose herd on the western side of the Tetons, estimated to number 150-200 moose [158]. Due to budget limitations and the difficulty of the terrain, aerial surveys of this herd have been limited, but the herd is thought to be declining at a similar rate as the Jackson Hole herd.

Since the early 1990s, WGFD has dropped the number of hunting licenses permitted for the Jackson herd from 500 to 10, but the population of moose has not rebounded. Beginning slightly earlier, around the mid-1980s, the ratio of calves relative to cows also began to drop below 0.5 (1 calf for every 2 cows) and dipped as low as 0.2 (1 calf for every 5 cows) in the 2000s [157]. This ratio provides a good indication of the reproductive success of a population; the low cow:calf ratio shows that moose in the JH area are not reproducing as successfully as they are in other, more stable populations.

What has caused this precipitous decline in the moose population? In all likelihood, there are multiple factors at play [6, 157]. First, it seems that the high number of moose found here from the 1960s to early 1990s was not sustainable. Moose likely benefited greatly from the absence of predators and from colonizing a new habitat, but by the 1960s there was evidence that moose were significantly overbrowsing their habitat [155]. Managers and researchers generally believe that the moose population had exceeded the carrying capacity of this area and some kind of population decline was inevitable [154]. However, they also think that moose numbers have now dropped well below the expected carrying capacity. In fact, moose winter ranges are no longer overbrowsed [123], yet moose numbers have not rebounded. Research over the past decade points to a number of other factors impacting moose.

Beginning in the late 1990s, wolves and grizzly bears began to recolonize the Jackson Hole region, exerting new levels of predation pressure on moose. Although initial analyses indicated that wolves were not having a great impact on moose, potentially because of an abundance of easier-to-catch elk [124], new analyses show that wolf predation is actually the most important factor affecting moose population growth [159]. Studies of GTNP wolves also show that moose make up a variable and sometimes large fraction of wolf kills; in the winters of 2011-2013, the percent of located wolf kills that were moose ranged from 5-45% of all kills, and wolves seem to take down moose cows more than any other demographic category of moose [160–162]. However, the moose decline started before predators were re-introduced in the GYE so predators cannot be solely responsible for this decline.

The legacy of the extensive fires in the GYE, as well as several dry years in the 2000s, appear to have caused a decline in the overall quality of food available to moose. Moose captured in the Buffalo Valley in 2005 and 2006 showed evidence of nutritional stress, with surprisingly high adult mortality that was not linked to predation [124, 163]. A subsequent study found that forage quality was low in moose summer ranges in the Teton Wilderness, and individual animals that spent their summers in areas burned in the 1988 fires had lower rates of pregnancy and calf survival, leading to lower population growth rates than moose that summered in unburned areas [123]. A more recent analysis concluded that the 1988 fires have not have such a strong effect on moose, but instead a period of dry conditions from 2000-2007 had a substantial negative impact on their population growth [159].

Dry and hot conditions can challenge moose in several different ways, and a warming climate over the last 35 years has likely contributed to their decline. Dry spring and summer conditions, as well as rapid spring greenup, leads to less nutritious forage. A study across 18 Shiras moose herds in Wyoming, Utah, and Colorado found that dry spring and summer conditions and rapid spring greenup were both associated with lower moose reproductive success in the following year [154]. Starting in the 1980s, spring and summer conditions have become more hot and dry, and spring greenup has occurred more rapidly for these moose herds; these factors seem to have contributed to many herds' declines [154].

Warming temperatures are also probably stressing moose directly. Moose cannot tolerate heat well. They can shift their behaviors somewhat to avoid heat — by staying in the shade, for example. But doing this can limit their ability to forage in optimal habitat or forage for enough hours each day, leading to

lower body condition [152]. In the Shiras moose study, higher spring and summer temperatures resulted in lower moose reproductive success, probably because cows that experienced high temperatures entered their pregnancy with low body fat [154]. This was especially true in the 8 out of 18 herds that were declining, including the Jackson herd.

In recent years, two other processes related to a warming climate have also started to impact moose: increased tick loads and prevalence of carotid artery worm. Winter ticks tend to be more abundant on moose in warmer years and in animals living in the southern part of the Jackson herd's area [157]. Ticks cause moose to scratch themselves and lose hair, which exposes them to cold and stress, lowering body condition. Carotid artery worms (*Eleaophora schneideri*) have more dramatic effects on moose. These nematodes live in the carotid arteries of ungulates, substantially reducing blood flow to the head and brain. Infected animals can experience frostbite and gangrene on their ears, blindness, difficulty eating, and nervous system damage that leads to abnormal behavior (e.g. lethargy, aimless wandering). A survey of hunter-harvested moose from the Jackson herd in the 1970s found zero prevalence of carotid artery worm, whereas a survey in 2009 found that nearly 50% of moose were infected [164]. This dramatic increase in infection rate is probably linked to a warming climate; carotid artery worm is spread by horseflies that benefit from warmer conditions [164]. Although the effects of carotid artery worms are usually not directly lethal, they contribute to animals' poor body condition and chances of being killed by predators or vehicles.

Finally, human development has also probably contributed to declines in moose numbers. Although many of the Jackson Hole moose live in protected land in GTNP or BTNF, others live at least partially in the more developed private lands of southern Jackson Hole. Development has reduced moose habitat along the Snake River corridor, particularly between Moose and Wilson, and along the Flat Creek corridor through the NER, the town of Jackson, and residential areas south of Jackson. Although moose still use many of these areas, the amount of habitat and forage available to them is considerably less now than it would have been prior to human settlement.

Moose, like other ungulates, are also impacted by roads and vehicles. Roads cut through moose habitat in many places in the Jackson Hole area, threatening their habitat connectivity. The high traffic volumes on highways 22, 390, and 89/189 through GTNP make it particularly challenging for moose to cross those roads and expose them to the risk of being hit by vehicles. The junction of highways 22 and 390 and the first mile in all three directions from that junction together make one of the worst locations for moose-vehicle collisions in Wyoming.

Threats to Moose

1. **Climate change — warming temperatures and thermal stress — High, Extensive.** Moose are adapted to cold climates and have a limited capacity to tolerate heat. Behavioral changes can help moose reduce heat stress, but only up to a point. Climate change will bring a higher proportion of very hot summer days and winter days above freezing, placing a direct physiological stress on moose and inhibiting their ability to search for food. These conditions may make it difficult or impossible for moose to survive in the Jackson Hole area.
2. **Climate change — altered hydrological processes and forage quality — Low.** Hotter, drier spring and summer conditions, as well as associated changes to hydrological dynamics in riparian areas, are causing moose forage quality to decrease, impacting moose nutritional status and ability to reproduce successfully. This is likely to become more of a problem as the climate warms. However, the overall threat is probably less than some of the other threats posed by climate change; without other threats, moose might be able to cope with reduced forage quality.
3. **Increased frequency of forest fires — Moderate, Extensive.** Fires are expected to become much more frequent and extensive in the GYE over the next 50 years due to a warming climate. The impact of forest firest on moose forage quality is somewhat debated; small, patchy fires can

improve forage quality, whereas the extensive 1988 fires reduced forage quality. A greater concern is the impacts that frequent fires could have on forest cover and shade for moose. According to some predictions, large areas of the GYE may become treeless or covered in very small trees within the next 50-75 years [110]. This could have a serious impact on moose's ability to find the shade they need to survive.

4. **Increased incidence of vector-borne disease — Moderate, Extensive.** Carotid artery worms are already found in at least 50% of moose in Wyoming and are probably indirectly responsible for a large proportion of moose mortalities, since infected moose can lose vision and mental capabilities. Increases in this fly-borne disease are attributed to warmer climates that favor the host flies. Ever-warmer temperatures may facilitate further prevalence of carotid artery worm in moose.

5. **Roads — Moderate, Local.** Rising traffic volumes in the Jackson Hole area are making roads more and more impermeable for moose. Maintaining habitat connectivity is important for large mammals such as moose that have large home ranges. It is also critical for helping moose to cope with adverse impacts of a warming climate; animals that are constrained in their movements are less likely to have access to habitat features that help them thermoregulate, e.g. shade, water, and higher elevation areas. Roads are also a source of moose mortalities; although the total number of moose mortalities due to collisions with vehicles is small, every mortality is consequential for this declining population.

6. **Residential and commercial development — Moderate, Local.** Development is not a threat for moose in GTNP and BTNF lands, but it is a significant threat to moose in the private lands along the Moose-Wilson corridor and around Jackson. People tend to value real estate along rivers and streams, and valleys and bottomlands are the most developed and rapidly-developing areas in Jackson Hole. Thus development often falls right in the middle of moose habitat, reducing the forage available to moose and exposing them to the stresses of co-habitating with humans (e.g. being chased by dogs, getting trapped and entangled in fences and outdoor decorations, etc.).
7. **Recreation — Low, Extensive.** Hikers, bikers, and skiers often disturb moose from their habitat, likely stressing animals.

Opportunities & Multi-Partner Cooperation

Moose are a tremendously charismatic species and much-adored by residents and visitors alike. It is a species people are motivated to conserve. This is good, because the threats facing moose are considerable and their future survival in the Jackson Hole area should not be taken for granted. Climate change, ultimately the greatest threat to moose, is not something that can be stopped at a local or regional level. However, there is scope to help buffer moose against the worst impacts of climate change. Reducing other threats to moose is key. This includes minimizing further development in moose habitat and ensuring habitat connectivity through developed areas and across roads.

Moose are a WGFD Species of Greatest Conservation Need, and the decline of the Jackson and Targhee herds are a concern for WGFD and Grand Teton National Park. Citizen groups, particularly residents of the West Bank north of Wilson, are also motivated to protect moose. The Village Road Association, for example, has worked with partners and independently to raise awareness about moose on highway 390 and urge drivers to slow down and be alert. There is a significant need to know more about the movements and habitat use of moose in southern Jackson Hole in order to ensure that their habitat and connectivity among key habitat resources are both maintained. Conservation of moose in the Jackson Hole area will require vigilance, action to protect their habitat, and cooperation among multiple partners.

Information Gaps

- The effects of human disturbance, especially recreation, on moose are poorly understood.
- Key moose movement corridors and habitat use around Wilson and Jackson need to be studied.

[This chapter by Corinna Riginos]

Northern Goshawk — Indicator of an Intact Mature Forest Mosaic

Overview

Summer hikers along a deep-forest trail suddenly are alarmed by a high-pitched, rapid “kikikikikik” call and then they see a large bird diving at them, talons bared. Or in winter, a homeowner is looking out at his bird feeder to see a magpie disappear in a poof of feathers. These people have just witnessed a Northern Goshawk, the largest accipiter in North America.

Northern Goshawks — (*Accipiter gentilis* subsp. *atricarpillus)* — are year-round, but mostly unseen, residents in JH. To nest successfully, they require stands of older aged trees surrounded by an extensive mosaic of mixed coniferous forest. They will defend the area around their nests if anyone gets too close; and if continually disturbed, parents may abandon a nest site entirely. Goshawks can fly fast, weaving through trees to catch a variety of medium-sized birds (woodpeckers, grouse) and mammals (red squirrels, snowshoe hares) on the wing. In winter, goshawks will often move near residential areas in the valley where there is easy prey, such as birds and red squirrels at bird feeders. One may spy a mob of magpies harassing a goshawk out of a dense evergreen tree.

We have chosen Northern Goshawk as a conservation target to help focus attention on the large tracts of conifer forest that skirt the lower slopes of the Jackson Hole area. Connected forest provides habitat and corridors for larger mammals, such as moose, elk, mule deer, black and grizzly bears, as well as pine marten and rarely lynx. A suite of raptors — hawks and large and small owls — and many songbirds thrive in this forest. Squirrels, chipmunks, voles, and hares live within old snags, fallen trunks, and dense understory found only in older forests. Many of these species, including goshawks, are year-round residents and, therefore, rely on this forest for their persistence in our region. Goshawks need both extensive forest and a diversity of prey to sustain their populations, which makes them a good indicator species — a species that can be used as a proxy to determine the biological condition of a particular ecosystem — in this case the older-aged mosaic of lodgepole pine, Douglas fir, aspen, and some spruce and fir.

Threats to this forest include development, invasive exotics, forest management actions, and intense recreation, all of which can cause direct habitat loss and degradation as well as fragmentation. Stimulated by climate change, forest fires and pest outbreaks are expected to increase in their extent and intensity, adding to the changes to the forest mosaic.

Goshawk Ecology

Northern Goshawk is found in low densities in conifer and hardwood forests throughout most of northern North America where such forest habitats occur. Similar in size to Red-tail Hawk, the goshawk is the largest of three North American hawks in the genus *Accipiter*, which includes Sharp-shinned and Cooper’s Hawks. This genus has characteristic long tails, legs, and talons, all of which provide the agility to chase and capture prey through trees [165]. As opportunistic feeders, Northern Goshawks are successful in a variety of regional forest types — from boreal forests to ponderosa pine. In this region, they feed primarily upon red squirrels, Uinta ground squirrels, snowshoe hares, corvids (ravens, crows, magpies), grouse, and woodpeckers. They will sometimes consume small songbirds, raptors, and waterfowl. Their winter diet may vary from their summer diet to include more squirrels and rabbits. [22]

While they are often considered forest habitat generalists due to their use of a wide range of forest types, Northern Goshawks in fact have some particular requirements [166, 167]. In the western states, they are typically found in mature, older growth conifer forests and/or aspen stands during the breeding season. The type of nest trees can vary from region to region. In the Caribou-Targhee National Forest (CTNF), most goshawks use Douglas-fir for nesting (78%) [168]. However, a recent Jackson Hole

area study determined that here goshawks will nest in a diversity of suitable trees: 33% nested in spruce/fir forests, 25% in lodgepole pine, 25% in Douglas fir, and 17% in mixed conifer/aspen stands [169, 170].

Perhaps more important than tree species, a certain forest structure is required for breeding success [167]. In the CTNF along the western flank of the JH area, mature timber averaged 68% in the nest area [168]. Nesting birds often choose the oldest stand or tallest group of trees within the surrounding forest. Trunks of mature trees are relatively large in diameter and tall. Trees form a relatively high (70-85%) canopy cover — wide crowns (top branches) that together connect to shade the ground below. The forest understory is often relatively open with few saplings or entangled shrubs beneath, although this feature can vary. In lodgepole pine forests, the relatively even-aged stands typically have a high canopy cover. These high, dense canopies provide thermal regulation and cover from predators for nests, as well as provide open areas beneath for birds to seek prey [170]. It was previously thought that open woods enabled them to fly through the trees and that younger, denser growth would encumber flight and sight; however, goshawks are actually remarkably successful hunters even in dense forest stands (S. Patla, personal communication). Other research suggests that timbering can reduce nest occupation [171], emphasizing the need for larger tracts with older trees.

Nesting and foraging territory varies depending on region [166]. Most nesting occurs between 6,500 ft (2,000 m) and 9,000 ft (2,750 m) elevation, below the subalpine zone where subalpine fir and Engelmann spruce dominate. High intensity nest use in CTNF is estimated to be 200 acres (81 ha), and foraging territory around the nest sites was estimated to be 6,000 acres (2,428 ha). [168] In Teton County, WY, patch size for high intensity nest use may be 0.13-0.3 square miles (34-80 ha) and goshawk may need a foraging area of 9.3 square miles (24,087 ha) for sufficient food and undisturbed foraging [22, 170]. It is likely, that in the JH area, most territories where goshawks nest contain at least 50% mature forest habitat with the highest density of older trees surrounding the actual nest sites (S. Patla, personal communication). Whatever its territory, goshawks are particularly aggressive in defending it after the young hatch, often flying and screaming at intruders, including hikers and researchers.

Goshawks invest considerable time and effort in raising young each year. They start breeding in the JH area beginning in late March and early April. They lay 2-4 eggs by early May, with hatching occurring in early June. Young depend on adults and remain in the nest or nest tree for almost 5 weeks into the summer. For another two months, fledglings continue to depend on adults as they learn to feed themselves. Thus, for over six months this undisturbed core nesting and fledgling area is extremely important for reproduction and survival. Fledglings disappear by early to mid-September. Adults may move out of their summer home range between September and December, although not necessarily very far. Pairs seldom use the same nest tree year to year, and a territory may have up to 2-8 alternate nests in different trees. Adults will return to use earlier nest trees, sometimes years later. In two long-term studies, distance between nests used from one year to the next averaged over 1,600 feet (487 m) [167, 171]. In undisturbed habitat, goshawks can be found using the same territories for many decades (S. Patla, personal communication). Nesting is typically on northern or eastern facing slopes, perhaps because the trees tend to have larger canopies in more moist conditions [6]. To breed successfully, goshawks need large foraging territories with a variety of prey around traditional nesting areas [167].

As local migrants, goshawks may shift their foraging territory from summer on the mountain slopes to winter in the valley floor. Females range more widely, while males are more likely to stay within or near their breeding territory. Consequently, homeowners may see these birds in neighborhoods snatching birds at feeders. Also, these large accipiters have been observed in mixed conifer/cottonwood forest of the Snake River floodplain and coniferous forest at the base of the Tetons [170].

The JH area has a significant goshawk population, likely due to the large area of extensive forests covering gradual mountain slopes. Stands of lodgepole pine, Douglas-fir, mixed with some Engelmann spruce and subalpine fir, typically grow in a mosaic. The combination and density of tree species depends on the slope, soil, temperature, and moisture regimes, as well as fire history and other

natural disturbances. The large amount of conifer forest within the JH area is essential to the connectivity of conifer forest throughout the GYE [172]. The Bridger-Teton National Forest and Yellowstone National Park rank high in the ecological intactness analysis of forested areas compared with much of the Middle Rocky Mountain Ecoregion [172]. Presence of nesting goshawks is an indicator of the integrity of this regionally significant forest mosaic.

Status and Trends of Goshawks in the Jackson Hole Area

While goshawks are not endangered or generally rare, they are of interest to federal and state agencies. The U.S. Forest Service lists goshawk as a “sensitive species” and “management indicator species” [92]. When the U.S. Forest Service develops forest plans for timber harvest and thinning, managers assess the impact of these practices on nesting habitat and populations [173]. WGFD lists Northern Goshawk as a SGCN, Tier 1 species [22] and the Teton County NRTAB selected it as a focal species for the purposes of developing Teton County planning regulations [150].

Population assessments and trends are difficult to determine for goshawk. Birds are widely dispersed in large tracts of forest and their nests are hidden in high canopies. New models defining survey units incorporate slope degree (steepness) and aspect (direction of the slope), large unfragmented sections of forest, tree species, and age to help narrow the area for on-the-ground searches; but even so, it may take a team of surveyors many days to find a single nest [173]. It is impossible to tell older aged forest habitat from aerial photos, although experienced surveyors on the ground know it when they are in it (B. Bedrosian, personal communication). Often it is the response call to a recording or an aggressive parent bird that enables surveyors to zero in on the nest site. Determining nesting success, e.g. number of eggs and fledgling survival, to determine productivity, demands much more extensive efforts [173, 174]. Finally, survey parameters have been inconsistent over the years, making it difficult to compare the results of a survey some years ago with a survey today. However, survey parameters are now more consistent and models more refined, enabling researchers to track trends in the future [173].

National estimates indicate a decline in Northern Goshawk populations, as do more local surveys, but again trends to date can be difficult to establish. Federal and state biologists have conducted regional surveys in Wyoming and Idaho over the last decade or so [22, 171, 175]. Currently, it is thought that the Wyoming population is stable [22]. However, because this wide-ranging bird utilizes different habitats and prey in different locations, local assessments are important to assist with management. Teton County has mapped possible core nesting habitat for goshawks to indicate potential nesting habitat around the valley [170]. The USFS has commissioned an assessment of potential goshawk habitat within the proposed Teton to Snake Fuel Management Area [176]. This work can help determine where to concentrate survey efforts and what the JH area goshawk population may need in terms of forest patch size and forest type, age, and structure throughout the valley (S. Patla, personal communication).

Mature Older Age Forest

Goshawks require mature or older aged forest stands set within a mosaic of more extensive forested habitat — primarily lodgepole pine, Douglas-fir, and some aspen. Mature or older-aged forests (there is no formal definition of terms) differ from younger forests as different species of trees grow old in different ways. In general, an older forest will contain large living trees and snags (dead standing trees), numerous fallen trees, denser understory, a variety of different tree sizes, and more canopy openings. This variable structure creates habitat for a diversity of wildlife species for foraging, travel, security, and reproduction. Significantly, decaying trees are utilized by fungi, insects, and microbes that in turn provide food to many animals and increase the nutrients available for plant growth. Different types of prey are available, which are important for forest generalists and year-round predators such as goshawk.

Given the rugged topography and elevation changes in our area, the forest is rarely uniform in its mix of tree species or seral (development, or successional) stages. Disturbance from wind, fire, disease, and forestry practices have all affected this mosaic over time, particularly the age and size of stands of lodgepole pine and Douglas-fir on lower mountain slopes.

Tree species have different abilities to withstand fire. Lodgepole pine and Douglas-fir are both fire-adapted trees — they are resilient within certain ranges of fire frequency and intensity. With their thick bark, older Douglas-fir trees can withstand low flames of fire that kill the competing shrub and tree growth. They grow on relatively lower elevation or drier sites with typically more frequent, low intensity fires. Lodgepole pine does not have heat resistant bark, but the species can reseed readily after a fire. Seeds stored in “serotinous” cones — cones that stay closed on trees for years and then open after a fire — disperse on breezes into burned areas, where they germinate on newly exposed mineral soil in the sun, fertilized by ash without competition. As lodgepoles grow in relatively moist conditions with snow lasting into spring, most fires in this forest type are small, if at all. Only in exceptionally dry years are the conditions conducive to extremely large, stand-replacing fires such as the 1988 fires in Yellowstone National Park [7].

Wildfire occurs on different scales and intervals. Naturally ignited by lightning, fires start from random strike points and spread to a lesser or greater extent depending on a variety of factors such as fuel load, slope aspect, and weather. Burn patches restart succession in different locations over different years, adding to the mosaic of age classes within the larger matrix of forest over centuries. Historically these patches have been relatively small, except in extreme drought years. Some tracts have the chance to grow old trees while other areas are set back to earlier stages of growth. In a large, intact forest area, these older growth areas are able to move around the landscape over the centuries, always providing habitat, although in different places, for wildlife dependent on mature forests.

Insect outbreaks play a similar role as fire in forming the forest mosaic. Mountain pine beetles (*Dentroctonus ponderosae*) kill larger (>8-inch {20-cm} diameter), older (>90 year-old) lodgepole pines, thereby recycling nutrients and opening up new areas for seedlings that require sun. Over the years, infestations move around the landscape. These patches were relatively small in the past as the beetles were killed by extremely cold winters in the high mountains before they could multiply and spread extensively [177]. Douglas-fir beetle (*Dendroctonus pseudotsugae*) is another species of bark beetle specialized on weakened or drought stressed Douglas-fir [92]. Douglas-fir beetle infestations typically run for 2-4 years and can claim 100 trees in a patch [178]. Large forested landscapes can absorb these disturbances while retaining enough older aged habitat for goshawks and other mature-forest species.

Other Species that Require Large Tracts of Forest Habitat

Below are a few highlighted species that depend on older aged forests, some with extensive area requirements. Note, not all use the exact same mix of forest types — some use more aspen, others more spruce and fir interspersed with or surrounded by lodgepole pine and Douglas-fir; however, these creatures depend on this broad forest mosaic, particularly older aged trees, for a significant part of their livelihood. Loss of goshawk habitat could affect these species as well.

Raptors

Older aged and mature forest habitat provides for a complex of raptors — both hawks and owls. During the day, Cooper's and Sharp-shinned Hawks are able to navigate quickly through trees to pick off forest birds. Cooper's Hawks eat larger prey compared to Sharp-shinned Hawk — including collared-doves at bird feeders, while Sharp-shinned Hawks are more likely to predate upon smaller birds, such as Mountain Chickadees, Red-breasted Nuthatches, Pine Siskins, and Ruby-crowned Kinglets. Highly adaptable Red-tail Hawks hunt a variety of prey in open habitats and nest in trees often on the edge of in forests.

In the JH area we have six owls of all sizes that feed on prey from moths to pocket gophers between dusk and dawn. Common owls include Great Horned Owl, Saw-Whet Owl, and Boreal Owl. Three owls are SGCN: Great Gray Owl, Northern Pygmy-Owl, and Flammulated Owl. For many years, little has been known about the presence of owls, as they are hard to detect. Recent research, with the help of call-back tapes and now nighttime recordings, is helping managers understand where owls live and what they require. Managing for goshawk populations will help preserve this suite of species.

Great Gray Owl (*Strix nebulos)*

The largest owl in North America, measuring 27 inches (68 cm) tall, the Great Gray Owl is rare in Wyoming. This global species is found in North America and Eurasia in boreal and taiga forests. Except for a disjunct population in the Sierra Nevada of California, the southernmost population of Great Gray Owls in the U.S. breeds in the mountain ranges of northwest Wyoming. These statuesque owls, which can be seen along the Moose-Wilson Road in summer or Spring Gulch Road in winter, are a particularly popular subject of photographers and nature watchers in JH area. They are a state SGCN and NRTAB focal species.

In our area, Great Gray Owls prefer mature deciduous and coniferous forests comprised of lodgepole pine, Douglas-fir, aspen, and narrow-leaf cottonwood, along with spruce at lower elevations than most goshawks. Nest locations are generally in close proximity to foraging habitat, which can include some small to medium clearings, such as wet meadows and openings in mature forests. They regularly forage in closed canopy forests [170]. Cottonwood riparian habitat in the Gros Ventre and Snake River

drainages has been found to provide nesting habitat and important wintering habitat in the JH area [80]. In the non-breeding season, Great Gray Owls will also use more open areas to forage. The presence of suitable prey -— primarily pocket gophers and voles — affects their movements both summer and winter [22, 174]. Remarkably, owls can detect and catch pocket gophers under two feet of snow [179].

Recent research adds to our knowledge of these great birds in the JH area [80]. Similar to goshawk, Great Gray Owls require large territories with mature forest habitat that features high canopy and alive or dead trees with large diameters for nesting. Nests are widely spaced — averaging almost 3,000 ft (1000 m) apart — well away from roads and undisturbed by humans. Core nest areas are estimated at 0.3 square miles (77 ha) and a foraging area of 3.2 square miles (829 ha). Great Gray Owls cannot manipulate twigs with their beaks to construct their own nests. They use large snags for nesting — often situated in the top of broken-off trunks, alternate goshawk nests, and witch's brooms. With the decline in the number of large broken-top snags, the use of goshawk nests may become even more important in the future for nesting Great Gray Owl.

Status and Trends: Although population trends in North America are considered stable, historical and recent trends for Great Gray Owl in Wyoming are unknown. One recent study in western Wyoming reported a decline in mean productivity from 3.0 fledglings/nest in the 1980s to 1.7 in 2013 — 2015. Nest structures and optimal locations including sufficient prey have been shown to be limiting factors for breeding in some areas [22].

Specific threats: Residential development in Snake River riparian forests from Moose to Snake River Canyon could reduce nesting and wintering habitat [170].

Northern Pygmy-Owl (*Glaucidium gnoma* subsp. *pinicola*)

This diminutive owl lives at the eastern edge of its range, which extends from Canada into Mexico, here in JH area. It is considered rare in Wyoming, having been documented breeding only in the northwestern mountains of the state. It does not migrate but may move to lower elevations in winter. The population status is listed as unknown by WGFD [22]. It is probably common where habitat is suitable (S. Patla, personal communication). The Northern Pygmy-Owl stands just under 7 inches (17 cm) tall. Its body is mostly gray-brown with a relatively long, barred tail and a streaked breast. It is distinguished from some other small owls by a white-flecked facial disc and two large eye-like spots on the back of its head, which help deter predators.

Northern Pygmy-Owl uses various forest types across its wide range. Observations in Wyoming record the species in mature spruce-fir forests dominated by tall, large-diameter trees as well as in mixed conifer lodgepole and Douglas-fir habitat. Other habitat elements within its range include mature, structurally diverse hardwood, conifer, and mixed forests and forests with high (> 50%) forest cover. Northern Pygmy-Owl is a secondary cavity nester, using either natural tree cavities or those made by woodpeckers. Several of these habitat elements are found in the forest mosaic preferred by goshawk. [22]

Status and Trends: Unknown. Wyoming Game and Fish Department and collaborators have conducted surveys for Northern Pygmy-Owl most years since 2009, including Bridger-Teton and Shoshone National Forests, along with an earlier survey for owls in the Grey's River. In all studies, Northern Pygmy-Owl was either one of the least-detected species or was not detected at all. Notably, these surveys did not include early morning surveys designed specifically for this crepuscular/diurnal owl, and therefore the low detection is likely an artifact of sampling method.

Specific threats: Loss of large trees and snags, loss of woodpeckers that create cavities in older trees, as well as pocket gophers and other prey, could affect breeding success.

Flammulated Owl (*Psiloscops flammeolus)*

Almost the same size as Northern Pygmy-Owls at 6.75 inches (17 cm), Flammulated Owls are finely streaked and heavily mottled and sport tiny ear tufts similar to Great Horned Owls. Unlike other JH area owls, which are non-migratory, Flammulated Owls appear in early May after wintering in the Neotropics. They arrive after other owl surveys have occurred (typically mid-March to April) and, therefore, were not detected until recently when surveys were conducted in May [22].

The first documented breeding of Flammulated Owls in Teton County occurred in 2016 [180]. Flammulated Owl call-back surveys in mid-May and June were conducted at 160 sites in the Bridger-Teton National Forest, the National Elk Refuge, and on private lands in Teton County. Flammulated Owl was detected at 10% of the sites surveyed or a total of 18 individual detections, indicating a potential for 14 nesting territories. Results reveal that owls occur primarily in aspen trees within 110 feet (100 m) of conifer forest. Woodpeckers create nesting holes in the soft wood of aspens, and moths, the primary food for the owl, live in nearby conifers. This is significant new information.

Information gaps: There is still much to know about nesting habitat quality, migration routes, and wintering areas for Wyoming Flammulated Owls. Also, studies are needed on how management activities (e.g. timber thinning and harvesting and prescribed fire) affect nesting populations [22]. Consequently, at this time, there is insufficient information on trends and status and likely threats.

Mammals

Many mammals — both common and rare — depend on older coniferous forests in the JH area. Researchers have documented a variety of connections between individual animal species and the

complex nature of the conifer forest itself. Older aged forest has many decaying trees that nourish fungi. Red squirrels, flying squirrels, and southern red-backed voles eat or store mushrooms, thereby dispersing fungal spores. This activity helps to spread fungi throughout the forest. Fungal strands (mycelia) grow in and around fine tree roots and extend out into the soil beyond, relaying phosphorus and other nutrients to the trees, while using the carbohydrates generated by the trees for their sustenance. The health of forest trees depends on this fungal network [181].

Red squirrels stockpile cones of different conifers — lodgepole pine, Engelmann spruce, and more rarely Douglas-fir — in middens. Middens are heaps of scales left over after cones have been devoured for their seeds [182]. Squirrels store freshly harvested cones in these piles for their winter food supply, and they defend their stashes vigorously and vociferously. Squirrels often will burrow into these mounds, which are several feet wide and high, for winter cover as well. Red squirrels choose groups of older trees with high cone production for their central territory. Pacific martens are more likely to den in or around these middens, preying upon red squirrels and using their tunnels themselves [183]. Industrious red squirrels can harvest enough cones to affect movements of nomadic Red Cross-bills — these avian cone specialists must find their food elsewhere [181]. Red squirrels are significant players in the ecology of the forest.

Flying squirrels are also found in older forests: they use taller trees for long glides, feed on fungus and lichens, and den in decaying trees or holes created by woodpeckers. They are primarily nocturnal and, therefore, are rarely seen except perhaps at bird feeders in winter. Flying squirrels are preyed upon by owls and martens. Southern red-backed voles are found primarily under decaying, coarse woody debris and serve as prey for Boreal Owls, Pacific marten, and other weasels. [181]

Many other small mammals — often overlooked — reside here as well. Chipmunks, including two SGCN species — Yellow-pine and Uinta, both edge-of-range species — use a combination of mature forest types. Snowshoe hares, which were the most common prey of goshawk in a CTNF study [168], can attract endangered Canada lynx, albeit extremely rarely. (No evidence of lynx has been found in recent surveys of the JH area {J. Wilmot, personal communication}). Bats, pygmy shrew, golden-mantled ground squirrel, western heather vole, and western jumping mouse add diversity. Porcupines perch in trees and eat twigs and bark [22, 181]. These quilled creatures are now rarely seen in the JH area (B. Raynes, personal communication). Most of these critters are potential prey for larger birds and carnivores.

Many of these species do not travel far beyond the safety and food of the forest. Some species will not cross clearcuts or other large open areas, and therefore small populations can be diminished and cut off, potentially affecting the viability of their populations [181]. Undisturbed forest habitat is essential for the livelihoods of many small mammals.

Also, it is important to note the other mammals found in these forests: elk, whitetail and mule deer, moose, and black and grizzly bears all use the forest habitats for forage, cover, and movement. Contiguous forests provide routes both north and south and to higher and lower elevations depending on the time of year. The forests in the JH area help connect large mammals throughout the GYE.

Status and Trends: Most of the small mammal species described above are not monitored either because they are considered sufficiently secure or because they are difficult to study. Pacific martens are no longer considered SGCN [22] and may no longer be considered a management indicator species in future U.S. Forest Service reports. State game records provide limited useful information on the population trends of trapped animals. Still these wide-ranging, mature-forest species are worthy of attention.

Information Gaps: While most species described above do not require as large a territory as Northern Goshawk, together many species utilize large, intact, older forest to thrive. Little is known as to the amount and configuration of the forest mosaic necessary to sustain viable populations of these species. Reduction in older aged forests may cause declines in species diversity.

Threats to Northern Goshawk, its habitat, and associated species

Threats to Northern Goshawk are primarily threats to its extensive, undisturbed forest mosaic and prey. Several interrelated factors determine the loss, degradation, and fragmentation of this forest. Fire, insect outbreaks, and exotic species invasions are becoming more extensive and intense in part due to climate change. Development for new houses and commercial purposes can fragment the forest while also creating social pressure for forest thinning programs in the wildland-urban interface (WUI). Other agency management plans, policies, and actions can have beneficial or perhaps negative impacts on older forests. Many of the threats are interrelated and synergistic.

Wildfire — High

With climate change, the frequency and extent of wildfires are expected to increase; however, it is very difficult to predict to what degree and where and what the impacts may be. Some predictions indicate that fire rotations (the time it takes for a fire to return to the same location) to be reduced to less than 30 years vs. the historic return of 100-300 years by mid-century [110]. This could shift the vegetation to more Douglas-fir forest or even predominantly juniper at lower elevations, while higher elevations trees that require more moisture, such as spruce and fir, will not be able to reseed into current locations due to increased warmth and drought.

Invasive Plant Species — Low to Moderate

Invasive exotic plant species can alter the ecology of forests by overwhelming native plants, altering soil chemistry, degrading forage for elk and other animals, and increasing fire frequencies. Plant species invading forests in the JH area include thistles (*Cirsium arvense* and *Carduus nutans)*, several knapweeds (C*entaurea* spp.), and leafy spurge (*Euphorbia ensula)* [92]. Of high concern to forest managers is the progress of cheatgrass as it extends north from Sublette County into Teton County forests and sagebrush/grassland habitats (M. Daluge, personal communication).

Cheatgrass *(Bromus tectorum*), an annual grass introduced from Eurasia, is an increasingly pervasive threat in disturbed forest communities. The grass germinates in late fall to early spring and grows, flowers, and fruits faster than many native grasses and wildflowers in the spring. The original plant then dies, leaving behind dozens of seeds per plant. These inconspicuous grains or seeds are encased by stiff points called awns, so sharp that wildlife and stock animals will not eat the ripened grass. The 1/2 inch (10-15mm), brittle spikes enable the seed to spread by wind or to attach to fur, clothing, and equipment including vehicles for dispersal into new sites. Seeds readily germinate in a variety of soils, exponentially increasing plant numbers the following year and for several years to come. Soon they can overwhelm and shift the diversity of vegetation to primarily cheatgrass. [184]

In forests, seeds travel easily along disturbed routes of forest roads and trails. When a fire occurs, cheatgrass is positioned to disperse its abundant seed even more widely onto the exposed ground. Furthermore, its dried dense grass is readily ignited by lightning strikes, campfire sparks, or a lit cigarette. More area is exposed to more colonization, and the cycle continues exponentially. Extensive stands of cheatgrass fuel more frequent, larger fires, thereby eliminating trees, overwhelming native understory plants, and changing the habitat altogether. Of particular concern are south facing slopes (M Daluge, personal communication).

Mountain Pine Beetle — Currently low, potentially moderate

Mountain Pine Beetle (*Dentroctonus ponderosae*) is a native insect whose numbers have increased significantly over the last 20 years throughout the Rocky Mountains. Infestations affect large tracts of primarily lodgepole pine, but also limber pine and high-elevation whitebark pine (also see whitebark pine chapter). At one time, outbreaks of this native species were relatively small in extent or short-term as the beetles were curtailed in part by winter cold and a 1- to 2-year (or more) lifecycle.

However, with warmer temperatures, in many locations they have adapted to a shorter, one-year life cycle. Also, pines are more stressed by drought and therefore more susceptible to infestations. Historically, an interspersion of younger successional (seral) stages of trees due to natural fires prevented extensive insect outbreaks. In some areas, fire suppression policies since the 1950s have contributed to much larger stands of older trees, which are particularly susceptible to mountain pine beetles. Outbreaks of mountain pine beetle have been more extensive, particularly to the south of GYE. The concern is that as the climate warms, mountain pine beetle infestations will continue to expand, causing large gaps in the forest mosaic. This effect may be compounded by other effects of climate changes (see below). [177]

Of note: So far, the forest in the JH area is relatively untouched by mountain pine beetles [172] and the current outbreak is dwindling [185]. This region may have the greatest long-term prospect of resisting the devastation of the beetle [172] in the Middle Rocky Mountain Ecoregion.

Fragmentation by Development — Moderate, local

Private and U.S. Forest Service lands are being developed with increasing density locally along the base of the mountains between 6,200-7,800 feet (1890-2380 m) in Jackson Hole. The relatively gradual slopes, accessibility, and forest setting with scenic vistas make private homes highly desirable, such as in Wilson along Fish and Fall Creek Roads and above the town of Jackson. Snow King and Jackson Hole Mountain Resorts lease U.S. Forest Service lands for commercial and recreational attractions. Jackson Hole Mountain Resort has expanded its footprint of ski trails in the past few years. At this time, Snow King Resort is requesting permits to add new ski trails and features. All these activities require additional roads, tree clearing, and grading. Occupied houses, commercial buildings, and recreation areas add noise and often pets to the disturbance of intact habitat. Goshawks and Great Gray Owls in particular are sensitive to commotion during nesting season. Finally, once an area is developed, property owners want to be safe from wildfires. Federal land agencies are obligated to protect these wildland-urban interfaces (see below).

Recreation — Moderate, extensive

Recreational use of National Park Service and U.S. Forest Service trails by hikers, backcountry skiers, mountain bikers, and in some places off-road vehicles is increasing. Demand for new routes, such as the recent development along the crest of Snow King and in the valley of Cache Creek, continues. The request to open Wilderness Study Areas is also driven in part by recreation demand (see below). Unfortunately, trails can fragment the forest with increased presence of people, often with dogs. Bikers can come across animals unexpectedly. The noise and visual impacts often extend well beyond the path itself and can be a disturbance to goshawks and Great Gray Owls in particular, but also to small and large mammals, which are wary of canines. Off-road vehicle use can greatly magnify these disturbance effects. More subtle than many other impacts, trails are a form of fragmentation and degradation of forest habitat. Many wildlife species avoid trails and roads and adjacent areas beyond.

Indirect Threats or Contributing Factors

Wildland-urban interface plans and fuels management practices

The U.S. Forest Service and other federal landholding agencies are required by federal law to prevent encroachment of wildfires from federal land onto private lands. Consequently, the Bridger-Teton National Forest is working with the Interagency Fire Management Team to develop wildland-urban interface (WUI) plans. One example is the Teton to Snake Fuels Management Plan. The plan covers almost 80,000 acres (32,375 ha) west of the Snake River from Teton Village south to South Park along the Teton and Snake River Ranges and involves 1,679 private lots [176]. Such Interagency Fire plans include reducing snags for firefighter safety and clearing out understory plants within at least ¼ mile (400 m) of private property to prevent fires from using these “ladder” fuels to climb into tree tops, thereby

supporting high-intensity crown fires. The practices can include prescribed burns or thinning tracts with heavy fuel loads to reduce flame heights or to interrupt rampaging fires. These activities — which may be beneficial to other types of wildlife and for human property and safety — can eliminate crucial elements of an older aged forest that benefit Northern Goshawks, Great Gray Owls, Northern Pygmy-Owls, and other forest dependent associates, including small mammals.

The 2017 revision to the Teton to Snake Plan incorporates prescriptions for birds: Northern Goshawk, Great Gray Owls, Boreal Owls, Bald Eagles, and other raptors; mammals: wolf dens, bears, elk calving, and small mammal habitat; as well as mature stands. Research is necessary to determine the success of maintaining sufficient older aged habitat for this suite of wildlife in the years to come. Other U.S Forest Service lands adjacent to private land are targeted for additional WUI plans. Management decisions regarding fuels management practices will continue to be complex from both a societal and ecological perspective.

Changes in Wilderness Study Area Status: Palisades, Shoal Creek

Another factor in the future of older aged forest is the status of Wilderness Study Areas (WSA). Wilderness Study Areas are lands designated by Congress for additional review before being designated as “wilderness”. During the interim, such areas are managed in the same way as wilderness areas. Under the Wilderness Protection Act of 1964, “wilderness” is a legal classification of national public lands that are essentially untrammeled, free, and wild. At this time, the status of Wilderness Study Areas in Wyoming is under review. Some lands could have protections strengthened, others weakened.

Currently, a stakeholder group organized by Teton County Commissioners, as part of the Wyoming Public Lands Initiative (WPLI), is reviewing the status of Palisades and Shoal Creek WSAs. Wilderness designation would provide maximum protection from timber management, other extraction activities, and recreational development. These areas were designated as WSAs in part because they are roadless, undisturbed lands, which in this case include large tracts of forest. The Palisades WSA stretches south from Teton Pass to the Snake River Canyon and into Idaho. It encompasses a total of 134,417 acres (54,400 ha) with 71,780 acres (2,900 ha) in Teton County. This is a large block of forested land in the heart of the JH area and contiguous to forests extending south [186]. The Shoal Creek WSA is adjacent to the southern border of the 285,413 -acre (121,00 ha) Gros Ventre Wilderness Area, and ranges into Sublette County. Of the total 32,373 acres (13,1000 ha), over one-third is within Teton County. It specifically contains goshawk habitat [187]. Loss of these areas to other management options, particularly the demand for mechanical recreational opportunities or resource extraction, could increase forest fragmentation not only within the WSA areas but also the surrounding forest.

Forest Management Plans

As with all national forests, Bridger-Teton National Forest has a mandate to manage for multiple uses including timber management, recreation, and in more recent years, biodiversity. Resource extraction is currently minimal in the JH area. The most recent BTNF plan update [92], which covers a significant portion of the JH area, provides guidelines for maintaining natural ecological processes, managing a variety of successional (seral) stages, and sustaining biodiversity to the “fullest practical extent”. The plan proposes a future condition where “12% or more of existing old-growth forest has been retained to provide for old-growth dependent animals…. There will be old-growth islands within the overall forested area.” The plan states that old-growth dependent species of pine marten and goshawk would be replaced in some areas by animals that live around openings. These proposed actions cause concern that various silvicultural practices will be used to replace extensive tracts of intact forest with a greater diversity of more common species, at the expense of rare goshawks, Great Gray Owls, and other older-aged forest-dependent species. A more comprehensive update of the Bridger-Teton National Forest management plan is scheduled for 2020 (P. Bode, personal communication). The revision of the plan for

the adjacent Caribou-Targhee forest is also due in the next few years. Any such planning is complex, requiring an assessment of a variety of ecological [188] and social factors.

Lack of adequate support for weed control programs

Agencies in Sublette and Teton County are working together to try to control cheatgrass from invading the Bridger-Teton National Forest and other federal and county lands. Several herbicides are currently being sprayed from backpack sprayers and a more recently proposed measure is to spray from helicopters. There is hope for a bio-control that fosters a root-rot specific to cheatgrass [184]. A cooperative effort to develop new control agents, to locate new occurrences of cheatgrass, and administer control measures on the ground are critical for curbing cheatgrass. Diminishment of county or federal funding for these projects would limit this control, although many adjacent landowners see the visible benefits of these programs and are likely to speak up for continued funding.

Information gaps:

1. Regional population numbers and needs of Northern Goshawk, Great Gray Owls, Flammulated Owls, Northern Pygmy owls, etc., including their prey base.
2. Impacts of forest management practices on these populations.
3. Extent and impacts of recreational use on goshawk and associated species.
4. Climate change impacts on frequency and extent of pine bark beetle, wildfires, and changes in vegetation.

[This chapter by Frances H. Clark]

Whitebark Pine

Overview

Whitebark pine (*Pinus albicaulis)* is an iconic keystone species found at timberline and subalpine zones in the mountains of the JH area. These broad-crowned, often multi-trunked evergreens grow for centuries on cold, windswept, dry slopes and ridges where other trees cannot survive. Yet, despite their age and adaptability over millions of years, whitebark pines are now challenged by the combined effects of mountain pine beetle (*Dendroctonus ponderosae*) outbreaks, fire exclusion policies, and the exotic fungus white pine blister rust (*Cronartium ribicola),* which are all potentially amplified by climate change.

Adding to their unique nature, Whitebark pines have an essential, mutualistic relationship with Clark's Nutcrackers (*Nucifraga columbiana*), a flashy, noisy, black-white-and-grey bird. This relative of jays caches the highly nutritious pine seeds for its winter food supply and, in the process, plants the pine's future in ideal habitat. Without Clark's Nutcrackers dispersing seed, whitebark pine would not survive as a species. Such a tight dependence between a plant and animal species is rare.

Whitebark pines also provide essential food and services for other high elevation plants and wildlife. Grizzly (*Ursus arctos*) and black bears (*Ursus americanus)*, red squirrels (*Tamiasciurus hudsonicus*), other small mammals, and mountain songbirds feast on the "nuts". The trees' presence serves to initiate forest succession, retain snow, slow spring runoff, increase summer stream flows, and maintain water quality—important ecological functions not only for wild communities on high but also for human settlements far below. Finally and ironically, this timberline tree may, in some ways, be more resilient to climate change than any forest tree that might replace it [189].

Unfortunately, the unique plant community centered on the whitebark pine is critically threatened throughout its range, including here in Grand Teton National Park and Bridger-Teton National Forest. We can see dead-gray forests while driving across Togwotee Pass, hiking to Amphitheater Lake, or exploring the Wind River Range. These ghost forests have succumbed to synergistic threats including fire exclusion, native mountain pine beetles, and currently most pervasive of all: white pine blister rust, an introduced fungal disease from Asia. These threats are enhanced in part by climate change and fire suppression. In other areas around the Rocky Mountain West, whitebark pine populations have declined by 90% over the past few decades [190]. In the GYE, roughly 50% of whitebark pine has been lost or compromised [191]. The loss of this keystone species will impact biodiversity, ecological services, as well as aesthetic and recreational qualities throughout our region.

Resource managers and researchers have been concerned about the future of whitebark pine and associated species and benefits for many years. *Whitebark Pine Communities: Ecology and Restoration* edited by Tomback, Arno, and Keane 2001 [192] provides extensive baseline knowledge drawn upon for this report. In addition, the Greater Yellowstone Coordinating Committee formed the Greater Yellowstone Whitebark Pine Subcommittee that has produced a Whitebark Pine Strategy for the Greater Yellowstone Area [191] and continues to update an Adaptive Action Plan [193] to provide a coordinated strategy for preserving and restoring key stands. The Whitebark Pine Foundation is another depository for the latest research. Selecting rust-resistant seed, managing key populations, growing and planting out seedlings, and restoring natural fire regimes are all elements of this complex ecological conservation effort.

We have chosen whitebark pine as a target species for its unique and essential ecological role in the JH area and throughout the Rocky Mountain West. This tree is irreplaceable, and its loss will affect the presence of Clark's Nutcracker, grizzly bears, and other wildlife in our region. While the prospects are daunting, especially in light of the prevalence, variability, and adaptability of white pine blister rust, a recent model indicates hope for maintaining and restoring viable whitebark pine populations over the long term [194]. Furthermore, this species may be more adaptable to warm weather and blister rust than previously thought [195]. The work and experience developed during the application of these adaptive management strategies can benefit other conservation challenges as well. Continued support of research and management action remains critical for the future of this iconic keystone species.

Description and Ecology

Whitebark pine is distinct and essential to the subalpine ecosystem in several ways. *Pinus albicaulis* is one of five "stone pines" in the world, with only one species in the Western Hemisphere, making it genetically unique in North America. It may have come across the Bering Strait land bridge between 600,000 to 1.3 million years ago, likely with the aide of its co-mutualist, a nutcracker (*Nucifraga* sp). Indeed, all the stone pines rely on nutcracker species to disperse their heavy seeds.

Whitebark pines grow in two broad areas of North America, one following the British Columbia Coast Ranges, the Cascade Range, and the Sierra Nevada, and the other covering the Rocky Mountains from Alberta to Wyoming, with its southernmost extent in the Rocky Mountains in the Wind and Salt River Ranges. Historically, it dominated many of the upper subalpine plant communities of the Western United States and has been a major component (10-15%) of subalpine forests in the northern Rocky Mountains. The GYE contains approximately 53% of whitebark pine in the U.S. [191, 196]. Grand Teton National Park includes 28,500 acres (11,535 ha) of whitebark pine. In roughly two-thirds of this area, it is co-dominant with other trees such as subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii)*. In other areas, it stands on its own [197]. Only a very small percent (5%) of Wyoming harbors this tree [6]. The higher elevations of the JH area include a critical portion of this unique species' distribution for the GYE, Wyoming, and the western United States.

Often growing as wide as tall, particularly in open subalpine habitat, whitebark pines feature evergreen crowns studded with thick cones and supported by hefty, often multi-stemmed trunks. At 20-30 years of age, trees begin to produce purplish 3-4 inch (7.6-10 cm) cones, but they do not produce significant cone crops for another 50-80 years. Trees can remain fertile for over 1,000 years. Whitebark pines produce bumper crops of cones intermittently. This “masting” every 3-4 years may vary in location from year to year and can affect local wildlife populations [198].

As with all stone pines, cones are thick and do not open to disperse their seeds. Most of our North American pines have cones which open wide and release winged seeds light enough to disperse by wind. Whitebark pine cones are co-adapted with Clark’s Nutcrackers to disperse the embedded heavy seeds. Whitebark pine seeds have a mean weight of 175 mg compared to limber pine (*Pinus flexillis*), the next heaviest, at 93 mg, and to the familiar lodgepole pine (*Pinus contorta*) at 4 mg [192]. Whitebark pine seeds consist of 21% carbohydrate, 21% protein, and 52% fat. They contain more calories per pound than chocolate [199]. The protein includes sixteen amino acids, including lysine, which is particularly important for birds. Also, the fat provides high-energy food needed by wildlife in winter, such as hibernating bears. These seeds or “pine nuts” play a key role in supporting the subalpine to timberline wildlife community.

The seeds have particular germination and growth requirements. Only Clark’s Nutcrackers can disperse these weighty seeds for successful germination. Using their bills, the birds plant the seeds ½-3/4 inches (1.2- 2.2 cm) deep in burned areas, openings, and exposed slopes at timberline and below in subalpine to montane zones. Fire is often important in clearing out plant competition, especially at these lower forested sites. Unlike other pines, and indeed other conifers, whitebark pine seed has complex dormancy requirements and may take 2-3 years to develop its embryo and sprout. As such, a seedbank remains viable for a few years after dispersal, allowing for at least a couple of chances to establish in favorable growing years.

Whitebark pines are particularly adapted to cold, exposed, windy conditions found at high elevations. They can also grow at lower elevations with sufficient sun, as found in fire-cleared areas; however, in these relatively moist, warmer, protected sites, lodgepole pine, subalpine fir, and Engelmann spruce are also well adapted. These species will eventually overtop and shade out whitebark pine by succession. Whitebark pine has the unique competitive edge only on the higher aspects of mountains, where it can become a climax tree. [200]

Key Associations

As a keystone species, whitebark pine serves a greater ecological role compared to other species in a given area. As a “foundational” species it defines the ecosystem structure, function, and process. It supports a range of species and services due to its large nutritious seeds and its ability to provide cover and structure in otherwise inhospitable habitat [191].

Clark’s Nutcrackers

Clark’s Nutcrackers have co-evolved with the only North American stone pine: whitebark pine. It is a truly remarkable species for its behavior and intelligence. Related to jays and crows — other members of the Corvid family — this medium-sized bird is readily identified by its long, strong bill, slate-gray head and body, with a contrasting flash of white and black on its wings and tail as it flies. While hiking at high elevations in summer, one often hears the raucous calls of family groups. Perched in the tops of trees and using their strong bills, nutcrackers jab open the thick resin-coated cones, deftly pick out the seeds, and toss up to 150 (usually an average of 77) seeds back down into a special sublingual (beneath their tongue) pouch to transport the seeds to cache sites. With bulging throats, birds will travel a few yards to several miles to an open, dry, often steep mountain slope, including areas where there are

high snow loads, poor soil development, and short growing seasons [191, 193]. Often nutcrackers prefer caching seeds in recently burned areas.

Nutcrackers are remarkable in their diligence and memory. A nutcracker will use its bill to swipe open a hole ½”-3/4” (1.2-2.2 cm) deep, chuck up the seed from its sublingual pouch to the front of its beak, and place the seed in the hole, for an average 2-5 seeds per hole. It sweeps soil over the hole, obscuring the location, and then pauses to calculate the position based on surrounding features. Then it starts another hole near by. It is estimated that a nutcracker can bury over 32,000 seeds in thousands of locations, remembering the exact spots for at least 180 days, if not a year [201]. They typically retrieve about half of the total harvest. This will be the critical food supply for adults in winter and families later in the season. Often other nutcrackers will choose the same area, thereby forming communal stashes.

In the GYE, nutcrackers feed on invertebrates and conifer seeds — particularly Douglas-fir, whitebark pine, and occasionally limber pine [202]. When whitebark pines have a low production year, nutcrackers fail to breed, likely due to insufficient nutrition from their seeds [203]. In productive years, nutcrackers will arrive in pine stands in June and by August start harvesting seeds for the winter. Nutcrackers breed in early March to mid June in the JH area [202]. Both parents have brood patches to take turns incubating the eggs through the cold. In some populations, hatchlings are fed the high-fat, protein-rich seeds retrieved from windswept slopes or other areas where snow melts relatively early. For several months thereafter, fledglings travel in noisy family groups, watching their parents find and stash seed. Juveniles must learn this essential survival behavior by early fall when they have to do it all on their own. In low mast years within a region, nutcrackers will travel widely to look for other whitebark stands or instead forage in Douglas-fir, limber, pinon, and ponderosa pines, often helping to disperse these species’ seeds as well. However, while nutcrackers can survive on other foods, whitebark pines absolutely depend on nutcrackers to spread their seeds; an unusual obligate mutualism between a plant and bird species.

Grizzly Bears, Red Squirrels, and Whitebark Pine

Whitebark pine is key to another intriguing relationship: in this case between the common red squirrel and endangered grizzly bear [198]. Red squirrels clip off ripening whitebark pine cones held high in the tree's canopy, far out of reach of bears, and store the cones in middens for their winter food supply. At higher elevations, red squirrels live in dense spruce-fir or even lodgepole pine forests and forage upslope for whitebark pine. Red squirrels are vociferous in defending their caches, but by making so much noise they help attract bears to the middens. In bountiful years, grizzly bears will raid these middens and eat primarily whitebark pine seeds from summer to fall until they hibernate. The bruins may even return to squirrel middens the following year. The large seeds are highly nutritious, with high fat content which readily converts to animal fat needed for hibernation. Grizzly bears are also known to eat a squirrel or two while they root for the cones. It is interesting that bears carefully remove the surrounding cone parts to consume only the seeds, not the bracts or scales. Any seeds that happen to be left behind do not germinate.

Whitebark pine seeds benefit grizzly populations in the GYE in several ways. Female grizzlies consume twice the amount of seeds compared to males. With the added nutrition, sows are more likely to raise three vs. one or two cubs successfully. Also, the high-elevation food source diverts the bruins from seeking food at lower elevations where they are more exposed to people around developments, ranches, and roads. Consequently, fewer bears are trapped or shot as nuisances or killed accidentally by vehicles [198].

This relationship of grizzly bears and whitebark pine seeds is, for the most part, characteristic in the GYE [198]. While grizzlies eat a variety of foods, in the GYE whitebark pine has been one of their four top food items, which include elk, cutthroat trout, and army cut worms. Introduced Lake Trout have significantly reduced the numbers and accessibility of spawning Yellowstone Cutthroat Trout. Elk numbers have declined over the years for a variety of contributing causes [204]. In the GYE, the reduction of whitebark pine by over 50% is a concern for sustaining grizzly populations in the JH area national parks and forests. However, others cite recent research indicating the grizzly bear as adapting well to other food items such as ungulates, roots, and truffles and assert that the bear population is reaching its carrying capacity, not declining due to lack of pine seeds [197].

Other Associates

While few other creatures benefit as directly as Clark's Nutcrackers and grizzly bears, other birds and mammals utilize the nutritious seeds and benefit from the structure of whitebark pine habitats. Several songbirds, such as woodpeckers, nuthatches, and Pine Grosbeaks, often forage, perch, and nest where whitebark pines grow. At timberline, whitebark pines provide nurse sites for other trees, shrubs, and wildflowers to become established. Yellow-pine chipmunks and golden-mantled ground squirrels harvest cones, often to have them taken by ravens, crows, or Stellar's Jays. Dusky Grouse feed on needles and buds in winter. None of these species are dependent on the whitebark pine community; however, the trees' presence enhances species diversity and numbers at otherwise inhospitable elevations.

Ecological Services

Depending on the location and situation, whitebark pine provides significant ecological services. Over time, seedlings grow up to provide shade and trap snow which help to provide shelter and moisture for seedlings of spruce and fir and other plants, beginning the successional process and slowly altering organic matter, soil nutrients, and water-holding capacity. Stands in alpine areas help to stabilize soil and

accumulate snow, retard spring run-off, reduce flooding and erosion, and improve water quality. These services also benefit wildlife and human communities downstream [22].

Status and Trends of Whitebark Pine in the Jackson Hole Area

Whitebark pine is receiving considerable attention from federal agencies, researchers, land managers, and non-governmental organizations (NGOs). *Pinus albicaulis* is listed as a candidate species under the Endangered Species Act and may be proposed for listing when funding and workload priorities for other listing actions allow [205].

The Wyoming Game and Fish Department emphasizes the whitebark pine community in its State Wildlife Action Plan and designates the closely associated Clark's Nutcracker and grizzly bear as SGCN [22]. Regionally, the Greater Yellowstone Coordinating Committee has taken a leading role by appointing the Greater Yellowstone Whitebark Pine Subcommittee to study the species' regional decline and management actions to restore it on the landscape within the GYE. Grand Teton National Park monitors and tracks whitebark pine.

These sources indicate a concern about whitebark pines decline. The Whitebark Pine Strategy for the Greater Yellowstone Area cites 40% of the GYA stands contained some level of canopy mortality in 2007 [191]. A 2008 study indicated mountain pine beetle activity in 50% of stands. A 2009 survey throughout the region showed 50% of all stands having high to complete mortality of overstory trees. Blister rust infection rates in some research plots were as high as 84% mortality. The SWAP states an 80% mortality of whitebark pine in the GYE [22], and the Whitebark Pine strategy report [191] states mortality of trees in some regions of the Rocky Mountains is as high as 90%. Whatever way measured, the species has been in serious decline.

Threats

Historical forest management practices, two pests — native mountain pine beetle and nonnative white pine blister rust — and effects from climate change are interrelated threats to whitebark pine and its high-elevation associates. Loss of support of cooperative research, planning, and management action would reduce hope for the trees' long-term survival.

White Pine Blister Rust — High

While mountain pine beetle infestations are variable and are waning in the GYE for the time being (see below), blister rust is becoming more prevalent and is killing trees of all ages throughout much of the area. White pine blister rust is an introduced fungal disease that arrived in the U.S. from Asia via Europe in the early 1900s on forestry stock. It infects five-needled pines, such as towering eastern and western white pines, heavy-seeded limber and whitebark pines, and ancient bristlecone pine. The life cycle of *Cronartium ribicola* is complex with 5 different kinds of spores alternating on four host species: from white pines to primarily shrubby *Ribes* sp. — wild currants and gooseberries — or to a lesser extent colorful paintbrushes (*Catilleja*) and louseworts (*Pedicularis*). Fungal spores circulate by wind, land on hosts at particular stages of growth, and colonize readily with conditions of high humidity and cool temperatures. Thus, the spread of blister rust varies depending on the weather and climate, topography, proximity of infected plants, the individual pine's genetic resistance, and the particular genetic strain of the rust itself. [177, 206, 207]

Blister rust spreads unseen at first. Travelling by wind from *Ribes* leaves, spores lodge on the stomata (tiny openings) of pine needles or on open wounds. They quickly germinate and begin to colonize into the vessel system of twigs and eventually spread down into the tree trunk. Blister-like cankers erupt, exuding a different type of spore that will continue to infect and reproduce until the tree's vessel system is so clogged and the protective bark is so ruptured that the tree dies. Visible evidence of

blister rust includes reddish dead needles, orange swellings or blisters on twigs, dead twigs, and trunks with wounds seeping resin. Rodents will gnaw at these wounds, adding to a tree's vulnerable condition. It can take at least a year for signs of infection to appear. [177]

All sizes of pines succumb to blister rust, either within months for seedlings or years for large trees. In large whitebark pines, blister rust can reduce growth, cone production, and seed size for years before rust girdles the trunk, killing the whole tree. Meanwhile, rust continues to spread infectious spores throughout the pine community.

In areas of high blister rust infection and consequently low seed production, researchers are concerned that Clark's Nutcrackers will consume most of the seeds instead of leaving some cached seed for regeneration. In Glacier National Park, which has lost a significant component of whitebark pine, Clark's nutcrackers are now a rare visitor [199] (D. Reinhart, personal communication). The reduction or loss of nutcrackers in the region would further reduce whitebark pine reproduction [191, 202].

Mountain pine beetle — Medium

Mountain pine beetle (*Dendroctonus ponderosae*) is a native species with intermittent outbreaks on pine species across the west. In the past, cold winter temperatures have limited infestations to primarily lodgepole pines at lower elevations and to one brood cycle every couple of years. However, climate warming and beetle adaptations have shortened and synchronized the beetle's generation time to only one year in many areas. Within the last two decades, beetles have infested areas of high elevation ecosystems that were once considered beyond threat [191, 208]. Drought can also increase vulnerability to infestations. Fortunately, at this time in the GYE, mountain beetle infestations appear to be waning [197].

More specifically, these small beetles attack large, mature whitebark pines, as well as limber and lodgepole pines. Beetles require trees with sufficient cambium (the vessel and growth cells just under the bark) to support larvae. Typically, infected trees tend to be greater than 8 inches (20 cm) in diameter and older in age, such as 80 years old for lodgepole pines. Under certain conditions, female beetles mass attack the lower 15 feet (4.5 m) of tree trunks, boring though the bark, then creating vertical galleries into the phloem or sap system just underneath to deposit eggs. Coincidentally, adult beetles transport fungal spores into the tree which grow fungal strands (mycelia) into the phloem and sapwood (outer wood). Larvae excavate galleries horizontally while consuming the plant's sap and also the fungus. Together, the beetles and fungus deprive the tree of nourishment and water, clog transport vessels, and limit resin defense systems [177]

Healthy trees can "pitch out" (overwhelm with resin) attacking females, a reaction indicated by scattered wads of consolidated resin, sawdust, and beetles around holes on the tree trunk. But with trees weakened by drought or other pests such as blister rust, beetles overwhelm the tree's defensive resin system. Often within a year or two, the whole tree will die, leaving clues as to the cause; rusty-red needles, a trunk peppered with tiny holes often obscured by mounds of cream-to-red exudate, and fine sawdust at its base. Bark flakes off, revealing the extensive system of beetle galleries. Trees may also have large holes from woodpeckers prospecting for beetles. Sawed logs exhibit a bluish-gray discoloration on the outer rings of wood caused by the fungus. [177]

As pines have co-evolved with mountain pine beetles, there is a historical resilience to intermittent epidemics. However, with additional stressors of climate change causing drought, shorter beetle generational times, and increased incidence of fire, ecologists are concerned that both lodgepole and whitebark pine communities will shift to different community types.

Climate change, direct effects — Medium

Climate change can exacerbate current declines, potentially limiting populations to mountain tops or northern portions of the species' range [191]. Warmer temperatures both in summer and winter, as well as drought, could create novel types of environments which are not suitable for growth. More tolerant species such as spruce and fir may be able to succeed into higher elevations where whitebark once dominated. Increased frequency and severity of fires or mountain pine beetle outbreaks may eliminate whitebark pine trees before they reach sufficient reproductive age at 40-80 years old. Finally, the enhanced spread of white pine blister rust can eliminate trees of all ages.

On the other hand, some researchers propose that whitebark pine may be more adaptable than first thought [195]. Pollen samples from lake-bottom cores indicate that whitebark pines grew at a variety of lower elevations and higher temperature regimes thousands of years ago. The trees' distribution was eventually limited by succession of other species slowly returning after the retreats of glaciers. Still, while whitebark pine has the genetic capacity to adapt to warmer summers, it may not be to the warmer winters predicted in climate change. Other stressors may inhibit population establishment and increase [191].

Indirect Threats or Contributing Factors

Loss of support for research and cooperative work

Ongoing support for research and planning is essential to the future of whitebark pine. While the task to sustain whitebark pine communities appears daunting, the species is unlikely to maintain viable natural populations without management intervention.

Devising effective management plans is complicated not only by the ecology of the whitebark pine community and its threats [196], but also by our cultural restrictions. Working groups (see below) are researching genetics, climate change predictions, seed collection and propagation techniques, as well as planting practices and microsites. They are developing cooperative plans for fire and disease

management, along with reintroductions using sophisticated models incorporating on-the-ground observations to discern best options for the long term. However, some ideas meet social resistance: translocating different phenotypes to new locations or "assisted migration," conducting experiments within designated Wilderness Areas and National Parks, and thinning and burning treatments. In addition, securing federal grants for these types of programs is always a challenge. Indeed, maintaining whitebark pine on the landscape is a decades-long conservation investment.

Forest management practices and succession

Historical fire exclusion efforts in some areas have prevented fires from spreading into whitebark habitats. Consequently, spruce and fir have succeeded to overtop this shade-intolerant species [190]. Stressed from competition with spruce and fir, whitebark pines may be less resistant to mountain pine beetles. Also, with denser, more extensive spruce-fir forests, reintroduction of natural fire becomes a complex management challenge. One author argues that "Restoration and maintenance of native fire regimes… is the most important management action… to ensure persistence of whitebark pine" [201].

Future management plans can impact the persistence of whitebark pine. The natural fire return interval for whitebark pine communities is complex and variable, ranging from 60-300 years [190]. Prescribed fires can reduce competition from Engelmann spruce and subalpine fir and expose soils for seed establishment by nutcrackers, thereby facilitating early successional stands of whitebark pine. Furthermore, periodic fires typically prevent the growth of extensive, dense tracts of forest with accumulated fuel loads and continuous canopies, which increases spread of stand-replacing fires, diseases, and insect pests, such as mountain pine beetles. Periodic fire helps to clear out dead and old conifers, opens areas to light, and recycles nutrients, thereby encouraging establishment of young stands to grow once again into ancient trees.

Cooperation and Opportunity

While threats to whitebark pine appear overwhelming, many groups are coordinating priorities to sustain the species in the region. Here is a summary of some recent findings and efforts that provide encouragement.

Recent findings

- A recent model indicates that with a "low to moderate level of management action" it is possible to maintain and restore viable whitebark pine populations on the landscape [194].
- The JH area has substantial Douglas-fir forests that have sustained Clark's Nutcracker populations in low whitebark pine mast years [202]. Perhaps this alternative food source will be sufficient to attract enough nutcrackers to this region to distribute whitebark pine seeds naturally in years to come.
- Whitebark pines have an ancestral genetic resistance to white pine blister rust. Both whitebark pine and the white pine blister rust evolved together in Asia millennia ago, before travelling their separate ways to the western United States. It is likely whitebark pines retain rust-resist genes. In fact, resistant strains have been found here in the JH area [195].

Cooperation

In 2000, the Greater Yellowstone Coordinating Committee established the Whitebark Pine Subcommittee to coordinate whitebark pine efforts. This workgroup, which consists of several federal agencies, has produced and continues to update an Adaptive Action Plan [193]. It maintains an annotated

bibliography of published research and holds annual meetings to present current research findings. Furthermore, in 2010 it established a whitebark pine distribution and condition assessment for the GYE in partnership with the Greater Yellowstone Monitoring Network (GRYN) to develop monitoring protocols. They plan to monitor the health, status, and populations of the pine in the GYE indefinitely [191, 193].

The Whitebark Pine Subcommittee is applying this research to on-the-ground actions. It has determined "priority resource zones," rust resistant "superior" trees, and "restoration target areas." It works with the U.S. Forest Service and Grand Teton National Park to collect, test, and propagate rust-resistant strains for outplanting into "restoration target areas."

More specifically, the JH area has several components described in the Adaptive Action Plans. A cluster of 5-6 "seed source protection priority areas" lie within the Tetons, with additional sites south of Jackson. These are at the core of the protection areas covered for the GYE. "Genetically unique areas and rust-resistant elite tree locations" have been found within Grand Teton National Park and Caribou-Targhee National Forest to the west. Indeed, Grand Teton National Park protects the 1st and 4th most rust-resistant trees tested to date in the GYE [185]. Furthermore, the JH area encompasses "restoration target areas." The JH area has a central role to play in efforts to retain whitebark pine in the GYE.

Also, the Wyoming Game and Fish Department supports whitebark pine efforts. Its most recent plan outlines steps for management of whitebark pine habitat, including restoration of native fire regimes, removal of insect and diseased trees in surrounding areas, collection of and eventual planting of rust-resistant seed, and thinning existing stands of whitebark pine to increase individual tree vigor [22].

In short, we have a committed community of agencies, researchers, and supporters to help sustain these iconic trees and their wildlife communities in the mountains that surround us.

[This chapter by Frances H. Clark]

Watch List

These species and habitats are ones we did not select as top-priority focal conservation targets for the Jackson Hole area. Nevertheless, they are species and habitats of importance and conservation concern. We highlight them here to acknowledge their importance and need for protection, and to explain why we did not choose them as conservation targets.

Large carnivores (wolves, grizzly bears, mountain lions)

A healthy population of large carnivores is one of the hallmarks of the Greater Yellowstone Ecosystem and something that sets this region apart from many others in the continental United States. Wolves, grizzly bears, and mountain lions are all integral players in the ecosystem. They are also all threatened in various ways. However, wolf and bear populations have increased substantially in the last two decades and are stable for the time being. Mountain lion populations are declining in the Jackson Hole area, but they are not a globally threatened species. Conserving these species in the JH area and the GYE is a high priority, but will require coordinated efforts at a regional scale. For these reasons, we did not choose any of the large carnivores as conservation targets, but we recommend that their status be closely monitored.

Aspen

Aspens are one of the most valued habitat types in the western US and are second in wildlife diversity to riparian habitats in Wyoming. They support 17 SGCN in the JH area. With their rich understory of shrubs and wildflowers, aspen stands provide habitat for many animals. Large mammals such as elk, moose, and deer feed and find shelter in their stands. Small mammals such as porcupines, squirrels, pocket gophers, mice and voles use aspen part of the year. Beaver cut aspen for food and construction materials. The soft-wooded trees provide essential nesting sites for woodpeckers and sapsuckers, whose holes later are used by breeding American Kestrels, Flammulated owls, and many smaller birds such as chickadees, nuthatches, Mountain Bluebirds, and Tree Swallows. Many aspen forests are renewed by fires, and if they do not burn periodically, some areas will become dominated by conifers. They have been the focus of management efforts for years to retain their biodiversity and value for preserving stream flows.

The status of aspen in the Jackson Hole area and the degree of decline, and therefore threats, are difficult to determine. Members of an informal Aspen Working Group are researching the extent of historical stands; burn history e.g. location and frequency of burns; and current health and age of populations. Aspen are common in the low hills and lower mountains slopes around the JH valley, extending into the Gros Ventre and Wind River Ranges. Several stands have burned over the last 10-20 years — either through controlled or wildfires, adding to the diversity of age-classes. Climate change could affect these forests by increasing drought that could stress and kill the trees, and/or the frequency and intensity of fires. Determining management strategies amidst this uncertainty is particularly complex. We place this important plant community on our watch list because it is currently relatively abundant and because of the high uncertainty about how future drought and fire frequency will affect aspen stands and their associated species.

Pika

Pika are small mammals that live in the rocky screes of the alpine zone of the Tetons and mountains across the West. They are significantly threatened by climate change in the GYE and across their range. Pika cannot tolerate high temperatures in the summer and rely on deep snowpacks in the winter to protect them from exposure. As the climate warms, summers are getting hotter and winter

snowpacks are becoming less reliable. Although the threat of climate change is considerable, recent research indicates that pika may be more adaptable than previously thought (E. Hall, personal communication). Pika inhabit a unique habitat; they would not be considered an umbrella species. For these reasons, we put pika on our watch list but did not choose them as a conservation target.

Loons, harlequin ducks, trumpeter swans, and amphibians:

See Snake River and Wetlands Complex chapter.

Meso-carnivores (lynx, wolverine):

Lynx and wolverine are both vulnerable species throughout their range. Wolverines are particularly threatened by climate change. Wolverines are known to occur in the Jackson Hole area, and lynx have been found here historically. However, detecting these animals and surveying their numbers is extremely difficult, making it virtually impossible to assess any status or trend relative to historic numbers. For this reason we do not include lynx and wolverine as conservation targets, although we recognize the considerable conservation need surrounding these species.

References

1. Omernik, J. M., & Griffith, G. E. (2014). Ecoregions of the conterminous United States: evolution of a hierarchical spatial framework. *Environmental Management*, *54*, 1249–1266.
2. Foundations of Success. (2009). *Conceptualizing and planning conservation programs: a training manual based on the Conservation Measures Partnership's Open Standards for the Practice of Conservation*. Retrieved from http://cmp-openstandards.org/wp-content/uploads/2016/02/FOS-CMP-Online-Training-Guide-Steps-1-and-2-updated-8-Feb-2012.pdf
3. Conservation Measures Partnership. (n.d.). *Conservation Measures Partnership*. Retrieved September 17, 2017, from http://www.conservationmeasures.org/
4. Conservation Measures Partnership. (n.d.). *Threats classification - the Open Standards*. Retrieved September 1, 2017, from http://cmp-openstandards.org/using-os/tools/threats-taxonomy/
5. Mitch, W. J., & Gosselink, J. G. (2000). *Wetlands (third edition)*. New York, NY: John Wiley & Sons, Ltd.
6. Wyoming Game and Fish Department. (2010). *State wildlife action plan 2010*. Wyoming Game and Fish Department.
7. Knight, D. H., Jones, G. P., Reiners, W. A., & Romme, W. H. (2014). *Mountains and plains: the ecology of Wyoming landscapes*. New Haven, CT: Yale University Press.
8. U.S Fish and Wildlife Service. (2015). *Comprehensive conservation plan — National Elk Refuge, Wyoming*. U.S. Department of the Interior, Fish and Wildlife Service, Mountain-Prairie Region.
9. Hauer, R. F., Locke, H., Dreitz, V. J., Hebblewhite, M., Lowe, W. H., Muhlfeld, C. C., …

Rood, S. B. (2016). Gravel-bed river floodplains are the ecological nexus of glaciated mountain landscapes. *Science Advances*, *2*(6), e1600026.

10. Copeland, H. E., Tessman, S. A., Girvetz, E. H., Roberts, L., Enquist, C., Orabona, A., … Kiesecker, J. (2010). A geospatial assessment on the distribution, condition, and vulnerability of Wyoming's wetlands. *Ecological Indicators*, *10*(4), 869–879.
11. Alder Environmental, LLC, Ravenworks Ecology, and Teton Conservation District. (2015). *Snake River Valley (Jackson) wetland complex: regional wetlands conservation plan*. (S. Patla, Ed.). Jackson, WY: Wyoming Game and Fish Department.
12. Wyoming Game and Fish Department. (2015). *Strategic habitat plan*. Wyoming Game and Fish Department.
13. Dykaar, B. B., & Wigington, P. J. (2000). Floodplain formation and cottonwood colonization patterns on the Willamette River, Oregon, USA. *Environmental Management*, *25*(1), 87–104.
14. Patten, D. T. (1998). Riparian ecosystems of semi-arid North America: diversity and human impacts. *Wetlands*, *18*(4), 498–512.
15. Clark, M. L., Sadler, W. J., & O'Ney, S. (2004). *Water-quality characteristics of the Snake River and five tributaries in the Upper Snake River basin, Grand Teton National Park, Wyoming, 1998-2002* (No. 2004-5017, Scientific Investigations Report). U.S. Department of the Interior, U.S. Geological Survey.
16. Wright, P. R. (2013). *Hydrogeology and water quality in the Snake River alluvial aquifer at Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012* (No. 2013–5184, Scientific Investigations Report). U.S. Department of Interior, U.S. Geological Survey.
17. Tonina, D., & Buffington, J. M. (2009). Hyporheic exchange in mountain rivers I: mechanics and environmental effects. *Geography Compass*, *3*(3), 1063–1086.
18. Marston, R. A., Mills, J. D., Wrazien, D. R., Bassett, B., & Splinter, D. K. (2005). Effects of Jackson Lake Dam on the Snake River and its floodplain, Grand Teton National Park,

Wyoming, USA. *Geomorphology* , *71*(1), 79–98.

19. Walla Walla District, Corps of Engineers. (2000). *Jackson Hole, Wyoming environmental restoration draft feasibility study: appendices C-I*. U.S. Army Corps of Engineers.
20. Hines, B. (2013). *Distribution, seasonal movement, age, growth and health of bluehead suckers in the Snake River drainage, Wyoming*. Wyoming Game and Fish Department.
21. Homel, K. M. (2013). *Spatial ecology and life-history diversity of Snake River finespotted cutthroat trout* Oncorhynchus clarkii behnkei *in the Upper Snake River, WY* (PhD). (R. Gresswell, Ed.). University of Montana.
22. Wyoming Game and Fish Department. (2017). *State wildlife action plan 2017*. Wyoming Game and Fish Department.
23. Eddy-Miller, C. A., Sando, R., MacDonald, M. J., & Girard, C. E. (2016). *Estimated nitrogen and phosphorus inputs to the Fish Creek watershed, Teton County, Wyoming, 2009-15* (No. 2016–5160, Scientific Investigations Report). U.S. Department of Interior, U.S. Geological Survey.
24. Nico, L., Fuller, P., and Li, J. (2015, January 22). Silver carp (*Hypophthalmichthys molitrix*). *U.S. Geological Survey, Nonindigenous Aquatic Species Database*. Retrieved September 14, 2017, from https://nas.er.usgs.gov/queries/factsheet.aspx?speciesID=549
25. Wyoming Game and Fish Department. (2015, May). Jackson region fisheries newsletter.
26. U.S. Fish and Wildlife Service. (n.d.). New Zealand mudsnail. Retrieved September 9, 2017, from https://www.fws.gov/columbiariver/ANS/factsheets/mudsnail.pdf
27. Benson, A.J., R.M. Kipp, J. Larson, and A. Fusaro. (2014, June 26). *Potamopyrgus antipodarum* (New Zealand mudsnail). *U.S. Geological Survey - Nonindigenous Aquatic Species Database*. Retrieved September 14, 2017, from https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=1008
28. U.S. National Park Service. (n.d.). Yellowstone National Park. Retrieved September 15, 2017, from http://www.nps.gov/yell

29. Benson, A.J., Raikow, D., Larson, J., Fusaro, A. , and Bogdanoff, A.K. (2017, June 5). *Dreissena rostriformis bugensis* (quagga mussel). *U.S. Geological Survey - Nonindigenous Aquatic Species Database*. Retrieved September 3, 2017, from https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=95
30. U.S. Geological Survey. (n.d.). *Dreissena polymorpha* (zebra mussel). *U.S. Geological Survey - Nonindigenous Aquatic Species Database*. Retrieved September 3, 2017, from https://nas.er.usgs.gov/queries/factsheet.aspx?speciesID=5
31. Treier, U. A., Broennimann, O., Normand, S., Guisan, A., Schaffner, U., Steinger, T., & Müller-Schärer, H. (2009). Shift in cytotype frequency and niche space in the invasive plant *Centaurea maculosa*. *Ecology*, *90*(5), 1366–1377.
32. Zouhar, K. (2001, July). *Centaurea maculosa*. *Fire Effects Information System*. U.S. Department of Agriculture, U.S. Forest Service. Retrieved September 3, 2017, from https://www.fs.fed.us/database/feis/plants/forb/censtom/all.html
33. Teton County Weed and Pest District. (2015). Wyoming designated and Teton County declared noxious weed & pest list. Retrieved September 14, 2017, from http://www.tcweed.org/weed-pests-programs/noxious-weeds/weed-id/
34. U.S. Forest Service. (2014). *Field guide for managing perennial pepperweed in the Southwest* (No. TP-R3-16-23). U.S. Department of Agriculture, Forest Service, Southwestern Region.
35. Teton County Weed and Pest District. (n.d.). Perennial pepperweed. Retrieved September 29, 2017, from http://www.tcweed.org/?noxious_weeds=perennial-pepperweed
36. State of Washington, Department of Ecology. (n.d.). Non-native invasive freshwater plants: salt cedar (*Tamarix*). Retrieved September 29, 2017, from http://www.ecy.wa.gov/programs/wq/plants/weeds/aqua013.html
37. Wenger, S. J., Isaak, D. J., Luce, C. H., Neville, H. M., Fausch, K. D., Dunham, J. B., … Williams, J. E. (2011). Flow regime, temperature, and biotic interactions drive differential

declines of trout species under climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(34), 14175–14180.

38. Whitney, J. E., Al-Chokhachy, R., Bunnell, D. B., Caldwell, C. A., Cooke, S. J., Eliason, E. J., … Paukert, C. P. (2016). Physiological basis of climate change impacts on North American inland fishes. *Fisheries*, *41*(7), 332–345.
39. Al-Chokhachy, R., Alder, J., Hostetler, S., Gresswell, R., & Shepard, B. (2013). Thermal controls of Yellowstone cutthroat trout and invasive fishes under climate change. *Global Change Biology*, *19*(10), 3069–3081.
40. Savoy, L. (2015). *Initiating a pilot study to evaluate a long-term Harlequin Duck breeding population monitoring study in Wyoming's Grand Teton National park*. Biodiversity Research Institute.
41. Savoy, L. (n.d.). Waterfowl: movement studies: *Biodiversity Research Institute*. Retrieved September 15, 2017, from http://www.briloon.org/harlequin-duck-study-in-wyoming
42. Wyoming Game and Fish Department. (2017, June 29). Harlequin ducks find farthest east home in Wyoming. *Wyoming Game and Fish Department*. Retrieved September 2, 2017, from https://wgfd.wyo.gov/Wildlife-Update/Harlequin-ducks-find-farthest-eastern-home-in-Wyom
43. Spagnuolo, V. (2015). *Threatened, endangered, and nongame bird and mammal investigations: annual completion report*. Wyoming Game and Fish Department.
44. Spagnuolo, V. (2017, June 28). *Loons in Wyoming (and elsewhere)!* Presented at the Jackson Hole Bird and Nature Club meeting.
45. Spagnuolo, V. (2016). Wyoming Common Loon (*Gavia immer*) summary report 2015. In A. C. Orabona (Ed.), *Threatened, endangered, and nongame bird and mammal investigations: annual completion report* (pp. 291–330). Wyoming Game and Fish Department.
46. U.S. Fish and Wildlife Service. (2017). *Trumpeter Swan survey of the Rocky Mountain population, U.S. breeding segment: fall 2016*. U.S. Fish and Wildlife Service, Migratory

Birds and State Programs, Mountain Prairie Region.

47. Patla, S. (2016). Monitoring and management of the Rocky Mountain population of Trumpeter Swans (*Cygnus buccinator*). In A. C. Orabona (Ed.), *Threatened, endangered, and nongame bird and mammal investigations: annual completion report* (pp. 19–40). Wyoming Game and Fish Department.
48. Groves, D. J. (2017). *The 2015 North American Trumpeter Swan survey: a cooperative North American survey*. U.S. Fish and Wildlife Service, Division of Migratory Bird Management.
49. Patla, S. (2017). Trumpeter Swan. In M. Smith & B. Remlinger (Eds.), *Focal species habitat mapping for Teton County* (pp. 133–143). Jackson, WY: Alder Environmental LLC.
50. Tavesky, A., & Beauvais, G. P. (2014). *Species assessment for the Trumpeter Swan (*Cygnus buccinator*) in Wyoming*. United States Department of the Interior, Bureau of Land Management, Wyoming State Office .
51. Fryer, J. L. (2011). *Alnus incana*. *Fire Effects Information System, U.S. Department of Agriculture, Forest Service*. Retrieved September 6, 2017, from https://www.fs.fed.us/database/feis/plants/tree/alninc/all.html
52. Olechnowski, B. F. M., & Debinski, D. M. (2008). Response of songbirds to riparian willow habitat structure in the Greater Yellowstone Ecosystem. *The Wilson Journal of Ornithology*, *120*(4), 830–839.
53. Smith, M. A. (2017). MacGillivray's Warbler. In M. Smith & B. Remlinger (Eds.), *Focal species habitat mapping for Teton County* (pp. 107–109). Alder Environmental LLC.
54. Finch, D. M. (1989). Habitat use and habitat overlap of riparian birds in three elevational zones. *Ecology*, *70*(4), 866–880.
55. Rosenberg, K. V., Kennedy, J. A., Dettmers, R., Ford, R. P., Reynolds, D., Alexander, J. D., … Others. (2016). Partners in flight landbird conservation plan: 2016 revision for Canada and continental United States. *Partners in Flight Science Committee*.

56. Baker, B. W., Ducharme, H. C., Mitchell, D. C. S., Stanley, T. R., & Peinetti, H. R. (2005). Interaction of beaver and elk herbivory reduces standing crop of willow. *Ecological Applications*, *15*(1), 110–118.

57. Rosell, F., Bozsér, O., Collen, P., & Parker, H. (2005). Ecological impact of beavers *Castor fiber* and *Castor canadensis* and their ability to modify ecosystems. *Mammal Review*, *35*(3-4), 248–276.

58. McKinstry, M. C., Caffrey, P., & Anderson, S. H. (2001). The importance of beaver to wetland habitats and waterfowl in Wyoming. *Journal of the American Water Resources Association*, *37*(6), 1571–1577.

59. Brown, D. J., Hubert, W. A., & Anderson, S. H. (1996). Beaver ponds create wetland habitat for birds in mountains of southeastern Wyoming. *Wetlands*, *16*(2), 127–133.

60. Hossack, B. R., Gould, W. R., Patla, D. A., Muths, E., Daley, R., Legg, K., & Corn, P. S. (2015). Trends in Rocky Mountain amphibians and the role of beaver as a keystone species. *Biological Conservation*, *187*, 260–269.

61. Patla, D., St-Hilaire, S., Ray, A., Hossack, B. R., & Peterson, C. R. (2016). Amphibian mortality events and ranavirus outbreaks in the Greater Yellowstone Ecosystem. *Herpetological Review*, *47*(1), 50–54.

62. Popescu, V. D., & Gibbs, J. P. (2009). Interactions between climate, beaver activity, and pond occupancy by the cold-adapted mink frog in New York State, USA. *Biological Conservation*, *142*(10), 2059–2068.

63. Gribb, W. J., & Harlow, H. J. (2004). A survey of beaver location and habitat to model their distribution in Grand Teton National Park, Wyoming. *University of Wyoming National Park Service Research Center Annual Report*, *28*, 31–40.

64. Collins, T. C. (1977). Instream flows for beaver populations: effects of a midwinter drawdown of the Snake River and drought in Grand Teton National Park. *University of Wyoming National Park Service Research Center Annual Report*, *1*, 18–23.

65. Gribb, W. (2011). Determination of central foraging strategies and location of beaver (*Castor canadensis*) in Grand Teton National Park. *University of Wyoming National Park Service Research Center Annual Report*, *33*, 29–35.

66. Wyoming Game and Fish Department. (n.d.). Furbearing animal trapping. Retrieved September 7, 2017, from https://wgfd.wyo.gov/Regulations#Furbearing-Animal-Trapping

67. Patla, D. (2016). *Amphibian monitoring on the National Elk Refuge, 1998-2014*. Northern Rockies Conservation Cooperative.

68. Stuart, S. N., Chanson, J. S., Cox, N. A., Young, B. E., Rodrigues, A. S. L., Fischman, D. L., & Waller, R. W. (2004). Status and trends of amphibian declines and extinctions worldwide. *Science*, *306*(5702), 1783–1786.

69. Whittaker, K., Koo, M. S., Wake, D. B., & Vredenburg, V. T. (2013). Global declines of amphibians. In S. A. Levin (Ed.), *Encyclopedia of biodiversity (second edition)* (pp. 691–699). Waltham: Academic Press.

70. Gould, W. R., Patla, D. A., Daley, R., Corn, P. S., Hossack, B. R., Bennetts, R., & Peterson, C. R. (2012). Estimating occupancy in large landscapes: evaluation of amphibian monitoring in the Greater Yellowstone Ecosystem. *Wetlands*, *32*(2), 379–389.

71. Patla, D. (2017). Chorus frog. In M. Smith & B. Remlinger (Eds.), *Focal species habitat mapping for Teton County* (pp. 164–176). Alder Environmental LLC.

72. Patla, D. A., & Keinath, D. (2005). *Columbia spotted frog (Rana luteiventris formerly R. pretiosa): a technical conservation assessment*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Region.

73. Chanson, J., Hoffmann, M., Cox, N., & Stuart, S. (2008). The state of the world's amphibians. In S. N. Stuart, M. Hoffmann, J. S. Chanson, N. A. Cox, R. J. Berridge, P. Ramani, & B. E. and Young (Eds.), *Threatened amphibians of the world* (pp. 33–52). Lynx Edicions, IUCN, and Conservation International.

74. National Park Service. (2017, February 10). Amphibian Monitoring. Retrieved October 2,

2017, from https://science.nature.nps.gov/im/units/gryn/monitor/amphibians.cfm

75. Piha, H., Luoto, M., Piha, M., & Merilä, J. (2007). Anuran abundance and persistence in agricultural landscapes during a climatic extreme. *Global Change Biology*, *13*(1), 300–311.
76. Muths, E., Scherer, R. D., & Pilliod, D. S. (2011). Compensatory effects of recruitment and survival when amphibian populations are perturbed by disease. *Journal of Applied Ecology*, *48*(4), 873–879.
77. Pilliod, D. S., Muths, E., Scherer, R. D., Bartelt, P. E., Corn, P. S., Hossack, B. R., … Gaughan, C. (2010). Effects of amphibian chytrid fungus on individual survival probability in wild boreal toads. *Conservation Biology*, *24*(5), 1259–1267.
78. Stettler, R. F. (2009). *Cottonwood and the river of time: on trees, evolution, and society*. Seattle, WA: University of Washington Press.
79. Patla, S. (2016). Bald Eagle (Haliaeetus leucocephalus) monitoring in western Wyoming. In A. C. Orabona (Ed.), *Threatened, endangered, and nongame bird and mammal investigations: annual completion report* (pp. 61–67). Wyoming Game and Fish Department.
80. Bedrosian, B., Gura, K., & Mendesohn, B. (2016). Occupancy, nest success, and habitat use of Great Gray Owls in western Wyoming. In A. C. Orabona (Ed.), *Threatened, endangered, and nongame bird and mammal investigations: annual completion report* (pp. 61–68). Wyoming Game and Fish Department.
81. Hester, S. G., & Grenier, M. B. (2005). *A conservation plan for bats in Wyoming*. Wyoming Game and Fish Department, Nongame Department.
82. Keinath, D. A. (2005). *Bat inventory of the Greater Yellowstone Network*. National Park Service, Greater Yellowstone Network, Inventory and Monitoring Program.
83. U.S. Fish and Wildlife Service. (2017, August). White-nose syndrome map. *White-nose syndrome.org: a coordinated response to the devastating bat disease*. Retrieved September 6, 2017, from https://www.whitenosesyndrome.org/resources/map

84. Mohr, K., & Dahlby, E. (2017, September 13). Rabid bat confirmed, a first for the county. *Jackson Hole Daily*. Retrieved September 19, 2017, from http://www.jhnewsandguide.com/news/health/rabid-bat-confirmed-a-first-for-the-county/article_d6afc9b7-8d4d-566f-b613-7760f1a84554.html
85. Texas Health and Human Services. (2016, March 8). Human deaths in the United States attributed to bat rabies variants. Retrieved from https://www.dshs.texas.gov/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=8589957722
86. Remlinger, B. (2017). Snake River cutthroat trout. In M. Smith & B. Remlinger (Eds.), *Focal species habitat mapping for Teton County* (pp. 154–163). Alder Environmental LLC.
87. Van Kirk, R. W., Capurso, J. M., & Novak, M. A. (2006). Exploring differences between fine-spotted and large-spotted Yellowstone cutthroat trout. In *Symposium Proceedings, Idaho Chapter, American Fisheries Society*.
88. Wyoming Game and Fish Department. (2009, May). Jackson region fisheries newsletter.
89. Koel, T. M., Mahony, D. L., Kinnan, K. L., Rasmussen, C., Hudson, C. J., Murcia, S., & Kerans, B. L. (2007). Whirling disease and native cutthroat trout of the Yellowstone Lake ecosystem. *Yellowstone Science*, *15*(2), 25–33.
90. Elwell, L. C. S., Stromberg, K. E., Ryce, E. K. N., & Bartholomew, J. L. (2009). *Whirling disease in the United States: a summary of progress in research and management* (p. 203). Montana State University, Montana Water Center.
91. Machtinger, E. T. (2007). *Cutthroat trout (Oncorhynchus clarki)*. U.S. Department of Agriculture, Natural Resources Conservation Service. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_010039.pdf
92. Bridger-Teton National Forest. (2015). *Bridger-Teton National Forest land and resource management plan, with corrections and amendments*. U.S. Department of Agriculture, Forest Service.
93. Nolan, B. T., & Miller, K. A. (1995). *Water resources of Teton County, Wyoming, exclusive*

of Yellowstone National Park (No. 95-4204, Water-Resources Investigations). U.S. Department of Interior, U.S. Geological Survey.

94. Suring, L. H., Rowland, M. M., & Wisdom, M. J. (2005). Identifying species of conservation concern. In M. J. Wisdom, M. M. Rowland, & L. H. Suring (Eds.), *Habitat threats in the sagebrush ecosystem: methods of regional assessment and applications in the Great Basin* (pp. 150–162). Lawrence, KS: Alliance Communications Group.
95. Miller, R. F., Knick, S. T., Pyke, D. A., Meinke, C. W., Hanser, S. E., Wisdom, M. J., & Hild, A. L. (2011). Characteristics of sagebrush habitats and limitations to long-term conservation. In S. T. Knick & J. W. Connelly (Eds.), *Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats* (Vol. 38, pp. 145–184). Berkeley, CA: University of California Press.
96. Davies, K. W., Boyd, C. S., Beck, J. L., Bates, J. D., Svejcar, T. J., & Gregg, M. A. (2011). Saving the sagebrush sea: an ecosystem conservation plan for big sagebrush plant communities. *Biological Conservation*, *144*(11), 2573–2584.
97. D'Antonio, C. M., & Vitousek, P. M. (1992). Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and Systematics*, *23*, 63–87.
98. Baker, W. L. (2006). Fire and restoration of sagebrush ecosystems. *Wildlife Society Bulletin*, *34*(1), 177–185.
99. Balch, J. K., Bradley, B. A., D'Antonio, C. M., & Gomez-Dans, J. (2013). Introduced annual grass increases regional fire activity across the arid western USA (1980–2009). *Global Change Biology*, *19*, 173–183.
100. Bradley, B. A., & Mustard, J. F. (2008). Comparison of phenology trends by land cover class: a case study in the Great Basin, USA. *Global Change Biology*, *14*, 334–346.
101. Knick, S. T., & Connelly, J. W. (2011). Greater Sage-Grouse and sagebrush: an introduction to the landscape. In S. T. Knick & J. W. Connelly (Eds.), *Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats* (Vol. 38, pp. 1–9).

Berkeley, CA: University of California Press.

102. Connelly, J. W., Hagen, C. A., & Schroeder, M. A. (2011). Characteristics and dynamics of Greater Sage-Grouse populations. In S. T. Knick & J. W. Connelly (Eds.), *Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats.* (Vol. 38, pp. 53–67). Berkeley, CA: University of California Press.

103. Connelly, J. W., Rinkes, E. T., & Braun, C. E. (2011). Characteristics of Greater Sage-Grouse habitats. In S. T. Knick & J. W. Connelly (Eds.), *Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats* (Vol. 38, pp. 69–83). Berkeley, CA: University of California Press.

104. Chambers, J. C., Beck, J. L., Campbell, S., Carlson, J., Christiansen, T. J., Clause, K. J., … Pyke, D. A. (2016). *Using resilience and resistance concepts to manage threats to sagebrush ecosystems, Gunnison Sage-Grouse, and Greater Sage-Grouse in their eastern range: a strategic multi-scale approach* (No. RMRS-GTR-356, General Technichal Report). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

105. Schulwitz, S., Bedrosian, B., & Johnson, J. A. (2014). Low neutral genetic diversity in isolated Greater Sage-Grouse (*Centrocercus urophasianus*) populations in northwest Wyoming. *The Condor*, *116*(4), 560–573.

106. Upper Snake River Basin Sage-Grouse Local Working Group. (2014). *Upper Snake River Basin sage-grouse conservation plan*.

107. Bedrosian, B., Crandall, R., & Craighead, D. (2010). *Jackson Hole Sage-grouse Project completion report: 2007-2009*. Craighead Beringia South.

108. Bradley, B. A. (2009). Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. *Global Change Biology*, *15*(1), 196–208.

109. Patterson, R. L. (1952). *The sage-grouse in Wyoming*. Denver, CO: Sage Books.

110. Westerling, A. L., Turner, M. G., Smithwick, E. A. H., Romme, W. H., & Ryan, M. G. (2011). Continued warming could transform Greater Yellowstone fire regimes by mid-21st

century. *Proceedings of the National Academy of Sciences*, *108*(32), 13165–13170.

111. Abatzoglou, J. T., & Kolden, C. A. (2011/9). Climate change in western US deserts: potential for increased wildfire and invasive annual grasses. *Rangeland Ecology & Management*, *64*(5), 471–478.

112. Fryxell, J. M., & Sinclair, A. R. (1988). Causes and consequences of migration by large herbivores. *Trends in Ecology & Evolution*, *3*(9), 237–241.

113. Fryxell, J. M., Greever, J., & Sinclair, A. R. E. (1988). Why are migratory ungulates so abundant? *The American Naturalist*, *131*(6), 781–798.

114. Bolger, D. T., Newmark, W. D., Morrison, T. A., & Doak, D. F. (2008). The need for integrative approaches to understand and conserve migratory ungulates. *Ecology Letters*, *11*(1), 63–77.

115. Berger, J. (2004). The last mile: how to sustain long-distance migration in mammals. *Conservation Biology*, *18*(2), 320–331.

116. Harris, G., Thirgood, S., Hopcraft, J., Cromsight, J., & Berger, J. (2009). Global decline in aggregated migrations of large terrestrial mammals. *Endangered Species Research*, *7*, 55–76.

117. Sawyer, H., Lindzey, F., & McWhirter, D. (2012). Mule deer and pronghorn migration in western Wyoming. *Wildlife Society Bulletin*, *33*(4), 1266–1273.

118. Sawyer, H., Hayes, M., Rudd, B., Kauffman, M.J. (2014). *The Red Desert to Hoback mule deer migration assessment*. Wyoming Migration Initiative.

119. Cole, E. K., Foley, A. M., Warren, J. M., Smith, B. L., Dewey, S. R., Brimeyer, D. G., … Cross, P. C. (2015). Changing migratory patterns in the Jackson elk herd. *Journal of Wildlife Management*, *79*(6), 877–886.

120. Jones, J. D., Kauffman, M. J., Monteith, K. L., Scurlock, B. M., Albeke, S. E., & Cross, P. C. (2014). Supplemental feeding alters migration of a temperate ungulate. *Ecological Applications*, *24*(7), 1769–1779.

121. Whitfield, M. B. (1983). *Bighorn sheep history, distribution and habitat relationships in the Teton Mountain Range, Wyoming* (M.S.). Idaho State University, Pocatello, ID.

122. Courtemanch, A. B., Kauffman, M. J., Kilpatrick, S., & Dewey, S. R. (2017). Alternative foraging strategies enable a mountain ungulate to persist after migration loss. *Ecosphere* , *8(6):e01855. 10.1002/ecs2.1855*.

123. Vartanian, J. M. (2008, December). *Habitat condition and the nutritional quality of seasonal forage and diets: demographic implications for a declining moose population in northwest Wyoming, USA* (M.S.). University of Wyoming.

124. Becker, S. A. (2008). *Habitat selection, condition, and survival of Shiras moose in northwest Wyoming* (M.S.). University of Wyoming.

125. Bischof, R., Loe, L. E., Meisingset, E. L., Zimmerman, B., Van Moorter, B., & Mysterud, A. (2012). A migratory northern ungulate in the pursuit of spring: jumping or surfing the green wave? *The American Naturalist*, *180*, 407–424.

126. Aikens, E. O., Kauffman, M. J., Merkle, J. A., Dwinnell, S. P. H., Fralick, G. L., & Monteith, K. L. (2017). The greenscape shapes surfing of resource waves in a large migratory herbivore. *Ecology Letters*, *20*(6), 741–750.

127. Merkle, J. A., Monteith, K. L., Aikens, E. O., Hayes, M. M., Hersey, K. R., Middleton, A. D., … Kauffman, M. J. (2016). Large herbivores surf waves of green-up during spring. *Proceedings of the Royal Society B*, *283: 20160456*.

128. Sawyer, H., & Kauffman, M. J. (2011). Stopover ecology of a migratory ungulate. *Journal of Animal Ecology*, *80*(5), 1078–1087.

129. Sawyer, H., Kauffman, M. J., Nielson, R. M., & Horne, J. S. (2009). Identifying and prioritizing ungulate migration routes for landscape-level conservation. *Ecological Applications*, *19*(8), 2016–2025.

130. Sawyer, H., Kauffman, M. J., Middleton, A. D., Morrison, T. A., Nielson, R. M., & Wycoff, T. B. (2013). A framework for understanding semi-permeable barrier effects on migratory

ungulates. *Journal of Applied Ecology*, *50*(1), 68–78.

131. Wakeling, B. F., Gagnon, J. W., Olson, D. D., Lutz, D. W., Keegan, T. W., Shannon, J. M., … Schroeder, C. (2015). *Mule deer and movement barriers*. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies.

132. Courtemanch, A. B. (2014, May). *Seasonal habitat selection and impacts of backcountry recreation on a formerly migratory bighorn sheep population in northwest Wyoming, USA* (M.S.). University of Wyoming.

133. Cromley, C. M., & Others. (2000). Historical elk migrations around Jackson Hole, Wyoming. *Yale School of Forestry and Environmental Studies Bulletin*, *104*, 53–65.

134. Middleton, A. D., Kauffman, M. J., McWhirter, D. E., Cook, J. G., Cook, R. C., Nelson, A. A., … Klaver, R. W. (2013). Animal migration amid shifting patterns of phenology and predation: lessons from a Yellowstone elk herd. *Ecology*, *94*(6), 1245–1256.

135. Seidler, R. G., Long, R. A., Berger, J., Bergen, S., & Beckmann, J. P. (2015). Identifying impediments to long-distance mammal migrations. *Conservation Biology*, *29*(1), 99–109.

136. Sawyer, H., Rodgers, P. A., & Hart, T. (2016). Pronghorn and mule deer use of underpasses and overpasses along U.S. Highway 191. *Wildlife Society Bulletin*, *40*(2), 211–216.

137. Beckmann, J. P., Murray, K., Seidler, R. G., & Berger, J. (2012). Human-mediated shifts in animal habitat use: sequential changes in pronghorn use of a natural gas field in Greater Yellowstone. *Biological Conservation*, *147*(1), 222–233.

138. Harrington, J. L., Conover, M. R., & Mason. (2006). Characteristics of ungulate behavior and mortality associated with wire fences. *Wildlife Society Bulletin*, *34*(5), 1295–1305.

139. Paige, C. (2012). *A landowner's guide to fences and wildlife: practical tips to make your fences wildlife friendly*. Wyoming Land Trust.

140. Riginos, C., Copeland, H., Smith, C., Sawyer, H., Krasnow, K., & Hart, T. (2016). *Planning-support for mitigation of wildlife-vehicle collisions and highway impacts on*

migration routes in Wyoming (No. FHWY-WY-16/10F). Federal Highway Administration.

141. Riginos, C., Krasnow, K., Hall, L. E., Graham, M., Sundaresan, S. R., Brimeyer, D., … Wachob, D. (2013). *Mule deer (*Odocoileus hemionus*) movement and habitat use patterns in relation to roadways in northwest Wyoming* (No. FHWA-WY-12/08F). Federal Highway Administration.

142. Sawyer, H., Nielson, R. M., Lindzey, F., & McDonald, L. L. (2006). Winter habitat selection of mule deer before and during development of a natural gas field. *Journal of Wildlife Management*, *70*(2), 396–403.

143. Sawyer, H., Kauffman, M. J., & Nielson, R. M. (2009). Influence of well pad activity on winter habitat selection patterns of mule deer. *Journal of Wildlife Management*, *73*(7), 1052–1061.

144. Edmunds, D. R., Kauffman, M. J., Schumaker, B. A., Lindzey, F. G., Cook, W. E., Kreeger, T. J., … Cornish, T. E. (2016). Chronic wasting disease drives population decline of white-tailed deer. *PLOS One*, *11*, e0161127.

145. Kreeger, T., Cornish, T., Creekmore, T. E., Edwards, W. H., & Tate, C. (2011). *Field guide to diseases of Wyoming wildlife*. Wyoming Game and Fish Department.

146. Thorne, E. T. (1997). Brucellosis: the disease in elk. In E. T. Thorne (Ed.), *Brucellosis, bison, elk, and cattle in the Greater Yellowstone Area: defining the problem, exploring solutions* (pp. 33–44). Cheyenne, WY: Wyoming Game and Fish Department.

147. Thorne, E. T. (2001). Brucellosis. In E. S. Williams & I. K. Barker (Eds.), *Infectious diseases of wild mammals* (pp. 372–395). Ames, IA: Iowa State University Press.

148. Geremia, C., Miller, M. W., Hoeting, J. A., Antolin, M. F., & Hobbs, N. T. (2015). Bayesian modeling of prion disease dynamics in mule deer using population monitoring and capture-recapture data. *PloS One*, *10*, e0140687.

149. Rytwinski, T., Soanes, K., Jaeger, J. A. G., Fahrig, L., Findlay, C. S., Houlahan, J., … van der Grift, E. A. (2016). How effective is road mitigation at reducing road-kill? A meta-

analysis. *PloS One*, *11*(11), e0166941.

150. Smith, M., & Remlinger, B. (Eds.). (2017). *Focal species habitat mapping for Teton County*. Alder Environmental LLC.

151. Renecker, L. A., & Hudson, R. J. (1986). Seasonal energy expenditures and thermoregulatory responses of moose. *Canadian Journal of Zoology*, *64*, 322–327.

152. van Beest, F. M., & Milner, J. M. (2013). Behavioural responses to thermal conditions affect seasonal mass change in a heat-sensitive northern ungulate. *PloS One*, *8*(6), e65972.

153. Murray, D. L., Cox, E. W., Ballard, W. B., Whitlaw, H. A., Lenarz, M. S., Custer, T. W., … Fuller, T. K. (2006). Pathogens, nutritional deficiency, and climate influences on a declining moose population. *Wildlife Monographs*, *186*, 1–30.

154. Monteith, K. L., Klaver, R. W., Hersey, K. R., Holland, A. A., Thomas, T. P., & Kauffman, M. J. (2015). Effects of climate and plant phenology on recruitment of moose at the southern extent of their range. *Oecologia*, *178*(4), 1137–1148.

155. Houston, D. B. (1968). *The Shiras moose in Jackson Hole, Wyoming* (No. 1, Technical Bulletin). Grand Teton Natural History Association.

156. Brimeyer, D. G., & Thomas, T. P. (2004). History of moose management in Wyoming and recent trends in Jackson Hole. *Alces* , *40*, 133–143.

157. Courtemanch, A. (2015). *Jackson moose herd unit population objective review*. Wyoming Game and Fish Department.

158. Courtemanch, A. (2017). *Jackson-Pinedale region 2016 job completion report for moose*. Wyoming Game and Fish Department.

159. Oates, B. A. (2016, December). *Effects of predators and resource limitation on demography and behavior of moose in the Greater Yellowstone Ecosystem* (M.S.). University of Wyoming.

160. Stephenson, J., Dewey, S., & Cain, S. (2013). Wildlife research: wolf predation. In S.

Cain (Ed.), *Wildlife Conservation, Management and Research 2013* (pp. 54–55). Grand Teton National Park.

161. Stephenson, J., Jimenez, J., Dewey, S., & Cain, S. (2012). Wildlife research: wolf predation. In S. Cain (Ed.), *Wildlife Conservation, Management and Research 2012* (pp. 1–2). Grand Teton National Park.

162. Stephenson, J., Jimenez, J., Dewey, S., & Cain, S. (2011). Wildlife research: wolf predation. In S. Cain (Ed.), *Wildlife Conservation, Management and Research 2011* (pp. 56–57). Grand Teton National Park.

163. Becker, S. A., Kauffman, M. J., & Anderson, S. H. (2010). Nutritional condition of adult female Shiras moose in northwest Wyoming. *Alces* , *46*, 151–166.

164. Henningsen, J. C., Williams, A. L., Tate, C. M., Kilpatrick, S. A., & David Walter, W. (2012). Distribution and prevalence of *Elaeophora schneideri* in moose in Wyoming. *Alces* , *48*, 35–44.

165. Sibley, D. A. (2001). *National Audubon Society: the Sibley guide to bird life and behavior*. New York, NY: Alfred A. Knopf.

166. Squires, J. R., & Kennedy, P. L. (2006). Northern Goshawk ecology: an assessment of current knowledge and information needs for conservation and management. *Studies in Avian Biology*, *No. 31*, 8–62.

167. Reynolds, R. T., Wiens, J. D., & Salafsky, S. R. (2006). A review and evaluation of factors limiting northern goshawk populations. *Studies in Avian Biology*, *31*, 260.

168. Patla, S. (1997). *Nesting ecology and habitat of the Northern Goshawk in undisturbed and timber harvest areas on the Targhee National Forest, Greater Yellowstone Ecosystem* (Masters of Science). Idaho State University.

169. Bedrosian, B. (2017). Goshawk. In M. A. Smith & B. Remlinger (Eds.), *Focal species habitat mapping for Teton County* (pp. 110–117). Alder Environmental LLC.

170. Bedrosian, B. (2017). Great Gray Owl. In M. Smith & B. Remlinger (Eds.), *Focal species*

habitat mapping for Teton County (pp. 83–92). Alder Environmental LLC.

171. Patla, S. M. (2005). Monitoring results of Northern Goshawk nesting areas in the greater Yellowstone ecosystem: is decline in occupancy related to habitat change? *Journal of Raptor Research*, *39*(3), 324.

172. Bureau of Land Management. (2012). *Middle Rockies rapid ecoregional assessment* (No. II-3-C, Final Memorandum). Department of Interior, Bureau of Land Management, Rapid Ecological Assessments.

173. Woodbridge, B., & Hargis, C. D. (2006). *Northern Goshawk inventory and monitoring technical guide* (No. WO-71, General Technical Report). U.S. Department of Agriculture, Forest Service.

174. Berven, J. (2014). Wyoming Range Northern Goshawk (*Accipiter gentilis*) nest search and monitoring. In A. C. Orabona & N. Cudworth (Eds.), *Threatened, endangered, and nongame bird and mammal investigations: annual completion report* (pp. 149–184). Wyoming Game and Fish Department.

175. Berven, J. (2010). Northern Goshawk bioregional monitoring in the Bridger-Teton National Forest. In A. C. Orabona (Ed.), *Threatened, endangered, and nongame bird and mammal investigations: annual completion report* (pp. 85–99). Wyoming Game and Fish Department.

176. U S Forest Service. (2013). *Scoping Teton to Snake fuels management project*. U.S. Department of Agriculture, Forest Service.

177. Gibson, K., Kegley, S., & Bentz, B. (2009). *Mountain pine beetle* (No. 2, Forest insect and disease leaflet). U.S. Department of Agriculture, Forest Service.

178. Kegley, S. (2011). Douglas-fir beetle management. *USDA Forest Service*. Retrieved September 5, 2017, from https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5187396.pdf

179. Cornell Lab of Ornithology. (2015). Great Gray Owl. *All about birds*. Retrieved

September 5, 2017, from https://www.allaboutbirds.org/guide/Great_Gray_Owl/lifehistory

180. Teton Raptor Center. (2016). *Teton County Flammulated Owl survey*. Teton Raptor Center.

181. Buskirk, S. W. (2016). *Wild mammals of Wyoming and Yellowstone National Park*. Oakland, CA: University of California Press.

182. Finley, R. B. (1969). *Cone caches and middens of Tamiasciurus hudsonicus in the Rocky Mountain region* (No. 51, Miscellaneous Publications). University of Kansas, Museum of Natural History.

183. Clark, F. H. (2016, October 11). Mast years and middens – central to red squirrel survival. *Jackson Hole Wildlife Foundation Blog*. Retrieved September 4, 2017, from http://jhwildlife.org/mast-years-and-middens-central-to-red-squirrel-survival/

184. Skinner, M., Ogle, D. G., St. John, L., Briggs, J., & Neese, E. (n.d.). Cheatgrass *Bromus tectorum* L. *USDA NRCS Plant guide*. Retrieved September 5, 2017, from https://plants.usda.gov/plantguide/pdf/pg_brte.pdf

185. National Park Service. (2016). *Grand Teton National Park & John D. Rockefeller, Jr. Memorial Parkway: vital signs 2015*. U.S. Department of Interior, National Park Service, Science and Resource Management.

186. U.S. Forest Service. (2016). *Palisades Wilderness Study Area - fact sheet*. U.S. Department of Agriculture, Forest Service, Bridger-Teton and Caribou-Targhee National Forests.

187. U.S. Forest Service. (2016). *Shoal Creek Wilderness Study Area - fact sheet*. U.S. Department of Agriculture, Forest Service, Bridger-Teton National Forest.

188. Reynolds, R. T., Graham, R. T., & Boyce, D. A. (2006). An ecosystem-based conservation strategy for the Northern Goshawk. *Studies in Avian Biology*, *31*, 299.

189. Tomback, D. F., & Achuff, P. (2010). Blister rust and western forest biodiversity: ecology, values and outlook for white pines. *Forest Pathology*, *40*(3-4), 186–225.

190. Keane, R. E., Tomback, D. F., Aubry, C. A., Bower, A. D., Campbell, E. M., Cripps, C. L., … Smith, C. M. (2012). *A range-wide restoration strategy for whitebark pine (Pinus albicaulis)* (No. RMRS-GTR-279, General Technical Report). U.S. Department of Agriculture, Forest Service, Rocky Mountain Institute.

191. Greater Yellowstone Coordinating Committee, Whitebark Pine Subcommittee. (2011). *Whitebark pine strategy for the Greater Yellowstone Area*.

192. Tomback, D. F., Arno, S. F., & Keane, R. E. (Eds.). (2001). *Whitebark pine communities: ecology and restoration*. Washington, DC: Island Press.

193. Greater Yellowstone Coordinating Committee, Whitebark Pine Subcommittee. (2015). *Adaptive action plan: whitebark pine in the Greater Yellowstone Area*.

194. Keane, R. E., Holsinger, L. M., Mahalovich, M. F., & Tomback, D. F. (2017). Evaluating future success of whitebark pine ecosystem restoration under climate change using simulation modeling. *Restoration Ecology*, *25*(2), 220–233.

195. Iglesias, V., Krause, T. R., & Whitlock, C. (2015). Complex response of white pines to past environmental variability increases understanding of future vulnerability. *PloS One*, *10*(4), e0124439.

196. Hansen, A., Ireland, K., Legg, K., Keane, R., Barge, E., Jenkins, M., & Pillet, M. (2016). Complex challenges of maintaining whitebark pine in Greater Yellowstone under climate change: a call for innovative research, management, and policy approaches. *Forests*, *7*(3), 54.

197. National Park Service. (2017). *Grand Teton National Park & John D. Rockefeller, Jr. Memorial Parkway: vital signs 2016*. U.S. Department of Interior, National Park Service. Science and Resource Management.

198. Mattson, D. J., Kendall, K. C., & Reinhart, D. P. (2001). Whitebark pine grizzly bears and red squirrels. In D. F. Tomback, S. F. Arno, & R. E. Keane (Eds.), *Whitebark pine communities: ecology and restoration* (pp. 121–136). Washington DC: Island Press.

199. Schaming, T. (2012, January 15). Clark's Nutcrackers find whitebark pine decline a tough nut to crack. *Cornell Lab of Ornithology: All about birds*. Retrieved September 5, 2017, from https://www.allaboutbirds.org/clarks-nutcrackers-find-whitebark-pine-decline-a-tough-nut-to-crack/

200. Keane, R. E., & Parsons, R. A. (2010). *Management guide to ecosystem restoration treatments: whitebark pine forests of the northern Rocky Mountains, USA* (No. RMRS-GTR-232, General Technical Report). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

201. Tomback, D. (2001). Clark's Nutcracker: agent of regeneration. In D. F. Tomback, S. F. Arno, & R. E. Keane (Eds.), *Whitebark pine communities: ecology and restoration* (pp. 89–104). Washington DC: Island Press.

202. Schaming, T. D. (2016). Clark's Nutcracker breeding season space use and foraging behavior. *PloS One*, *11*(2), e0149116.

203. Schaming, T. D. (2015). Population-wide failure to breed in the Clark's Nutcracker (*Nucifraga columbiana*). *PloS One*, *10*(5), e0123917.

204. MacNulty, D. R., Stahler, D. R., Wyman, C. T., Ruprecht, J., & Smith, D. W. (2016). The challenge of understanding northern Yellowstone elk dynamics after wolf reintroduction. *Yellowstone Science*, *24*(1), 25–33.

205. U.S. Fish & Wildlife Service. (2011). Endangered and threatened wildlife and plants; 12-month finding on a petition to list *Pinus albicaulis* as endangered or threatened with critical habitat. *Federal Register*, *76*(138), 42631–42650.

206. McDonald, G. I., & Hoff, R. J. (2001). Blister rust: an introduced plague. In D. F. Tomback, S. F. Arno, & R. E. Keane (Eds.), *Whitebark pine communities: ecology and restoration* (pp. 193–220). Washington, DC: Island Press.

207. Schwandt, J., Kearns, H., & Byle, J. (2013). *White pine blister rust general ecology and management* (No. 14.2, Insect and Disease Management Series). U.S. Department of

Agriculture, Forest Service.

208. Macfarlane, W. W., Logan, J. A., & Kern, W. R. (2010). *Using the landscape assessment system (LAS) to assess mountain pine beetle-caused mortality of whitebark pine, Greater Yellowstone Ecosystem, 2009: project report*. Greater Yellowstone Coordinating Committee, Whitebark Pine Subcommittee.