Yellowstone National Park
Greater Yellowstone Network, Inventory & Monitoring Program
Montana, Wyoming, Idaho

National Park Service
U.S. Department of the Interior

The State of Yellowstone Vital Signs and Select Park Resources 2017

Clockwise from top left: stemless mock goldenweed flowers growing along a ridgeline. NPS Photo-J. Frank; Brewer's sparrow nest and eggs. NPS Photo-J. Frank; bull bison grazing in Lamar Valley. NPS Photo-J. Frank; and land snail along Sepulcher Mountain Trail. NPS Photo-N. Herbert.

Cover photos, clockwise from top left: NPS Photo-N. Herbert; NPS Photo-J. Frank; and NPS Photo J. Frank.

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The State of Yellowstone Vital Signs and Select Park Resources 2017

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The Vital Signs Report Series

In 2008, 2011, and 2013, Yellowstone National Park (YNP) published *Vital Signs* reports. Initially, these reports provided information on the park's key natural resources; but in 2013, key cultural resources were also included. These reports referred to all resources as vital signs, even if they were not recognized as a "vital sign" in the National Park Service's (NPS) 2005 *Vital Signs Monitoring Plan for the Greater Yellowstone Network*. In this updated report, our goal is to provide information on a more robust set of park resources, which includes resources that were specifically identified as vital signs in the *Vital Signs Monitoring Plan*. As a result of the greater inclusion of park resources, we changed the report's title to *The State of Yellowstone Vital Signs and Select Park Resources, 2017*. Vital signs resources that help measure the overall health or pulse of the park and will be identified by this symbol ( ). Instead of reporting on reference conditions, we have highlighted key concerns for each resource. We recognize that, at this time, most resources do not have defined reference conditions. However, all resources have identified concerns that may cause managers to take action to protect resources (rather than attempting to return the resources to an unknown past condition).

In this report, we highlight 41 natural and cultural resources; 21 are identified as vital signs and 20 as select park resources. Each resource summary includes a resource history and background information, recent research and monitoring findings, current status and trends, and future concerns and management priorities.

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Report Contributors

Yellowstone Center for Resources

The Yellowstone Center for Resources (YCR) is entrusted to research, monitor, and manage YNP's unique and valuable resources. Since the 1872 act that created the park for conservation and recreation, National Park Service (NPS) staff and cooperators have inventoried and studied many aspects of the park. Today, the YCR staff strive to understand and protect a wide range of resources, from hot springs to wildlife to the park's archeological sites, and how these resources may be affected by stressors such as a changing climate and visitation.

In 2014, the park completed a *Foundation Document*, identifying key park resources and values and serving as a basis for ongoing park planning, research priorities, and management actions. Documenting general conditions, trends, threats, opportunities, and data needs for various park resources, the *Foundation Document* took a broad-brush approach at reviewing these resources (e.g., YNP's large, nearly intact temperate ecosystem). Yellowstone's Vital Signs report series provides detailed, up-to-date information on individual resources (grizzly bears, alpine plant communities, etc.), building upon the information in the *Foundation Document*. To read Yellowstone's *Foundation Document,* go to https://www.nps.gov/yell/learn/management/upload/YELL_FD_508.pdf.

Greater Yellowstone Inventory and Monitoring Network

The Greater Yellowstone Network (GRYN) is one of 32 networks of the NPS Inventory and Monitoring Division designed to support park managers to improve their understanding of key natural resources and to provide the best available science for decision making. Each NPS network collaborated with park specialists and scientists to develop a long-term monitoring strategy. In 2005, the GRYN published the *Vital Signs Monitoring Plan for the Greater Yellowstone Network*. This plan identified and prioritized a number of vital signs for Yellowstone and Grand Teton national parks, Bighorn Canyon National Recreation Area, and the John D. Rockefeller, Jr. Memorial Parkway. Twenty-one of the GRYN-identified vital signs are featured in this report. Currently, GRYN leads research and monitoring on seven of those 21 vital signs, while the others are overseen by specialists in the YCR. For a full copy of the *Vital Signs Monitoring Plan*, go to https://www.nps.gov/im/gryn/index.htm.

In addition to the YCR and the GRYN, YNP has over 135 independent research groups that conduct work annually. Of these groups, and others, the following have contributed directly to this report: Phil Farnes, Snowcap Hydrology; Marie Gore; C. Barre Hellquist, Massachusetts College of Liberal Arts, Emeritus; C. Eric Hellquist, SUNY-Oswego; Infographics Lab, University of Oregon; Barkley Sive, USGS-Air Resources Division; Mike Tercek, Walking Shadow Ecology; USGS-Water Resources Division; Yellowstone Volcano Observatory.

What Are Vital Signs?

As defined by the NPS Inventory and Monitoring Program, vital signs are "a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of a park, known or hypothesized effects of stressors, or elements that have important human values" (e.g., air and water quality). While some vital signs may be a species (e.g., whitebark pine), others have been categorized as ecosystem drivers, ecosystem stressors, or environmental quality:

- Ecosystem Drivers - The major external driving forces that have large-scale influences on natural systems. Drivers can be either natural forces or anthropogenic influences.

- Ecosystem Stressors - Physical, chemical, or biological agents that cause significant changes in the ecological components, patterns, and relationships in natural systems or cultural resources. The effects of stressors on park resources can be positive or negative. In this report, most of the stressors are having negative effects on other resources.

- Environmental Quality - Parameters that are part of our environment and have a direct effect on humans and other organisms (e.g., water, soundscapes). The effect can be positive, neutral, or negative, depending on the state of the environmental quality parameter. In addition, environmental quality can be affected by human activities and natural influences (e.g., fire, geothermal influences) that occur both inside and outside of the park.

In this report, we will summarize 21 vital signs and 20 select park resources. Some of the individual species we report on (e.g., grizzly bears) are not a vital sign but are part of a larger vital signs group (e.g., large carnivores). Therefore, for the select park resources that fall under an umbrella of a larger vital sign, we will identify their original vital sign on the tables in this report.

Why We Monitor Vital Signs and Key Park Resources

Yellowstone National Park was established in 1872, primarily to protect geothermal areas that contain about half the world's active geysers. At that time, the natural state of the park's other landscapes, waters, and wildlife was largely taken for granted. As development throughout the West increased, the park's 2.2 million acres containing forests, mountains, meadows, rivers, and lakes became an important sanctuary for the largest concentration of diverse wildlife in the lower 48 states. The park also preserved important prehistoric and historic cultural resources, such as archeological sites and historic buildings.

Today, YNP and the surrounding Greater Yellowstone Ecosystem (GYE) are recognized as one of the largest, nearly intact temperate ecosystems in the world. The park has been designated by the United Nations Educational, Scientific, and Cultural Organization as a Biosphere Reserve site and as a World Heritage site. These designations reinforce the international significance of YNP as a critically important conservation area.

Although YNP is largely protected due to its status as a national park, and there are federal laws and policies that safeguard individual resources, it remains critical to continue monitoring the status and trends of the park's natural and cultural resources. To determine whether observed changes to resources are a result of natural, ecological, or human influences requires careful study. These influences can occur both within and outside of the park; for example, the survival of some animal species depends on seasonal migrations or the use of habitat that extends beyond the park's boundaries. Within the park, introduced non-native plant and animal species may reduce the presence of native species through competition, predation, or disease, or even change natural ecological processes such as fire regimes. High levels of visitation can lead to soil compaction and trail degradation, resulting in disturbance of natural vegetation and cultural sites. For these reasons, it is important to pay careful and regular attention to the state of park resources.

In our effort to monitor the status and trends of the park's ecosystem, we focus on select resources, including those that are defined as vital signs by the NPS's Greater Yellowstone Network. While a number of resources have had data collected over a long time period, thereby enabling us to determine trends for these resources, others have shorter data records not yet conducive to trend reporting. This report summarizes the status and, when available, the trend of the park's natural and cultural resources, and makes this information available for use in science-based decision making by park managers.

NPS Photo-J. Peaco

VITAL SIGNS SUMMARY TABLE

Vital Sign Category	Vital Sign	Key Monitored Indicators	Current Conditions	Current Status	Resource Concerns
Ecosystem Drivers	Climate	Daily temperature (Mammoth)	2010–2017: average min = 30°F, average max = 54°F	Average temperatures are exceeding historical norms	• seasonal rain, snow, stream flow changes • reduced water supply or shift in seasonal water supply • longer growing season, shift in plant species composition • declining snow pack
		Annual precipitation (Mammoth)	2010–2017 average annual precipitation = 14.9 inches		
		Accumulated growing degree days above 40°F (Mammoth)	2010–2017 average AGDD40 = 3,072		
		Peak snow water equivalent (Northeast Entrance)	2010–2017 average peak SWE = 10.4 inches		
		Peak streamflow (Corwin Springs)	2017 peak = 20,500 cfs		
	Fire	Average acres burned per year (1972–2017; minus 1988)	5,936	Stable	• increase in size and frequency of fires due to climate change
		Average number of fires per year (1972–2017; minus 1988)	26		
	Geothermal Systems/ Subsurface Geologic Processes	Thermal output (chloride discharge through major rivers, heat flux in hydrothermal areas)	Within normal variation	Stable	• degradation of hydrothermal features by visitors • changes to hydrothermal system recharge due to changes in precipitation patterns
		Earthquakes per year (2017)	3,427; elevated due to Maple Creek swarm		
		Ground deformation in caldera (2016)	Subsiding few cm/year in caldera; uplifting few cm/year near Norris		
	Geomorphology	Yellowstone Lake level (peak, 2017)	~3.5 m peak relative to benchmark at Grant dock	Stable	• changes to annual snowpack and precipitation patterns • changes in river incision and erosion patterns
		River discharge, peak rates (2017)	Increased nearly twofold from 2016 at some major rivers		
	River and Stream Hydrology	Timing of peak flows	Shifting earlier in spring	Stable to Declining	• increased temperatures • shifts in precipitation patterns • earlier snowmelt
		Magnitude of peak flow	Variable and site specific		
		Base flows	Earlier and lower		
Environ-mental Quality	Air Quality	Visibility, 5-year average (2011–2015)	2.7 deciviews	Summer-Stable to Declining; Winter-Stable	• increase in magnitude and frequency of wildfires • damage to plants, disruption in soil nutrient cycling • increasing Western U.S. nitrogen (and other) emissions
		Ozone (W126), 5-year average (2011–2015)	8.6 ppm/hr		
		Nitrogen in precipitation, 5-year average (2011–2015)	4.9 kg/ha/yr		
		Sulfur in precipitation, 5-year average (2011-2015)	1.7 kg/ha/yr		
		Particulate matter, annual 98th percentile 24-hour average, West Yellowstone (2016)	43.1 mg/m^3		
		CO, winter max 1-hour average, West Yellowstone (2016)	13.0 ppm		
		NO^2, winter max 1-hour average West Yellowstone (2016)	25.2 ppb		
	Water Quality	Arsenic, dissolved nitrogen, and phosphorus in Yellowstone, Lamar, and Madison rivers (2016)	Within natural variation and not outside historical range	Stable with exception of Soda Butte Creek (Improving)	• earlier snowmelt and runoff • increasing water recreation (fishing, swimming, boating)
		Soda Butte Creek iron, copper, and lead levels	Improved, after 7 decades of mine-related impairment and reclamation		
	Natural Soundscapes	Median sound levels, West Entrance sound station, (July 2017)	52.2 dBA	Summer-Stable to Declining; Winter-Improving	• increase in extent/events of human-caused noise in summer months
		Median sound levels, West Entrance sound station, (Winter 2017)	28 dBA		
Resources	Amphibians	Potential sites suitable for breeding (2016)	66%	Stable	• spread of chytrid fungus and other diseases • climate-induced effects on wetlands/breeding
		Catchments occupied by boreal chorus frogs (2016)	75%		
		Major drainages with 4 native species (2016)	75%		
	Alpine Plant Commu-nities	Species richness (at GLORIA site)	127 species	Unknown	• warming climate • competition from invasive species
		Soil temperature; growing degree days above 5°C (2011–2016; at GLORIA site)	100 days		
	Beavers	Beaver colonies (2015; partial survey with colonies in northeast YNP estimated)	102	Stable	• willow recovery and recolonization of historical areas
	Insects	Butterflies-species present, butterfly species count-ed (1997–2007)	Xeric affinity species increased; hydric affinity species decreased	Unknown	• effects of changing climate (i.e., drought) on host plant availability • increase in mercury levels in air • shifts in phenology
		Dragonflies-mercury (Hg) levels in larvae	Hg increasing in some areas and decreasing in other areas		

Vital Sign Category	Vital Sign	Key Monitored Indicators	Current Conditions	Current Status	Resource Concerns
Resources	Shrub-steppe Communities	Percent cover of native and non-native species, bare ground, and litter in all plots across the landscape (2016)	Landscape is largely comprised of native species, with few locations heavily impacted by invasives	Few locations near North Entrance Declining, majority are Stable	• increased temperatures, change in timing of spring runoff, loss of native species to non-natives • changes in fire regime due to warm, dry conditions and increased fuel from non-natives
	Whitebark Pine	GYE percent blister rust infection (2015)	14–26%	Stable to Declining	• increased temperatures leading to drought and increased intensity/frequency of fires • white pine blister rust infection rates • exposure to insect and plant pathogens • competition from other tree species
		GYE tree mortality, 4-year trend (2015)	26%		
		GYE trees with reproduction potential (i.e., cone producing; 2015)	25%		
		GYE regeneration	51 understory trees/500m^2		
Ecosystem Stressors	Aquatic Invasive Species (AIS)*	Inspected watercraft with AIS (2016)	Less than 0.5% detection of suspected AIS on inspected watercraft	Stable	• increased in AIS from visitor boats and fishing gear • effects of warming temperatures, making park waters more optimal for AIS • expansion of known AIS beyond current locations
		Gastropods (red-rimmed melania, New Zealand mud snails) in select waterways (2016)	2		
		Aquatic invasive vegetation (2016)	0		
	Invasive Plants*	Change in density of targeted invasive species after treatment	Varies by species	Increasing	• warmer temperatures increase habitat suitability for invasive species • increased introduction of invasives plants via visitors and vehicles • spread of invasive plants in disturbed sites (e.g., road corridors, construction areas)
		Invasive plant species (as ratio of known park vascular plants)	18%		
	Lake Trout (non-native) in Yellowstone Lake*	Reduction in lake trout, age 2+ (2012–2017)	-15%	Decreasing	• logistical difficulties and financial cost of long-term suppression operations
		Removal of lake trout (2017)	397,000		
		Reduction in lake trout, age 6+ (2012–2017)	-60%		
		Reduction in lake trout biomass (2012-2017)	-33%		
	Land Use	Population estimate-GYE (2010)	924,000	Stable	• change in private land use (including recreational use) outside the park • potential mineral, gas, or geothermal development near park boundary
		Land use changes (public to private)	No known changes since 2010		
	Mountain Goats (non-native)	Estimate of numbers in and near Yellowstone's boundary (2016)	More than 200	Increasing	• potential competition for resources and potential for disease transmission with bighorn sheep • effects on alpine vegetation
	Visitor and Recreational Use	Annual visitation (2017)	4,116,525	Backountry recreation-Stable; Visitiation-Increasing	• increase in wildlife habituation and interactions • increase in visitor impacts (invasive species introduction, social trails, thermal area damage) • increase in unsanitary conditions (human waste, trash, contaminated water)
		Backcountry person use nights (2016)	44,507		
	Wildlife Diseases	Brucellosis prevalence (adult female bison and elk)	Bison ~60%; elk ~10%	Stable to Increasing	• wildlife, domestic animals, and humans share an increasing number of infectious diseases, which pose a risk to high densities of visitors and wildlife within Yellowstone • proximity of confirmed diseases near the park boundary or within adjacent states (chronic wasting disease, white-nose syndrome)
		Chronic wasting disease (mule deer and elk)	Detected in mule deer outside park's east boundary		
		Chytrid fungus, ranavirus prevalence (amphibians)	Widespread		
		Distemper and mange prevalence (wolves)	Distemper not detected since 2008; mange low		
		Hantavirus (deer mice)	Seasonally 30–40% at actively infected sites		
		West Nile virus (birds)	Mosquito host present; virus not detected		
		White-nose syndrome (bats)	Not detected		

SELECT RESOURCES SUMMARY TABLE

Resource	Key Monitored Indicators	Current Conditions	Current Status	Resource Concerns
Archeological Sites	Percentage of park inventoried	<3%	Stable	• effects of environmental change (wildfire, floods, erosion, retreating ice patches, insect infestation, etc.) • unauthorized collecting
	Percentage of documented sites in good condition	57%		
Arctic Grayling and Westslope Cutthroat Trout*	Occupied stream habitat-kilometers (past decade)	Restored 74 stream kilometers and 20 lake surface hectares	Improving	• competition and hybridization with invasive species • potential climate-induced changes to habitat (temperature), affecting food availability, disease exposure, survival
Bald Eagles	Productivity (average, 1984–2016)	0.71	Stable	• prey availability and switching among prey species due to decrease in cutthroat trout in Yellowstone Lake
	Nest success (average, 1984–2016)	50%		
	Brood size (average, 1984–2016)	1.4		
Bats	Number of species identified	13	Unknown	• potential for exposure to white-nose syndrome • protection of maternal colonies in buildings
Bighorn Sheep**	Northern range count (2017)	353	Stable	• exposure to pneumonia-inducing pathogens • potential competition/disease transmission with mountain goats
	Lambs per 100 ewes (2017)	27		
Bison**	Population estimate-summer (2016)	5,500	Stable	• large-scale management reductions due to limited tolerance in surrounding states • limited capacity within park • recent shifts in preference for habitats on the northern range
Colony Nesting Birds+	American white pelicans fledged (2016)	308	Declining	• high water levels in Yellowstone Lake • decreased availability of primary food source, Yellowstone cutthroat trout • disturbances by visitors • increased predation by eagles
	Caspian terns fledged (2016)	0		
	California gulls fledged (2016)	0		
	Double-crested cormorants fledged (2016)	34		
Common Loons++	Adult loons (2016)	31	Stable to Declining	• human disturbance of shoreline nests • loss of breeding habitat • mercury toxicity in prey fish
	Loonlets fledged (2016)	9		
Elk**	Population count-northern range (2017)	5,349	Stable to Improving	• combined effects of a diverse and large predator guild, including human harvests outside the park
	Recruitment (2017)	21 calves/per 100 adult females		
Golden Eagles	Nesting success (2016)	41%	Unknown	• reproduction is low in most years due to unknown factors; research has been initiated
	Productivity (2016)	0.45 per occupied territory		
Gray Wolves◊	Wolves in Yellowstone (2016)	108	Stable	• habituation to park visitors
	Breeding pairs, Yellowstone (2016)	7		
Grizzly Bears◊	GYE population estimate (2016)	690	Stable to Improving	• human-caused disturbance and mortality, especially to females
	Distribution of females with cubs (2016)	18/18 bear management units occupied		
	Annual mortality: Adult female (2016)	6		
	Annual mortality: Adult male (2016)	19		
	Annual mortality: Dependent young (2016)	9		
Historic Structures, Districts, and Cultural Landscapes	Historic properties documented	66%	Stable to Declining	• ongoing need for maintenance and improvements due to continual human use • backlog on evaluations, documentation
	Historic properties documented in good condition	77%		
	Cultural landscape properties documented	25%		
	Cultural landscape properties in good condition	85%		
Museum Collections	Museum objects cataloged (2016)	81%	Improving	• storage space (including vehicle storage) and staffing

*Park resource that is included in the Greater Yellowstone Network (GRYN)-identified Native Aquatic Assemblages vital sign.
**Park resource that is included in the GRYN-identified Ungulates vital sign.
+Park Resource that is included in the GRYN-identified Land Birds vital sign.
++Park Resource that is included in the GRYN-identified Birds of Concern vital sign.
◊Park resource that is included in the GRYN-identified Large Carnivores vital sign.

Resource	Key Monitored Indicators	Current Conditions	Current Status	Resource Concerns
Peregrine Falcons	Annual nesting success (2016)	43%	Stable	• low nesting and productivity levels over the last decade
	Brood size (2016)	1.8		
	Productivity per occupied territory (2016)	0.8		
Pronghorn**	Northern range spring count (2017)	506	Stable to Improving	• limited forage availability on winter range • reestablishing migration and dispersal; removal of barriers to movements • increased fequency/magnitude of fires
	Recruitment: fawns/100 adult females (2016)	37		
Songbirds+	Abundance-birds per survey plot (2016)	6.6	Stable	• range-wide decreases in songbirds • climate-induced changes to habitat availability
	Species richness per survey plot (2016)	18.6		
Trumpeter Swans++	Resident adults and subadults, fall count (2016)	29	Declining	• decrease in nesting pairs and low productivity • human disturbance • flooding of nests
	Nesting pairs (2016)	2		
	Cygnets fledged (2016)	3		
Wetlands	Percentage of wetlands dry (2016)	35%	Stable	• Increasing annual percentages of dry wetlands • loss of species diversity and wetland habitat
Yellowstone Cutthroat Trout*	Average fish/net-fall (2017)	20.5	Improving	• predation by non-native lake trout
	Average observed-spawning streams (2017)	157 in 4 streams		
	Average caught/hour by anglers (2017)	0.85		

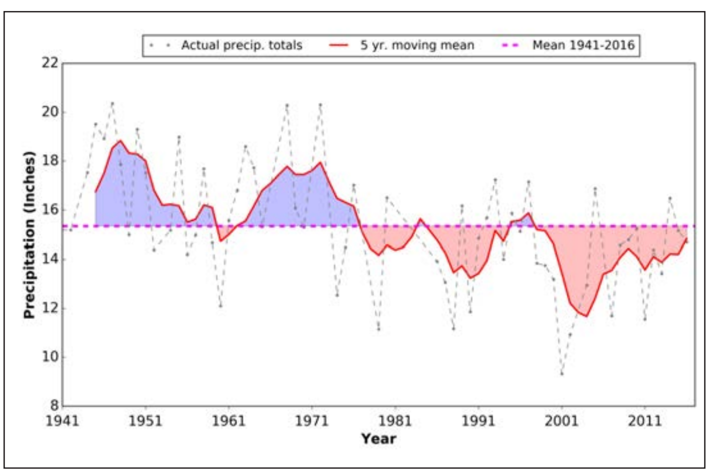
**Park Resource that is included in the GRYN-identified Ungulates vital sign.
+Park Resource that is included in the GRYN-identified Land Birds vital sign.
++Park Resource that is included in the GRYN-identified Birds of Concern vital sign.

NPS Photo-J. Frank

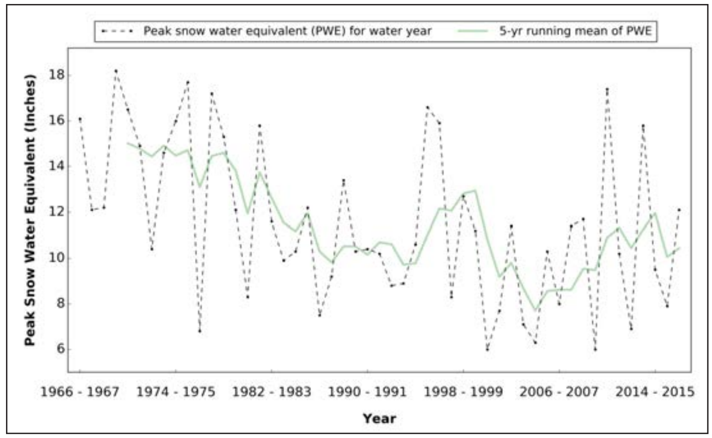
Climate

Climate is the set of long-term, average meteorological conditions that occur over several decades or longer. Unlike weather, which fluctuates greatly in the short-term and is difficult to predict, climate is relatively stable and many organisms have adapted to its predictable rhythms. As a result, climate is a driving force behind many ecological processes. For example, average temperature and moisture determine which species can live in an area, the rate at which they grow, and the frequency and severity of forest fires. Temperature and precipitation regimes also strongly influence the intensity and timing of stream flows, which are important factors in both agricultural and natural ecosystems.

The GYA is becoming more arid, and global climate models project this trend will continue in the future. Precipitation has declined in many locations throughout the GYA in recent decades as temperatures have increased. At Mammoth Hot Springs, the five-year running mean of average annual daily maximum temperature has increased by 1.2° Celsius (2.1°F) and the average annual daily minimum temperature has increased by 2.2° Celsius (3.9°F) during 1941–2016. Total annual precipitation at Mammoth Hot Springs since 1976 has been generally below the long-term mean of 15.3 inches (38.9 cm; see figure bottom left). The five-year running mean of annual peak snowpack (expressed as peak snow water equivalent, or PWE) at the Northeast Entrance has declined 30% since 1966, from 15.02 inches to 10.44 inches (from 38.2 cm to 26.5 cm; see figure above right).



Annual precipitation at Mammoth Hot Springs, YNP, 1941–2016. The running mean is based on a time series with 21.1% missing values. The five-year moving mean includes the current year and previous four years.



Peak snow water equivalent (PWE) at YNP's Northeast Entrance, 1966–2017. Five-year running average included current year and 4 previous years.

Snowy conditions have been prevailing for a shorter period during the year. The 10-year running mean of winter length (annual number of days with snow water equivalent > 0) at the Northeast Entrance SNOTEL station has decreased 15% during 1966–2017, from 216 to 183 days. Even if precipitation recovers to historical levels, which models indicate is possible, increased temperatures and evapotranspiration will reduce water availability.

In the future, changes in the seasonal patterns of rain, snow, and stream flow will be as important to management as the reduction in total water availability during the course of the year. Also, a greater proportion of annual precipitation will likely fall as rain rather than snow. Instead of being stored in the snowpack and gradually released during the year, this rain will be rapidly lost to streams and unavailable for plants and animals during the growing season. The snow that does accumulate will likely melt more quickly as a result of the projected warming trends, producing earlier and more intense spring runoff. Total annual stream discharge may remain steady or decline; but as a greater proportion becomes compressed into an increasingly intense spring runoff, streams could be lower in summer months, contributing to water scarcity. Hotter, drier summers and shorter winters will likely cause larger and more frequent wildfires, as well as changes in the amount and type of motorized winter recreation that will be possible in the park.

Fire

Fire has been a key factor in shaping the ecology of YNP; vegetation has adapted to fire, and in some cases, species like lodgepole pine rely on it to regenerate. Park policy is to allow naturally ignited fires to burn when at all feasible for resource benefits, and to suppress fires which are human caused or endanger people or property. During the last 45 years of reliable fire records, YNP has averaged 26 fires per year (an average of six human-caused and an average of 20 lightning-caused), and an average of 5,936 acres (2,402 ha) burned per year from 1972 to 2017, excluding 1988. In 2017, less than one acre (.4 ha) burned from eight known wildfire starts. Six fires were caused by human activity and were suppressed, while two fires went out naturally. The summer of 2017 had the least amount of acreage burn in the park since 1983.


NPS Photo-B. Fleming

The size and frequency of fires are affected by several factors such as location, amount of lightning, type and amount of fuels, fuel moisture, weather, drought, and long-term climate. Within the park, climate trends show precipitation is declining and temperatures are increasing. Current statistics show there are fewer fires burning an equal or greater number of acres on average, per year, than in the past. In the last 10 years (2008–2017), the park has averaged 14 fires and 11,996 acres (4,855 ha) burned per year, and had fire on the ground for over 100 days during 5 of the last 10 years. In addition to more acreage burning on average per year, due to declining precipitation and increasing temperatures, the average number of days a non-suppression, naturally ignited fire burned has increased from 21 days for the last 40 years, to 32 days during the last 10 years. If climate trends continue along their current trajectory, fires within the park will continue to be larger, burn for longer durations, and may continue to be longer than average fire seasons.

Fire management personnel have been actively monitoring fire growth in previously burned areas where forests are less than 50 years old, and are currently working on determining weather, drought, and vegetation condition thresholds that may indicate when these areas will reburn.


NPS Photo-J. Page

Geothermal Systems/Subsurface Geologic Processes

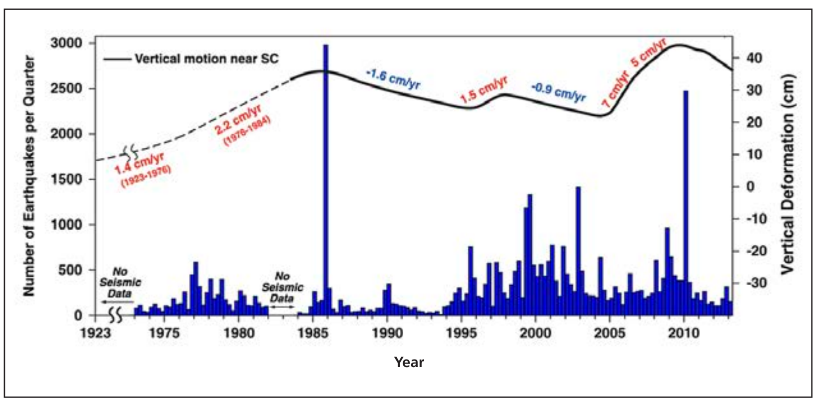
Yellowstone's geysers (e.g., Old Faithful, Grand, Castle, and Steamboat) draw in millions of visitors every year. With over 500 active geysers and 10,000 thermal features, YNP is renowned for its hydrothermal activity. Despite these attractions serving as incentives for tourism and scientific investigation, many questions remain unanswered surrounding the mechanisms that control geyser activity. Thermal features can appear overnight and, reciprocally, go dormant just as suddenly. Other thermal features express highly varied properties (e.g., water level, temperature, eruption length, duration, and periodicity).

In an attempt to understand the variations in geyser activity, including temperature, duration, and periodicity, YNP's geology program monitors hydrothermal features with a series of data loggers placed in key thermal basins. Data loggers were first placed on a handful of hydrothermal features in 1994. Since then, monitoring has flourished, capturing data on 132 distinct hydrothermal features. Today there are 57 hydrothermal features that are continuously monitored with telemetric, Bluetooth, and other electronic systems. Monitoring hydrothermal features has helped reveal relationships between geyser activity, weather patterns, and seismicity; however, there are still numerous unanswered questions about the mechanics of and driving influences on geyser systems.

One question is how seismicity affects geyser activity. Seismic activity in the park has been regularly monitored since 1973 and thousands of earthquakes have been documented annually. The vast majority of the earthquakes in YNP are too small for people to feel. On average, roughly 50% of these earthquakes occur in seismic swarms occurring in a focused area over a short period. At times, 1,000+ minor (< magnitude 4) seismic events occur in a seismic swarm. In June 2017, the Maple Creek seismic swarm began. The largest event of this swarm, a magnitude 4.4 earthquake, occurred in June near West Yellowstone, Montana. The swarm concluded in September; about 2,400 recorded seismic events were attributed to it, making it the second largest earthquake swarm recorded in the Yellowstone region (the largest being in 1985). Leading up to and following these seismic swarms, the ground within the park may rise and fall. The Earth's surface across the park can rise as quickly as 7 centimeters (2.7 in) per year leading up to the peak of a swarm and subside up to 1.6 centimeters (.6 in) per year as the swarm tapers off.

Yellowstone works with the University of Utah, UNAVCO, and the U.S. Geological Survey within the framework of the Yellowstone Volcano Observatory to monitor seismic and ground deformation activity. While recent earthquakes have produced no notable damage or obstruction to visitors, geological evidence suggests the region has experienced earthquakes of larger than magnitude 7.0. For example, in 1959 the magnitude 7.3 Hebgen Lake earthquake triggered a massive landslide that killed many people and damaged infrastructure.

Despite no indications that the 2017 earthquake swarm has caused major changes to geyser activity, observations from Norris Geyser Basin suggest two small hot springs had lower water levels following the magnitude 4.4 earthquake. The water levels of these pools returned to pre–earthquake levels in the weeks that followed the event; however, this thermal response raises the fundamental question—why did this change occur? Furthermore, what specifically was this activity related to? In an effort to quantitatively answer these questions and track the relationships between thermal activity, earthquakes, and deformation, YNP geologists have been compiling 20+ years of geyser outflow temperature data from across the park into a structured database. The analyses of these data aim to identify statistically robust relationships between the different geological components.

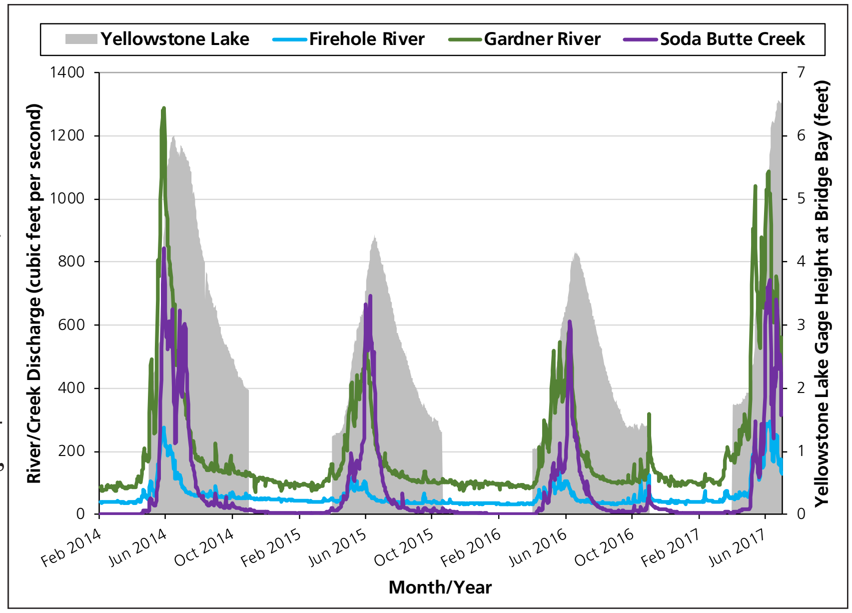


History of YNP seismicity and deformation. The 1985 and 2010 seismic swarms occur around changes in deformation. The 2017 Maple Creek seismic swarm earthquake counts exceed that of the 2010 swarm but fall short of the 1985 swarm. Solid line at top depicts vertical motion at the Sour Creek Dome. There are no changes of deformation associated with the Maple Creek swarm. Source: Yellowstone Volcano Observatory (https://volcanoes.usgs.gov/volcanoes/yellowstone/).

Geomorphology

Despite having several peaks over 3,048 meters (10,000 ft) above 44° latitude, YNP hosts no glaciers. However, glaciers did play an important role in forming the watersheds and topography across the GYA. The effects of pre–historic glaciation continue to affect the park into the present day.

The Yellowstone Plateau was subject to at least two glacial events in the last 200,000 years. The most recent, the Pinedale Glaciation, ended roughly 14,000 years ago. During the Pinedale Glaciation, ice sheets thickened to 1,219 meters (4,000 ft) over the Yellowstone Plateau, and the recession of the Pinedale ice sheet is responsible for several signature geographical features observed in the park. An ice dam formed, flooding the Hayden Valley and contributing to its modern sweeping slopes. Moreover, the plateau glacier helped to define several of the water drainages we observe today. For example, once the ice dam broke, the draining water contributed to the formation of the Grand Canyon of the Yellowstone. The plateau ice sheet itself contributed in shaping the modern Yellowstone Lake.



Yellowstone Lake levels at Bridge Bay and discharge rates for the Firehole River, Gardner River, and Soda Butte Creek from February 2014–July 2017. Yellowstone Lake levels have been recorded since 1927. Firehole River, Gardner River, and Soda Butte Creek discharge rates have been recorded since 1929, 1965, and 1996, respectively. Temporal discontinuities in the Yellowstone Lake level data result from the absence of data collection during winter months. River and creek discharge rates are sourced from the U.S. Geological Survey (USGS) streamflow database. Yellowstone Lake level data courtesy of Phil Farnes, Snowcap Hydrology.

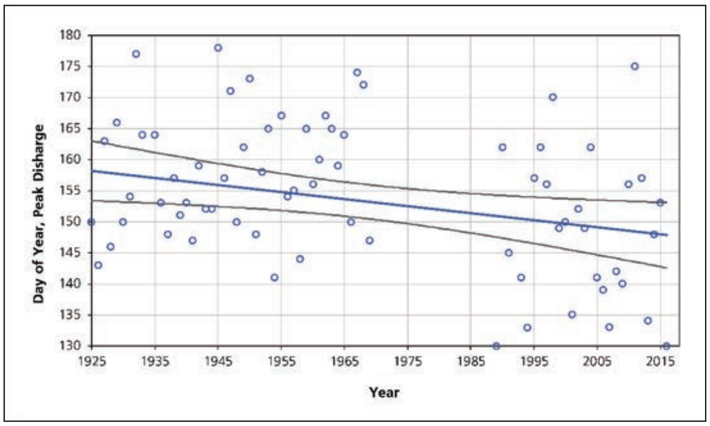
These watersheds play an important role in keeping YNP staff informed of conditions throughout the park. A partnership between the NPS and the U.S. Geological Survey has monitored lake levels and stream discharge on a daily basis for more than nine decades. With climate change hypothesized to alter future snowpack and rainfall levels, lake and river discharge rates will also change. Already, the park has experienced discharge rates that nearly double one year to the next (e.g., 2014 to 2015) and then halve in a following year (e.g., 2016 in comparison to 2017). As the park experiences increased precipitation variability, erosional events and incision patterns will also change. These changes are important to the function of park activities as erosion and incision affect slope stability. In short, more precipitation results in lower slope stability.

The connection between precipitation and slope stability also tie back to the Pinedale Glaciation as the event served to reshape ridges and slopes. Once the glaciers retreated, the steep topography lost its support from the buttressing glaciers. The over-steepened glacial sediments are inherently unstable, but groundwater acts as a lubricant for these sediments and increases the probability of slope movement. Evidence of prehistoric landslides similar to the 1959 Hebgen Lake landslide can be found across the park. These landslide deposits are still settling today as landslide deposits commonly creep sub-centimeter distances annually. With highly variable precipitation rates brought on by our changing climate, the velocities at which these landslides creep is likely to change.

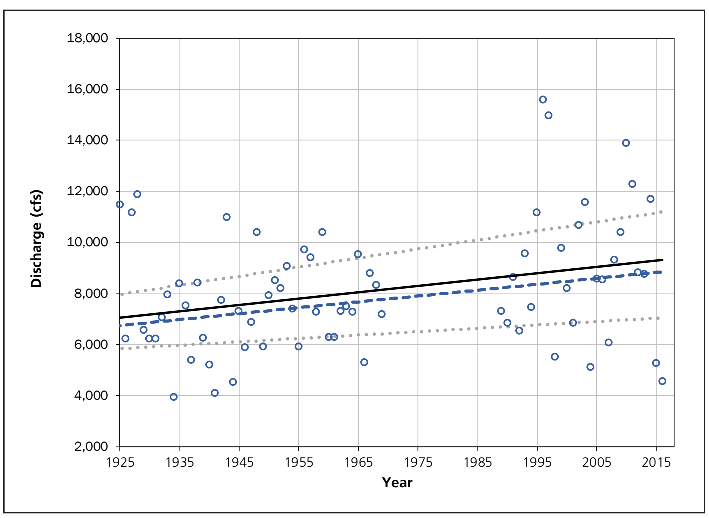
The travel corridor between Mammoth, Wyoming and Gardiner, Montana is of particular interest to geologists as the roads along this corridor are at risk from creeping landslide deposits. The NPS and the Federal Highway Administration are working together to ensure this vital park corridor remains open to safe travel for visitors and staff. The current mapping and monitoring of these slide deposits can provide critical input into understanding the risk and disturbance landslide creep could produce. As climate change presents the potential of variable creep rates, the Geology Program at YNP is considering new methods using remote sensing techniques to monitor these geological features.

River and Stream Hydrology

River and stream flows are regarded as vital to the health of aquatic and terrestrial communities, susceptible to climate and land use impacts, and important to visitor experiences and downstream neighbors. For these reasons, river and stream hydrology was identified as a vital sign for long-term monitoring in YNP and neighboring parks. Shifts in temperature and precipitation regimes over the last several decades have already altered river flow patterns in the Rocky Mountains, and projected shifts in global and regional climatic conditions are anticipated to further influence river and stream flow.



Plot showing the day of year when peak flow occurs (where January 1=day 1 and July 1= day 182 [non-leap years]) as a function of year for the Lamar River near Tower Ranger Station. Mean trend is blue line. Gray line represent 95% confidence intervals.



Scatter and quantile plot of peak flow in cubic feet per second (cfs) for the Lamar River near Tower Ranger Station, as a function of year. Trends showing the mean trend line (black solid line), the median trend (blue dashed line), and 25th and 75th quantile trend lines (gray dotted lines).

Rivers and streams in YNP and the GYA are changing in a manner that is consistent with changes throughout the Rocky Mountains and principally as a result of changes in air temperature and precipitation regimes. Major drivers of change for this region are a shift in precipitation from snow to rain and an earlier season snowmelt. The effects of these changes are numerous and include the drying of surface wetlands (see Wetlands Vital Sign, page 41) and an increase in summer water temperatures. Since low flow conditions occur earlier in the summer, they now coincide with warm, late-summer air temperatures. Across the GYA, this is expected to increase stream water temperatures between 0.8°C and 1.8°C (1.4°F –3.2°F) by 2069.

Combined changes in flow patterns and water temperature may strongly influence how visitors experience the park. As an example, popular fishing rivers in this region include the Lamar, Madison, Snake, and Yellowstone rivers. In 2016, unseasonably warm winter and spring air temperatures contributed to earlier snow runoff and historic low flow conditions across the region. The Snake River near Flagg Ranch and the Lamar River near Tower had the lowest average August daily flows in their respective time series (33 years for the Snake River and 75 years for the Lamar River). As low flow changes occur, there are also shifts in the timing and magnitude of annual peak flows. In the Lamar River, peak flows are occurring more than 5 days earlier in the spring (see figure above left). They are larger than they were historically, nearly 2,500 cubic feet per second (70.8 m^3/s) larger now than in the 1920s; see figure below left). Temperature-influenced low and high flow conditions may trigger additional ecological changes, including shifting biological communities and increased opportunities for the establishment of invasive species.

Although waters in YNP are experiencing earlier peak flows and reduced summer flows, there is also a high degree of variation in the magnitude of changes across rivers and streams. Understanding these differences is a necessary first step to identifying which rivers and streams are most sensitive and most resistant to future change. River and stream monitoring, coupled with groundwater research, can also clarify the effects of these changes to both hydrothermal systems and surface water systems. NPS staff are also working on other programs to further restore the resiliency of rivers and streams, including eradication of non-native fishes, restoration of areas affected by mine runoff, protection of private water rights, and research on beavers.

Air Quality

As a federally designated Class I area, YNP is required to protect air quality and resources that may be affected by air pollution. Although the park is in compliance with the national regulatory standards for air pollutants, pollutant levels measured in YNP are impacting park resources.

Some YNP ecosystems have a very high sensitivity to nutrient-enrichment effects. Nitrogen deposition may disrupt soil nutrient cycling, affecting biodiversity of some plant communities, especially in alpine areas. While nitrogen deposition has declined in many parts of the country, it has increased over the past two decades in the park. Although national regulatory efforts have focused on emissions reductions from large point sources, nitrogen emissions have been increasing in parts of the western U.S. from agriculture, oil and gas operations, and wildfire smoke. Wet nitrogen deposition warrants significant concern at YNP based on the 2011–2015 deposition value of 4.9 kg/ha/yr.

Sulfur pollution can harm ecosystems by acidifying soils and surface waters. Wet sulfur deposition also warrants significant concern at YNP based on NPS benchmarks and the 2011–2015 estimated wet sulfur deposition value of 1.7 kg/ha/yr. This level would normally warrant a moderate concern; however, the status has been elevated to significant concern because park ecosystems may be highly sensitive to sulfur acidification effects.

Elevated levels of mercury are dangerous for both wildlife and humans. Mercury deposition at YNP warrants significant concern. The 2013–2015 estimated wet Hg deposition ranged from low (3.4 mg/m^2) to very high (21.1 mg/m^2). Past studies have shown high mercury accumulation in some fish, birds, and dragonfly larva. Importantly, natural geothermal mercury sources occur throughout YNP, though it is unclear how much they contribute to mercury bioaccumulation.

Air visibility is affected by fine particles and gaseous air pollution that form haze in the atmosphere. Increases in the frequency and magnitude of wildfires have a negative effect on park visibility. The Clean Air Act visibility goal requires improved visibility on the 20% haziest days and no degradation on the 20% clearest days. For 2011–2015, the haze in the air has reduced the visibility on mid-range days (days in the middle of the range between haziest and clearest) by about 70 kilometers (43 mi), warranting moderate concern. The 2006–2015 trend in visibility at YNP shows improvements for the 20% clearest days while remaining relatively unchanged (no statistically significant trend) on the 20% haziest days.

Ground-level ozone is a toxic air pollutant that is detrimental to human health and vegetation. The human health risk from ground-level ozone warrants moderate concern at YNP based on the 2011–2015 ozone value of 63.6 parts per billion (ppb). For 2006–2015, there is a decreasing trend of 0.6 ppb/yr; however, the long-term trend shows no significant change.

Carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), and oxides of nitrogen ($NO_x = NO+NO_2$) are monitored to better assess the impacts of oversnow vehicles (OSVs) and emissions on winter air quality. The CO and $PM_{2.5}$ data show these pollutants have decreased since 2002, as a result of fewer snowmobiles in the park and the "Best Available Technology" (BAT) requirement. Although the BAT-required, 4-stroke engines emit less CO than 2-stroke snowmobile engines, the 4-stroke engines emit about 15 times more nitrogen dioxide (NO_2). The annual one-hour maximum NO_2 values from West Yellowstone indicate levels are approaching those of moderate concern.

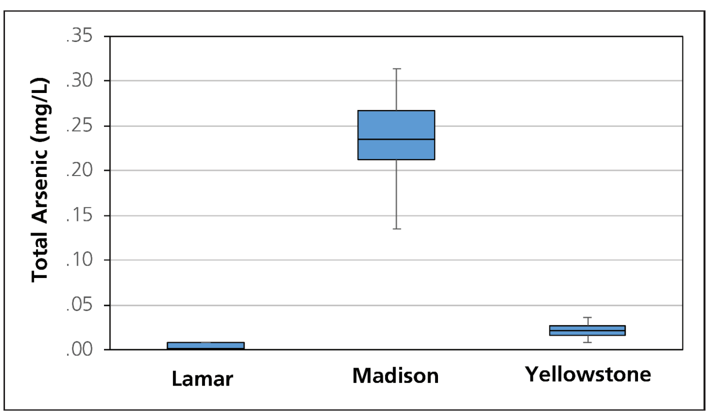
Emerging issues related to air pollution are smoke from wildfire, nitrogen deposition, mercury deposition and methylmercury formation, ozone, and the associated effects of these pollutants on human health and ecosystems.

While visitors to Yellowstone typically experience clear skies with no haze, the potential increase in fire frequency and severity poses an ongoing concern. NPS Photo-N. Herbert

Water Quality

Water quality describes the state of water, especially with regard to its appearance and suitability. In a regulatory context, measures of the suitability of water include whether it is appropriate for a particular use (e.g., swimming, drinking, or fishing) based on its physical, chemical, biological, and aesthetic characteristics. Water quality is a function of natural (geological, climatological, topographical, and biological) and human (road runoff and sewage treatment discharges) influences in the watershed. Water quality varies seasonally, changing with snowmelt, weather conditions, river flow, and lake levels.

Due largely to its protected status, the quality of water in YNP is generally high. However, the natural chemistry of YNP's waters is nearly as varied as its terrain. Inside YNP, water quality is largely characterized by the degree to which a water body is influenced by geothermal sources as well as by seasonal effects (i.e., snowmelt and runoff) that influence flow patterns (see River and Stream Hydrology, page 16). Outside of park boundaries, mining, grazing, and other human influences have contributed to water quality deterioration. Soda Butte Creek, for example, is a tributary of the Lamar River whose water quality was impacted by historic mining activity near Cooke City, Montana. A former gold mill situated in the floodplain of Soda Butte Creek produced elevated levels of iron, copper, and lead that regularly surpassed the State of Montana water quality standards.



Total Arsenic (mg/L), 2014–2017 for Lamar, Madison, and Yellowstone rivers. Arsenic occurs naturally in rocks and soil and is often associated with volcanic activity. Most arsenic in YNP is believed to originate from geologic sources and not human influences (mining, coal combustion). Generally, showering or wading in water that contains arsenic does not present a danger to humans; however, consumption of water with elevated arsenic is not recommended.

Water quality is monitored in the Yellowstone, Madison, and Lamar rivers. Total arsenic levels are variable, with the highest levels occurring in waters with significant geothermal influences. For example, arsenic levels are naturally high in the Madison River near West Yellowstone, Montana, and regularly exceed the Montana water quality standard. Arsenic has been shown to be high in the Madison River, and these elevated levels have been attributed to high concentrations of arsenic from geothermal sources, including geothermal springs found in the Firehole and Gibbon river drainages. Other characteristics of geothermal influence include mercury, fluoride, and selenium. Arsenic levels in the Yellowstone River at Corwin Springs, Montana, were less than the Madison River but twice those documented in the Lamar River.

Dissolved nitrogen concentrations were low in surveyed rivers. Dissolved phosphorus was generally lower in the Lamar and Yellowstone rivers. In the Madison River, dissolved and total phosphorus levels were higher in late summer when base flow conditions occur. Higher levels of phosphorus in the Madison River during base flow suggest groundwater may be contributing disproportionately to phosphorus levels. Water quality in the Lamar and Yellowstone rivers exhibited the greatest variability during high flows. For example, sulfate, sodium, and arsenic levels are generally lower during high flows. In contrast, total suspended solids and total phosphorus levels were highest during high flows.

Future goals for water quality are to continue monitoring efforts in the Yellowstone, Madison, and Lamar rivers to track long-term changes to important water resources. Additionally, water quality will periodically be monitored in stream segments where impairment could occur, such as areas near road improvement activities or following restoration or reclamation actions. For example, a recent reclamation effort on Soda Butte Creek removed the tailings from the McLaren mill site that had long leached metals into Soda Butte Creek and posed an ongoing threat to YNP. Following reclamation of the former mill site, water quality monitoring documented significant improvements downstream of the former mill site. The reclamation of the McLaren mill site represents a milestone in the restoration of Soda Butte Creek from mining-related impacts. The improvement in water quality has also facilitated the return of Yellowstone cutthroat trout in Soda Butte Creek and the greater Lamar River watershed. This segment of Soda Butte Creek has been recommended for delisting as an impaired watershed to the Environmental Protection Agency.

Natural Soundscapes

Yellowstone's soundscape and acoustic environment encompass all sounds, including human-caused and natural sounds. The natural soundscape (all sounds other than human-caused) predominates at night near the developed areas of the park and at all times in the backcountry. The natural soundscape is important for both wildlife and positive visitor experience. Many animals rely on sounds to locate food, avoid predators, attract and defend mates, and keep social groups together; sounds serve other communication purposes even if unintentional. Visitors enjoy hearing natural sounds and derive a health benefit from their restorative effects. The park's largely intact fauna and flora and the presence of diverse abiotic sounds including wind, rock fall, thunder, rain, and snowfall create a healthy natural soundscape in the absence of noise.

Managers are concerned about vocal invasive species (e.g., birds), as well as changes in the composition of animal communities driven by climate change that could affect the natural soundscape. However, the primary concern is impacts from human noise.

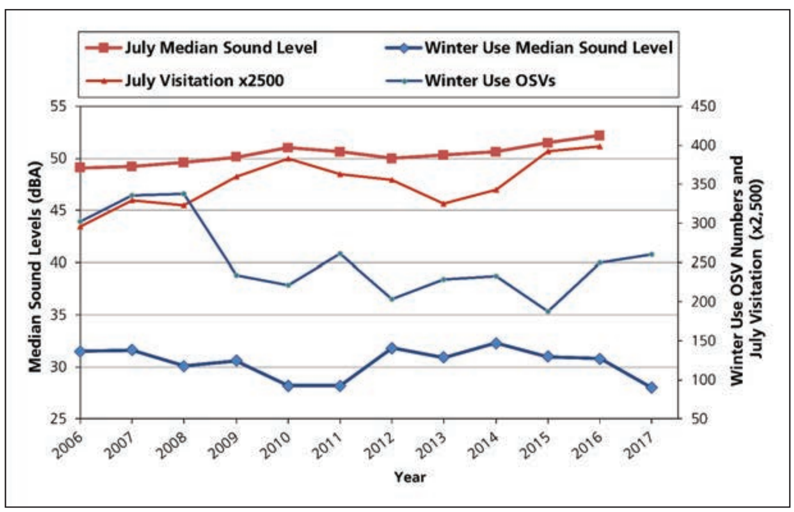
The areas of YNP a few kilometers away from roads and developed areas are generally devoid of most human noise (unwanted or extraneous sounds), except for the occasional road and aircraft noise. Aircraft noise is audible about 5% of the day throughout YNP, caused mostly by high commercial jets but also by administrative (research, search and rescue, fire, and maintenance) propeller aircraft and helicopters.

Yellowstone and Lewis lakes have visitors recreating in motorized boats during the warm weather months. Sounds travel well over water, so motorboat noise can be heard far from the actual activity. Overall boat noise is generally at low sound levels unless near launch areas or the boats themselves. In the southern part of Yellowstone Lake near Frank Island, boat motors can be audible up to 35% of the day.

The road system is the source of the most prevalent noise in YNP. Noise from nearly constant traffic during the summer pervades road turnouts and nearby features, and can propagate several kilometers into the backcountry. Modified exhaust pipe motorcycles are the loudest vehicles during the summer and have been recorded 13 kilometers (8 mi) from the nearest road. During the summer, high levels of visitation result in both increased traffic and noise long the road corridors.

During the winter, oversnow vehicles are the most prevalent noise source. Snowmobiles and snowcoaches have been actively managed in recent winters and, in regards to noise, the management is a success story. Intensive acoustic monitoring of winter soundscapes has been conducted since 2003 following NPS protocols. Annual reports provide details (found online at https://www.nps.gov/yell/learn/management/winter_monitoring.htm) demonstrating that the thresholds set forth in the winter use plan are being met. The sound level and percent time audible of oversnow vehicles are decreasing.

Park administrative activity and visitation inevitably cause noise, but there are clear paths to minimize the noise impact on the natural soundscape. The winter use plan provides a template for some specific actions, namely using quieter technology and reducing speed limits. Public and staff educational efforts to relay the importance of the natural soundscape and the benefits of minimizing noise can be effective.



Median sound levels (dBA) from long-term sound monitoring along the West Entrance Road, 2006–2017. Sampling period was 7 a.m. to 7 p.m. in summer and 8 a.m. to 4 p.m. in winter. In recent years, median sound levels follow trends in visitation during summer but not during winter, providing evidence of the benefits of winter use management plan.

Bald Eagles

Bald eagles *(Haliaeetus leucocephalus)* are an iconic YNP species. The recovery of this species is representative of the recovery of natural ecosystem processes in the park following the ban of DDT (dichloro-diphenyl-trichloroethane) use within the GYE. The bald eagle was protected as an endangered species in the United States in 1967 due to a population decline caused by habitat degradation, illegal shooting, and organochlorine pesticide use, in particular DDT. As in several other raptor species, DDT contributed to eagle eggshell thinning and caused declines in productivity; the pesticide also caused toxicity in adults. Subsequent to their listing, habitat protection and the banning of DDT in the 1970s contributed to substantial increases in bald eagle abundance; and in 2007, the species was declared recovered. Resident and migratory bald eagles are now found throughout YNP, with nesting sites primarily along the shorelines of lakes and larger rivers.

There are 50 known extant and historical bald eagle territories in YNP, about one-half of which are occupied by a mated pair each year. Since 1987, the parkwide population of bald eagles appears fairly stable, with an average nest success of 50.7% and average productivity of 0.71 young per occupied territory. In 2016, nest success in occupied territories was 50%, just below the 30-year average. Productivity has been above the 30-year average for the past five years (2012–2016).

Historically, more than half of all breeding pairs of bald eagles nested near Yellowstone Lake and foraged on local waterfowl and fish. Nesting success near the lake declined from 1987 to 2007, possibly as a result of the catastrophic decrease in one prey species, the Yellowstone cutthroat trout. Cutthroat trout declined following the illegal introduction of a non-native, predatory lake trout in the late 1980s. During the last five years (2012–2016), however, bald eagle nesting success along Yellowstone Lake has been higher than the 30-year average for the park, likely because eagles have increasingly targeted other non-fish prey, including waterfowl and the colonial waterbirds nesting on the Molly Islands. Eagle nest success may also be related to the severity of spring weather in the park.

The population stability of eagles in the park is dependent upon local demographics (reproduction and survival) as well as the migration and dispersal of eagles into the park from other areas. Eagle productivity in particular appears susceptible to climate change and invasive species, as both have the potential to alter the availability of key food resources for breeding adults and chicks. The park will continue the long-term monitoring of the abundance, distribution, and demographics of bald eagles.

NPS Photo-J. Peaco

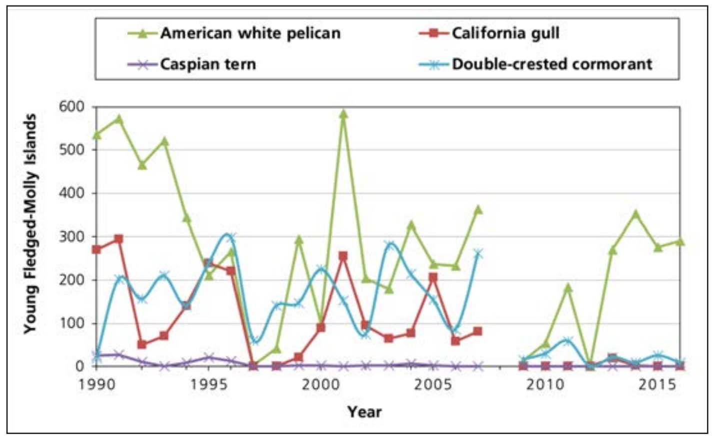
Colony Nesting Birds

The tiny Molly Islands (~1 acre; 0.4 ha) in the southeastern arm of Yellowstone Lake have supported colony nesting birds since at least 1890, including American white pelicans *(Pelecanus erythrorhynchos)*, double-crested cormorants *(Phalacrocorax auritus)*, California gulls *(Larus californicus)*, and Caspian terns *(Hydroprogne caspia)*. The Molly Islands provide the only colony nesting area for these four bird species. Colonial birds are a key part of the Yellowstone Lake food web that has recently collapsed due to the introduction of non-native lake trout.

Historically, nesting on these islands has been "boom or bust," with hundreds of fledglings in some years and virtually none in others. These species begin nesting soon after the ice melts off the lake and continue for as long as 15 weeks. Dramatic fluctuations in productivity appear to be largely related to annual variations in lake water levels. During years with high peak water levels, much of the Molly Islands are submerged and the majority of nests flood. In years with persistent high water, birds are also prevented from re-nesting and may suffer from reduced foraging success; these species, with the exception of cormorants, generally obtain fish in relatively shallow waters. Late melting of the lake ice also shortens the nesting season and reduces foraging success. Water levels and ice-out dates are influenced by snow pack, ambient temperatures, and spring precipitation. It is uncertain and difficult to predict how these factors will change and interact with a warming climate. However, consistently higher water levels could threaten the productivity and viability of this nesting site. Given their sensitivity to water level, these colony nesting birds may be useful indicators of climate change within the park.

Although there is significant variability between years, the number of waterbirds fledged from the Molly Islands has declined substantially since the early 1990s. For example, in 2016 approximately 414 American white pelican nests fledged 308 young and 57 double-crested cormorant nests fledged 34 young. These counts were down from observations in 1990, when 522 pelican nests fledged 572 young and 107 cormorant nests produced 203 young. Strikingly, 157 California gull nests fledged 295 young in 1990; but in 2016, none of only 12 nest attempts were successful. Caspian terns have not nested on the Molly Islands since 2005.

Nesting success of these colonial birds is also likely adversely affected by the catastrophic decrease in their primary food source, Yellowstone cutthroat trout, following the illegal introduction of predatory lake trout in the mid- to late 1980s. This decrease in cutthroat trout also may be inducing bald eagles to seek alternate prey, including Molly Islands' nesting birds and their young. Biologists continue to monitor waterbirds and shifting predator regimes as the efforts to remove lake trout and restore native cutthroat trout continue at Yellowstone Lake. Long-term monitoring of the abundance, distribution, and demographics (reproduction, survival) of colony nesting birds in YNP will help determine the underlying causes for the annual variability as well as long-term declining population trends.



Number of young fledged from the Molly Islands, 1989–2016. No survey was conducted in 2008.

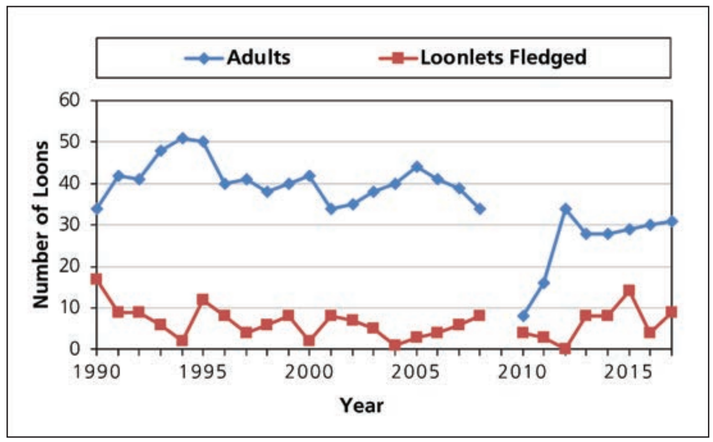
Photo © D.& L. Dzurisin

Common Loons

Yellowstone is home to the majority of Wyoming's breeding common loons *(Gavia immer)*. The species is iconic, easily recognized, and favored by park visitors for both viewing and photography. The common loon is listed as a Species of Special Concern in Wyoming because of its limited range, small population, sensitivity to human disturbance, susceptibility to contaminants, and loss of breeding habitat outside of the park.

Common loons are long-lived, but have relatively low annual chick production and poor ability to colonize new breeding areas. In the western United States, common loons breed in Idaho, Montana, Washington, and Wyoming and overwinter along the coast from Washington to California. The total western breeding population is estimated at only 115 territorial pairs. The Wyoming population is one of the most southerly breeding populations in North America and is isolated from the nearest population to the north by more than 322 kilometers (200 mi). When establishing a new breeding territory, young loons disperse, on average, only 12 miles from their natal territories. Thus, the Wyoming population is likely both geographically and genetically isolated from populations in Montana, making it particularly vulnerable to extirpation.

Since the mid-2000s, the loon population in Wyoming has declined by 38%; numbers within YNP have gradually decreased since surveys began in 1989. The Wyoming population now totals approximately 20 territorial pairs, including 13 in YNP. Following a decrease that began in 2007, however, productivity in the Wyoming population was relatively high from 2012 to 2016. In 2016, 14 of 17 surveyed lakes were occupied by at least one loon and, in total, 31 adult loons were observed. Nine loon pairs attempted to nest and seven successful pairs produced nine loonlets. Research from 2012 to 2017 by the Biodiversity Research Institute and YNP staff indicated the number of loons present in YNP varies widely from year to year. Continuing research will analyze trends in productivity, nesting success, and numbers of breeding pairs to determine why some years are more productive than others. A female loon fit with a geolocator device during summer 2015 migrated south in autumn and spent the winter around the southern end of the Baja Peninsula. This evidence suggests the Wyoming loon population may winter separately from the birds that breed in Montana and Washington.



Common loon adults and fledglings in YNP, 1989–2016. No survey was conducted in 2008.

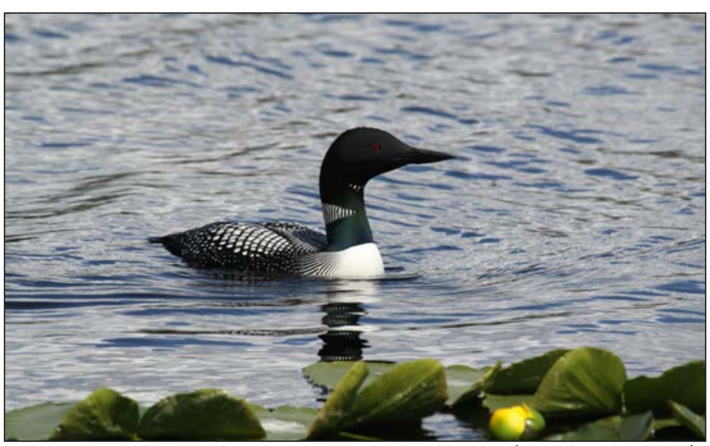


Photo © V. Spagnuolo

The breeding loon population in Wyoming is at risk of extirpation due to its small size and isolation. Human disturbance of shoreline nests lowers productivity and survival of young, as does the loss of breeding habitats due to spring flooding. Predation by bald eagles and other predators can also be significant due to the limited number of nesting pairs. Mercury toxicity also threatens adult and loonlet survival; fish sampled for mercury from lakes regularly occupied by loons during the breeding season exceeded the threshold at which fish-eating birds may be affected by mercury toxicity. In addition, loons are occasionally caught and drown in the gill nets used to suppress lake trout in Yellowstone Lake. The NPS is committed to conserving resident common loons and preserving habitat for migrants through YNP. The goal is to increase territorial pairs and, in turn, the probability of long-term persistence. With this in mind, managers have identified the most productive nesting areas and restricted human access to minimize disturbance.

Golden Eagles

There are growing concerns about the status of golden eagles *(Aquila chrysaetos)* across the western United States (Wyoming in particular) and their interactions with energy development (wind, gas, solar) and human activity. Golden eagles in YNP have only been monitored since 2011, so their status (stable, increasing, decreasing) is still unknown. The density of nesting eagles in northern YNP is relatively high compared to other areas, with one territory per 50 square kilometers (19 mi^2). Likewise, occupancy rates of 28 known territories have been consistently high, near 100%. In contrast, productivity has been low, averaging 0.4 young per occupied territory, resulting from infrequent nesting attempts and/or high nest failure rates. Our current goal is to identify the resource use and environmental drivers associated with the reproduction and survival of golden eagles in YNP. This information will contribute to building the framework for a long-term monitoring program of golden eagles in the park.

Nesting success and productivity of golden eagles in YNP, 2011–2016.

Photo © D. Schneider

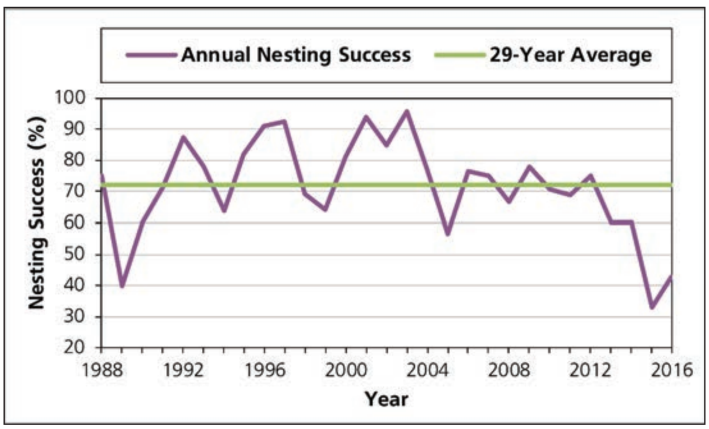
Dietary specialization is often associated with high golden eagle productivity throughout their range; however, no key food source has been identified in Yellowstone. Preliminary data suggest they have a diverse diet. This diversity in prey selection, coupled with acute changes in weather during spring, may translate to lower food intake and reduced nest success. Furthermore, the availability of winter-killed (starvation) ungulate carcasses when eagles are initiating nesting and prior to the emergence of other prey sources (ground squirrels, marmots) has decreased following the recovery of large predators during the 1990s and 2000s. Reduced carcass availability may reduce food availability during nesting (both prior to egg laying and during incubation), which may also result in lower productivity.

Establishing linkages between the diet composition, weather, and productivity of golden eagles in YNP is critical. A three-year project has been initiated to characterize food habits of nesting eagles, track movements, monitor productivity, identify survival, and record the weather experienced by nesting eagles, ultimately linking variations in movements, foraging, and weather to golden eagle demography. The relatively high density of golden eagles in northern YNP may limit productivity through competition for food resources, and may be most limited during late winter and early spring (crucial period for egg laying). Low reproductive rates warrant concern about the stability of the local population, which may be dependent on immigration from outside areas. Alternatively, low productivity could be offset by high survival, which is a primary component of population stability.

Peregrine Falcons

Peregrine falcons *(Falco peregrinus anatum)* reside in YNP from April through October, nesting on tall cliffs. The recovery of this species is representative of the recovery of natural ecosystem processes in the park, following the ban of DDT (dichloro-diphenyl-trichloroethane) use within the GYE.

Peregrine falcons were once an imperiled species in North America because of widespread use of organochlorine pesticides, such as DDT. During the 1940s–1970s, these pesticides killed birds directly and contributed to eggshell thinning and impaired reproduction. A ban on DDT, and restrictions on other organochlorine pesticides, was implemented in the United States and Canada during the 1970s. In the 1980s, approximately 6,000 captive-reared falcons were released, including 36 within YNP. Following the success of these recovery efforts, peregrine falcons were removed from protection under the Endangered Species Act in 1999. Subsequent monitoring across the United States, by the U.S. Fish & Wildlife Service through 2015, indicated territory occupancy, nest success, and productivity were above target values and the peregrine falcon population is stable, self-sustaining, and likely at saturation.



Peregrine falcon nesting success during 1988–2016 and comparison with the 29-year average.

The numbers of nesting pairs and fledglings in YNP has steadily increased from zero in 1983 to 32 pairs and 47 fledglings by 2007. Nesting success (74%), productivity (1.62 young per territorial pair), and brood sizes (2.18 young per successful pair) were relatively high from 1984 to 2013. Overall, peregrine falcons in YNP have a relatively high nesting success and numbers are considered stable. In 2016, biologists monitored 19 of 33 known breeding territories from late April through July. Sixteen territories were occupied by at least one adult. Six of the sixteen pairs successfully fledged at least 15 young for a nesting success per occupied territory of 43%. On average, peregrines produced 0.8 young per occupied territory in 2016, with an average brood size of 1.8 young fledged per successful pair. Nesting success has decreased below the 34-year average in 7 of the last 10 years. Similarly, productivity has been below average since 2004. Although these fluctuations are minor and the population appears largely stable, these trends warrant closer monitoring and further study to determine the cause(s). To evaluate the potential lingering impacts of DDT, biologists analyzed eggshell fragments from peregrine falcon territories across YNP from 2010 through 2013. Although eggshells were 4% thinner than pre–DDT measurements, the data indicate eggshell thinning is no longer a significant factor impairing falcon reproduction in the park.

The park plans to continue the long-term monitoring of the abundance, distribution, and demographics (reproduction, survival) of peregrine falcons in YNP. Monitoring of eggshell thickness will also continue, given this was the original cause of the population decline and other environmental contaminants have been shown to affect eggshell thickness.

Photo © D. Cordner

Songbirds and Woodpeckers

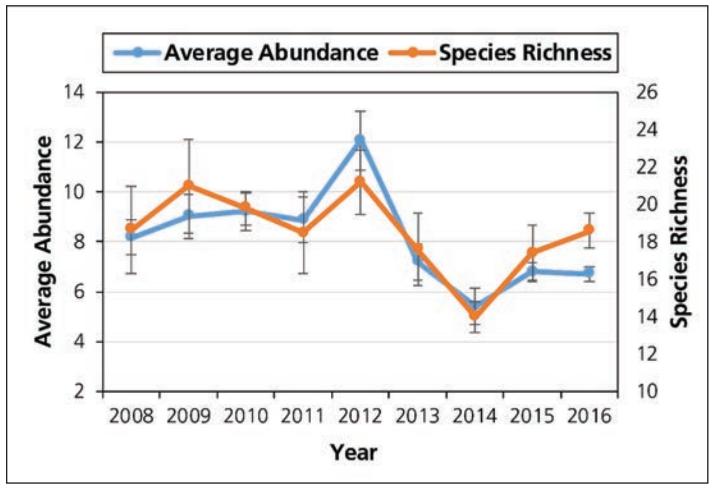
Songbirds, and woodpeckers, are a large and diverse group that, across North America, are widely threatened by habitat loss and degradation, non-native predators, and climate change. In YNP, there are numerous songbird and woodpecker species. Willow nd other riparian vegetation provide breeding habitat for nearly 80% of bird species. However, they are susceptible to excessive browsing as well as climate change. Other birds specialize in old-growth forests or grasslands, which are vulnerable to changes in climate and fire regimes. Fire is a natural ecosystem process in YNP, and recently burned forests represent a temporary, although important, habitat for cavity-nesting songbirds and woodpeckers.

From 2008 through 2016, biologists monitored songbird communities in riparian willow stands across northern YNP. Heavily browsed, short willows host different songbird communities than taller willow stands. Riparian/willow specialists, including common yellowthroat *(Geothlypis trichas)*, warbling vireo *(Vireo gilvus)*, yellow warbler *(Setophaga petechia)*, willow flycatcher *(Empidonax traillii)*, and Wilson's warbler *(Cardellina pusilla)*, all concentrate in taller willow stands. Fox sparrows *(Passerella iliaca)* and gray catbirds *(Dumetella carolinensis)* avoided the shortest willow stands altogether. Thus, riparian songbird communities may act as bellwethers for the quality of willow habitat in YNP.

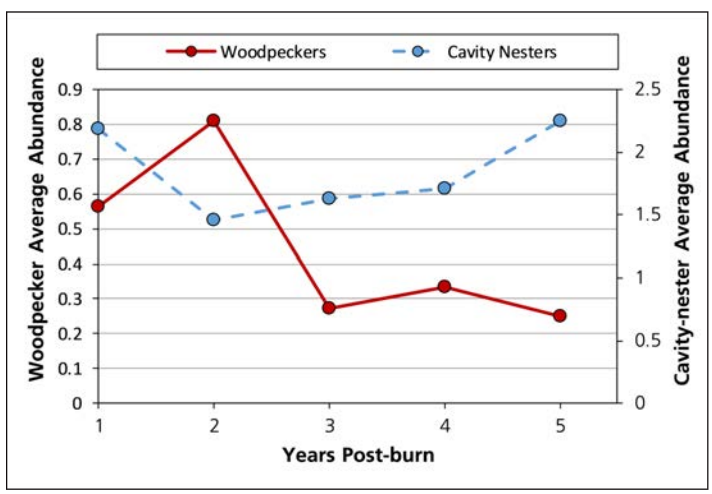
Despite a peak of 11.7 birds per survey plot in 2012, average songbird abundance observed during willow monitoring has declined slightly from 8.4 birds per plot in 2008 to 6.6 birds per plot in 2016. Total songbird species richness remained relatively stable, around an average of 23.3 species per survey plot per year.

Recently burned forest provides habitat for numerous cavity-nesting species, depending on the time since the burn as well as the fire size and intensity. For example, black-backed woodpeckers *(Picoides arcticus)* appear to target burned forests approximately two years post–fire, while tree swallows *(Tachycineta bicolor)*, secondary cavity-nesters, are more common in burned areas four or five years post–fire. Across the entire suite of cavity-nesting birds, however, species diversity remains relatively stable during the five years post–fire. Cavity-nesters appear most abundant in the first year post–fire and again after five years of regrowth and recovery.

Climate warming is predicted to continue, and may contribute to further willow growth and increased availability of this vital habitat. However, shifting precipitation and fire regimes may lead to more frequent or intense fires, resulting in the loss of old-growth forests and native grasslands. The degradation of these important habitats would likely change the local songbird community and lead to the extirpation of some habitat specialists. Our current goal is to continue the long-term monitoring of the abundance and distribution of songbird species in riparian areas and recent burns across the park. In 2017, park biologists began surveying songbird communities in old-growth forests; and in 2018, they will assume responsibilities for a grassland songbird monitoring study first initiated by the University of Montana.



Average songbird abundance and species richness across willow stands in the northern portion of YNP, 2008–2016. Error bars are standard error.



Average abundance of woodpeckers and cavity-nesting birds in select burned forests in YNP.

Trumpeter Swans

Trumpeter swans *(Cygnus buccinator)* in YNP have considerable historical significance because their protection and survival in the park during the early 1900s helped facilitate the recovery of the species in the GYE and elsewhere. Trumpeter swans are part of the natural biota of YNP and are a bird species favored by visitors for viewing and photography.

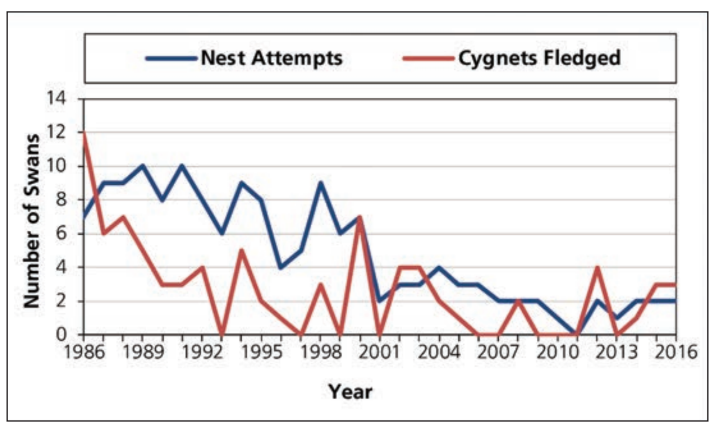
Photo © D.& L. Dzurisin

Trumpeter swans were nearly extirpated in North America by 1900 due to overharvest and habitat destruction. However, a small group of swans survived by remaining year-round in remote portions of the GYE, including Yellowstone. The number of trumpeter swans that resided and nested in the park increased to a high of 69 adults in 1961, but then decreased to fewer than 10 swans each year since 2007. The number of nesting attempts peaked in 1989 and 1991 at 10, but then decreased to 2 breeding pairs. Production was 10 to 20 cygnets per year during the 1950s, but fewer than 5 cygnets per year after the 1960s.

Yellowstone supports resident trumpeter swans throughout the year, as well as regional migrants from the GYE and longer-distance migrants from Canada during winter. However, nesting and productivity remain critically low. Two pairs of trumpeter swans nested during 2016. A pair at Grebe Lake successfully fledged two cygnets, while a pair at Riddle Lake fledged one cygnet. Three cygnets raised in captivity by the Wyoming Wetlands Society were released on the Madison River to augment the population and establish more breeding pairs. Twenty-nine swans (23 adults, 6 cygnets) were observed within YNP during a survey in late September 2016.

Yellowstone may be reliant on swans dispersing from more productive areas within the ecosystem, with the dynamics of resident swans being influenced by management actions outside the park. The high-elevation habitat in YNP provides marginal conditions for nesting, which results in chronically low numbers of nesting pairs and fledglings. This effect has been compounded over the last several decades by changes in habitat, such as decreased wetlands due to long-term drought and climate warming, as well as the recovery of predator populations.

There are concerns that habitat conditions in YNP have become so marginal for nesting that trumpeter swans may soon consist of ephemeral residents and wintering aggregations of migrants from elsewhere. If it is not possible to establish and sustain more territories, then the park may no longer retain a nesting population. The NPS is committed to conserving resident trumpeter swans and preserving habitat for winter migrants in YNP. The goal is to increase territorial pairs and, in turn, the probability of long-term persistence. Managers have identified the most productive nesting areas, restricted human access at wetland areas frequently used by trumpeter swans, installed nest platforms on some lakes to prevent nest flooding, and partnered with the Wyoming Wetlands Society to release captive-raised cygnets and incubate eggs in captivity for later release. Twenty cygnets have been released in the park since 2013.



Trumpeter swan nest attempts and cygnets fledged in YNP, 1986–2016.

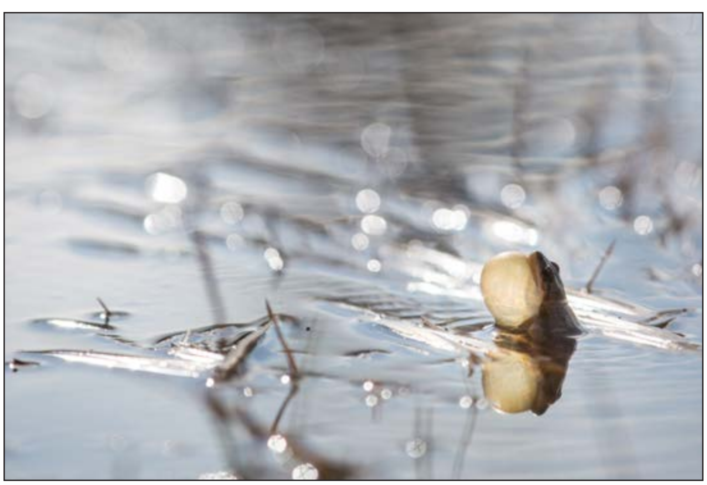
Amphibians

Amphibians were identified as a vital sign in YNP, in part, because of shrinking distributions or disappearance in parks and protected areas. Each year, the NPS, in collaboration with agency, university, and non-governmental cooperators, monitor amphibians throughout YNP. Since 2006, amphibian surveys have identified four native species: boreal chorus frog (*Pseudacris maculata*), Columbia spotted frog (*Rana luteiventris*), Western tiger salamander (*Ambystoma mavortium*), and Western toad (*Anaxyrus boreas* = *Bufo boreas*). Chorus frogs and spotted frogs are the most widely distributed species. Tiger salamanders and toads appear to be less common. The plains spadefoot toad (*Spea bombifrons*) was recently described in Yellowstone's Lower Geyser Basin, but their presence elsewhere in YNP has not been documented.

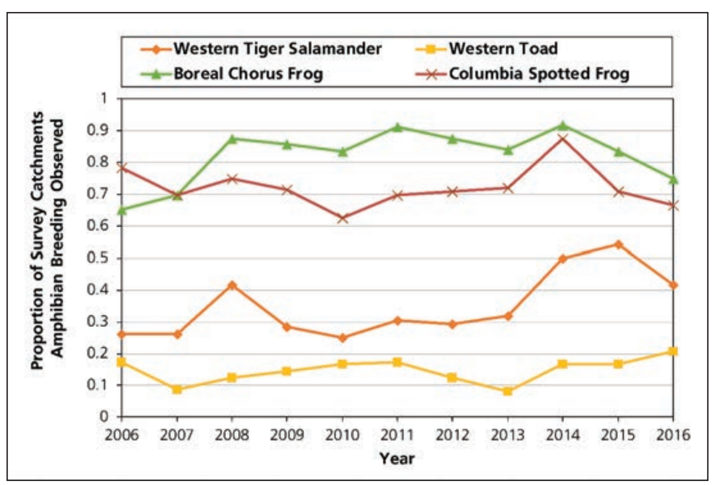
All amphibians in the region are dependent on wetlands and shallow ponds for breeding. With the exception of tiger salamanders, amphibian larvae in YNP metamorphose two to four months following egg deposition. Salamander larvae may complete metamorphosis the same summer eggs were laid or overwinter as larvae for one or more years. In permanent waters, salamanders can reach sexual maturity in a water-dependent (i.e., paedomorphic) form. Annual amphibian surveys are timed to coincide with breeding activity, and breeding evidence is documented through the detection of eggs, larvae (e.g., tadpoles), and metamorphic forms (i.e., transitional forms between aquatic and terrestrial life stages). Surveys are conducted in 31 permanent monitoring catchments (i.e., watersheds). Monitored catchments measure approximately 500 acres (202 ha) in size and vary in the amount of permanent and seasonal water they contain. Since 2006, surveys have documented variations in the proportion of catchments where amphibian breeding was observed.

In 2016, none of the 24 catchments monitored in YNP contained breeding evidence by all of the four widespread species. This was down from one catchment in 2015 and three catchments in 2014 that contained breeding evidence by all four species. This also highlights the variability of inter-annual breeding that takes place, even in protected areas. In 2016, 252 individual wetland sites spread across the 24 catchments were visited; 165 sites with standing water present were surveyed. Of those surveyed wetland sites (i.e., sites with water), 65% were occupied by at least one species of breeding amphibian.

Annual variations in breeding are tied to hydrologic fluctuations driven by annual meteorological conditions. Specifically, variations in runoff and evapotranspiration alter the extent and mosaic of wetlands and can affect amphibian reproduction. The percentage of visited wetland sites that supported surface water suitable for breeding varied between 54% in 2007 and 96% in 2011. In 2016, it was estimated that 66% of visited wetland sites were flooded and available for breeding. While all amphibians require wetlands for breeding, habitat needs differ among species and may leave some species more vulnerable to changes in wetland condition. Warmer temperatures are predicted for YNP and could reduce wetland habitat available for amphibian breeding; these impacts are expected to disproportionately impact amphibians relying on shallow wetlands.



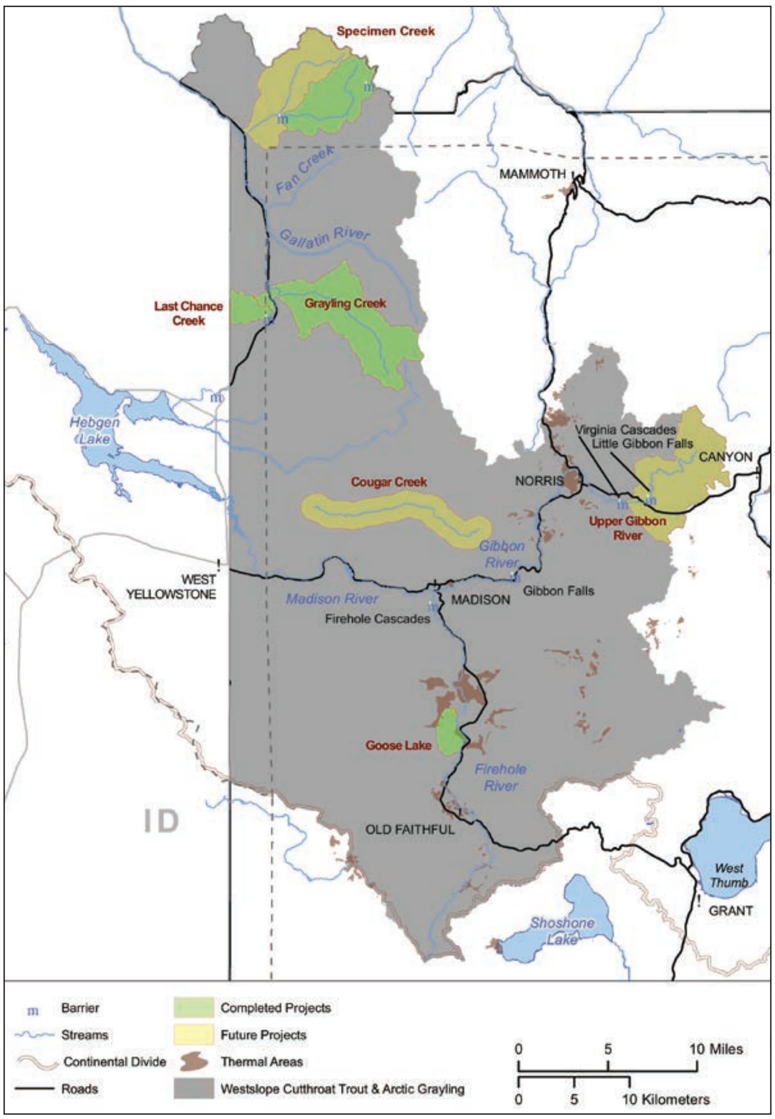
NPS Photo-N. Herbert



Proportion of surveyed catchments where breeding was observed in YNP, 2006–2016.

Arctic Grayling and Westslope Cutthroat Trout

Arctic grayling *(Thymallus arcticus)* and westslope cutthroat trout *(Oncorhynchus clarkii lewisi)* are unique native species that comprise an important component of the region's natural biota and cultural history. Arctic grayling and westslope cutthroat trout are considered a sensitive species and subspecies, respectively, in need of special management to keep them from becoming threatened or endangered. Hundreds of miles of rivers and streams in the northwest portion of YNP, including the Madison and Gallatin river drainages, were once occupied by abundant populations of river-dwelling (fluvial) arctic grayling and westslope cutthroat trout. Early in the park's history, however, non-native trout (brown, brook, and rainbow) were widely stocked in these waters to provide additional fishing opportunities for visitors. Following these introductions and changes in land and water use, fluvial arctic grayling were eliminated by 1935; indigenous westslope cutthroat trout existed in only 1.9 kilometers (1.2 mi)of Last Chance Creek, a tributary of Grayling Creek in the Madison River drainage.

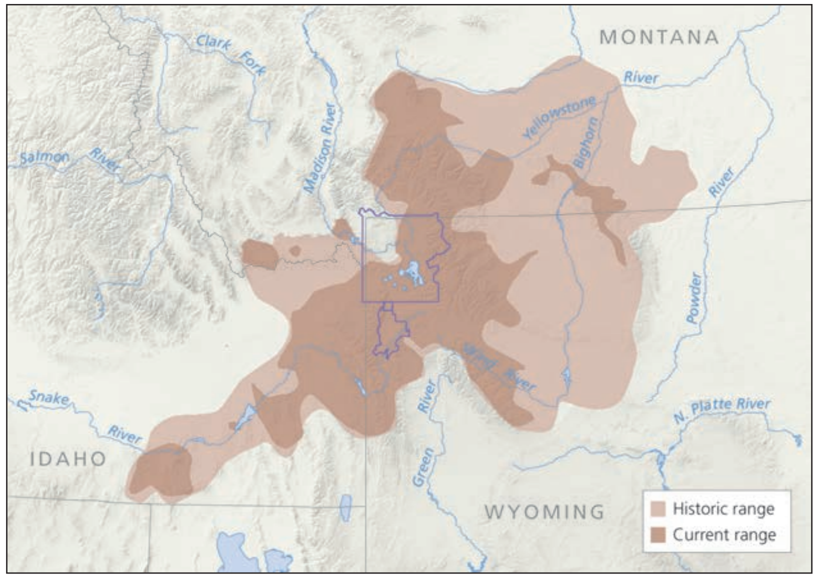


Madison and Gallatin river watersheds in YNP. Completed projects (green) and future projects (yellow) for westslope cutthroat trout and fluvial (river-dwelling) Arctic grayling current range.

Over the past decade, park biologists have worked closely with Montana Fish, Wildlife & Parks; the U.S. Forest Service; and several other partners to restore arctic grayling and westslope cutthroat trout to 74 kilometers (46 mi) of streams and 49 acres (20 ha) of lakes within YNP. By constructing in-stream barriers or enhancing waterfalls and removing non-native fishes using an approved fish toxin, headwater refuges for these native fishes were created in East Fork Specimen Creek, High Lake, Grayling Creek, and the Goose Lake chain of lakes. Remote-site incubators for hatching embryos in streams and the stocking of adults were used to restore genetically pure native fish to these areas. To evaluate the success of restoration efforts, biologists conduct electrofishing surveys in streams and use seines, nets, and snorkel surveys in lakes. These methods have validated successful natural reproduction and identified different age and size classes of fish that indicate the restored populations can sustain themselves.

There is a continued need to preserve and restore native fish populations across YNP to mitigate for further advancement of invasive non-native fishes as climate-driven changes to aquatic habitats occur. Early spring runoff and warming of streams is advantageous to non-native trout, giving them a competitive edge in watersheds where they occur with native cutthroat trout. The NPS will continue to enhance the resiliency of native fish to climate warming in Yellowstone by replacing non-native trout with arctic grayling and westslope cutthroat trout in the upper Gibbon River system above Virginia Cascades, as well as restoring westslope cutthroat trout to the North Fork and Mainstem of Specimen Creek and Cougar Creek. These actions will restore nearly 100 additional miles and more than 200 lake acres to ensure the long-term persistence of native fish in the park.

Yellowstone Cutthroat Trout



Historical and current range of Yellowstone cutthroat trout distribution. Image © 2012 University of Oregon, *Atlas of Yellowstone.*

Yellowstone cutthroat trout *(Oncorhynchus clarkii bouvieri)* are a unique native species that comprise an important component of the region's natural biota, cultural history, and natural heritage. Prior to the invasion of lake trout, Yellowstone Lake supported the largest population of genetically pure Yellowstone cutthroat trout in existence which, in turn, supported a $36 million annual sport fishery and provided food for about 20 species of birds and mammals. Yellowstone cutthroat trout are considered a sensitive species in need of special management to keep them from becoming threatened or endangered. Early in the park's history, more than 15 million non-native brown, brook, and rainbow trout were stocked in lakes, rivers, and streams in YNP to provide additional fishing opportunities for visitors. These introductions led to a drastic decrease in the abundance and distribution of native Yellowstone cutthroat trout due to competition and hybridization. In addition, the population of about 4 million Yellowstone cutthroat trout in Yellowstone Lake was decimated to about 10% of this level after the 1980s following the unintentional introduction of non-native predatory lake trout, an outbreak of whirling disease, and extended drought.

Yellowstone's Native Fish Conservation Plan calls for recovering numbers of Yellowstone cutthroat trout in Yellowstone Lake to levels documented in the late 1990s and maintaining access for spawning cutthroat trout in the lake's tributaries. Lake trout in Yellowstone Lake have been killed by netting since 1996, with a significant surge during 2012 through 2017 that killed 1.9 million lake trout. This netting will continue in future years. Also, a combination of electrofishing, mandatory kill regulations for anglers, headwater isolation, fish toxin (rotenone) treatments, and reintroductions are being used in certain areas to protect and restore cutthroat trout in streams.

Consistent, annual monitoring programs indicate an increase in the number of juvenile cutthroat trout since 2012. Angler success for cutthroat trout has also increased, and grizzly and black bears have returned to feed on spawning cutthroat trout in some tributary streams. In addition, two-thirds of the park's rivers and streams that were part of the species' native habitat outside the Yellowstone Lake watershed still contains genetically pure Yellowstone cutthroat trout. The other watercourses have cutthroat trout hybridized with introduced rainbow trout. Yellowstone cutthroat trout have been reintroduced to the Elk Creek complex of streams, and populations in upper Soda Butte and Slough creeks are being protected by in-stream barriers and the removal of brook trout and rainbow trout.

There is a continued need to preserve and restore native fish populations across YNP to mitigate for further advancement of invasive non-native fish as climate-driven changes to aquatic habitats occur. The early spring runoff and warming of streams is advantageous to non-native trout, giving them a competitive edge in watersheds where they occur with native cutthroat trout. Also, disease outbreaks may be more frequent and widespread if water temperatures warm substantially. Park managers will continue to conserve Yellowstone cutthroat trout and enhance their resiliency to climate warming by maintaining their current spatial extent in streams, restoring them to Tower Creek and the Buffalo Fork of Slough Creek, stemming the spread of rainbow trout into the upper reaches of the Lamar River, and continuing to suppress non-native lake trout in Yellowstone Lake.

For additional information regarding the status of cutthroat trout and management actions being taken in Yellowstone Lake, see the lake trout summary in the Stressors section (page 48).

Insects

USGS-Bee Inventory and Monitoring Lab

Worldwide, there are approximately 1.5 million described insect species, which outnumber all other known species combined by a factor of three. Insects provide many critical ecosystem services, including pollinating native plant communities; providing a food source for hundreds of bird, amphibian, reptile, and mammal species; acting as primary and secondary decomposers; recycling nutrients to create organic soil; acting as predators and parasites to keep pest species in check; and providing economic benefits through crop pollination, honey, wax, silk, and other products. Despite these crucial functions, insects in YNP are studied only opportunistically through external research projects.

Over the last several decades, insect studies have been conducted to document easily recognizable groups. The majority of groups, even at the order-level, remain unstudied. Yellowstone has genus or species level records for the following orders: Hymenoptera (bees, wasps, ants, and sawflies) – 67, orthopteran (grasshoppers and cicadas) – 51, Diptera (true flies) – 403, Coleoptera (beetles) – 487, Ephemeroptera (mayflies) – 72, Hemiptera (true bugs) – 38, Lepidoptera (moths and butterflies) – 237, Odonata (dragonflies) – 47, Plecoptera (stoneflies) – 92, Trichoptera (caddis flies) – 141, and Megaloptera (alderflies) – 2.

Recent analysis of a 27-year study in Germany, which is illustrative of global trends possibly found in YNP, documented an 82% mid-summer decline in flying insect biomass regardless of habitat type and unexplained by changes in weather, land use, or habitat characteristics. Except for a few groups, YNP insect diversity, abundance, trends, or baseline species lists remain largely unknown. Studies in the park have included the following: investigation of the respiratory physiology and thermal preference of water scavenger beetles in thermal features (2011–2013), benthic macroinvertebrate surveys to detect aquatic invasive species, annual butterfly counts (2003–2017), a thermal area tiger beetle project to investigate heavy metal metabolization (initiated in 2017), analysis of dragonfly larvae to detect methylmercury levels (2013–2017), a Bioblitz that documented 391 species (2009), a project that studied bee diversity and documented 350 species (2010–2012), and several insect studies that examined the effects of the 1988 fires and more recent beetle-kill forest die-offs. Recently, the western bumblebee *(Bombus occidentalis)*, has become a candidate for listing under the Endangered Species Act, so a survey to document its occurrence in the park was conducted in 2017.

The National Environmental Observatory Network (NEON) will initiate a 30-year project to monitor ground beetle diversity and tick-borne disease occurrence in the park. Yellowstone staff plan to replicate the NEON beetle monitoring protocols at a series of climate monitoring sites across large elevation gradients. This effort will examine a sentinel order (Coleoptera) to infer population trends across other insect groups. It is currently unknown how the combination of climate change and the continual spread of invasive plant species will affect insects and native plant pollination, which are key to ecosystem functions supporting ungulates and bird habitat.

Monitoring representative groups to detect changes over time is important. Park managers may also consider conducting a comprehensive order-level baseline survey, cryo-preservation, and gene-banking of park insect species to mitigate potential species extirpation or extinction events.

Bats

Bats account for more than 20% of all mammal species, and provide many essential ecological and economic services such as pollination, seed dispersal, and consumption of insects. Thirteen species of bats have been identified in YNP, with the little brown bat *(Myotis lucifugus)* being the most common. The park contains suitable habitat for bat reproduction and over-winter survival. Echolocation calls of multiple species have been recorded across winter months and some natural hibernacula have been identified. Buildings sustain strong roost fidelity and productivity of maternity colonies for little brown bats.

The survival of bats across North America is threatened by the disease white-nose syndrome (WNS) which causes bats to arouse more frequently during winter hibernation than can be supported by their energy and water reserves, ultimately leading to death through starvation and dehydration. This fungal disease has not been detected in YNP. However, it has caused significant levels of mortality in hibernating bats elsewhere and has led to regional extirpations of several species in northeastern North America. The disease has been spreading westward across the United States and was recently detected in the state of Washington.

A proactive monitoring effort is underway for the early detection of WNS and associated impacts to YNP bats. The focus is to describe the status, distribution, and roost locations of bat species through mist-netting, radio-telemetry, and acoustic monitoring. From 2012 to 2015, 65 little brown bats were radio-tagged and tracked to their day roosts. Winter residents emerged from hibernation in early spring; bats remained active on their summer range well into autumn, though nighttime temperatures were frequently below freezing. Female little brown bats at high elevations in the park extensively relied on building structures during the reproductive season, whereas males primarily used natural roosts.

Most of the bat species in YNP are expected to be susceptible to WNS. Bats are poorly suited for recovery from substantial population declines, such as those caused by WNS, because most species rear only a single young per female each year. Several roosts (e.g., building attics) in the park are critical for the continued reproductive success of little brown bats, which have been severely impacted by WNS in the eastern United States. The occupancy of building attics by bats often leads to exclusion efforts by humans that may displace important maternity colonies. Mitigation measures are being implemented in the park to protect these roosts.

Yellowstone has implemented a comprehensive monitoring program for bats to inform park managers of impacts and promote recovery efforts. Specific goals are to (1) develop baseline indices of bat activity and relative abundance, (2) identify important roosts needed for reproduction, (3) describe species distributions within specific habitat types across the landscape, (4) identify the thermal conditions inside maternity roosts to better understand reproductive needs, and (5) develop an automated monitoring program using radio-frequency identification tags to track roost fidelity and the daily movements of hundreds of bats simultaneously.

NPS Photo

Beavers

NPS Photo-N. Herbert

Beavers *(Castor canadensis)* are a "keystone" species in YNP that enhance biodiversity by creating habitat for other plants and animals, particularly birds, amphibians, and fish. Also, their presence is considered critical to nutrient cycling and the functioning of wetland ecosystems. Beavers are widespread across the park in stream and lake habitats; they occur at high densities if adequate willow is available. They are not uniformly distributed due to vast areas of coniferous forest and steep gradient streams that are unsuitable for settlement. Their influence on aquatic areas is critical to providing habitat for other plants and animals through physical modification of the landscape. Substantial fluctuations in beaver population size over time have influenced the abundance and distribution of other species. The fur trade, which focused on beavers, greatly reduced populations across the Yellowstone area and western United States. The establishment of YNP in 1872 protected beavers; thus, their numbers increased. This relatively large population used streamside aspen trees – their preferred food – which did not grow back due to competition with elk, which also forage on aspen *(Populus tremuloides)*. Willow was also reduced by elk; and together, these changes led to a substantial and sustained beaver population decrease, especially in northern YNP. Beginning in the late 1990s, the population began to increase due to an increase in willow height brought about by carnivore restoration, reduced elk numbers, human management actions, and other factors. This population increase has affected songbirds by enhancing willow stands, as well as other species.

Historically, beavers were not intensively studied in YNP. Several partial surveys were conducted in the 1920s, 1930s, 1980s, and 1990s; the first complete aerial survey was conducted in 1996. The park currently conducts an aerial census of colonies every other year. The number of active colonies has increased since 1996, when 49 colonies were recorded parkwide; the most recent complete survey in 2011 found 112 active colonies, down from a high of 127 in 2007. This relatively modest change over a four-year period suggests the population has stabilized. Three areas of dense occupation occur in the park's northwest region, the Yellowstone River delta, and the Bechler region. Lower numbers of colonies exist in northern YNP, especially along Slough Creek, as well as in the Snake River region in the southern portion of the park.

NPS Photo-N. Herbert

Beaver populations are secure within YNP. Recent population increases and expansion in distribution have occurred since willow recovered along suitable streams. Drought may impact colony longevity, making beaver impoundments more important to wetland areas; alternatively more frequent high water years due to high snow pack may be disruptive to ponds, leading to unknown impacts on riparian species assemblages. The park will continue to monitor beaver abundance and distribution in an effort to detect major changes in population status, which may impact aquatic communities.

Bighorn Sheep

The GYA supports one of the most abundant concentrations of bighorn sheep *(Ovis canadensis)* in North America, with about 5,000–9,000 animals. Bighorn sheep are a critical faunal resource in YNP and are enjoyed by visitors. Also, many state hunters place high value on the challenge of harvesting bighorn sheep in areas near the park boundary.

From European settlement until the 1930s, the abundance and distribution of bighorn sheep in the western United States decreased substantially due to market hunting, habitat loss, and diseases introduced by domestic livestock. Protection, habitat conservation, and restoration efforts over the next 80 years contributed to a recovery of the species. However, periodic die-offs and poor recruitment caused by diseases are still prevalent throughout the species' distribution. About 10–13 interbreeding bands of bighorn sheep occupy steep terrain in the upper Yellowstone River drainage. From the 1890s to the mid-1960s, total abundance in this population fluctuated between 100 and 400. There was a high count of 487 sheep in 1981, but a pinkeye epidemic reduced numbers by 60% the following winter. Numbers decreased to a low of 134 sheep after the severe winter of 1996–97, raising concerns about the long-term viability of the population. The overall trend in total abundance since 2003 has been upward, though band sizes and recruitment rates are still relatively low. In 2017, 353 bighorn sheep were counted from Point of Rocks in the southern Paradise Valley of Montana, to Barronette Peak within YNP; this is similar to the 10-year average of 358 sheep. A ratio of 27 lambs per 100 ewes was observed, compared to an average of 28 lambs per 100 ewes during 1995–2017.

Bighorn populations in the western United States are threatened by continuing pneumonia outbreaks that are not well understood. Occasional outbreaks of pneumonia have been observed in bighorn sheep occupying Mount Everts and Cinnabar Mountain, most recently during the winter of 2015. The Greater Yellowstone Area Mountain Ungulate Project, initiated in 2009 by Montana State University with federal and state agencies, studies bighorn sheep and their interactions with mountain goats (see http://www.mtbighorninitiative.com/gyamup-home.html). There are also concerns about the potential for resource competition and disease transmission (e.g., pneumonia-causing pathogens) from mountain goats to bighorn sheep. Bighorn sheep bands in the upper Yellowstone River drainage are relatively small, slow growing, and low in productivity. As a result, year-to-year variations in lamb and yearling survival have substantial effects on population dynamics. Low recruitment can limit the ability of these bands to respond to decreases in abundance caused by disease outbreaks or severe weather events, thereby increasing their susceptibility to extirpation.

Our goal is to increase and sustain a viable population of bighorn sheep in the upper Yellowstone River drainage that migrate and disperse through their historical range and whose behaviors, movements, survival, and reproductive success are predominantly affected by their own daily decisions and natural selection, not by humans.

NPS Photo-P. Olliff

NPS Photo-N. Herbert

Bison

Yellowstone bison *(Bison bison)* are important due to their large population size within the park, high genetic diversity, lack of interbreeding with cattle, and wild behaviors and adaptive capabilities like their ancestors. They are special to many Native American tribes because they are the last living link to the indigenous herds of bison that once roamed across North America. They also allow visitors to observe this symbol of the American frontier in a wild, unfenced setting. Unfortunately, many bison are infected with the disease brucellosis, which was introduced by cattle, reduces pregnancy rates, and poses a risk of transmission back to cattle. The potential of brucellosis transmission, concerns about property damage, human safety, and competition with cattle for grass limit tolerance for bison outside the park and prevent relocations elsewhere to restore the species.

Following the mass slaughter of bison during the late 1800s, there were about 23 indigenous bison remaining in the GYA, all within the central region (Pelican Valley) of YNP. As a result, in 1902 managers created another breeding herd in the northern portion of the park (Lamar Valley), with 18 female bison from northwestern Montana and 3 male bison from Texas. After several decades, the indigenous and reintroduced herds began seasonally migrating, mixing, and interbreeding, which has substantially increased in recent decades as bison numbers have increased. Today, bison in YNP comprise the largest conservation population of plains bison, with about 5,500 counted during summer 2016.

Bison numbers in northern YNP have doubled since 2010, with numbers in central YNP decreasing by several hundred. Overall reproductive and survival rates remain high. The two independent genetic lineages are present in approximately equal proportions after more than a century, with high genetic diversity indicative of a healthy population. To reduce numbers in northern YNP, managers removed approximately 1,275 bison from the population during winter 2017 using harvests in Montana and culls in YNP. Monitoring since the 1990s has not detected brucellosis transmission from YNP bison to cattle.

Increasing bison densities in northern YNP have led to concerns about high grazing intensities on some summer ranges that may not be sustainable over time. The recent transition from an elk- to a bison-dominated grazing system is unprecedented in the park's history and, therefore, the long-term effects on the grassland communities are unknown. Scientists are monitoring indicators and drivers of undesired plant community changes and will continue to evaluate the impacts of grazing by bison on plant productivity, species composition, and nutrient cycling.

The intensive management of bison migrating outside YNP during winter continues to be a contentious issue involving the NPS, State of Montana, Animal and Plant Health Inspection Service, Native American tribes, U.S. Forest Service, and other stakeholders. The culling and shipment of many hundreds of bison to slaughter facilities during winters is extremely controversial. To reduce shipments to slaughter, the NPS has decided to implement a quarantine program to identify brucellosis-free bison for release on public and tribal lands. For further recovery, plains bison need similar access to habitat and tolerance that other wildlife species are given in the Yellowstone area, including year-round access to other public lands besides the park.

NPS Photo-N. Herbert

Elk

NPS Photo-N. Herbert

Elk *(Cervus elaphus)* are the most abundant ungulate species found in YNP. They play a critical role in the park's ecosystem. They are also enjoyed by visitors for viewing and photography, especially during calving and rutting seasons. Hunters also place a high value on harvesting elk that migrate outside the park in autumn and winter. During 1892 to 1967, about 14,657 elk were captured within YNP and relocated to other areas worldwide, primarily to establish new populations.

Elk from at least seven populations (Clarks Fork, Cody, Jackson, Madison Valley, Madison headwaters, Paradise Valley, northern Yellowstone) summer in YNP, with most of these elk migrating to lower elevations outside the park during autumn and winter. The most intensely studied of these populations (northern Yellowstone) spends winter on a range extending from the Lamar Valley in YNP to the southern Paradise Valley in Montana. Annual counts of this population are typically conducted during a single day; and consequently, counts underestimate actual population size because not all elk are observed. About 17,000 Northern Yellowstone elk were counted when wolf reintroduction occurred during 1995 to 1997. Counts then varied between 11,000 and 15,000 during 1998 to 2002 when wolf predation had comparatively smaller effects on elk population dynamics because wolf numbers were relatively low, elk numbers were high, and wolves primarily selected younger and older elk that produce few calves and are more prone to starvation. Harvests focused on reproductive-aged elk and removed 1,100–3,300 per year, which exceeded estimates of wolf predation. However, elk counts decreased to 3,915 during 2003 to 2013 as an abundant and diverse predator community (bears, cougars, wolves), in combination with weather and modest harvests in Montana, reduced recruitment and limited numbers. Estimates of predation now exceed the number of harvested elk.

Winter counts of northern Yellowstone elk ranged between 4,844 and 5,349 during 2015 to 2017. These counts were within or above objectives developed by Montana Fish, Wildlife & Parks for the winter range north of the park, with 4,776 elk observed in Hunting District 313 (objective = 3,000–5,000) and 3,298 elk north of Dome Mountain (objective = 2,000–3,000) during 2017. Recruitment since 2015 has been above the objective of 20 calves per 100 adult females included in the state's management plan or annual counts of Northern Yellowstone elk (see figure on page 36).

For decades, Montana Fish, Wildlife & Parks has designed harvests of northern Yellowstone elk based on the premise that a substantial portion of the population remained in the park and was not subject to harvest. Since 2008, however, a larger portion of the smaller elk population has migrated outside the park where elk are vulnerable to harvest (1997–2006 average = 10,785 elk counted and 160 bulls harvested; 2007–2016 average = 5,410 elk counted and 204 bulls harvested). There has been a substantial decrease in the number of brow-tined* bull elk north of YNP since 2002 due to lower recruitment combined with an increase in the proportion of bulls harvested in Montana.

The park's goal is to sustain a viable population of elk in the upper Yellowstone River drainage that migrate and disperse through their historic range and whose behaviors, movements, survival, and reproductive success are predominantly affected by their own daily decisions and natural selection.

**Brow-tined elk:* A bull elk with an antler or antlers that have a visible point on the lower half of either main beam that is greater than or equal to four inches long.

Gray Wolves

The reintroduction of wolves *(Canis lupus)* to YNP was a transformational event that completed the restoration of native, large carnivores in the ecosystem. Wolves are a dominant, top carnivore whose sociality makes them formidable predators and competitors with substantial effects on community dynamics (e.g., trophic cascades) and ecological processes (e.g., herbivory, predation, scavenging). Yellowstone is one of the premier places in the world to watch wild wolves, providing great enjoyment to millions of people.

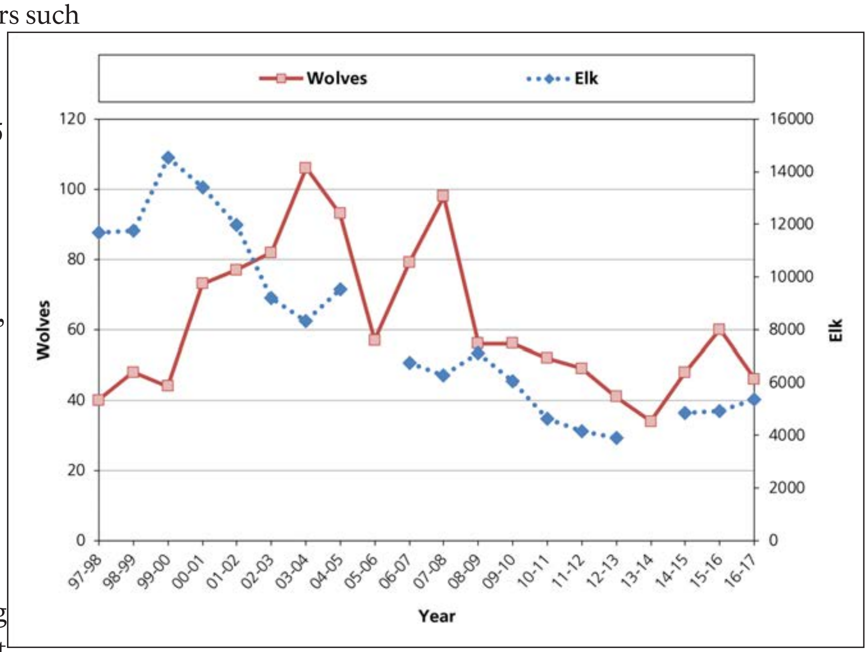
NPS Photo-N. Herbert

The last known wolf in YNP was killed in 1926. The loss of wolves and drastic reductions in other predators such as bears and cougars led to changes in the ecosystem; elk numbers proliferated and browsing effects altered vegetation communities. From 1995 to 1997, 41 wolves were reintroduced into YNP; numbers increased to 174 wolves in as many as 16 packs over the next decade. Wolf restoration, concurrent with the recovery of bear and cougar populations, harvests of elk in surrounding states, drought, and severe winters, facilitated a substantive decrease in some elk populations, primarily through sustained low recruitment. However, predator numbers necessarily decrease in response to less prey, and wolf numbers in YNP decreased by 40% or more since 2009.

There were 108 wolves in 11 packs in YNP during 2016, including 7 breeding pairs. This is the largest protected assemblage of wolves in the northern Rocky Mountains. Numbers in the park have been relatively stable; there were between 95 and 110 wolves in 7–10 packs since 2009. The population has high levels of genetic variation and low levels of inbreeding, with gene flow to other areas in the Rocky Mountains.

The recovery of multiple large predators in the Yellowstone area is quite recent in ecological time; scientists continue to study how the ecosystem changes over subsequent decades as an increasing human presence, warming climate, and these predators and their prey interact. The abundance of wolves within YNP will fluctuate in response to their prey and other factors (e.g., competition, disease). While the effects of wolves on elk is contentious, research has shown that multiple influences affect elk populations (including other predator species), not just wolves alone.

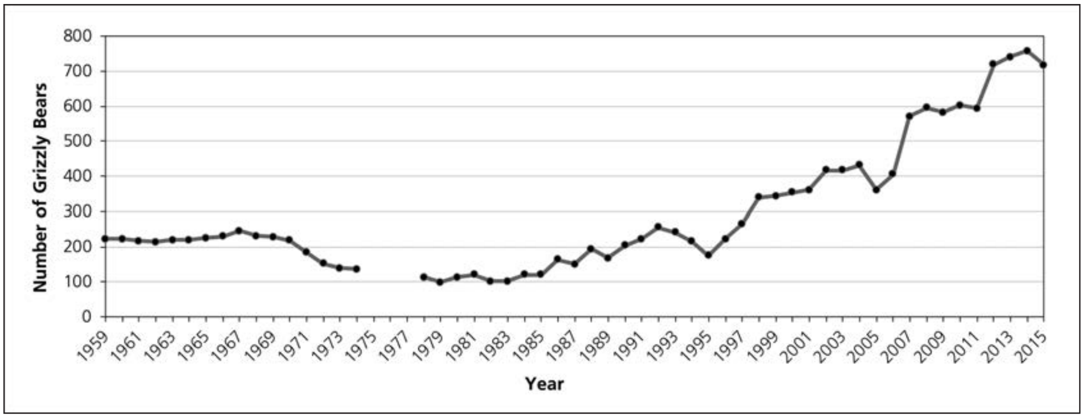
Some wolf packs residing in YNP occasionally travel outside the park to hunt prey, especially during autumn and winter when elk migrate to lower elevations. State hunting seasons for elk and wolves occur at this time, which results in the legal harvest of some of these wolves. The NPS consults with states to reduce the chance of entire packs or well-known wolves being shot when they leave the park. Park managers have recommended no more than 5–7% harvest of the total wolves living in Yellowstone near the boundary, with harvests distributed among packs.



Counts of wolves and elk in the Northern Winter Range, 1997–2017. Wolf counts include wolves from packs both inside and outside the park. Official elk counts were not generated in the winters of 2005–2006 and 2013–2014.

Grizzly Bears

The Yellowstone grizzly bear *(Ursus arctos horribilis)* was protected as threatened with extinction under the Endangered Species Act in 1975 due to high levels of mortality and loss of habitat. It became a national symbol of the modern conservation and wilderness movements. Grizzly bears have a sacred place in the culture of many Native American tribes and symbolize wildness to many people. The high visibility of bears foraging for foods in roadside meadows has made YNP one of the most popular bear viewing destinations in the world.



Counts or estimates of the number of grizzly bears in the GYE, 1959–2016. Numbers were estimated from counts of bears at garbage dumps (1959–1974), extrapolated from the number of females with cubs (1978–2006), and estimated using the Chao2 model (2007–2016).

Perhaps a few hundred grizzly bears survived Euro-American colonization and predator eradication efforts in the Yellowstone area during the mid-1800s to the mid-1900s, with YNP providing refuge to many of these bears. Early in the park's history, bears learned to obtain human foods along roadways, in campgrounds, and at garbage dumps. Managers initially tolerated this behavior; as human injuries and property damage increased, regulations prohibiting feeding were enforced and garbage dumps were closed. Many food-conditioned bears dependent on human food sources were removed from the population. Remaining bears began subsisting on natural foods. Over time, bear numbers increased and surpassed goals needed for a viable population.

NPS Photo-J. Peaco

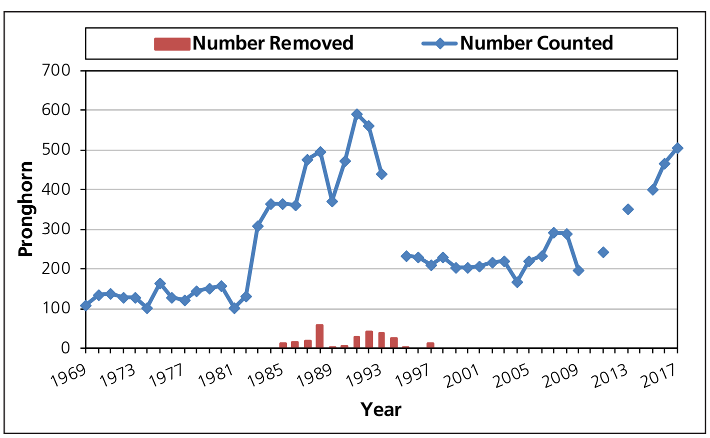
During 2016, about 690 grizzly bears occupied more than 25,000 square miles in the GYE. There are at least three times more grizzly bears, occupying more than twice the area, than during the mid-1970s when they were protected. Genetic analyses indicate a low rate of inbreeding and stable genetic diversity since 1985. Periodic immigration or relocation of bears from other populations should forestall future losses of genetic diversity. The Interagency Grizzly Bear Study Team, which includes YNP biologists, has monitored and conducted research on the Yellowstone grizzly bear population for many decades. Continuation of this cooperative interagency program will be crucial to ensure the long-term health of the population and assess if population and habitat standards in the *Yellowstone Grizzly Bear Conservation Strategy* are being achieved.

During summer 2017, the U.S. Fish and Wildlife Service published regulations to remove the GYE population of grizzly bears from the Endangered Species List. The NPS supports delisting and will continue to achieve the population and habitat standards described in the Conservation Strategy. However, there are some future concerns. The sustainability of grizzly bears in the GYE depends on their having access to large expanses of suitable habitat, with a low risk of death from conflicts with people. Conflicts have increased as bears expand into habitats with more human presence on landscapes that have not been occupied by grizzly bears for many decades. Also, there is uncertainty regarding the future extent of climate-related changes, the magnitude of effects on grizzly bears, and the resilience of bears to adapt to changes. In addition, potential harvests of bears following delisting would be a significant change in population management from the recovery period.

Pronghorn

Pronghorn *(Antilocapra americana)* were once numerous (1,000–1,500) in YNP and migrated 80 to 130 kilometers down the Yellowstone River from higher-elevation summer ranges in what is now YNP to lower-elevation winter ranges in Montana. Human settlement reduced pronghorn numbers and eliminated their migration outside the park sometime before 1920. Also, there were several precipitous decreases in counts during the 1950s, 1960s, and again in the 1990s, possibly related to diminished food resources on their winter range. These decreases raised concerns about the long-term viability of the population.

NPS Photo-N. Herbert



Counts and harvests of YNP pronghorn, 1969–2016. No counts were conducted in 1994, 2010, 2012, and 2014. Harvests occurred in Montana north of the boundary of YNP through 1997 and resumed in 2016 (hunting figures from 2016 are unknown).

Pronghorn abundance has been consistently increasing since 2012 and recruitment has been relatively high since 2014. During spring of 2017, 506 pronghorn were counted, the highest count since 1993. Yellowstone pronghorn possess much of the genetic variation formerly widespread in the species. The population retains one of only a few long-distance migrations by pronghorn in the GYE. Historical migratory patterns north of YNP have been reestablished through efforts led by the National Parks Conservation Association, who are working with landowners and federal and state agencies to remove and modify fences in critical migratory bottlenecks.

In the early 2000s, a small herd of pronghorn was detected approximately 30 kilometers (19 mi) north of YNP in the southern portion of the Paradise Valley in Montana. This herd increased to 120 animals in 2014 and represents the first substantial return of pronghorn to the southern Paradise Valley since the early 1900s. Genetic and telemetry data indicate this population was started or supplemented by pronghorn from YNP and is still maintained by frequent dispersal from the park. Dispersal and gene flow between the two populations improves their long-term viability.

Our goal is a sustainable Yellowstone-area pronghorn population that migrates and disperses through its historical range. The population's behavior, movements, survival, and reproductive success should be predominantly affected by their own daily decisions and natural selection, rather than by humans. A long-term concern is that the pronghorn population appears to be limited by forage availability on its winter range. Large parts of the range are degraded due to historical farming and excessive grazing, as well as widespread invasions of non-native plants such as cheatgrass, annual wheatgrass, and desert alyssum. Pronghorn numbers can decrease rapidly in response to decreased food availability, especially during periods of extended drought or severe winters. Thus, the continued ability to migrate and disperse to areas outside the park is essential.

Alpine Plant Communities

Alpine environments in YNP occur above 2,743 meters (9,000 ft) and are some of the lesser visited areas in the park. These environments comprise less than 9% of the park area, and consist predominantly of talus and rock outcroppings that are intermixed with alpine meadows and high-elevation forests dominated by whitebark pine.

The alpine environment is known for extreme conditions, such as high winds, low temperatures, scouring and burial by snow and ice, high incident solar radiation, thin atmosphere, and a short growing season. Flora adapt to these conditions by having a low stature, determinant growth cycles, and specific leaf morphology. Alpine communities are threatened by changes in climate patterns, changes in air quality that affects soil nutrients available to plants, and disturbance.

In 2011, a permanent alpine monitoring site was established along the park's east boundary, north of Lamar Mountain. This site is monitored following a standardized NPS protocol, based on internationally-recognized methods (i.e., the Global Observation Research Initiative in Alpine Environments protocol). There are similar monitoring sites located across the Rocky Mountains that offer opportunities for comparison. The site is visited every five years to gather data used to meet the objectives of this long-term monitoring program. The objectives are to determine the status and trend in vegetation composition and structure of native and invasive plant species, soil condition and temperature, and assess community vulnerabilities.

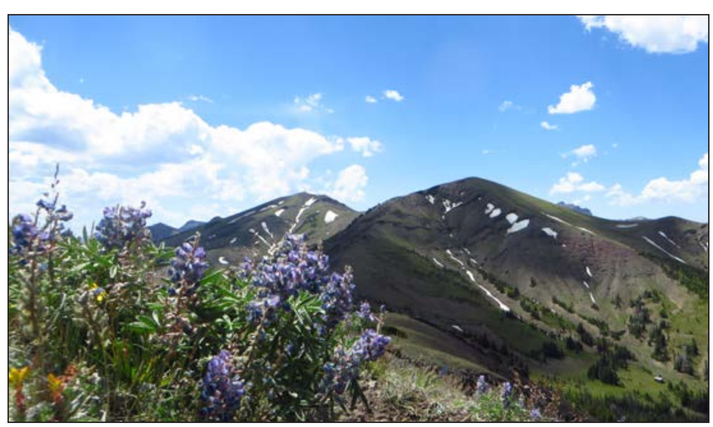
The site was most recently monitored in 2016; 127 vascular plant species were recorded, including 54 species not documented during the 2011 sampling effort. While it seems species richness increased since 2011, future monitoring will help to determine whether species richness increased or whether the change was due to an improved understanding of what taxa to expect at the site. There was no significant change in soil temperature. However there was a statistically significant increase in some soil nutrients, including phosphorus, nitrogen, and potassium, which could be a result of regional deposition. Little evidence of disturbance was documented.

Additional alpine areas in YNP have been inventoried for vascular and non-vascular (e.g., lichens) plants. The underlying geology across alpine ecosystems varies from volcanic to sedimentary rocks, which may lead to different plant taxa. While accessible alpine zones such as on Mount Washburn have been surveyed, more remote areas in southern and northwest YNP have had limited surveys or have not been surveyed. By the end of 2016, over 550 flora taxa were documented in YNP's alpine zones.

NPS Photo-J. Frank

Projected increased temperatures and variations in precipitation patterns (shorter periods of snow pack and more rain events) may affect alpine areas. Invasive plants may become established due to more favorable habitat conditions and many native alpine species may be lost if they are unable to adapt. Integrating soil temperature data and climate station site data with vegetation data will allow managers to more clearly understand how changes in climate may drive the composition of alpine vegetation.

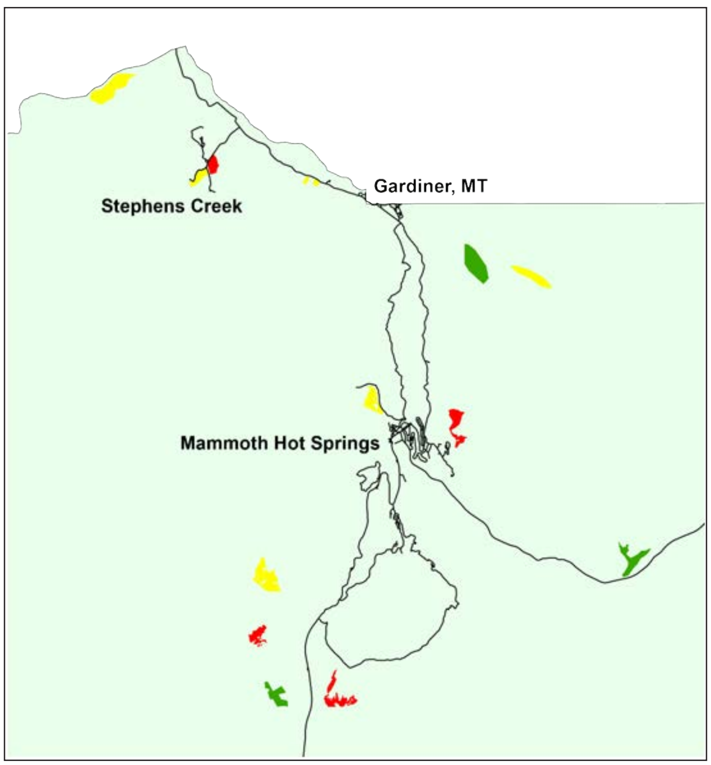
The permanent alpine site on the park's east boundary will be monitored again in 2021, with visits every two years to download soil sensors. During these visits, plants will be identified and a comprehensive species list will be developed for future monitoring. Alpine areas throughout the park will be visited periodically to identify plants to improve our understanding of alpine vegetation composition across the different areas of the park.



NPS Photo-D. Thoma

Shrub-steppe Communities

Much of the sagebrush steppe throughout the western U.S. has been lost to overgrazing by domestic livestock, shrub removal to increase grass production, land use conversion to commercial agriculture, and plant-community conversion by/to invasive species. While YNP has largely been managed to preserve natural resources, there are threats to the integrity of the sagebrush steppe, such as grazing/trails/wallows by wildlife, climate changing to warmer and drier summers, and invasive species. Big sagebrush *(Artemisia tridentata)* systems are often characterized by cool-season bunch grasses with a fairly high amount of bare soil. These characteristics make the system very susceptible to non-native plant invasions by some of the means stated above. Of particular concern are annual grasses and forbs that can operate as winter annuals, such as cheatgrass *(Bromus tectorum)* and desert alyssum *(Alyssum sp.)*. The silver sagebrush systems *(A. cana)* are characterized by native bunch grasses and can have a very high forb component. They are much more productive and have a higher total plant cover. In some places, gophers are constant sources of disturbance and keep much of the flora in early seral species.



A subset of the sagebrush steppe monitoring frames in the northern range of YNP. Frames are color-coded to indicate the foliar coverage abundance of invasive plants: red for high, yellow for medium, and green for low. Of particular interest are the frames with low cover of invasive species adjacent to high invasives cover (Stephens Creek), and the potential for increased cover for those frames with medium cover of invasives.

In 2015, YNP initiated a sagebrush monitoring program, which follows the established protocols used by the NPS's Upper Columbia Basin and Greater Yellowstone I&M networks in seven other national park units. The primary focus of the monitoring program in YNP is to collect data to aid in the detection (and expansion) of invasive species and the change in composition of the native flora. This will be accomplished by analyzing the changes through time of the percent cover of bare soil, litter, and individual plant species within permanent sample frames. Sample frame locations were selected to capture the breadth of species composition represented by disturbance history, elevation, slope, and aspect. Data will be collected on a schedule of five-year intervals except for locations that have been selected to be read annually. There are 11 sample frames with temperature sensors located on them which, when combined with the vegetation, will help elucidate a vegetation response to climate on a localized scale.

To date, the most abundant (highest cover) and most frequently occurring species across the entire study is Idaho fescue *(Festuca idahoensis)*, a native bunch grass. The top 10 most abundant species are all natives except for Kentucky bluegrass *(Poa pratensis)*, and the top 10 most frequent species are all native. Of most concern are the invasive plants that have significant frequency due to the ability to spread, as well as those which are very abundant. Using the spatial component of the data set, staff can identify areas that are more susceptible to invasion and identify areas for treatment. As the dataset increases, the ability to make more complex analyses, including assessing the role of the changing climate, will be possible.

The data from YNP, as well as other park units involved in sagebrush monitoring, is made available to the public via VegViz.org. It is also uploaded to NPS Integrated Resource Management Applications Portal (irma.nps.gov/portal). Open access on these websites allows others to use the data and facilitates collaboration with other NPS work groups within YNP and the NPS I&M networks assisting national parks. Future products include large landscape analysis of sagebrush systems across the I&M network park units and developing on-line analysis tools.

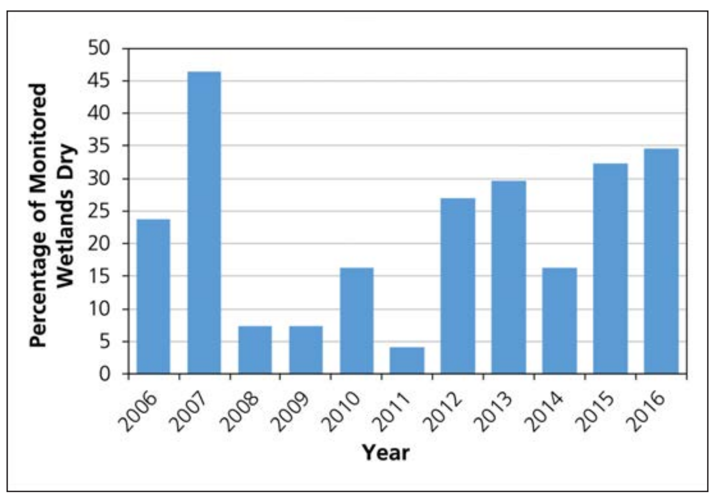
Wetlands

Wetlands in YNP represent approximately 10% of the landscape. Despite their limited size, the contribution of wetlands to the biodiversity of the park and the surrounding regions is presumed to be significant given the dependence of many organisms on wetlands for some stage of their life cycle. For example, almost 70% of Wyoming bird species, nearly half of all bat species, all native amphibians in the GYA, and upwards of 40% of all of plant species of YNP are associated with wetlands.

Glacial erratic showing water loss and lichen cap in former wetland along the Hellroaring Trail, south of the Yellowstone River. Photo © C. E. Hellquist-SUNY Oswego.

Park scientists and their cooperators have been monitoring wetland taxa: aquatic plants, trumpeter swans, common loons, beaver, bats, and amphibians. Botanical surveys of YNP wetlands have identified a number of rare species. Two new species to Montana (the Andean water-milfoil or *Myriophyllum quitense*, and the strait-leaf pondweed or *Potamogeton strictifolius)* and three species new to Wyoming (the spiny-spore quillwort, or *Isoetes echinospora*, the wavy water nymph, or *Najas flexilis*, and the yellowish-white bladderwort, or *Utricularia ochroleuca)* were documented. Annual visits to >200 wetlands sites spread across YNP show the number of wetlands without water present (dry wetlands) varies substantially across years. Dry wetlands are noted each year and the 11-year (2006–2016) median percentage of dry wetlands was 24%. In 2007, greater than 45% of wetlands visited were dry and in 2011 only 4% of wetlands visited were dry. Across our time series the percentage of dry wetlands documented annually in YNP is strongly negatively correlated with annual April–June precipitation ($r = -0.897$, $p < 0.001$) and runoff totals ($r = -0.855$, $p < 0.001$) for monitored wetlands.

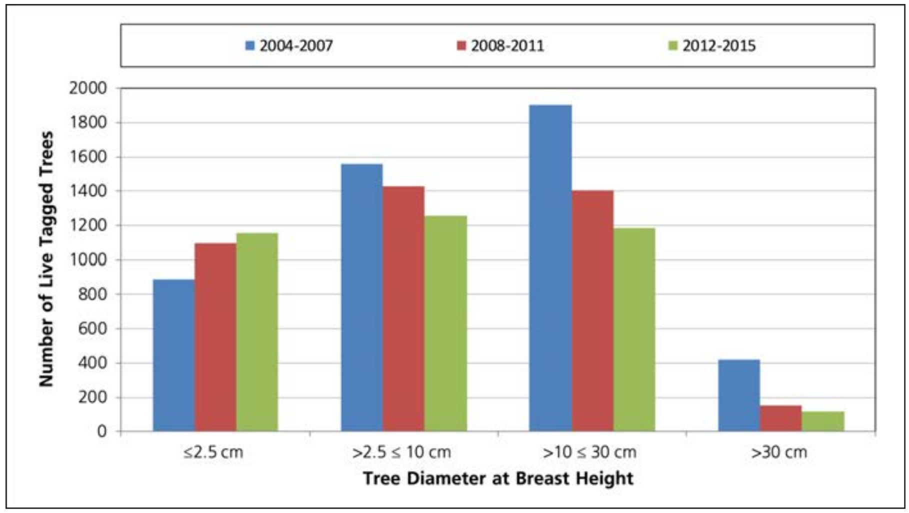
Within the boundaries of protected areas such as YNP, climate change serves as the leading stressor to wetland change. In the northern range of YNP, wetland area has contracted over the last century. A sizable reduction in the number of permanent and ephemeral wetlands occurred in just the last three decades. As species redistribute themselves in response to climate change and human use, the need for documenting plant communities is especially important. Aquatic vascular plants (hydrophytes) are critical components of aquatic ecosystems, providing habitat structure and food that is essential for wildlife. Lakes, ponds, rivers, streams, and wetlands are refugia for aquatic and semi-aquatic organisms in an increasingly arid landscape. Park researchers have been documenting the aquatic flora in YNP to provide an ecological baseline for monitoring successional change in aquatic plant communities. They have located 94 hydrophyte species in Yellowstone and sampled more than 335 sites, with more than 2,000 herbarium records. They also identified over 150 sites that contained state listed species of concern or species new to the state floras. During these surveys, no non-native aquatic plant species were found in the park. In general, the northern range of Yellowstone and Hayden Valley survey sites had some of the greatest aquatic plant diversity.



Percentage of YNP wetlands surveyed that were dry, per year, 2006–2016.

Whitebark Pine

Whitebark pine (*Pinus albicaulis*) forests are biologically significant components of YNP and other high-elevation regions of the northern Rocky Mountains. In these upper ranges, this iconic coniferous species plays a variety of ecological roles, including regulation of snowpack and providing high-energy food sources to birds and mammals. Throughout its historical range, whitebark pine has decreased significantly as a major component of high-elevation forests. Impacts from biotic and abiotic factors including white pine blister rust (*Cronartium ribicola*), mountain pine beetle (*Dendroctonus ponderosae*), wildland fire, and climate change dynamics, have individually and collectively presented major challenges to the long-term persistence of whitebark pine in the GYE. Whitebark pine has been designated as a candidate species as warranted but precluded under the Endangered Species Act, and the U.S. Fish and Wildlife Service is reviewing this status with a decision expected in 2019. The NPS-led Interagency Whitebark Monitoring Program has been tracking the overall trajectory of whitebark pine in the GYE since 2004. Between 2004 and 2016, a total of 5,215 live, tagged whitebark pine trees (greater than 1.4 m tall; 4.6 ft) on 176 transects located throughout the GYE have been evaluated for the presence of white pine blister rust, mountain pine beetle, wildland fire, and other influences on tree health and vigor. On a four-year schedule, the monitoring program assesses trends in whitebark pine health in the GYE. For the most recent four-year trend report ending in 2015, the estimated proportion of whitebark pine mortality across the ecosystem was 26% with larger sized trees (>10 centimeters diameter at breast height; 3.9 in dbh) experiencing the highest death rate. The predominance of mortality occurred from 2008 to 2011 when endemic mountain pine beetle populations escalated to epidemic proportions following three consecutive years of above average temperatures (2006–2008). This mortality has resulted in a noticeable shift from larger diameter, mature whitebark pine trees to those of smaller diameter trees.



Size class distribution shift in live, tagged trees from 2004 to 2015, primarily attributed to the most recent mountain pine beetle outbreak.

While mortality rates attributed to mountain pine beetle have decreased, white pine blister rust continues to be a persistent presence in whitebark pine stands throughout the ecosystem. Data indicate white pine blister rust infection has remained relatively consistent since the inception of the monitoring program, with the proportion of live whitebark pine infected between 14–26% at the end of 2015. When infected with white pine blister rust, smaller diameter trees typically experience higher and more rapid mortality rates than larger trees. With the mountain pine beetle-driven population shift to smaller diameter trees, white pine blister rust may, in the upcoming decades, become the most probable cause of whitebark pine mortality in the GYE.

The monitoring program also documents the reproductive potential and regeneration of whitebark pine. As of 2015, approximately 25% of the live, tagged trees were cone producing, and the understory trees (<1.4 meters tall; 4.6 ft) averaged to about 51 trees per 500 meters square (5,382 ft^2). So while there has been considerable mortality in the mature whitebark pine population, there is continued recruitment of whitebark pine.

The future of whitebark pine in the GYE is contingent upon how it responds to the dynamic nature of our changing climate, pathogens including white pine blister rust, insect outbreaks, and other impacts such as wildland fire in conjunction with range-wide restoration efforts. The long-term whitebark pine monitoring program will continue to document emerging patterns in whitebark pine health. It will also provide data that is scientifically relevant, but also relevant to land managers responsible for the conservation of whitebark pine in the GYE.

Archeological Sites

Roughly 223 square kilometers (86 mi^2) or less than 3% of YNP has been inventoried for archeological resources. At least 1,850 archeological sites have been identified throughout the park, from river valleys to high-elevation areas with perennial ice patches. Archeologists continue to locate and record new sites every year. These resources are the primary source of information about human occupation in the park until the last few hundred years. Alongside are traditional stories and place names from park's 26 traditionally associated tribes whose ancestors visited and lived in the Yellowstone region for millennia. Collectively, this information helps us better understand the human history of one of the most treasured landscapes in the world.

Archeological evidence indicates people began using this area continuously from more than 11,000 years ago through present day. Prehistoric sites include base camps, lithic quarries, hunting blinds, and scatters. Many thermal areas contain evidence that early people camped there. Obsidian Cliff, a National Historic Landmark, was one of the most important stone quarries in North America. Its volcanic glass was quarried for the manufacture of tools and ceremonial artifacts traded through a network extending over thousands of miles. At one park site, campsites from five distinct periods of indigenous use spanning over 9,700 years are stacked upon each other, revealing how tool manufacture and foodways changed over time. At a site on the shore of Yellowstone Lake, evidence was found of a 9,360-year-old camp containing stone tools and concentrations of burned and butchered bone, which is also the first evidence found in the park of fishing and fish consumption. Late 19th and early 20th century sites in YNP include the remains of fur trappers, U.S. army soldier stations and patrol cabins, as well as early tourist hotels and park and private sector concession staffs.

The park completed an archeological inventory in 2014 of 60 square kilometers (23 mi^2) of the Lewis and Snake river valleys; both served as major transportation corridors. Newly identified sites include prehistoric quarries, campsites, and lithic scatters dating to between 10,000 and 1,500 years ago, as well as historic period quarries, campsites, and refuse dumps.

Left: A field crew conducting an archaeological survey in the Maple Fire burn area. Right: A late Archaic Pelican Lake point, manufactured from Obsidian Cliff material and found near YNP's Upper Geyser Basin. NPS Photos-D. McDonald

The prehistoric sites are changing our understanding of past human strategies of lithic raw material procurement. Most sites in the park show evidence of a heavy reliance on Obsidian Cliff materials and chert, a cryptocrystalline sedimentary rock. However, along the Lewis and Snake rivers, a more diverse range of materials were used for manufacturing tools. Obsidian was primarily locally sourced from local Warm Spring, Teton Pass, and Park Point quarries, while orthoquartzite, a clastic sedimentary rock, was the most common material used for manufacturing tools.

Archeological resources are unique in that they can inform upon paleoclimate, paleoenvironment, and the human response to climate change, but are themselves threatened by climate change. Wildfire events have increased in intensity and acreage in recent decades within the park. In 2016 the park responded by embarking on a multi-year project to assess wildfire impacts on archeological resources. Condition assessments are completed for over 70 sites and analysis of data collected is ongoing. Preliminary results indicate sites subjected to intense heat and vegetation loss are more susceptible to post–fire erosion, flooding, and other landscape processes.

Park archeologists also assess the condition of previously discovered sites. Archeologists determined 1,013 sites are in good condition, 383 sites are in fair condition, 191 sites are in poor condition, 25 sites have been destroyed, and 238 sites are lacking data. Of the 1,850 archeological sites within YNP, 405 sites are listed on or eligible for the National Register of Historic Places, 374 sites are considered ineligible, and 1,071 sites remain unevaluated.

Historic Structures, Districts, and Cultural Landscapes

The majority of YNP's hotels, lodges, general stores, residences, maintenance shops, and offices are listed on or eligible for listing on the National Register of Historic Places. They exemplify evolving trends and policies regarding the preservation and enjoyment of the world's first national park. Many of the park's developed areas are within historic districts, which collectively contain hundreds of cultural resources, such as buildings, bridges, linear resources (e.g., trails, roads), and cultural landscape features (e.g., overlooks, vegetation).

Park staff time is mostly dedicated to addressing National Historic Preservation Act compliance requirements for projects that involve the rehabilitation of historic properties that currently serve the park's and visitors' needs. Alterations are sometimes required by modern building codes, safety requirements, industry standards, energy efficiency requirements, ADA accessibility, and other needs. Under Section 106 of the National Historic Preservation Act, park staff consult with relevant State Historic Preservation offices. Consultation with these offices ensures historic properties are not adversely affected by any proposed changes to buildings, through careful design and construction practices that are in accordance with the Secretary of the Interior's Standards for the Treatment of Historic Properties. Many historic buildings, such as the Roosevelt Lodge, Haynes Headquarters Building in Mammoth Hot Springs, Lake Hotel, and Canyon Lodge have been successfully rehabilitated within the past few years. The Grand Loop Road Historic District, and overlooks and trails along the Grand Canyon of the Yellowstone Historic District are examples of ongoing multi-phased rehabilitation projects.

Buildings within the Fort Yellowstone National Historic Landmark District are used for park offices, maintenance shops, and employee housing. NPS Photo-Olmstead Center for Landscape Preservation

One of the most pressing challenges to the preservation and use of historic structures, roads, trails, and other historic properties is the cost of deferred maintenance. The park's historic properties are subject to deterioration caused by YNP's harsh climate and by wear caused by high visitation and use. Due to limited resources, the park can complete only a portion of recommended preservation maintenance.

The NPS documents these historic properties within the List of Classified Structures (LCS) and the Cultural Landscape Inventory (CLI). The condition of properties is recorded in these evaluated inventories and is required to be updated every six years, though this does not always occur due to lack of staff. The NPS Facilities Management Software System (FMSS) also records updated condition assessments of many of these historic properties and YNP concessioners likewise monitor the condition of historic structures they lease. There are 895 buildings, roads, bridges, and grave markers that have been documented in the LCS. Many of YNP's historic structures, buildings, trails, and cultural landscapes have not been evaluated for their historic significance.

Condition assessments document 77% of the park's 895 historic structures are in good condition, 19% fair, and 4% poor. Since 2013, there has been no change in the overall number of buildings determined to be in good condition, and there has been further deterioration of buildings that are in fair and poor condition. Most of the buildings in good condition are in use, while those that are in fair condition are used for non-visitor functions such as storage. Most buildings that are in poor condition are currently unoccupied.

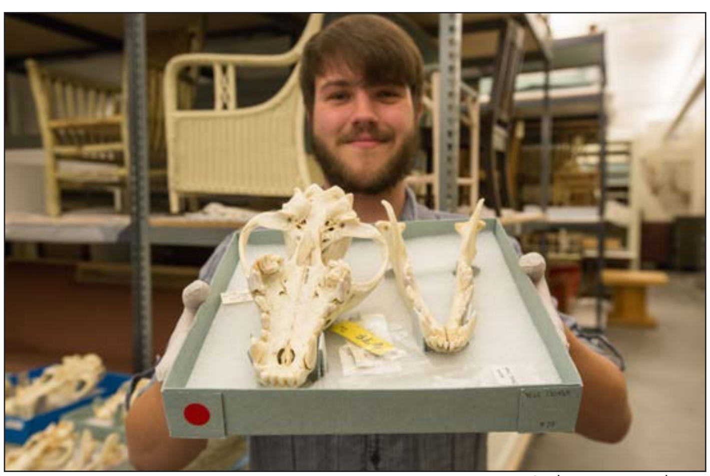
Museum Collections

NPS Photo

Yellowstone's museum collections include archival documents, photographs, archeological and ethnographical artifacts, fossils, uniforms, historic vehicles, hotel furnishings, souvenirs, biological and geological specimens, and works of art. These items form one of the largest collections in the NPS, and exist to document and preserve the cultural and natural resources of the nation's first national park. Some of the items are exhibited in the park's visitor centers, museums, and the Yellowstone Heritage and Research Center (HRC) where most of the collection is stored. The HRC facility was completed in 2004 according to regulations and standards set by the NPS, American Alliance of Museums, and the National Archives and Records Administration. Opened in 2005, it is considered a state of the art collections storage and research facility. The remainder of the park's collection items are held in 35 non-federal repositories worldwide, as well as loaned to accredited museums and institutions for exhibits. In 2016 there were 103,934 objects in 51 outgoing loans, compared to 106,443 objects that were part of 37 outgoing loans in 2013.

While documenting and preserving tangible evidence of the park's cultural and natural resources are key parts of the HRC's mission for the museum collections, making them accessible to researchers is also extremely important. Collections must be cataloged in order to allow researchers to access them, and YNP has made incredible strides in reducing the number of uncataloged collections. Due to innovative archives cataloging and processing techniques incorporated by the park's archivist, as well as numerous volunteer and student assistants, the park's museum collections are 81% cataloged as of 2016 (an increase of almost 42% since the 2013 Vital Signs report). Usage of the collections in 2016 included 1,324 researchers, compared to 1,421 in 2013 (this includes on-site researchers as well as requests made via email, telephone, and mail).

HRC staff evaluate proposed additions to the museum collections through implementation of the park's Scope of Collections Statement (SOCS). The SOCS is updated every five years and defines what items should be included in the collection, taking into consideration the expense of curation and preservation, and ensuring only items that are the best representation and documentation of YNP's cultural and natural history are accessioned into the collections. While the HRC was designed to accommodate 35 years of growth for the museum collections, storage space is filling quickly; additional mobile compact storage units will need to be procured and installed in the near future to ensure YNP's collections are properly preserved and managed. Even with the stringent regulation of incoming objects, the ever-growing size of the natural resources collection from research collections, and the continued growth of the park archives as records (housed in accordance with NPS standards), the collection will require HRC staff to use innovative storage techniques and designs to ensure the facility does not soon reach storage capacity.



NPS Photo-N. Herbert

Aquatic Invasive Species

In addition to lake trout in Yellowstone Lake, two non-native aquatic invasive species (AIS) are having a significant detrimental effect on the park's aquatic ecology. First detected in the park in 1994, New Zealand mud snails *(Potamopyrgus antipodarum)* are now in all of the major watersheds, where they form dense colonies and compete with native species. Confirmed in the park in 1998, the parasite *Myxobolus cerebralis* that causes whirling disease in cutthroat trout and other species has been found in the Firehole River and the Yellowstone Lake watershed.

Another AIS, the red-rimmed melania *(Melanoides tuberculata)*, a small trumpet snail imported by the aquarium trade, was discovered in the warm swimming area at the confluence of the Boiling River with the Gardner River in 2009. Subsequent surveys of popular hot springs have found melania only in the Boiling River soaking area and downstream approximately 1 kilometer (0.6 mi). The species has a narrow temperature tolerance (18°–32° Celsius; 64°–90° F) and is unlikely to survive downstream of the Boiling River during the winter, but it could appear in other thermal waters in the park.

In light of the November 2016 detection of larvae of the highly invasive and destructive dreissenid mussels in Tiber and Canyon Ferry reservoirs and other waterways in Montana, but outside of YNP, the park is working to increase monitoring efforts for detecting these mussels as well as other AIS, using e-DNA sampling and deploying settlement plates. Preventing the introduction of dreissenid mussels and other AIS from watercraft, equipment, or gear that contacts park waterways is key to managing the AIS risk. In 2016, 3,131 watercraft were inspected, including 100% of the motorized watercraft and all but six non-motorized watercraft (which included angler float tubes). Sixty-three watercraft were determined to be high-risk for AIS and underwent non-chemical decontamination prior to launch. Suspect AIS were found on 11 watercraft, including five suspect plants and six species of snails. Other AIS risk management strategies and planned actions include installation of wader cleaning stations, a rapid response mussel preparedness exercise, and an AIS information exchange meeting to evaluate Yellowstone's management approach to AIS prevention.

Zebra mussels removed from a boat during the cleaning process. NPS Photo-J. Frank

A park boat is being cleaned in compliance with the park's aquatic invasive species protocols. NPS Photo

Invasive Plants

At least 225 species among 33 different taxonomic families of non-native plants have been documented in Yellowstone, representing about 18% of the known vascular plant species found in the park. Some non-native plants are known from one to a few occurrences and have been eradicated, while others are widespread either locally or parkwide. Some have been purposely introduced, but most plants are unintentional migrants to the park.

Many, but not all, non-native plants are invasive. Invasive plants have the ability to flourish and spread aggressively outside their native range when introduced into new habitats. Such plants can completely change the structure and function of native plant communities by altering soil properties and related processes; increasing the frequency of disturbances such as fire; altering the abundance, distribution, and foraging activity of native ungulates; compromising the existence of restricted native endemic plants; and negatively affecting the aesthetics and viewshed of geothermal areas and cultural landscapes. Many factors influence the establishment and spread of invasive plants, including the biology of the plants; climate; soil type; land use history; activities that promote ground disturbance; grazing and/or transport by wildlife; and transport by contaminated equipment, stock feed, gravel, and fill material.

Law and NPS policy mandate the control of plants categorized as "noxious weeds" by the adjoining states. In addition, other plants not designated as noxious but are otherwise exotic and invasive, can also be subject to control. The park updated its Invasive Vegetation Management Plan in 2013 to include protocols that prevent the entry and establishment of new invasive plants, and control existing populations of invasive plants through eradication, reduction in their size and density, or containment of spread. The plan further recognized the need to monitor for control effectiveness, as well as to restore native plant communities disrupted or replaced by invasive plant populations. To guide control efforts, the park prioritized invasive plant species based on their presence and distribution in the park, plant aggressiveness, and effectiveness of control. Consequently, approximately 35 different species are targeted for mechanical and/or chemical control annually throughout the park.

Control effectiveness can vary widely over time and among species, as revealed by monitoring select plant species' responses to herbicide control over a three-year period. The variable response reflects a variety of factors, including the species' biology, timing of control, and susceptibility to the chemical or mechanical control undertaken. Some species responded to chemical control with density reductions of 82%, while other species experienced a range of both reductions and increases in density. In the case of spotted knapweed, increases in density following chemical control reflect the longevity and viability of seed in the soil seed bank (>10 years), allowing for a flush of germination in response to a competitive release from older plants. Such monitoring efforts demonstrate that control needs to be persistent and continuous, in order to exhaust the seed bank of established populations.

Following invasive plant control, a plant ecologist rakes a site that was seeded with a native plant seed mixture collected locally. NPS Photo-J. Frank

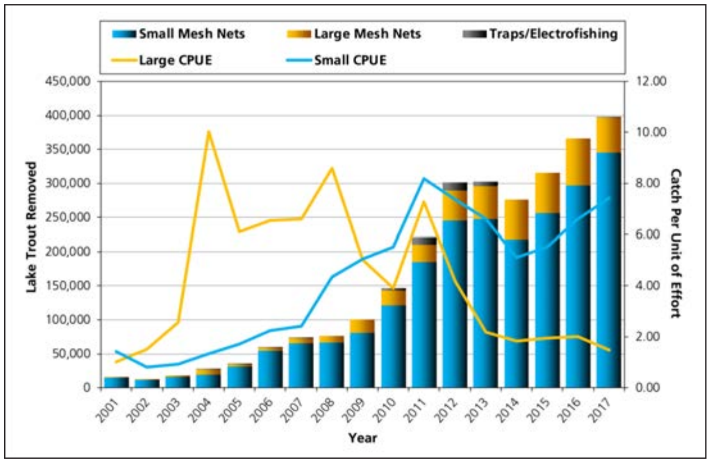
Invasive Species	Mean Change In Density (%)	Range of Density Change (%)
Houndstongue *(Cynoglossum officinale)*	-82.6	-98 to -67
Dalmation toadflax *(Linaria dalmatica)*	-87.4	-100 to -48
Yellow toadflax *(Linaria vulgaris)*	-97.5	-100 to -90
Oxeye daisy *(Leucanthemum vulgare)*	-36.0	-100 to +92
Spotted knapweed *(Centaurea maculosa)*	+30.8	-61 to +133

Monitoring results of chemical control on select species (≥ three plots) parkwide over a three-year period.

Lake Trout in Yellowstone Lake

Predatory, non-native lake trout *(Salvelinus namaycush)* were illegally introduced into Yellowstone Lake during the 1980s, with numbers exceeding one million by 2012. Lake trout eat Yellowstone cutthroat trout and could compete with them for food. Thus, there was a precipitous decline in Yellowstone Lake's cutthroat trout population to about 10% of the four million that existed in the mid-1980s. This catastrophic decline displaced several consumers of cutthroat trout, including bears, eagles, otters, ospreys, and pelicans. Lake trout have been killed by netting since 1996, with a significant surge by contracted crews during 2012 through 2017 that killed almost two million lake trout.

More than 2.8 million non-native lake trout have been killed in Yellowstone Lake since 1996, with a substantial decrease in the abundance of older (6+ years) lake trout (-60%) and overall biomass (-33%) since 2012. However, recruitment remains high because mature lake trout are very fecund. In addition to suppression via netting, biologists are developing methods to kill lake trout embryos by experimenting with dredging, electroshocking, tarping, and covering spawning substrate with lake trout carcasses. If effective egg suppression methods can be developed, this will be an important technique to aid in maintaining relatively low lake trout numbers after a population crash. Concurrently, a telemetry study is identifying potential lake trout spawning congregations and movements throughout the year to aid in targeting both the adults and embryos. An independent scientific review panel evaluates suppression activities and provides feedback annually.



Total lake trout removed from Yellowstone Lake, 2001–2017. Although 2017 saw an all-time high number of lake trout caught, catch per unit of effort (number of lake trout caught per 100 meters [328 ft] of net/night) remained below the high seen in 2011 in the small meshes and actually dropped in the larger meshes that tend to catch adult fish.

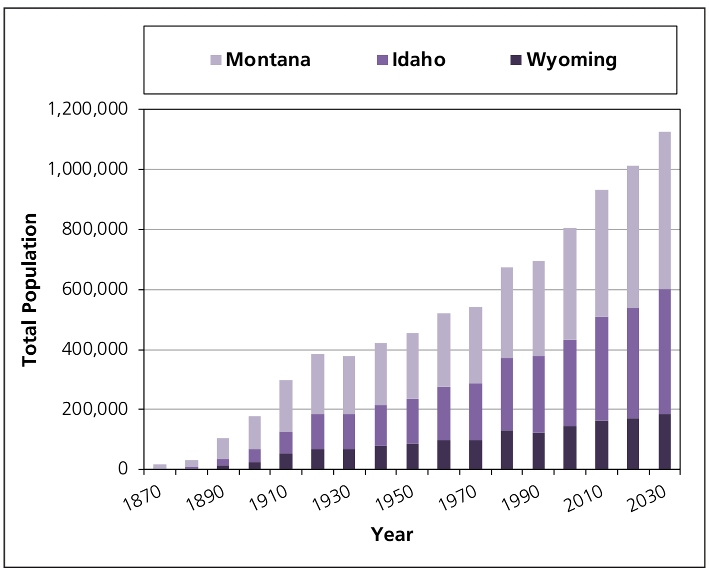
A 30-pound lake trout captured in 2011. NPS Photo

Fisheries biologists believe suppression will reduce the lake trout population by 80%, thereby allowing the ecological recovery of cutthroat trout, if current levels of netting can be sustained for at least 10 more years. Also, alternative suppression methods should continue to be researched as a way to assist in maintaining relatively low lake trout numbers after a population crash. However, these projects are difficult to sustain because costs are $2 million per year and rely substantially on donated funds.

Yellowstone's Native Fish Conservation Plan, finalized in 2010, calls for recovering numbers of Yellowstone cutthroat trout in Yellowstone Lake to levels documented in the late 1990s and maintaining access for spawning cutthroat trout in the lake's tributaries. Thus, the NPS intends to continue the suppression of lake trout, especially older and larger fish, in coming years. To gauge the success of this recovery effort, the NPS will monitor for increases in the abundance, age, and size distribution of Yellowstone cutthroat trout; spawning activity; and feeding by bears, birds, and otters in tributaries of the lake.

Land Use

Land use is the human influence on landscapes for purposes such as agriculture, transportation, residential and commercial development, recreation, and resource extraction. The geographic region surrounding and including YNP is called the Greater Yellowstone Area (GYA). The GYA is one of the largest, nearly intact temperate zone ecosystems on Earth. At 89,031 square kilometers (34,375 mi^2), the GYA is a mosaic of public lands and privately-owned parcels. In the counties that comprise the GYA, about 27% of the land is privately owned; the remaining 73% is managed by federal, state, Native American, or local governments. Public lands in the GYA are managed following the policies and mandates of their governing agencies (e.g., USDA Forest Service).



Summary by state of the total population in 34 counties within or adjacent to the GYA, 1870-2030.

Human land use within the GYA dates back at least 11,000 years. People traveled throughout YNP and the GYA to access seasonally available resources used for subsistence, shelter, trade goods, and making tools. The first European Americans arrived in YNP in the 1800s; when the park was first protected in 1872, there were still a few permanent settlements and businesses inside the park. The 2010 U.S. Census Bureau population projection for the 34 counties within and adjacent to the GYA was 924,000 people. The current population is approximately one million.

The ways that humans use lands outside of the park can affect species and ecological processes within YNP. For example, several species migrate and forage in and around the park; ungulates in particular use low-elevation grasslands outside the park boundaries as winter range. Other influences on ecosystem functions within YNP include the frequency and magnitude of fires, changes in species distributions, fragmentation of habitat, and introduction of non-native plants and animals.

Park staff track certain types of land use patterns and changes that influence YNP's resources, including residential and agricultural development; mineral, gas, and geothermal prospecting and development; and changes in major vegetation cover types. The park does not conduct studies directly on land use outside its boundaries; however, park staff work closely with other land management entities and universities to stay informed about land use and land use-related research. Two prime examples of coordination are the Greater Yellowstone Coordinating Committee and the Great Northern Landscape Conservation Cooperative. Participation in these groups helps park staff to understand issues that may affect the park and assists in coordinating responses with other partners. In addition, the NPS's Greater Yellowstone Network released a comprehensive report on GYA landscape dynamics in 2011. The standardized protocol used for detecting changes in landscape dynamics provides the basis for periodic future reports to help park staff understand and manage the complex environmental setting of YNP.

In the 34 counties within and adjacent to the GYA, there was a 35% increase in population from 1990 to 2010. A recent academic study on protected areas related to the GYA projected a 30% increase in area housing units by 2030. A separate NPS report documented an increase in both rural residential (< 6 units/km^2) and exurban residential (7–145 units/km^2) land development through 2010. With these and future studies in mind, the park will continue to monitor changes in housing density adjacent to natural areas and in important migratory habitat, such as valley bottoms and riparian areas. These areas are key to ungulates, songbirds and waterfowl, grizzly bears, and other species.

Mountain Goats

NPS Photo-B. Fuhrmann

The NPS considers mountain goats *(Oreamnos americanus)* a non-native species in YNP that could adversely affect native bighorn sheep and alpine vegetation communities. However, many park staff and visitors consider mountain goats valuable, charismatic components of the ecosystem, while hunters place high value on the challenge of harvesting goats in areas near the park boundary.

There is no convincing historical evidence that mountain goats are native to YNP. If they were present, the lack of historical accounts suggests they were rare and secluded. Since 1990, however, descendants of mountain goats introduced in the Absaroka and Madison mountain ranges of Montana have almost completely colonized suitable habitat within the park. Outside YNP, management objectives in Montana and Wyoming are to sustain mountain goat populations in these areas, though liberal harvests could be implemented in some areas in an attempt to impede further range expansion. Regardless, mountain goats will likely continue to occupy these habitats and disperse into the park for the foreseeable future.

Recent surveys and analyses suggest perhaps as many as 600 mountain goats live in and around YNP. Mountain goats are breeding and found at relatively high abundance (more than 200) in the northeast and northwest portions of the park, with suitable, continuous habitat along the eastern and western boundaries. Their abundance and distribution appears to be increasing.

Managers at YNP are working with state and university partners to evaluate potential impacts of mountain goats on native natural resources. Studies of alpine vegetation in the northeast portion of the park did not document substantial, widespread impacts to native vegetation communities. Another research effort, the Greater Yellowstone Area Mountain Ungulate Project, was initiated in 2009 by Montana State University with federal and state agencies. Its focus is to study interactions between bighorn sheep and mountain goats in the Yellowstone ecosystem (see http://www.mtbighorninitiative.com/gyamup-home.html). Future concerns include the potential for resource competition and disease transmission (e.g., pneumonia-causing pathogens) from mountain goats to bighorn sheep, as well as decreases in alpine ridgetop vegetation in areas with high mountain goat use.

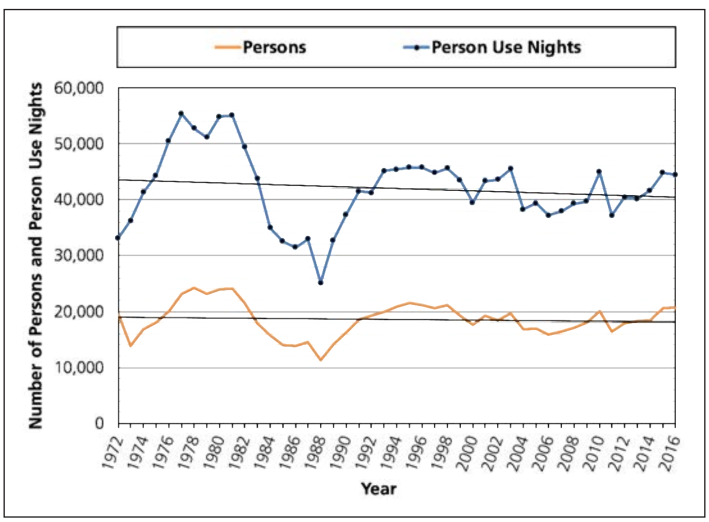
National Park Service policy allows for the removal of non-native species that interfere with native wildlife or habitats if such control is prudent and feasible. However, an eradication or control program to limit mountain goats in YNP would involve intrusive, costly, and dangerous aerial and ground operations to capture or kill many hundreds of goats in hazardous mountainous terrain for the foreseeable future, with little certainty of success. Also, the removal or killing of mountain goats in the park or on adjacent national forest service lands would be a highly sensitive and controversial issue for park staff, visitors, state hunters, and others. Given these existing circumstances and conditions, managers at YNP do not plan to initiate removal operations of mountain goats in the immediate future.

Visitor and Recreational Use

In 1872, Congress designated YNP as "...a pleasuring ground for the benefit and enjoyment of the people." Yellowstone has seen more than a century of steady growth in frontcountry visitation. In the last 10 years, park visits have increased by more than 40%, shocking the capacity of park systems. The park has documented changes in visitor demographics, expectations, and preparedness; these changes create challenges for visitors, park partners, and park staff. It is anticipated that frontcountry visitation is likely to increase.

With waterfalls, lakes, and numerous mountain ranges, YNP is also a prime destination for backcountry hikers, horseback trips, and boaters. Backcountry visitation, as measured by overnight use, has generally been steady, if slightly decreasing. While the park experienced spikes in backcountry use in the 1970s, use from 1990 to present is stable. Years with decreased backcountry use are generally attributed to backcountry closures due to fire or poor weather conditions. While overnight backcountry use remains relatively unchanged, the park currently does not have significant data on day use of backcountry locations.

While YNP has long researched the impacts of visitation and backcountry recreation on resources, the park is expanding monitoring efforts. In order to better understand the effects of changing frontcountry visitation, the park implemented two major studies. The results of a 2016 visitor survey showed YNP visitors most value the park for its natural character. Park resources and values, such as natural scenery, viewing wildlife in their natural habitat, thermal features, a largely intact ecosystem, experiencing a wild place, and hearing sounds of quiet/nature, were highly rated by most visitors. A majority of visitors think parking, too many people in the park, and traffic are big or moderate problems.



The number of persons and person use nights in YNP's backcountry, 1972–2016. Note backcountry travel was curtailed in 1988, 2000, and 2016 due to wildfires. In other years, low backcountry visitation was correlated with poor weather conditions.

The results of a 2016 transportation study revealed most park traffic is concentrated in corridors connecting the West Entrance with geyser basins and Canyon Village, an area representing roughly one-third of park roadways. During peak summer months and times of day, parking demand in these focal corridors is well above capacity and road segments perform at sub-standard conditions. Outside of these corridors, roadway volumes are also high, with vehicles following other vehicles more than 60% of the time.

A current concern related to frontcountry and backcountry visitation is an increase in impacts to vegetation and soils in and around the park's focal attractions, trails, and backcountry campsites. Visitors are also creating new "social trails" (i.e., undesignated trails formed by regular use), which remove native vegetation and can lead to colonization by non-native plants. As more visitors are unable to find parking in designated areas, many park their vehicles in grassy areas along roadways, damaging vegetation and creating new trails. In 2014, the park began monitoring both frontcountry and backcountry areas for impacts to resources. Staff monitor impacts at backcountry campsites, backcountry trails, and trailheads. In addition, staff map and monitor impacts associated with the creation and use of social trails along the road corridor and at popular attractions. The data gathered will be used to develop indicators of change, further assess impacts, and monitor for change in future years.

Yellowstone is also beginning to assess other possible resource impacts associated with visitation, including vandalism to thermal features, the effects of wildlife-visitor interactions on wildlife health and visitor safety, unsanitary conditions in the backcountry associated with restroom limitations, diminishment of the natural soundscape, and resource theft and other backcountry impacts.

Wildlife Diseases

Wildlife, domestic animals, and humans share an increasing number of infectious diseases, which pose a risk to visitors and wildlife within YNP. Land use practices near the park boundary, movements of migratory wildlife, and the presence of over four million annual global visitors create conditions that facilitate disease transmission. Thus, the monitoring and surveillance of diseases that threaten the health of visitors and wildlife are needed to respond to disease threats in a timely manner. Currently, several infectious diseases or their agents, such as brucellosis, West Nile virus, chronic wasting disease, white-nose syndrome, and hantavirus, could threaten the health of park staff and visitors (though there is currently no known risk of white-nose syndrome to humans), as well as the long-term conservation of wildlife. Dealing with threats from disease is challenging due to the high volume of people that may interact with potentially infectious wildlife.

A sophisticated disease surveillance laboratory and monitoring program have been developed to identify the presence of infectious disease agents in wildlife. Disease monitoring in YNP has been conducted with the assistance of over 20 different collaborators. Research on brucellosis in YNP bison has helped distinguish true infection from past exposure and provided insights into whether a vaccination program could be successful. Hantavirus studies are helping managers identify and manage the risk of the virus to park staff and visitors. The prevalence of hantavirus in deer mice ranged from 30% to 40% during spring and early summer months in locations with infected populations. Amphibian disease monitoring efforts have described the distribution and prevalence of important diseases that have decimated amphibian populations worldwide. Amphibian disease agents, such as chytrid fungus and ranavirus, are widespread within YNP. Chronic wasting disease, a fatal disease of deer, elk, and moose, has continued to spread north and west across the state of Wyoming during the past 15 years and has been confirmed in mule deer in Wyoming along the eastern border of the park. A surveillance plan for detecting and managing chronic wasting disease has been developed. Pneumonia is suspected to be the cause of increased mortality in bighorn sheep, and the pathogens most associated with pneumonia continue to be identified in samples collected from dead bighorn.

Many diseases of wildlife are transmissible to humans, such as plague, hantavirus, West Nile virus, tularemia, rabies, and brucellosis. The transmission of disease agents from wildlife to people is difficult to observe, and symptoms may develop long after being exposed. Disease risks to people are influenced by several factors, including environmental conditions that change across time and over a large spatial area. Thus, there is a need to understand the conditions that increase the risk of human exposure and disease outbreaks in wildlife. The goals for disease monitoring of YNP's wildlife resources include (1) comprehensive surveillance of important diseases that pose a risk to visitors and wildlife, (2) development of a sophisticated wildlife health laboratory to safely and cost-effectively analyze biological samples, and (3) timely communication of information and management recommendations for mitigating disease risks from wildlife to visitors and staff.

Park biologists conduct surveys to detect chytrid fungus and ranavirus in select amphibian species. NPS Photos

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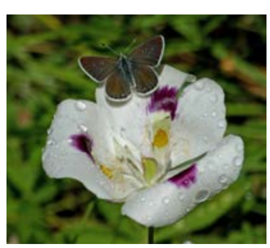

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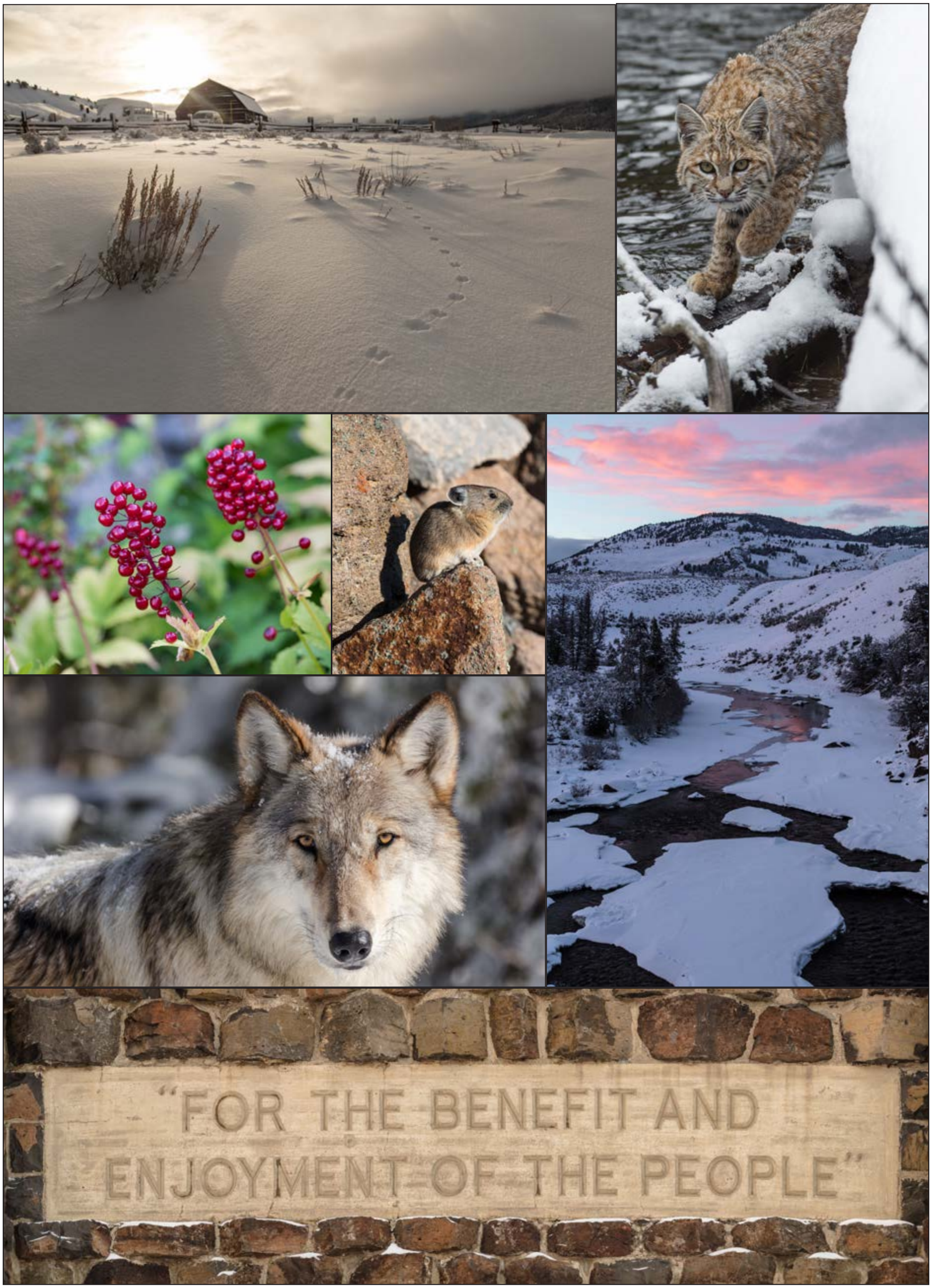

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