Climate-Change Vulnerability Assessment for Priority Wildlife Species



Prepared for:

The Navajo Nation Department of Fish and Wildlife

HEINZ CENTER FOR SCIENCE ECONOMICS & ENVIRONMENT

In Partnership With:

The H. John Heinz III Center for Science, Economics and the Environment

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The H. John Heinz III Center for Science, Economics and the Environment

Jonathan Mawdsley, Ph.D., Program Director

Rachel Lamb, Project Assistant

With assistance from: Matthew Grason, Sandra Grund, Schneka Hines, Dennis Murphy, Martha Surridge, Caroline Sweedo, Stacia VanDyne

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1. Executive Summary

The Navajo Nation Department of Fish and Wildlife and the H. John Heinz III Center for Science, Economics and the Environment jointly developed a climate-change vulnerability assessment for priority wildlife and plant species and habitats on the Navajo landscape. The priority species and habitats included in this analysis were identified by the entire staff of NNDFW through a structured planning process.

This report provides a summary of projected climate-change impacts for the southwestern United States and Navajo lands as well as an assessment of attributes promoting climate vulnerability and resilience for priority wildlife and plant species. Animal species discussed in this report are the Golden Eagle, Mule Deer, Desert Bighorn Sheep, Mountain Lion, and American Black Bear. Plant species discussed in this report include Pinyon Pine, Yucca spp., Mesa Verde Cactus, Navajo Sage, and Salt Cedar (Tamarisk).

This vulnerability assessment provides a conceptual framework for further climate adaptation planning on the Navajo landscape within an adaptive management context. Specific climate adaptation actions that are proposed in this report include: conservation of wildlife movement corridors; “climate smart” reintroductions of Desert Bighorn Sheep; consideration of Golden Eagles in the planning and siting of renewable energy developments; and actions to reduce human conflicts with Black Bears. An example is provided to show how landscape connectivity analyses can be used to identify areas where “on-the-ground” conservation actions can be implemented.

2. Introduction

2.1 Purpose and Scope of this Document

This document summarizes the results of a collaborative project between the Navajo Nation Department of Fish and Wildlife (NNDFW) and the H. John Heinz III Center for Science, Economics and the Environment (the Heinz Center), to identify management actions that NNDFW could take to reduce or ameliorate the effects of climate change on key wildlife species and their habitats. The current Strategic Plan for the Navajo Nation Department of Fish and Wildlife (NNDFW) recognizes the importance of incorporating information about climate change into the Department's existing plant, habitat and wildlife management activities. Through the strategic planning process, the entire staff of NNDFW worked together to identify a set of high-priority plant and animal species and wildlife habitats for management focus and attention. With follow-on funding from the Bureau of Indian Affairs, NNDFW and the Heinz Center compiled information about potential and observed climate-change impacts on these species. This information was discussed at two meetings of the entire NNDFW staff in 2012 and 2013, and a set of provisional climate adaptation strategies was developed. In one case, these strategies led to the identification of specific, "on the ground" conservation actions that could help maintain landscape connectivity for large mammal species in the face of climate change. The report is intended to serve as a catalyst for further action towards building resilient ecological communities on the Navajo landscape in the face of a changing climate.

2.2 Overview of the Navajo Nation and its Lands

The Navajo Nation is roughly 16 million acres in size (about 27,000 square miles), located within the south-central portion of the Colorado Plateau. The Nation overlaps with northeastern Arizona, the southeastern corner of Utah, and northwestern New Mexico and also includes three "satellite" areas in New Mexico (Ramah, Canoncito, and Alamo Navajo). A treaty with the U.S. government in 1868 set aside land for a Navajo Reservation, representing only a portion of the original Navajo homeland which extends from Blanca Peak in Colorado, Mount Taylor in New Mexico, the San Francisco peaks in Arizona, and Big Sheep Mountain or Hesperus Peak in Colorado (Lavin and Lavin 2008, O'Neill 2005). The Nation contains many majestic landscapes such as the Canyon de Chelly, Monument Valley, the Painted Desert, and Window Rock, among others.

Mountain ranges within the Navajo Nation political boundaries include the Chuska Range (including the Carrizo mountains), Black Mesa, the Zuni Mountains, Navajo Mountain, and the San Juan Mountains. The Navajo Nation is partially bordered on the north and northwest side by the Colorado River; two other important watershed systems include the San Juan River in the northeast corner and the Little Colorado River in the southwestern corner of the Nation.

The 2010 population reported by the U.S. Census Bureau is roughly 174,000 (USCB 2011) although a Navajo Nation government website places the population closer to 250,000 (Navajo Nation 2011), including enrolled members who live in adjacent towns outside the political boundaries of the Nation. The capitol of the Navajo Nation is Window Rock, Arizona, and Navajo Nation government offices can be found there. The Navajo Tribal Council (now called the Navajo Nation Council) was established in 1923 and is led by the Tribal Chairman. In 1938 the U.S. Department of the Interior issued new by-laws in place of a constitution called "Rules for the Tribal Council," which form the general framework for the Navajo Nation government.

2.3 Overview of Navajo Nation Department of Fish and Wildlife (NNDFW)

Established under Title 23 of the Navajo Nation Code, the Navajo Nation Department of Fish and Wildlife serves as the official wildlife management agency of the Navajo Nation government. NNDFW is charged with the legal authority for the management of fish, wildlife, and plant resources on the Navajo lands. The mission statement of NNDFW is "Conserve, protect, enhance, and restore the Navajo Nation's fish, wildlife and plants through aggressive management programs for the spiritual, cultural, and material benefit of present and future generations of the Navajo Nation."

NNDFW currently has six Sections: Administration, Animal Control, Management and Research, Navajo Natural Heritage Program, Wildlife Law Enforcement, and the Navajo Nation Zoological and Botanical Park. An official description of the activities, responsibilities, and mission of each section follows.

2.4 Scope of the Document

This document presents a review of the scientific literature on climate change on the Navajo landscape and a climate vulnerability assessment of key species on Navajo Nation land. Some of the information presented in this report was carefully and respectfully gathered from staff of NNDFW during a series of workshops held in 2011, 2012, and 2013. Chapter 3 outlines the key components of vulnerability and the full methodology used to index climate change vulnerability for each target species. This chapter also outlines four steps towards addressing vulnerability and increasing resilience. Chapter 4 provides an overview of the major climate change stressors projected for the Southwestern region of the country. Chapter 5 describes the ranking process for target vegetation and a synopsis of climate impacts on their range and distribution. Chapter 6 outlines the process for ranking target wildlife species and gives a complete vulnerability assessment for each species. This chapter also discusses the outcomes of each species-assessment table and highlights the areas of highest vulnerability. Chapter 7 provides an overview of climate adaptation planning and recommends general and specific strategies for translating the information contained into this report into detailed management actions.

3. Methodology for Climate Vulnerability Assessment

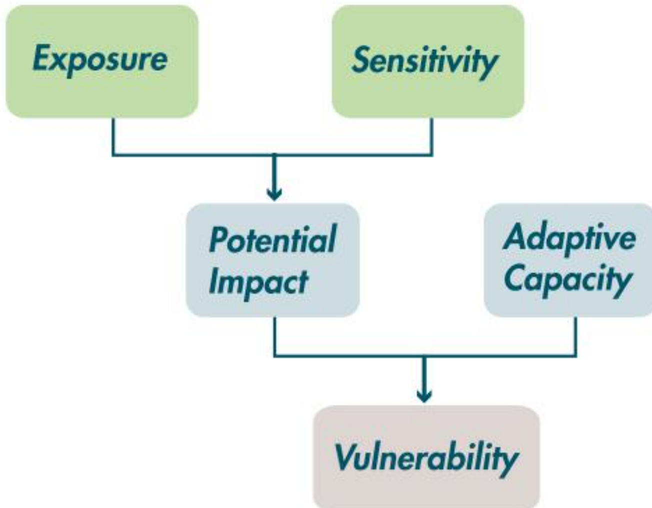
3.1 Key Components of Vulnerability

The overall vulnerability of species or ecological communities to climate change can be determined by assessing the relationship between three primary components: exposure, sensitivity, and adaptive capacity. In the context of this report, measurements of exposure and sensitivity are primarily biophysical in nature. Exposure is the degree or magnitude of stress placed upon a species or habitat due to changing climate conditions or increased climate variability (IPCC 2001). This could be measured in relationship to direct climate effects like drought and heat stress. Exposure can also be assessed relative to indirect factors such as natural or man-made barriers to distribution and land-use changes in response to climate change.

Sensitivity is the degree to which a species or habitat will be affected by or is responsive to climate changes and variability (Smit et al 2000). For any given species, the level of sensitivity could relate to dispersal ability, physical habitat specificity, or temperature and precipitation requirements. Other areas of sensitivity may be determined by assessing the nature of interspecies interactions and population and genetic responses to change.

When combined, exposure and sensitivity determine the potential impact of the threat on the individual species or habitat of concern. The potential impact is then weighed in relationship to the adaptive capacity of a species of ecosystem to determine overall vulnerability. Adaptive capacity is the potential or capability of a species or habitat to adjust to climate change as a means to moderate potential damages, take advantage of opportunities, or to cope with consequences (Smit and Pilifosova 2001). Generally, the higher the adaptive capacity of an organism or wildlife habitat is relative to the potential impact of the threat, the lower the overall vulnerability (See Figure 1).

Figure 1: Key Components of Vulnerability



3.2 Metrics for Assessment

The primary methodology for assessing high and low vulnerability in this report is adapted from the NatureServe Climate Change Vulnerability Index, a spreadsheet-based tool that estimates a species' relative vulnerability to climate change. Exposure and sensitivity can be measured separately and then evaluated simultaneously in the spreadsheet tool to determine a vulnerability ranking. When sensitivity and exposure are low, overall vulnerability is low. Conversely, when a high sensitivity ranking is paired with a high exposure ranking, the resulting vulnerability is high. Figure 2 is a matrix, which displays the range of vulnerability and three possible generalized outcomes (high, moderate and low) obtained under this method of evaluation.

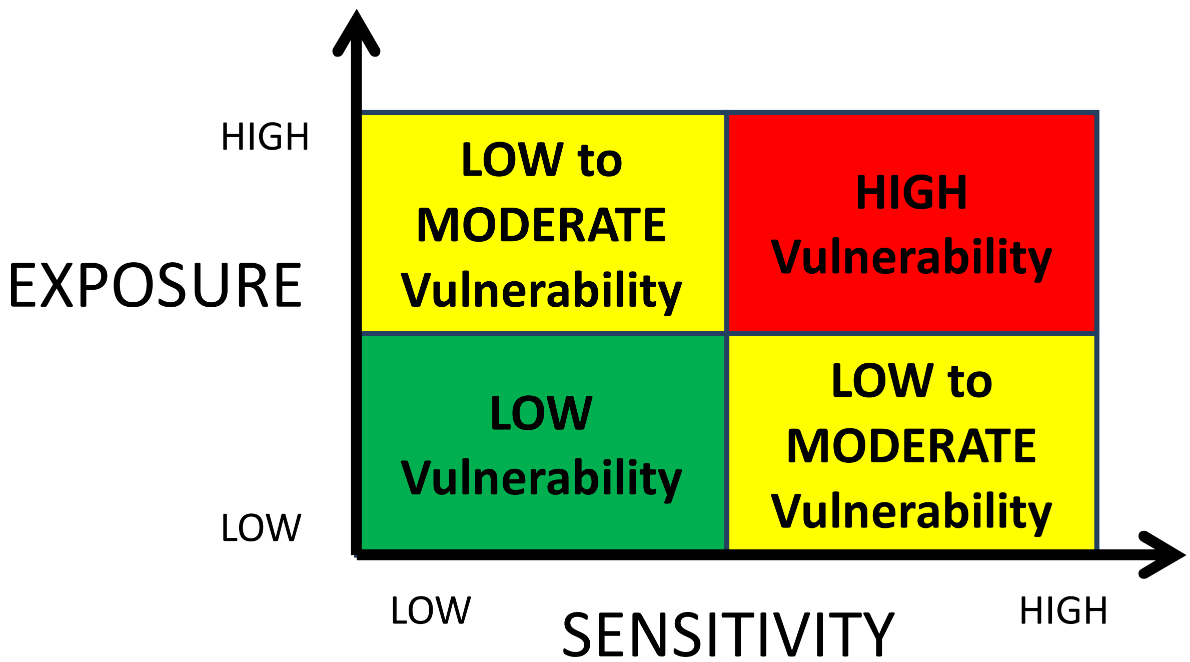
After a review of the primary scientific literature for each of the animal species, a Climate Change Vulnerability Worksheet was completed for each species. This worksheet contains a series of questions designed to illuminate areas of vulnerability by assessing categories of potential exposure and sensitivity. The categories of evaluation include dispersal ability, interspecies interactions and physical habitat specificity. The information from this worksheet was then used to complete a species-assessment table to further index and classify the species' overall vulnerability.

Each species-assessment table contains nine categories including: Man-made barriers, Dispersal Ability, Temperature, Precipitation, Habitat Requirements, Interspecies

Interactions, Diet, Population/Genetics, and Human Interactions. As sensitivity and exposure is evaluated under each category, the species is given a color-coded vulnerability ranking. Corresponding with Figure 2, red indicates high vulnerability, yellow signifies low to moderate vulnerability, and green reflects low vulnerability.

Assessing vulnerability can be complicated because one must factor in not only exposure and sensitivity, but also traits that make a species resilient in the face of climate change. This method of assessment implicitly includes an evaluation of a species' adaptive capacity when a color-coded vulnerability ranking is assigned to a given category.

Figure 2: Vulnerability Matrix



3.3 Steps Towards Addressing Vulnerability and Increasing Resilience

Changing the status of a species or habitat from vulnerable to resilient can be realized through a four-step process. The first step is to determine the primary objective and overall scope of a vulnerability assessment. At a 2011 workshop facilitated by the Heinz Center, the NNDFW determined the target flagship species and habitats in preparation for the Long-Term Strategic Plan. Through conversations, worksheets, and a ranking exercise, workshop participants were able to determine a reasonable scope of inquiry that represented their ecological and cultural concerns and values.

The second step of this process is to gather and incorporate relevant data and expertise on the species and habitats of concern. Alongside the primary literature review, the Heinz Center asked workshop participants to share their own knowledge of and experience with flagship species as a way to further identify vulnerabilities. One mechanism for doing this was through an observation handout that included the nine categories from the species-assessment table. Participants were asked to comment on each category with a focus on local data and observations.

This report includes information about the third step in the process, assessing the individual components of vulnerability. The vulnerability assessment is the primary outcome of this effort and, in turn, informs the fourth step of the process, applying the assessment results in adaptation planning. Adaptation planning sessions were held with the staff of the NNDFW in 2012 and 2013 to review the information presented in this report and identify management actions to help species and ecological communities cope with the effects of climate change. The ongoing goal of adaptation planning is to build resilience in species and ecosystems where there is known vulnerability to climate change and uncertainty in future climatic conditions.

4. Climate Change in the Southwestern United States

4.1 Projected Climate Changes in Region

Climate change is a well-documented global phenomenon that has been most notably analyzed through the Intergovernmental Panel on Climate Change (IPCC) assessment reports. Although scientists agree that change is happening everywhere, they have also observed that it is happening at different rates (and in different ways) depending on the location. Their predictions on the rate and type of change are most often made by region, including for the Southwestern United States, which is home to the Navajo Nation, other tribes, and growing urban and suburban populations.

In general, the changes anticipated throughout the southwestern United States include: an increase in the frequency of high intensity storms, decrease in winter snowfall and increase in winter rain, an earlier snowmelt in the spring, and a decrease in annual precipitation. Signs of climate change that are already being observed include: an increase in air and water temperatures, increased drought severity, changing of timing of spring events, and shifts in species distribution and range (EPA 2013). For instance, according to the U.S. Global Change Research Program, data shows that recent warming in the Southwest is significantly higher than the global average.

4.2 Climate-Change Related Stressors

Climate changes in the Southwest region are projected to add numerous stressors to local habitats, wildlife and communities. Examples of such stressors include:

4.2.1. Increased drought severity

Drought occurs when precipitation is significantly below normal levels and it often has adverse impacts on natural resources (IPCC 2007b). Common effects of drought are soil moisture depletion, vegetation stress and die-off, intensified wildfires, and degraded wildlife habitat (SWCCN 2008), all of which have effects that reverberate throughout the environment. Drought impacts are magnified by other climatological processes, including higher temperatures and increased evaporation from an increase in the amount of sunlight penetrating through cloudless skies.

Historically, many significant droughts have occurred in this region. Among the most remarkable on record are the “Dust Bowl” of the 1930s, a record drought in the 1950s, and some of the longest-documented mega-droughts ever experienced on the planet in the late 1500s. However, more recent droughts have the added disadvantage of combining rising temperatures with humaninduced impacts such as land-use changes, invasive species, and habitat fragmentation. Over time droughts will continue to take place, but modeling shows they will become hotter and thus more severe (USGCRP 2009). The natural impacts from droughts will also become record breaking; already this can be seen in forest die-offs observed in the western United States during droughts earlier this century (SWCCN 2008).

4.2.2 Wildfires

Ecosystems in the western U.S. are predicted to experience more frequent and intense wildfires under altered climate regimes (UCCSP 2009). A study by Westerling (2006) shows wildfires in the west have already "suddenly and markedly" increased since the mid-1980s. Compared to historical fire regimes, these more recent fires are larger, longer lasting, start earlier in the spring, and spread over a longer season (Westerling 2006, AZ FRTF 2010). The National Interagency Fire Center concurs with this finding, stating that there has been a significant increase in wildfires, particularly in the last 10 years (US NPS 2010).

This new wildfire regime can be linked to a number of climate change related stressors, including: rising temperatures, spring snowpack reductions, changes in precipitation patterns, decreased soil moisture, and insect outbreaks that weaken trees and other vegetation. The proliferation of invasive species and the anticipated spread of grasslands under altered climate regimes will also likely increase the risk and extent of fires by causing them to burn more swiftly or intensely (USGCRP 2009, US NPS 2010). Other environmental changes less directly associated with climate change, such as over-grazing and fire suppression, are apt to exacerbate the issue (USCCSP 2009).

4.2.3 Flooding

Warmer climate and an intensified weather cycle likely mean that the region will also experience the opposite extreme of drought: increased flooding. For instance, winter precipitation in the Southwest is becoming increasingly variable, trending towards more frequent extremely dry and extremely wet winters (USGCRP 2009). This change is being seen globally and nationally as well, where precipitation patterns are shifting to more heavy downpours of rain that can lead to flooding. A shift from less snowfall to more rainfall in winter months, combined with earlier and increased snowmelt, may cause an increased risk of flooding in mountain regions (USGCRP 2009).

4.2.4 Shifts in Species Distribution and Range

Invasive species are known to disrupt native ecosystems by altering or overrunning key habitats, displacing native animals and plants, fragmenting native ecosystems, and altering critical aspects of ecosystem function. Climate change may cause certain invasive species to thrive, altering both their impact and distribution. Changes in global climate can also provide opportunity for the establishment of new invasive species. Although evidence suggests that climate change will drive changes in the impacts of invasive species in the Southwest, the particular species that will be affected and the magnitude of these changes are poorly understood to date.

One example is tamarisk, a priority plant species for NNDFW, also known as salt cedar (*Tamarix* spp.). Studies anticipate that tamarisk is likely to expand its geographic distribution as a result of global climate change (Bradley et al. 2009). This species of shrubs and small trees is considered one of the most aggressive invaders of southwestern riparian ecosystems (Kerns et al. 2009). Tamarisk uses more water than native flora and creates relatively poor habitat for many native plant and animal species. Potential impacts of tamarisk invasion include reductions in species diversity and abundance, reductions in waterway flows, drying of desert springs, and reduction in lake levels (Hellmann et al. 2007). According to Schneider and Root (2002) increased tamarisk populations will impact wildlife ranging from bighorn sheep and endangered pupfish to the Southwestern Willow Flycatcher.

4.2.5 Changes in Water Availability

The IPCC predicts that many arid and semi-arid areas will experience reductions in water resources in the future due to climate change (IPCC 2007a). The Southwest is one of the few regions in the world where there is consistent agreement among climate models that there will be reduction in water sources (Dominguez 2009, see also Christensen et al. 2007).

Higher temperatures, changes in precipitation, and increased water evaporation will lead to lower water levels in lakes, reservoirs, rivers, and streams during summer months (AZ CCAG 2006). The changes in snowpack amounts – compounded by increases in winter rain rather than snow - in conjunction with earlier spring snowmelt will mean less spring and summer runoff (AZ CCAG 2006). Aquifers will receive less groundwater recharge, a challenging scenario as populations are already progressively relying on groundwater withdrawals for irrigation and drinking water supplies.

Two studies conducted in the Colorado River Basin show that recent rising water evaporation from higher temperatures lowers river flows and heightens drought conditions throughout the Southwest. One study estimates a 50% probability that live storage in lakes Mead and Powell, the two largest reservoirs in the Colorado system, will be depleted by 2021 (Dominguez 2009, Christensen et al. 2007). Also, the Colorado River is predominantly a snowmelt-driven system, so changes in winter precipitation and runoff amounts will likely affect its flow. Conservative estimates predict sizeable impacts to the Colorado River system by the end of the century, including a 15% reduction in annual runoff (AZ CCAG 2006).

Finally, it is important to note that with a burgeoning human population, areas of the Southwest may soon face a higher water demand than they can meet for human activities, which may leave less water for fish and wildlife habitat needs (AZ CCAG 2006, USGCRP 2009, Christensen et al. 2007).

5. Climate Change and Priority Plant Species

5.1 Process for Species Selection

During the Farmington meeting of NNDFW facilitated by the Heinz Center, the entire staff of NNDFW brainstormed a list of plant species that are important to the Department and to the Navajo Nation as a whole. The frequency with which any individual species was mentioned was also recorded. Some of the species mentioned most frequently were those with cultural significance (e.g., yucca, Navajo tea). Others were threatened or endangered species (e.g., Brady pincushion cactus, Mesa Verde cactus). A number of species are important for providing wildlife habitat (e.g., sage, pinyon pine, Ponderosa pine). The list also included some invasive species as an example of plants that are undesirable yet important to manage (e.g., salt cedar).

Following is a description of five of the most frequently mentioned plant species and any known or anticipated climate-change impacts.

5.2 Pinyon Pine

The Two-leaf or Colorado Pinyon (*Pinus edulis* Engelm.) can be found through the southern Rocky Mountains region, including Utah and Colorado south to New Mexico and Arizona, with a few populations in Wyoming, Oklahoma, Texas, California, and Mexico. These trees can be found between 5000-7000 feet in elevation, either alone or with junipers, on rocky foothills, mesas, plateaus, and lower mountain slopes (Little 1980).

Various wildlife utilize pinyon pine for habitat, including elk, Mule Deer, white-tailed deer, pronghorn, coyote, Mountain Lion, bobcat, birds, and small mammals (Anderson 2002). Breshears et al. (2005 and 2009) reported pinyon pine mortality as a result of a severe drought earlier in that decade, which was significant for its nearly complete tree mortality regardless of size or age class. Furthermore, they noted that drought stress also made pinyon pines more susceptible to bark beetle infestations. They predicted that future droughts will further stress these trees, and that a relaxing of drought conditions may not allow re-establishment of pinyon pines. Climatic changes that brought about significant increase in drought conditions would likely lead to a loss in pinyon pines.

A decrease in pinyon pine habitat will particularly affect the small mammal and bird species dependent on them as a food source. One such species is the pinyon jay (*Gymnorhinus cyanocephalus*). This bird co-evolved with pinyon pine trees, and consumes pinyon pine nuts as a primary food source. Pinyon jays can be found throughout the southwestern U.S., and portions of the intermountain west, sometimes pushing into the fringes of its range when pine nuts aren't available. (Balda 2002).

5.3 Yucca

The genus *Yucca* includes 30 species in the United States, spanning a broad geographic range from low elevations in California to elevations of 8,000 feet or more in the Colorado mountains (USDA 2011). They are most commonly found growing in sands and gravels (Webber 1953). They can be short and shrub-like or as tall as small trees, with spiky leaves and white flowers.

Numerous species of yucca are reported from Navajo Nation lands, including banana (*Yucca baccata* Torr.), soapweed (*Yucca glauca* Nutt.), Navajo (*Yucca baileyi* Woot. and Standl.), and narrowleaf (*Yucca angustissima* Engelm. ex Trelease) yuccas, among others (Heil and O'Kane, Jr. 2005).

Some livestock and wildlife utilize various yucca species as browse or cover. Soapweed yucca is reported to be browsed primarily during drought years, when other more desirable forage is unavailable (Groen 2005a). Cattle and other livestock have been known to utilize soapweed, along with Mule Deer, bighorn sheep, and pronghorn. Various birds and small mammals use it as both a food source and as shelter. Similarly, banana yucca is sometimes browsed by livestock or big game species, and is utilized by small mammals and birds (Groen 2005b). Elk have been known to eat banana yucca in the nearby Jemez Mountains (Allen 1996).

Yucca species are well adapted to dry climates and may be more robust than other plant taxa to the effects of extended climate change.

5.4 Mesa Verde Cactus

This cactus is listed as threatened on the Navajo Endangered Species List. A U.S. national recovery plan was developed after the Mesa Verde Cactus (*Sclerocactus mesae-verdae*) was listed as threatened by the U.S. Fish and Wildlife Service in 1979. Recovery criteria as outlined in the plan included protecting the five known populations at the time around the Colorado and New Mexico state borders, plus the creation of two new habitat areas (to be established on Navajo Nation lands and on land administered by the Bureau of Land Management), in addition to the provision of 10,000 plants per year for five years for commercial purposes (US FWS 1984).

As of 2004, the population was restricted to San Juan County, New Mexico, and adjacent Montezuma County in Colorado. At least 70% of the population was estimated to occur on Navajo Nation lands, with at least 50 population sites from San Juan County, and from the Colorado border south to near Naschitti (NNHP 2004). The 2004 monitoring report noted that a drought in 2002 severely impacted 83% of naturally occurring cacti and 89% of the transplanted cacti.

A subsequent Status Assessment Report (Ladyman 2004) prepared for the Navajo Natural Heritage Program noted several threats to the population's recovery, including habitat loss due to ORV use, energy development, urban development, and overgrazing, in addition to illegal collection and biological threats (e.g., arthropod infestations, drought). The report also highlighted the importance of establishing new populations as widely across the landscape as possible to dilute risks from threats across the larger population, and to improve genetic diversity.

In 2011, the U.S. Fish and Wildlife Service conducted a five-year review of the Mesa Verde cactus. Their report noted that there has been a 58% loss of individual cacti throughout its range since the early 2000s. Although recent survey results on Navajo Nation and BLM lands have shown mature plant increases in some populations, other population areas still have not recovered from the 2002 drought or have disappeared completely (e.g., Sheep Springs on the Navajo Nation). The report recommended retaining the threatened designation for Mesa Verde cactus, with close monitoring for future population trends, new population discoveries, and the level of cumulative threats (particularly OHV activity, likely future increase in the frequency and severity of drought, slow recovery of baseline populations, and a restricted distributional range). Climate change will likely exacerbate existing threats to the species, particularly through the effects of drought.

5.5 Navajo Sage

Sagebrush was noted by NNDFW staff in the Farmington meeting as an important plant, both because of its ecological dominance in some areas, as well as for its ceremonial uses and medicinal properties. While research for this report did not uncover a "Navajo Sage" species identified in the scientific literature, there are numerous types of sagebrush found in the vicinity of the Navajo Nation which would be recognized as such.

According to Heil and O'Kane (2005), there are approximately 14 species of the genus *Artemisia* that occur on the Colorado Plateau (in addition to numerous varieties within specific species). Some of the more common species include silver sagebrush (*A. cana*), black sagebrush (*A. nova*), big sagebrush (*A. tridentata*), and sand sagebrush (*A. filifolia*

Torr.). Many wildlife species utilize sagebrush habitat for food or for cover. For example, big sagebrush is sometimes eaten by Mule Deer, pronghorn, elk, and domestic sheep, although various sagebrush subspecies are more palatable than others (Tirmenstein 1999). Important grassland bird species utilize general sagebrush habitat, including Brewer's sparrow (*Spizella breweri*), sage sparrow (*Amphispiza belli*), and sage thrasher (*Oreoscoptes montanus*).

Sagebrush habitat is impacted by a number of threats and stressors, some of which may be irreversible even with aggressive management (Knick et al. 2003). Increased number and acreage of fires, encroachment of pinyon-juniper woodlands at higher elevations, invasion of cheatgrass at lower elevations, habitat conversion to human uses such as agriculture and urban development, livestock grazing and movement, and energy development are among the major threats and stressors affecting this habitat system (Connelly et al. 2004). Climate change has the potential to lead to increases in severity of several of these stressors, including increase fire frequency, cheatgrass invasion, and new energy developmens.

5.6 Salt Cedar (*Tamarix* spp.)

Tamarisk (*Tamarix* spp.) is a shrub native to Asia and southeast Europe. It was introduced to the U.S. for ornamental purposes and for erosion control. *Tamarix* spp. is currently found in nearly every U.S. state, but salt cedar (*Tamarix ramosissima* Ledeb. or *Tamarix chinensis* Luor) is found particularly in riparian and "wet" habitats in the western and southern U.S. at elevations up to 5000 feet, and can grow up to 16 feet or more (Little 1980, USDA 2011, Zouhar 2003). Its deep roots and high water usage outcompete other riparian plant species, particularly in dry areas. It is difficult to eradicate because of its rapid growth and its ability to spread by either seeds or cuttings (Little 1980).

Invasive populations of tamarisk have been studied for several decades in the United States (for a few examples, see Graf 1978, Everitt 1980, Bush and Smith 1995, and Zavaleta 2001). Recently, considerable attention has been paid to the benefits and drawbacks of using biocontrol agents on tamarisk. A leaf beetle, *Diorhabda elongata*, is a known pest that defoliates tamarisk in its native habitat. Beginning around 1999, this beetle was tested in U.S. labs, and then field-tested, as an alternative to mechanical tamarisk removal throughout the southwestern U.S. However, the southwestern willow flycatcher, a listed endangered species, was found to be impacted by biological control of tamarisk because of its use of tamarisk bushes for habitat (particularly in the absence of the willow trees it normally inhabits). Thus the practice of biological control was halted by the U.S. Department of Agriculture last year, although the conversation continues in the scientific literature. Hultine et al. (2009) explored the ecological and societal implications of biocontrol, and concluded by recommending: 1) intensive monitoring of ecosystem services as a result of biological control projects, and 2) the establishment of a comprehensive policy and research framework to address impacts of biological control agents. There are current studies looking at how biocontrol of tamarisk affects wildlife, and whether the restoration of native vegetation following biocontrol is feasible (Dudley 2010).

Tamarisk is well adapted for dry environments and will likely benefit from increased aridity in the Navajo landscape. Because of its aggressive growth patterns, tamarisk has the potential to cause significant fragmentation of areas of native riparian vegetation along perennial and seasonal rivers on the Navajo lands. This fragmentation could, in turn, lead to loss of connectivity in these important movement corridors for many wildlife species. The presence of non-native tamarisk plants could place additional stress on riparian and wetland vegetation systems that are already experiencing stress from drought, increased intensity of storm events, and other more direct effects of climate change. Management of tamarisk is one possible adaptation strategy, especially for riparian vegetation corridors.

6. Wildlife Species

6.1 Process for Species Selection

Given the limited resources for managing and monitoring species and ecosystems, it is often desirable to select a set of highest-priority species, ecosystems, or vegetation communities that can serve as foci for NNDFW management activities. During the workshop, NNDFW staff were asked to brainstorm which wildlife species on their lands are a high conservation priority for their particular Section, and/or for the Department as a whole.

After creating a comprehensive list of approximately seventy wildlife species, the list was displayed at the front of the room and the group was asked to take part in a Priority Setting Exercise designed to identify shared priorities among the Department staff. The goal of this exercise is to identify those wildlife species viewed by the greatest number of staff as a priority for conservation and/or cultural value. Priority species could be important to the Department for a variety of reasons - because they are an income source for the Department, because of their status as an endangered or threatened species, or because they have cultural significance to the Navajo Nation as a whole.

Each workshop participant was given ten "votes" (dot stickers) to place next to the name of the species they felt was most important. Participants were allowed to allocate their votes however they saw fit; all votes could be given to one species, or they could be divided among several. The resulting "top ten" species included those that are managed for recreation (e.g., Elk), are important for generating revenue for the Department (e.g., Desert Bighorn Sheep, Mule Deer), are endangered species (e.g., Colorado Cutthroat Trout), and species for which more monitoring information is needed (e.g., Bobcat, Mountain Lion).

During the second workshop, participants were each given a paper ballot to further refine their species list by voting for their top *five* priority wildlife species. Again, this exercise would highlight the target species that are important for management and monitoring of fish and wildlife.

6.2 Methods for Climate-Change Vulnerability Assessment

For each species, we examined attributes of the species, its biology, and its distribution that could lead to either vulnerability or resilience in the face of anticipated climate change on the Navajo lands. The attributes that we examined are derived in part from the primary literature and also form part of the NatureServe Climate Change Vulnerability Index spreadsheet analysis tool.

Specific attributes that we examined for each species are: **population size** (species with small populations are generally thought to be more vulnerable to climate change), **range and dispersal ability** (species with small geographic ranges and/or limited dispersal ability are generally thought to be more vulnerable to climate change), habitat associations (species with more restrictive habitat requirements are generally thought to be more vulnerable to climate change), **response to man-made barriers and other anthropogenic activities** (species that respond poorly to man-made barriers are thought to be more vulnerable to climate-change), and **diet flexibility** (species that have narrow dietary requirements may be more vulnerable to climate change)>

Because all of the animal species treated here are widespread and have relatively large population sizes, they generally will receive lower priority scores on the full spreadsheet version of the NatureServe Climate Change Vulnerability Index. However, each of these species has certain attributes that suggest that it may be resilient or vulnerable to certain aspects of climate change. Because these species are actively being managed by Navajo Nation Department of Fish and Wildlife, we believe it is important to describe the characteristics of each of these species that may lead to vulnerability or resilience.

We use a simple red-yellow-green schematic (see Table 1 below) to illustrate the different areas of vulnerability (red), resilience (green) or moderate to no impact (yellow) for each of the priority wildlife species.

6.3 Golden Eagle (*Aquila Chrysaetos*)

Population

A 2004 study conservatively estimated the Golden Eagle population in much of the western U.S. (not including Alaska) as roughly 30,000 individuals (Good et al. 2004). The population's status and trends within the U.S. is unclear, however some researchers believe this number may be declining as external pressures on the species rise. These pressures include a reduction in prey availability and habitat loss due to issues such as invasive species and increasing fire frequency, as well as other human activity and development (Good et al. 2004; Kochert and Steenhof 2002). The Golden Eagle population on Navajo lands is also significantly impacted by poaching.

Range and Dispersal

Golden Eagles have a large dispersal range and the Navajo Nation is part of the Golden Eagle's year-round range. The eagle's wide geographical dispersal range and ability to migrate seasonally over long distances, increases the bird's overall adaptive capacity. However, drought is thought to have contributed to declining populations particularly around urban areas in the Southwest (WRI 2009, Nielson et al 2010). Furthermore, renewable energy development, in the form of turbine construction, may also create a barrier to migration. The Golden Eagle is listed on the NNDFW endangered species list as a group three species whose "prospects of survival or recruitment are likely to be in jeopardy in the foreseeable future" (NNDFW 2008).

Habitat

Despite their great dispersal capability, Golden Eagles have some specific habitat requirements. They prefer cliffs or large trees for nesting and for viewing hunting grounds. Consequently, their nests are often found in open or semi-open country rather than densely forested areas, which would make hunting more difficult (Kochert et al. 2002). Urbanization, agricultural development, and changes in wildfire regimes have compromised nesting and hunting grounds in southern California and in the sagebrush steppes of the inner West.

Man-made Barriers

The greatest conservation challenge involved in managing Golden Eagle populations is offsetting the adverse effects of human activity. Of the Golden Eagles found dead in the early 1960s to the mid-1990s, 73% died from human-related causes (WDWF 2012). Golden Eagles can be particularly sensitive to disturbances near areas that are important for roosting or foraging. Extensive disturbance can stress eagles to a degree that leads to reproductive failure or mortality. Renewable energy development, an indirect effect of climate change, has led to increasing rates of electrocution due to new power lines and loss of habitat due to solar farm construction.

Flexible Diet

The Golden Eagle has a varied diet both in type and size of prey. Its adaptable diet consists of small to medium medium-sized reptiles, birds and mammals and carrion. A recent Navajo Nation study found that most of their diet is jackrabbits and cottontails, with prairie dogs to a lesser extent (Stahlecker 2009). Golden Eagles can also prey upon larger mammals, such as smaller wild ungulates and domestic livestock, and fast for days between feedings. The availability of prey may be impacted by climate change as temperature extremes can reduce prey populations. There are also suggested links between declines in Golden Eagle territory occupancy due to the loss of shrubland habitat and subsequent jackrabbit population declines (Kochert et al 1999, Steenhof et al 1997). Fewer available food sources can impact eagle reproductive success.

Climate-Related Vulnerability and Resilience Ranking

The areas of highest vulnerability for the Golden Eagle relate to man-made barriers such as energy development, population/genetic sensitivities, and human interactions (see Table 1)

Table 1: Vulnerability Ranking for the Golden Eagle

	Golden Eagle
Man-made barriers	
Dispersal Ability	
Temperature	
Precipitation	
Habitat requirements	
Interspecies interactions	
Diet	
Population/Genetics	
Human interactions	

6.4 Mule Deer (*Odocoileus hemionus*)

Population

The Mule Deer is considered a species of least concern by the IUCN (Sanchez Rojas and Gallina Tessaro 2008). However, some wildlife management agencies in the western U.S. and Canada believe Mule Deer populations are declining overall in large parts of their range. Mule Deer populations generally fluctuate significantly through boom an bust cycles (Mule Deer Working Group 2004). Yet, uncharacteristic and dramatic population declines in Arizona and New Mexico during the 1960s and 1990s were attributed to a combination of factors including drought. As an important game species in the region, wildlife managers must be sensitive to population fluctuations and adjust hunting permits appropriately (NBII undated---b; Mule Deer Working Group 2004).

Range and Dispersal

Mule Deer are native to parts of Canada, Mexico, and the Western United States, and are an important game species hunted for food and sport (Sanchez Rojas and Gallina Tessaro 2008; NBII undated-b). The Navajo Nation is among the top trophy hunting areas for Mule Deer in the U.S. (NNDFW 2010). The habitat range of this highly adaptable species includes sagebrush steppe, pinyon---juniper, pine, and mountain meadows. They generally prefer open systems that provide ample ground cover to hide fawns and serve as sustenance (NBII undated---b; BLM 2010). The wide range of Mule Deer makes them particularly adaptable to climate changes. Mule Deer migration routes are characterized by a series of stopover sites connected by movement corridors though which deer move quickly (Sawyer 2009). Research suggests that human development, including fences, has little impact on Mule Deer use of habitat or movement. Crossings located alongside water catchments receive the highest use by herbivores (Sawyer 2009). It is likely that Mule Deer will be able to move as needed to respond the changing climate in their habitat.

Precipitation and Forage

The carrying capacities and population densities of Mule Deer vary according to the availability of food as well as the vegetation cover and overall quality of the occupied habitat (Mackie 1976). Mule Deer are more resilient during drought because they can eat a variety of species and absorb water from their food. However, the density of deer populations and overall body condition will likely decline during periods of drought. This would suggest that there are limits to the climatic conditions Mule Deer can tolerate before they are forced to disperse.

Sufficient supplies of succulent and highly digestible forage are required for deer to reach optimum levels of growth and productivity (Misuraca 2013). For example, diets consisting primarily of woody twigs cannot meet nutritional maintenance requirements of Mule Deer (Misuraca 2013). The nutritional constitution of deer forage can be predicted based on the quantified relationships between rainfall, temperature, and forage characteristics (Marshal et al 2005). In general, humid regions of the country have fewer, and smaller, permanent deer populations because the soil produces less protein (Dasman 1963). Furthermore, while Mule Deer can survive and bear young with little to no access to free water, reduced rainfall indirectly affects body condition due to quality of forage (Frisina 1996).

Interspecies Interactions

An additional influence on Mule Deer population numbers is predation from Mountain Lion, coyote, bobcat, Golden Eagles, domestic and feral dogs, and Black Bears (Altendorf 2001). Competition with other herbivores for forage, particularly domestic livestock, is another potential regulator of population density. In general, bighorn sheep appear to utilize grasses more and browse less than Mule Deer; however, there is some overlap in plant habitat, which suggests local competition (Mackle 1976). More extensive competition with livestock occurs where plant growth has been reduced by drought and where livestock grazing begins too early or extends too late (Mackle 1976). As climate change affects other species, it can have ripple effects on Mule Deer.

Climate-Related Vulnerability and Resilience Ranking

The Mule Deer appears to be relatively resilient to climate change across all categories. Because the effects of drought and consequent unavailability of water can have an impact on the quality of forage, the species has moderate vulnerability to temperature, precipitation and diet (See Table 2)

Table 2: Vulnerability Ranking for the Mule Deer

	Mule Deer
Man-made barriers	
Dispersal Ability	
Temperature	
Precipitation	
Habitat requirements	
Interspecies interactions	
Diet	
Population/Genetics	
Human interactions	

6.5 Desert Bighorn Sheep (*Ovis canadensis*)

Population

The Desert Bighorn Sheep lives in open, steep, rocky areas of desert mountain ranges in the southwestern U.S., specifically eastern California, much of Nevada, northwestern Arizona, and southern Utah, as well as northern Mexico (Biotics Database 2005). The current species population numbers are estimated at around 13,000 individuals, which is only approximately 10 percent of their pre-settlement population (NPS 2006).

Although bighorn sheep are listed as a game species on Navajo lands, Navajo Tribal members are limited to only one permit per year. Approximately 15 years ago, the NNDFW began instituting a management program to reverse the bighorn's decreasing population numbers. Since the late 1990s, the population has grown from 36 sheep to somewhere between 125 to 300 individuals, including a herd inhabiting the San Juan River Canyon of the Navajo Nation in southeastern Utah (UDWR 2008).

Range and Dispersal

Bighorn sheep are sometimes referred to as a wilderness species because they typically inhabit naturally remote and inaccessible areas (UDWR 2008). However, many populations are encroaching closer to urban settlements and have demonstrated that bighorns can live in close proximity to humans. Bighorns prefer open habitat types with adjacent steep rocky areas for escape and safety; this rugged terrain includes canyons, gulches, talus cliffs, steep slopes, mountaintops, and river benches (Shackleton et al. 1999). Desert Bighorns are not migratory and thus have a more limited dispersal range than Rocky Mountain Bighorn Sheep.

Since the mid-20th Century, Desert Bighorn Sheep have begun moving to high elevation areas and greater precipitation due to a changing climate. The mobility of bighorns is contingent upon the species' ability to shift its range in the face of climate change, disease, and human infrastructure development (Running and Mills 2009).

Although the Desert Bighorn is not listed as threatened or endangered under the Endangered Species Act, it has been identified as a Species of Greatest Conservation need in the Arizona State Wildlife Action Plan and is included in Group 3 of the Navajo Nation Endangered species list. NNDFW anticipates decreased habitat availability for Desert Bighorn Sheep on Navajo lands, primarily due to livestock grazing pressures as well as other factors like climate change.

Man-made Barriers

The primary threats facing Bighorns include: parasites and diseases (e.g., Psoroptic mange, Pasteurellosis), loss or degradation of habitat, competition with domestic livestock, other wild ungulates, and feral animals; human disturbance, predation (e.g., Mountain Lions), and poaching (UDWR 2008). The degree to which vulnerability can be decreased in any one of these areas, is likely commensurate to the degree of resilience which Bighorns may be able to reestablish in the face of climate change.

Population Genetics

Populations of Desert Bighorn Sheep in low-elevation habitats generally have lower genetic diversity, which may reflect founder effects and greater fluctuations in population size (Epps et al 2006). Conversely, higher-elevation habitats act as "reservoirs of genetic diversity" that are particularly susceptible to fragmentation and reduced levels of habitat connectivity (Epps et al 2006). Maintaining and increasing higher levels connectivity among high-elevation habitats may be one way to mitigate the negative impacts associated with climate change and increase population resilience.

Recently, there have been some population translocation attempts by land managers as well as a number of studies looking at subpopulation genetics (Gutierrez-Espeleta et al 2000 and 2001; Epps et al 2004, 2005, 2006, 2010). However, these studies have not yet been extended to subpopulations in or near the Navajo Nation.

Water Dependence

Water is especially important for Bighorn survival; especially when lactating ewes must trek daily to a spring or water hole in order to feed their calves (NPS 2006). This trek, however, can be particularly dangerous for the sheep in areas where Mountain Lions are present. Increasing water stress throughout the Southwest due to climate change may make water developments particularly important for Bighorns. According to a 2006 study, the provision of freestanding water for Bighorn Sheep in areas of greatest need became an effective means of mitigating other negative anthropogenic influences in the habitat (Dolan 2006).

Climate-Related Vulnerability and Resilience Ranking

The areas of highest vulnerability for Desert Bighorn Sheep relate to man-made barriers, precipitation, population/genetic sensitivities, and human interactions. Climate change is a more substantial threat to bighorn sheep compared to Mule Deer because of the sheep's lesser dispersal ability and higher dependence on water (See Table 3).

Table 3: Vulnerability Ranking for the Bighorn Sheep

	Bighorn Sheep
Man-made barriers	
Dispersal Ability	
Temperature	
Precipitation	
Habitat requirements	
Interspecies interactions	
Diet	
Population/Genetics	
Human interactions	

6.6 Mountain Lion (*Puma concolor*)

Population

In the early 1990s, the western U.S. population of the Mountain Lion was estimated at roughly 10,000 individuals, however an accurate and current census is needed to determine the species population and conservation needs (Caso et al. 2008; NatureServe 2010b). No population estimates are available at present for Navajo lands.

The Mountain Lion is considered a species of least concern by the IUCN because the species is still widespread, even though its population is considered to be declining (Caso et al. 2008). NatureServe's Global Heritage Status Rank rates the species as secure globally (G5) and vulnerable at a sub-national level (S3) (Navajo Nation Heritage Program 2008). The species is also currently included in CITES Appendix II. Factors that influence population numbers include habitat fragmentation and loss due to human encroachment, reduced prey base, and hunting. Sport hunting is allowed in many states while additional harvest of problem animals can occur due to concerns about livestock depredation, or threats to human life (NPS 2007; Caso et al. 2008).

As in states throughout the west, NNDFW staff see a need for additional information on the population size and location of the species on Navajo lands. Staff also mentioned that some residents believe there are increased livestock and other damage caused by the species, and fear this will increase over time.

Range and Dispersal

The Mountain Lion (*Puma concolor*) is native to North America and the largest member of the continent's cat family. Their range is limited to the 12 western---most states and one endangered population in Florida. The Mountain Lion is highly adaptable and lives in a broad range of habitats including forests, and lowland and montane deserts. While deer make up the majority of their diet (60-80 % in the western states population), they also eat other ungulates and smaller mammals such as squirrels and rabbits (Caso et al. 2008; NPS 2007).

Very Flexible Diet

While deer make up the majority of their diet (60-80 % in the western states population), they also eat other ungulates and smaller mammals such as squirrels and rabbits (Caso et al. 2008; NPS 2007). This provides them considerable flexibility if one food source is threatened by climate change.

Climate-Related Vulnerability and Resilience Ranking

Based on the known facts about the species' biology, distribution, and dietary requirements, the Mountain Lion might be expected to fare well in the face of climate change. However, without good data on the population in the region and on Navajo lands it is difficult to say for certain how exactly Mountain Lions will respond to climate change (See Table 4).

Table 4 : Vulnerability Ranking for the Bighorn Sheep

	Mountain Lion
Man-made barriers	
Dispersal Ability	
Temperature	
Precipitation	
Habitat requirements	
Interspecies interactions	
Diet	
Population/Genetics	?
Human interactions	

6.7 American Black Bear (*Ursus americanus*)

Population

The American Black Bear is found throughout much of the United States, including on Navajo lands. It is estimated that the total contiguous U.S. population is over 300,000 individuals (Garshelis 2008). Habitat loss and overexploitation have reduced the population size from its historical proportions. Although there is no specific population information for Navajo Nation land, the average bear density in the region is 3-4.2 per square km. The most significant threats to Black Bear population growth are hunting, poaching, conflict with humans, human encroachment, and habitat loss and fragmentation from activities such as suburban development, agriculture, timber harvesting, energy development, and roads (Garshelis 2008).

Range and Dispersal

Despite these challenges, the American Black Bear's range and size has generally expanded over the last twenty years, due in large part to the species' resource adaptability. For example, in terms of habitat, the Black Bear can reside in a number of systems including high-elevation and low-elevation coniferous and deciduous forests, pinyon-juniper woodlands, chaparral, desert grasslands, desert scrub, swamps, pocosins, and hammocks (Ulev 2007). The American Black Bear is considered a species of least concern by IUCN and it is not listed as threatened or endangered under the Endangered Species Act. However, the American Black Bear has been listed in Appendix II of CITES since 1992 due to concerns about the international trade in bear parts.

Man-made Barriers

Black Bears seldom cross major highways, and crossing of smaller roads is inversely related to traffic volume. Man-made barriers, such as roads, pose a significant hurdle to the Black Bear's dispersal ability as it will make it less able to "take flight" from climate change.

Habitat and Diet

Fires can be beneficial for bear diet and habitat needs as they maintain open meadows and are often zones of high fruit and berry production. Bears exhibit a strong selection for high shrub densities, which suggests that sufficient shrub patches ought to be a priority in fire management plans (Cunningham et al 2003). Prescribed fires may also be a means to control forest advances under climate change and maintain bear habitat (LeCount 1980). Black Bears and Bighorn sheep utilize the same plants (primarily grasses and forbs) when there is limited abundance. Competition between bears and sheep occurred when they utilized the same plants (primarily grasses and forbs) that were limited by either abundance or seasonal availability. Additional conflict, resulting in losses of sheep to bear predation, occurred during concurrent habitat use by bears and sheep.

Human Interaction

The Black Bear was identified as a priority species by NNDFW workshop participants for a number of reasons, including the lack of information about the species population on Navajo lands (i.e., whether population numbers are increasing, decreasing, or stabilized). Additionally, no management strategy is currently in place to address human interactions with problem bears (which is perceived to be increasing). As the climate warms and gets drier, the problem of bear encounters will only increase. Between 1982-

2001, human-bear encounters occurred 4.7 times more often during dry years than El Niño wet years (Zach et al 2003).

In a recent study by Spencer et al, most (75%) federal agencies surveyed relocated problem bears, but only 15% believed relocation was an effective tool (Spencer et al 2007). Relocation is rarely successful because the bears readily return to their initial home range, even without familiar landscape cues. Bears with access to human foods can reproduce nearly twice as often as those without such access; these bears often become problematic for humans living in the area.

Climate-Related Vulnerability and Resilience Ranking

The areas of highest vulnerability for Black Bears relate to man-made barriers such as and increased human interactions. Moderate levels of vulnerability surround threats to their habitat requirements and diet, which depend on changing fire regimes (See Table 5).

Table 5: Vulnerability Ranking for the Black Bear

	Black Bear
Man-made barriers	
Dispersal Ability	
Temperature	
Precipitation	
Habitat requirements	
Interspecies interactions	
Diet	
Population/Genetics	
Human interactions	

6.8 Vulnerability and Resilience Rankings Across all Species

The following table summarizes the vulnerability and resilience rankings across all five priority wildlife species for the Navajo Nation Department of Fish and Wildlife.

Table 6 : Vulnerability Rankings for All Species

	Golden Eagle	Mule Deer	Bighorn Sheep	Mountain Lion	Black Bear
Man-made barriers					
Dispersal Ability					
Temperature					
Precipitation					
Habitat requirements					
Interspecies interactions					
Diet					
Population/Genetics				?	
Human interactions					

7. Development of Climate Adaptation Strategies

At two workshops in 2012 and 2013, the entire staff of the Navajo Nation Department of Fish and Wildlife explored climate adaptation options for the Department's priority fish and wildlife species and habitats. We began by reviewing general climate change strategies that have been identified in the conservation literature for wildlife species and ecosystems. We then discussed the concept of adaptive management, as a general framework for implementing climate adaptation activities. Finally, we discussed potential adaptation activities that the Department and its Sections could implement, as part of their annual and long-term work plans.

7.1 General Climate-Change Adaptation Recommendation

For purposes of this report, climate-change adaptation activities are defined as actions that are intended to improve or enhance the ability of species and ecological communities to respond to changes in climate. There has been extensive discussion of climate adaptation approaches in both the technical and "grey" literature, with multiple adaptation strategies recommended for vulnerable species and their habitats (Heller and Zavaleta 2009; Mawdsley et al. 2009; Rose 2010).

One of the most widely recommended climate adaptation strategies is the conservation or protection of wildlife movement corridors, as a way to protect the dispersal ability of one or more species of conservation interest. Riparian areas and other natural movement corridors are generally thought to be of particularly high value in promoting natural species movements in response to climate change. Along with corridors, it is also important to identify and protect climate refugia, which are areas in a regional landscape that are likely to experience a lesser degree of change in the future. These refugia function essentially as safe havens in the regional landscape that biodiversity can persist in and potentially expand from, under a changing climate (Yale 2013). Refugia have the potential to provide vulnerable species with a measure of stability which could mitigate the threat of extirpation over a geographic area.

Climate change has the potential to exacerbate other existing vulnerabilities that species have to biotic and abiotic stressors. Reducing other stressors on species and ecosystems can indirectly increase resilience to regional biotic and abiotic environmental condition changes. These stressors may include invasive species, habitat loss and fragmentation, and the spread of disease.

Species translocation is actively debated in the literature on climate adaptation, although it is widely practiced by fish and wildlife agencies, particularly in the management of recreational fisheries and game species. Sometimes translocation is one of the only options available for managing a highly threatened species. While species translocations have shown varying degrees of success in the past, this approach can be vital to preserving a particular gene pool or general species presence in a geographical area.

One final important element that can help to inform climate adaptation strategies is to monitor ecosystems and species at-risk more consistently. Land managers will need to identify the most appropriate time for intervention and this decision-making process requires current and accurate data. Monitoring is one of the primarily tools used for adaptation planning because it provides managers with the information he or she needs to quickly and comprehensively respond to threatened habitat or species. This approach is especially important for species and ecological systems that are likely to experience dramatic, and at times unpredictable, effects of climate change.

7.2 Adaptive Management as a Tool for Climate-Change Adaptation

The literature on climate adaptation places strong emphasis on the use of adaptive management approaches for managing the effects of climate change. In wildlife and natural resource management practice, the phrase "adaptive management" refers to a set of management approaches that allow managers to learn from past management activities and develop new management actions based on the best available information (Willams et al. 2007). Adaptive management combines modeling exercises that estimate the projected effects of management actions with monitoring programs that collect data on management effectiveness (Walters 1986). Information about actual effectiveness is then used to refine and adjust future management prescriptions, as well as the underlying models and associated monitoring programs (Walters 1986; Margoluis and Salafsky 1998; Williams et al. 2007). Adjustments to management prescriptions, models, and monitoring programs will undoubtedly be necessary as managers attempt to respond to the profound changes already observed in many wildlife populations and ecosystem dynamics.

Adaptive management provides managers with a framework for adjusting their activities in response to actual changes in ecosystems (Walters 1986; Margoluis and Salafsky 1998; Williams et al. 2007). Most of these approaches employ a multi-step process:

1. Define the management problem by selecting a conservation target and identify goals and objectives for its management;

2. Identify actions that could achieve the stated management objectives;
3. Use a modeling exercise to predict the outcomes of these management actions, based on best available scientific data, and design a monitoring program to determine whether or not the management actions achieve the desired effect;
4. Implement the management activities and monitoring program; and
5. Review the results of the monitoring program and update management activities accordingly.

If properly implemented, an adaptive management approach provides managers with considerable flexibility for testing and learning from past and present management activities. Conservation activities designed to protect or manage land and water resources as well as individual species, can be deployed within an adaptive management framework.

7.3 Guides for Adaptive Management: Modeling and Monitoring

The literature on climate adaptation suggests that managers take advantage of both modeling and monitoring approaches in order to develop robust management prescriptions for species affected by climate change.

Models can be useful tools in helping to develop climate adaptation strategies for particular wildlife species or particular landscapes. There are intense debates in the wildlife conservation literature about the relative merits of particular modeling approaches. Academic wildlife biologists are often interested in developing the most rigorous model, while wildlife managers need clear guidance on where and when to take management actions.

The adaptive management framework provides a useful focus for wildlife population modeling efforts by directing attention towards the models and approaches that will be most reliable at helping managers identify potential management actions. Keeping this objective in sight will help prevent managers from becoming bogged down in technical discussions about the relative merits of the models that are now available. A wide variety of modeling approaches have been described in the literature, including simple box-and-arrow diagrams (Margoluis and Salafsky 1998), qualitative scenarios (Peterson et al. 2003), static models (Carroll 2005), dynamic models (Carroll 2005); and approaches that couple climate models or climate projections with static or dynamic models of populations or ecosystems (Peterson et al. 2003; Carroll 2005; McRae et al. 2008). Different modeling approaches may be more or less appropriate for addressing particular management questions (Carroll 2005). Managers will undoubtedly find it helpful to enlist the assistance of local and regional climate modeling experts, in order to find the sources of climate information and the modeling approaches that are most appropriate for answering questions about a particular conservation target.

Many of the most useful models for wildlife and natural resource managers are those that are spatially explicit and specify particular areas and sites where conservation activities should be directed (Lang 1998; Groves 2003; Carroll 2005). Geographic Information Systems (GIS) and other spatial analysis tools have an important role to play in wildlife management (Schumaker et al. 2004; Hannah and Hansen 2005). Spatially explicit models can also be helpful in the identification of potential corridors and other pathways where movements of plant and animal populations might occur in the future as a result of climate change (Carroll 2005; Phillips et al. 2006). The refuge areas and habitat corridors identified through these spatial analyses could then serve as the focus for land and water protection or management activities (Inkley et al. 2004; Julius and West 2007).

Monitoring programs are also an integral part of adaptive management approaches and likewise are commonly mentioned in the literature on climate change and other key stressors for wildlife and plants (Adger et al. 2003; Fischlin et al. 2007; The Heinz Center 2008). Monitoring programs can track the actual effects of conservation activities on wildlife and ecosystems, allowing managers to target their activities in order to meet specific management challenges (Inkley et al. 2004). In adaptive management, data from monitoring programs is also used to assess the effectiveness of conservation actions and refine models and future management prescriptions (Walters 1986). Both modeling and monitoring information are important for the management of climate change effects on wildlife and ecosystems, and both are essential for the successful implementation of adaptive management (Walters 1986; Williams et al. 2007).

7.4 Specific Climate Adaptation Strategies for NNDFW

Following the discussion of the general climate change adaptation strategies outlined above, the staff of the NNDFW began to discuss specific adaptation strategies for the priority fish and wildlife species. The vulnerability information presented in this assessment provides a basic conceptual grounding for climate adaptation planning and can help to support this decision-making process.

7.4.1 Connectivity Analysis and Corridor Conservation

One of the most important adaptation strategies for the Navajo landscape is the conservation of movement and migratory corridors for wildlife species such as the Desert Bighorn Sheep and the Black Bear. Conservation of these movement corridors, especially those along natural features such as riparian areas, has the potential to yield significant benefits for multiple wildlife species. Further work is needed to identify and map wildlife corridors on the Navajo landscape. Field studies by NNDFW can be designed to help identify current movement corridors for key species. Field research can also identify areas of suitable habitat where particular wildlife species may move in the future as the climate changes.

Connectivity analyses also represent another useful tool for identifying potential movement corridors under future climate scenarios. Through a project funded by the Southern Rockies Landscape Conservation Cooperative, connectivity analyses have already been performed for several of the NNDFW priority species on the Navajo landscape. We present a worked example below that uses modeled habitat suitability data for Mule Deer in order to develop specific, on-the-ground habitat restoration and management prescriptions.

7.4.2 "Climate Smart" Species Translocation

NNDFW has a highly successful translocation program for Desert Bighorn Sheep that has led to significant increases in the Bighorn population on Navajo lands. Future translocations can take into account potential effects of climate change on the preferred habitat of the sheep. There is a potential, as discussed above, that climate change may result in increased fragmentation of sheep populations. Sheep could potentially move in response to vegetation changes, changes in predator abundance, or water stress. Monitoring of the existing sheep populations could help to detect any changes in habitat use or distribution of the sheep on the Navajo landscape. Further translocations could be planned for areas that are projected to support suitable habitat for Desert Bighorn Sheep under future climate scenarios. Based on the discussion above, such areas may be at higher elevations or further upstream from existing populations.

7.4.3 Renewable Energy and Golden Eagles

The NNDFW may also want to consider careful development of renewable energy to reduce the potential for adverse impact on Golden Eagles. Successful eagle conservation may also require cooperation with other agencies along eagle movement routes. Updated eagle population data that is currently being gathered will help to reveal any declines in the species that may be a result of climate change.

7.4.4 Reduce Human Conflicts with Black Bears

Black Bears encounters are on the rise with longer periods of drought and higher levels of human interaction. The NNDFW may want to consider finding ways to reduce these encounters as part of an overall plan to decrease human-bear conflicts on Navajo lands.

7.5 Connectivity Analysis Leads to Management Prescriptions

Complementing this climate vulnerability assessment, a landscape connectivity study was conducted by Erica Fleishman at UC-Davis and Brett Dickson at Northern Arizona University. The Fleishman-Dickson modeling effort, supported in part by the Southern Rockies Landscape Conservation Cooperative (see: http://southernrockieslcc.org/project/connectivity-of-habitats-on-navajo-nation-lands/), has provided the Navajo Nation Department of Fish and Wildlife (NNDFW) with a series of geospatially explicit maps showing probable movement corridors for individual priority wildlife species (principally large mammalian taxa such as mule deer, mountain lion, black bear, and desert bighorn sheep) under current and future climate regimes. These maps can be used to identify potential upland and riparian habitat restoration sites that will help improve connectivity for priority wildlife species on the Navajo landscape.

Upland Terrestrial Restoration Sites

The connectivity maps provided to NNDFW show a gap developing within a currently-existing wildlife corridor that links the Chuska Mountains at the heart of the Navajo reservation to the San Juan Mountains to the northeast (see Figure 3 below). A similar gap appears in connectivity maps developed for multiple large mammalian species, suggesting that this feature may be a significant barrier to wildlife movements. This gap has the potential to lead to isolation of multiple large mammalian species in the Chuska Mountains and thus is of significant management interest to NNDFW. The Chuska Mountains are an important wildlife conservation area for the Navajo Nation, supporting populations of priority species such as Mule Deer.

The NNDFW is planning terrestrial habitat restoration work (vegetation treatments and plantings) that would be focused in this gap (see Figure 8 below). This work would maintain and promote areas of suitable habitat for large mammal species within the gap area. Because of the large size of this gap, and the limited nature of available funding, the actual restoration sites will be designed to serve as "stepping stones" for large mammal species moving through the gap area. At each site, vegetation treatments will remove invasive shrub and grass species that increase fire risk and associated vegetation conversion and soil erosion. Plantings will include native forb, grass, and shrub species that have attributes suggesting resilience to climate change (e.g. drought tolerance) and that provide important habitat features (e.g. forage, browse, shade, cover for prey) for NNDFW's priority mammalian species.

In addition to the benefits to large mammals, we also anticipate (based on data on species occurrences and movement patterns collected by the Navajo Nation Natural Heritage Program) that these habitat restoration projects will also help to provide habitat for small mammals, reptiles, and birds within this larger landscape.

Riparian Corridor Restoration Sites

Riparian corridors on the Navajo landscape support a wealth of native plant and animal species, including fish, aquatic invertebrates, amphibians and reptiles, birds, and small mammals, and also serve as important movement corridors for large mammals. The Fleishman-Dickson connectivity models identified several riparian corridors that are likely to have high value as movement corridors for multiple large mammal species under future climate regimes. Riparian restoration projects are being designed that are intended to promote habitat connectivity along these movement corridors. Restoration activities will take place along the mainstem of the San Juan River to the northwest of Shiprock. These projects are designed to remove non-native vegetation and plant native riparian species in areas where the native riparian vegetation is expected to have a good chance of recovery following treatment and plantings.

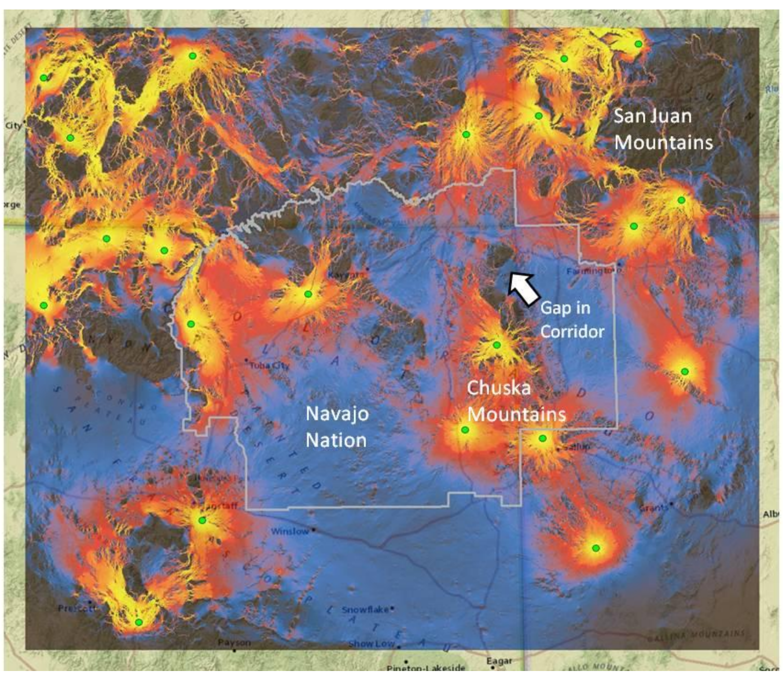


Figure 3: Landscape connectivity map for Mule Deer, showing the gap in the movement corridor between the Chuska Mountains and the San Juan Mountains. Similar gaps were observed in this same area in landscape connectivity maps developed for other large mammal species. The arrow points to the location where upland restoration treatments are planned.

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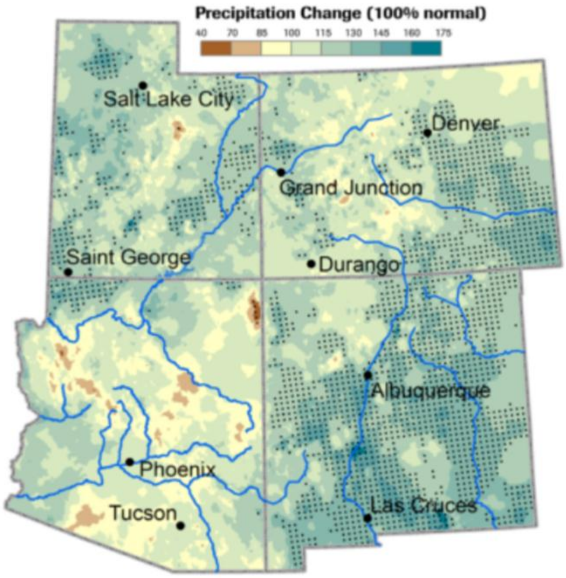
9. Appendix – Useful Figures for Understanding Climate Change

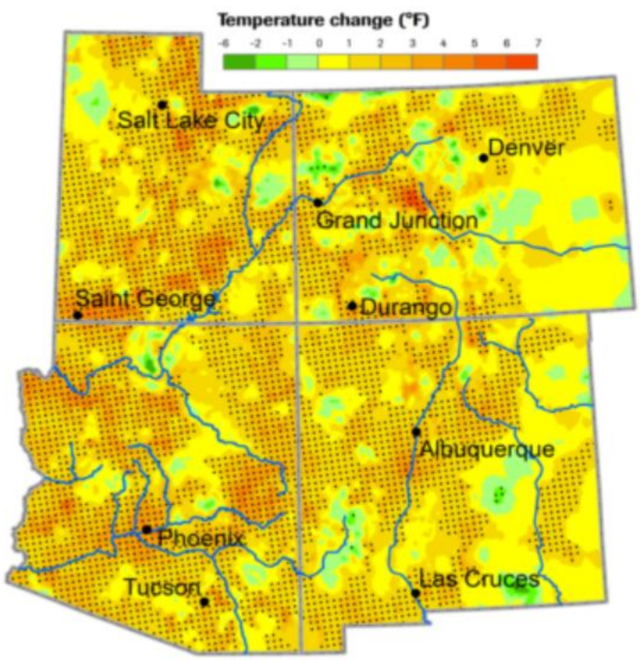


4-Corner States	117%
Arizona	105%
Colorado	115%
New Mexico	128%
Utah	120%

Table shows changes in mean annual precipitation by state.[15,21] Map shows precipitation changes across all locations in the Southwest. Dots on map indicate where the trend is significant ($p < 0.05$).[22] The average of mean annual precipitation at each location from 1951-2006 was set to 100%. Locations with values near 100% have experienced no trend in precipitation in the last half century. Locations with values less than 100% have become drier. Locations with values greater than 100% have become wetter.

See Supporting Information S1 for more detailed description of climate data.

Figure 4: Precipitation Change 1980-2006



4-Corner States	+1.5
Arizona	+1.9
Colorado	+1.1
New Mexico	+1.2
Utah	+1.8

Table shows changes in mean annual temperature by state. Map shows temperature changes across all locations.[15,21] Dots on map indicate where the trend is significant ($p < .05$).[22] Locations with values near 0 experienced little change in temperature on average from 1951–2006. Locations with positive values experienced warming. Locations with negative values experienced cooling.

See Supporting Information S1 for more detailed description of climate data.

Figure 5: Temperature Change 1980-2006

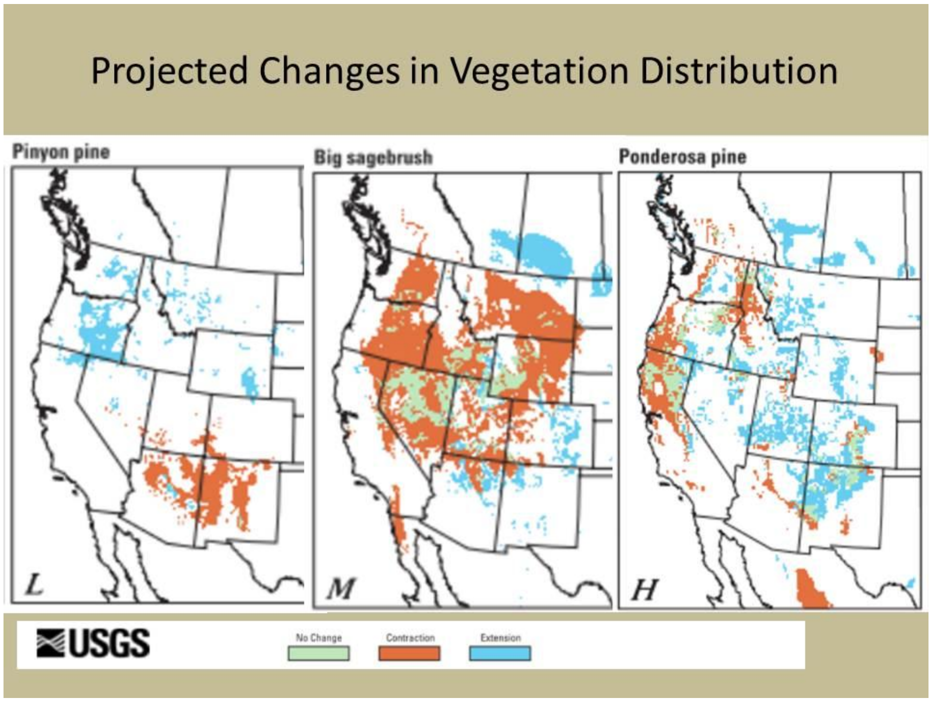


Figure 6: Projected Changes in Vegetation Distribution

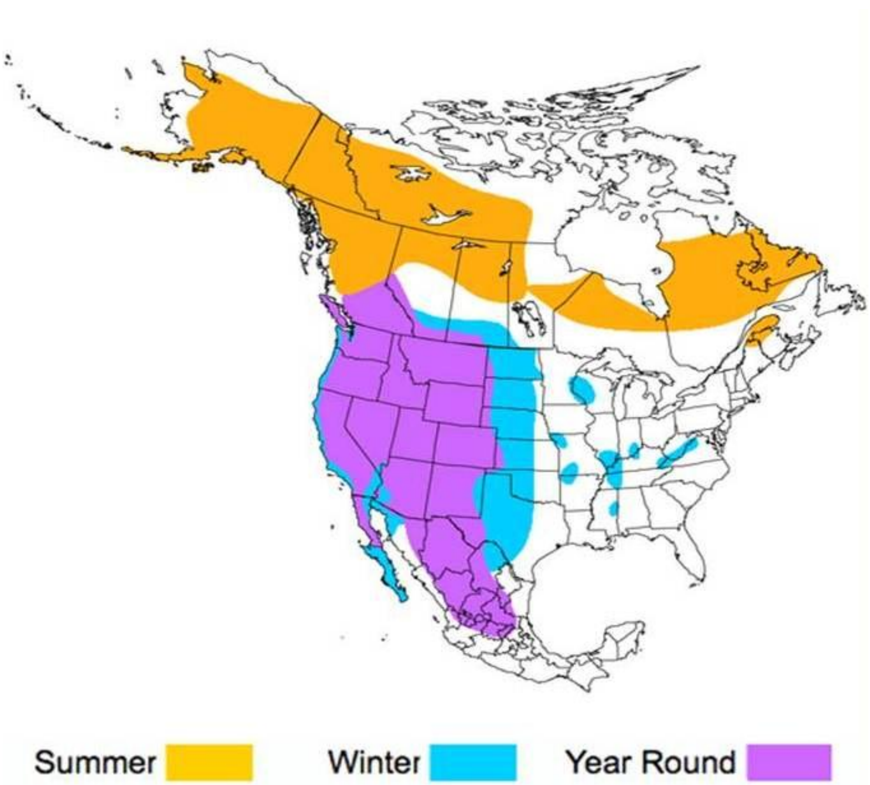


Figure 7: Range Map of the Golden Eagle

Figure 8: Year Round Range of Desert Bighorn Sheep

Figures 4 and 5

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Figure 6

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Figure 7

Dr. Biology. 2009. Bird Details. ASU - Ask A Biologist. Retrieved October 29, 2013 from http://askabiologist.asu.edu/bird

Figure 8

US Geological Society. 2008. Range of Bighorn Sheep. Accessed on October 29, 2013 downloaded from http://gapanalysis.usgs.gov/species-viewer/