Adapting to Climate Change:

Agency Science Needs

to Adapt Game Management

to Changing Global Climate

A Report to the

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By the

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Executive Summary

This document describes predicted impacts on wildlife and habitat based on widely accepted climate change models and the science and research needs necessary to intelligently engage in adaptive management. While there is uncertainty about the predictability of climate change impacts, there is no uncertainty that agencies need to be able to proactively identify, detect and adapt to climate-induced changes in habitat and population characteristics.

Based on published scientific reports and expert opinion, biologists predict that climate change will substantially alter the habitat characteristics of biomes throughout North America. As the environment changes, wildlife will adapt, perhaps flourish, or perish. Agencies need the ability to adapt game management programs as habitats transform.

The changes will be substantial: in the north, ruffed grouse and moose abundance will decrease while white-tailed deer and northern bobwhite abundance will increase as winters moderate. In the West, mule deer, elk, pronghorn and desert bighorn sheep will need to adapt to the northward or higher elevational shift of drier habitats.

It is clear that due to the myriad of potential impacts climate change may have on populations and habitat, additional monitoring, surveys, and research will be necessary to successfully manage the impacts' effect. Baseline information must be established to detect climate change impacts, ongoing monitoring and surveys must be conducted to ascertain the effect of those impacts, and research must be undertaken to solve questions that arise due to the effects on fish and wildlife. Given the potential geographic extent and multitude of impacts associated with climate change, the current level of research funding for federal and state fish and wildlife management agencies is inadequate to meet the science needs associated with global climate change.

Wildlife response to climate change impacts has a direct bearing on the activity of more than 87 million Americans. Those residents most directly affected are the 12.5 million hunters and 29.9 million anglers whose activities are regulated by government entities. Public participation in government decisions to allocate wildlife resources, will demand a better understanding of and ability to adapt to climate change and its impacts on wildlife.

Steps are outlined that wildlife agencies should take to identify priority tasks and maximize the opportunity to capture federal funding for climate change impacts. Key elements of an adaptive management strategy aimed at implementation of actions related to climate change are presented. Specific recommendations are proposed at the regional level for some of the principal game species and at the national level for operational and programmatic purposes. We estimate additional funding in the range of $500 million to $1 billion will be needed for state wildlife agencies to address climate change adequately.

INTRODUCTION

Our planet has experienced climate change for millions of years but only since the Industrial Revolution have humans contributed to factors (ozone, carbon dioxide, particulates, etc.) augmenting climate change. The current global warming cycle and associated climate change impacts pose substantial challenges to wildlife and the humans who enjoy them. As scientists grapple with the predicted impacts of climate change, one thing is certain—humans have the opportunity to take decisive actions to ameliorate the impacts taking place on wild species and their habitats.

Throughout time, humans have relied on fish, wildlife, and their habitat for spiritual, economic, recreational, consumptive, and ecological reasons. The decisive actions necessary to maintain the role of fish and wildlife in human society and adapt to the impacts of climate change will only be as successful as the science behind the decisions. This document describes the science and research needs necessary to intelligently engage in the newest form of adaptive management—climate change.

Humans have managed wildlife populations for thousands of years. Around the turn of the 20th century, spurred by public demand for conservation, federal and state governments developed treaties, laws, rules and regulations to protect and conserve fish and wildlife resources. Agencies, established by these government entities, were charged with managing the nation's fish and wildlife resources in trust for the American public.

Today, elaborate management systems exist to ensure the long-term sustainability of fish and wildlife species and populations. State fish and wildlife agencies periodically gather information concerning the population status and selected characteristics of wildlife populations. In a similar fashion, they assess the quantity and quality of habitat upon which these species depend.

Agencies employ a variety of monitoring, survey and research projects to assist in making management decisions. These decisions include allowable and appropriate harvest levels, timing of hunting seasons, carrying capacity of available habitat, acquisition of conservation lands, and habitat management practices. Management decisions are driven by public input, established management goals, and decision models. Hunters are the ultimate benefactors and beneficiaries of these decisions. Hunter activity is highly regulated and directly linked to the status of wildlife and its habitat. Changes in either wildlife population status or habitat can lead to enhancement or diminution of hunting activity. Therefore, hunters have a unique perspective on factors that may alter current management goals and decision models.

Wildlife biologists and managers focus much of their efforts on measuring population and habitat characteristics. Population characteristics include population dynamics, spatial distribution, and external biotic influences. The measurement of population dynamics includes: abundance, density, productivity, survival and mortality, age structure and sex ratios. Spatial distribution of wildlife populations includes their range, distribution, mobility, daily movements, and seasonal movements or migration. Habitat characteristics of interest to wildlife managers include species composition, habitat structure, spatial distribution, function, and invasive species. Species composition and habitat structure refers to the type and condition of plant species within a population's range and the successional stage or relative age of habitat types. The spatial distribution of habitat types includes the uniqueness of species, the amount and distribution of key species (patchiness and interspersion), and the juxtaposition of habitat types. Habitat corridors, the space that connects preferred habitat types, are especially important for those species that migrate. The life function that habitat plays is a key habitat characteristic for wildlife species or groups of wildlife species. Habitat is typically characterized food, water, vegetative cover and space for thermoregulation, escape, breeding and brood rearing. Invasive species (both plant and animal) may be a major factor in the long-term health of habitat.

The potential interactions between climate change impacts—increases or decreases in temperature, precipitation, timing of weather events, phenology, extreme weather events, and spatial extent of these impacts, singularly and in combination—and the myriad of population and habitat characteristics described above are astounding. Each of the climate change impacts listed above has the potential to affect one or more of the population and/or habitat characteristics positively or negatively. Wildlife managers must be prepared to recognize the effect and to respond in an appropriate manner. In many cases, this response may have a direct impact on hunters who are the most directly affected by rules and regulations regarding allowable and appropriate hunting activity.

The complexity of potential impacts of climate change on populations and habitat demands additional monitoring, surveys, and research. Baseline information must be established in order to detect climate change impacts, ongoing monitoring and surveys must be conducted to ascertain the effect of those impacts, and research must be undertaken to solve questions that arise due to the effects on fish and wildlife. Given the potential geographic extent and multitude of impacts associated with climate change, and the current and future human development pressures affecting wildlife and their habitat, the current level of research funding for federal and state fish and wildlife management agencies is inadequate to meet the science needs associated with global climate change.

Government response to climate change is expected to address human health, agricultural, transportation, infrastructure, and related issues. Wildlife response to climate change impacts has a direct bearing on the activity of more than 87 million Americans. Those residents most directly affected are the 12.5 million hunters and 29.9 million anglers whose activities are regulated by government entities. Public participation in government decisions to allocate wildlife resources will demand a better understanding of and ability to adapt to climate change and its impacts on wildlife.

Because the natural resources of a nation are critical to that nation's sustainability and productivity, the science needed to manage its fish and wildlife resources properly must also be addressed.

METHODS

We separated our investigation of science and research needs into three distinct phases, roughly organized by biome, and aggregated into each regional assessment. First, we queried published literature and/or internet-based resources to determine the types of changes predicted for habitats in each biome. Using those predicted changes as our foundation, we then used published literature and/or expert opinion to translate the changes in habitat to likely changes in game populations. For each species, a long list of potential impacts was possible. In most cases, however, the ability to quantify impacts proved impossible with the current level of monitoring data. In addition, the complexity of interactions between climate change, habitat, and population response have not been documented for many of the species we include. Our estimates, therefore, are descriptive to the extent possible, but frequently speculative. Finally, we relied on published literature and expert opinion to describe the research and science needs of agencies to fully adapt to predicted changes in both habitat and population characteristics.

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FINDINGS

Predicted General Climate Change Impacts on Wildlife

By applying what is known about wildlife response to changes in climate, the following general scenarios seem likely:

1) There is a close link between climate change and vegetation or habitat change.
2) Climate change will cause changes in animal abundance, ranges, phenology, community composition, interactions and behavior (Root and Schneider 2002).
3) Some changes will be considered positive and some negative (Inkley et al. 2004).
4) Ranges of both flora and fauna will generally shift upwards in elevation and northward in latitude (Intergovernmental Panel on Climate Change (IPCC 2002). It has been assumed boreal habitat zones will ascend in elevation 500 m (1,640 ft) for every 3 °C rise in average temperature (Murphy and Weiss 1992).
5) As species move northward, they will move at different rates and directions, not as a group. Therefore, future communities will be comprised of different species (Root and Schneider 2002).
6) Habitat specialist species that have restricted distribution, low colonization ability and poor dispersal are the most prone to extinction during climate change (Travis 2003).
7) Species with a high rate of reproduction, able to move long distances, rapidly colonize new habitats, tolerate humans and survive within a broad range of biophysical conditions will be most successful in finding new niches. (Gray 2005).
8) Species with relatively wide geographic ranges are the most resilient to the effects of climate change. (Travis 2003).

9) Below a critical rate of climate change, most species will maintain high patch occupancy. Above the critical rate, many species will be unable to keep pace with climate change and patch occupancy will decline rapidly (Travis 2003).

10) The richness of vertebrate ectotherms will increase over most of the conterminous United States. Mammal and bird richness are predicted to decrease in much of the southern United States and to increase in cool, mountainous areas. Woody plant richness is likely to increase throughout the North and West and to decrease in southwestern deserts. These projections represent changes that are likely to occur over long time scales (millennia); short-term changes are expected to be mainly negative (Currie 2001).

Northeast and Northcentral Region

Description

The Eastern Temperate Forest region includes Laurentian Mixed Forest Province forests in the northcentral lake states, northern Pennsylvania, New York, interior New England, and the Eastern Deciduous Forest Province forests of the southcentral lake states, and of the Ozark, Ouachita, and Appalachian mountain ranges (Bailey 1995). Elevation ranges between sea level and 4,000 ft (1,200 m), generally with tallest mountain peaks 5,000 ft (1,500 m) or higher.

Climate

Climate varies with latitude with the northernmost portions experiencing strong seasonal contrasts in temperature with ample precipitation all year, especially during the summer (Bailey 1995). In southern forests, climate is characterized by hot summers and cool winters (Bailey 1995). Snow cover is deeper and lasts longer in northern forests. Rainfall decreases with distance from the ocean. Average annual precipitation is from 24 to 45 in (60–115 cm) in the north to 35 to 60 in (90–150 cm) in the south (Bailey 1995).

Vegetation

Forest vegetation ranges from boreal forest transition types in the north to deciduous forest zones in the south. Major forest cover types include:

1. White-red-jack pine forest cover type—Forests in which eastern white pine, red pine, or jack pine dominate or, in combination, are co-dominates. Current distribution of the type

includes scattered blocks in eastern and coastal Maine, central New Hampshire and Vermont, northeastern New York, northern Michigan, and northern Wisconsin (Prasad et al. 2007).

2. Spruce-fir forest cover type—Forests in which spruce or true firs dominate or, in combination, are co-dominates. Common associates include white cedar, tamarack, birch, maple and hemlock. Current distribution of the type includes northern Maine, the White and Green Mountains of New Hampshire and Vermont, respectively, and northern Michigan, Wisconsin and Minnesota (Prasad et al. 2007).
3. Elm-ash-cottonwood forest cover type—Forests in which elm, ash, or cottonwood dominates or in combination, are co-dominates. Common associates include willow, sycamore, American beech, and maples. Current distribution of the type includes central New York and the central Midwest (Prasad et al. 2007).
4. Oak-hickory forest cover type—Forests in which upland oaks or hickories dominate or, in combination, are co-dominates. Common associates include yellow-poplar, elms, maples, and black walnut. The type currently occurs in the Appalachian region of Virginia, West Virginia and extends into the central Midwest (Prasad et al. 2007).
5. Oak-pine forest cover type—Forests in which hardwoods (usually upland oaks) comprise a plurality of the stocking, but in which softwoods, except cypress, comprise 25 to 49% of the stocking. Common associates include gums, hickories, and yellow-poplar. The type currently occurs in the transition between loblolly-shortleaf pine and oak-hickory forest type regions (Prasad et al. 2007).
6. Maple-beech-birch forest cover type—Forests in which maple, beech, or yellow birch dominate or, in combination, are co-dominates. Common associates include hemlock,

elm, basswood, and white pine. The type currently occurs in West Virginia, Pennsylvania, New York, New England, northern Michigan and northern Wisconsin (Prasad et al. 2007).

7. Aspen-birch forest cover type—Forests in which aspen, balsam poplar, or paper birch dominate or, in combination, are co-dominates. Common associates include maple and balsam fir. The type currently is common in northern Minnesota, northern Wisconsin, and northern Michigan (Prasad et al. 2007).

Principal Game Species

For purposes of this report, the primary game species to consider include white-tailed deer, moose, ruffed grouse, pine marten, Canada lynx, bobcat, fisher, snowshoe hare, gray squirrel, bobwhite quail and black bear.

Trends and Predictions of Climate Change on Game Species Habitat

Temperature

By the end of this century, winters could warm by 5 to 7.5° F (2.8–4.2° C) in winter and 3 to 7° F (1.7–3.9° C) in summer under the low emissions scenario and 8 to 12° F (4.4–6.7° C) and summers by 6 to 14° F (3.3–7.8° C) under the high emissions scenario (Union of Concerned Scientists (UCS) 2006).

Snow Depth and Duration

In the last century, the New England region, especially the northernmost region, had significant decreasing trends in percentage of total precipitation made up by snow for annual and winter periods (Wake and Markham 2005).

As winter temperatures rise, more precipitation will fall as rain and less as snow. By the end of the century, the length of the winter snow season could be cut in half (UCS 2006).

Over the past 30 years, stations in northern New York and northern New England have experienced significant decreases in snowfall, with several locations showing a decrease of 60 in (150 cm) or more (Wake and Markham 2005). Overall, the southern portions of the region have experienced a decrease in snowfall, although the decrease is smaller compared with northern regions (Wake and Markham 2005). When averaged, the Northeast stations reveal that there were, on average, 16 fewer days with snow on ground in 2001 than in 1970 (Wake and Markham 2005).

The character of the seasons will change significantly, with spring arriving three weeks earlier by the end of the century, summer lengthening by about three weeks at both its beginning and end, fall becoming warmer and drier, and winter becoming shorter and milder (UCS 2006). Under the low emission scenario, winter snow season could experience a 25% loss, with arrival of spring one to two weeks earlier by century's end; summer would arrive only one week earlier and extend a week and a half longer into the fall (UCS 2006).

Rainfall

Precipitation in the Northeast has increased by an average of 3.3 in (8.3 cm) (8 %) over the past century (Wake and Markham 2005). Climate models predict increases in the likelihood and severity of heavy rainfall events, including more than a 10% increase in the number of annual extreme rainfall events and a 20% increase in the maximum amount of rain that falls in a five-day period each year (UCS 2006).

The frequency of late summer and fall droughts is projected to increase significantly under the high emission scenario, with short-term droughts (lasting one to three months) becoming as frequent as once per year over much of the Northeast by the end of the century (UCS 2006).

Sea-level Changes

Relative sea level has risen in the last century due to a combination of natural processes and human influences (Wake and Markham 2005). Under the high emissions scenario, sea-level rise will continue, reaching anywhere from a few inches to more than one foot by mid-century (UCS 2006). By the end of the century, global sea level could rise from eight in (20 cm) up to nearly three ft (91 cm) (UCS 2006). Changes in sea level can also contribute to increased erosion and saltwater contamination of freshwater ecosystems and loss of salt marshes and cordgrass (Donnelly and Bertness. 2001, Wake and Markham 2005).

Seasonal Climate Changes

A combination of higher temperatures, increased evaporation, expanded growing season, and other factors that will cause summer and fall to become drier, with extended periods of low streamflow (UCS 2006).

Forest Composition

The USDA Forest Service models the potential habitat distribution for tree species and forest types based on the three prevailing general circulation models (GCMs) (Prasad et al. 2007). Tree distribution predictive outputs are based on the average of the three GCMs under both the high-and low-emission predictions. Model outputs include potential changes in geographic range and potential change in abundance (importance value) (Prasad et al. 2007).

1. White-red-jack pine forest cover type—Under the high and the low emission scenarios, the forest type is predicted to disappear from the current range (Prasad et al. 2007).
2. Spruce-fir forest cover type—Under the high and the low emission scenarios, the forest type is predicted to disappear from the current range (Prasad et al. 2007).
3. Elm-ash-cottonwood forest cover type—Under the high emission scenario, the type increases in prevalence in Minnesota and the central Midwest and disappears from the mid-Atlantic region (Prasad et al. 2007). Under the low emission scenario, the type appears as in the high emission scenario except that it persists in New York (Prasad et al. 2007).
4. Oak-hickory forest cover type—High emission models suggest that oak-hickory will expand northward into New England and the northcentral states (Prasad et al. 2007). Low emission models suggest the type will increase in importance in currently occupied ranges but not experience a significant northward range expansion (Prasad et al. 2007). Both emission models predict a significant northward range expansion and increase in importance values for northern red oak and white oak (Prasad et al. 2007).
5. Oak-pine forest cover type—The low emission scenario suggests a wider distribution of the type in Ohio, West Virginia, western Pennsylvania and the southcentral Midwest (Prasad et al. 2007). The high emission model predicts a significant increase in the type in Pennsylvania, New York, New England, Wisconsin and Michigan (Prasad et al. 2007).
6. Maple-beech-birch forest cover type—The high emission scenario predicts a northward movement of the type into northern WISCONSIN, northern MI, northern New England

and the Adirondacks of New York and disappearance of the type in the remaining sections of New York, Pennsylvania and southern New England (Prasad et al. 2007). The low emission model projects generally the same range but an increase in importance (Prasad et al. 2007)

7. Aspen-birch forest cover type—The low emission model predicts the type will persist in northeastern MN and disappear elsewhere (Prasad et al. 2007). The high emission scenario predicts the disappearance of the type from its current range (Prasad et al. 2007).

Forest Land Area

Izaurralde et al. (2005) modeled the changes in area coverage of major ecosystems in the United States under six different climate models. Model results suggest that at 1.0° C increase in temperature and a carbon dioxide concentration of 560 ppmv, area of temperate deciduous forest would increase from 45 to 225%. If temperatures increased by 2.5° C combined with a carbon dioxide concentration of 560 ppmv, area of temperate deciduous forest would increase from 250 to 300%.

Fire/Disturbance

Modeled predictions on fire severity (Flannigan et al. 2000) suggest that fire severity will increase 10 to 20% for the Northeast. Wooton and Flannigan (1993) predict fire seasons will be 30 days longer in Canada if carbon dioxide doubles.

Predictions of Climate Change Impacts on Game Species

White-tailed deer

White-tailed deer in the northern regions of the eastern temperate forest migrate to winter ranges that provide shelter from deep snow and cold temperatures. The benefits of winter range are primarily related to lowered energy expenditure. White-tailed deer increase body fat reserves from September to December, and then essentially live off those reserves until spring green-up in March or April. To slow the use of fat reserves, deer concentrate in areas with reduced snow depth and stable temperatures. Winter ranges are frequently coniferous, with thick, overlapping overstories and understories (Dumont et al. 1998), but steep south-facing hardwood slopes also may be used (Dickinson 1976). The primary purpose of winter range is to lessen the energetic demand of withstanding low temperatures and traveling through deep snow. Deer densities on winter range often are 10 times greater than on summer range (Broadfoot et al. 1996) because deer concentrate in these topographically or vegetative unique areas.

Winter ranges are predominately coniferous forest stands and, depending upon the ecological land type, usually are dominated by red spruce-balsam fir, eastern hemlock or white cedar. The coniferous forest stand structure in winter range results in less snow depth and harder crusts due to sublimation, and more stable and warmer temperature regimes due to the sheltering function of regenerating conifers. Less snow depth allows deer to move using lower energy expenditure. Stable and warmer temperatures lessen energy expended to maintain core temperature. Because deer are nutritionally limited, energy reserves and the subsequent demand on energy determine winter mortality.

Winter mortality exerts a profound influence on deer populations. A Quebec white-tailed deer population decreased by 71% in 8 years, with winter mortality rates exceeding 40% of the population in some years (Potvin et al. 1981). Mech et al. (1987) found that 36-51% of the variation in fawn/doe ratios was explained by the summation of snow accumulation over the three previous winters. Mech et al. (1987) believed that fecundity and fawn survival in any one year reflected accumulated effects of winter severity, either directly through fawn mortality or indirectly through the diminishment of physical condition of adult females. Williamson (2003) documented a negative relationship between deer population size (as indexed by buck harvest) in more than 500 deer management units in the northeastern U.S. and eastern Canada and winter severity (Figure 1). Williamson (2003) also suggested that the negative relationship between deer population size and winter severity was in part driven by decreases in fawn frequency

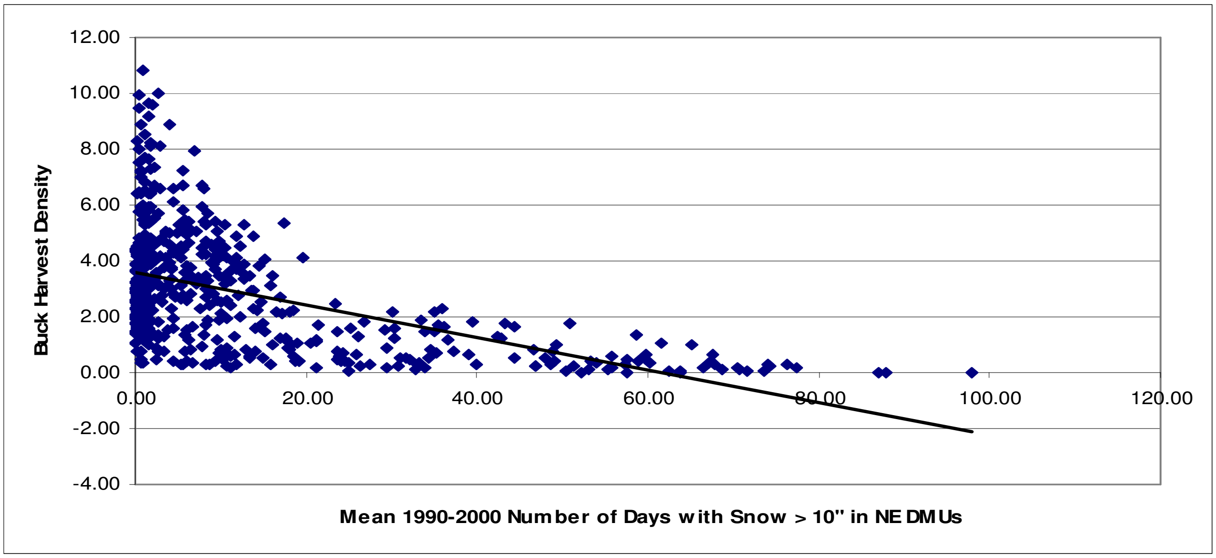

Figure 1: Relationship between buck harvest density and the mean 1990-2000 number of days with snow >10 in (25 cm) in northeastern DMUs (Williamson 2003).

Winter severity is expressed by the number of days between October and April with more than 10 in (25 cm) of snow on the ground. Snow depths >10 in (25 cm) generally conform to the time that deer are confined in winter range.

Information and Research Needs for White-tailed Deer

Lessening of winter severity due to a warming climate will remove a substantial source of mortality from northern deer populations and deer populations will respond by growing rapidly. Deer populations in a warmer climate will increase and may pass thresholds whereby population regulation through density dependence replaces density independent winter mortality. Managers thus need the ability to monitor and understand changes in population size and population dynamics through the emergence of density dependent forms of mortality. Higher deer populations will likely influence existing patterns of predation, herbivory, parasitism and interspecific competition and managers must understand the dynamics of those influences.

Vegetation changes will also likely support higher deer populations. Replacement of maple-beech-birch forest types with oak-dominated types increases the availability of hard mast as a food type. Managers must understand the changes in the dynamics of deer populations brought by increased nutritional levels and higher carrying capacities.

Moose

Moose inhabit the eastern forest biome in the states of Minnesota, Michigan, Wisconsin, New York, Vermont, New Hampshire and Maine, with scattered low-density populations in Massachusetts and Connecticut (Karns 1998). Moose generally overlap the geographical distribution of spruce (Karns 1998).

Moose have evolved to minimize cold stress with large surface areas, behavioral adaptations and super-insulating coats (Renecker and Schwartz 1998), but such adaptations make moose susceptible to heat stress. Moose experience heat stress and exceed the upper level of the thermoneutral zone when ambient temperatures exceed 57º F (14º C) (Renecker and Hudson 1986, 1990).

Recent studies of moose population dynamics suggest that warming climate is partially responsible for moose population decreases in Minnesota (Murray et al. 2006).

During the study period, mean winter and summer temperatures were higher, the growing season averaged 12 days longer, and the March and September thermoregulation thresholds for moose were exceeded more frequently during the period of population decline as compared with climate factors during an earlier period of increase. Negative population rate of change was associated with summer temperature during the previous year with such changes manifesting themselves in body condition and pregnancy rate declines. The authors suggest that the observed population decline may reflect a recent northward shift in the thermoneutral zone resulting in a widespread northward shift in the southern distribution of moose in North America.

Information and Research Needs for Moose

A warming climate is predicted to affect the continued presence of moose in the eastern temperate forest biome. In the Murray et al. (2006) study, the proximate cause of mortality in the declining moose population appeared to be a combination of chronic malnutrition and parasitism. Managers, therefore, must be able to detect and understand various indices of population health in order to detect if global climate change is affecting abundance and distribution of moose. In addition, populations are likely to become fragmented and moose habitat selection will change. Questions about the continued presence of moose will only be answered through a viable regional monitoring effort to detect changes in population size, population health and survival. If white-tailed deer populations expand in the region, inter-specific competition may increase, as will the likelihood of parasites and diseases common to deer spreading to moose.

Changes in forest composition will also affect moose population dynamics because loss of the aspen/birch and spruce/fir forest types will remove important moose browse plants from the landscape.

Ruffed Grouse

Ruffed grouse are common in the eastern forest biomes and can be found in many different forest types in North America, although deciduous or mixed forest types are preferred. Quaking and bigtooth aspen forests can support ruffed grouse population densities that greatly exceed those typically attained in other forest communities (Dessecker et al. 2006). Indeed, the range of the ruffed grouse and that of quaking aspen are remarkably similar and the relationship between these two species has been well documented in eastern forests (Gullion 1984, Kubisiak 1985).

Dessecker et al. (2006) calculated expected population sizes for Bird Conservation Regions (BCRs) inhabited by ruffed grouse, based on forest composition and age structure. Drumming male densities were interpreted from existing studies and predicted to be from 1-2 drumming males/100 acres (40 ha) in the central hardwood forests of the Midwest, central and southern Appalachians, and northern hardwood forests in the northern tier of states (Thompson and Dessecker 1997). Aspen forests of the Great Lakes region were believed to support 4–8 drumming males/100 acres (40 ha) (Kubisiak 1985, Manitoba DNR 1994).

Estimates of ruffed grouse density presented in Dessecker et al. (2006) were recalculated based on predictions of forest type composition changes made by Prasad et al. (2007). In BCR 12 –Boreal Hardwood Transition, for example, aspen-birch represents 33% of the forest area (Dessecker et al. 2006). If aspen/birch disappears from the BCR, then ruffed grouse density will likely be affected.

The recalculation of grouse densities based on predicted changes in forest composition is a gross approximation of possible impacts of climate change on ruffed grouse populations. There is continued uncertainty about the scope and speed of composition change, and no information is available on forest age structure—a very important component of grouse habitat quality. The following estimates, therefore, should be viewed only as an exploratory analysis.

Four basic composition changes were modeled: the replacement of spruce-fir and pine by deciduous types, the replacement of the maple-beech-birch type by oak types, the replacement of aspen-birch by maple-beech-birch and the increase of elm-ash-cottonwood in the Midwest. Changes were modeled at the BCR level.

In total, ruffed grouse density decreases from a continental population of 3.8 million drummers (Dessecker et al. 2006) to a continental population of just over 3.0 million drummers. Regional changes are more pronounced. The northcentral states see the largest decline in grouse numbers as aspen-birch decreases in abundance; populations decrease by 33% in the two BCRs comprising the Lake States. New England also will witness a decrease as populations shrink by 20%. Populations in other regions largely stay the same, except for the Appalachian Mountains which is predicted to see an 8% increase in grouse populations.

Information and Research Needs for Ruffed Grouse

There is no coordinated regional ruffed grouse monitoring survey; although, some jurisdictions collect drumming or harvest-based estimates of grouse population size. To detect regional shifts in abundance as forest composition changes, a coordinated systematic monitoring effort will be required.

Managers have long relied on the model of habitat management developed in the aspen forests of the Midwest to stimulate grouse population growth. Losing the aspen-birch forest type will necessitate a new look at how to manage ruffed grouse. Differences in grouse population dynamics have been noted between oak-hickory and mixed mesophytic types (Devers et al. 2007), and silvicultural techniques long in vogue for grouse management will need to evolve as forest types change.

Furbearers

In northern regions of the eastern temperate forest, snowfall patterns influence the spatial distribution of terrestrial furbearers. Canada lynx and pine marten are adapted to deep snow conditions. Whereas, bobcat and fishers inhabit those regions with lower snowfall. Intra-specific competition between Canada lynx and bobcat (Hoving 2001, Parker et al. 1983) and between fisher and pine marten (Krohn et al. 1995, Krohn et al. 1997) is suspected. Hoving et al. (2005) suggest that climate changes that alter snowfall distribution could greatly affect distribution of lynx. Climate changes resulting in lower snowfall patterns may foretell decreases in Canada lynx and pine marten distribution and increases in fisher and bobcat distribution.

The main prey items of Canada lynx are snowshoe hare and pine squirrel, both of which inhabit spruce-fir forests. If forest composition in the northern reaches of the eastern temperate forest change as predicted (Prasad et al. 2007), the resulting deciduous-dominated landscape could adversely affect lynx (Hoving et al. 2001).

Information and Research Needs for Furbearers

Furbearer managers must be prepared to detect and understand changes in furbearer occurrence and population size as snowfall patterns change in relation to climate change.

Information and Research Needs for Gray Squirrel

Gray squirrels prefer mature deciduous and mixed forests with abundant supplies of mast (e.g., acorns, hickory nuts) (NatureServe Explorer 2007). If forest composition changes as predicted (Prasad et al. 2007), gray squirrel distribution and density will be positively affected, with ranges likely to move northward as oak-dominated forests replace northern hardwood forests in New England and the northcentral United States

Information and Research Needs for Snowshoe Hare

Snowshoe hares prefer the dense cover of coniferous and mixed forests, especially those forest stands with dense coniferous understories (NatureServe Explorer 2007). If forest composition changes as predicted (Prasad et al. 2007), snowshoe hare distribution and density will be adversely affected. Changes in distribution and abundance of snowshoe hares as a result of climate change will need to be monitored and adjustments to harvest opportunities should be applied accordingly.

Information and Research Needs for Northern Bobwhite Quail

The northern limit of northern bobwhite range likely is associated with the southern threshold of long-duration winter snowfall (Brennan 1999, Rosene 1969). As climate moderates, the barrier of snowfall to northern bobwhite population distribution may shift northward. Changes in distribution and abundance of bobwhite quail as a result of climate change will need to be monitored and adjustments to harvest opportunities should be applied accordingly.

Information and Research Needs for Black Bear

Oak mast is an important fall food for black bear (Martin et al. 1951). Mast allows black bears to forage and fatten one to two months longer each year than would otherwise be possible (Rogers and Lindquist 1991). Mast supplies significantly affect birth and survival rates of black bears (Alt 1980, Eiler et al. 1989, Kordek and Lindzey 1980, Pelton 1989).

If forest composition changes as predicted (Prasad et al. 2007), black bear population dynamics will be positively affected, with higher productivity and survival as oak-dominated forests replace northern hardwood forests in New England and the northcentral United States. Changes in distribution and abundance of black bear as a result of climate change will need to be monitored, and adjustments to harvest opportunities should be applied accordingly.

Southeast Region

Description

This area is comprised of the states of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas and Virginia. With the exception of the southern Appalachian Mountains, the topography in the region is mostly gently sloping to relatively flat. Elevations range from sea level to 1,300 feet. Most streams and rivers are sluggish. There are numerous marshes, swamps and wetland areas throughout the area, particularly along the coast and in association with major river systems (Bailey 1995).

Climate

The climate in the region is subtropical, marked by high humidity, especially in the summer. There's an absence of really cold winters, particularly in the Gulf Coast States. Normally, there is no dry season; even the driest summer month receives at least 1.2 in (30 mm) of rain. The average temperature of the warmest summer month is above 72° F (22° C). Rainfall is ample all year, but markedly greater during summer. Thunderstorms, whether of thermal, squall line or cold-front origin, are especially frequent in summer. Tropical cyclones and hurricanes strike the coastal areas occasionally, always bringing very heavy rains. Winter precipitation, some in the form of snow, is of the frontal type. Temperatures are moderately wide in range and comparable to those in tropical deserts, but without the extreme heat of a desert summer. Average annual precipitation decreases from east to west through the region from up to 60 in (152cm) per year in the east to as low as 15 in (37.5 cm) (Bailey 1995).

Vegetation

Prior to European settlement, the southern part of this region supported forests dominated by evergreen oaks, with gum and cypress common in the lowlands. Farther north were mixed stands of loblolly and shortleaf pine and deciduous trees, with oaks, hickories, gums and red maple being common. Farther west in the region, rainfall declined and presettlement vegetation changed to prairie parkland kinds of habitats with grasslands in the extreme west where the climate was semiarid (Bailey 1995).

Forest Composition

1. Loblolly-shortleaf pine forest cover type—Forests in which pines (except longleaf and slash pines) and eastern redcedar dominate or, in combination, are co-dominates. Common associates include oaks, hickories, and gums. Current distribution of the type includes the southeastern coastal plain from southern VA to eastern TX (Prasad et al. 2007).
2. Longleaf-slash pine forest cover type—Forests in which longleaf or slash pines dominate or, in combination, are co-dominates. Common associates include other southern pines, oaks and gums. The type currently is present in northern and western Florida and southern Georgia (Prasad et al. 2007).
3. Oak-gum-cypress forest cover type—Bottomland forests in which tupelo, blackgum, sweetgum, oaks, or southern cypress dominates or, in combination, are co-dominates.

The type currently occurs in southern Florida, southcentral Georgia, and coastal regions of North and South Carolina (Prasad et al. 2007).

4. Oak-pine forest cover type—Forests in which hardwoods (usually upland oaks) comprise a plurality of the stocking, but in which softwoods, except cypress, comprise 25 to 49% of the stocking. Common associates include gums, hickories and yellow-poplar. The type currently occurs in the transition between loblolly-shortleaf and oak-hickory forest type regions (Prasad et al. 2007).

Current Land Use

In recent years, cropland, Conservation Reserve Program (CRP) lands, rangeland/pastureland and forestland account for approximately 15, 1, 30 and 40%, respectively of the land use in the region. The remaining 15% is comprised of developed and urban/suburban areas and water (Natural Resources Conservation Service 2007).

Principal Game Species

Although there are several dozen game species in this region, northern bobwhites, mourning doves and American woodcock are among the most popular with hunters, and they generate millions of dollars in recreation for the area annually (U.S. Fish and Wildlife Service 2002).

Trends and Predictions of Climate Change on Game Species Habitat

Climate change will likely be highly variable and quite difficult to predict accurately for a particular time and location. However, a number of climate prediction models have been developed that can provide general guidance about to future trends in climate change, so are useful as planning tools. The models generally agree that the Southeast region will warm substantially (Inkley et al. 2004). There is far less agreement among models relative to changes in precipitation. However, there appears to be some consistency among models for a slight increase in winter precipitation for the northeastern section of the region (Inkley et al. 2004). Thompson et al. (2005) projects minimal changes in the core production areas for most crops, with the potential for a reduction in soybeans in the western portion of the region.

Changes in Forest Composition

Approximately 40% of the region is forestland. The USDA Forest Service predicts the potential habitat distribution for tree species and forest types based on the three prevailing (GCM) climate change models (Prasad et al. 2007). Predictions of tree distributions are based on the average of the three GCMs under both the high- and low-emission predictions. Model outputs include potential changes in geographic range and potential change in abundance (importance value) (Prasad et al. 2007).

1. Loblolly-shortleaf pine forest cover type—Under the low-emission scenario, the type extends westward into the Appalachians and generally increases in density of occurrence in regions currently occupied (Prasad et al. 2007). The high-emission models show the

type largely absent west of the Mississippi River and throughout the current range, a coast-ward shift in occurrence (Prasad et al. 2007).

2. Longleaf-slash pine forest cover type—Distribution of the type changes little under the low-emission scenario (Prasad et al. 2007). The high-emission model predicts a shift in the range of the type from northcental and panhandle Florida southward. The type also decreases in importance value (Prasad et al. 2007).
3. Oak-gum-cypress forest cover type—Both emission models suggest a coast-ward movement of the type, with the high-emission model suggesting an increase in distribution on coastal habitats (Prasad et al. 2007).
4. Oak-pine forest cover type—The low emission scenario suggests the type will increase in importance in the southern Appalachian Mountains, east Texas, east Oklahoma and western Arkansas (Prasad et al. 2007). The high-emission model predicts a significant increase in the type in East Texas, eastern Oklahoma, Arkansas, Mississippi and the Appalachian Mountain chain states (Prasad et al. 2007).

Predictions of Climate Change Impacts and Information Needs for Principal Game Species

Several factors that have potential to impact many important game species in the Southeast include changes in bottomland hardwood ecosystems, changes in distribution and abundance of exotic plants and animals, and a redistribution of disease and pests. While these phenomena are almost certain to occur with a change in climate, there are so many variables at play that an accurate prediction of outcome is difficult.

Relative sea level has risen in the last century due to a combination of natural processes and human influences (Wake and Markham 2005). Under the high emissions scenario, sea-level rise will continue, reaching anywhere from a few inches to more than 1 ft (30 cm) by midcentury (UCS 2006). By the end of the century, global sea level could rise by 8 to 36 in (20–91 cm) (UCS 2006). Changes in sea level can contribute to increased erosion, saltwater contamination of freshwater ecosystems and loss of salt marshes. Farther inland, hotter, drier climates and more extreme weather events, such as droughts and less frequent but more intense flooding events, could have significant impact on tree species composition in the Southeast's bottomland hardwood habitats.

In addition, although the proportion of the oak component is projected to increase in much of the Southeast's forested landscape (Prasad et al. 2007), gains made for oaks as result of climate change may be offset by increases in red oak borers, gypsy moths and sudden oak death syndrome.

Northern Bobwhite Quail

With most models projecting substantially increased temperatures and an increase in extreme precipitation events, including droughts (Inkley et. al. 2004), perhaps the most significant climate-change-related impact on bobwhite quail in the Southeast region will be a decrease in annual productivity due to hotter dryer weather during the spring and summer. Stanford (1972) reported that these conditions resulted in lower annual production of northern bobwhite quail in Missouri. Conversely, if hotter, dryer weather occurs consistently enough to slow that rate of loss of early successional habitats, losses in bobwhite productivity might be offset by higher overall habitat quality across the landscape.

Northern bobwhite quail are closely associated with agriculture and early successional habitats. Agricultural lands (cropland, CRP, pasture and rangeland) comprise approximately one-quarter of the lands in the region (Natural Resources Conservation Service 2007). It is not anticipated that climate change will cause a significant shift in the core productions areas for several of the major crops in the Southeast (Thompson et al. 2005). Therefore, changes in agriculture as a result of climate change in the region are not projected to have a major impact on bobwhite quail.

Information and Research Needs for Northern Bobwhite Quail

It will be important for managers to monitor quail productivity, recruitment, magnitude of annual population fluctuations and population response to high summer temperatures and droughts along with identifying adjustments to habitat components that could increase survival. With approximately 40% of the region comprised of forestland and with the projected climate-influenced changes in tree species composition and (Prasad et al. 2007), there could very well be opportunities for managers to enhance some of these forested lands for bobwhite quail. It should be noted here that enhancing Southeast forest landscapes for these birds is feasible, but more logistically difficult and expensive than working with early successional habitats and agricultural lands. Given that much of the existing forest landscape could be enhanced for quail, this is an opportunity that might be better exploited if new and different approaches can be developed.

Mourning Doves

While some mourning doves remain in more northern latitudes during the winter, the majority of birds that spend summers in the north migrate and spend the winter months in the southern United States (Ruble and Urban 1977). If, as projected, climate change causes winters in the Midwest and Northeast to begin later, end earlier and be generally less severe, migration timing, rates, distances and final locations might very well change for mourning doves. Clearly, changes in these factors would have a direct bearing on changes in harvest rates, distribution and opportunity both in the North and the south. Similarly, recruitment, survival and natural mortality almost certainly will be affected by changes in climate.

Information and Research Needs for Mourning Doves

Managers will need to monitor closely for changes in migration timing, rates, distances and final locations along with changes in recruitment, survival and natural mortality and anticipate the need for adjustment, particularly in terms of harvest regulations.

American Woodcock

American woodcock occupy southeastern and gulf coast forests during winter, where they concentrate in habitats that support earthworms, their primary food (Owen 1977). Woodcock were thought to primarily use bottomland areas and secondarily use pineland areas during winter (Roberts 1993, Straw et al. 1994), but Myatt and Kremmetz (2007) found that, during migration and on the winter grounds, most woodcock were located in upland oak, pine, or pine–hardwood forests. Moisture levels play an important role in woodcock habitat selection, and mixed pine–hardwood stands, hardwood drainages and bottomlands likely are more suitable habitat than predominantly pine areas during dry periods (Boggus and Whiting 1982).

Forest composition changes predicted with global climate change (Prasad et al. 2007) will not adversely impact to woodcock habitat needs on winter ranges. The replacement of pine dominated forests with oak-pine mixtures should increase habitat suitability. More frequent or longer duration droughts, however, will negatively affect woodcock by reducing feeding areas.

Information and Research Needs for American Woodcock

To provide proper stewardship of wintering American woodcock, managers need to assess carefully the integration of forest type changes with soil moisture regimes in winter.

Midwest Region

Description

This region encompasses lands from central Ohio and southern Michigan westward through Indiana, Illinois, Missouri, Iowa, southern Wisconsin and Minnesota, Kansas, Nebraska, North and South Dakota to the eastern portions of Montana, Wyoming and Colorado. This is basically the “Corn Belt,” plus the rangelands westward to the Rocky Mountains. The topography is mostly gently rolling. Some areas are nearly flat, others have high, rounded hills and steep bluffs border some of the valleys. Elevations typically range from 300 to 2,500 ft (91.4–762 m) and reach as high as 5,000 ft (1,524 m) in the far western portions of the region. The northern portion of the area was glaciated (Bailey 1995).

Climate

Summers are usually hot. Winters are cold in the northern part of the region and shorter and milder in the southern parts. Average annual temperatures may reach 40° F (4° C) in the north and 60° F (16° C) in the south. The frost-free season ranges from fewer than 100 days in the northwest to 120 days along the northern fringe to 235 days in the southeastern portion of the region (Bailey 1995). Average annual precipitation decreases from east to west through the region from 35 to 40 in (89–101 cm) per year in central Ohio to 15 to 20 in (37.5–50 cm) per year in the Dakotas (National Oceanic and Atmospheric Administration 2007).

Vegetation

Prior to European settlement, the eastern part of this region supported dense stands of deciduous forest dominated by several species of oaks and hickories with significant tracts of mixed beech and sugar maple on the wetter sites (Bailey 1995). The decrease in precipitation from east to west caused a transition in presettlement vegetation, from dense woodlands in the east to mixed forest-prairie habitats to tall-grass prairies and finally to short-grass prairie in the west (Bailey 1995). The combination of fertile soils and warm temperatures coupled with abundant rainfall during the growing season make this region ideally suited for the production of agricultural crops. Row crops, basically corn and soybeans, currently dominate in the eastern part of the region, where summer precipitation is highest. Farther to the west, as rainfall declines, cereal crops, primarily wheat and hay replace row crops. In the extreme western portion of the region, grazing is the main agricultural activity on much of the rangeland (Thompson et al. 2005). Due to the relatively high value of row crops, irrigation is used to extend corn and soybean production to portions of the western part of the region. Also, recent advances in row crop genetics are providing varieties of these crops that are capable of producing harvests at a level economically viable on some of the drier landscapes to the west.

The Conservation Reserve Program (CRP), administered by the U.S. Department of Agriculture, affects significant acreage throughout the region and has had a major positive influence on wildlife. The primary objective of CRP is to remove environmentally sensitive lands from crop production and establish a cover crop of grasses an d forbs that are managed in a way to minimize soil erosion, improve water quality and enhance wildlife habitat. In recent years, cropland, rangeland/pastureland and CRP account for approximately 45, 35 and 5%, respectively, of the land use in the region with higher proportions of row crops in the east and relatively larger percentages of rangelands and CRP in the west. The remaining 15% is comprised of forestland, water and urban areas (Natural Resources Conservation Service 2007).

Principal Game Species

While there are several dozen game species found in this region, white-tailed deer, ring-necked pheasants, northern bobwhite quail and mourning doves are among the most popular with hunters and generate millions of dollars in recreation for the area annually (U.S. Fish and Wildlife Service 2002). It should also be noted that the Midwest contains the U.S. portion of the prairie pothole region, which is the primary waterfowl production area on the continent. Climate change impacts on waterfowl will be addressed separately from this document.

Trends and Predictions of Climate Change on Game Species Habitat

Whereas climate change very likely will be highly variable and difficult to predict accurately for a particular time and location, a number of climate prediction models can provide good general guidance relative to future trends in climate change. The models are in general agreement that the Midwest will warm substantially (Inkley et al. 2004). By the end of this century, winters could warm by 5 to 12° F (3–7° C) and, summers by 5 to 20° F (3–11° C) (Kling et al. 2003).

There is far less agreement among models relative to changes in precipitation, with some projecting slight decreases and others a slight increase (Inkley et al. 2004)e. However, because evapotranspiration is temperature sensitive, most models predict decreases in soil moisture in the region, which will lead to reduced runoff, lower lake levels and fewer wetlands. Finally, many models predict an increased intensity of extreme precipitation events, including hot summer droughts.

As indicated earlier, land use on 85% of the region involves agriculture. While climate change may cause some adjustments to cropping patterns and some shifting between row crops, cereal grains, hay and grazing in some areas, it is anticipated that this region will remain under intensive agricultural management through the end of the century. Thompson et al. (2005) projects minimal changes in the core production areas for corn and wheat in the region with soybeans more variable (most of the changes for this crop are projected to occur outside of the Midwest). Loss of wetlands likely will be the most significant impact of climate change on habitats in the region with much of the area remaining under some sort of intensive agricultural production. The quantity and quality of wildlife habitat in the area probably will be more dependent on such factors as federal farm-assistance programs and crop genetics, which provide for crop production on areas that formerly were unsuitable.

Predictions of Climate Change Impacts and Information Needs for Principal Game Species

In general, since the region likely will remain in its current, primarily agricultural land use and, since the current ranges of white-tailed deer, mourning doves and ring-necked pheasants include the warmer, drier habitats to the south, it is anticipated that impacts on these species will be relatively minor compared with other factors. Northern bobwhite quail, primarily a southern species with the northern limits of their range mostly dictated by winter weather, could benefit from climate change in the Midwest.

As soil moisture decreases and wetlands and lakes shrink or disappear in the Midwest, water-dependent migratory species are expected to alter their migration routes and wintering habitat. As winter temperatures increase, some migratory species probably will migrate shorter distances or not migrate at all. Both mourning doves and waterfowl could respond positively.

Increased droughts and extremely high temperatures during nesting and brood-rearing periods could decrease annual production rates for both pheasants and quail in the region. In addition, increased frequencies of extreme winter weather events could adversely impact populations of both species.

Information and Research Needs for Northern Bobwhite Quail

Managers throughout the region must adapt to changes in bobwhite distribution to manage the species effectively through any change in climate. It will be important to identify barriers to bobwhite range expansion and opportunities to connect noncontiguous tracts of suitable habitats. Range expansion, productivity, recruitment and magnitude of annual population fluctuations will need to be monitored so that harvest management can be adjusted accordingly.

Population response to extreme weather events (winter storms, summer droughts and high temperatures) will need to be monitored and research conducted to identify adjustments of habitat components that will increase survival during these times.

In additional, there will likely be opportunities to bolster bobwhite populations by (re)introductions into suitable, unoccupied habitats. If management agency deems this to be feasible and desirable, then it would need to identify areas that probably would not be populated through natural range expansion due to fragmentation, barriers, etc. The minimum geographical size and habitat characteristics needed for self-sustaining populations in isolated tracts will need to be ascertained. The minimum number and necessary sex and age ratios needed for successful (re)introductions will need to be determined. In addition, the demographic relationships and differences between long-term occupied habitats and newly colonized habitats should be determined and the maximum-allowable harvest rates on isolated populations should be identified.

Information and Research Needs for Mourning Doves

With shorter, milder winters, changes in mourning dove migration rates and patterns could be the most significant impacts of climate change on this species in the Midwest. It will be important to monitor changes in the species' migration timing, rates and distances. Harvest rates and locations also will need to be scrutinized for changes as a result of adjustments to fall migration and wintering areas, and harvest regulations might need to be adjusted accordingly.

Climate change also could affect dove productivity, recruitment, survival rates, natural mortality and annual population fluctuations. These, too, will need to be monitored.

Finally, climate change might enhance opportunities for expansion into the region by exotics, such as Eurasian collared doves, that could impact mourning dove habitat use, survival and productivity. Impacts of invasive species will need to be determined.

Information and Research Needs for White-tailed Deer

Unlike some other parts of the country where white-tailed deer populations are heavily influenced by weather and climate, particularly in the winter, whitetail numbers in the Midwest are largely controlled by hunter harvest. Deer harvest management in the region is heavily dependent on population models. Climate change almost certainly will have some effects on productivity, recruitment, survival and natural mortality rates for this species. Managers will need to anticipate that these changes in order to adjust population models accordingly.

Managers should also anticipate increased occurrence of epizootic hemorrhagic disease and monitor for outbreaks.

Information and Research Needs for Ring-necked Pheasants

If the climate models are correct and the Midwest is subjected to increased severe weather events, such as winter storms and hot summer droughts, it will be important to monitor pheasant population responses to these phenomena. It also will be necessary to identify adjustments to habitat components that will increase survival. In addition, research is needed to identify grasses and forbs that can tolerate lower soil moisture and still produce suitable pheasant habitat.

Finally, as with mourning doves, climate change will likely affect ringneck productivity, recruitment, survival rates, mortality and annual population fluctuations. These will need to be monitored.

Southwest Region

Description

Numerous vegetative communities are represented in the Southwest. Generally, southwestern vegetation falls in the dry domain ecosystem (dry domain)(Bailey 1995). Within the dry domain, the following divisions would be representative of the Southwest: tropical/subtropical steppe, tropical/subtropical desert, temperate steppe (mountain provinces) and the temperate desert (Bailey 1995). Elevations vary from 2,000 to over 14,000 ft (610 m–4,300 m).

Climate

The essential feature of a dry climate is that annual losses of water through evaporation at the earth's surface exceed annual water gains from precipitation (Bailey 1995). Thus, by definition the southwestern provinces are characterized by dry climates and desert or steppe habitats. These are complex communities with highly variable climates and varying elevational and topographical features that exacerbate the complexity. Precipitation varies widely across the region with annual precipitation rates from 2 in (5 cm) in desert regions to more than 20 in (50 cm) in higher mountain zones. Temperatures exceeding 100° F (43° C) are common in desert areas. Humidity is low. Characteristically, summers are hot and dry, and winters are cold. Downpours may fall in short periods of time, resulting in torrential stream flows. Mountain provinces receive most of their moisture as snow.

Climate in the West is greatly influenced by the interannual and interdecadal climate variability driven by the El Niño-La Niña cycles. In addition, oceanic interdecadal oscillations, such as the Pacific Decadal Oscillation (PDO), the Artic Oscillation, and the North Atlantic Oscillation, add to climate variability (Neilson et al. 2005). Periods of drought are common, and much of the southwestern United States is currently experiencing severe drought.

Vegetation

Shortgrass and xerophytic species, like blue gramma and buffalo grass, predominate in arid grasslands. Xeric shrub species also are common. Deserts are typified by thorny shrubs, like mesquite and a variety of cactus species. Ocotillo is common on rocky slopes in desert regions. Creosote bush is common in the drier areas. Sagebrush is a dominate shrub in the steppe provinces. Other shrubs, like mountain mahogany, bitterbrush and gambel oak, are common across the provinces. Greasewood dominates on alkaline soils. Principal trees include cottonwoods (along riparian zones) with oak and pinion-juniper woodlands grading into ponderosa pine, lodgepole pine, aspen, Douglas fir, subalpine fir and Engelmann spruce forests (at higher elevations). (Bailey 1995)

Principal Game Species

Game species of interest for this report include mule deer, elk, pronghorn, scaled quail and Gambel's quail. Either one or more of these five species occupy most, if not all of the described provinces.

Predictions of Climate Change Impacts on Game Species Habitat

Obviously, the complexity of vegetation and climate across the region causes difficulty in predicting global climate change impacts with any one model. Predictions of global climate change undoubtedly will be more reliable than predictions of regional or local climate changes. Various regional climate systems operate at smaller scales and will influence local temperatures and precipitation rates. However, there are several expected major impacts of climate change on habitats that warrant attention (Neilson et al. 2005). These would include changes in snowpacks and water availability, in overstory (trees and shrubs) extent and distribution, in biotic life zones and in disturbances, like fires.

Generally, in the West predictions call for warmer temperatures and greater precipitation (Izaurralde et al. 2005, Neilson et al. 2005). Temperature increases in areas like the Great Basin carry more certainty than do precipitation increases (Neilson et al. 2005). The primary uncertainties regarding temperature are the magnitude and timing of increases and the resulting impact on frost lines (Neilson et al. 2005). The West is the region of the United States where simulated land-use changes under climate change are most dramatic (Izaurralde et al. 2005). Many scientists predict that the West will experience the effects of climate change sooner and more intensely than other regions (Service 2004). For instance, the Australian Bureau of Meteorology Research Centre (BMRC) model predicts the arid shrubland steppe will spread significantly across the Southwest (Izaurralde et al. 2005).

Snowpack and Water Availability

Many modeling scenarios typically predict changes based on temperature increases of 1 to 2.5° C (Izaurralde et al. 2005). However, predictions are that global average temperatures generally will increase as much as 5° C (10° F) during the 21st Century. It is further predicted that higher temperatures will result in snow packs that form later in the winter, accumulate in smaller quantities and melt earlier in the season (McCarthy et al. 2001). Snow packs are extremely important to water supplies and availability across the region. That factor significantly will affect the availability of runoff in streams, especially in late summer. Snow levels and coverage in all habitats and seasons will likely be significantly different from historic ones.

Even though it is predicted that total precipitation may increase with climate change, it does not mean there will be more water available. Higher temperatures will result in higher evaporation rates, resulting in less water (Frederick and Gleick 1999). Computer-simulation studies suggest that precipitation must increase 10% to balance losses from evaporation losses resulting from a 4° C temperature increase (Gleick 2000).

Recent modeling predicts that the Southwest will dry significantly in the 21st century and that recent droughts across the region will soon become a permanent feature (Seager et al. 2007). This work predicts that global warming will cause a very different type of drought than more recent, ocean-driven droughts have been. Warming will send rainstorm and snowstorm tracks northward and also will cause greater evaporation rates across the region.

Overstory Extent and Distribution

As discussed previously, complexity of vegetative communities and topographies in the Southwest make predicting changes in overstory (trees and shrubs) difficult. However, some general patterns seem to emerge. GCMs predict that there will be significant decreases in tree richness (number of species) across the deserts of the Southwest (Currie 2001).

Predicted changes in the distribution of southwestern tree and shrub species under climatic conditions simulated by atmospheric GCMs as well as regional climatic models with two times preindustrial carbon dioxide levels have been made (Thompson et al. 2003). Major forest trees and range shrubs (Engelmann spruce, Douglas fir, lodgepole pine and big sagebrush) were predicted to contract across much of their modern range. Ponderosa pine would contract much of its current distribution and generally move its distribution eastward. White oaks from California and Oregon would expand into the Southwest where wet winters and dry summers are predicted. Gambel's oak and piñyon pine distributions would contract across the Southwest, and creosote bush would significantly expand its range (Thompson et al. 2003).

Drought, increased temperatures and greater insect activity in recent years have resulted in significant losses of piñyon pine across the Southwest (Jensen 2005, Whitham 2005). Aerial surveys conducted by the U.S. Forest Service in 2002 and 2003 of piñyon -pine woodlands in the Southwest revealed die-offs covering more than 4,600 mi^2 (12,000 km^2) (Jensen 2005). It could be expected that climate changes would result in further large-scale changes in distribution of important southwestern species. Many areas of the Intermountain West are already suffering extensive losses of pine forests to the mountain pine beetle, and warmer winters have been suggested as one of the main causes.

The predicted losses in the range of sagebrush are significant. There are several climatic features of the sagebrush ecosystem that are vulnerable to climate change (Neilson et al. 2005). The system is continental, which means it is hot in summer and is subject to recurrent hard frost in winter. It also has a Mediterranean climate, being wet in the winter and dry in the summer, and it is a semiarid ecosystem (Neilson et al. 2005). As a result of the cold winter climate, the plants are frost tolerant and are dependent on deep soil water, recharged from winter precipitation, to meet summer transpiration demands.

Much of the sagebrush ecosystem is bounded on the south by hot deserts. The desert ecosystems are separated from the sagebrush ecosystem by a 2,000 ft (610 m) scarp (Neilson et al. 2005). This scarp creates a very definite frost line that prevents expansion of cold sensitive evergreen broadleaf trees and shrubs like oaks (Neilson et al. 2005). Climate change predictions indicate a removal of the frost barrier and extensive expansion of broadleaf shrub and tree species at the expense of sagebrush. It is predicted that for each increase in Celsius degree, there will be a loss rate of approximately 33,350 mi^2 (87,000 km^2) of sagebrush, or 12% of the present coverage will result (Neilson et al. 2005).

Riparian habitats are very important to wildlife in the Southwest. Cottonwoods are a very important component of the overstory in riparian areas and are dependent upon water in the streams. Increased temperatures, smaller snowpacks and faster runoff are threats to streams and to their associated habitats, especially in late summer.

Biotic Life Zone Changes

Climate change in the mountainous habitats in the Southwest will impact biotic life zones. As climate warms, belts of vegetation on mountain range slopes move upward in elevation (Murphy and Weiss 1992). It has been assumed that boreal habitat zones will ascend to 500 m (1,640 ft) for every 3-degree rise, in Celsius, in average temperature (Murphy and Weiss 1992).

It is expected that alpine tundra species will be eliminated as the alpine coniferous forests move upward. Not all plant species would acclimate in a similar manner, resulting in fragmented plant communities among the various elevational zones. Paleoecological records found in pack rat middens demonstrate that elevational shifts and vegetative shifts have occurred as climates have changed over the past 40,000 years (Betancourt et al. 1990).

Fire Disturbance

GCMs as well as regional models predict warmer temperatures, longer growing seasons, reduced snowpacks and greater precipitation levels for much of the West and the Southwest. This combination of factors suggests a growing wildfire risk (Millar and Urban 1999, Westerling et al. 2006). Greater fire frequency is a response to fuel's moisture while fire extent tends to depend more on woody biomass or other species composition (Millar and Urban 1999).

Recent droughts throughout the West indicate what to expect with climate change. Almost seven times more forested federal land burned during the 1987 to 2003 period than during the prior 17 years, and large fires occurred about 4 times more often during the latter period (Westerling et al. 2006). It was determined that year-to-year changes in wildfire frequency were strongly linked to annual spring and summer temperatures and to the timing of snowmelt. Timing of the snowmelt is important as an earlier melt results in areas drying earlier providing for a longer fire season (Westerling et al. 2006). In addition, increased dust in the atmosphere due to drier conditions is blowing onto snowpacks and causing faster snow melt. (Painter et al. 2007)

An irony of increasing wild fires and climate change (Neilson et al. 2005) is, on one hand, we would like to increase storage of large amounts of carbon in natural ecosystems to offset carbon dioxide emissions in the atmosphere. It is estimated that the United States is currently storing about 0.3 Pg of carbon per year in ecosystems and that between one third and one half of that is going into the expansion of woody vegetation in the western United States (Hurtt et al. 2002). On the other hand, increased wild fires spurred by climate change will result in greater release of carbon dioxide to the atmosphere.

Climate change that results in modified plant communities will also exacerbate the potential for invasion of invasive species. In the Great Basin, one example that has resulted from warmer climates, droughts, and increased wildfires is the greater amount of cheatgrass on many western sagebrush and other shrub habitats (Pellant 1990, Prater et al. 2006). Cheatgrass greens up early in the spring and dries quickly. The dried herbage carries wildfire much more efficiently than native shrubs, resulting in an increased fire frequency. Many of the native shrub species are not fire resistant, and the increased frequency of fires removes them from the ecosystem. Invasive plants seem to be more successful in responding to increases in temperature and changes in precipitation patterns than are native species.

Predictions of Climate Change Impacts on Game Species

The synergistic, or combined, effects of habitat fragmentation and climate change represent one of the most potentially serious global change problems (Root and Schneider 2002). In today's modern world, wildlife habitats are already significantly altered and fragmented by human developments, which limits the ability of wildlife species to adjust to climate change by migrating to appropriate habitats.

Animals demonstrate many different types of changes related to climate. These include changes in ranges, abundances, phenology (timing of an event), morphology, physiology, community composition, biotic interactions and behavior (Root and Schneider 2002). Those species with large ranges (i.e., birds and large mammals) and capable of larger movements will be less impacted than species with restricted ranges. Smaller mammals and herptological species (amphibians and reptiles) will obviously be more limited (Root and Schneider 2002). Ability to move greater distances will allow some animals to seek habitat conditions more favorable to their life needs. Specialist species, like sage grouse that are dependent upon one vegetation type, are more vulnerable than generalist species.

Timing, amount and type of moisture received are all important factors. Phenology of plant species is critically related to important life needs of wildlife species. Differential responses by species to these events could cause existing animal communities to undergo a reformulation (Root and Schneider 1993). Climate change may also impact species of wildlife in more indirect ways, for instance, by increasing their susceptibility to current and new diseases or to predation.

Mule Deer and Elk

Mule deer and elk are two important, big-game species occupying a wide variety of habitats throughout the Southwest. Both species are highly mobile, and most populations demonstrate some level of migratory behavior, principally moving to seasonal habitats as climatic conditions dictate. Typically these movements are elevationally related and, in colder environments, directly are influenced by snow depth and structure.

Many of the key vegetation types in the Southwest, such as sagebrush and piñyon - juniper woodlands, are heavily utilized by mule deer and elk and are predicted to be highly impacted by climate change. Degree of impact from climate change will largely depend upon the stability of these communities. Disturbances, like fire, will largely shape the future of both species. Invasive species, like cheatgrass in shrub steppe habitats, are also a concern to mule deer and elk habitats.

Model predictions for warmer temperatures and lower snowpacks would suggest enlarged ranges for both species, especially those ranges found in winter habitats. In the colder, more northern habitats, both species could benefit from this outcome provided that plant composition in these habitats is suitable as forage. It would be expected that historical seasonal distributions for the two species would be significantly altered as climate changes. In mountainous habitats, both species would be expected to occupy higher elevation habitats during all seasons. Previously determined habitats important for breeding and young-rearing will change.

Minimal research has been done in North America on effects of climate change on cervid species. In studies of spring temperatures on red deer in Scotland, however, juvenile deer grew faster in warm springs, a trait positively correlated with adult reproductive success (Schneider and Root 2002). In Rocky Mountain National Park, projected climate changes were predicted to result in elk being in better body condition, reproducing faster and experiencing less mortality (Wang et al. 2001).

As winter conditions change, interactions with other species, such as predators, could be altered. In Banff National Park, predation by wolves was greater on elk in more severe winters with deeper snow (Hebblewhite 2005).

Impacts of climate change on disease threats to mule deer and elk are unknown. However, warmer and wetter environments could result in greater densities and distributions of insects that could introduce diseases into new environments.

Information and Research Needs for Mule Deer and Elk

Climate change will alter the seasonal and annual migrations and the distribution patterns for both mule deer and elk populations. There will be a need for development of viable regional monitoring efforts to detect changes in population size, distribution and mortality (survival) patterns. These data will be needed to update existing population models and herd unit maps. Key population parameters in computer models used to predict performance of big-game animals may need critical updates and changes to correspond to new realities (Inkley et al. 2004). Viable regional monitoring methods for the detection of disease outbreaks will also be needed as disease prevalence may change with global climate changes.

Snow depths are critically important to the distribution and movement of large herbivores. Predictions of snow pack changes with global warming require that viable regional monitoring efforts to detect snow lines and snow depths will be needed.

The potential for landscape changes in forest overstories due to climate change requires that regional monitoring efforts be designed to detect and quantify these changes. As forest canopies change, so will the composition and structure of understory plant species. Nutritional capabilities of altered landscapes will change dramatically, and it will be important for managers to understand the changes in the dynamics of deer populations brought by changing nutritional levels and an area's carrying capacities. The distribution and extent of invasive plant communities must also be monitored. It is especially recommended that all water sources, such as streams, springs, snowpacks and precipitation be monitored carefully. To better understand and predict wildfires, “forest health” parameters, such as tree diseases, insect loads and fuel loads, should be monitored.

Human recreational use patterns may change dramatically impacting wildlife habitats and populations. Fixed borders of our existing, protected areas may no longer be appropriate for the ecological communities of tomorrow. Maps depicting deer and elk management units may need to be changed as populations shift distributions. Finally, historical records on hunter success by management unit and hunter-participation rates may also change. It will be necessary for managers to critically evaluate and update these data as new information is obtained.

Pronghorn

In the Southwest desert pronghorn populations often live in environments near their tolerance limit. This is especially true for the endangered Sonoran pronghorn population in southwestern Arizona and in northwestern Sonora (deVos and Miller 2005). Fawn survival is often a population concern and is directly correlated with timing, duration, and distribution of rainfall during the winter months and summer monsoon season (Bright and Hervert 2005). Rainfall is critical for necessary plant growth for forage (deVos and Miller 2005). Increased summer temperatures under climate change would result in changes of plant phenology, species composition and abundance (Walther et al. 2002). Timing and amount of rainfall could also be altered as the climate changes. With small populations, these changes could decrease habitat suitability and could lead to extirpation of populations before all habitats become unsuitable (deVos and Miller 2005). This same concern was raised about small populations of desert bighorn sheep in California (Epps et al. 2004).

Pronghorn populations in the Great Basin will face many of the same concerns outlined for mule deer and elk. Primary among these will be the status and distribution of sagebrush as temperatures increase under global warming. As with desert populations, pronghorns elsewhere are dependent upon nutritious forage at key times, such as fawning periods. Phenological changes in plants due to climate change could disrupt these relationships.

Information and Research Needs for Pronghorn

Small and isolated populations of wild animals will be especially vulnerable and impacted by global climate change. Measures that would help identify fragmentation of existing pronghorn ranges would be valuable. Use of remote sensing technology should be applied to this problem. Pronghorn are highly dependent upon nutritious forage. It will be necessary to monitor changing forage dynamics for pronghorn as vegetation communities change. Warming may also result in more snow-free areas thus altering and expanding the distribution of pronghorn. Viable regional monitoring schemes will be necessary to document these changes.

Scaled and Gambel's Quail

Native habitats in the Southwest are under serious threat from increasing human developments. This is especially true for Gambel's quail. Habitats are being fragmented and lost. It is predicted that climate change will only exacerbate these impacts by placing further stresses on the habitats and quail populations.

Many southwestern desert habitats are important for scaled and Gambel's quail. Impacts of global warming on quail, such as the increase of invasive species (Kuvlesky et al. 2002), could be many. One invasive species that is expected to increase with climate change in southern Arizona is Lehmann lovegrass (Geiger et al. 2003). This and other invasive species would be detrimental to quail habitats by replacing native plant species.

As with so many desert species, quail are dependent upon timing and amount of precipitation. Gambel's quail abundance is directly linked to winter season (October through April) precipitation (Swank and Gallizioli 1954). As winter moisture goes, so do quail populations. Green vegetation is key. Reserves of vitamin A, obtained from green vegetation, stimulate reproductive organ development and positively influence reproductive success in this species (Hungerford 1964). Drier and hotter climates would lower quail reproduction.

Riparian vegetation is important to quail and would be threatened with reduced stream flows.

Depending upon the timing and habitat involved, increased fires could be beneficial to scaled quail grassland habitats invaded by woody species.

Increased droughts accompanying climate change may increase negative impacts from livestock grazing on quail habitats.

Information and Research Needs for Scaled and Gambel's Quail

Winter moisture is critical for desert quail species. Traditional patterns of seasonal moisture will be altered with changing climates. Wildlife managers will have to develop regional monitoring schemes to detect and document these changes. Invasive plant species are a real threat to native quail habitats. It will be necessary to monitor invasive plant species to be able to predict capability of habitats to support quail.

Northwest Region

Description

The region includes: (1) lowland mixed forest of the Willamette and Puget Sound valleys between the Coast Range and the Cascade Mountains and isolated hills and low mountains; (2) mixed forests, coniferous forests and alpine meadows of the steep, rugged mountains in the Coast Range and Cascade Mountains bordered in places by a narrow coastal plain; and (3) mixed forests, coniferous forests and alpine meadows in the southernmost portion of the Cascade Mountains, the northern Coast Range, Klamath Mountains and Sierra Nevada, which are mostly covered with steeply sloping to precipitous mountains crossed by many valleys with steep gradients. Elevations in the region range from sea level to 14,000 ft (4,267 m) (Bailey 1995).

Climate

The climate of this region is temperate and rainy, with warm summers. Precipitation is abundant throughout the year but is markedly reduced during summer. Cooler air temperatures reduce evaporation and produce a very damp, humid climate with much cloud cover. The moderate rainfall reaches its maximum in winter; summer has a slight moisture deficit. To the north, the summer dry season shortens, and the proportion of precipitation falling as snow increases. On high mountains, all precipitation may be snow. Eastern slopes are much drier than western slopes, accumulating less than 20 in (50 cm) of precipitation per year (Bailey 1995).

In the southernmost portion of the Cascade Mountains, the northern Coast Range, Klamath Mountains, and Sierra Nevada, average temperatures are lower and decrease with rising elevation. The base of Sierra Nevada's western slope receives only about 10 to 15 in (25–38 cm) of rainfall per year and has a long, unbroken, dry summer season. At higher elevations, the dry summer season shortens and precipitation rises to as much as 70 in (179 cm), with a larger portion falling as snow. Prevailing west winds influence climatic conditions for the whole region. Eastern slopes are much drier than western slopes. Winter precipitation makes between 80% and 85% of the total; at high elevations, it is mostly snow. The greatest total precipitation reported is on slopes between 3,000 and 7,000 ft (914–2,134 m), which support the luxuriant mixed conifer forests of the montane zone. The subalpine zone coincides with the altitude of greatest snowfall (Bailey 1995).

Vegetation

Before cultivation, dense coniferous forest dominated the vegetation of the lowland mixed forests. Principal trees are western redcedar, western hemlock and Douglas-fir. In interior valleys, the coniferous forest is less dense than along the coast and often contains deciduous trees, such as big-leaf maple, Oregon ash and black cottonwood. There are prairies that support open stands of oaks or are broken by groves of Douglas-fir and other trees; principal indicator species are Oregon white oak and Pacific madrone. Poorly drained sites with swamp or bog communities are abundant (Bailey 1995).

At the lowest elevations of the Cascade Mountains and Coast Range, there is a dense conifer forest of Douglas-fir, western redcedar, western hemlock, grand fir, silver fir, Sitka spruce and Alaska-cedar. Numerous species of shrubs grow exceptionally well in this forest and around its margins. In many places, this vegetation is practically impenetrable. In the humid conifer forests of southwestern Oregon, Alaska-cedar is replaced by silver fir and redwood. In the fog belt along the coast of northwestern California, redwood is the characteristic tree. A dry forest of ponderosa pine grows along the eastern slopes of the Cascades. The high, snowcapped mountains of the Cascades have a well-marked subalpine forest belt that consists of mountain hemlock, subalpine fir, whitebark pine and Alaska-cedar. All but the highest peaks are covered by forest. Above timberline, there is an alpine zone with rich communities of shrubs and herbs (Bailey 1995).

The lower slopes and foothills of the Sierra Nevada are covered by coniferous and shrub associations. On higher slopes, digger pine and blue oak dominate, forming typical open or woodland stands. Most of the low hills are covered by close-growing evergreen scrub, or chaparral, in which buckbrush and manzanita predominate. Several oaks are common associates. Above 2,000 ft (610 m) in the southern Cascades and at about 5,000 ft (1,524 m) in the central Sierra Nevada, the most important trees are ponderosa pine, Jeffrey pine, Douglas-fir, sugar pine, white fir, red fir and incense cedar. At even higher elevations, mountain hemlock, California red fir, lodgepole pine, western white pine, and whitebark pine are important (Bailey 1995).

Riparian forests in the Pacific Northwest are an exception to the general rule that conifers dominate in the region. Along the region's many rivers and streams, needleleaf trees are replaced by broadleaf species, such as black cottonwood and red alder. This forest occurs from southern Alaska south through Washington, Oregon, Idaho and western Montana, continuing into northern California and the Sierra Nevada (Bailey 1995).

Principal Game Species

For purposes of this report the primary game species to consider include mule deer, elk, black-tailed deer, mountain quail and California (or valley) quail.

Predictions of Climate Change Impacts on Game Species Habitat

Snowpack and Water

The modeling scenarios show temperature across Oregon increasing from the present time to the end of the 21st century by between 7º and 8º F, which can lengthen the growing season by at least four to six weeks. For precipitation, the scenarios show a range in winter of 10% decrease to 24% increase but a range in summer of 10 to 40% decrease (a relatively small amount since summers are generally dry). The potential winter decrease is important because previous studies had shown significant increases in the Northwest's precipitation (Millar et al. 2006). The foremost impact of a warming climate will be the reduction of regional snowpacks, which presently supplies water for ecosystems and human uses during the dry summers (Mote et al. 2003).

In the future climate scenario, more winter precipitation fell as rain instead of snow producing higher winter flows, a reduced snowpack and decreased spring and summer flows in the American River. In addition, there was a large increase in the frequency and magnitude of winter flooding, primarily due to an increase in the number of rain-on-snow events (Wigmosta and Leung 2002).

The change was much less dramatic in the Middle Fork Flathead River. The seasonal pattern of stream flow remains intact and the incidence of flooding was reduced for the future climate scenario. This study suggests that the impacts of climate change on stream flow and flooding in forested watersheds are highly region specific (Wigmosta and Leung 2002).

However, a 2.5° C increase in global mean temperature (GMT) would cause major losses in net primary productivity (NPP) throughout the country. This would lead, implicitly, to large changes in ecosystem structure.

Forest Extent and Composition

The following changes in area of temperate conifer forest across the Northwest are predicted for each of the models (baseline = 1,036 10^3 x km^2) (Izaurralde et al. 2005):

- BMRC +2.5 = 951 (365) to 1,143 10^3 km^2 (560 ppmv)
- UIUC +2.5 = 2,235 (365) to 1,244 10^3 km^2 (560 ppmv)
- UIUC + sulfate +2.5 = 2,958 (365) to 1,844 10^3 km^2 (560 ppmv)

It is predicted that forests will expand in the western part of the Pacific Northwest and in north-central California (Bachelet et al. 2003). In the western states, particularly southern California, precipitation and vegetation density will increase and forests will expand under all but the hottest scenarios (Bachelet et al. 2001). Wet coniferous forests in the Northwest are predicted to decrease by 9% on average. The potential range of interior western pines would also change (Hansen et al. 2001). Overall, the predicted temperature change would not alter the role of the Pacific Northwest forests as a major storage location of terrestrial carbon. However, changes in precipitation patterns or in disturbance frequency or intensity that might occur with climatic warming could alter these predictions (Dale and Franklin 1989).

The forest types particularly vulnerable to climatic change would be Douglas fir at low elevation or latitude, alpine fir-spruce at higher elevations, and low-elevation pine types (Neilson 1995). Potential ranges of two California endemic oaks, blue oak and valley oak, would shrink considerably (to 59% and 54% of modern potential range sizes, respectively) and their ranges would shift northward. (Kueppers et al. 2005). In addition, less than 50% of protected land area currently containing these endemic oak species is expected to contain them under a future midrange business-as-usual path of greenhouse gas emissions (Kueppers et al. 2005).

The predictions for response of ponderosa pine to projected climatic change are problematic, with wetter falls increasing growth and drier summers decreasing growth (Kusnierczyk and Ettl 2002). Ponderosa pine was much more sensitive to precipitation than temperature. And, predicting this arid species' response to climatic change is difficult, due to uncertainty in future precipitation patterns. (Kusnierczyk and Ettl 2002).

In the Olympic Mountains under warmer climate the dominant tree species would shift upwards to between 984 and 1,968 ft (300–600 m) in the Southwest, with subalpine meadows and mountain hemlock forests being replaced by Pacific silver fir forests at higher elevations. At lower elevations Pacific silver fir forests would be replaced by western hemlock forests. In the Northeast, drought-tolerant species would become dominant approximately 656 ft (200 m) lower than present, with subalpine fir dominating the northern aspect and lodgepole pine dominating the southern aspect (Zolbrod and Peterson 1999).

In Sequoia National Park impacts on woody biomass and species composition from climatic change would be site specific and dependent upon the environmental constraints of a site and of the environmental tolerances of the tree species (Millar and Urban 1999).

Alpine, Subalpine and Tree Line

Impacts to alpine habitats under climate change are dramatic. Alpine ecosystems all but disappear from the western mountains, being overtaken by encroaching forests (Hansen et al.

2001). In some areas, novel ecosystems likely will replace existing subalpine, alpine, boreal forest and tundra ecosystems. Large changes in ecosystem composition, structure and function are expected to occur at the more northern latitudes and higher altitudes. (Gray 2005).

Climatic change is also expected to cause dramatic shifts in low-elevation tree lines in mountainous environments (Kusnierczyk and Ettl 2002). Data indicate that stability of the mountain hemlock ecotone is strongly influenced by climate. If warming induced by greenhouse gases does occur as climate models predict, then the structure and dynamics of near timberline forests in the Pacific Northwest will change (Taylor 1995).

Upper-montane and tree line ecosystems have responded directionally to century-long climate trends and are also expected to exhibit abrupt and reversible effects as a consequence of interdecadal climate variability with complex interactions of temperature and moisture (Millar et al. 2004). Loss of alpine ecosystems will occur as high-elevation species move upward (Pauli et al. 2003, Millar et al. 2006).

Fire and Other Disturbance

The "greening up" (i.e., increases in density) of temperate lowland and montane forests, followed by "browning down" (mortality) as a result of epic forest diebacks under global warming will result in uncharacteristically severe wildfires (Westerling et al. 2003, Breshears et al. 2005, Millar et al. 2006).

Under some model scenarios, browning down is driven by both increasing temperatures and decreasing precipitation. This is most notable in the southeastern and northwestern United States. It is predicted that, following a period of gradual carbon sequestration, the enhanced evapotranspiration experienced under global warming will overtake the greening processes producing a rapid dieback in woody biomass. Turnaround from green up to dieback occurs about now for the temperate forests and about a decade from now in the boreal forests, initiating an extended period of rapid losses of ecosystem carbon (Lenihan et al. 2005). It is predicted the number of escaped fires (those exceeding initial containment limits) will increase 51% in the southern San Francisco Bay area, 125% in the Sierra Nevada, and will not change on the northern coast (Fried et al. 2004).

Present El Niño events and the warm phase of the PDO tend to be associated with below-average snowpacks, streamflows, flood risks, below-average salmon survival, below-average forest growth and above-average risk of forest fire (Mote et al. 2003). Fire frequency responded most directly to climate's influence on fuel moisture. Whereas, fire extent was affected by changes that occurred in either woody biomass or species composition (Millar and Urban 1999). Future fires in the Sierra Nevada could be both more frequent and of greater spatial extent if GCM predictions prove true. (Millar and Urban 1999)

Predictions of Climate Change Impacts on Game Species

There is a close link between climate change and vegetation or habitat change. Wildlife species with a high rate of reproduction that are able to move long distances, to rapidly colonize new habitats, to tolerate humans and to survive within a broad range of biophysical conditions will be most successful in finding new niches (Gray 2005).

Below a critical rate of climate change, a species maintains high patch occupancy throughout the period of climate change. Above the critical rate, the species is unable to keep pace with climate change, and patch occupancy rapidly declines (Travis 2003).

It is predicted that specialist species with low colonization ability and poor dispersal are the most prone to extinction during climate change (Travis 2003). Species with relatively wide ranges are the most resilient to the effects of climate change (Travis 2003). Climatic change also has the potential to influence the stability of this community by altering the dynamics and stability at any single, or all three, of the individual trophic levels. Because self-regulation (i.e., direct density dependence) was relatively weaker at the top and bottom trophic levels (though not significant statistically), it may be these levels at which climate change alters stability of the community (Post and Forchhammer 2001).

Because of the conflicting influences of environmental variability and intrinsic processes on population stability, a direct influence of climate on the dynamics at all three trophic levels, it is suggested that climate change alters stability of the community. However, theoretical considerations suggest that, if it does, such alteration is most likely to result from changes in stability at the top or bottom trophic levels, where the influence of climate was strongest (Post and Forchhammer 2001).

Climate change models predict that the richness of vertebrate ectotherms will increase over most of the conterminous United States (Currie 2001). Mammal and bird richness is predicted to decrease in much of the southern United States and to increase in cool, mountainous areas. Woody plant richness is likely to increase throughout the North and the West and to decrease in southwestern deserts. These projections represent changes that are likely to occur over long-time scales (millennia); short-term changes are expected to be mainly negative to species richness (Currie 2001). Given that the 20th and 21st centuries are undergoing rapid change in climate with high variability, we would expect population demographics and species ranges to be highly unstable (Millar et al. 2006).

Quail

In climate modeling exercises, species known to respond to limiting factors in the abiotic environment, such as quail, showed the strongest associations with moisture and temperature gradients (McKenzie et al. 2003). Thus, it would be expected that climate change would have considerable influence on quail populations. California quail productivity appears to be a function of (in order of importance): (1) soil moisture in late April, (2) proportion of breeding females over one year old and (3) the seasonal rainfall from September through April (Tom Blankenship, California Game and Fish Department, personal communication 2007).

In southern California, precipitation may strongly influence survival of young mountain quail (Bishop, In Press). In California, most mountain quail observations in the northern part of the state came from mixed shrub and mixed forest communities (Brennan et al. 1987). In central-coastal California, mountain quail are most often found in mixed evergreen forest, and in southern California mountain quail are most often found in chaparral and mixed desert scrub (Gutierrez and Delehanty 1999).

The "Sierra Nevada Bird Conservation Plan" (from California Partners in Flight) lists a number of habitat objectives, some of which could be expected to benefit mountain quail. These include protecting existing high-quality meadow, riparian and oak-woodland habitat. In addition, maintenance of early-successional shrub stands and forbs could also be expected to benefit mountain quail. Increased incidence of fire with climate change could provide beneficial disturbance to maintain early successional shrubs and forbs for quail. However drying of meadow, riparian, and other habitats associated with less precipitation would be potentially detrimental to mountain quail populations.

The predicted shrinking range of endemic oaks in California would likely be detrimental to quail as oak habitats are important to their survival. All quail species would be expected to be sensitive to changes in the availability of water due to predicted changes in precipitation and snowpacks.

Information and Research Needs for Quail

The dependency of quail on moisture and temperature gradients highlight the need for development of viable regional monitoring efforts to detect changes in these parameters. Soil moisture has been demonstrated to be an important variable, so measures of soil moisture in important quail habitats would be useful. Monitoring efforts are also needed to document changes in distribution and extent of the endemic oak species.

Deer and Elk

The dynamics of midtrophic level game species, such as mule deer and elk, may be less likely to become unstable due to climactic change than the dynamics of predators or species at bottom trophic levels. Increased fires in forested habitats (that are predicted) would produce more desirable seral stages of vegetation for deer, providing sufficient moisture for plant growth. Fires would remove overstory species important as cover for elk.

Distribution patterns for mule deer and elk would be expected to change, especially with tree line changes predicted. Lessened snowpacks would also impact movements of large cervids, especially during spring and fall. Predictions of vegetation maturing earlier in the growing season would lower the food quality for all herbivores, especially during summer.

Information and Research Needs for Deer and Elk

Nutritional quality of understory forages is a critical element in determining the ability of habitats to support deer and elk populations. Predicted changes in overstory and understory plant communities require that viable regional monitoring efforts to document these changes on important deer and elk ranges be done. Low nutritional quality of forages is known to be a key limiting factor for deer and elk populations in the Northwest, and knowing how deer and elk populations perform on forages that have responded to changing climates will be important.

Overarching Continental Science and Research Needs

Monitoring

There is a need for development of methods to overcome difficulty in detecting effects of climatic change. Because individual plants, unlike animals, cannot “pick up and move,” they migrate by dying in some areas while expanding in others. These may appear poorly segregated on the landscape—with patchiness and irregular characteristics—making the effects difficult to evaluate while they’re happening (Millar et al. 2006). The difficulty is that causes may be attributed readily to other proximal factors, such as to insects and pathogens, or to human-induced effects, such as fire suppression, even where climate is the underlying, ultimate factor (Millar et al. 2006). Monitoring will be most useful and needed in areas of disturbance. Because forests are so long-lived, it may be that many climate change effects on forests are most easily observed in places where the successional pathway has been disrupted by a disturbance (Dale et al. 2000).

The scale of monitoring is paramount. Managers must determine the scale at which areas should be identified and prioritized. The basic question of what size of area is needed to support game populations and genetic diversity must be addressed.

There is a need for inclusion and enhancement of some historic and time-tested natural history approaches. Efforts to identify species and life history attributes that are highly vulnerable to the effects of climate change should be made. For those species identified, monitoring data should then be gathered on the identified distributions and habitat characteristics (Lucier et al. 2006).

There is a need for improvement of long-term collection and archiving of biological materials (e.g., genomic data, biotic vectors, organisms) over large spatial scales with corresponding climatic, location, and life history data. (Lucier et al. 2006).

Priorities should be placed on digitizing museum records of species distributions, historical maps and current species' ranges to facilitate access and analysis of important historic data (Lucier et al. 2006).

There is a need to develop criteria and protocol for monitoring and prioritizing habitats for conservation (e.g. quality of habitat, risk factors).

There is a need to identify the climatic factors that currently affect the distribution of plant and animal species and the occurrence of diseases to help predict likely changes in distribution over time.

Climatic change will influence population densities and distribution of many game species. Systems to monitor these changes need to be in place, so harvest opportunities can be adjusted accordingly.

There is a need to identify species and life history attributes that are highly vulnerable to the effects of climate change. For these species, data must be obtained on their distributions and habitat characteristics (Lucier et al. 2006).

It will necessary to focus on those studies and measures that will produce the most useful information for the question addressed. It is suggested that efforts be focused on those species and habitats that are on the precipice, or are most vulnerable to climate changes; examples would be alpine habitats, very dry habitats and riparian habitats.

There is a need for research and monitoring to be focused on measures of community composition, species distributions and plant vigor within key wildlife habitats.

There is a need for monitoring to focus on all water sources such as streams, springs, snowpacks and precipitation rates.

Monitoring to better understand and predict wildfires and threats to forest health, such as tree diseases, insect loads and fuel loads, should be prioritized.

Monitoring protocols that rely on remote sensing technology should be developed.

Monitoring efforts should be shared among agencies and private industry to increase efficiencies.

For game species, monitoring should be focused on measures of species seasonal distributions, including population shifts and population parameters (survival, reproductive and mortality).

Monitoring on timing of key biological processes like breeding, birthing and deaths should be routinely done to help understand impacts of climate change on key game species.

Models

New models are needed to predict impacts of future climate change on the environment because future precipitation and temperatures are likely to be very different from the conditions experienced in the past (Dale et al. 2000).

Future models for understanding impacts of climate change must be spatially-explicit. These models should build upon monitoring data collected regarding the relationship between climate and disturbances. And, it should include methods to observe effects of both climate and disturbances upon the function, structure and composition of ecological systems. Field, laboratory and greenhouse experiments that explore these relationships must be conducted, and resulting data should be built into models (Dale et al. 2000).

Population models will have to be adjusted as changes in climate influence productivity.

There is a need to develop better process-based models of environmental factors controlling species ranges (Lucier et al. 2006).

Key population parameters in computer models used to predict performance of big-game animals may need updates and changes to correspond to new realities (Inkley et al. 2004).

Evaluations using computer models must be developed that include not only the changes in a habitat type at a point in time, but also the changes in space (Shugart et al. 2003).

Managing Variability—Predicting Unpredictability

Predicted outcomes from climate models underscore the critical importance of addressing uncertainties with respect to ecosystem water balance and the direct effects of elevated carbon dioxide concentrations (Lenihan et al. 2005). There is a need for species and site-specific responses to be characterized at mesoscale (e.g., wet versus dry climatic regime) and microscale (e.g., north versus south aspect) resolutions to quantify the variation in potential effects of climatic change on forest vegetation in mountainous regions (Zolbrod and Peterson 1999).

Integration of Science and Management

There is a need to develop the ability to translate climatic change to habitat impacts. It will be important to understand the spatial distribution of changes in precipitation and temperature within forest types because each responds to climate in unique ways, and each is partially dependent upon current environmental conditions (Dale et al. 2000).

Little is known about the demographic performance of organisms across gradients in climate and land use (Hansen et al. 2001), so there is a need to begin learning more about this relationship.

Research aimed at improving understanding of factors that are expected to influence the rate at which game habitat types are able to migrate is needed. Specific studies to measure intrinsic migrational capabilities, barriers to migration, the role of outlier populations in increasing migration rates, the role of climate in setting range limits and variation in species range sizes is needed. Global warming may require migration rates much faster than those observed during postglacial times and, hence, has the potential to reduce biodiversity by selecting for highly mobile and opportunistic species (Malcolm et al. 2002).

It will be critical to develop criteria and protocol for assessing and prioritizing habitats for conservation (e.g., quality of habitat, risk factors). Areas protected from human-induced impacts will be needed to better understand the impacts of climate change. Natural research areas should be designated and monitored closely.

There is a need to investigate the potential for establishing barriers to block northward expansion of undesirable plants, animals and diseases. Managers must improve their understanding of factors that are expected to influence the rate at which animals are able to migrate, including intrinsic migrational capabilities, barriers to migration, the role of outlier populations in increasing migration rates, and the role of climate in setting range limits and variation in species range sizes. Global warming may require migration rates much faster than those observed during post-glacial times and hence has the potential to reduce biodiversity by selecting for highly mobile and opportunistic species (Malcolm et al. 2002).

There is a need to map areas to account for habitat movement in response to climate change. In addition, there is a need to update management documents, like species plans and habitat plans which may become obsolete otherwise. Maps detailing critical habitats may be outdated and will need changes.

There is a need to document human recreational use patterns as they may change with global warming. Fixed borders of our existing protected areas may no longer be appropriate for the ecological communities of tomorrow. Maps depicting game management units may need to be changed as populations shift distributions. Finally, historic records on hunter success by management unit and hunter participation rates may also change. It will be necessary for managers to critically evaluate and update these data as new information is obtained.

Adaptive Management

There is a need to implement adaptive management by conducting long-term monitoring of responses of habitats to climatic change along altitudinal and latitudinal gradients (Arvai et al. 2006, Shugart et al. 2003). These evaluations should be enhanced by using computer models that include not only the changes in a habitat type at a point in time but also changes in space (Shugart et al. 2003). This process would also benefit by mapping areas to account for habitat movement in response to climate change by developing better process-based models of environmental factors controlling species ranges (Lucier et al. 2006).

There is a need for managers to recognize that global change will be a factor in future wildlife conservation (Inkley et al. 2004) and to be prepared to adapt to diverse conditions by employing rigorous and effective monitoring and adaptive management principles.

Personnel

Detecting, understanding and adapting to change in game habitat and to populations resulting from climate change may be the single, most unifying challenge facing wildlife agencies. Failure to adapt to change may put hunting programs at risk. Agencies are currently operating at full capacity to address existing challenges and opportunities. Addressing climate change will be in addition to efforts that are already underway or that need to be initiated for these issues. Agencies, therefore, need to implement staffing plans that embrace the new challenges facing them. Long-term strategic planning is necessary to optimize staff with the proper skills and expertise.

Few agencies will be able to afford the necessary, full-time staff to cover the unknowns of climate change. Agencies must investigate citizen science initiatives and must use those resources efficiently and effectively.

Training

An assessment of agency expertise will highlight gaps in the ability of agencies to conduct sound science and management practices to address climate change. Climate-change impacts will be complex and difficult to reliably separate from other forces driving changes in habitats and populations. Additionally, there is currently almost a complete lack of information, particularly on a site-specific or local basis, so expertise will need to be developed with little background information initially. Training programs must keep pace with the rapidly evolving science of climate change. In addition to the science-based needs, agencies will need to provide staff with the tools needed to address the sociological demands that will be presented to their staff as a result of climate change. As with many actions undertaken by agencies, there will be political liabilities associated with responding to climate change. Stakeholders will react—some positively and some negatively. Training of agency personnel about human-dimensions needs and applications relative to climate change will be especially valuable.

Funding

Detection, analysis and adaptation to climate change will demand an infusion of new funds into state and federal wildlife management agencies. States, for example, will need to add to current population and habitat monitoring activities because those activities are not designed to detect changes brought by climate change, even though states are already expending significant funding on monitoring activities. For example, states currently spend between $30 and $50 million of wildlife restoration funds on research activities to investigate population evaluation, life history, biology and habitat. Translating research projects into full scale monitoring activities will increase subsequent operational costs much. States currently spend between $7 and $10 million of wildlife restoration funds on land acquisition and $25 million annually on habitat restoration and management (U.S. Fish and Wildlife Service Federal Aid Information Management System 2007). As climate change affects species distribution and habitat profiles, these costs will multiply. Finally, the coordination and administration of conservation programs will increase in complexity and will substantially increase the $40 to $50 million that state wildlife agencies expend currently. Taken together within a wildlife restoration program alone, it is reasonable to expect increases of $100 to $200 million because of the new demand for services to offset impacts of climate-change. Sport fish restoration and state wildlife grants demands will likely be substantially higher. Added together, without an infusion of approximately $1 billion in new funds, states will be hampered in their ability to address climate change.

To justify significant federal funding for addressing impacts of climate change, state wildlife management agencies and conservation organizations need to develop plans to effectively capture and utilize these funds for priority wildlife management purposes. Key factors to consider include: (1) prioritization of biomes and species under greatest threat, (2) creation of sources of dollars for federal match, (3) potential to channel new funding sources through existing mechanisms like the Pittman-Robertson Act, the Dingell-Johnson act and state wildlife grants, (4) need to integrate new funding sources with existing programs, and (5) need for stability of the funding, so long-term monitoring programs can be carried out without interruption.

In addition, wildlife agencies should begin immediately to outline steps necessary to plan for effective and efficient use of additional funding. Each wildlife agency should develop operational plans for how it might address threats of climate change in their respective states. States should look for efficiencies in delivery by focusing on opportunities for multistate collaborations. Operational plans should lead to identification of employee responsibilities and training needs. Once operation planning is completed, then an adaptive planning and implementation model should be developed. It is suggested this model should include the following key elements.

1. monitoring
2. increased analytical capacity
3. experimental research
4. changes in species management plans

5. changes in habitat management plans
6. changes in hunting regulations
7. changes in land acquisition priorities
8. changes in recovery mitigation
9. monitoring with adjustments as necessary.

In addition to funding at the state level, the U.S. Fish and Wildlife Service will need to take the lead with addressing this issue for federal trust species, including migratory game birds, and with habitat management and acquisition for the National Wildlife Refuge System. Other federal land management agencies (NPS, BLM, BOR, USFS and DOD for example) will require substantial funding to address impacts on federal lands which are their responsibility and for management of federal trust species on these lands. It is anticipated that these funding needs will be similar to that required for the states with an estimated total of $2 billion annually for state and federal agencies to adequately address the challenges of climate change as they affect management of the country's fish and wildlife resources.

Obviously, this will require multiple steps and complete cooperation within and among agencies and conservation organizations. However, the potential is there on this issue for the wildlife management community to be proactive. Securing necessary funding is the first and most important step.

Impacts on Hunting and Hunters: Human Dimensions Research Needs

According to the preliminary highlights of the 2006 National Survey of Fishing, Hunting, and Wildlife-associated Recreation (U.S. Fish and Wildlife Service 2007), more than 87 million U.S. residents 16 years old or older participated in recreational activities associated with fish and wildlife. This recreational activity resulted in spending more than $120 billion in 2006 (approximately 1% of the nation's gross domestic product). Hunters make up a significant portion of the participation and spending. In 2006, over 12 million hunters spent $23 billion on trips, equipment and other items.

Loss and changes in hunter participation rates will directly impact the financial status of state agencies entrusted with managing resident fish and wildlife species. License dollars and federal apportionment of wildlife restoration funds depend, in large part, on the number of hunters residing in the states. In fiscal year 2007 alone, wildlife restoration funds accounted for more than $266 million of revenue for state agency wildlife programs.

The effect that climate change will have on participation and the geographic patterns of participation are unknown. However, predicted habitat changes and accompanying shifts in wildlife distribution may change the activities of an estimated 10.7 million big-game hunters, 4.8 million small-game hunters, and 2.3 million waterfowl hunters (U.S. Fish and Wildlife Service 2007). The change in recreational activities will be a function of climate change impacts on wildlife and their habitat. Due to their sensitivity to climate change, areas in the southwestern United States and in mountain states should expect the most dramatic changes in hunting activity.

Migratory bird species will also demonstrate the impacts of climate change on their distribution. Although it is speculative, the observed 22% long-term decline in waterfowl-hunter numbers (U.S. Fish and Wildlife Service 2007) may reflect climate change impacts on wetland habitats, weather patterns, agricultural cropping patterns and human land use, which resulted in altered migratory patterns and the timing of migratory behavior. For instance, the increase in resident Canada geese that has occurred during the last two decades may be a result of increased habitat availability, and the cessation of migratory behavior of geese may be a result of increased goose populations in more northern latitudes than previously experienced.

In any event, wildlife response to climate change impacts has a direct bearing on the activity of more than 87 million U.S. citizens. Those residents most directly affected are hunters and anglers whose activities are regulated by government entities. Public participation in government decisions to allocate wildlife resources will demand a better understanding of and ability to adapt to climate change and to its impacts on wildlife.

What Information Is Needed

Decker et al. (2001) defined human dimensions of wildlife management as how people value wildlife, how they want wildlife to be managed, and how they affect or are affected by wildlife and wildlife management decisions. Impacts of global warming on wildlife management decisions will be considerable and will require hunters and other stakeholders to better understand these impacts and how they will impact their recreational pursuits.

An important first step will be for agencies to assess the awareness and knowledge of their employees about global warming. This will require application of human dimension methodologies for internal audiences. Training workshops must be designed and implemented.

Wildlife agencies would also be advised to develop human involvement processes that permit the effective input of hunters into how impacts of global warming will be managed. How to integrate this input into routine regulatory processes will be an important information need.

There is a strong need for wildlife agencies to better understand the awareness level of sportsmen and women with regard to global warming. And, agencies need to know how to communicate to them that global warming could impact their hunting experiences.

It is probable that seasonal distributions and local abundances of many hunted species will be altered, which hunters must be made aware of, so they can adjust their hunting locations as needed. For instance, traditional hunting unit boundaries may have to be changed to accommodate these movements. This will require the wildlife management agencies to be more flexible in their regulation and license distribution systems. To accommodate these changes, increased information outreach efforts will be required.

It could be expected that various wildlife diseases involving insect vectors will increase geographical distributions with global warming. This will necessitate additional efforts to monitor these changes and to communicate them to sportsmen and women. For diseases that have potential to affect human health, it will be even more critical that up-to-date and accurate information is provided.

According to Lucier et al. (2006), it is the responsibility of scientists to identify the most serious problems that could occur, to determine the probability that they actually will occur and to identify cost-effective ways to reduce the risk of occurrence. Without this information, society cannot rationally assess the costs and benefits of policy options. The obvious challenge with this politically charged issue will be how to address perceptions versus facts and how to communicate such to involved stakeholders. Answers to this challenge will lie in better understanding the human dimension elements involved in this issue.

What Information is Available

In 2006, a survey of 1,031 hunters and anglers was conducted for the National Wildlife Federation (NWF) to ascertain their opinions on various aspects of global warming (NWF 2006). The survey indicated that 76% of respondents strongly or moderately agreed that global warming was occurring. Only 13% strongly or moderately disagreed with this statement.

Seventy percent of respondents strongly or moderately agreed that global warming was a serious threat to fish and wildlife while 22% strongly or moderately disagreed. Further, 76% of respondents strongly or moderately agreed that legislation to address global warming should include funding to protect fish, wildlife and their habitat from the impacts of global warming. Seventeen percent either strongly or moderately disagreed with this statement.

This suggests that the community is at least aware of global warming and of its potential impacts to fish and wildlife habitats. However it is probable that it is not adequately informed on the specifics of how global warming could impact fish and wildlife habitats or their recreational opportunities.

Recommendations*

Because the natural resources of a nation are critical to that nation's sustainability and productivity, the science needed to properly manage its fish and wildlife resources must be addressed. Given the potential geographic extent and multitude of impacts associated with climate change, the current level of research funding for federal and state fish and wildlife management agencies is inadequate to meet the science needs associated with global climate change and needs to be increased.

1. A national strategy that incorporates collaboration and cooperation of all state and federal agencies with a stake in this issue along with relevant nongovernmental organizations needs to be developed to coordinate efforts around the country.
2. Detection, analysis and adaptation to climate change will demand an infusion of new funds into state and federal wildlife management agencies. We estimate additional annual funding in the range of $1 billion will be needed for state wildlife agencies to adequately address climate change impacts to resident and certain federal trust species. Federal land management agencies (FWS, NPS, BLM, BOR, USFS, DOD and others) will require similar funding to address impacts on federal lands and for their management of federal trust species.
3. Methods to overcome the difficulty of separating the effects of climate change that can easily be confused as being caused by other factors, such as fire, exotics, insects and disease, need to be developed.
4. The wildlife species that are most vulnerable to climate change need to be identified.
5. Protocols for monitoring and prioritizing habitats for conservation need to be developed.
6. Climatic factors that currently affect distribution of plant and animal species and the occurrence of diseases need to be identified to predict changes in distribution over time.
7. Monitoring protocols that rely on remote sensing technology should be developed.
8. Information relative to monitoring efforts and results should be coordinated and shared among agencies and private industry to increase efficiencies.
9. Changes in climate will cause changes in productivity, survival and mortality rates for many game species. These will need to be monitored and documented so models can be adjusted accordingly.

10. Specific research to determine migrational capabilities, barriers to migration, the role of outlier populations in increasing migration rates, and the role of climate in establishing range limits and variation in range sizes will be needed for a number of species.
11. The potential for establishing barriers to block northward expansion of undesirable plants animals and diseases needs to be investigated.
12. Human recreational use patterns need to be monitored, and changes must be documented.
13. Changes in game species' densities and distribution need to be closely monitored so harvest opportunities can be adjusted accordingly.
14. Training programs that keep pace with the rapidly evolving science of climate change need to be established for agency staff.
15. Mechanisms to solicit public input relative to actions to address climate change need to be developed and agency staff need to be trained to implement them.
16. Long-term, historical, biological information over large spatial scales needs to be assembled by species and analyzed in comparison with long-term, climatic data to enhance insight of species response to previous changes in climate and improve reliability of projected responses.
17. Because future climate change will likely be very different from conditions that occurred in the past, new models will need to be developed to enhance reliability of projected changes in habitats and populations.
18. To be most useful to managers, new models need to be more spatially explicit and adjusted frequently as better information is generated.
19. Management documents, such as species and habitat plans, will need to be updated.

20. Managers should anticipate adjustments in populations, habitats and recreational use as a result of climate change and should implement adaptive management principles based on comprehensive monitoring systems.

21. State wildlife agencies need to develop operational plans to address threats and opportunities relative to climate change in their respective states and to improve efficiencies in delivery by focusing on multistate or regional approaches.

*Regional recommendations for selected game species are incorporated within the specific regional sections.

Literature Cited

Alt, G. L. 1980. Rate of growth and size of Pennsylvania black bears. *Pennsylvania Game News*. 51(12):7–17.

Arvai, J, G. Bridge, N. Dolsak, R. Franzese, T. Koontz, A. Luginbuhl, P. Robbins, K. Richards, K. Smith Korfmacher, B. Sohngen, J. Tansey, and A. Thompson. 2006. Adaptive management of the global climate problem: Bridging the gap between climate research and climate policy. *Climatic Change*. 78: 217–25.

Bachelet, D., R. P. Neilson, J. M. Lenihan, R. J. Drapek. 2001. Climate change effects on vegetation distribution and carbon budget in the United States. *Ecosystems*. 4(3):164–85.

Bachelet, D., R. P. Neilson, T. Hickler, R. J. Drapek, J. M. Lenihan, M. T. Sykes, B. Smith, S. Sitch, and K. Thonicke. 2003. Simulating past and future dynamics of natural ecosystems in the United States. *Global Biogeochemical Cycles*. 17(2): 1,045.

Bailey, R. G. 1995. *Descriptions of Ecoregions of the United States. U.S.D.A. Forest Service*. http://www.fs.fed.us/land/ecosysmgmt/ecoreg1_home.html.

Betancourt, J. L., T. R. Van Devender, and P. S.Martin, eds., 1990. *Fossil packrat middens: The last 40,000 years of biotic change*. University of Arizona Press.

Bishop, R. In Press. *Western quail conservation plan*. Washington, DC: Association of Fish and Wildlife Agencies.

Boggus T. G., Whiting R. M. Jr. 1982. Effects of habitat variables on foraging of American woodcock wintering in East Texas. *U.S. Fish and Wildlife Service Wildlife Research Report*. 14:148–53.

Brennan, L.A., W.M. Block, and R. J. Gutierrez. 1987. Habitat used by mountain quail in northern California. *Condor*. 89:66–74.

Brennan, L. A. 1999. Northern bobwhite (*Colinus virginianus*). In *The birds of North America, No. 397*, eds. A. Poole, and F. Gill, Philadelphia, PA.

Breshears, D. D. et al. 2005. Regional vegetation die-off in response to global-change-type drought. *Proceedings of the National Academy of Science*. 102 (42): 15,144–8.

Bright, J. L., and J. J. Hervert. 2005. Adult and fawn mortality of Sonoran pronghorn. *Wildlife Society Bulletin*. 33(1):43–50.

Broadfoot, J. D., D. R. Voigt and T. J. Bellhouse. 1996. White-tailed deer, *Odocoileus virginianus*, summer dispersion areas in Ontario. *Canadian Field Naturalist*. 110: 298–302

Currie, D. J. 2001. Projected effects of climate change on patterns of vertebrate and tree species richness in the conterminous United States. *Ecosystems*. 4(3):216–25.

Dale, V. H., and J. F. Franklin. 1989. Potential effects of climate change on stand development in the Pacific Northwest. *Canadian Journal of Forest Research*. 19(12):1,581−90.

Dale, V. H, L.A. Joyce, S. McNulty, and R.P. Neilson. 2000. The interplay between climate change, forests, and disturbances. *The Science of the Total Environment*. 262: 201−4.

Decker, D. J., T. L. Brown, and W. F. Siemer, eds., 2001. *Human dimensions of wildlife management in North America*. Bethesda, MD: The Wildlife Society.

Dessecker, D. R., G. W. Norman and S. J. Williamson. 2006. *Ruffed grouse conservation plan*. Washington, DC: Association of Fish and Wildlife Agencies.

Devers, P. K, D. F. Stauffer , G. W. Norman, D. E. Steffen, D. M. Whitaker.2007 Ruffed Grouse Population Ecology in the Appalachian Region. *Wildlife Monographs*. 168(1):1–36.

Dickinson, N. R. 1976. Observation on steep-slope deer wintering areas in New York and Vermont. *New York Fish and Game Journal*. 23:170–4.

Donnelly, J. P., and M. D. Bertness. 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. *Proceedings of the National Academy of Sciences of the United States*. 98:14,218–23.

deVos, J. C. Jr., and W. H. Miller. 2003. Habitat use and survival of Sonoran pronghorn in years with above-average rainfall. *Wildlife Society Bulletin*. 33(1):35–42.

Dumont, A., J. P Ouellet, M. Crete, and J. Huot. 1998. Characteristics of forest populations as seen in the white-tailed deer in winter at the northern limit of its distribution area. *Canadian Journal of Zoology*. 76:1,024–36.

Eiler, J. H., W. G. Wathen, and M. R. Pelton. 1989. Reproduction in black bears in the southern Appalachian Mountains. *Journal Wildlife Management*. 53:353–60.

Epps, C. W., D. R. McCullough, J. D. Wehausen, V. C. Bleich, and J. L. Rechel. 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. *Conservation Biology*. 18:102–13.

Flannigan, M. D., B. J. Stocks, and B.M.Wooton. 2000. Climate change and forest fires. *The Science of the Total Environment*. 262: 221–30.

Frederick, K. D., and P. H. Gleick. 1999. *Water and global climate change: Potential impacts on U.S. water resources*. Arlington, VA: The Pew Center on Global Climate Change.

Fried, J. S., M.S. Torn, and E. Mills. 2004. The impact of climate change on wildfire severity: A regional forecast for Northern California. *Climatic Change*. 64(1/2):169–91.

Geiger, E., T. Mau-Crimmins, and H. Schussman. 2003. Spread of a nonnative grass across southern Arizona: Multiple data sources to monitor change. *USDA Forest Service Proceedings RMRS*. 30:116–9.

Gleick, P. H. et al.. 2000. *Water: The potential consequences of climate variability and change for the water resources of the United States*. Oakland, CA: Pacific Institute for Studies in Development, Environment, and Security.

Gray, P. A. 2005. Impacts of climate change on diversity in forested ecosystems: Some examples. *Forestry Chronicle*. 81(5): 655−61.

Gullion, G. W. 1984. *Managing northern forests for wildlife*. Thermopolia, PA: Ruffed Grouse Society.

Gutierrez, R. J., and D. J. Delehanty. 1999. Mountain Quail (*Oreortyx pictus*). In *The birds of North America, No. 457*, eds., A. Poole and F. Gill.

Hansen, A. J., R. P. Neilson, V. H. Dale, C. H. Flather, L. R. Iverson, D. J. Currie, S. Shafer, R. Cook, and P. J. Bartlein. 2001. Global change in forests: Responses of species, communities, and biomes. *Bioscience*. 51(9): 765-779.

Hebblewhite, M. 2005. Predation by wolves interacts with the North Pacific oscillation (NPO) on a western North American elk population. *Journal of Animal Ecology*. 74:226–33.

Hoving C. L. 2001. Historical occurrence and habitat ecology of Canada lynx (*Lynx canadensis*) in eastern North America. Master's thesis, University of Maine, Orono.

Hoving C. L., D. J. Harrison, W. B. Krohn, R. A. Joseph, and M. O'brien. 2005. Broad-scale predictors of Canada lynx occurrence in eastern North America. *Journal of Wildlife Management*. 69(2):739–51.

Hungerford, C. R. 1964. Vitamin A and productivity in Gambel's quail. *Journal of Wildlife Management*. 28:141–7.

Hurtt, G. C., S. W. Pacala P. R. Moorcroft, J. Caspersen, E. Shevliakova, R. A. Houghton, and B. Moore, III. 2002. Projecting the future of the U.S. carbon sink. *Proceedings of the National Academy of Sciences*. 99:1,389–94

Inkley, D. B., M. G. Anderson, A. R. Blaustein, V. R. Burkett, B. Felzer, B. Griffith, J Price, and T. L. Root. 2004. Global climate change and wildlife in North America. *Wildlife Society Technical Review*. 4(2).

McCarthy, J. J., O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White, eds. 2001**.** Climate change 2001: Impacts, adaptation, and vulnerability. A contribution of working group II to the third assessment report of the intergovernmental panel on climate change. New York, NY: Cambridge University Press.

Intergovernmental Panel on Climate Change. 2002. *Climate change and biodiversity. Technical paper*. V.

Izaurralde, R. C., A. M. Thomson, N. J. Rosenberg, and R. A. Brown. 2005. Climate change impacts for the conterminous USA: An integrated assessment. Part 6. Distribution and productivity of unmanaged ecosystems. *Climatic Change*. 69: 107–26.

Jensen, M. N. 2005. Massive piñyon pine die-off. Underlying cause revealed: Arizona agricultural experiment station report. http://ag.arizona.edu/pubs/general/resrpt2005/article14_2005.pdf.

Karns, P. D. 1998. Population distribution, density and trends *In Ecology and management of the North American moose*, eds. A. W. Franzmann, and C. C. Schwartz, 125–39 Washington, DC: Smithsonian Institution.

Kling, G. W., K. Hayhoe, L. B. Johnson, J. J. Magnuson, S. Polasky, S. K. Robinson, B. J. Shuter, M. M. Wander, D. J. Wuebbles, D. R. Zak, R. L. Lindroth, S. C. Moser, and M. L. Wilson. 2003. *Confronting climate change in the Great Lakes Region: Impacts on our communities and ecosystems*. Washington, DC: Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America.

Kordek, W. S., and J. S. Lindzey. 1980. Preliminary analysis of female reproductive tracts from Pennsylvania black bears. *Int. Conf. Bear Res. and Manage*. 4:159-61.

Krohn W. B., K. D. Elowe, and R. B. Boone. 1995. Relations among fishers, snow, and martens: Development and evaluation of two hypotheses. *The Forestry Chronicle*. 71:97–105.

Krohn W. B., W. J. Zielinski, and R. B. Boone. 1997. Relations among fishers, snow, and martens in California: Results from small-scale spatial comparisons. In *Martes:*

Taxonomy, ecology, techniques, and management, eds. G. Proulx, H. N. Bryant, and P. M. Woodard, 211–232. Edmonton, Alberta: Provincial Museum of Alberta,

Kubisiak, J. F. 1985. Ruffed grouse habitat relationships in aspen and oak forests of central Wisconsin. *Wisconsin Department of Natural Resources, Technical Bulleti*n. 151.

Kueppers, L. M. , M. A. Snyder, L. C. Sloan, E. S. Zavaleta, and B. Fulfrost. 2005. Modeled regional climate change and California endemic oak ranges. *Proceedings of the National Academy of Sciences of the United States of America*. 102(45):16,281–6.

Kusnierczyk, E. R., and G. J. Ettl. 2002. Growth response of ponderosa pine (*Pinus ponderosa*) to climate in the eastern Cascade Mountains, Washington, U.S.A.: implications for climatic change. *Écoscience*. 9(4):544–51.

Kuvlesky, W. P., Jr. T. E. Fulbright, R. Engel-Wilson. 2002. The impact of invasive exotic grasses on quail in the Southwestern United States. *In Quail V: The fifth national quail symposium*, eds. S. J. DeMaso, W. P. Kuvlesky, Jr., F.Hernandez, M. E. Berger, 118–28. Austin, TX: Texas Parks and Wildlife Department.

Lenihan, J. R., R. Neilson, D. Bachelet, and R. Drabek. 2005. Widespread dieback of forests in North America under rapid global warming: response to the VINCERA future climate scenarios simulated by the MC1 DGVM, abstract #B21B-1025. American Geophysical Union.

Lucier, A., M. Palmer, H. Mooney, K. Nadelhoffer, D. Ojima, and F. Chavez. 2006. *Ecosystems and climate change: research priorities for the U.S. Climate Change Science Program. Recommendations from the scientific community. Report on an ecosystems workshop, prepared for the ecosystems interagency working group. special series no. SS-92-06.*

Solomons, MD: University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory.

Malcolm, J. R., A. Markham, R. P. Neilson, and M. Garaci. 2002. Estimated migration rates under scenarios of global climate change. *Journal of Biogeography*. 29(7): 835−49.

Manitoba Forestry and Wildlife Management Project. 1994. *Habitat suitability index model for the ruffed grouse (*Bonasa umbellus*), version 2*. Manitoba: Manitoba Wildlife Branch, Department of Natural Resources.

Martin, A. C, H. S. Zim, and A. L. Nelson. 1951. *American wildlife and plants: A guide to wildlife food habits*. New York, NY: Dover Publications, Inc.

McKenzie, D., D. W. Peterson, and D. L. Peterson. 2003. Modelling conifer species distributions in mountain forests of Washington State, USA. *Forestry Chronicle*. 79(2):253–8.

Mech, L. D., R. E. McRoberts, and R. O. Peterson. 1987. Relationship of deer and moose populations to previous winters' snow. *Journal of Animal Ecology*. 56:615–27.

Millar, C., and D. L. Urban. 1999. Forest pattern, fire, and climatic change in the Sierra Nevada. *Ecosystems*. 2(1):76−87.

Millar, C. I., R. D. Westfall, D. L. Delany, J. C. King, and L. J. Graumlich. 2004. Response of subalpine conifers in the Sierra Nevada, California, U.S.A., to 20th-century warming and decadal climate variability. *Arctic, Antarctic, and Alpine Research*. 36(2):181–200.

Millar C., R. Nielson, D. Bachelet, R. Drapek, and J. Lenihan. 2006. *Climate change at multiple scales in forest, carbon and climate change*. Oregon Forest Resources Institute.

Mote, P. W., E. A. Parson, A. F. Hamlet, W. S. Keeton, D. Lettenmaier, N. Mantua, E. L. Miles, D. W. Peterson, D. L. Peterson, R. Slaughter, and A. K. Snover. 2003. Preparing for climatic change: The water, salmon, and forests of the Pacific Northwest. *Climatic Change*. 61(1/2):45–88.

Murphy, D. D., and S. B. Weiss. 1992. Effects of climate change on biological diversity in Western North America: Species losses and mechanisms. In *Global warming and biological diversity*, ed. R. L. Peters, and T. E. Lovejoy, Castleton, New York: Hamilton Printing.

Murray, D. L., E.W. Cox, W. B. Ballard, H. A. Whitlaw, M. S. Lenarz, T. W. Custer, T. Barnett and T. K. Fuller. 2006. Pathogens, nutritional deficiency, and climate influences on a declining moose population. *Wildlife Monograph*. 166:1–30.

Myatt N. A., and D. G. Krementz. 2007. Fall migration and habitat use of American woodcock in the central United States. *Journal of Wildlife Management*. 71(4):1,197–205.

National Oceanic and Atmospheric Administration. 2007. *Average precipitation and temperatures for selected U.S. cities, 1961−1990*. http://www.noaa.gov (accessed March 2007).

National Wildlife Federation. 2006. National Wildlife Federation nationwide survey of hunters and anglers March/April 2006. Arlington, VA: Responsive Management.

Natural Resources Conservation Service. 2007. National resources inventory-2003 annual NRI-Landuse. National Resources Conservation Service.

NatureServe Explorer. 2007. *Comprehensive report species*—Lepus americana. http://www.natureserve.org/explorer.

NatureServe Explorer. 2007. *Comprehensive report species*—Sciurus carolinensis. http://www.natureserve.org/explorer.

Neilson, R. P. 1995. A model for predicting continental scale vegetation distribution and water balance. *Ecological Applications*. 5:362–85.

Neilson, R. P., J. M. Lenihan, D. Bachelet, R. J. Drapek. 2005. Climate change implications for sagebrush ecosystems. *Transactions of the North American Wildlife and Natural Resources Conference*. 70:145–59.

Owen, R. B., Jr. 1977. American woodcock. In *Management of migratory shore and upland game birds in North America*, ed. G. C. Sanderson, 149–86, Washington, DC: International Association of Fish and Wildlife Agencies

Painter, T. H., A. P. Barrett, C. C. Landry, J. C. Neff, M. P. Cassidy, C. R. Lawrence, K. E. McBride, and G. L. Farmer (2007), Impact of disturbed desert soils on duration of mountain snow cover. *Geophysical Research Letters*. 34: L12502,doi:10.1029/2007GL030284.

Parker G. R., J. W. Maxwell, L. D. Morton, and G. E. J. Smith. 1983. The ecology of the lynx (*Lynx canadensis*) on Cape Breton Island. *Canadian Journal of Zoology*. 61:770–86.

Pauli, H., M. Gottfried, T. Dirnboeck, S. Dullinger, and G. Grabherr. 2003. Assessing the long-term dynamics of endemic plants at summit habitats. *Ecological Studies*. 167:195–207.

Pellant, M. 1990. The cheatgrass-wildifre cycle—Are there any solutions? In *Proc. Symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. Gen Tech. Rep. INT-GTR-276*, compilers E. D. McArthur, E. M. Romney, S. D. Smith, and P .T. Tueller, 11–8. Ogden, UT: USDA Forest Service, Int. Res. Sta.

Pelton, M. R. 1989. The impacts of oak mast on black bears in the southern Appalachians. In *Proc. Workshop on Southern Appalachian Mast Management*, ed. C.E. McGee, 7–11. Knoxville, Tennessee.

Post, E. and M. C. Forchhammer.2001. Pervasive influence of large-scale climate in the dynamics of a terrestrial vertebrate community. *BMC Ecology*. 1:5.

Potvin, F., J. Huot, and F. Duchesneau. 1981. Deer mortality in the Pohenegamook Wintering area, Quebec. *Canadian Field Naturalist*. 95:80–4.

Prasad, A. M., L. R. Iverson., S. Matthews., M. Peters. 2007-ongoing. *A climate change atlas for 134 forest tree species of the eastern United States [database]*. Delaware, Ohio: Northern Research Station, USDA Forest Service.

Prater, M. R., D. Obrist, J. A. Arnone III, and E. H. DeLuca. 2006. Net carbon exchange and evapotranspiration in postfire and intact sagebrush communities in the Great Basin. *Oecologia*. 146:595–607.

Renecker, L. A., and R. J. Hudson. 1986. Seasonal energy expenditure and thermoregulatory response of moose. *Canadian Journal of Zoology*. 64:322–27.

Renecker, Lyle A., and C. C. Schwartz. 1998. Food habits and feeding behavior. In *Ecology and management of the North American moose*, eds. A. W. Franzmann and C. C. Schwartz, 403–39. Washington, DC: Smithsonian Institution Press.

Renecker, L. A., and R. J. Hudson. 1990. Behavioral and thermoregulatory responses of moose to high ambient temperatures and insect harassment in aspen dominated forests. *Alces*. 26:66–72.

Roberts, T. H. 1993. The ecology and management of wintering woodcocks. *Biological Report*. 16:87–97.

Rogers, L. L., and E. L. Lindquist. 1991. Black bears and the oak resource in northeastern Minnesota. In *The oak resource in the upper Midwest—Implications for management*, eds. S. B. Laursen and J. F. DeBoe, 107–14. Minnesota, St. Paul: Minnesota Extension Serv., Univ. Minnesota.

Root, T. L., and S. H. Schneider. 1993. Can large-scale climatic models be linked with multi-scale ecological studies? *Conservation Biology*. 7: 256–70.

Root, T. L., and S. H. Schneider. 2002. Climate change: Overview and implications for wildlife. In *Wildlife responses to climate change: North American case studies*, eds. Washington DC: Island Press.

Rosene, W. 1969. *The bobwhite quail: Its life and management*. New Brunswick, NJ: Rutgers Univ. Press.

Ruble, P., and D. Urban. 1977. *Seasonal movements of the Ohio morning dove. Ohio fish and wildlife report no.6*. Ohio Division of Wildlife.

Schneider, S. H., and T. L Root, eds. 2002. *Wildlife responses to climate change: North American case studies*. Washington, DC: Island Press.

Seager, R., M. Ting, I. Held., Y. Kushnir, J. Lu, G. Vechhi, Huei-Ping Huang, N. Harnik, A. Leetmaa, Ngar-Cheung Lau, C. Li, J. Velez, N. Naik.. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*. April 9:DOI: 10.1126/science.1139601.

Service, R. F. 2004. As the West goes dry. *Science*. 303:1,124–7.

Shugart, H., R. Sedjo, and B. Sohngen. 2003. *Forests and global climate change: Potential impacts on U.S. forest resources. A report prepared for the Pew Center on Global Climate Change*.

Stanford, J. A. 1972. Bobwhite quail population dynamics: relationships of weather, nesting, production patterns, fall populations characteristics and harvest. *Proceedings of the National Bobwhite Quail Symposium*. 1:115–39.

Straw, J. A., Jr., D. G. Krementz, M. W. Olinde, and G. F. Sepik. 1994. American woodcock. In *Migratory shore and upland game bird management in North America*, eds. T. C. Tacha, and C. E. Braun, 96–116. Washington, DC: International Association of Fish and Wildlife Agencies.

Swank, W. G., and S. Galliozioli. 1954. The influence of hunting and rainfall on Gambel's quail populations. *Transactions of the North American Wildlife and Natural Resources Conference*. 19:283–96.

Taylor, A. H. 1995. Forest expansion and climate change in the mountain hemlock (*Tsuga mertensiana*) zone, Lassen Volcanic National Park, California, USA. *Arctic and Alpine Research*. 27(3):207–16.

Thompson, F.R., III, and D. R. Dessecker. 1997. Management of early-successional communities in central hardwood forests, general technical report NC-195. U.S. Department of Agriculture Forest service,

Thompson, R. S., K. H. Anderson, and P. J. Bartlein. 2003. *Assessment of potential future vegetation changes in the Southwestern United States*. USDI. U.S. Geological Survey. http://geochange.er.usgs.gov/sw/impacts/biology/veg_chg_model/

Thompson, A. M., R. Brown, N. Rosenberg, R.C. Izaurralde, and V. Benson. 2005. Climate change impacts for the conterminous USA: An integrated assessment. Part 3. Dryland production of grain and forage crops. *Climatic Change*. 69:43–65.

Travis, J. M. J. 2003. Climate change and habitat destruction: a deadly anthropogenic cocktail. *Proc. R. Soc. Lond*. 270:467–73.

Union of Concerned Scientists. 2006. *Climate change in the U.S. Northeast*. Cambridge, MA: Northeast Climate Impact Assessment.

U.S. Fish and Wildlife Service. 2002. *2001 National survey of fishing, hunting and wildlife-associated recreation*. Washington, DC: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service. 2007. *2006 National survey of fishing, hunting and wildlife-associated recreation: National overview*. Washington, DC: U.S. Fish and Wildlife Service.

Wake, C. P., and A. Markham. 2005. *Indicators of climate change in the Northeast 2005. Clean Air—Cool Planet*. Portsmouth, NH:.

Walther, G. R., E, Post, P. Convey, A. Mensel, C. Parmesan, T.J.C. Beebee, J. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological response to recent climate change. *Nature*. 416:389–95.

Wang, G., N. T. Hobbs, F. Singer, D. Ojima, and B. Lubow. 2001. Impacts of climate change on elk population dynamics in Rocky Mountain National Park, Colorado, U.S.A. *Climatic Change*. 54:205–23.

Westerling, A. L., T. J. Brown, A. Gershunov, D. R. Cayan and M. D. Dettinger. 2003. Climate and wildfire in the western United States. *Bulletin of the American Meteorological Society*. 84(5):595–604.

Westerling, A.L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. *Science*. 313 (5,789): 940–3.

Whitham, T. G. 2005. Community and evolutionary consequences of record drought in the Southwest. MTNCLIM.

Wigmosta, M. S., and L. R. Leung. 2002. Potential impacts of climate change on streamflow and flooding in snow-dominated forested basins. In *Environmental changes and geomorphic hazards in forests*, ed. R. C. Sidle, 7–23.

Williamson, S. J. 2003. *White-tailed deer harvest management and goal setting in the Northeast*. Washington DC: The Wildlife Management Institute.

Wooton, B. M. and M.D. Flannigan. 1993. Length of the fire season in a changing climate. *Forestry Chronicle*. 69:198-192.

Zolbrod, A. N., and D. L. Peterson. 1999. Response of high-elevation forests in the Olympic Mountains to climatic change. *Canadian Journal of Forest Research*. 29(12):1,966–78.