Annex A: Case Studies

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Annex Contents

RMNP managers have been proactive in addressing many of the resource issues faced by the Park. Yet they recognize there is still more to be done, particularly in human resource management. Complex issues require broad and flexible ways of thinking about them, and creative new tools for their management. Professional development programs for current resource managers, rangers, and park managers could be strengthened so that all employees understand the natural resources that are under the protection of the NPS, the causes and consequences of threats to these resources, and the various management options that are available.

The skill sets for new National Park Service (NPS) employees should reflect broad systems training. University programs for natural resource management could shift from traditional training in fisheries, wildlife, or recreational management to providing more holistic ecosystems management training. Curricula at universities and colleges could also emphasize critical and strategic thinking that embraces science and scientific tools for managing adaptively, and recognizes the need for lifelong learning. Climate change can serve as the catalyst for this new way of managing national park resources. Indeed, if the natural resources entrusted to RMNP—and other parks—are to persist and thrive under future climates, the Park Service will need managers that see the whole as well as the parts, and act accordingly.

A3 National Wildlife Refuges Case Study

A3.1 Alaska and the Central Flyway

Warming trends in Alaska and the Arctic are more pronounced than in southerly regions of the United States, and the disproportionate rate of warming in Alaska is expected to continue throughout the coming century (IPCC, 2001) (see Fig. 5.3a in the National Wildlife Refuges chapter). Migratory birds are one of the major trust species groups of the National Wildlife Refuge System (NWRS), and birds that breed in Alaska traverse most of the system as they use portions of the Pacific, Central (see Fig. A3.1), Mississippi, and Atlantic Flyways during their annual cycle. Projected warming is expected to encompass much of the Central Flyway but is expected to be less pronounced in the remaining flyways (IPCC, 2001). Historical records show strong warming in the Dakotas and a tendency toward cooling in the southern reaches of the flyway (see Fig. 5.3a in the National Wildlife Refuges chapter). Pervasive and dramatic habitat shifts (see Fig. 5.9 in the National Wildlife Refuges chapter) are projected in Alaska and especially throughout the Central Flyway by the end of the century.

Figure A3.1. Central Flyway Waterfowl Migration Corridor.[17]

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[17] **U.S. Fish and Wildlife Service**, 2007: Central flyway. U.S. Fish and Wildlife Service, Pacific Flyway Council Website, http://pacificflyway.gov/Documents/Central_map.pdf, accessed on 6-2-0007.

Migration is an energetically costly and complex life history strategy (Arzel, Elmberg, and Guillemain, 2006). The heterogeneity in warming and additional stressors along migratory pathways along with their potential effects on productivity and population levels of migratory birds emphasize the importance of strong interconnections among units of the NWRS and the need for a national vision and a comprehensive management strategy to meet the challenge of climate change in the next century. The following case study examines warming and additional stressors, as well as management options in Alaska and the Central Flyway, which together produce 50–80% of the continent's ducks (Table A3.1).

A3.1.1 Current Environmental Conditions

A3.1.1.1 Changes in Climate and Growing Season Duration

Climate

In recent decades, warming has been very pronounced in Alaska, with most of the warming occurring in winter (December–February) and spring (March–May) (Serreze *et al.*, 2000; McBean *et al.*, 2005). In western and central Canada, the increases in air temperature have been somewhat less than those observed in Alaska (Serreze *et al.*, 2000). While precipitation has remained largely stable throughout Alaska and in Canada in recent decades, several lines of evidence indicate that Alaska and western Canada are experiencing increased drought stress due to increased summer water deficits (Barber, Juday, and Finney, 2000; Oechel *et al.*, 2000; Hogg and Bernier, 2005; Hogg, 2005; Hogg, Brandt, and Hochtubajda, 2005).

Growing Season Duration

The seasonal transition of northern ecosystems from a frozen to a thawed condition represents the closest analog to a biospheric "on-off switch" that exists in nature, dramatically affecting ecological, hydrologic, and meteorological processes (Running *et al.*, 1999). Several studies based on remote sensing indicate that growing seasons are changing in high-latitude regions (Dye, 2002; McDonald *et al.*, 2004; McGuire *et al.*, 2004; Smith, Saatchi, and Randerson, 2004; Euskirchen *et al.*, 2006). These studies identify earlier onset of thaw in northern North America, but the magnitude of change depends on the study. Putting together the trends in the onset of both thaw and freeze, Smith, Saatchi, and Randerson (2004) indicate that the trend for longer growing seasons in northern North America (3 days per decade) is primarily due to later freezing. However, other studies indicate that the lengthening growing season in North America is primarily due to earlier thaw (Dye, 2002; Euskirchen *et al.*, 2006). Consistent with earlier thaw of terrestrial ecosystems in northern North America, lake ice has also been observed to be melting earlier across much of the Northern Hemisphere in recent decades (Magnuson *et al.*, 2000). The study of Euskirchen *et al.* (2006) indicates that trends for earlier thaw are generally stronger in Alaska than in the Central Flyway of Canada and northern United States, but trends for later freeze are stronger in the Central Flyway of Canada and the northern United States than in Alaska.

A3.1.1.2 Changes in Agriculture

Agriculture and migratory waterfowl are intimately related because waterfowl make significant use of agricultural waste on staging and wintering areas. Much of the agricultural production in the United States is centered in the Central Flyway. Dynamic markets, government subsidies, cleaner farming practices, and irrigation have changed the mix, area, and distribution of agricultural products during the past 50 years (Krapu, Brandt, and Cox, Jr., 2004). Genetically engineered crops and resultant changes in tillage practices and the use of pesticides and herbicides, as well as development of drought resistant crop varieties, will likely add heterogeneity to the dynamics of future crop production. While corn acreage has remained relatively stable during the past 50 years, waste corn available to waterfowl and other wildlife declined by one-quarter to one-half during the last two decades of the 20th century, primarily as a result of more efficient harvest (Krapu, Brandt, and Cox, Jr., 2004). While soybean acreage has increased by approximately 600% during the past 50 years, metabolizable energy and digestibility of soybeans is noticeably less than for corn, and waterfowl consume little, if any, soybeans (Krapu, Brandt, and Cox, Jr., 2004). These changes in availability of corn and soybeans suggest that nutrition of waterfowl on migratory staging areas may be compromised (Krapu, Brandt, and Cox, Jr., 2004). If a future emphasis on bio-fuels increases acreage in corn production, the potential negative effects of the recent increase in soybean production on waterfowl energetics may be ameliorated.

A3.1.1.3 Changes in Lake Area

Analyses of remotely sensed imagery indicate that there has been a significant loss of closed-basin water bodies (water bodies without an inlet or an outlet) over the past half century in many areas of Alaska (Riordan, Verbyla, and McGuire, 2006). Significant water body losses have occurred primarily in areas of discontinuous permafrost (Yoshikawa and Hinzman, 2003; Hinzman *et al.*, 2005; Riordan, Verbyla, and McGuire, 2006) and subarctic areas that are permafrost-free (Klein, Berg, and Dial, 2005). In an analysis of approximately 10,000 closed-basin ponds across eight study areas in Alaska with discontinuous permafrost, Riordan, Verbyla, and McGuire (2006) found that surface water area of the ponds decreased by 4–31% while the total number of closed-basin ponds surveyed within each study region decreased by 5–54% (Riordan, Verbyla, and McGuire, 2006). There was a significant increasing trend in annual mean surface air temperature and potential evapotranspiration since the 1950s for all the study regions, but there was no significant trend in annual precipitation during the same period. In contrast, it appears that lake area is not changing in regions of Alaska with continuous permafrost (Riordan, Verbyla, and McGuire, 2006). However, in adjacent Canada, significant water body losses have occurred in areas dominated by permafrost (Hawkings, 1996).[18]

Warming of permafrost may be causing a significant loss of lake area across the landscape because the loss of permafrost may allow surface waters to drain into groundwater (Yoshikawa and Hinzman, 2003; Hinzman *et al.*, 2005; Riordan, Verbyla, and McGuire, 2006). While permafrost generally restricts infiltration of surface water to the sub-surface groundwater, unfrozen zones called taliks may be found under lakes because of the ability of water to store and vertically transfer heat energy. As climate warming occurs, these talik regions can expand and provide lateral subsurface drainage to stream channels. This mechanism may be important in areas that have discontinuous

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[18] See also **Hawkings**, J. and E. Malta, 2000: Are northern wetlands drying up? A case study in the Old Crow Flats, Yukon. *51st AAAS Arctic Science Conference*.

permafrost such as the boreal forest region of Alaska. However, the reduction of open water bodies may also reflect increased evaporation under a warmer and effectively drier climate in Alaska, as the loss of open water has also been observed in permafrost-free areas (Klein, Berg, and Dial, 2005).

In the Prairie Pothole Region (PPR) of the Central Flyway, changes in climate accounted for 60% of the variation in the number of wet basins (Larson, 1995), with partially forested parklands being more sensitive to increasing temperature than treeless grasslands. When wet basins are limited, birds may overfly grasslands for parklands and then proceed even farther north to Alaska in particularly dry years in the pothole region. Small- and large-scale heterogeneity in lake drying may first cause a redistribution of birds and, if effects are pervasive enough, may ultimately cause changes in the productivity and abundance of birds. Fire and vegetation changes in the PPR and in Alaska may exacerbate these effects.

A3.1.2 Projections and Uncertainties of Future Climate Changes and Responses

A3.1.2.1 Projected Changes in Climate and Growing Season Duration

Climate

Projections of changes in climate during the 21st century for the region between 60° and 90° N indicate that air temperature may increase approximately 2°C (range ~1–4°C among models) and that precipitation may increase approximately 12% (range ~8–18% among models) (Kattsov and Källén, 2005). The increase in precipitation will be due largely to moisture transport from the south, as temperature-induced increases in evaporation put more moisture into the atmosphere. Across model projections, increases in temperature and precipitation are projected to be highest in winter and autumn. Across the region, there is much spatial variability in projected increases in temperature and precipitation, both within a model and among models. For any location, the scatter in projected temperature and precipitation changes among the models is larger than the mean temperature and precipitation change projected among the models (Kattsov and Källén, 2005).

In comparison with northern North America, climate model projections indicate that the Central Flyway of the United States will warm less with decreasing latitude (Cubasch *et al.*, 2001). Mid-continental regions such as the Central Flyway are generally projected to experience drying during the summer due to increased temperature and potential evapotranspiration that is not balanced by increases in precipitation (Cubasch *et al.*, 2001). Projections of changes in vegetation suggest that most of the Central Flyway (see Fig. A3.1 and Fig. 5.9d in the National Wildlife Refuges chapter) will experience a biome shift by the latter part of the 21st century (Bachelet *et al.*, 2003; Lemieux and Scott, 2005).

Growing Season Duration

One analysis suggests that projected climate change may increase growing season length in northern and temperate North America by 0.4–0.5 day per year during the 21st century (Euskirchen *et al.*, 2006), with stronger trends for more northern latitudes. This will be caused almost entirely by an earlier date of thaw in the spring, as the analysis indicated essentially no trend in the date of freeze. Analyses of this type need to be conducted across a broader range of climate scenarios to determine if this finding is robust. If so, then one inference is that lake ice would likely melt progressively earlier throughout northern and temperate North America during the 21st century.

A3.1.2.2 Changes in Lake Area

It is expected that the documented loss of surface water of closed-basin ponds in Alaska (Riordan, Verbyla, and McGuire, 2006) and adjacent Canada will continue if climate continues to warm in the 20th century. The ubiquitous loss of shallow permafrost (Lawrence and Slater, 2005) as well as the progressive loss of deep permafrost (Euskirchen *et al.*, 2006) are likely to enhance drainage by increasing the flow paths of lake water to ground water. Also, it is likely that enhanced evaporation will increase loss of water. While projections of climate change indicate that precipitation will increase, it is unlikely that increases in precipitation will compensate for water loss from lakes from increased evaporation. An analysis by Rouse (1998) estimated that if atmospheric CO_2 concentration doubles, an increase in precipitation of at least 20% would be needed to maintain the present-day water balance of a subarctic fen. Furthermore, Lafleur (1993) estimated that a summer temperature increase of 4^{o}C would require an increase in summer precipitation of 25% to maintain present water balance. These changes in precipitation to maintain water balance are higher than the range of precipitation changes (8–18%) anticipated for the 60–90^{o} N region in climate model projections (Kattsov and Källén, 2005).

A3.1.3 Non-Climate Stressors

In Alaska, climate is the primary driver of change in habitat value for breeding migrants through its effects on length of the ice-free season (U.S. Fish and Wildlife Service, 2006) and on lake drying (Riordan, Verbyla, and McGuire, 2006). Throughout the Central Flyway, projected major changes in vegetation are expected to occur by the end of the century (see Fig. 5.9d in the National Wildlife Refuges chapter) (Bachelet *et al.*, 2003; Lemieux and Scott, 2005). Additional stressors in the Central Flyway include competing land uses on staging areas outside the NWRS, changes in the distribution and mix of agricultural crops that may favor/disfavor foraging opportunities for migrants on migratory and winter ranges, and anthropogenic disturbance that may affect nutrient acquisition strategies for migrants in both spring and fall by restricting access to foraging areas. In southern regions of the Central Flyway, rising sea level and increasing urbanization may cause reductions in refuge area and increased insularity of remaining fragments. All stressors contribute to uncertainty in future distribution and abundance of birds. Climate dominates on Alaskan breeding grounds, and additional stressors complicate estimation of the net effects of climate on migrants and their use of staging and wintering areas in central and southern portions of the Central Flyway.

A3.1.4 Function of Alaska in the National Wildlife Refuge System

Alaska is a major breeding area for North American migratory waterfowl. Alaska and the adjacent Yukon Territory are particularly important breeding areas for American widgeon (~38% of total in 2006), green-winged teal (~31%), northern pintail (~31%) and greater and lesser scaup combined (~27%). Substantial proportions of the North American populations of western trumpeter swans, Brant geese, light geese (Snows) and greater sandhill cranes also breed in Alaska (U.S. Fish and Wildlife Service, 2006).

Alaska both contributes to NWRS waterfowl production and provides a vehicle to conceptually integrate most of the NWRS. Waterfowl that breed in Alaska make annual migrations throughout North America and are thus exposed to large-scale heterogeneity in potential climate warming effects. Migrants use the Pacific, Central, Mississippi, and to a lesser extent the Atlantic, Flyways on their annual spring and fall migrations. Their migration routes extend to wintering grounds as far south as Central and South America.

The spatial heterogeneity in warming, variable energetic demands among life history stages, and variable number and intensity of non-climate stressors along the migratory pathways creates substantial complexity within the NWRS. This complexity emphasizes that performance (*e.g.*, weight gain, survival, reproduction) of any species in any life history stage at any location within a region may be substantially affected by synergistic effects of climate and non-climate stressors elsewhere within the NWRS. A successful response to this complexity will require a national vision of the problems and solutions, and creative local action.

A3.1.4.1 Potential Effects of Climate Change on the Annual Cycle of Alaska Breeding Migrants

Abundance of waterfowl arriving on the breeding grounds is a function of survival and nutritional balance on the wintering grounds and on spring migration staging areas. Two types of breeding strategies are recognized. “Income” breeders obtain the energy for egg production primarily from the nesting area while “capital” breeders obtain energy for egg production primarily from wintering and spring staging areas. Regardless of whether species are income or capital breeders, food availability in the spring on breeding grounds in the Arctic is important to breeding success (Arzel, Elmberg, and Guillemain, 2006).

Breeding conditions for waterfowl in Alaska depend largely on the timing of spring ice melt (U.S. Fish and Wildlife Service, 2006). In the short term, earlier springs that result from warming likely advance green-up and ice melt, thus increasing access to open water and to new, highly digestible vegetation growth and to terrestrial and aquatic invertebrates. Such putative changes in open water and food resources in turn may influence the energetic balance and reproductive success of breeders and the performance of their offspring. Flexibility in arrival and breeding dates may allow some migrants to capitalize on earlier access to resources and increase the length of time available for re-nesting attempts and fledging of young. Some relatively late migrants, such as scaup (Austin *et al.*, 2000), may not be able to adapt to warming induced variable timing of open water and food resources, and thus may become decoupled from their primary resources at breeding.

In the long term, increased temperatures and greater length of the ice-free season on the breeding grounds may contribute to permafrost degradation and long-term reduction in the number and area of closed-basin ponds (Riordan, Verbyla, and McGuire, 2006), which may reduce habitat availability, particularly for diving ducks. Countering this potential reduction in habitat area may be changes in wetland chemistry and aquatic food resources. Reductions in water volume of remaining ponds may result in increased nutrient or contaminant concentrations, increases in phytoplankton, and a shift from an invertebrate community dominated by benthic amphipods to one dominated by zooplankton in the water column.[19] This has variable implications for foraging opportunities for waterfowl that make differential use of shallow and deep water for foraging. The net effects of lake drying on waterfowl populations in Alaska are not known at this time, but the heterogeneity in relatively local reductions and increases in lake area in relation to breeding waterfowl survey lines (see Fig. A3.2) may make it difficult to detect any effects that have occurred.

Figure A3.2. Heterogeneity in closed-basin lakes with increasing and decreasing surface area, 1950–2000, Yukon Flats NWR, Alaska. Net reduction in lake area was 18% with the area of 566 lakes decreasing, 364 lakes increasing, and 462 lakes remaining stable. Adapted from Riordan, Verbyla, and McGuire (2006).

Departure of waterfowl from breeding grounds in the fall may be delayed by later freeze-up. The ability to prolong occupancy at northern latitudes may increase successful fledging and allow immature birds to begin fall migration in better body condition. Later freeze-up may allow immature birds, particularly large species such as swans, to delay their rate of travel southward and increase their opportunities for nutrient intake during migration. Changes in the timing of arrival at various southern staging areas may affect waterfowl's access to and availability of resources such as waste grain and may result in re-distribution of birds along the migration route as they attempt to optimize foraging opportunities. The primary effect of this later departure and reduced rate of southward migration may be observed in more northerly fall distributions of species and a northward shift in harvest locations as has already been observed for some species. Later freeze-up and warmer winters may allow species to "short-stop" their migrations and winter farther north. Observations by Central Flyway biologists indicate that 1) numbers of wintering white-fronted geese numbers have increased in Kansas in recent years, evidently as a result of diminished proclivity to travel further southward to Texas and Mexico for the winter; 2) portions of the tundra swan population now winter in Ontario rather than continuing southward; and 3) the winter distribution of Canada geese has shifted to more northern latitudes. The energetic and population implications of these putative northerly shifts in distribution in winter will ultimately be determined by the interaction of migratory costs, food availability, non-climate stressors such as anthropogenic disturbance and shifting agricultural practices, and harvest risk.

Earlier spring thaw may advance the timing of spring migration and increase the amount of time that some species, such as greater sandhill cranes, spend on their staging grounds in Nebraska. Increased foraging time during spring migration should benefit larger species, which tend to accumulate nutrients for breeding on the wintering grounds and on

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[19] **Corcoran**, R.M., 2005: Lesser scaup nesting ecology in relation to water chemistry and macroinvertebrates on the Yukon Flats, Alaska. Masters Thesis. Department of Zoology and Physiology, University of Wyoming, Laramie, 1-83.

spring migration stopovers, more than smaller species, which tend to obtain nutrients necessary for breeding while on the breeding ground (Arzel, Elmberg, and Guillemain, 2006) although the explicit resolution of this concept needs to be quantified on a species-by-species basis. Warming-induced changes in the timing of forage availability on spring migration routes may cause redistribution of waterfowl or dietary shifts as they attempt to maximize the results of their strategic feeding prior to breeding. Increased understanding of the relative value of spring migration staging areas to reproductive success and annual population dynamics of different waterfowl species is a critical need in order to adapt management strategies to a changing climate.

A3.1.4.2 Implications for Migrants

Climate change adds temporal and spatial uncertainty to the problems associated with accessing resources necessary to meet energy requirements for migration and reproduction. Because birds are vagile, the primary near-term expected response to climate change is redistribution as birds seek to maintain energy balance.

Lengthened ice-free periods may result in earlier arrival on breeding grounds, delayed migration (*e.g.,* trumpeter swans and greater sandhill cranes), and wintering farther north (*e.g.,* white-fronted geese) among other phenomena. Warmer conditions that result in lake drying may result in birds over-flying normal breeding areas to areas farther north (*e.g.,* pintail ducks). Warmer temperatures may reduce water levels but increase nutrient levels in warmed lakes. Community composition of the invertebrate food base may change and life cycles of invertebrates may be shortened; amphipods may be disfavored and zooplankton favored with differential implications for birds with different feeding strategies. Changes in hydrologic periods may cause nest flooding or make nesting habitats that are normally isolated by floodwater accessible to predators. Either effect may alter nest and nesting hen survival.

The primary challenge to migratory waterfowl, and all other trust species for that matter, is that the spatial timing of resource availability may become decoupled from need. For example, late nesters such as lesser scaup may be hampered by pulsed resources that appear before nesting. Other species such as trumpeter swans may benefit from increased ice-free periods that enhance the potential to fledge young and provision them on southward migrations. Earlier and longer spring staging periods may benefit energetic status of migrating sandhill cranes. Harvest may shift northward as birds delay fall migrations.

Alaska and the Central Flyway (see Fig. A3.1) encompass substantial spatial variation in documented (see Fig. 5.3 in the National Wildlife Refuges chapter) and expected climate warming. This spatial variation in warming is superimposed on the variable demands of spatially distinct seasonal life history events (*e.g.,* nesting, staging, wintering) of migrants. Variance in success in any life history stage may affect waterfowl performance in subsequent stages at remote locations, as well as the long-term abundance and distribution of migrants. Performance of migrants at one location in one life history stage may be affected by climate in a different life history stage at a different location. The superimposition of spatially variable warming on spatially separated life history events creates substantial complexity in both documenting and developing an understanding of the potential effects of climate warming on major trust species of the NWRS. This unresolved complexity does offer a vehicle to focus on the interconnection of spatially separated units of the system and to foster a national and international vision of a management strategy for accommodating net climate warming effects on system trust species.

A3.1.5 Management Option Considerations

A3.1.5.1 Response Levels

Response to climate change challenges must occur at multiple integrated scales within the NWRS and among partner entities. Individual symptomatic challenges of climate change must be addressed at the refuge level, while NWRS planning is the most appropriate level for addressing systemic challenges to the system. Flyway Councils, if they can be encouraged to include a regular focus on climate change, may provide an essential mid-level integration mechanism. Regardless of the level of response, the immediate focus needs to be on what can be done.

A3.1.5.2 Necessary Management Tools

Foremost among necessary management tools are formal mechanisms to increase inter-agency communication and long-term national level planning. This could be accomplished through the establishment of an interagency public lands council or other entity that facilitates collaboration among federal land management agencies, NGOs, and private stakeholders. Institutional insularity of agencies and stakeholders at national and regional levels needs to be eliminated. The council should foster intra- and inter-agency climate change communication networks, because *ad hoc* communication within or among agencies is inadequate. Explicit outreach, partnerships and collaborations should be identified and target dates for their implementations drafted. In addition, the council should develop and implement national and regional coordination mechanisms and devise mechanisms for integrating potential climate effects into management decisions. The council needs to increase effective communication among wildlife, habitat, and climate specialists.

Within the NWRS there needs to be adequate support to insure the development of an increased capacity to rigorously model possible future conditions, and explicit recognition that spatial variation in climate has differential effects on life cycle stages of migrants; performance in one region may be affected by conditions outside a region. Enhanced ability to assist migratory trust species when “off-refuge” and enhanced ability to facilitate desirable range expansions within and across jurisdictions are needed.

Comprehensive Plans and Biological Reviews need to routinely address expected effects of climate change and identify potential mechanisms for adaptation to these challenges. The ability to effectively employ plans and reviews as focus mechanisms for potential climate change effects will be enhanced by institutionalization of climate change in job descriptions and increased training for refuge personnel.

A3.1.5.3 Barriers to Adaptation

The primary barriers to adaptation include the lack of a spatially explicit understanding of the heterogeneity and degree of uncertainty in effects of changing climate on seasonal habitats of trust species—breeding, staging and wintering—and their implications for populations. Currently there is concern about effects of climate change on trust species, but insufficient information on which to act. This lack of understanding hampers the development of an explicit national vision of potential net effects of climate change on migrants. In addition, the lack of a secure network of protected staging areas, similar to the established network of breeding and wintering areas, limits the ability of the NWRS to provide adequate security for migratory trust species in a changing climate. More efficient use of all types of resources will be needed to minimize these national-level barriers to adaptation of the NWRS to climate change.

A3.1.5.4 Opportunities for Adaptation

One of the greatest opportunities may lie in creating an institutional culture that rewards employees for being proactive catalysts for adaptation. This would require the acceptance of some degree of failure due to the uncertain nature of the magnitude and direction of climate change effects on habitats and populations. In addition, managers and their constituencies could be energized to mount successful adaptation to climate change by emphasizing the previous successful adaptations by the U.S. Fish and Wildlife Service (USFWS) to the first three management crises of market hunting, dust bowl habitat alteration, and threatened and endangered species management.

The capacity to provide more rigorous projections of possible future states will require the creative design of inventory and monitoring programs that enhance detection of climate change effects, particularly changing distributions of migratory trust species. Monitoring programs that establish baseline data regarding the synergy of climate change and other stressors (*e.g.*, contaminants, habitat fragmentation) will especially be needed. These monitoring programs will need to be coordinated with private, NGO and state and federal agency partners.

In stakeholder meetings, refuge biologists were emphatic that they needed more biological information in order to clearly define and to take preemptive management actions in anticipation of climate change. Thus, effective adaptation to climate change will require education, training and long-term research-management partnerships that are focused on adaptive responses to climate change. The following strategy is proposed for the activities of such a research-management partnership:

- Synthesize extant biological information relevant to biotic responses to climate change;
- Educate and train refuge mangers and other staff regarding climate change, its potential ecological effects, and the changes in management and planning that may be necessary;
- Evaluate possible management and policy responses to alternative climate change scenarios in multiple regional and national workshops;
- Conduct workshops involving managers, researchers and stakeholders to identify research questions relevant to managing species in the face of climate change;

- Conduct research on questions relevant to managing species in the face of climate change. This may require the development of tools that are useful for identifying the range of responses that are likely;
- Apply management actions in response to biotic responses that emerge as likely from such research; and
- Evaluate of the effectiveness of management actions and modification of management actions in the spirit of adaptive management.

Synthesis workshops should be held every few years to identify what has been learned and to redefine questions relevant to the management of species that depend on the NWRS.

There are a number of examples of recent climate-change-related challenges and potential and implemented adaptations in Alaska and the Central Flyway:

Potential adaptations:

- The development of a robust understanding of the relative contribution of various NWRS components to waterfowl performance in a warming climate is an immediate challenge. There is a clear research need to elucidate the relative contribution of staging and breeding areas to energetics and reproductive performance of waterfowl, and to clarify the interdependence of NWRS elements and their contributions to waterfowl demography. A flyway-scale perspective is necessary to understand the importance of migratory staging areas and to assess the relative importance of endogenous/exogenous energetics to reproduction and survival. These studies should address, in the explicit context of climate warming, strategic feeding by waterfowl, temporal shifts in diets, and the spatial and temporal implications of climate induced changes in the availability of various natural and agricultural foods (Arzel, Elmberg, and Guillemain, 2006).

- Providing adequate spatial and temporal distribution of migratory foraging opportunities is a chronic challenge to the NWRS. Spring staging areas are under-represented and this problem is likely to be exacerbated by a warming climate. It will be necessary to strengthen and clarify existing partnerships with private, NGO, and state and federal entities and to identify and develop new partnerships throughout the NWRS in order to provide a system of staging areas that are extensive and resilient enough to provide security for migratory trust species. Strategic system growth through fee-simple and conservation easement acquisition will be a necessary component of successful adaptation.

Implemented adaptations:

- Indigenous communities on the Aleutian Island chain (Alaska Maritime NWR) are concerned about the potential effects of increased shipping traffic in new routes that may become accessible in a more ice-free Arctic Ocean. Previous introductions of non-endemic species to islands have had severe negative effects on nesting Aleutian Canada geese. The ecosystem management mandate of the refuge facilitates a leadership role for the refuge that has been implemented through 1) development of monitoring partnerships that are designed to detect the appearance of invasive species and of contaminants, and 2) initiation of timely prevention/mitigation programs.

- Indigenous peoples that depend on Interior Alaska NWRs are concerned about the potential effects of climate-induced lake drying and changing snow conditions on their seasonal access to subsistence resources, and on the availability of waterfowl for subsistence harvest. The refuges have promoted enhanced capacity for projecting possible future conditions, and have educated users regarding observed and expected changes while clarifying conflicting information on the magnitude and extent of observed changes in lake number and area and in snow conditions.

- Warming-induced advances in the timing of ice-out can bias waterfowl population indices that are derived from traditional fixed-date surveys. The Office of Migratory Bird Management has developed quantitative models to project the arrival date of migrants based on weather and other records. This allows the office to dynamically adjust survey timing to match changing arrival dates and thereby reduce bias in population indices.

A4 Wild and Scenic Rivers Case Studies

As emphasized throughout the Wild and Scenic Rivers (WSR) chapter, the effects of climate change on rivers will vary greatly throughout the United States depending on local geology, climate, land use, and a host of other factors. To illustrate the general “categories” of effects, we have selected three WSRs to highlight in the following case studies (Box A4.1). We selected these rivers because they span the range of some of the most obvious issues that managers will need to grapple with as they develop plans for protecting natural resources in the face of climate change. Rivers in the Southwest, such as the Rio Grande, will experience more severe droughts at a time when pressures for water extraction for growing populations are increasing. Rivers near coastal areas, such as the Wekiva, face potential impacts from sea level rise. A combination of groundwater withdrawals and sea level rise may lead to increases in salinity in the springs that feed this river. Rivers that are expected to experience both temperature increases and an increased frequency of flooding, such as the Upper Delaware, will need proactive management to prevent loss or damage to ecosystem services.

There are also key outstandingly remarkable values that the WSR program focuses on. One of those areas is anadromous fish. Box A4.2 provides an overview of potential climate change impacts to anadromous fish and offers management actions that may be taken to lessen those impacts.

A4.1 Wekiva River

The Wekiva River Basin, located north of Orlando, in east-central Florida, is a complex ecological system of streams, springs, seepage areas, lakes, sinkholes, wetland prairies, swamps, hardwood hammocks, pine flatwoods, and sand pine scrub communities. Several streams in the basin run crystal clear due to being spring-fed by the Floridan