5 National Wildlife Refuges

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Chapter Structure

5.1 Background and History
Describes the origins of the National Wildlife Refuge System (NWRS), the multiple "purposes" that guide its management, and the formative factors that shaped its mission and goals

5.2 Current Status of Management System
Reviews existing system stressors, management practices currently used to address the NWRS' goals, and the implications of climate change on an ecoregional basis

5.3 Adapting to Climate Change
Discusses approaches to adaptation for planning and management in the context of climate change both within and outside refuge borders

5.4 Case Study: Alaska and the Central Flyway
Explores methods for and challenges to incorporating climate change into management activities and plans in Alaska and along the Central Flyway

5.5 Conclusions

5.1 Background and History

5.1.1 Introduction

The National Wildlife Refuge System (NWRS)—the largest system of protected areas in the world established primarily to manage and protect wildlife—was born in and has evolved in crises. The first crisis was the threat to egrets, herons, and other colonial nesting waterbirds caused by hunting for feathers and plumes for the millinery trade; the second was the loss of wildlife habitat, accelerated by the Great Depression, drought, and agricultural practices in the dust bowl era. The third—still ongoing—is species extinction triggered by a growing human population and its demand on natural resources. The first two crises were largely regional in their influence and impact. Although the third crisis—extinction—is international, the response to it is local. The influence of the fourth crisis—climate change—is global and covers the full breadth and depth of the NWRS.

In response to the first threat, President Theodore Roosevelt established America's first national wildlife refuge (NWR), Pelican Island, Florida. Nearly three decades later, in response to depression-era threats, Ira Gabrielson and Ding Darling had a vision for a system of refuges that would ensure the survival of recreationally viable populations of waterfowl for future generations of Americans. Whereas the first response resulted in an ad hoc collection of refuges, the second was the birth of the NWRS as the vision of Gabrielson and Darling, which was carried forward by three generations of wildlife biologists and managers. The U.S. Fish and Wildlife Service (USFWS), which manages the NWRS, has responded to the current extinction crisis in a number of ways, including the establishment and management of 61 refuges to recover threatened and endangered species. That response has been insufficient to meet the challenge of biodiversity loss, which will only progress as it is exacerbated by climate change.

Now, more than a century after Theodore Roosevelt established Pelican Island NWR, 584 refuges and nearly 30,000 waterfowl production areas encompassing 93 million acres and spanning habitats as diverse as tundra, tropical rainforests, and coral reefs, dot the American landscape (Figs. 5.1 and 5.2). Today, climate change threatens not only the existence of species and ecosystems on individual refuges but also across the entire U.S. landscape and thus the diversity, integrity, and health of the NWRS itself. These refuges—conservation lands—support many activities, especially wildlife-dependent outdoor recreation, which attracts more than 35 million visitors a year (Caudill and Henderson, 2003), and other economic activities where compatible with refuge purposes.

Figure 5.1. Structure of the NWRS. Adapted from Fischman (2003), Refuge Administration Act (1966), and FWS Regulations – CFR 50.

Figure 5.2. The National Wildlife Refuge System. Adapted from Pidgorna (2007)

Direct uses of the NWRS such as wildlife-dependent outdoor recreation and farming are the most readily valued in monetary terms. Ecological functions that provide services to humans include water filtration in wetlands and aquifers, buffering from hurricanes by coastal wetlands, and maintenance of pollinator species that pollinate agricultural plants off the NWRS. A recent estimate of the value of ecosystem services provided by the NWRS was $29.8 billion/year (Ingraham, Foster, and Czech, In Press).

Refuges were established as fixed protected areas, conservation fortresses, set aside to conserve fish, wildlife, and plant resources and their habitats. The NWRS design principles assumed an environment that varied but did not shift. Populations and ecosystems were thought to be in dynamic equilibrium, where species could move freely among the refuges and threats could be dealt with through local management actions. Much has changed since then. The population of the United States in 1903 was 76 million, and gross domestic product (GDP) was $300 billion[1] with no interstate highways. On the 100th anniversary of Pelican Island NWR America's population reached 290 million, its GDP increased by a factor of 36, and more than 46,000 miles of interstate highways both linked and fragmented America's landscape. The assumption of plant and animal populations moving freely among refuges could no longer be made. Yet, with climate change the need for such free movement is greater. It is now apparent that species' ranges are dynamic, varying in space and time. Climate change exacerbates the misfits between the existing NWRS and ecological realities. Coastal refuges face inundation, migrations supported by refuges are out of synch with the changing seasons, invasive species extend their ranges into new refuges, and appropriate climate, soils, and habitat drift away from the refugia for imperiled species.

Today, a system established to respond to local threats is faced with a global challenge, but also—as with the first three crises—with an opportunity. The NWRS is only beginning to consider how to address projected climate change impacts through management activities; however, using our new understanding of how nature works and the administrative mandates of the NWRS Improvement Act of 1997, the USFWS is better equipped to take on this new crisis. Success will demand new tools, new ways of thinking, new institutions, new conservation partnerships, and renewed commitment for maintaining the biological integrity, diversity, and health of America's wildlife resources on the world's largest system of dedicated nature reserves. No longer can refuges be managed as independent conservation units. Decisions require placing individual refuges in the context of the NWRS. The response must be global to match the scale of the threat. Such a response is unprecedented in the history of conservation biology.

The ability of individual refuges and the entire NWRS to respond to the threat of climate change is a function of the system's distribution, size, and ecological context. Familiarity

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[1] In 1992 dollars.

with the legal, ecological, geographical and political nature of the NWRS is necessary for understanding both challenges and opportunities to adapting to climate change on the NWRS. It is equally important to understand that existing legal and policy guidelines direct refuge managers to manage for a set of predetermined conservation targets (trust species). Meeting legal and policy guidelines for maintaining biological integrity, diversity, and environmental health of the NWRS will require careful evaluation of the continuing role of individual refuges in the face of climate change.

With climate change there is a renewed realization that species' distributions are dynamic, and changes in the distributions of species are occurring at much faster rates. This requires the NWRS to manage for change in the face of uncertainty. Climate change effects will be enduring, but existing models and projections typically span 100 years, which is, unless otherwise specified, the time frame for adaptation measures described in the chapter.

The pages that follow: (1) describe the institutional capacity of the NWRS to respond to the threat of climate change; (2) document threats to integrity, diversity, and health of species, refuges, and the NWRS; describe projected impacts of climate change on refuges; (3) identify research themes and priorities, most vulnerable species and refuges, and important needs; and (4) suggest new partnerships for conservation success.

5.1.2 Mission, Establishing Authorities, and Goals

The NWRS is managed by the USFWS (Fig. 5.3) under two sets of "purposes" (Fischman, 2003). The first is the generic (or System) "purpose," technically called the "mission," defined in the NWRS Improvement Act of 1997: "The mission of the NWRS is to administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans." The Act goes on to define the two most flexible terms of the mission, conservation and management, as a means "to sustain and, where appropriate, restore and enhance, healthy populations" of animals and plants utilizing methods associated with "modern scientific resource programs" (U.S. Congress, 1997). In 2006, the USFWS interpreted this first congressional purpose in a policy (601 FW1; U.S. Fish and Wildlife Service, 2000b), which lists five goals that derive from the mission and other objectives stated in statute (see Box 5.1). The USFWS policy gives top priority to the first three goals listed in Box 5.1, which focus most directly on the ecological concerns that impel adaptation to climate change.

Figure 5.3. Organizational chart (U.S. Fish and Wildlife Service, 2007a).

The second set of purposes is individual purposes specific to individual refuges or specific tracts or units within a refuge that may have been acquired under different authorities (Fig. 5.1). These are the authorities under which the refuge was originally created, as well as possibly additional ones under which individual later acquisitions may have been made. While it is difficult to conceive of a conflict between the NWRS mission and individual refuge purposes, in such an event the latter, or more specific, refuge purpose takes precedence. Furthermore, where designated wilderness (or some other overlay system, such as a segment of a wild and scenic river) occurs within a refuge boundary, the purposes of the wilderness (or any other applicable overlay statute) are additional purposes of that portion of the refuge.

Establishing authorities for a specific refuge may derive from one of three categories: presidential, congressional, and administrative (Fischman, 2003). Refuges established by presidential proclamation have very specific purposes, such as that for the first refuge, Pelican Island (a “preserve and breeding ground for native birds”). Congressional authorities stem from one or more of 15 different statutes providing generally for new refuges, such as the Migratory Bird Conservation Act (“for use as an inviolate sanctuary or for any other management purpose for migratory birds”) (U.S. Congress, 1929). Or, they may be specific to a single refuge, such as the Upper Mississippi River NWR (as a refuge for birds, game, fur-bearing animals, fish, other aquatic animal life, wildflowers and aquatic plants) (U.S. Congress, 1924). The third source of refuge purposes are administrative documents such as public land orders, donation documents, and administrative memoranda (Fischman, 2003). These, however, are less clearly understood and documented, and are not addressed further in this document.

5.1.3 Origins of the NWRS

The first significant legislative innovation to systematically assemble protected areas was the Migratory Bird Conservation Act of 1929, which authorized acquisition of lands to serve as “inviolate sanctuaries” for migratory birds (U.S. Congress, 1929) (Fig. 5.4). But funds to purchase refuges were scarce. In the early 1930s, waterfowl populations declined precipitously. Congress responded with the Migratory Bird Hunting Stamp Act of 1934 (U.S. Congress, 1934). It created a dedicated fund for acquiring waterfowl conservation refuges from the sales of federal stamps that all waterfowl hunters would be required to affix to their state hunting licenses. This funding mechanism remains the major source of money for purchasing expansions to the NWRS. A quick glance at a map of today’s NWRS (Fig. 5.2) confirms the legacy of the research findings and funding mechanism of the 1930s: refuges are concentrated in four corridors. The geometry of the NWRS conservation shifted from the enclave points on the map to the flyway lines across the country (Gabrielson, 1943; Fischman, 2005; Pidgorna, 2007).

Figure 5.4. Timeline of milestone events of the NWRS (U.S. Fish and Wildlife Service, 2007d)

After the push for protecting habitat of migratory waterfowl, the next impetus for NWRS growth came in the 1960s as Congress recognized that a larger variety of species other than just birds, big game, and fish needed protection from extinction. The Endangered Species Preservation Act of 1966 sought to protect species, regardless of their popularity or evident value, principally through habitat acquisition and reservation. In doing so, the law provided the first statutory charter for the NWRS as a whole. Indeed, the part of the 1966 law dealing with the refuges is often called the Refuge Administration Act (U.S. Congress, 1966).

The 1966 statute consolidated the conservation land holdings of the USFWS: it was the first statute to refer to this hodgepodge as the "NWRS" and it prohibited all uses not compatible with the purpose of the refuge. The compatibility criterion, established by statute in 1966, but practiced by the USFWS for decades before that, would become a byword of international sustainable development in the 1980s. In 1973 the Endangered Species Act (U.S. Congress, 1973) replaced the portion of the 1966 law dealing with imperiled species, and succeeded it as an important source of refuge establishment authority (U.S. Congress, 1973). The ESA also provides a broad mandate for the Interior Department to review the NWRS and other programs and use them in furtherance of imperiled species recovery (U.S. Congress, 1973).

In 1980 Congress enacted the Alaska National Interest Lands Conservation Act. This added over 54 million acres to the NWRS.

5.1.4 The 1997 NWRS Improvement Act

The NWRS Improvement Act (NWRSIA) of 1997 (U.S. Congress, 1997) marked the first comprehensive overhaul of the statutory charter for the NWRS since 1966. It is also the only significant public land "organic legislation" since the 1970s (Fischman, 2003). The term "organic legislation" describes a fundamental piece of legislation that either signifies the organization of an agency and/or provides a charter for a network of public lands. The key elements of the NWRSIA are described below.

The NWRSIA sets a goal of conservation, defined in ecological terms (*e.g.*, sustaining, restoring, and enhancing populations) (U.S. Congress, 1997). The 1997 statute envisions the NWRS as a national network of lands and waters to sustain plants and animals. This realigns the geometry of refuge conservation from linear flyways to a more complex web of relationships. The NWRSIA requires each refuge to achieve the dual system-wide and individual refuge purposes, with the individual establishment purpose receiving priority in the event of a conflict with the NWRS mission (U.S. Congress, 1997).

5.1.4.1 Designated Uses

The NWRSIA constructs a dominant use regime where most activities must either contribute to the NWRS goal, or at least avoid impairing it. The primary goals that dominate the NWRS are individual refuge purposes and the conservation mission. The next level of the hierarchy are the "priority public uses" of wildlife-dependent recreation, which the statute defines as "hunting, fishing, wildlife observation, and photography, or environmental education and interpretation" (U.S. Congress, 1997). These uses may be permitted where they are compatible with primary goals. The statute affirmatively encourages the USFWS to promote priority public uses on refuges.

5.1.4.2 Comprehensive Conservation Plans (CCPs)

The NWRSIA requires comprehensive conservation plans ("CCP") for each refuge unit (usually a single refuge or cluster of them). The CCPs zone refuges into various areas suitable for different purposes and set out desired future conditions. The Improvement Act requires the USFWS to prepare a CCP for each non-Alaskan unit within 15 years and to update each plan every 15 years, or sooner if conditions change significantly (U.S. Congress, 1997). Planning focuses on habitat management and visitor services. The planning policy models its procedure on adaptive management (U.S. Fish and Wildlife Service, 2000c). Once approved, the CCP becomes a source of management requirements that bind the USFWS, though judicial enforcement may not be available (U.S. Congress, 1997; Norton v. Southern Utah Wilderness Alliance).

The majority of refuges are still in the process of completing their CCPs. In a review of 100 completed refuge CCPs available online as of February 1, 2007, only 27 CCPs included terms such as "climate change," "climate variability," "global change," or "global warming." None of these CCPs has identified explicit adaptation management strategies that are currently being implemented. This suggests that the perception of climate variability and change as a threat is just emerging in the refuge management community. Much of the information needed to implement an effective response to climate change is unavailable to refuge managers. Furthermore, the system-wide nature of the climate change threat will require system-wide responses. The magnitude of the threat posed by climate change is unprecedented in scale and intensity. The challenges presented by climate change exceed the capabilities of individual refuges. National coordination and guidance is needed, which would also help minimize redundancy and reduce cost.

5.1.4.3 Cross-Jurisdictional Cooperation

Like all of the modern public land organic laws, the NWRSIA calls for coordination with states, each of which has a wildlife protection program. This partnership with states is, of course, limited by federal preemption of state law that conflicts with USFWS management control on refuges. For instance, a state may not impose its own management programs or property law restrictions on the NWRS under circumstances where they would frustrate decisions made by the USFWS or Congress (North Dakota v. United States1983; State of Wyoming v. United States, 2002). USFWS policy emphasizes state participation in most refuge decision-making, especially for comprehensive conservation planning and for determination of appropriate uses.

5.1.4.4 Substantive Management Criteria

The NWRSIA imposed many substantive management criteria, some of which are unprecedented in public land law. First, the Act expanded the compatibility criterion as a basic tool for determining what uses are allowed on refuges. The USFWS may not permit uses to occur where they are incompatible with either the conservation mission or individual refuge purposes. The Act defines “compatible use” to mean “a wildlife-dependent recreational use or any other use of a refuge that, in the sound professional judgment of the Director, will not materially interfere with or detract from the fulfillment of the mission of the NWRS or the purposes of the refuge” (U.S. Congress, 1997). The USFWS compatibility policy promises to assure that “densities of endangered or otherwise rare species are sufficient for maintaining viable populations” (U.S. Fish and Wildlife Service, 2000b). The USFWS interprets its policy to prohibit uses that reasonably may be anticipated to fragment habitats (U.S. Fish and Wildlife Service, 2000a). Second, the NWRSIA requires that the USFWS maintain “biological integrity, diversity, and environmental health” on the refuges (U.S. Congress, 1997). This element of the 1997 Act, discussed in more detail directly below, is the closest Congress has ever come to requiring a land system to ensure ecological sustainability, and creates a mandate unique to federal land systems in the United States.

5.1.4.5 New Emphasis on Biological Integrity, Diversity, and Environmental Health

The *Policy on Biological Integrity, Diversity, and Environmental Health* (U.S. Fish and Wildlife Service, 2000b) presents the process by which the NWRS fulfills the NWRSIA mandate to “…ensure that the biological integrity, diversity, and environmental health of the System are maintained…” The 2001 USFWS policy correspondingly focuses on the three distinct yet largely overlapping concepts of biological integrity, diversity, and environmental health. The core idea of the policy is maintaining composition and function of ecosystems (Fischman, 2004). Though climate change may make that impossible within the boundary of some refuges, it remains an appropriate guiding principle for the system as a whole. The policy’s guidance on the biological integrity, diversity, and environmental health mandate is the single most important legal foundation for leadership in shifting NWRS management toward needed adaptations. There are other path-breaking criteria especially relevant to adaptation, but the USFWS has yet to implement them through new policies or other major initiatives. However, as climate change increases in importance to the public and refuge managers, the USFWS will find itself increasingly challenged by its 1997 duty to: (1) acquire water rights needed for refuge purposes; (2) engage in biological monitoring; and (3) implement its stewardship responsibility (U.S. Congress, 1997). While the 2001 policy provides a basis for ecological sustainability, climate change presents new challenges at unprecedented scales for maintaining biological integrity, diversity, and environmental health of refuges and the refuge system.

Rather than compare refuge conditions with existing reference sites, the USFWS policy encourages managers to use “historic conditions” (for integrity and health, but not diversity) as a benchmark for success. “Historic conditions” are those present before significant European intervention and form a baseline from which to plan management objectives. Where physiographics of the land and resource base still permit, and when coincident with refuge purpose, one would normally consider “historical conditions” as the ideal and either maintain or restore habitats in something approximating them. In many or most cases, this would mean the “historical” dynamic. For example, if fire or flood or other intermittent ecological process maintained the historic ecosystem, managers would work to replicate such processes and maintain a dynamic at some successional sere rather than allow the community to evolve to an "unnatural" climax.

With climate change the future species composition of the community may be quite different from that of the time when the refuge was established. However, the opportunity to manage the biological integrity, diversity, and environmental health of refuges and the NWRS, regardless of changes in species composition, remains. The policy on biological integrity, diversity, and environmental health does not insist on a return to conditions no longer climatically appropriate. Instead, it views historical conditions as a frame of reference from which to understand the successional shifts that occur within ecological communities as a result of climate change. The policy also implies that we can use the knowledge and insights gained from such analysis to develop viable site-specific management targets for biological integrity, diversity, and environmental health despite the changing climate.

In addition to addressing ecosystems or ecological communities, the policy also governs target fauna and flora, stressing that native populations in historic sex and age ratios are generally preferable over artificial ones, and that invasives or non-indigenous species or genotypes are discouraged. In general, except for species deemed beneficial (*e.g.*, pheasants), managers would consistently work to remove or suppress invasive and exotic species of both plants and animals. The policy directs special attention to target densities on refuges for rare species (viable densities) and migratory birds (higher-than-natural densities to accommodate loss of surrounding habitat). These targets, where extended to a broader spatial scale, provide good starting points for NWRS adaptation to climate change.

Meeting the NWRS's statutory and policy mandates will require an approach and philosophy that sees the "natural" condition of a given community as a moving target. A refuge manager must plan for the future in the context of past and present conditions and the likelihood of an altered community within the bounds of a new climate regime.

5.2 Current Status of the NWRS

5.2.1 Key Ecosystem Characteristics on Which Goals Depend

One of the primary goals of the NWRS—to conserve the diversity of fish, wildlife, plants, and their habitats—is reflected in the design of the NWRS, which is the largest system of protected areas in the world primarily designated to manage and protect wildlife (Curtin, 1993). The NWRS includes 584 refuges and more than 30,000 waterfowl production areas[2] (Fig. 5.1) that encompass an area of over 93 million acres, distributed across the United States (Fischman, 2003; Scott *et al.*, 2004). The NWRS contains a diverse array of wildlife, with more than 220 species of mammals, 250 species of amphibians and reptiles, more than 700 species of birds, and 200 species of fish reported.

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[2] Grouped into 37 wetland management districts

Another important goal of the NWRS is to maintain its trust species, which include threatened and endangered species, marine mammals, anadromous and interjurisdictional fish, and migratory birds. Of these, the latter remain the NWRS's largest beneficiary, with over 200 refuges established for the conservation of migratory birds (Gergely, Scott, and Goble, 2000). Shorebirds and waterfowl are better represented on refuges compared with landbirds and waterbirds (Pidgorna, 2007).

Twenty percent of refuges were established in the decade immediately following the enactment of the Migratory Bird Treaty Act (1930–1940). The NWRS captures the distribution of 43 waterfowl species in the continental United States at a variety of geographic, ecological, and temporal scales (Pidgorna, 2007).

The fact that many refuges were established in areas important to migratory birds, and especially waterfowl, can account for the abundance of wetland habitat found in the NWRS today and for the fact that refuges are found at lower elevations and on more productive soils compared with other protected areas in the United States (Scott *et al.*, 2004). Besides wetlands, other commonly occurring landcover types include shrublands and grasslands (Scott *et al.*, 2004).

The NWRS is characterized by an uneven geographic and size distribution. Larger refuge units are found in Alaska, with Alaskan refuges contributing 82.5% of the total area in the NWRS and average sizes more than two orders of magnitude greater than the average size of refuges found in the lower 48 states. Nearly 20% of the refuges are less than 1,000 acres in size and effectively even smaller because more than half of the refuges in the system consist of two or more parcels. Median refuge area is 5,550 acres and the mean area is 20,186 acres (Scott *et al.*, 2004). In contrast, the median area of Alaskan refuges is 2.7 million acres.

Approximately one sixth of the nation's threatened and endangered species are found on refuges. More than 50% of all listed mammals, birds, and reptiles are found on refuges (Davison *et al.*, 2006) while the percentage of listed invertebrates and plants is much lower. These and the 10% of the threatened and endangered species for which refuges have been established realize a conservation advantage over species not found on refuges (Blades, 2007). The NWRS plays an important role in the conservation of threatened and endangered species, providing core habitat, protection, and management. However, as most refuges are small, fragmented, and surrounded by anthropogenic habitats (Scott et al. 2004 and Pidgorna 2007), it may prove difficult for the NWRS to support and restore a diverse range of taxonomic groups and to maintain viable populations of some larger threatened and endangered species (Czech, 2005; Blades, 2007).

The distribution of refuges in geographical and geophysical space has given Americans a network of protected areas that function differently from other protected areas in the United States. In a nutshell, most refuges, with the exception of those in Alaska, are small islands of habitat located in a predominantly and increasingly anthropogenic landscape. Refuges contain lower-elevation habitat types important to the survival of a large number of species that are not included in other protected areas. Their small size and close proximity to anthropogenic disturbance sites (such as roads and cities) makes refuges vulnerable to external threats and highly susceptible to a wide array of stressors. The lands surrounding individual refuge units (matrix lands) in the lower 48 states and Hawaii also decrease the ability of species to move from refuge to refuge; the barriers are far greater for species that cannot fly than for those that can. The positive side is that their proximity to population centers provides them with an opportunity to serve as educational centers for the public to learn more about the diversity of fish, wildlife, plants, and their habitats, as well as ecological processes and the impacts of climate change. They also provide sites for researchers to develop new understanding of the ecology and management of conservation landscapes.

However, the ability of individual refuges to meet the first three of the USFWS goals as well as the biological integrity, diversity, and environmental health clause of the NWRSIA will depend upon the ability of refuge managers to increase habitat viability through restoration and reduction of non-climate stressors. This would in turn provide species the opportunity to: adapt to a changing environment; integrate inholdings into refuge holdings; and strategically increase refuge habitat through CCPs, increased incentive programs, establishment of conservation easements with surrounding landowners, and, when desired by all parties, fee-title acquisitions of adjacent lands.

At the level of the NWRS, the integration of the USFWS's five goals and the biological integrity, diversity, and environmental health of species, ecosystems, and plant and animal communities may be achieved through increased representation and redundancy of target species and populations on refuge lands through strategic growth of the NWRS. The need for any such strategic growth has to be carefully evaluated in the context of maintaining the biological integrity, diversity, and environmental health of the NWRS trust species today and the uncertain impacts of climate change. A national plan should be developed to assess the projected shifts in biomes and develop optimal placement of refuge lands on a landscape that is likely to exist 100 or more years into the future. Waterfowl provides an exemplar of what might be achieved for other trust species. Robust populations of ducks and geese have been achieved through seven decades of strategic acquisitions and cooperative conservation (Pidgorna, 2007), and a vision of a NWRS that conserved recreationally viable populations of North American waterfowl—a vision that was shared with many others (U.S. Fish and Wildlife Service and Canadian Wildlife Service, 1986). However, the ability to meet the objectives of the USFWS's five goals and the mandate of the NWSRIA necessitates strategic growth of the NWRS to increase the biological integrity, diversity, and environmental health of threatened and endangered species and at-risk ecosystems and plant communities.

Climate change provides an important urgency for rethinking the NWRS the future. It presents an opportunity for the USFWS to fully integrate the mandate of the NWRSIA into the broader mission of the USFWS, especially with respect to the first three goals: to conserve a diversity of species and their habitats; develop and maintain a network of habitats; and conserve unique, rare, declining, and underrepresented ecosystems. It also presents an opportunity to integrate more fully the needs of the USFWS endangered species program with those of the NWRS. In addition, climate change increases the opportunity to integrate the goals of the USFWS endangered species program and NWRS with the goals of state wildlife action plans, which have integrated many results of other conservation assessments and plans such as the Gap Analysis Program, The Nature Conservancy's ecoregional planning, and Nature Serve's Heritage programs.

5.2.2 Threats to the NWRS

5.2.2.1 2002 Survey of Threats to NWRS

In an effort to quantify threats to the refuges, the NWRS surveyed all refuges and wetland management districts in 2002 with an extensive questionnaire. The result was a large database of threats and management conflicts experienced by the NWRS. It contains 2,844 records, each representing a different threat to a refuge or a conflict with its operations.

The most common threats to refuges that could be exacerbated by climate change are ranked by frequency of reporting in Table 5.1. Each record covers a specific threat, so a single refuge could have reported multiple records for the same category (*e.g.,* invasive species or wildlife disease), which are grouped for discussion purposes. The responses from the survey regarding threats generally fall into four themes: off-refuge activities, on-refuge activities, flora and fauna imbalances, and uncontrollable natural events.

Off-refuge activities such as mining, timber harvest, industrial manufacturing, urban development, and farming often produce products or altered ecological processes that influence numbers and health of refuge species. The off-refuge activities often result in a range of environmental damage that affects the refuge, including erosion; degraded air and water quality; contaminants; habitat fragmentation; competition for water; expansion of the wildland-urban interface that creates conflicts over burning and animal control; noise and light pollution; and fragmentation of airspace with communication towers, wind turbines, and power lines.

Other activities that threaten refuges occur within refuge boundaries but are beyond USFWS jurisdiction. These activities include military activities on overlay refuges, development of mineral rights not owned by the USFWS, commercial boat traffic in navigable waters not controlled by USFWS, off-road vehicles, some recreational activities beyond USFWS jurisdiction, and illegal activities such as poaching, trespassing, dumping, illegal immigration, and drug trafficking, and other concerns.

Imbalances in flora and fauna on and around the refuge also threaten refuges and the NWRS. Such concerns take the form of exotic or native invasives, disease vectors such as mosquitoes, or unnaturally high populations of larger animals, usually mammals. The latter group includes small predators that take waterfowl or endangered species, beaver and muskrat that damage impoundments, and white-tailed deer that reduce forest understory (Garrott, White, and White, 1993; Russell, Zippin, and Fowler, 2001). Invasive exotic and native plant species are far and away of the most concern, both within this category and within the NWRS overall (Table 5.1).

Extreme events such as hurricanes, floods, earthquakes, and volcanic eruptions also threaten refuges. While far less common than other threats, the ecological and economic damage wrought by such events can be significant. For example, hurricanes can affect large coastal areas and multiple refuges, and cause habitat change (*e.g.*, from forest blowdowns), saline intrusion into freshwater wetlands, and loss of coastal wetlands and barrier islands. Equipment and infrastructure damage and loss can be significant and costly to repair or replace. The increasing ecological isolation of refuges and the species that reside on them decreases the ability of refuge managers to respond to impacts of climate change and other stressors. Tools and strategies used to respond to past stressors and threats are many of the same tools that can be used to mitigate predicted impacts of global climate change.

5.2.2.2 Interactions of Climate Change with Other Stressors of Concern

Over the last 100 years, average annual temperatures in the United States have risen 0.8°C, with even greater increases in Alaska over the same period (2–4°C) (Houghton *et al.*, 2001). Global average surface temperatures are projected to rise an additional 1.1–6.4°C by 2100 (IPCC, 2007b). Most areas in the United States are projected to experience greater-than-average warming, with exceptional warming projected for Alaska (Houghton *et al.*, 2001). Coastal areas have experienced sea-level rise as global average sea level has risen by 10–25 cm over the last 100 years (Watson, Zinyowera, and Moss, 1996). Global average sea level is projected to increase by 18–59 cm by 2100 (IPCC, 2007b). Due to thermal expansion of the oceans, even if greenhouse gas emissions were stabilized at year-2000 levels, the committed sea level rise would still likely be 6–10 cm by 2100, and sea level would continue to rise for four more centuries (Meehl *et al.*, 2005).

Other impacts of climate change include altered hydrological systems and processes, affecting the inland hydrology of streams, lakes, and wetlands (Frederick and Gleick, 1999; Poff, Brinson, and Day, Jr., 2002). Warmer temperatures will mean reduced snowpack and earlier spring melts (Barnett, Adam, and Lettenmaier, 2005; Milly, Dunne, and Vecchia, 2005), changes in flood magnitudes (Knox, 1993), and redistribution of lakes and wetlands across the landscape (Poff, Brinson, and Day, Jr., 2002). Climate change will also affect other physical factors such as fire and storm intensity (Westerling *et al.*, 2006; IPCC, 2007b).

Climate changes may have cascading effects on ecological systems (Walther *et al.*, 2002; Parmesan and Yohe, 2003; Root *et al.*, 2003; Parmesan, 2006). These include changes in species' phenologies, distributions, and physiologies.

Climate change will magnify the influences of other threats—including habitat loss and fragmentation, changes in water quality and quantity, increased transportation corridors, etc.—on the NWRS. Climate change will also introduce new threats or variations on existing ones, primarily by accelerating a convergence of issues (*e.g.*, water scarcity, non-native invasives, off-refuge land-use change, and energy development), or creating such convergences where none existed before. Current and projected threats have the potential to undermine the mission of the NWRS and the achievement of its goals. The following pages of this section summarize the main threats to the NWRS that could be exacerbated by climate change (see also Section 5.8, the Appendix). There is, however, a great deal of uncertainty associated with these predictions, making it possible to show the overall trend but not the specific effect on an individual refuge. For example, IPCC (2007a) projects future increases in wind speeds of tropical cyclones, but do not yet offer detailed spatial data on projected terrestrial surface wind patterns. Changes in wind patterns may affect long-distance migration of species dependent on tail winds.

Invasive Non-Native Species

Invasive non-native species are currently one of the most common threats to the NWRS and could become even more serious with climate changes (Table 5.1) (Sutherst, 2000). Since species are projected to experience range shifts as a result of climate change and naturally expand and contract their historic ranges, it is important to distinguish between non-native species and native species. We define non-native species as those that were relocated to a new habitat through direct anthropogenic activity, either deliberate or by accident. Species that naturally expand or contract their historic ranges, for example in response to climate change, should be considered native species. Both native and non-native species can be invasive and non-invasive. It is, however, the non-native invasive species that present the greatest threat and are discussed here and elsewhere in this chapter.

An increase in the number and spread of non-native invasive species could undermine the NWRS's goal of maintaining wildlife diversity and preserving rare ecosystems and plant communities. By replacing native organisms, non-native invasive species often alter the ecological structure of natural systems by modifying predator-prey, parasite, and competitive relationships of species. Shifting distribution of native species in response to climate change will further increase the rate of change in species' composition, structure, and function on refuges.

Range shifts that result in range contractions and range expansions are the best-studied effects of climate change on invasive non-native species. Range expansions refer to the expansion of established invasive non-native species into previously unoccupied habitats. A rise in temperatures could allow invasive non-native species to expand their ranges into habitats which were previously inaccessible to them. For example, Westbrooks (2001) describes the expansion of the balsam wooly aphid (*Adelges piceae*) into stands of subalpine fir (*Abies amabilis*). Currently the aphid is restricted to areas of low and middle elevation because of its temperature requirements; however, an increase of 2.5ºC would allow the aphid to expand its range to higher elevations where it would affect native subalpine fir. Species that are considered tropical today may also expand their ranges into more northern latitudes if the climate grows warmer. When temperatures become suitable, non-native invasive species could spread into new habitats and compete with stressed native species (Westbrooks, 2001).

Although climate change might not benefit non-native invasive species over native species in all cases, it is likely that non-native invasive species will benefit from a transitional climate (Dukes and Mooney, 1999). Non-native invasive species are highly adaptable and spread quickly. Many such non-native invasives may extirpate native plants or even lead to complete regime shifts within vegetative communities. All of these traits make non-native invasive species much more likely to survive predicted climate change impacts compared to many of the native species.

Disease

Climate change has the potential to affect the prevalence and intensity of both plant and animal diseases in several ways. First, changes in temperature and moisture may shift the distribution of disease vectors and of the pathogens themselves (Harvell *et al.*, 2002; Logan, Regniere, and Powell, 2003; Pounds *et al.*, 2006). For example, Hakalau Forest NWR, now largely free of avian malaria, harbors one of the few remaining population centers of endangered Hawaiian forest birds. Climate change may eliminate this and other such refugia by changing conditions to favor avian malaria (LaPointe, Benning, and Atkinson, 2005). Second, climate-induced changes in hydrology can alter the spread and intensity of diseases in two key ways. First, in wetlands or other water bodies with reduced water levels and higher water temperatures, diseases may be able to spread much more quickly and effectively within a population. Increased temperatures have been demonstrated to speed pathogen and/or vector development (Rueda *et al.*, 1990). Second, increases in precipitation may result in increased connectivity among aquatic systems in some areas, potentially facilitating the spread of diseases among populations. Finally, climate change may also indirectly increase the prevalence and the magnitude of disease impacts by affecting host susceptibility. Many organisms that are stressed due to changes in temperature or hydrology will be more susceptible to diseases. Corals are an excellent example of increased temperatures leading to increased disease susceptibility (Harvell *et al.*, 2001).

Urbanization and Increased Economic Pressure

Urbanization has the potential to further isolate refuges by altering the surrounding matrix, increasing habitat loss and fragmentation, and introducing additional barriers to dispersal. Roads and human-built environments pose significant barriers to the movement of many species. Poor dispersers (*e.g.*, many amphibians, non-flying invertebrates, and small mammals and reptiles) and animals that avoid humans (*e.g.*, lynx) will be more isolated by increased urbanization than more mobile or more human-tolerant species. This increased isolation of wildlife populations on refuges will prevent many species from successfully shifting their distributions in response to climate change.

Urbanization has the potential to interact with climate change in two additional ways. First, increased urbanization creates more impervious surfaces, increasing runoff and potentially confounding the effects of climate-altered hydrological regimes. Second, urbanization has the potential to affect local climatic conditions by creating heat islands, further exacerbating the increases in temperature and increased evaporation.

Refuges are highly susceptible to the effects of management activities on surrounding landscapes. More pressure will likely be put on the U.S. economy with rising energy demands, which will result in a push for increased oil and gas development in the western states. This will also increase habitat loss and fragmentation on lands surrounding refuges and could result in extraction activities within refuges themselves. Economic and social pressure for alternative energy sources may increase efforts to establish wind plants near refuges, or promote agricultural expansion or conversions to produce biofuels, including nearby biofuel production and transport facilities.

Although habitat loss and fragmentation will likely have a negative effect on the NWRS's biodiversity conservation goals, it could provide additional recreational and educational opportunities for people who will become attracted to the NWRS as open space becomes scarce. This could increase the number of visitors to the NWRS, which would raise public visibility of the refuges. Management of visitors and their activities to minimize impact on refuges and refuge species will be a challenge.

Altered Hydrological Regimes

Water is the lifeblood of the NWRS (Satchell, 2003) because much of the management of fish, migratory waterfowl, and other wildlife depends upon a reliable source of clean freshwater. Climate change is likely to result in significant changes to water resources at local, regional, and national scales, with varying effects on economies and ecosystems at all levels. The primary effects to water resources within the NWRS from climate change can be placed into two broad categories: changes in the amount of precipitation and changes in seasonality of surface water flows. In addition, reductions in precipitation would result in slower recharge of groundwater aquifers, further stressing water availability.

While climate change models vary in predicting changes to precipitation to any given geographical area, at least some parts of the United States are predicted to experience reduced precipitation (*e.g.*, Milly, Dunne, and Vecchia, 2005). Parts of the country where current water supplies are barely meeting demand—in particular, portions of the western United States—are especially vulnerable to any reduction in the amount, or change in timing, of precipitation. In 1995, central and southern California and western Washington experienced some of the largest water-withdrawal deficits in the United States (Roy *et al.*, 2005). Future projected increases in deficits are not just limited to the western United States, but are spread across much of the eastern part of the country as well (Roy *et al.*, 2005). Less precipitation would mean less water available for ecosystem and wildlife management, even at refuges with senior water rights. Refuges possessing junior water rights would be particularly susceptible to losing use of water as demand exceeds supply.

The other major consequence of climate change to water resources is a seasonal shift in the availability of water. Mountain snowpacks act as natural reservoirs, accumulating vast amounts of snow in the winter and releasing this stored precipitation in the spring as high flows in streams. Many wildlife life histories and agricultural economies are closely tied to this predictable high volume of water. Warmer temperatures would result in earlier snowmelt at higher elevations as well as more precipitation falling in the form of rain rather than snow in these areas. The result would be both high and low flows occurring earlier in the year, and an insufficient amount of water when it is needed. This effect is most likely to affect the western United States (Barnett, Adam, and Lettenmaier, 2005).

Water quality is also likely to decline with climate change as contaminants become more concentrated with reduced precipitation and lower stream flows. In addition, warmer surface water temperatures would result in lower dissolved oxygen concentrations and could jeopardize some aquatic species. In the far north, current thawing of permafrost has resulted in an increase in microbial activity within the active soil layer. This has resulted in less dissolved organic carbon reaching estuaries and lowering productivity (Striegl *et al.*, 2005).

Climate change will offer a challenge for the NWRS to maintain adequate supplies of water to achieve wildlife management objectives. Although it is not currently possible to predict precisely where the greatest impacts to water resources will occur, refuges in areas where demand already exceeds supply, as well as those in areas highly dependent upon seasonal flows from snowmelt, appear to be especially vulnerable.

Waterfowl occurring on refuges in areas such as the Prairie Pothole Region (PPR), for which warmer and drier conditions are predicted (Poiani and Johnson, 1991; Sorenson *et al.*, 1998), may be expected to face more stressful conditions than those in areas that are predicted to be warmer and wetter, such as the Northeast. The projected drying of the PPR—the single most important duck production area in North America—will significantly affect the NWRS's ability to maintain migratory species in general and waterfowl in particular. Maintaining endangered aquatic species, such as the desert hole pupfish, which occurs naturally in a single cave in Ash Meadows NWR in Nevada, will present even more challenges because, unlike waterfowl that can shift their breeding range northward, most threatened and endangered species have limited dispersal abilities and opportunities.

Sea Level Rise

The NWRS includes 161 coastal refuges. Approximately 1,045,925 acres of coastal wetlands occur on refuges in the lower 48 states. On a given refuge, the extent of coastal inundation resulting from sea-level rise will be influenced by hydrology, geomorphology, vertical land movements, atmospheric pressure, and ocean currents (Small, Gornitz, and Cohen, 2000).

Historically, accretion of sediments and organic matter have allowed coastal wetlands to "migrate" to adjacent higher ground as sea levels have risen. However, wetland migration may not keep pace with accelerating rates of sea-level rise because of upstream impoundments and bulkheaded boundaries. Also, in many cases topography or the structures and infrastructure of economically developed areas (essentially bulkhead refuges) impede migration (Titus and Richman, 2001). In both scenarios, coastal wetlands will be lost, along with the habitat features that make them valuable to species the NWRS is intended to conserve, *e.g.*, waterfowl.

Along the mid-Atlantic coast, the highest rate of wetland loss is in the middle of the Chesapeake Bay region of Maryland. One example is Blackwater NWR near Chesapeake Bay in Maryland. This refuge has been affected by sea level rise for the past 60 years. Models project that in 50 years, continued sea level rise in conjunction with climate change will completely inundate existing marshes (Fig. 5.5) (Larsen *et al.*, 2004b; see also U.S. Climate Change Science Program, 2007). Along the Gulf Coast, substantial wetland loss is also occurring. For example, in Louisiana, the combination of sea level rise, high rates of subsidence, economic growth, and hurricanes has contributed to an annual loss of nearly 25,000 acres of wetlands, even prior to Hurricane Katrina (2005) (Erwin, Sanders, and Prosser, 2004). Sea level rise threatens a lesser extent of NWRS wetlands along the Pacific coast because few refuges there have extensive coastal wetlands, in part due to steep topography. Conversely, a higher proportion of these wetlands have limited potential for migration for the same topographical reasons. Additionally, up-elevation movements of plant and animal species among these refuges is prevented by presence of highways, industrial and urban areas, and other products of development. They are, in effect, "bulkheaded." Alaskan refuge wetlands appear to be least at risk of sea-level rise effects because of countervailing forces, most notably isostatic uplift (Larsen *et al.*, 2005), which has accelerated as a function of climate change and melting of glaciers (Larsen *et al.*, 2004a). In Alaska, permafrost thawing and resulting drainage of many of the lakes is a greater threat to wetlands, both coastal and non-coastal. In Florida, Pelican Island NWR, the system's first refuge, is among the 161 coastal refuges threatened by sea level rise.

Figure 5.5. Blackwater National Wildlife Refuge, Chesapeake Bay, Maryland. Current land areas and potential inundation due to climate change (Larsen *et al.*, 2004b).

Recent studies have attempted to quantitatively predict the potential impact of sea level rise on NWRS wetlands. For example, the Sea Level Affecting Marshes Model (SLAMM) was used to project coastal wetland losses for four refuges in Florida: Ding Darling (Fig. 5.6), Egmont Key, Pine Island, and Pelican Island. At each refuge, significant wetland losses are projected, but the types and extent of changes to wetlands may vary considerably. SLAMM was also used to model sea level rise at San Francisco Bay NWR (Galbraith *et al.*, 2002). The projections suggested that the refuge will be inundated in the next few decades. The projected inundation is a result of a combination of global sea level rise and aquifer depletion, land compaction and subsidence.

Figure 5.6. Results of the Sea Level Affecting Marshes Model (SLAMM) for Ding Darling National Wildlife Refuge. Source: USFWS unpublished data (McMahon, Undated, 2007).

The effects of climate change on wetlands will not be uniform. For example, sea level rise could create new wetlands along the coast. However, changes in hydrological regimes and precipitation patterns will cause some existing wetlands to dry out and change the geomorphology and sedimentation of wetlands.

Extreme Weather Events

Increased frequency of extreme weather events, such as hurricanes, floods, or unusually high tides could significantly alter coastal and other habitats. Observed and predicted impacts include: loss of barrier islands and coastal marshes; damage or loss of storm- and tide-dampening mechanisms and other refuge equipment and infrastructure; and pollution of refuge habitats from storm-borne pollutants from nearby urban centers and industrial sites, increasing the strain on tight budgets. The loss of equipment and property damage could hinder both recreational and educational activities on refuges, thus affecting the ability of the NWRS to fulfill its relevant mandates as well as cutting individual refuges' income.

The potential effects of hurricanes and other extreme weather events on the NWRS's conservation target species and their habitats are complex and difficult to prevent and mitigate. Threatened and endangered species are likely to be the most affected. Documented negative impacts of extreme weather events on threatened and endangered species and their habitats include the loss of 95% of breeding habitat of the red-cockaded woodpecker, loss of habitat for five red wolves in South Carolina, and diminished food supply for the Puerto Rican parrot as a result of hurricane Hugo (Anonymous, 1989).

The effects of storms and hurricanes are not limited to terrestrial species. Aquatic species managed by the USFWS on the NWRS could also be affected by some of the side effects of storms and hurricanes, such as oxygen depletion, retreating salt water, mud suffocation, and turbulence (Tabb and Jones, 1962). Such effects could also severely damage recreational fishing opportunities on affected refuges. Projected effects of tropical storms on southeastern wetlands (Michener *et al.*, 1997) could pose additional challenges to other NWRS trust species, such as migratory birds, which use those wetlands. Hurricane Hugo caused soil erosion on Sandy Point NWR, which had an adverse affect on nesting leatherback turtles (Anonymous, 1989).

5.2.2.3 Regime Shifts

Much of the NWRS lies in areas that could experience vegetation shifts by 2100 (Gonzalez, Neilson, and Drapek, 2005). Species may respond to climate change in several ways: ecologically (by shifting distributions), evolutionarily/genetically, behaviorally, and/or morphologically. One of the more profound effects of climate change is total "regime shift," where entire ecological communities are transformed from their "historical" conditions. Such shifts are even now being witnessed in the black spruce forests of southern Alaska due to northern expansion of the spruce bark beetle, and the coastal shrublands of central and southern California, due to increased frequency of wildfires. Similar changes, though difficult to predict, will likely occur with the changing rainfall patterns, as well as other shifting wildlife patterns. Increased moisture may create wetlands where none existed before, whereas declining rainfall may eliminate prairie potholes or other significant wetlands, especially in marginally wet habitats such as vernal pools and near-deserts.

Where such regime shifts occur, even on smaller scales, it may become impossible to meet specific refuge purposes. For example, a highly specialized refuge (such as one established for an endangered species) might shift away from the specialized habitat occupied by the species for which the refuge was established; *e.g.*, Kirtland's Warbler Wildlife Management Area (Botkin, 1990). Likewise, shifts in migratory bird habitats in the prairie potholes of the Midwest might diminish available breeding habitat for waterfowl (Sorenson *et al.*, 1998; Johnson *et al.*, 2005). Less obvious, increasing competition for water in areas such as California's Central Valley, southern New Mexico, or Arizona may restrict a refuge's access to that critical resource, thus making attainment of its purposes virtually impossible. As suggested by emerging research, there will be winners and losers among the species and habitats currently found on the NWRS (Peterson and Vieglais, 2001; Peterson, Ball, and Cohoon, 2002; Parmesan and Yohe, 2003; Peterson *et al.*, 2005; Parmesan, 2006). Existing species' compositions in refuges may change; however, it will be possible to maintain the integrity, diversity, and environmental health of the NWRS, albeit with a focus on the composition, structure, and function of the habitat supported by the refuges rather than any particular species or group of species that utilize that habitat.

The prospect of regime shifts makes it more crucial that the USFWS provide guidance for refuge managers to apply in ascertaining how specific refuges can assess changing climate and their role in support of the system-wide response. Without such guidance it will be increasingly challenging to define what a refuge should "conserve and manage," and impossible in most cases to "restore" a habitat in an ecological milieu that no longer supports key species. This raises the question of what refuge managers are actually managing for: single species occurrences or maintenance of evolutionary and ecological change in self-sustaining ecosystems.

5.2.3 Ecoregional Implications of Climate Change for the NWRS

The NWRS is characterized by an uneven geographic and ecological distribution (Scott *et al.*, 2004). There are a total of 84 ecoregions in North America (Omernik, 1987), ranging from temperate rainforests to the Sonoran desert. Eleven of these ecoregions host almost half of all refuges (Scott *et al.*, 2004). Over all the ecoregions, Alaskan ecoregions dominate; however, the Southern Florida Coastal Plain ecoregion has the largest area representation within the NWRS in the lower 48 states: 3.7%.

This section describes some of the implications of climate change on an ecoregion-by-ecoregion basis, based on a hierarchical agglomeration of the 84 ecoregions mentioned above (Omernik, 1987; level 1 ecoregions) (Fig. 5.7).

Figure 5.7. Ecoregions of North America (Level 1) (U.S. Environmental Protection Agency, 2007).

5.2.3.1 Arctic Cordillera, Tundra, Taiga, and the Hudson Plain (18 NWRs)

Although there are only 18 refuges in this ecoregion, they capture more than 80% of the area of the NWRS, provide important breeding habitat for waterfowl, and offer key habitat for many high-latitude species. The high latitudes have experienced some of the most dramatic recent climatic changes in the world. Arctic land masses have warmed over the last century by at least 5°C (McCarthy *et al.*, 2001). In North America, the most warming has occurred in the western Arctic region, including Alaska, and has been concentrated in the winter and spring (Serreze *et al.*, 2000). This warming has resulted in a decrease in permafrost (McCarthy *et al.*, 2001). Melting permafrost has implications for vegetation, hydrology, and ecosystem functioning. The thawing permafrost also releases carbon, which results in a positive feedback loop generating further warming (Zimov, Schuur, and Chapin, III, 2006). Furthermore, melting permafrost may connect shallow lakes and wetlands to groundwater, resulting in draining and the loss of many shallow-water systems (Marsh and Neumann, 2001).

Due to the rugged coast and lack of low-lying coastal areas, sea level rise is not predicted to strongly affect Alaska except where sea ice affects the shoreline. The extent of Arctic sea ice has been decreasing at a rate of 2.7 % per decade from 1980 to 2005 (Lemke *et al.*, 2007). Loss of Arctic ice in areas near NWRs will decrease and eliminate foraging opportunities for those seabirds and mammals that congregate at the sea-ice interface.

Climate change will likely have large effects on the composition of ecological communities on many refuges in the northern ecoregions. As temperatures increase, many species will continue to shift their ranges to the north. For example, the boreal forest is predicted to expand significantly into the tundra (Payette, Fortin, and Gamache, 2001). In the tundra itself, mosses and lichens will likely be replaced by denser vascular vegetation, resulting in increased transpiration and further altering hydrology (Rouse *et al.*, 1997). There will also be changes in animal communities as range shifts introduce new species. Some native species will likely be affected by new predators and new competitors. For example, red foxes have expanded their range to the north (Hersteinsson and Macdonald, 1992), potentially increasing competition with Arctic foxes for resources. This range expansion is likely to continue (MacPherson, 1964; Pamperin, Follmann, and Petersen, 2006).

Climate change will also amplify a number of the factors that already affect refuges in these ecoregions. The large projected increases in temperature may result in the introduction of new diseases and an increase in the impacts of diseases already present on the refuges. For example, recent warming has already led to a shortening of the lifecycle of a specific nematode parasite, resulting in decreased fecundity and survival in musk oxen (Kutz *et al.*, 2005). Higher temperatures will potentially increase the role that fire plays in northern ecoregions and increase the frequency of ignition by dry lightning. Fires in the boreal forest are, for example, predicted to increase in frequency with further warming (Rupp, Chapin, and Starfield, 2000). Finally, the combination of warming and acidification of streams and lakes in the boreal forest will have combined negative impacts on freshwater fauna (Schindler, 1998).

Because the refuges of the northernmost ecoregions cover more than 80% of the area of the NWRS and because the high latitudes are expected to undergo some of the most dramatic changes in climate, climate-driven impacts to these refuges will greatly affect the ability of the NWRS to meet many of its mandated goals to maintain existing species assemblages. As a result of range shifts, recreational and conservation targets may change. This yet again raises the question of where conservation and management activities should be directed—at species, ecosystem, or conservation landscape scales.

5.2.3.2 Northern Forests and Eastern Temperate Forests (207 NWRs)

These two ecoregions cover almost all of the eastern United States (Fig. 5.7). In the northeastern United States, recent documented seasonal warming patterns, extended growing seasons, high spring stream flow, and decreases in snow depth are predicted to continue; new trends such as increased drought frequency, decreased snow cover, and extended periods of low summer stream flow are predicted for the coming century (Hayhoe *et al.*, 2007). Changes in stream flow, drought frequency, snow cover, and snow depth have significant implications for precipitation-fed wetlands on many northeastern refuges. Decreases in water availability will affect breeding habitat for amphibians, and feeding and nesting habitat for wading birds, ducks, and some migratory songbirds (Inkley *et al.*, 2004).

In both the northern forests and the eastern temperate forests, climate change will likely result in shifts in forest composition and structure (Iverson and Prasad, 1998). In addition, global vegetation models project the conversion of many southeastern forests to grasslands and open woodlands in response to changes in atmospheric CO_2 and climate (Bachelet *et al.*, 2001). Shifts of this magnitude will greatly change the availability of habitat for many species on national wildlife refuges. Shifts in the dominant vegetation type or even small changes in the understory composition may result in significant changes in animal communities. In addition, climatic changes in these regions will have implications for both terrestrial and aquatic ecosystem functioning (Allan, Palmer, and Poff, 2005) which, in turn, will affect wildlife. For example, increases in temperature will affect dissolved oxygen levels in the many lakes of this region, resulting in changes in lake biota (Magnuson *et al.*, 1997).

Urbanization continues across much of the eastern United States, and most significantly across the East Coast states. Urbanization and residential development have the potential to further isolate refuges and reduce the ability of organisms to move from one protected area to another. Concurrent warming, reduced stream flow, and increased urbanization may lead to increased bioaccumulation and potentially biomagnification of organic and inorganic contaminants from agriculture, industry, and urban areas (Moore *et al.*, 1997). Finally, climate change will likely accelerate the spread of some exotic invasive species and shift the ranges of others (Alward, Detling, and Milchunas, 1999).

5.2.3.3 Great Plains (139 NWRs)

Changes in hydrology likely present the largest threat to refuges in the Great Plains. Several of these refuges encompass portions of the PPR, which is the most productive waterfowl habitat in the world. The population numbers for many waterfowl species in the area are positively correlated with the number of May ponds available in the PPR in the beginning of the breeding season (Batt *et al.*, 1989). Predicted continued rise in temperatures will cause severe drought in the central part of the PPR and a significant drop in waterfowl population numbers (Johnson *et al.*, 2005). Increased temperatures will result in increased evaporation and lead to decreased soil moisture and the likely shrinkage and drying of many wetlands in the region (Sorenson *et al.*, 1998). More specifically, these changes have been predicted to result in fewer wetlands (Larson, 1995), along with changes in hydroperiod, water temperature, salinity, dissolved oxygen levels, and aquatic food webs (Poiani and Johnson, 1991; Inkley *et al.*, 2004). The likely cascading effects on waterfowl on refuges across the region include reduced clutch sizes, fewer renesting attempts, and lower brood survival (Inkley *et al.*, 2004). Earlier projections of potential population declines for waterfowl have ranged from 9–69% by 2080 (Sorenson *et al.*, 1998).

In addition, stresses from agricultural lands surrounding refuges in the Great Plains will likely be exacerbated by future climatic changes. In particular, decreases in precipitation and increases in evaporation have the potential to increase demands for water for agriculture and for refuges. In contrast, increases in precipitation have the potential to increase agricultural runoff.

The loss of waterfowl habitat in the PPR may greatly limit the ability of the NWRS to provide viable populations of many species for which it currently manages.

5.2.3.4 Northwestern Forested Mountains and Marine West Coast Forest (59 NWRs)

Together, these two ecoregions account for most of the mountainous areas in the western United States (Fig. 5.7). The Marine West Coast Forest ecoregion is generally relatively wet with temperate ocean-influenced climates. The Northwestern Forest Mountains ecoregion is generally drier. Future projections for the region are for intermediate temperature increases and increased precipitation.

Some of the largest impacts to this region are likely to come from changes in hydrological regimes resulting from reduced snowpack and earlier snowmelt. The resulting changes in stream flow and temperature will negatively affect salmon and other coldwater fish (Mote *et al.*, 2003). In addition, competition among different users for scarce summer water supplies will be intensified as snowpack is reduced and spring melts come earlier (Mote *et al.*, 2003). Water-use conflicts are already a major issue (National Research Council, 2007) in dry summers following winters with minimal snowpack (*e.g.*, Klamath Basin NWR Complex).

Climate change is also likely to affect fire regimes in the mountains of the western United States (Westerling *et al.*, 2006). Larger and more intense fires have implications for refuges at lower elevations that receive much of their water from the forested mountains. These fires will alter stream flows and sediment loads, changing the hydrology and vegetation in downstream wetlands. Changes in wetland habitats in the western mountains, whether driven by changing hydrology, fire regimes, or shifting vegetation patterns, have the potential to affect the ability of the NWRS to protect habitat and provide viable populations of species on refuges.

5.2.3.5 Mediterranean California (28 NWRs)

As in the two mountainous ecoregions of the western United States, changes in snowpack in the Sierra Mountains has the potential to affect the hydrology and habitat of refuges in the central valley and on the coast of California. Based on projections from two general circulation models, under the lower SRES B1 greenhouse gas emissions scenario, the Sierra Mountains will experience 30–70% less snowpack. Under the higher SRES A1FI emissions scenario they are projected to have 73–90% less snowpack (Hayhoe *et al.*, 2004). The snow-fed streams draining the Sierras into the Central Valley of California will have lower summer flows and earlier spring flows, significantly changing the hydrology of the valley. Reduced stream flows and increased temperatures may result in increased salinity in bays and estuaries such as the San Francisco Bay, significantly affecting the biological integrity, diversity, and health of species and populations in the San Francisco Bay NWR Complex. Sea level rise will compound these effects for refuges in low-lying estuaries and bays along the California coast.

As in the Northwest Forested Mountains ecoregion, the competition for water for agricultural, residential, industrial, and natural resource use will be severely strained (Hayhoe *et al.*, 2004).

5.2.3.6 North American Deserts and Southern Semiarid Highlands (53 NWRs)

Like the rest of the United States, the arid Southwest has been warming over the last century. Parts of southern Utah and Arizona have had greater than average increases in temperature (*e.g.*, 2–3°C) (NESDIS, NCDC, NOAA). Furthermore, the southwestern United States is one of the few regions in the country that has experienced a reduction in precipitation in the last 100 years (Houghton *et al.*, 2001).

Continued warming and drying in the arid ecoregions of the United States could have profound impacts on many refuges. These climate trends will lead to changes in hydrology that, in turn, will have the largest effects on wetlands and other shallow water bodies. Although precipitation-fed systems are most at risk, groundwater-fed systems in which aquifer recharge is largely driven by snowmelt may also be heavily affected (Winter, 2000; Burkett and Kusler, 2000). Reductions in water levels and increases in water temperatures will potentially lead to reduced water quality, in terms of increased turbidity and decreases in dissolved oxygen concentrations (Poff, Brinson, and Day, Jr., 2002). Increased productivity, driven by increased temperature, may lead to increases in algal blooms and more frequent anoxic conditions (Allan, Palmer, and Poff, 2005).

More so than in the other ecoregions, water resources in the arid portions of the western United States are already in high demand. Decreases in available water will exacerbate the competition for water for agriculture, urban centers, and wildlife (Hurd *et al.*, 1999). Competition for water already threatens the Moapa dace on the Desert NWR Complex in the Moapa Valley of Nevada and the wildlife of the Sonny Bono Salton Sea NWR in southern California.

Dams and other small water diversions, combined with the prevalence of east-west flowing rivers, will hinder migration of aquatic species to cooler waters (Allan, Palmer, and Poff, 2005). In addition, many endemic fish in arid ecoregions are highly adapted to local conditions and quite limited in distribution. Many of these species are projected to go extinct in response to temperature increases of just a few degrees (Matthews and Zimmerman, 1990). Reduced water levels and increased water temperatures may also lead to increases in disease outbreaks.

Grazing by cattle on refuges in the arid ecoregions will likely exacerbate the effects of drought stress and aid in the spread of exotic species. Furthermore, refuges may be sources of scarce water resources in the future, making them even more attractive to cattle. Grazing will also likely interact with climate-driven vegetation changes to further alter plant communities and wildlife habitat on refuges in arid regions (Donahue, 1999). Although reduced precipitation and increased temperatures may reduce productivity in some arid regions, global vegetation models have predicted an expansion of grasslands, shrublands, and woodlands into arid regions in response to increased water-use efficiency driven by increased atmospheric CO_2 concentrations (Bachelet *et al.*, 2001). These shifts would result in dramatic changes in wildlife communities in the affected areas. Overall, we would see a reduction in the number of desert species and an increase in species that inhabit dry grasslands, shrublands, and woodlands.

5.2.3.7 Sub-Tropical and Tropical Ecosystems (7 NWRs)

In the continental United States, the tropical wet forest ecoregion occurs only in southern Florida. The largest climate-driven threat to the refuges in this ecoregion is sea level rise. With its extensive low-lying coastal areas, much of this region will be underwater or inundated with salt water in the coming century. The several refuges in the Florida Keys, Florida Panther NWR, and Key Deer NWR are all particularly at risk.

Invasive native and non-native species are also a major threat in this ecoregion. As temperatures rise, South Florida will likely be the entry point of many new tropical species into the United States. Five new species of tropical dragonfly had established themselves in the country by 2000—each suspected to be the result of a northward range shift from populations in the Caribbean. Loss of land due to sea level rise in southern Florida will increase development pressure inland and in the north, potentially accelerating urbanization and exacerbating the isolating and fragmenting effects of development.

5.2.3.8 Coastal and Marine Systems: Marine Protected Areas (161 NWRs)

Low-lying coastal refuges face several climate-driven threats. Sea level rise will likely be the largest threat to refuges in the southeastern United States. Low-lying coastal areas on the East and Gulf Coasts are some of the most vulnerable in the country. Some of the most vulnerable refuges include: the Chincoteague NWR, on the Delmarva Peninsula; the Alligator River NWR on the Albemarle Peninsula of North Carolina; San Francisco Bay NWR in California; and Merritt Island NWR in Florida. In fact, many of the refuges in New England, the Middle Atlantic states, North Carolina, and Florida are coastal and susceptible to sea level rise. For many of these refuges, sea level rise will drastically alter habitat by inundating estuaries and marshes and converting forests to marshes. Beach-nesting birds such as the piping plover, migratory birds using the refuges as stopovers, and species using low-lying habitats such as the red wolf and Florida panther will likely lose habitat to sea level rise (Schlyer, 2006). In addition, sea level rise may destroy coastal stopover sites used by birds migrating up and down the East Coast (Galbraith *et al.*, 2002; Huntley *et al.*, 2006).

Warming ocean temperatures also threaten coastal and marine refuges. In fact, warming ocean temperatures are already having severe effects on many marine organisms. For example, increased water temperatures have resulted in increases in the frequency of toxic algal blooms (Harvell *et al.*, 1999), and future climate changes are predicted to result in more intense tropical storms, resulting in increased disturbance for many coastal refuges (IPCC, 2007b). Coral bleaching is another effect of increased ocean temperatures and has had profound effects on reefs in the Caribbean. Increased ocean acidity (from the accumulation of carbonic acid in the water)—a direct result of more CO_2 entering the ocean from the atmosphere and combining with water) will dissolve calcium-rich shells, dramatically changing the species composition of zooplankton and having cascading effects on entire marine ecosystems (Guinotte *et al.*, 2006).

Over-fishing, eutrophication, and increasing temperatures may lead to toxic algal and jellyfish blooms (Jackson *et al.*, 2001). Temperature-stressed corals will be more susceptible to disease. Invasive species are likely to expand their ranges as water temperatures rise. And finally, pathogens and disease vectors may move with climate change. An example of this latter threat is given by the expansion of an oyster parasite, *Perkinsus marinus,* up the East Coast of the United States in response to warmer waters (Ford, 1996).

5.3 Adapting to Climate Change

Adaptation measures aim to increase the resilience of species, communities, and ecosystems to climate change (Turner, II *et al.*, 2003; Tompkins and Adger, 2004). The law governing management of the NWRS affords the USFWS great latitude in deciding what is best for the system. Especially in dealing with a topic as fraught with scientific uncertainty as the effects of climate change, the USFWS can act assertively within the broad power Congress delegated to make judgments about how best to achieve the system's objectives. Maintaining biological integrity, diversity, and environmental health (U.S. Congress, 1997) and sustaining healthy populations of species (U.S. Congress, 1997), two of the chief goals for the NWRS, provide ample bases to support adaptation. The uncertainty associated with climate change influences on refuges, the NWRS, and ecosystems, and the complexity of conservation targets and their interactions, requires a structured and integrative approach to decision-making and management actions. The scale of the impacts of climate change is global and the scale of desired conservation responses—flyways, entire species' ranges—require that management actions be implemented and conservation target responses be measured in areas unprecedented in their size and in their area of extent (Anderson *et al.*, 1987; Nichols, Johnson, and Williams, 1995; Johnson, Kendall, and Dubovsky, 2002).

National wildlife refuges are not yet implementing adaptation strategies to explicitly address climate change. However, various management approaches (*e.g.,* riparian reforestation, assisted dispersal) currently used to address other stresses could also be used to address climate change stresses within individual refuges. More importantly, beyond the scale of individual refuges, climate change warrants system-wide adaptive management.

Representation, redundancy, and resilience are key conservation principles that could be used to strengthen the NWRS in the face of climate change within and beyond existing refuge boundaries (Shaffer and Stein, 2000). The resilience/viability of populations and ecosystems on an individual refuge level may be increased through habitat augmentation, restoration, reduction/elimination of environmental stressors, acquisition of inholdings, and by enhancing the surrounding matrix through conservation partnerships, conservation easements, fee-title acquisitions, etc. At the NWRS scale, opportunities for refuge species to respond and adapt to climate change effects can be obtained by capturing the full geographical, geophysical, and ecological ranges of a species on as many refuges as possible. The goal of these management responses is not to create artificial habitats for species but to restore and increase habitat availability and reduce stressors to provide species maximum opportunity to respond and adapt to climate change.

The adaptation measures presented in the following sections will most effectively facilitate ecosystem adaptation to climate change when implemented within the framework of adaptive management.

5.3.1 Adaptive Management as a Framework for Adaptation Actions

Adaptive management lends itself well to the adaptation of natural resource management actions to climate change. Adaptive management is an iterative approach that seeks to improve natural resource management by testing management actions and learning from the results (Holling, 1978; Walters, 1986; Salafsky, Margoluis, and Redford, 2001). Each management action can have a desired impact to influence the distribution and abundance of the target species. However, depending on the type of management action, there can also be a number of unintended consequences. Adaptive management provides a research/management tool to asses the frequency and intensity of unintended impacts. It is an approach that is useful in situations where uncertainty about ecological responses is high, such as climate change. Adaptive management proceeds generally through seven steps: (1) Establish a clear and common purpose; (2) Design an explicit model of your system; (3) Develop a management plan that maximizes results and learning; (4) Develop a monitoring plan to test your assumptions; (5) Implement your management and monitoring plans; (6) Analyze data and communicate results; (7) Iteratively use results to adapt and learn (Salafsky, Margoluis, and Redford, 2001). Public participation, scientific monitoring, and management actions based on field results form the core principles of adaptive management.

Adaptive management also incorporates a research agenda into plans and actions so that they may yield useful information for future decision-making. For instance, the planning process for refuges and the NWRS does not end when a plan is adopted. It continues into a phase of implementation and evaluation (U.S. Fish and Wildlife Service, 2000c). Under adaptive management, each step of plan implementation is an experiment requiring review and adjustment.

In general, the law provides authority to USFWS for adaptive management. The general principles of administrative law give the USFWS wide latitude for tailoring adaptive management to the circumstances of the refuges. One element of adaptive management, monitoring, is affirmatively required by the NWRSIA of 1997 (U.S. Congress, 1997). The only legal hurdle for adaptive management is the need for final agency action in adopting Comprehensive Conservation Plans (CCPs) and making certain kinds of decisions involving findings of no significant impact (FONSIs) under the National Environmental Policy Act (NEPA).

Although the USFWS policy implementing its planning mandate makes a strong effort to employ adaptive management through modeling, experimentation, and monitoring, legal hurdles remain for the insertion of truly adaptive strategies into CCPs. Not only do the Administrative Procedure Act, NEPA, and the NWRSIA all emphasize finality in approval of a document, but the relative formality of the development of an administrative record, the preparation of an environmental impact statement for proposals significantly affecting the environment, and the need to prepare initial plans for all refuges by the statutory deadline of 2012 all tend to front-load resources in planning. Once the USFWS adopts an initial CCP for a refuge, adaptive management would call for much of the hard work to come in subsequent implementation. However, from a legal, budgetary, and performance-monitoring standpoint, few resources are available to support post-adoption implementation, including monitoring, experimentation, and iterative revisions. Despite these drawbacks, adaptive management remains the most promising management strategy for the NWRS in the face of climate change. The research and management objectives described below are thought out within the framework of adaptive management.

5.3.2 Adaptation Strategies Within Refuge Borders

One of the most important comparative advantages of the NWRS for adaptation (compared with other federal agencies) is its long experience with intensive management techniques to improve wildlife habitat and populations. The NWRSIA of 1997 provides for vast discretion in refuge management activities designed to achieve the conservation mission. Some regulatory constraints, such as the duty not to jeopardize the continued existence of listed species under the ESA, occasionally limit this latitude. Generally, intensive management occurs within the boundaries of an existing refuge, but ambitious adaptation projects may highlight certain locations as high priority targets for acquisition. Also, programs such as animal translocations will require cooperation with all the involved parties within the organism's range (McLachlan, Hellmann, and Schwartz, 2007).

The chief legal limitation in using intensive management to adapt to climate change is the limited jurisdiction of many refuges over their water. Both the timing of water flows as well as the quantity of water flowing through the refuge are often subject to state permitting and control by other federal agencies, as discussed above. But, in general, the USFWS has ample proprietary authority to engage in transplantation-relocation, habitat engineering (including irrigation-hydrologic management), and captive breeding.

Because government agencies and private organizations already protect a network of remarkable landscapes across the United States, resource managers will need to develop specific land management actions that will help species adapt to changes associated with sea-level rise, changes in water availability, increased air and water temperatures, etc. These measures may provide time for populations to adapt and evolve, as observed in select plant and animal species in the past few decades of increasing temperatures (Berteaux *et al.*, 2004; Davis, Shaw, and Etterson, 2005; Jump and Peñuelas, 2005). Strategic growth of the NWRS to capture the full ecological, genetic, geographical, behavioral, and morphological variation in species will increase the ability of refuge managers and the NWRS to meet legal mandates of maintaining biological integrity, diversity, and environmental health of biological systems on NWRS lands. These habitats will increase chances that species will be more resilient to the challenges posed by climate change (Scott *et al.*, 1993).

The tools available to the NWRS to confront and manage for climate change are those it has historically used so successfully to address past crises: prescribed burning, water management, land acquisition, inventory and monitoring, research, in some cases grazing and haying, etc. Critically, however, the NWRS needs to regroup and reassess in a collective way the value of these tools—as well as where and how to apply them—in the context of the changing environmental dynamic now occurring. For example, 2007 has presented a dramatic shift in historic wildfire patterns in the contiguous United States, as the "fire season" and fire risk areas have expanded to the East Coast in addition to the traditionally notorious West. As of June, 2007, the Big Turnaround Complex Fire burning on and around Okefenokee NWR in southeastern Georgia has surpassed 600,000 acres and is now the largest wildfire in history within the lower 48 states. This suggests that the application of fire to habitat management fuel reduction on refuges throughout the eastern United States may need reconsideration. Some potential climate adaptation measures that could be used by the NWRS for terrestrial ecosystems include:

- *Prescribed burning to reduce risk of catastrophic wildfire*. Climate change is already increasing fire frequency and extent by altering the key factors that control fire temperature, precipitation, wind, biomass, vegetation species composition and structure, and soil moisture (IPCC, 2001; IPCC, 2007a). In the western United States, increasing spring and summer temperatures of 1ºC since 1970 have been correlated to increased fire frequency of 400% and burned area of 650% (Westerling *et al.*, 2006). Analyses project that climate change may increase future fire frequencies in North America (Flannigan *et al.*, 2005). Wildfires may also create a positive feedback for climate change through significant emissions of greenhouse gases (Randerson *et al.*, 2006). Prescribed burns could prevent catastrophic impacts of stand-replacement fires in ecosystems characterized by less intense fire regimes. Fire management could also increase the density of large-diameter trees and long-term standing biomass.

- *Facilitate the growth of plant species more adapted to future climate conditions*. Future conditions may favor certain types of species; for example, broadleaved trees over conifers. Favoring the natural regeneration of species better adapted to projected future conditions could facilitate the development of functional ecosystems. Nevertheless, high genetic diversity of species at the low-latitude edge of their range may require special protection in those areas (Hampe and Petit, 2005). Additional research is needed to better understand the long-term effects that such regeneration might have on natural communities.

- *Assisted dispersal*. Endemic species that occur in a limited area threatened with complete conversion by climate change may face extinction. Assisted dispersal is the deliberate long-distance transport by people of plants or animals in their historically occupied range and introduction into new geographic areas. Assisted dispersal offers an extreme measure to save such species (Hulme, 2005; McLachlan, Hellmann, and Schwartz, 2007). It risks, however, the release of non-native species into new areas and may not be as effective in altered environments. It also raises social and ethical issues and should be viewed only as a last resort and considered on a case-by-case basis.

- *Interim food propagation for mistimed migrants*. The decline of long-distance migratory birds in Europe and the United States may originate in mistiming of breeding and food abundance due to differences in phenological shifts in response to climate change (Sauer, Pendleton, and Peterjohn, 1996; Both *et al.*, 2006). To compensate for the resource, it may become necessary to propagate food sources in the interim. The USFWS has provided food for waterfowl wintering on various refuges. For example, at Wheeler NWR, water levels are regulated in order to promote additional vegetation growth on the refuge. Parts of Columbia NWR are devoted to crop production, which is then available for waterfowl and other birds. Although a common practice on many refuges, it is important to remember that food propagation does not promote the biological integrity, diversity, and health of the refuges and the NWRS, nor the ability of the species to adjust to a changing landscape.

- *Riparian reforestation*. Reforestation of native willows, alders, and other native riparian tree species along river and stream banks will provide shade to keep water temperatures from warming excessively during summer months. This will create thermal refugia for fish and other aquatic species while also providing habitat for many terrestrial species. This adaptation strategy will only be sustainable if the riparian species are tolerant to the effects of climate change.

- *Propagation and transplantation of heat-resistant coral*. Climate change has increased sea surface temperatures that, in turn, have caused bleaching and death of coral reefs. The Nature Conservancy leads a consortium of 11 government and private organizations in the Florida Reef Resilience Program, a program to survey coral bleaching and test adaptation measures in the Florida Keys, an area that includes four refuges. The program has identified heat-resistant reefs and established nurseries to propagate live coral from those reefs. The program plans to transplant the heat-resistant coral to bleached and dead reefs.

On many refuges, external threats are controlled principally by federal agencies other than the USFWS. Water flows may be as dependent on decisions of sister federal agencies, such as the Federal Energy Regulatory Commission (for hydropower dams), the U.S. Army Corps of Engineers (for navigational and impoundment operations), and the Bureau of Reclamation (dam and water supply projects). Adaptation to climate change will require increased cooperation of these agencies with the USFWS if refuge goals are to be met.

Other possible management actions that could be applied to address climate change impacts include building predator-free nest boxes, predator control programs, nest parasite control programs, translocation to augment genetics or demographics, prescribed burns to maintain preferred habitat types, creation of dispersal bridges, removal of migration barriers, habitat restoration, etc. Caution should be observed when any actions that assist one species over another are taken. The degree of assistance has to be evaluated on a case-by-case basis.

5.3.3 Adaptation Strategies Outside Refuge Borders

Adaptation to climate change requires the USFWS to consider lands and waters outside of refuge boundaries. In some instances acquisition of property for refuge expansion will best serve the conservation mission of the NWRS. In most cases, however, coordination with other land managers and governmental agencies will be more practical than acquisition. Coordination, like acquisition, can both reduce an external threat generated by a particular land or water use and increase the effective conservation area through cooperative habitat management. Though the NWRSIA does little to compel neighbors to work with the USFWS on conservation matters external to the NWRS boundary, there are some regulatory hooks that USFWS managers can leverage. There are also several partnership incentive programs that could be used to create collaborative conservation partnerships (such as the Partners for Fish and Wildlife Program (U.S. Fish and Wildlife Service, 2007e), Refuge Partnership Programs (U.S. Fish and Wildlife Service, 2007f), Safe Harbor agreements (U.S. Fish and Wildlife Service, 2007g), Habitat Conservation Plans (HCPs) (U.S. Fish and Wildlife Service, 2007c), Candidate Conservation Agreements (CCAs) (U.S. Fish and Wildlife Service, 2002), Natural Resources Conservation Service (U.S. Department of Agriculture, 2007a), etc.) Increased partnerships of refuges with other service programs—the Endangered Species programs, in particular—could result in cost savings and increased achievement of the USFWS's five goals that they could not achieve acting individually.

Abating External Threats through Increased Coordination. The 2001, USFWS biological integrity, diversity, and environmental health policy tells refuge managers to seek redress before local planning and zoning boards, and state administrative and regulatory agencies, if voluntary or collaborative attempts to forge solutions do not work (U.S. Fish and Wildlife Service, 2000b). In 2004 USFWS officials helped stop a 19,250-seat concert amphitheater on a tract of land adjacent to the Minnesota Valley NWR by testifying before the local county commissioners in opposition to a permit application. NWRS leaders may take such actions to achieve conservation as climate changes.

Abating External Threats through the Regulatory Process. In addition to land use planning, other state legal procedures can offer refuge managers opportunities to address external threats. The Clean Water Act requires states to revise water quality standards every three years (U.S. Congress, 2002). The USFWS participation in this process could work to ensure that water quality does not limit adaptation to climate change. Designation of "outstanding national resource waters" in refuges, strengthening of water quality criteria, and establishment of total maximum daily loads of key stressors are three state tasks that can enhance the NWRS's adaptive capacity (See U.S. Congress, 1998). Also, some states establish minimum stream flows or acquire instream water rights. Federal law requires the Secretary of the Interior to acquire water rights needed for refuge purposes (U.S. Congress, 1997).

The ESA regulates private activities that may harm listed species and may be an important tool, particularly for listed species on refuges that suffer from external threats (U.S. Congress, 1973). Over the past 15 years, the ESA prohibitions have induced private cooperation to enhance conservation of species through tools such as habitat conservation plans and safe harbor agreements. The USFWS can encourage incorporation of adaptation terms into these tools.

5.3.3.1 Building Buffers, Corridors, and Improving the Matrix

Resilience is the capacity of an ecosystem to tolerate disturbance without changing into a different state controlled by a different set of processes (Holling, 1973). Fundamental ecosystem functions including nutrient cycling, natural fire processes, maintenance of food webs, and the provision of habitat for animal species often require land areas of thousands of square kilometers (Soulé, 1987; Millennium Ecosystem Assessment, 2006). Consequently, the relatively small size of most refuges and other conservation areas in the United States, their location in landscapes often altered by human activity, incomplete representation of imperiled species across the full range of their geographical, ecological, and geophysical range, and incomplete life history support on those refuges where it occurs, raise fundamental obstacles to achieving resilience on individual refuges and the NWRS (Grumbine, 1990). Indeed, the existing NWRS cannot fully support even genetically viable populations for a majority of threatened and endangered species (Czech, 2005). For those threatened and endangered species for which refuges were specifically established, the numbers are similar (Blades, 2007).

In response to the obstacle of small reserve size, the USFWS and other organizations engage in landscape-scale natural resource and conservation planning. A bolder strategic growth initiative may be needed to mitigate the projected impact of climate change on refuge species if the biological integrity, diversity, and health of the NWRS are to be maintained. For example, the biological integrity, diversity, and environmental health of the least Bell's vireo (*Vireo bellii*) could be enhanced through restoration of riparian habitats on those refuges where it is found. Conservation partnerships with adjacent land managers and owners to increase the area and quality of least Bell's vireo habitat would include conservation easement and fee simple acquisition, where appropriate, and strategic acquisition of new refuges within the least Bell's vireo habitat range. The potential applications of these approaches to facilitate ecosystem adaptation to climate change concentrate on the optimum size and configuration of new and existing conservation areas at a landscape scale. State Wildlife Action Plans also provide an opportunity to create more favorable environment adjacent to refuges through which species disperse, by identifying strategic habitat parcels within the range of the least Bell's vireo.

The USFWS already engages in planning to prioritize land acquisition (U.S. Fish and Wildlife Service, 1996). Acquisition of easements often represents an attractive option for building a support network around refuges to facilitate adaptation. The USFWS has great flexibility in crafting easements to address the particular dynamic circumstances of climate uncertainty. Federal courts have consistently upheld federal easements even in the face of state laws that imposed term limitations or contravened negotiated property restrictions (see North Dakota v. United States, 1983). However, given the predicted increases in the American population and its demands on natural resources, options for easements may be fewer and pressure to remove existing easement restrictions may increase in the future. This potential currently is playing out as the U.S. Department of Agriculture considers policy proposals to reduce enrollment in the Conservation Reserve Program (CRP) in order to stimulate crop production for biofuels. These factors attest to the necessity of creating a strategically planned conservation network today capable of meeting the challenges posed by climate change tomorrow.

Opportunities for maintaining the viability of refuge species, ecosystems, and ecosystem processes may be achieved through conservation partnerships, incentive programs, conservation easements, and fee simple acquisitions with willing sellers on refuge inholdings and adjacent properties. The USFWS already plays a leadership role in these best practices for conserving wildlife within watersheds and regions. The aspirational goals of refuge law along with the expertise of USFWS personnel are consistent with these outreach efforts, which may be informal or memorialized in memoranda or agreement among local landowners and jurisdictions surrounding refuges.

The drastic alteration of habitat from climate change vegetation shifts produces one of the most significant challenges to conservation because it reduces the viability of existing conservation areas. The targeted acquisition of new conservation areas, together with a structured configuration of the network of new and existing conservation areas across the landscape, offers an important approach to facilitating ecosystem adaptation. Landscape-scale adaptation strategies and tools—drawn from the literature and expert opinion—could include:

- *Establish and maintain wildlife corridors*. Connectivity among habitat patches is a fundamental component of ecosystem management and refuge design (Harris, 1984; Noss, 1987). Corridors provide connectivity and improve habitat viability in the face of conventional threats such as deforestation, urbanization, fragmentation from roads, and invasive species. Because dispersal and migration become critical as vegetation shifts in response to climate changes, corridors offer a key adaptation tool (*e.g.*, highway over- and underpasses, Yellowstone to Yukon corridor) and help maintain genetic diversity and higher populations size (Hannah *et al.*, 2002).

- *Acquire new conservation areas in climate change refugia*. Climate change refugia are locations more resistant to vegetation shifts due to wide climate tolerances of individual species, to the presence of resilient assemblages of species, or to local topographic and environmental factors. Because of the lower probability of drastic change, these refugia will likely require less intense management interventions to maintain viable habitat and cost less than management of vulnerable areas. Acquisition of new land in potential climate change refugia will likely change past priorities for new conservation areas. This will require integration of climate change data from tools identified below into the USFWS Land Acquisition Priority System (LAPS). Currently, The Nature Conservancy is analyzing impacts of climate change in the seven ecoregions that cross the State of New Mexico in order to identify climate change refugia and to guide the development of new conservation areas under ecoregional plans developed in collaboration with government and private partners. Identification of refugia requires field surveys of refugia from past climate change events or spatial analytical tools that include dynamic global vegetation models (DGVMs), bioclimatic models of individual species, and sea level rise models; each of these are described in more detail below.

- *Eliminate dispersal barriers and create dispersal bridges*. This topic was addressed to some extent previously, but additional opportunities exist, including removal of dispersal barriers in and near refuges, establishing dispersal bridges by eliminating hanging culverts, building highway under- and overpasses, modification of land use practices on adjacent lands through incentive programs, habitat restoration, enhancement, and conservation partnerships with other public land managers.

- *Improve compatibility of matrix lands*. Strict preservation of a core reserve and multiple-use management reflecting decreasing degrees of preservation in concentric buffer zones around the core constitutes another climate change adaptation tool. These land use changes may be achieved through new acquisitions, conservation partnerships, or conservation incentives programs, all focused on meeting the needs of NWRS species subject to climate change stresses. In the United States, a national park, wilderness area, or national wildlife refuge often serves as the core area, with national forests serving as an immediate buffer zone and non-urbanized state and private lands forming the outermost buffer zone. A conservation easement is a legal agreement that restricts building on open land in exchange for lower taxes for the landowner. It offers a mechanism for habitat conservation without the great expense and governmental processes required to purchase additional land for federal agencies through fee title acquisitions. As climate change shifts vegetation and animal ranges, conservation easements offer an adaptation tool to provide room for dispersal of species and maintenance of ecosystem function. If the ecosystem(s) maintained within a core conservation area and on lands adjacent to it is resilient, then even if climate changes cause a shift in species composition, that core conservation area will remain an important part of a conservation network because new species will be able to expand their ranges into it.

- *Restore existing and establish new marshland vegetation as sea level rise inundates coastal land.* The Nature Conservancy and USFWS are collaborating on a project in Alligator River NWR and on adjacent private land on the Albemarle Peninsula, North Carolina, to establish saltwater tidal marsh as the ocean inundates coastal land. The Nature Conservancy also plans to establish dune shrub vegetation in upland areas as coastal dunes move inland. In the Blackwater NWR in Chesapeake Bay, Maryland, the USFWS may be restoring marshland that oceans have recently inundated by using clean dredging material from ship channels to recreate land areas.

- *Establish other marshland vegetation where freshwater lake levels fall.* Decreasing summer precipitation and increasing evapotranspiration may decrease water levels in the Great Lakes by 0.2–1.5 m (Chao, 1999). Depending on the slope of shoreline areas, the drop in lake level could translate into shore extensions 3 m wide or more. Managers of the Ottawa NWR at Lake Erie, Ohio, and other refuges on the Great Lakes may need to preemptively establish freshwater marshes as shoreline areas become shallower.

- *Reduce human water withdrawals to restore natural hydrologic regimes*. Water conservation in agricultural or urban areas may free up enough water to compensate for projected decreases in runoff due to climate change. NWR managers could work with water managers to change the timing of water flows as climate change alters fish behavior. For example, climate change has shifted the adult migration of Atlantic salmon half a day earlier in 23 years (Juanes, Gephard, and Beland, 2004).

- *Install levees and other engineering works*. Levees, dikes, and other engineering works have been widely used to alter water availability and flows to the benefit of refuge species. Their use to hold back the changes brought by sea level rise and increases in storm intensity remains largely untested.

5.3.3.2 Preventing Change

These actions are primarily about reducing greenhouse gases. Refuges can participate by being educational centers for solutions to climate change, developing energy-saving practices on refuges (*e.g.*, using fuel-efficient vehicles (Eastern Neck NWR) or electrical vehicles, use of solar (Imperial NWR, Mississquoi NWR) and wind (Eastern Neck NWR, Mississquoi NWR) energy, geothermal heating and cooling (The John Heinz NWR at Tinicum, Chincoteague NWR), and, possibly, sequestering carbon through reforestation actions when consistent with refuge objectives, although the latter needs to be further researched.

5.3.3.3 Managing for Change

Rather than managing to retain species currently on refuges, refuges could manage to provide trust species the opportunity to respond to and evolve in response to emerging selective forces. Managing for change in the face of uncertainty is about buying time while planning for change.

Planning for change means identifying strategic planning for changes in the NWRS to meet the challenges of climate change. It also means working with other conservation land managers to increase linkages between protected areas and with conservation partners on matrix lands to increase suitability of these lands for the services to conservation targets. The scientific literature and expert opinion suggest the following possible management actions to improve the surrounding matrix:

- Creating artificial water bodies
- Gaining access to new water rights
- Reducing or eliminating stressors on conservation targets, *e.g.*, predator control, nest parasite control, control of non-native competitors
- Introducing temperature-tolerant individuals, *e.g.*, resistant corals (see previous discussion) (Urban, Cole, and Overpeck, 2000)
- Eliminating barriers to dispersal
- Building bridges for dispersal
- Increasing food availability.

Additional measures to help mitigate the impact of climate change on refuges could include building new aquatic habitats, acquiring new water sources, creating habitat islands near sea-ice foraging sites for seabirds, adding drip irrigation to increase humidity and moisture levels in amphibian microhabitats, etc. The possible unintended impacts and side effects of these and other management actions need to be further researched.

Management/conservation partnerships with adjacent landowners to establish more refuge-compatible land are another useful tool for dealing with the effects of climate change on the NWRS. For example, refuges could enter into partnerships with organizations such as the Natural Resources Conservation Service in the USDA (U.S. Department of Agriculture, 2007b), which offers an extensive list of programs and opportunities to manage and improve the landscape and to better meet challenges of climate change. Also, refuges could use existing general statutory (programmatic) authorities to manage collaboratively with federal, state, tribal, and local governments to meet the challenges of climate change. The NWRS has approximately six such resource-related (non-administrative) programs. Each program has one or more statutes that guide or govern their activities, and some of these statutes overlap among programs. Examples include the Migratory Birds and State Programs (guided by the Migratory Bird Treaty Act, Pittman-Robertston, Dingell-Johnson) and the Endangered Species program (Endangered Species Act of 1973, Marine Mammals Act, etc.).

It is probable that the stress from climate change will continue to increase over time, forcing national wildlife refuge managers and scientists to communicate, collaborate, manage, and plan together with managers and scientists from adjacent lands. One possible mechanism that the Department of the Interior could consider to enhance such collaboration is establishing national coordination entities for both management and informational aspects of responding to climate change. The National Interagency Fire Center, in Boise, Idaho (National Interagency Fire Center, 2007), is a potential model to consider. Establishing entities such as a national interagency climate change council and a national interagency climate change information network could help ensure that refuges are managed as a system, which will be a key element in climate change adaptation, as the scale of climate change impacts are such that refuges must be managed in concert with all public lands, not in isolation. A cabinet-level interagency committee on climate change science and technology integration has already been created by the current administration (The White House, 2007). This committee is co-chaired by the secretaries of commerce and energy and oversees subcabinet interagency climate change programs.

A coordinated information network could assemble information on successful and unsuccessful management actions and adaptations, and provide extensive literature information and overviews of all climate-change related research. It could also offer technical assistance in the use of all available climate change models as well as support for geographic information systems, databases, and remote sensing for managers within each of the participating agencies.

The scale of the challenge presented by climate change and its intersection with land-use changes and expanding human populations necessitates new research and management partnerships. Building on existing partnerships between USGS and the USFWS, agencies could convene a national research and management conference bringing together managers and researchers to identify research priorities that are management-relevant and conducted at scales that are ecologically relevant (Box 5.2). The biannual Colorado Plateau Research conference provides a model to emulate (van Riper, III and Mattson, 2005).

The size and distribution of refuges presents a challenge when it comes to maintaining biological integrity, diversity, and environmental health. Yet, it is also a strength in that the NWRS has a great deal of experience with land- and water-intensive management, habitat restoration, and working across jurisdictional boundaries to achieve population objectives. These skills are critical to effective climate change adaptation. External threats to refuge goals have forced refuge managers to deal with transboundary issues more than most other land managers. Also, because refuge land management is often similar to private land management in a surrounding ecoregion, refuges can demonstrate practices that private landowners might adopt in responding to climate change.

In order to be efficient in managing refuges in the face of changing climate, the NWRS should produce a "Strategic Plan for Adaptation to Global Climate Change." This plan would include research priorities, management strategies, and adaptation scenarios that will guide the USFWS in its task of managing refuges.

The collaborative science paradigm must guide the management-science relationship in order to meet the challenge of global climate change. A beginning would be a small (8–12 individuals) workshop of service managers and scientists to flesh out the dimensions of the challenge using this report and those prepared for other public land managers. Further collaboration could be facilitated by a national conference of managers and researchers on challenges of climate change to conservation areas. A central piece of the conference would be the use of alternative refuge scenarios, documenting the past and current characteristics of the refuge (including their ecological content and context) and what they might become, under three alternative climate change scenarios and perhaps two to three different management scenarios. The fundamental questions throughout this conference would be: what are we managing toward? What do we expect the NWRS to be 100 years from now? Which will be the target species and where will they be? What will be the optimal configuration of refuges under such a climate shift and large scale changes in vegetation? This national conference could be followed by regional conferences hosted by each of the USFWS regions. A manager/researcher conference would need to include thematic breakout sessions to frame management-relevant questions, identify possible funding sources, and develop collaborative relationships. Ultimately these conferences would be focused on building bridges between research and management. To be successful, they would be convened every two years. The highly successful manager/researcher partnership on the Colorado Plateau (van Riper, III and Mattson, 2005) and the recent (February 2007) joint USGS-USFWS Alaska Climate Change Forum offer models for such efforts.

5.3.4 Steps for Determining Research and Management Actions

Modeling efforts are one tool that researchers and managers may use to predict the impacts of climate change on conservation target species and ecosystems. The following section describes the different tasks that can be accomplished using modeling tools, highlight research and management priorities in the face of climate change, and provide examples where these tools have been successfully applied (Box 5.3).

5.3.4.1 Modeling and Experimentation

In general, federal law encourages public agencies to employ science in meeting their mandates. The USFWS has a stronger mandate than most. Indicative of the

Congressional encouragement to partner with scientists and use refuges as testing grounds for models is the statutory definition of key terms in the NWRS mission:

> *The terms "conserving," "conservation," "manage," "managing," and "management," mean to sustain and, where appropriate, restore and enhance, healthy populations of fish, wildlife, and plants utilizing … methods and procedures associated with modern scientific resource programs. Such methods and procedures include, … research, census, … habitat management, propagation, live trapping and transplantation, and regulated taking (U.S. Congress, 1997).*

This definition provides ample authority and encouragement for modeling and experimentation.

Monitoring

The NWRS is unique among federal public lands in having a legislative mandate for monitoring. Congress requires the USFWS to "monitor the status and trends of fish, wildlife, and plants in each refuge" (U.S. Congress, 1997). However, as with other federal land management agencies, chronic budget shortfalls severely restrict implementation of monitoring. Enlisting outside researchers to study natural resources in refuges can ameliorate the budget limitations, but cannot substitute for a systematic effort to monitor key indicators identified in unit plans and consistent with a national (or international) system of data collection. The USFWS policy guiding comprehensive refuge planning is rife with monitoring mandates, including exhortations to establish objectives that can be measured (U.S. Fish and Wildlife Service, 2000b), to create monitoring strategies (id. at 3.4C(4)(e)), and to perform the monitoring (id. at 3.4C(7)). The National Park Service has developed an extensive survey monitoring program as well as one suitable for adaptive management (Oakley, Thomas, and Fancy, 2003). Information from monitoring efforts may be used to document how species respond to alternative management actions and thus inform adaptive management decisions for the next generation of management actions. Thus, well-designed and -implemented monitoring programs are absolutely necessary to conducting rigorous adaptive management efforts.

Understand and Model Interactions Between Populations and Habitat

As climate change drives habitat transformation, the abundance and distribution of wildlife populations will shift, often in unanticipated ways. Therefore, it will become increasingly important to support adaptive management efforts with greater understanding of the relationships between habitat and focal species or groups of focal species. By modeling these relationships, the work to protect and restore additional habitat, promote connectivity, and manipulate habitat through intensive management can be evaluated against population objectives.

There will be winners and losers among the species currently found on the NWRS. The challenge is to predict possible shifts in species distributions, phenologies, and interspecific relationships, and shifts in ecological and hydrological regimes, and then to manage toward these new assemblages and distributions. Essential to that process will be a comprehensive review of the literature. The NWRS is operating in a data-deficit environment. It does not have an all-taxa survey of refuges; while 85% of refuges have presence/absence information for birds, many of those that do have no information on abundance or seasonal occurrence (Pidgorna, 2007). It is the rare refuge that has even presence/absence data for lesser-known vertebrates. Checklists for plants and invertebrates are almost unknown. The initial survey effort should be directed at refuges in which the greatest change is anticipated, and at those species that are identified as most vulnerable to the effects of climate change, *e.g.*, species occurring on a refuge that is at the northernmost extreme of a species' range. More explicitly, the NWRS could carry out the following tasks to target adaptation efforts:

- *Task*: Facilitate identification of species that occur on refuges.

  Tools: Different tools are available to help facilitate the identification of species that occur on refuges (Pidgorna, 2007). The Cornell Lab of Ornithology and Audubon have created an interactive database called "eBird" (National Audubon Society and Cornell Lab of Ornithology, 2007). It allows birders from North America to add their observations to existing data on bird occurrences across the continent. The data can then be queried to reveal information on birds sighted at specific locations, *e.g.*, the NWRS. Refuge employees could also be engaged in providing bird occurrence information for refuges, and this database could later be expanded to include other taxonomic groups.

- *Task*: Develop a vision for the NWRS on its 150th anniversary in 2053.

  Tools: What will the conservation targets be: those species that currently occur on the NWRS, those species for which refuges were established, or threatened and endangered species for which refuges were established? Or, possibly, some subset of one of those categories, *e.g.*, waterfowl of North America? Threatened and endangered species? Invertebrates? Once target species are selected, what level of abundance will be targeted: minimally viable, ecologically viable, evolutionarily viable populations, recreationally viable or something else? It is important to also consider species that are currently absent from the NWRS, but that could expand their ranges into the NWRS and become conservation targets in the future, *e.g.*, Mexican song birds and hummingbirds.

  Due to the uncertainty associated with climate change, it is essential that conservation targets not be static. Stopgap targets eventually will contribute to failure of the adaptation process. Ambiguity and conflict among targets are potential problems. Regulations and statutes may need to be assessed and amended in some cases. Refuges with broad mission statements, such as those created as a result of the Alaska National Interest Lands Conservation Act (ANILCA), will have the greatest flexibility to accommodate future change in species composition. Non-ANILCA refuges will be required to emphasize species identified in refuge creation mission statements.

- *Task*: Identify those species and ecosystems most vulnerable to impacts of climate change. Strategic decisions for refuges and the NWRS regarding the biological integrity, diversity, and health of refuge species require understanding which occurrences of a species on NWRS lands are most or least likely to be affected by climate change.

  Tools: Species/populations that will be most vulnerable can be identified through reviews of the literature to identify species that have already shown shifts in phenology, distribution, or abundance, consistent with climate change, and through vulnerability assessment to identify the species likely to be most vulnerable to climate change, *i.e.*, species with poor dispersal capabilities; those that occur at the extremes of their ecological, geophysical, or geographical ranges; narrowly distributed species; species with small populations and/or fragmented distributions; and species susceptible to predation or crowding out by invasive non-native species.

- *Task*: Identify refuges within the NWRS that are most vulnerable to climate change

  Tools: In considering system-wide responses to the threat of global climate change managers need to think about management actions necessary to maintain the integrity, diversity, and health of the NWRS as well as that of individual refuges. This will require identifying those refuges that are most vulnerable to climate change through a system-wide vulnerability assessment. A quick review of work to date suggests that the 161 refuges that are characterized as Marine Protected Areas, the 16 refuges in Alaska account for 82% of the total area in refuges, and the 70 refuges in the Prairie Pothole Region—thus nearly 250 refuges and perhaps 90% of the area of refuges—occur in areas subject to significant climate changes.

- *Task*: Develop detailed inventory of species, communities, and unique ecological features. Few, if any, detailed inventories of the species, communities, and unique ecological features on refuges have been conducted. The exceptions, *e.g.*, waterfowl numbers and reproductive success, provide valuable information by which refuge managers may measure the impacts of climate change on this group of species. Without these data it will be impossible to monitor changes and to determine how to allocate resources to protect the biota of the different refuges.

  Tools: Traditional inventory and monitoring methods (Anderson *et al.*, 1987; Nichols, Johnson, and Williams, 1995) could be used to develop information (in a database) on sensitivity of all management targets to climate change. These sensitivities are described in the previous section. Additional information may be derived from literature searches and existing digital databases. The species monitoring program used by the National Park Service and the eBird database (described above) could also be used to facilitate this effort. This will also help fulfill the USFWS mandate to determine the biological integrity, diversity, and environmental health of the NWRS, which is also an important research priority.

- *Task*: Develop renewed and enhanced management/science partnerships between USFWS, USGS, other state and federal agencies, and academia.

  Tools: Collaborative relationships could be fostered through host researcher/manager conferences locally, regionally, nationally, and internationally that would allow researchers/managers working together to frame management-relevant research questions. The answers to such questions would increase the ability of refuges and the NWRS to meet the legal mandate of maintaining biological integrity, diversity, and environmental health in the face of the change and uncertainty predicted to occur with climate change.

  Because the ecological needs of many refuge species are more complex than what is supported by the current NWRS design, their biological integrity, diversity, and environmental health can only be managed through partnerships with the National Park Service, U.S. Forest Service, and other public managers with stewardship responsibilities for America's publicly held conservation lands. For example, the harlequin duck breeds in clear and sparkling mountain stream habitats of Olympic National Park and in the U.S. Forest Service's Frank Church Wilderness, and it may be found wintering in the marine waters of Willapa NWR and Oregon Islands NWR.

- *Task*: Use designated wilderness areas to track environmental changes due to climate change.

  Tools: The larger, more intact wilderness tracts would be key elements in our ability to track environmental changes due to climate change. The larger wilderness tracts are predominantly free of the "environmental noise" of more developed areas; therefore, observed changes in ecosystems within wilderness areas could more easily and reliably be attributed to climate change rather than some other factor. Selected wilderness areas should be considered as priority locations to institute baseline inventory work and long-term monitoring.

- *Task*: Obtain fine-resolution ($\leq 1\ km^2$) projections of future climate. Projected trends in climate must be summarized and made available to refuge managers at scales and in forms that are useful to them. The USFWS raw climate projections from climate models are at a coarse spatial resolution (on the order of thousands of km^2). Much finer resolution projections ($\leq 1 km^2$) of future climate for all of the most recent model outputs are needed.

  Tools: Finer-resolution projections could be generated from down-scaled climate model output using statistical downscaling approaches (*e.g.*, Wilby *et al.*, 1998), but more preferably would be generated using regional climate models (*e.g.*, Giorgi, 1990) capable of running off of boundary conditions generated by one or more global climate models.

- *Task*: Climate data need to be summarized to produce estimates of uncertainty and model concurrence.

  Tools: This task can be accomplished with comprehensive analyses of the variability across different climate model projections. Specifically, maps of model agreement and disagreement can be produced using recently derived methods (*e.g.*, Dettinger, 2005; Araújo and New, 2007). Both maps and concise summaries of the future projections written for managers and field biologists need to be made readily available on an easily accessed website and easily downloaded for any given region.

- *Task*: Weigh predicted losses of waterfowl, other conservation targets and their habitat with possible acquisition of new refuges and establish new conservation partnerships outside refuge lands as future conditions dictate.

  Tools: If and when refuges are managed as part of a larger conservation landscape, gains and losses will have to be weighed in terms of the refuges' conservation partners' activities (*e.g.*, the Bureau of Land Management, U.S. Forest Service, The Nature Conservancy, National Park Service), the continental or ecoregion system of public and private reserves, as well as land-use practices on matrix lands.

- *Task*: Project climate-induced shifts in vegetation, individual species ranges, and ranges of invasive and exotic species and summarize data for managers and field biologists. These projections of climate-induced shifts will aid mangers in determining how specific species or communities on refuges are likely to change in response to climate change. The challenge of climate change to biotic interactions has been a focus of attention for over a decade (Kareiva, Kingsolver, and Huey, 1993; Peters and Lovejoy, 1994; Parmesan and Yohe, 2003; Lovejoy and Hannah, 2006; Parmesan, 2006). These types of projections for both plants (Bachelet *et al.*, 2001; Shafer, Bartlein, and Thompson, 2001) and animals (Price and Glick, 2002) in North America are now becoming available, but more projections at finer resolutions are needed. As with the climate data, these data need to be summarized and made available to managers and field biologists. In addition to projecting shifts in the distributions of species that are currently protected on the refuges, models can be used to project the expansion of ranges of invasive and exotic species (*e.g.*, Peterson and Vieglais, 2001; Scott *et al.*, 2002).

  Tools: Dynamic global vegetation models (DGVMs) simulate the spatial distribution of vegetation types, biomass, nutrient flows, and wildfire by iterative analysis of climate and soil characteristics against observed characteristics of plant functional types and of biogeochemical, hydrologic, and fire processes. The LPJ DGVM (Sitch *et al.*, 2003) and the MC1 DGVM (Daly *et al.*, 2000) are the two most extensively tested and applied DGVMs (Neilson *et al.*, 1998; Bachelet *et al.*, 2003; Lenihan *et al.*, 2003; Scholze *et al.*, 2006). The Nature Conservancy, the USDA Forest Service, and Oregon State University are currently engaged in a collaborative research effort to run MC1 globally at a spatial resolution of 0.5 geographic degrees, approximately 50 km at the Equator, in order to estimate spatial probabilities of climate change vegetation shifts and to identify climate change refugia (Gonzalez, Neilson, and Drapek, 2005). The Nature Conservancy is using these data in order to help set global ecoregional priorities for site-based conservation, based on climate change and other threats to habitat (Hoekstra *et al.*, 2005).

The Nature Conservancy-USDA Forest Service-Oregon State University project is analyzing potential impacts from a set of general circulation models (GCMs) of the atmosphere and Intergovernmental Panel on Climate Change (2000) greenhouse gas emissions scenarios. This analysis is producing four spatial indicators of climate change: temperature change, precipitation change, estimated probability of vegetation shift at the biome level, and refugia, defined as areas that all emission scenarios project as stable (Fig. 5.8.) Many of the refuges in the NWRS are projected to experience a biome shift and thus be outside refugia by 2100, and there is substantial heterogeneity among administrative regions. Even vegetation changes that do not constitute a biome shift may have substantial implications for trust species populations as well.

Figure 5.8. Potential climate change vegetation shifts across North America. A. Vegetation 1990. B. Projected vegetation 2100, HadCM3 general circulation model, IPCC (2000) SRES A2 emissions scenario. C. Projected change as fraction of ecoregion area. D. Potential refugia (Gonzalez, Neilson, and Drapek, 2005).

Several other modeling tools and mapping efforts will be required to address the threats posed by climate change. An easily applied hydrological model is needed to assess the relative vulnerability of all refuges to changes in temperature and precipitation. Several hydrological models exist and could be applied to individual refuges. This would be a major, but important, undertaking. It will also be critical to assess the current and projected future level of connectivity among refuges and among all protected lands in general. Maps of current land-cover can be used to derive estimates of which refuges are most isolated from other protected lands, and where potential future corridors should be located to connect protected lands. These maps can be integrated with projections of future development to determine where additional reductions in connectivity will likely occur. Land-cover analyses can also be used to identify areas where there will likely be increased conflicts over water-use for agriculture, residences, and refuges.

While DGVMs model the biogeography of vegetation types, bioclimatic models for individual species simulate the range of single species (Pearson *et al.*, 2002; Thomas *et al.*, 2004b; Thuiller, Lavorel, and Araujo, 2005). These models generally identify areas that fall within the climate tolerance, or envelope, of a species. Alternatively, some bioclimatic models define species-specific climate envelopes by correlating field occurrence and climate data. Like DGVMs, bioclimatic models generally do not simulate dispersal, inter-specific interactions, or evolutionary change (Pearson and Dawson, 2003). Analysis of climate envelopes for 1,103 plant and animal species and the impact of climate change on habitat areas defined by species-area relationships indicates that climate change places 15–37 % of the world's species at risk of extinction (Thomas *et al.*, 2004a).

The USDA Forest Service has analyzed climate envelopes and projected potential range shifts for 80 North American tree species (Iverson, Schwartz, and Prasad, 2004) and has posted all of the spatial data at http://www.fs.fed.us/ne/delaware/atlas. These data are available for anyone proficient in GIS. Natural resource managers could use these species-specific data to locate refugia or to anticipate migration of new species into an area.

Intercomparisons of bioclimatic models for animal and plant species (Lawler *et al.*, 2006; Elith *et al.*, 2006) show variation among models, although MARS-COMM (Elith *et al.*, 2006) and random forests estimators (Breiman, 2001) have demonstrated abilities to correctly simulate current species occurrences. Nevertheless, research has not adequately tested the ability of bioclimatic models to simulate the new and unforeseen distributions and assemblages of species that climate change may generate (Araújo and Rahbek, 2006). The computer-intense and specialized nature of bioclimatic models has restricted them to academic research.

Observing species' responses to climate change will be crucial for developing models to predict responses in abundance, migration arrival and departure dates, and distribution for those species that have not yet responded to climate change (Root *et al.*, 2003). Once the predicted responses are available, it will be possible to identify relevant management options and strategies. It may also be important to predict responses of competitors, parasites, and host species of conservation targets in order to better manage conservation targets and also prevent invasions of refuges by non-native weedy species.

- *Task*: More detailed coastal elevation maps are needed. Addressing sea level rise will require more detailed maps of coastal elevations and accurate, easily applied models to integrate these maps with projected sea level increases and to translate predicted habitat changes into population changes and remedies for conservation targets. Expansion of sea water as climate change increased sea temperatures, along with increases in ocean water volume as terrestrial ice melted, increased global mean sea level 17 ± 5 cm in the 20th century and may raise sea level another 18–59 cm by 2100 (IPCC, 2007a). As a first approximation, reserve managers can use topographic maps and local surveys of high tide levels and add

> 18–59 cm to estimate areas subject to inundation from climate change.
>
> *Tools*: Coastal geomorphology and other factors determine local patterns of sea level rise. The U.S. Geological Survey has analyzed sea level rise projections, geomorphology, shoreline erosion and accretion, coastal slope, mean tidal range, and mean wave height to generate a coastal vulnerability index for the entire coast of the lower 48 states (Thieler and Hammar-Klose, 1999; 2000a; 2000b) and posted the GIS data at http://woodshole.er.usgs.gov/project-pages/cvi.
>
> Because local topography determines actual inundation patterns, only detailed elevation surveys can identify exact areas subject to flooding from climate change. The U.S. Geological Survey has flown light detection and ranging (LIDAR) surveys and produced a topographic data layer with a 30 cm contour interval for the Blackwater NWR on Chesapeake Bay, Maryland, which lies entirely below 1 meter above sea level and has lost land area since at least 1938 (Larsen *et al.*, 2004b). The Blackwater inundation model identifies the land areas that may go underwater by 2100 (Fig. 5.5), providing USFWS staff the information needed to plan potential new fee title acquisitions or conservation easements in contiguous upland areas and potential restoration of inundated wetlands using clean dredging material from ship channels.
>
> In order to estimate local effects of subsidence, isostatic adjustment, sedimentation, and hydrologic structures on sea level rise in the Ding Darling, Egmont Key, Pelican Island, and Pine Island refuges in Florida, the USFWS, the National Wildlife Federation, and Virginia Polytechnic State University used the Sea Level Affecting Marshes Model (SLAMM) (Park *et al.*, 1989). The output of these and similar models include maps that provide “before and after” images of coastal habitats and tables that provide data on habitat transformations corresponding to a specific period of time. However, SLAMM requires considerable skill with GIS and is expensive to use.

There are four other key research priorities that will likely involve a combination of predictive modeling and empirical studies. First, managers need information on how climate change will affect the prevalence and the intensity of wildlife and plant diseases and pathogens that pose threats to refuge species. Are outbreaks of certain diseases mediated by changes in temperature and moisture? How will a given disease respond to a change in temperature? How will the geographic ranges of diseases change with climate?

A second research need is projections of how the disturbance regimes on refuges will change. For example, how sensitive to an increase in temperature is the current fire regime or drought cycle at a given refuge?

A third priority is to investigate the implications of key translocations or “assisted dispersals.” For species that will likely need to be moved to new sites or other refuges, where are these new sites, and what are the ecological implications of introducing the new species?

Finally, research priorities should include developing methods to identify and select the best possible management actions under alternative climate change scenarios. Tools for gaming alternative scenarios would enhance a manager's ability to anticipate changes for individual refuges and the NWRS by using climate models and existing information on species occurrences on refuges to predict alternative management scenarios under different climate scenarios. The future of those refuges and the ecosystems, species, and ecological processes would be predicted under each scenario. One could also query species and ecosystem impacts with current management practices, strategic growth of the refuge, strategic growth of the NWRS, or establishment of coastal barriers.

5.4 Case Study: 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 (Houghton *et al.*, 2001) (Fig. 5.9). Migratory birds are one of the major trust species groups of the NWRS, and birds that breed in Alaska traverse most of the system as they use portions of the Pacific, Central (Fig. 5.10), 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 (Houghton *et al.*, 2001). Historical records show strong warming in the Dakotas and a tendency toward cooling in the southern reaches of the flyway (Fig. 5.9). Pervasive and dramatic habitat shifts (Fig. 5.8) are projected in Alaska and especially throughout the Central Flyway by the end of the century.

Figure 5.9. Annual mean temperature trends 1901–2003. Note warming in northern two-thirds of Central Flyway and cooling in southern third of the flyway. Data are from NOAA National Climatic Data Center (2006).

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 5.2).

5.4.1 Current Environmental Conditions

5.4.1.1 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 in Alaska and 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.

5.4.1.2 Changes in Agriculture

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 biofuels increases acreage in corn production, the potential negative effects of the recent increase in soybean production on waterfowl energetics may be ameliorated.

5.4.1.3 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 *et al.* (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; Hawkings and Malta, 2000).

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 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 PPR of the Central Flyway, 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.

5.4.2 Projections and Uncertainties of Future Climate Changes and Responses

5.4.2.1 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 predicted 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 predicted 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 and Meehl, 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 and Meehl, 2001). Projections of changes in vegetation suggest that most of the Central Flyway (Figs. 5.8d, 5.10) will experience a biome shift by the latter part of the 21st century (Bachelet *et al.*, 2003; Lemieux and Scott, 2005).

Figure 5.10. Central Flyway Waterfowl Migration Corridor (U.S. Fish and Wildlife Service, 2007b).

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.

5.4.2.2 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 (Hawkings and Malta, 2000) 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°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° N region in climate model projections (Kattsov and Källén, 2005).

5.4.3 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 (Fig. 5.8d) (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.

5.4.4 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.

5.4.4.1 Potential Effects of Climate Change on the Annual Cycle of Alaska Breeding Migrants

Abundance of waterfowl 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, 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 (Corcoran, 2005). 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 (Fig. 5.11) may make it difficult to detect any effects that have occurred.

Figure 5.11. 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 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.

5.4.4.2 Implications for Migrants

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

Reduced 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 (Fig. 5.10) encompass substantial spatial variation in documented (Fig. 5.9) 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.

5.4.5 Management Option Considerations

5.4.5.1 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.

5.4.5.2 Necessary Management Tools

Foremost among necessary management tools is the establishment of an interagency public lands council that facilitates long-term national-level planning, conducted in 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 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.

5.4.5.3 Barriers to Adaptation

The primary barriers to adaptation include lack of adequate resources and funding mechanisms, and the lack of a spatially explicit understanding of the 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 resources and 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.

5.4.5.4 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 heterogeneity in 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 USFWS to the first three management crises of market hunting, dust bowl habitat alteration, and threatened and endangered species management.

The ability to execute enhanced prediction 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 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:

- Convening of a meeting to address possible management and policy responses to alternative climate change scenarios;
- Synthesis of extant biological information relevant to biotic responses to climate change;
- Workshops involving both managers and researchers to identify research questions relevant to managing species in the face of climate change;
- Research conducted 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;
- Application of management actions in response to biotic responses that emerge as likely from such research; and
- Evaluation 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 exotic species introductions 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/exotic species and 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 predicting 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 predict 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.

5.5 Conclusions

Climate change is the largest challenge ever faced by the NWRS. It threatens the integrity, diversity, and health of the refuges in ways that no other challenge has. This challenge calls for a clear vision for the future of the NWRS. The historic vision of refuges as fixed islands of safe haven for species met existing needs at a time when the population of the United States was less than half its current size and construction of the first interstate highway was a decade away. At that time, climates and habitats were perceived to be in dynamic equilibrium, and species were able to move freely among refuges. Today, the landscape is highly fragmented, much of the wildlife habitat present in the 1930s and 1940s has been lost, and researchers know that ecological systems are in a constant state of change. While Congress' aspiration for the refuges to serve as a national network for the support of biological diversity remains sound, the challenge now is to make the refuge network more resilient and adaptive to a changing environment. Changes have already occurred that are consistent with those predicted under climate change, thus increasing confidence that future changes in species distribution and behavior will occur with increasing frequency. Refuge managers are faced with a dilemma of managing for a future threat without fully understanding where and when the changes will occur and how they might best be dealt with. How can USFWS fulfill the key legal mandate to maintain the integrity, diversity, and health of conservation targets in an environment that allows for evolutionary response to the impacts of climate change and other selective forces?

This chapter has identified research initiatives, management/research partnerships, and efforts to increase the integrity, diversity, and health of refuge lands. Alaskan refuges, where impacts of climate change are already apparent, have been used to illustrate some of the challenges facing researchers and managers locally, regionally, and nationally. While there is uncertainty about the impact and scale of the predicted effects of climate change on sea level rise, species distributions, phenologies, regime shifts, precipitation, and temperature, most of these changes have already begun and will most likely significantly influence the biological integrity, diversity, and health of the NWRS. These changes will require management actions on individual refuges to restore habitat; build dispersal bridges for species; eliminate dispersal barriers; increase available habitat for species through strategic fee title acquisitions, easements and other tools; and increase cooperative, consultative conservation partnerships to maintain biological integrity, diversity, and environmental health of refuge populations and systems.

However, actions on individual refuges alone will be insufficient. NWRS-wide threats require system-wide responses. The USFWS's response to the three previous threats faced by the NWRS (overhunting in the late 1800s, dust bowl era effects, and the ongoing loss of biodiversity that began in the second half of the 20th century) helped shape the current system, which is viewed worldwide as a model of what a natural areas system can be. Climate change, the fourth crisis facing the NWRS, offers us the opportunity to build on past successes and to do so with a more complete understanding of ecological systems. While the scale of climate change is unprecedented, so are the opportunities to make a difference for the future of wildlife and the ecosystems on which they depend. A response sufficient to the challenge will require new institutional partnerships; management responses that transcend traditional political, cultural, and ecological boundaries; substantially more appropriations; greater emphasis on trans-refuge management and research; political leadership far exceeding that which has been experienced to date; and reenergized collaborations between the USFWS and its research partners in USGS, other federal, state, tribal and private organizations, and academic institutions. The magnitude of expected changes—inundation of coastal refuges, regime shifts, shifts in species distributions and phenologies—threatens the viability of populations on single refuges as well as the existence of trust species (threatened and endangered species, migratory birds, marine mammals, and anadromous and interjurisdictional fish). The most important tool available is the species themselves and their ability to evolve genetic, physiological, morphological, and behavioral responses to changing climates, interspecific relationships, and environments. The opportunities for species to evolve in response to changing environments can be enhanced by ensuring that the full range of the target species' biogeographical, ecological, geophysical, morphological, behavioral, and genetic expression is captured in the NWRS (Scott *et al.*, 1993; Shaffer and Stein, 2000).

A national interagency climate change council, a national interagency climate change information network, researcher/manager conferences, research themes and management strategies, and the species inventories and monitoring programs identified in this chapter represent some of the tools that could enable the USFWS to best meet the challenge of global climate change. The most important take-away messages about the management of the NWRS in the face of climate change are summarized below.

5.5.1 Take Away Messages About the Management Actions Required in the Face of Climate Change

- ☐ *Establish coordinating bodies such as a national interagency climate change council and a national interagency climate change information network to advise and oversee the management of ecosystems and resources*. The scale of climate change impacts are such that public lands (including refuges) and private lands may be best managed in concert rather than in isolation. Management and information mechanisms could be established to support this new level of cooperation. Adaptation to climate change will likely require an entirely new level of coordination among public lands at multiple spatial scales. Such coordination could involve regional councils that bring together federal, state, county, and private land owners. Increased international cooperation will also be necessary, since climate change does not respect political borders. Lessons could be learned from the work done by the intergovernmental Arctic Council and its six working groups.

- ☐ *Conduct vulnerability assessments and identify conservation targets*. National and regional assessments could be carried out to identify ecosystems, species, and protected areas facing the greatest risks and those that may serve as climate refugia; this information then could be used to develop shared conservation targets and objectives. The most vulnerable species on refuges include species with restricted ranges, limited dispersal capabilities, and those that occur on a refuge that is at the geographical, ecological, or geophysical extreme of a species range and/or on a refuge that provides incomplete life history support.

- ☐ *Conduct a series of workshops on gaming alternative management scenarios.* A series of workshops on gaming alternative management scenarios in the face of climate change will provide refuge managers with a portfolio of tools, solutions, and actions to both proactively and reactively respond to the effects of climate change.

- ☐ *Manage lands as dynamic systems*. It may not be possible to manage for static conservation targets. Species ranges will shift, disturbance regimes will change, and ecological processes will be altered. Management actions to decrease non-climate stressors and enhance the biological integrity, diversity, and health of refuge species, ecosystems, and ecological processes could include: water impoundment; control of water flow; control and elimination of predators, competitors, and nest parasites on conservation targets; and enhancement of food resources and breeding habitat (*e.g.*, red-cockaded woodpecker).

- ☐ *Ensure that conservation targets provide a representative, resilient, and redundant sample of trust species and communities.* If the conservation targets are managed through adequate and well-coordinated interagency efforts, their evolutionary capabilities will be enhanced, viable populations will be maintained, and the potential for recreational and subsistence uses will be maximized.

- ☐ *Strategically grow the NWRS.* Adaptation to climate change may require strategic growth of individual refuges and the NWRS, to increase resilience and the conservation value of refuges and the NWRS through increased representation and redundancy of conservation target populations on refuges. A refuge that has "lost" its establishment and/or acquisition purpose could still be valuable to the NWRS, providing it is resilient enough to support different species and processes. The strategic growth of the NWRS and successful adaptation to climate change will require refuge managers, scientists, government officials and other stakeholders to look beyond any one species and any single refuge purpose. The mandate of the NWRS—to maintain biological integrity, diversity, and environmental health of the Refuge System—is so complex and broad that it would be difficult if not impossible to state that a refuge has lost its larger purpose and will no longer contribute to the fulfillment of this mandate. The size and distribution of refuges and whether or not they are capable of meeting the standards of maintaining biological integrity, diversity, and environmental health of various conservation targets needs to be vigorously assessed before decisions can be made about managing the system and disassembling refuges.

5.5.2 Take-Away Messages about the NWRS

- ☐ *The NWRS was designed principally as a migratory bird network.* The widely dispersed units provide for the seasonally variable life history requirements for trust species. Because many birds make use of different parts of the NWRS throughout the year, the performance of birds on any one component of the NWRS will be affected by climate-induced changes throughout the NWRS. Thus, innovative inter-flyway, inter- and intra-agency, and inter-regional communication and coordination are needed to understand and adapt to climate change.

- ☐ *The policy of managing toward pre-settlement biological integrity, diversity, and environmental health will be more problematic under projected future climate conditions.* Pre-settlement global temperatures were ~ 1°C colder than at present and temperatures will continue to warm throughout the 21st century. Historical conditions may no longer exist, and maintaining integrity, diversity, and health of biological systems defined by historical conditions will be problematic if current policies are not revisited. Therefore, more research is needed for establishing baselines other than “historic conditions.”

- ☐ *The NWRS has extensive experience working with private landowners and can be a model for private landowner responses to climate change.* With 4 million acres in easements, the NWRS has developed valuable experience working with landowners to craft agreements that support system-wide objectives. Because refuge lands are more productive and at lower elevation than other protected areas, they are more similar in these characteristics to private lands and thus better suited to demonstrate practices that private landowners might adopt in responding to climate change. All public lands should be models for other landowners, but the refuges may be the most relevant models in many parts of the country.

- ☐ *Refuges are more disturbed and fragmented than other public land units.* These characteristics may exacerbate the challenges presented by climate induced habitat changes. However, the NWRS has substantial experience with intensive management, a wide range of habitat restoration methods, and cross-jurisdictional partnerships that should enhance the refuges’ ability to achieve objectives compared with other federal land management systems.

The challenge today is to manage for change in the face of uncertainty. If responses to predicted climate change impacts fail to occur at scales that match the threats, it may not be possible to meet the legal mandate of managing refuges and the NWRS to maintain their biological integrity, diversity, and environmental health. The USGS and USFWS cross-programmatic, strategic, habitat conservation initiative illustrates the type of thinking and planning that will be needed to tackle climate change within the NWRS and across the USFWS and other agencies (National Ecological Assessment Team, 2006). The integrity and functioning of ecological systems will be maintained only if USFWS manages for change and reintegrates refuges into the American mind and the American landscape. Isolated conservation fortresses managed to resist change will not fulfill the promise of the NWRSIA, nor will they meet the needs of American wildlife.

5.6 References

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5.8 Appendix: Actions to Assist Managers in Meeting the Challenges Posed by the Threat of Climate Change[3]

Climate-related stressor	Ecological Impacts	Information Needed	Would it Require a Change in Management/ Can it be addressed?	Management Approach/ Activity	Opportunities	Barriers or Constraints
Changes in invasive species (increases or shifts in the types)	New invasive species may impact refuges; warming temperatures may enable the survival of exotic species that were previously controlled by cold winter temperatures.			Remove exotics; prevent and control invasive pests (Combes, 2003; as cited in Matson, 2006).		
Sea level rise	Loss of high and intertidal marsh; species impacted: migratory waterfowl, shorebirds, threatened and endangered species, anadromous fish.	Need better models and projections of sea level rise; more extensive use of SLAMM (Sea Level and Marsh Migration Model).	Refuge boundaries may need to be established in a different way (*e.g.*, Arctic refuge has ambulatory boundaries that are going to shift with sea level rise—meaning that the islands and lagoon will be lost); dikes and impoundments	Avoid acquiring additional bunkered/coastal lands; do acquire land further inland in areas where sea level projected to rise; avoid maladaptive activities such as moving wetland grasses/removing peat content.	Expand collaboration with other federal agencies, state agencies, private organizations to increase/share knowledge.	Need better monitoring system. Managers need adaptation tools.

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[3] The content of this table was taken from the ideas that emerged during the stakeholder workshop.

Climate-related stressor	Ecological Impacts	Information Needed	Would it Require a Change in Management/ Can it be addressed?	Management Approach/ Activity	Opportunities	Barriers or Constraints
			are temporary, so longer term solutions need to be sought.			
Salt water intrusion	Flooding of coastal marshes and other low-lying lands and loss of species that rely on marsh habitat, beach erosion, increases in the salinity of rivers and groundwater (Matson, 2006).		Yes, but will need to decide if managers should manage for original conditions or regime shift.	Restoration of saltmarshes may be facilitated by removal of existing coastal armoring structures such as dikes and seawalls, which may create new coastal habitat in the face of sea level rise. Presence of seawalls at one site in Texas increased the rate of habitat loss by about 20% (Galbraith *et al.*, 2002).		
Hydrologic changes	See Cinq-Mars and Diamond (1991) for discussion of how changes in precipitation may affect fish and wildlife resources. See Larson (1995) for a discussion on the effects of changes in precipitation on northern prairie wetland basins. Van Riper, III, Sogge, and Willey (1997) discuss the effects of lower precipitation on bird communities in the southwestern United States.	Need better models and projections of hydrological changes		Use projected changes in hydrology to help manage impacts caused by hydrologic changes. Cinq-Mars and Diamond (1991) recommend that "monitoring programs must be established for fish and wildlife resources; migration corridors must be identified and protected; and new concepts must be developed for habitat conservation."		
Melting ice and snow	Polar bears are increasingly using coastal areas as habitat changes due to sea ice melting;					

Climate-related stressor	Ecological Impacts	Information Needed	Would it Require a Change in Management/ Can it be addressed?	Management Approach/ Activity	Opportunities	Barriers or Constraints
	changes in wintering patterns for waterfowl due to food availability. Bildstein (1998) describes observations about how timing of cold fronts affects raptor migration. Changes in snowpack in the West will result in reduced summer streamflow, which could impact habitat.					
Diseases	Diseases may move around or enter new areas (*e.g.,* avian malaria in Hawaii may move upslope as climate changes). Diseases would seem to be a major concern considering shift in migration ranges, the changes in endemic disease patterns (northern shifts of traditionally "tropical" diseases, for example), and the ability for certain diseases to be spread rapidly through migratory bird populations.					
Warming temperatures	Species range shifts/phenology: loss of keystone species (*e.g.,* polar bears and seals, salmon, beaver); 90% decline in population of sooty shearwater; habitat loss for cold water fishes. Breeding range of	Need better models and projections of species shifts.	Yes; if species that are the purpose of a refuge shift out of the refuge area, management	(1) Baseline inventorying: need to determine what species are where; an available tool for doing this is eBIRD; (2) monitoring along gradient such as latitude, longitude, distance to sea; GLORIA:	Expand collaboration with other federal agencies, state agencies, private	Need better monitoring system. Fifteen-year planning cycle may limit ability to think

Climate-related stressor	**Ecological Impacts**	**Information Needed**	**Would it Require a Change in Management/ Can it be addressed?**	**Management Approach/ Activity**	**Opportunities**	**Barriers or Constraints**
	songbirds may migrate north, which could negatively affect forests (the birds eat gypsy moths and other pests) (Matson, 2006). Trees will become sterile and dying trees will become more susceptible to invasive pathogens (Abbott, McCracken, and Levasseaur, 2002; as cited in Matson, 2006). Native species will be affected by the change in tree species (Matson, 2006). Warmer conditions can lead to food spoiling prematurely for species that rely on freezing winter temperatures to keep food fresh until spring (Waite et al 2006 as cited in Matson 2006). Prolonged autumns can also delay breeding, which can lead to lower reproductive success. See also Hannah *et al.* (2005).		must be changed either to focus on management of different species or thinking about the refuge boundaries.	mountain top assessments of species shifts; GIS layers on land prices, LIDAR data (3) build redundancy into system (4) establish new refuges for single species (5) build connectivity into the conservation landscape (change where agriculture is located and what crops are planted to allow migratory corridors to exist); (6) acquire land to north when projected species shifts northward; (7) identify indicator species that will help detect changes in ambient temperatures.	organizations to increase/share knowledge.	about long-term implications. Managers need adaptation tools. Cannot deal with this issue in a piecemeal fashion because will likely be a great deal of spatial redistribution in and out of refuge system.
Wildfires	Fires are becoming more intense and longer in Alaska and elsewhere. Schoennagel, Veblen, and Romme (2004) discuss the interaction of fires, fuels, and climate in the Rocky Mountains.	It is known that fires are becoming more intense and longer, but managers not sure what to do about it		Pre-emptive fire management: use prescribed burning to mimic typical fires (increase fire frequency cycle to prevent more catastrophic fire later).		Need to tie into wildlife management goals, but managers are not sure how.

Climate-related stressor	Ecological Impacts	Information Needed	Would it Require a Change in Management/ Can it be addressed?	Management Approach/ Activity	Opportunities	Barriers or Constraints
More frequent and extreme storm events	Debris from human settlements may be blown in or washed into refuges and may include hazardous substances. Eutrophication due to excess nutrients coming in from flood events could stimulate excessive plant growth and negatively affect habitats (Matson, 2006). Soils could be affected through erosion, changes in nutrient concentrations, seed losses, etc. Hydrology could be affected through stream downcutting, changes in bedload dynamics, loss of bank stability, changes in thermal dynamics, etc.	It is uncertain what the refuge system can do to manage for this issue.		Space populations widely apart; if a catastrophic weather event occurs, population loss may be less (Matson, 2006).		Hulme (2005): Species translocation can lead to unpredictable consequences, so should only be used in extreme situations.

Climate-related stressor	Ecological Impacts	Information Needed	Would it Require a Change in Management/ Can it be addressed?	Management Approach/ Activity	Opportunities	Barriers or Constraints
Alaska central flyway (case study): stressors include early thaw/late freeze, sea level rise, storm events, warming temperatures	Early thaw/late freeze: resource access; increased rearing season length, crop mix, early spring migration, delayed fall migration, short-stopping, northward-shifted harvest, redistribution; warming: habitat access, disease.			Recognition and monitoring; establish secure network of protected areas.		Lack of a national vision; uncertainty; resources/ political climate; non-climate stressors: agricultural disturbances, urbanization, fragmentation, pollution.

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5.9 Text Boxes

Box 5.1. USFWS Goals for the NWRS (601 FW1; U.S. Fish and Wildlife Service, 2000b)

1. Conserve a diversity of fish, wildlife, and plants and their habitats, including species that are endangered or threatened with becoming endangered.
2. Develop and maintain a network of habitats for migratory birds, anadromous and interjurisdictional fish, and marine mammal populations that is strategically distributed and carefully managed to meet important life history needs of these species across their ranges.
3. Conserve those ecosystems, plant communities, wetlands of national or international significance, and landscapes and seascapes that are unique, rare, declining, or underrepresented in existing protection efforts.
4. Provide and enhance opportunities to participate in compatible wildlife-dependent recreation (hunting, fishing, wildlife observation and photography, and environmental education and interpretation).
5. Foster understanding and instill appreciation of the diversity and interconnectedness of fish, wildlife, and plants and their habitats.

Box 5.2. Research Priorities for NWRS

1. Identify
    a. Conservation targets;
    b. Vulnerable species.
2. Monitor and predict responses.
3. Select best management strategies.
4. Game alternative climate change scenarios.

Box 5.3. Adaptation Options for Resource Managers

National Wildlife Refuges:
Adaptation Options for Resource Managers

- ✓ Manage risk of catastrophic fires through prescribed burns.
- ✓ Reduce or eliminate stressors on conservation target species.
- ✓ Strictly preserve the core of a reserve, and have multiple use management reflect decreasing degrees of preservation in concentric buffer zones.
- ✓ Improve the matrix surrounding the refuge by partnering with adjacent owners to improve existing habitats or build new habitats.
- ✓ Install levees and other engineering works to alter water flows to benefit refuge species.
- ✓ Remove dispersal barriers and establish dispersal bridges for species.
- ✓ Use conservation easements around the refuge to provide room for species dispersal and maintenance of ecosystem function.
- ✓ Facilitate migration through the establishment and maintenance of wildlife corridors.
- ✓ Reduce human water withdrawals to restore natural hydrologic regimes.
- ✓ Reforest riparian boundaries with native species to create shaded thermal refugia for fish species in rivers and streams.
- ✓ Identify climate change refugia and acquire necessary land.
- ✓ Facilitate long-distance transport of threatened endemic species.
- ✓ Facilitate interim propagation and sheltering or feeding of mistimed migrants, holding them until suitable habitat becomes available.
- ✓ Strategically expand the boundaries of NWRs to increase ecological, genetic, geographical, behavioral and morphological variation in species.
- ✓ Facilitate the growth of plant species more adapted to future climate conditions.

5.10 Tables

Table 5.1. The most common threats to national wildlife refuges that could be exacerbated by climate change. Data source: USFWS unpublished data (2002).

Threat	**Number of Records**	**%**
Invasive, exotic, and native pest species	902	32
Urbanization	213	7
Agricultural conflicts	170	6
Natural disasters	165	6
Rights-of-way	153	5
Industrial/commercial interface	145	5
Predator-prey imbalances	93	3
Wildlife disease	93	3

Table 5.2. The annual cycle of migratory waterfowl that breed in Alaska may serve as an integrative focus for development of a national vision of climate effects and management adaptation options for the NWRS. The complexity of potential interactions among locations, life history stages, climate mechanisms, non-climate stressors, and options for management adaptation for migratory waterfowl that breed in Alaska demonstrates that inter-regional assessment and timely communication will be essential to the development of a national vision.

Location	**Life History**	**Climate Mechanisms**	**Non-Climate Stressors**	**Adaptation Options**
Alaska	Production: *Breeding* *Fledging*	Early Thaw: *Resource access* *Habitat area* *Season length*	Minimal	Assess System Predict Collaborate Facilitate
Prairie Potholes (*Central Flyway*)	Staging: *Energy reserves*	Late Freeze: *Habitat distribution* *Migration timing* *Harvest distribution*	Land use Crop mix Disturbance Alternate Energy Sources	Assess System Predict Partnerships Secure Network
Southern US	Wintering: *Survival* *Nutrition*	Sea Level: *Habitat access* Storms: *Frequency, Intensity*	Urbanization Fragmentation Pollution	Partnerships Education Acquisition Adaptive Mgmt.

5.11 Figures

Figure 5.1. Structure of the NWRS. Adapted from Fischman (2003), Refuge Administration Act (1966), and FWS Regulations – CFR 50.

Figure 5.2. The National Wildlife Refuge System. Adapted from Pidgorna (2007).

Figure 5.3. Organizational chart (U.S. Fish and Wildlife Service, 2007a).

Figure 5.4. Timeline of milestone events of the NWRS (U.S. Fish and Wildlife Service, 2007d).

Figure 5.5. Blackwater National Wildlife Refuge, Chesapeake Bay, Maryland. Current land areas and potential inundation due to climate change (Larsen *et al.*, 2004b).

Figure 5.6. Results of the Sea Level Affecting Marshes Model (SLAMM) for Ding Darling National Wildlife Refuge. Source: USFWS unpublished data (McMahon, Undated, 2007).

Figure 5.7. Ecoregions of North America (Level 1) (U.S. Environmental Protection Agency, 2007).

Figure 5.8. Potential climate change vegetation shifts across North America. A. Vegetation 1990. B. Projected vegetation 2100, HadCM3 general circulation model, IPCC (2000) SRES A2 emissions scenario. C. Projected change as fraction of ecoregion area. D. Potential refugia (Gonzalez, Neilson, and Drapek, 2005).

Figure 5.9. Annual mean temperature trends 1901–2003. Note warming in northern two-thirds of Central Flyway and cooling in southern third of the flyway. Data are from NOAA National Climatic Data Center (2006).

Figure 5.10. Central Flyway Waterfowl Migration Corridor (U.S. Fish and Wildlife Service, 2007b).

Figure 5.11. 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).