5 National Wildlife Refuges

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Chapter Contents

5.1 Summary

The U.S. National Wildlife Refuge System (NWRS) is the largest system of protected areas in the world. It encompasses more than 93 million acres (37.6 M ha) and is composed of 584 refuges plus 37 wetland management districts that include waterfowl production areas in 193 counties. Compared with other federal conservation estates, the units are relatively small, typically embedded in a matrix of developed lands, and situated at low elevations on productive soils. The key mandate of the NWRS Improvement Act of 1997 is to maintain the integrity, diversity, and health of trust species and populations of wildlife, fish and plants. This species mandate provides the system with substantial legal latitude to respond to conservation challenges. The system has emerged and evolved in response to crises that have included market hunting at the beginning of the 20th century, dust-bowl drought during the 1930s, and recognition of dramatic reductions in biodiversity in the 1970s. Ongoing conservation challenges include habitat conversion and fragmentation, invasive species, pollution, and competition for water. The most recent pervasive and complex conservation challenge is climate change.

Climate change will have NWRS-wide effects on species and their habitats. Mean global temperature has risen rapidly during the past 50 years and is projected to continue increasing throughout the 21st century. Changes in precipitation, diurnal temperature extremes, and cloudiness—as well as sea level rise—are some of the factors that are projected to accompany the warming. A coherent pattern of poleward and upward (elevation) shifts in species distributions, advances in phenology of plants, and changes in the timing of arrival of migrants on seasonal ranges in concert with recent climate warming has been well documented and is expected to have NWRS-wide effects.

The effects of most concern are those that may occur on NWRS trust species that have limited dispersal abilities. Climate related changes in the distribution and timing of resource availability may cause species to become decoupled from their resource requirements. For example, the projected drying of the Prairie Pothole Region—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 Devil's 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. Projected sea level rise has substantial negative implications for 161 coastal refuges, particularly those surrounded by human developments or steep topography. Projected climate-related changes in plant communities are likely to alter habitat value for trust species on most refuges; *e.g.*, grasslands and shrublands may become forested. Habitats for trust species at the southern limits of ecoregions and in the Arctic, as well as rare habitats of threatened or endangered species, are most likely to show climate-related changes.

Managing the "typical" challenges to the NWRS requires accounting for the interaction of climate change with other stressors in the midst of substantial uncertainties about how stressors will interact and systems will respond. Many NWRS trust species are migratory. Breeding, staging, and wintering habitats are typically dispersed throughout the system and on non-NWRS lands. The superimposition of spatially and temporally variable warming on spatially separated life history events will add substantial complexity to understanding and responding to ongoing conservation challenges. Climate change will act synergistically with other system stressors, and is likely to impose complex non-linear system responses to the "typical" challenges. It will be extremely difficult to clearly understand the influence of non-climate stressors on habitats, populations, and management actions without accounting for the effects of climate change. Local- to national-scale managers will face the dilemma of managing dynamic systems without fully understanding what, where, or when the climate related changes will occur, or how they might best be addressed. The actions suggested below will increase the chances of effectively resolving this dilemma.

Actions taken now may help avoid irreversible losses. Lost opportunities cannot be regained. The system is changing, and delaying action could result in irreversible losses to the integrity, diversity, and health of the NWRS. Heterogeneity in climate change effects will require diverse and innovative adaptations, increased emphasis on rigorous modeling projections at multiple scales, effective application of the experimental concepts fundamental to adaptive management, and enhanced collaboration with public and private stakeholders. However, expert opinion will need to be used in the initial response stages, and mistakes will be made while adaptation capabilities are being developed. Waiting for improved climate effect projections before acting would be inappropriate in view of the pervasive and immediate nature of the problem; developing a culture that rewards risk taking would enhance the speed of adaptation to climate change challenges. Expected decadal persistence of climate change effects suggests that a revision of contemporary planning and budgeting horizons will be necessary.

Knowing which species will be affected positively and negatively will allow NWRS managers to take advantage of positive outcomes and prepare for the management challenges of negative outcomes. If the near-term historical record is an accurate indicator, there will be substantial spatial heterogeneity in temperature and precipitation trends across the NWRS accompanying the system-wide increase in mean temperatures. As a result of this heterogeneity in regional- and local-scale climate change effects, some species will be "winners" and others will be "losers." Opportunities to capitalize on positive effects of climate change should be exploited. However, the scientific literature primarily documents negative effects. These negative effects of climate change present the NWRS with the most difficult management challenges. Once lost, conservation opportunities are extremely difficult to regain.

Responding to ecological effects may also be improved by projecting the possible futures of trust species, their NWRS habitats, and management options at all relevant management scales using the most rigorous scientific modeling tools, climate change scenarios, and suite of expected non-climate stressors. This activity would have several components: (1) clearly identifying conservation targets for the coming decades, and implementing effective and efficient monitoring programs to detect climate-related system changes; (2) identifying the species and systems most vulnerable to climate change, in the context of other system stressors, at the refuge, regional, and national scales, and prioritizing planning, budgeting, and management accordingly; (3) evaluating scale-specific (refuge > region > NWRS) suites of management and policy responses to alternative climate change scenarios; (4) developing objective criteria for choosing among these responses; and (5) proactively developing, comparing, executing, and evaluating multi-scale plans to mitigate vulnerability to climate change using adaptive management principles. Climate change can serve as a catalyst to develop an increased understanding of the ecological mechanisms affecting trust species and to improve the rigor of adaptive management programs.

A key requirement for adaptation to climate change is recognition that management for static conservation targets is impractical. The historical concept of refuges as fixed islands of safe haven for species is no longer viable. Except in special situations, such as the sole remaining habitat for a threatened or endangered species, management for the status quo will not be appropriate to the challenge of climate change. Managers and researchers will need to define and focus on a dynamic system “state” that provides representative, redundant, and resilient populations of trust species that fulfill the key legal mandate to maintain the integrity, diversity, and health of NWRS conservation targets. Managing for a dynamic system “state” that provides representative, redundant, and resilient populations of trust species provides the best opportunity to fulfill NWRS legal mandates in an environment that allows for evolutionary response to the effects of climate change and other selective forces.

The effective conservation footprint of the NWRS may be increased by using all available tools and partnerships. Maintaining and enhancing connectivity of system units is critical and may be accomplished by increasing the effective conservation footprint of NWRS. Approaches for increasing this footprint include new institutional partnerships; management responses that transcend traditional political, cultural, and ecological boundaries; greater emphasis on trans-refuge and trans-agency management and research; strong political leadership; and re-energized collaborations between the NWRS and its research partners at multiple spatial scales. Increasing the conservation footprint may bring about greater resilience of the NWRS to the challenge of climate change.

Actions that will enable more effective responses to climate change include initiating multi-scale communication, education, and training programs, and strengthening collaborations between USFWS and all conservation management and research partners. Effectively responding to climate-related complexity will be aided by substantial education and training, along with multi-scale, coordinated, and focused efforts by all NWRS partners (management, research, and other public and private land managers). Stronger management-research collaborations will help identify management- and policy-relevant climate-related ecological changes and responses, will keep decision makers informed, and will thus increase the likelihood that an effective response to climate change will be made. All levels and jurisdictions of management and research need to be integrated and empowered to meet the challenge of climate change. Climate change ignores administrative boundaries. Therefore it will be important to explore means of facilitating collaboration and communication among government and private land managers, such as an inter-agency climate information center that serves as a clearing house for documented climate change effects and available management tools.

A clearly elucidated vision of the desired state of the NWRS on the 150th anniversary of the system in 2053 would enhance the development of a framework for adaptation. This vision needs to explicitly incorporate the expected challenges of climate change and define the management philosophy necessary to meet this challenge. The complexity of expected climate effects and necessary management responses offers an opportunity to re-energize a focus on the interconnection of spatially separated units of the NWRS and to foster an integrated refuge-to-NWRS vision for managing climate change effects on system trust species.

Because climate change is a global phenomenon with national, regional, and local effects, it may be the largest challenge faced by the NWRS. Climate change adds a known forcing trend in temperature to all other stressors, and likely creates complex non-linear challenges that will be exceptionally difficult to understand and mitigate. New tools, new partnerships, and new ways of thinking will be required to maintain the integrity, diversity, and health of the refuges in the face of this complexity. 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 climate-related trends in ecological systems are well documented. 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.

5.2 Background and History

5.2.1 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 effect. 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. It will require national to local responses.

In response to the first challenge, President Theodore Roosevelt established America's first national wildlife refuge (NWR), Pelican Island, Florida. Nearly three decades later, in response to depression-era challenges, 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, 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). However, rapidly increasing mean global temperature during the past 100 years, which is predicted to continue throughout the coming century (*i.e.*, climate change, IPCC, 2007a), challenges 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. If the historical record is an indicator (Figs. 5.3a; 5.3b), there will be substantial heterogeneity in future trends for temperature and precipitation across the NWRS. 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,[1] and FWS Regulations.[2]

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

Figure 5.3. Observed annual trends in a) temperature and b) precipitation, 1901-2006, for the coterminous United States and Alaska. Data and mapping courtesy of NOAA's National Climate Data Center.

Direct uses of the NWRS, such as wildlife-dependent outdoor recreation and farming, are the most readily valued in monetary terms. Ecological functions of the refuges 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 $26.9 billion/year.[3]

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 challenges 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[4] 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, but showing a globally coherent response to climate change (Parmesan and Yohe, 2003). Climate change may exacerbate the misfits between the existing NWRS and ecological realities. Coastal refuges are likely to become inundated, migrations supported by refuges may become asynchronous with the changing seasons, non-native invasive species will likely extend their ranges into new

[1] P. L. No. 89-669, 16 U.S.C. '668dd
[2] FWS Regulations – CFR 50
[3] **Ingraham**, M.W., and S.G. Foster, in press: The indirect use value of ecosystem services provided by the U.S. National Wildlife Refuge System. *Ecological Economics*.
[4] In 1992 dollars.

refuges, and vegetation types may shift to plant communities that are inappropriate for refuge trust species.

Today, a system established to respond to local challenges 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 effects 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 system-wide as well as local to match the scale and effects of the challenge. Such a response is unprecedented in the history of conservation biology.

The ability of individual refuges and the entire NWRS to respond to the challenge of climate change is a function of the system's distribution, unit size, and ecological context. Familiarity 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. 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 decades to a century. Unless otherwise specified, we focus on the decadal time frame for adaptation measures described in this chapter. The scientific literature is dominated by reports of negative effects of climate change, and this dominance is reflected in our treatment of effects on refuges because the negative effects of climate change will present the greatest challenges to managers and policy makers.

In the pages that follow we focus on regional and national scales, and: (1) describe the institutional capacity of the NWRS to respond to the challenge of climate change; (2) document challenges to integrity, diversity, and health of species, refuges, and the NWRS; (3) describe projected effects of climate change on components of the NWRS; (4) identify research themes and priorities, most vulnerable species and regions, and important needs; and (5) suggest new partnerships for conservation success.

5.2.2 Mission, Establishing Authorities, and Goals

The NWRS is managed by the USFWS (Fig. 5.4) 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 using methods associated with “modern scientific resource programs.”[5] In 2006, the USFWS interpreted this first congressional purpose in a policy (601 FW1),[6] 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 5.4. Organizational chart.[7]

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”).[8] Or, they may be specific to a single refuge, such as the Upper Mississippi River NWR (as a refuge for birds, game,

[5] 16 USC 668dd P. L. 105–57
[6] U.S. Fish and Wildlife Service manual 601 FW 1
[7] **U.S. Fish and Wildlife Service**, 2007: America's national wildlife refuge system. FWS Website, http://www.fws.gov/refuges, accessed on 7-18-2007.
[8] 16 U.S.C. 715-715r; 45 Stat. 1222

fur-bearing animals, fish, other aquatic animal life, wildflowers and aquatic plants).[9] 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.

5.2.3 Origins of the NWRS

The first significant legislative innovation to systematically assemble protected areas was the Migratory Bird Conservation Act of 1929,[10] which authorized acquisition of lands to serve as "inviolate sanctuaries" for migratory birds (Fig. 5.5). 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.[11] 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 5.5. Timeline of milestone events of the NWRS.[12]

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.[13]

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[14] replaced the portion of the 1966 law dealing with imperiled species, and

[9] 16 USC § 721
[10] 16 U.S.C. 715-715r; 45 Stat. 1222
[11] 16 U.S.C. § 718-718h
[12] **U.S. Fish and Wildlife Service**, 2007: History of the national wildlife refuge system. U.S. Fish and Wildlife Service Website, http://www.fws.gov/refuges/history/index.html, accessed on 7-10-2007.
[13] P. L. No. 89-669, 16 U.S.C. § 668dd
[14] P. L. 93-205, 16 U.S.C. § 1531-1544, 87 Stat. 884

succeeded it as an important source of refuge establishment authority. 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.

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

5.2.4 The 1997 NWRS Improvement Act

The NWRS Improvement Act (NWRSIA) of 1997[15] 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). 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.

5.2.4.1 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."[16] 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.

5.2.4.2 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 NWRSIA 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. Planning focuses on habitat management and visitor services. The planning policy models its procedure on adaptive management.[17] Once approved, the CCP becomes a source of

[15] P.L. 105-57, 16 USC § 668dd
[16] P.L. 105-57, 16 USC § 668dd
[17] U.S. Fish and Wildlife Service manual 602

management requirements that bind the USFWS, though judicial enforcement may not be available.[18]

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 have identified explicit adaptation management strategies that are currently being implemented. This suggests that the perception of climate variability and change as a challenge 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 challenge will require system-wide responses. The magnitude of the challenge posed by climate change is unprecedented in scale and intensity, and the challenges exceed the capabilities of individual refuges. National coordination and guidance are needed. The CCPs provide a vehicle for engaging refuges in planning for response to climate change within the context of the NWRS.

5.2.4.3 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.[19] USFWS policy emphasizes state participation in most refuge decision-making, especially for comprehensive conservation planning and for determination of appropriate uses.

5.2.4.4 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.”[20] The USFWS compatibility policy promises to assure that “densities of endangered or otherwise rare species are sufficient for maintaining viable populations.”[21] The USFWS interprets its policy to prohibit uses that reasonably may be anticipated to fragment habitats.[22] Second,

[18] Norton v. Southern Utah Wilderness Alliance, 2004. 542 U.S. 55.
[19] North Dakota v. United States, 1983. 460 U.S. 300. and State of Wyoming v. United States, 2002. D.C. No. 98-CV-37-B, 61 F. Supp. 2d 1209-1225.
[20] 16 USC § 668dd
[21] U.S. Fish and Wildlife Service manual 601 FW 1 - FW 6.
[22] U.S. Fish and Wildlife Service manual 603, 65 Federal Register 62486

the NWRSIA requires that the USFWS maintain "biological integrity, diversity, and environmental health" on the refuges.[23] 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.

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

The Policy on Biological Integrity, Diversity, and Environmental Health[24] 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.[25] 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. Explicit performance goals and objectives tied to biological integrity, diversity and environmental health of refuges and the services conservation targets will be needed to assess the degree and effectiveness of NWRS response to the challenges of climate change.

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. This policy assumes a range of variation that is constant. That assumption is not consistent with projected environmental changes that may result from climate change. Rather, historical benchmarks and their variability may provide long-term perspective for developing strategies for the management of self-sustaining native populations and ecosystems in the face of change and uncertainty.

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 biological integrity, diversity, and environmental health of refuges and the

[23] 16 USC § 668dd
[24] U.S. Fish and Wildlife Service manual 601 FW 3
[25] 16 USC § 668dd

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 invasive 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.

5.3 Current Status of the NWRS

5.3.1 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[26] (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.

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).

[26] Grouped into 37 wetland management districts.

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 challenges 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 effects 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 through reduction of non-climate stressors, Other tools include integrating inholdings into refuge holdings, strategically increasing 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. These actions would in turn provide species with increased opportunities to adapt to a changing environment.

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 effects 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 species provide exemplars 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 effective conservation footprint of the NWRS to increase the biological integrity, diversity, and environmental health of threatened and endangered species and at-risk ecosystems and plant communities.

5.3.2 Challenges to the NWRS

5.3.2.1 2002 Survey of Challenges to NWRS

In an effort to quantify challenges 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 challenges and management conflicts experienced by the NWRS. It contains 2,844 records, each representing a different challenge to a refuge or a conflict with its operations.

The most common challenges to refuges that could be exacerbated by climate change are ranked by frequency of reporting in Table 5.1. Each record covers a specific challenge, 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 challenges 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 challenge 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; 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 challenge refuges and the NWRS. Such concerns take the form of invasive non-native species, 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 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 challenge refuges. While far less common than other challenges, 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 effects of climate change and other stressors. Tools and strategies used to respond to past stressors and challenges are many of the same tools that can be used to mitigate projected effects of global climate change.

5.3.2.2 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 effects 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 is also likely to 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 is likely to magnify the influences of other challenges—including habitat loss and fragmentation, changes in water quality and quantity, increased transportation corridors, etc.—on the NWRS. Climate change will also introduce new challenges or variations on existing ones, primarily by accelerating a convergence of issues (*e.g.*, water scarcity, non-native invasive species, off-refuge land-use change, and energy development), or creating such convergences where none existed before. Current and projected challenges 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 challenges 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 projections, 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 does 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 tailwinds.

Invasive Non-Native Species

Invasive non-native species are currently one of the most common challenges 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. There is distinction in state and federal law between native and non-native species.[27] The text of this report reflects those differences. We consider non-native species to be those species that have been introduced to an area as a result of human intervention, whether accidental or purposeful. Native species moving into new areas as a result of climate-change-induced range expansions continue to be native. Both native and non-native species can be considered to be invasive. It is, however, the non-native invasive species that present the greatest challenge 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 that previously were 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 invasive species 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 projected climate change effects 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

[27] P.L. 101-646, 104 Stat. 4761; 16 U.S.C. 4701; and P.L. 104-332, 16 USC 4701.

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 effects 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, 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 bio-fuels, 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 effect 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.

While climate change models vary in projecting changes to precipitation to any given geographical area, at least some parts of the United States are projected 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 in areas 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 reduced the amount of dissolved organic carbon reaching estuaries, 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 project precisely where the greatest effects 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 projected (Poiani and Johnson, 1991; Sorenson *et al.*, 1998), may be expected to face more stressful conditions than those in areas that are projected 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 million acres of coastal wetlands occur on refuges in the lower 48 states. Sea level rise is the result of several factors, including land subsidence, thermal expansion of the oceans, and ice melt (IPCC, 2007a). The sea-level rise at any given location depends on the local rate of land subsidence or uplift relative to the other drivers of sea level rise. 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, accretions 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 bulkheaded 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, part of the Chesapeake Marshlands NWR Complex. 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. 5.6) (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 challenges 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 are 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 challenge to wetlands, both coastal and non-coastal. In Florida, Pelican Island NWR, the system’s first refuge, is among the 161 coastal refuges challenged by sea level rise.

Figure 5.6. 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 project the potential effect 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. 5.7), Egmont Key, Pine Island, and Pelican Island. Significant wetland losses are projected at each refuge, 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. There is a need to model projected sea level rise, using a suite of models to address uncertainty, for each of the 161 coastal refuges to assess system-wide potential effects on refuge species and habitats.

Figure 5.7. Results of the Sea Level Affecting Marshes Model (SLAMM) for Ding Darling National Wildlife Refuge. Source: USFWS unpublished data.[28]

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 projected effects 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

[28] **McMahon**, S., Undated: USFWS unpublished data.

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 effects 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 (U.S. Fish and Wildlife Service, 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, that use those wetlands. Hurricane Hugo caused soil erosion on Sandy Point NWR, which had an adverse affect on nesting leatherback turtles (U.S. Fish and Wildlife Service, 1989).

5.3.2.3 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 demographically. 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 project, will likely occur with changing rainfall 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, the habitats of a highly specialized refuge (such as one established for an endangered species) might shift away from the 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 obviously, 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 uses that habitat.

The prospect of regime shifts makes it more crucial that the USFWS train and educate refuge managers in methods of 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 capacity for evolutionary and ecological change in self-sustaining ecosystems.

5.3.3 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 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. 5.8).

Figure 5.8. Ecoregions of North America (Level 1).[29]

5.3.3.1 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 (IPCC, 2001). In North America, the most warming

[29] **U.S. Environmental Protection Agency**, 2007: Ecoregions of North America. Environmental Protection Agency Website, http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Level%20I, accessed on 7-12-2007.

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 (IPCC, 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, the melting of 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 projected 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 projected 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 also will 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 effects 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, projected 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 effects 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 effects 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.

5.3.3.2 Northern Forests and Eastern Temperate Forests (207 NWRs)

These two ecoregions cover almost all of the eastern United States (Fig. 5.8). In the northeastern United States, recent documented seasonal warming patterns, extended growing seasons, high spring stream flow, and decreases in snow depth are projected to continue; new trends such as increased drought frequency, decreased snow cover, and extended periods of low summer stream flow are projected 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 biomagnifications 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).

5.3.3.3 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. 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). For example, the number of May ponds in the PPR dropped from approximately 7 million in 1975 to a little over 3 million in 1990, and then rose again to roughly 7 million by 1997. Mallard duck numbers tracked this trend, dropping from roughly 5 million in 1975 to a little under 3 million in 1990 and rising to roughly 6 million in 1997.[30] Hydrological models have been used to accurately simulate the effect of changing climate on wetland stage (Johnson *et al.*, 2005). The projected continued rise in temperatures will likely 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 projected 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 in 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.

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5.3.3.4 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. 5.8). 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 effects 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).

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[30] **U.S. Fish and Wildlife Service**, 2007: Migratory Bird Data Center. U.S. Fish and Wildlife Service Website, http://mbdcapps.fws.gov/, accessed on 11-20-2007.

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.

5.3.3.5 Mediterranean California (28 NWRs)

In the Sierra Mountains (as in the Northwest Forested Mountains ecoregion), the competition for water for agricultural, residential, industrial, and natural resource use will intensify (Hayhoe *et al.*, 2004). At the same time, changes in snowpack in the Sierra Mountains will also have 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, the Sierras 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 higher temperatures may result in increased salinity in bays and estuaries such as 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.

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

Like most of 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) (Figure 5.3a). The southwestern United States has experienced the smallest increase in precipitation in the last 100 years of any region in the coterminous United States (Figure 5.3b).

Climate models project drying and continued warming in the arid ecoregions of the United States, which could have significant effects on many refuges. These projected climate trends could lead to changes in hydrology that, in turn, may have large 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 challenges 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 projected an expansion of grasslands, shrublands, and woodlands into arid regions in response to increased water-use efficiency driven by increased atmospheric CO_2 concentrations. Increased abundance of invasive non-native grasses has altered fire regimes, increasing the frequency, intensity, and extent of fires in the American Southwest (D'Antonio and Vitousek, 1992; Brooks *et al.*, 2004).[31] These shifts could 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.

5.3.3.7 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 challenge 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 challenge 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

[31] **Brooks**, M.L. and D.A. Pyke, 2002: Invasive plants and fire in the deserts of North America. In: *Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species* [Gallery, K.E.M. and T.P. Wilson (eds.)]. Proceedings of the Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Management, Tall Timbers Research Station, pp. 1-14.

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.

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

Low-lying coastal refuges face several climate-driven challenges. Sea level rise will likely be the largest challenge to refuges in the southeastern United States (Daniels, White, and Chapman, 1993; Ross, O'Brien, and Sternberg, 1994). 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, South Carolina, and Florida are coastal and susceptible to sea level rise (Daniels, White, and Chapman, 1993; Titus and Richman, 2001). For many of these refuges, sea level rise will dramatically alter habitats 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.[32] 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 challenge 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 projected 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 challenge 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).

[32] **Schlyer**, K., 2006: *Refuges at Risk: the Threat of Global Warming and America's Ten Most Endangered National Wildlife Refuges*. Defenders of Wildlife, Washington, DC.

5.4 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 the scientific uncertainty associated with 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, and sustaining healthy populations of species, two of the chief goals for the NWRS, provide ample bases to support adaptation.[33] The uncertainty associated with climate change influences on refuges, the NWRS, and ecosystems, along with the complexity of conservation targets and their interactions, requires a structured and integrative approach to decision-making and management actions. The scale of the effects of climate change is global, and the scale of desired conservation responses—flyways, entire species' ranges—requires 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, both 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 enhanced 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.

Most of 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.

[33] 16 USC § 668dd

5.4.1 Adaptive Management as a Framework for Adaptation Actions

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.

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 hypotheses and learning from the results (Holling, 1978; Walters, 1986; Salafsky, Margoluis, and Redford, 2001). A management action can have the desired effect on 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 effects. 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 the system; (3) Develop a management plan that maximizes results and learning; (4) Develop a monitoring plan to test the assumptions; (5) Implement management and monitoring plans; (6) Analyze data and communicate results; and (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.[34] 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.[35] The only legal hurdle for adaptive management is the need for final agency action in adopting CCPs and making certain kinds of decisions involving findings of no significant effect 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. These hurdles are

[34] U.S. Fish and Wildlife Service manual 602
[35] 16 USC § 668dd

acknowledged in DOI policy on adaptive management (Williams, Szaro, and Shapiro, 2007). 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.

5.4.2 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, easement, or partnerships. 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 adapt to 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 current dynamic environmental conditions. 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 had surpassed 600,000 acres, and was 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 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 effects 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. Refuge managers have played a leadership role in the prescriptive use of fire to achieve management objectives and are well positioned to continue that role.

- *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 challenged 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, while providing dispersal corridors for many species. 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 challenges are controlled principally by federal agencies other than the USFWS. Water flows may be 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 effects 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. There is always the risk of unintended consequences. The degree of assistance has to be evaluated on a case-by-case basis.

5.4.3 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 (*e.g.*, voluntary land exchanges and conservation easements) will be more practical than acquisition. Coordination, like acquisition, can both reduce an external challenge 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,[36] Refuge Partnership Programs,[37] Safe Harbor agreements,[38] Habitat Conservation Plans,[39] Candidate Conservation Agreements,[40] Natural Resources Conservation Service,[41] 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 Challenges 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.[42] In 2004, USFWS officials helped stop development of a 19,250-seat concert

[36] **U.S. Fish and Wildlife Service**, 2007: Partners for fish and wildlife program. U.S. Fish and Wildlife Service Website, http://ecos.fws.gov/partners, accessed on 6-7-2007.
[37] **U.S. Fish and Wildlife Service**, 2007: Refuge partnership programs. U.S. Fish and Wildlife Service Website, http://www.fws.gov/refuges/generalInterest/partnerships.html, accessed on 6-7-2007.
[38] **U.S. Fish and Wildlife Service**, 2007: Safe harbor agreements. U.S. Fish and Wildlife Service Website, http://www.fws.gov/ncsandhills/safeharbor.htm, accessed on 6-7-2007.
[39] **U.S. Fish and Wildlife Service**, 2007: Endangered species habitat conservation planning. U.S. Fish and Wildlife Service Website, http://www.fws.gov/Endangered/hcp/, accessed on 6-7-2007.
[40] **U.S. Fish and Wildlife Service**, 2002: Candidate conservation agreements with assurances for non-federal property owners. U.S. Fish and Wildlife Service Website, U.S. Fish and Wildlife Service, http://www.fws.gov/endangered/listing/cca.pdf, accessed on 6-7-2007.
[41] **U.S. Department of Agriculture**, 2007: Natural resources conservation service. U.S. Department of Agriculture Website, U.S. Department of Agriculture, http://www.nrcs.usda.gov/, accessed on 6-7-2007.
[42] U.S. Fish and Wildlife Service manual 601 FW 1

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 Challenges through the Regulatory Process. In addition to land use planning, other state legal procedures can offer refuge managers opportunities to address external challenges. The Clean Water Act requires states to revise water quality standards every three years.[43] 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 water quality standards, antidegradation policy[44]). 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.[45]

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 challenges.[46] 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.

5.4.3.1 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

[43] 33 U.S.C. § 1251-1376
[44] 40 C.F.R. § 131.12, Parts 87-135
[45] 16 USC § 668dd
[46] 16 U.S.C. § 1531-1544, 87 Stat. 884

initiative to increase the effective conservation footprint of the NWRS may be needed to mitigate the projected effect of climate change on refuge species if the biological integrity, diversity, and health of the NWRS are all 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.[47] However, given the projected 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 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 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-

[47] See North Dakota v. United States, 1983. 460 U.S. 300.

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 challenges 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). In many areas, riparian corridors provide connectivity among conservation units.

- *Expand the effective conservation footprint 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 dramatic change, these refugia will likely require less-intense management interventions to maintain viable habitat, and should cost less to manage than vulnerable areas outside refugia. 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. Currently, The Nature Conservancy is analyzing effects 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, a half-day earlier migration of adult Atlantic salmon over the course of 23 years was associated with climate change (Juanes, Gephard, and Beland, 2004).

- *Install levees and other engineering works*. Levees, dikes, and other engineering works have been used widely 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.

5.4.3.2 Reducing the Rate of Change

In addition to the adaptation options described in this chapter, there are a number of actions that could be taken to mitigate climate change. These actions are primarily about reducing greenhouse gases. Refuges can participate by: being educational centers for solutions to climate change; developing and showcasing energy-saving practices on refuges, such as using fuel-efficient vehicles (Eastern Neck NWR) or electrical vehicles; using solar energy (Imperial NWR, Mississquoi NWR), wind energy (Eastern Neck NWR, Mississquoi NWR), and geothermal heating and cooling (The John Heinz NWR at Tinicum, Chincoteague NWR); and, sequestering carbon through reforestation actions when consistent with refuge objectives, although this strategy needs to be further researched.

5.4.3.3 Managing to Accommodate Change

Rather than managing in order 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. 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; and
- Increasing food availability.

Additional measures to help mitigate the effect 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 effects and side effects of these and other management actions need to be further studied.

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,[48] which

[48] **U.S. Department of Agriculture**, 2007: NRCS conservation programs. U.S. Department of Agriculture Website, U.S. Department of Agriculture, http://www.nrcs.usda.gov/Programs/, accessed on 6-7-2007.

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 its 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,[49] 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 effects 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.[50] This committee, co-chaired by the secretaries of commerce and energy, 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 projection 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

[49] **National Interagency Fire Center**, 2007: Welcome, National Interagency Fire Center. National Interagency Fire Center Website, National Interagency Fire Center, Boise, Idaho, www.nifc.gov, accessed on 6-7-2007.

[50] **The White House**, 2007: Addressing global climate change. The White House Website, http://www.whitehouse.gov/ceq/global-change.html, accessed on 6-7-2007.

Plateau Research conference provides a model to emulate (van Riper, III and Mattson, 2005).

The relatively small size and disjunct distribution of refuges presents a challenge to maintaining biological integrity, diversity, and environmental health. Yet, 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 challenges 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.

5.4.4 Steps for Determining Research and Management Actions

Modeling efforts are one tool that researchers and managers may use to project the effects of climate change on conservation target species and ecosystems. The following section describes the different tasks that can be accomplished using modeling tools, highlights research and management priorities in the face of climate change, and provides examples of the successful application of these tools (Box 5.3).

5.4.4.1 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.*[51]

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

Inventorying and 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."[52] However, as with other federal land management agencies, budgets have not prioritized the implementation of monitoring. Enlisting outside researchers can leverage resources and help achieve mutual goals for monitoring, but this 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,[53] to create monitoring strategies (ibid. at 3.4C(4)(e)), and to perform the monitoring (ibid. 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.

Understanding and Modeling 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

[51] 16 USC § 668dd
[52] 16 USC § 668dd
[53] U.S. Fish and Wildlife Service manual 601 FW 1 - FW 6

understanding of the relationships between habitat and focal species or groups of focal species. By modeling these relationships at management-relevant scales, 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 project 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 southernmost 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."[54] 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 species occurrence information for refuges, and this database could later be expanded to include other taxonomic groups.

- *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 effects 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

[54] **National Audubon Society and Cornell Lab of Ornithology**, 2007: North America's destination for birding on the web. eBird Website, www.eBird.org, accessed on 10-20-2006.

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, another important research priority.

- *Task*: Develop more detailed coastal elevation maps. 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. These maps and models are also needed to translate projected habitat changes into population changes and remedies for conservation targets. Expansion of sea water as climate change raised sea temperatures, along with increases in ocean water volume as terrestrial ice melted, increased global mean sea level by 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). The GIS data are available online.[55]

  Because local topography determines actual inundation patterns, only detailed elevation surveys can identify exact areas subject to flooding from climate change. USGS 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 be submerged by 2100 (Fig. 5.6), providing USFWS staff with 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 this and similar models include maps that provide "before and after" images of coastal habitats and tables that provide data on habitat transformations

[55] http://woodshole.er.usgs.gov/project-pages/cvi

corresponding to a specific period of time. However, SLAMM requires considerable skill with GIS and is expensive to use.

- *Task*: Provide estimates of uncertainty and model concurrence for climate projections.

  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*: Obtain projections of future climate at management-relevant scales. 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). Finer resolution projections of future climate for all of the most recent model outputs are needed. All downscaled climate data will require peer review and validation against actual observations.

  Tools: Finer-resolution projections could be generated from downscaled 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*: 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 projections should quantify uncertainty in order to account for the variability among future scenarios of 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; Parmesan, 2006; Lovejoy and Hannah, 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 management-relevant 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 challenges to habitat (Hoekstra *et al.*, 2005).

The Nature Conservancy-USDA Forest Service-Oregon State University project is analyzing potential effects from a set of general circulation models 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. 5.9). 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 5.9. 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 challenges 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, interspecific interactions, or evolutionary change (Pearson and Dawson, 2003). Analysis of climate envelopes for 1,103 plant and animal species and the effect 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.[56] 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. Moreover, ensemble forecasting of species distributions can reduce the uncertainty of future projections (Araújo and New, 2007). 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.

Documenting species' responses to climate change will be crucial for developing models to project 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 projected responses are available, it will be possible to identify relevant management options and strategies. It may also be important to project 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. Quantification of the uncertainty of projections of climate change, biome shifts, and changes in species ranges will allow natural resource managers to appropriately weight the results of modeling efforts that currently show moderate skill and will increase in skill over time.

[56] http://www.fs.fed.us/ne/delaware/atlas

Validation against field observations will allow objective assessment of climate, biome, and species data.

Paleoclimatic and paleobiological information may be used to estimate the range of historical changes in species and ecosystem distributions, as well as rates of past change and their possible implications for future management. However, past rates of change, and the conditions that caused them, may not be indicative of future conditions or rates of change. The future will be uncertain. Thus we suggest that, rather than managing for historical range of variation, or against historical benchmarks, refuges and the refuge system be managed to maintain self-sustaining native populations and ecosystems. Refuge managers can increase their options at the refuge level by reducing non-climatic stressors and increasing habitat quality and quantity. At the systems level, chances of species surviving on the refuge system are increased by insuring that the full range of a species' ecological, geographical, genetic and behavioral variation is found on refuges, and that it occurs in more than one refuge. For example occurrence of mallard ducks on a single refuge in the central flyway would be insufficient to insure the integrity, diversity, and health of mallards in the refuge system.

- *Task*: Identify those species and ecosystems most vulnerable to effects of climate change in the context of other pressures on the system(s). 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 those regions and refuges within the NWRS that are most vulnerable to climate change in the context of other pressures on the system(s).

  Tools: In considering system-wide responses to the challenge 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 that 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*: Use designated wilderness areas to track environmental changes that result from 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*: Weigh projected 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*: 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 projected 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 and private 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. As another example, the State of California has taken account of climate change in its latest state wildlife action plan (Bunn *et al.*, 2007), which identifies management opportunities for natural habitat that crosses state, federal, and private land boundaries.

- *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 songbirds and hummingbirds. Much of the success of the NWRS's efforts to conserve waterfowl species can be attributed to the clearly articulated vision of Ira Gabrielson and Ding Darling for a system of refuges that would provide habitat for recreationally viable populations of ducks and geese for the enjoyment of the American public.

  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.

There are four other key research priorities that will likely involve a combination of 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 challenges 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 that include developing and enhancing methods and tools to identify and select the best possible management actions under alternative climate change scenarios would provide managers with badly needed information. The use of rigorously tested models, and enhanced species occurrence information for assessing the costs and benefits of alternative climate change scenarios, would enhance the ability to anticipate and proactively respond to changes projected under different climate scenarios at both the refuge and NWRS scales. One could also project species and ecosystem effects with current or alternate management practices, strategic growth of the refuge, strategic growth of the NWRS, or establishment of coastal barriers. Developing these and other research questions in collaborative workshops of managers and researchers will likely increase chances that results of research will be relevant to managers and increase chances that the information will be used to make a difference on refuges.

5.5 Conclusions

Climate change may be the largest challenge ever faced by the NWRS. It is a global phenomenon with national, regional, and local effects. It adds a known forcing trend in temperature to all other stressors and likely creates complex non-linear challenges that will be exceptionally difficult to understand and to mitigate. New tools, new partnerships and new ways of thinking will be required to maintain the integrity, diversity, and health of the refuges in the face of this complexity. 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 the dynamic nature of ecological systems is well known. 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 projected under climate change, thus increasing confidence that future changes in species distribution and behavior will occur with increasing frequency. Refuge managers are faced with the dilemma of managing for a future challenge without fully understanding where and when the changes will occur and how they might best be addressed. 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 effects of climate change and other selective forces?

In this chapter we have identified research initiatives, management/research partnerships, and efforts that may be used to meet the challenges of climate change. Alaskan refuges, where effects of climate change are already apparent, have been used to illustrate some of the challenges facing researchers and managers locally, regionally, and nationally (see Case Study Summary 5.1). While there is uncertainty about the scale of the projected 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 or other tools; and increase cooperative, consultative conservation partnerships if biological integrity, diversity, and environmental health of refuge populations and systems is to be maintained. National wildlife refuges, especially those near urban centers, could increase public awareness of the challenges facing wildlife by developing educational kiosks that provide information on the effects of climate change, habitat loss and fragmentation on refuge species.

However, actions on individual refuges will be insufficient. NWRS-wide challenges require system-wide responses. The USFWS's response to the three previous challenges 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; greater emphasis on trans-refuge and trans-agency management and research; strong political leadership and reenergized collaborations between the USFWS and its research partners in USGS, other federal, state, tribal, and private organizations, and academic institutions. The scope and magnitude of expected changes—inundation of coastal refuges, regime shifts, shifts in species distributions and phenologies—challenges 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) in the refuge system. The most important tools available are the species themselves and their abilities to evolve genetic, physiological, morphological, and behavioral responses to changing climates, site-specific 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 initial tools that could enable the USFWS to best meet the challenge of global climate change. In particular, there is a need for in-depth studies of the projected effects of climate change on refuges in different ecoregions. Comparing and contrasting effects in different ecoregional setting may provide insights to future management, partnership and research opportunities.[57] The most important take-away messages about the management of the NWRS in the face of climate change are summarized below.

Response to climate change challenges must occur at multiple integrated scales. This must occur both 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. Both top-down and bottom-up approaches must be integrated. Due to the heterogeneous nature of observed (Figs. 5.3a and 5.b) and predicted changes in temperature and precipitation, a "one-size-fits-all" solution will not be appropriate.

Immediately convene a national research-management workshop. At this workshop, researches and managers could identify and discuss the challenges presented by projected effects of climate change and collectively identify, frame, and prioritize management-relevant research questions. Similar workshops could be convened regionally.

Establish coordinating bodies, such as a national interagency climate change information network, to provide information and advice on the management of ecosystems and resources. The scale of climate change is 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 national and regional councils that bring together federal, state, county, and private land owners to share information, and resources to develop cooperative management/research responses to climate change. Essential to this effort would be a center that would serve as a clearinghouse for information on climate change, its effects, and available management tools. 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. Peer reviewed and validated national and regional assessments could be carried out to identify ecosystems, species, and protected areas facing the greatest risks; this information then could be used to develop shared conservation targets and objectives. The most vulnerable species on refuges include those 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 that compare the costs and benefits of alternative management scenarios. A series of workshops that evaluate alternative management

[57] **U.S. Global Change Research Program**, 1997: Impact of land use and climate change in the southwestern United States. U.S. Geological Survey Website, http://geochange.er.usgs.gov/sw/, accessed on 11-17-2007.

scenarios in the face of climate change would 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 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 increase the effective conservation footprint of the NWRS. Adaptation to climate change may require strategic growth of individual refuges and the NWRS, to increase resilience of populations and the conservation value of the NWRS through increased representation and redundancy of conservation target populations in the NWRS. Increased emphasis on providing connectivity and dispersal corridors among units, especially for trust species that cannot fly, will be critical. A refuge that has "lost" its establishment and/or acquisition purpose could still be valuable to the NWRS, if it provides connectivity or 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 in the NWRS, and the question of whether individual refuges continue to be capable of contributing to maintenance of biological integrity, diversity, and environmental health of various conservation targets need to be vigorously assessed before any decisions regarding divestiture of existing refuge lands can be made.

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- and intra-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. Historical benchmarks and their variability may provide long-term perspective for managers, but historical conditions (species composition, abundance, distribution, and their variability) are unlikely to be reasonable management goals in the face of climate change. Pursuing such goals would force managers to attempt to sustain species in areas where environmental conditions were no longer suitable. However management for self-sustaining native populations and ecosystems in the face of change and uncertainty as the standard would be consistent with maintaining integrity diversity and health of native species and ecosystems.

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 develop collaborative conservation projects, conservation incentive programs, and 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.

Education and training of NWRS staff, at all levels, regarding potential implications of climate change for NWRS planning and sustainability is critical. To facilitate inclusion of climate change considerations into CCPs we suggest that workshops be held that instruct national, regional, and refuge staff on ways to identify options for responding to effects of climate change and means to incorporate this information in planning documents.

The challenge today is to manage to accommodate change in the face of uncertainty. If responses to projected climate change effects fail to match the scale of the challenges, 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, across the USFWS, and in collaboration with other agencies (National Ecological Assessment Team, 2006). The integrity and functioning of ecological systems will be maintained only if USFWS manages to accommodate change and reintegrates refuges into the American mind and the American landscape. Our challenge is no different than that faced by Ira Gabrielson, Ding Darling, and other professionals in the 1930s. Isolated conservation fortresses managed to resist change will not fulfill the promise (U.S. Fish and Wildlife Service, 1999) of the NWRSIA, nor will they meet the needs of American wildlife. We must articulate a vision of the NWRS that focuses on system status in 2053, the 150th anniversary of establishment of the first refuge. What will the NWRS contain, how healthy will it be, and what must we do to fulfill that vision?

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5.7 Acknowledgements

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5.8 Appendix: Actions to Assist Managers in Meeting the Challenges Posed by the Challenge of Climate Change[58]

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 affect refuges; warming temperatures may enable the survival of exotic species that previously were controlled by cold winter temperatures.			Remove exotics; prevent and control invasive pests.[59]		
Sea level rise	Loss of high and intertidal marsh; species affected: 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—	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.

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

[59] **Combes**, S., 2003: Protecting freshwater ecosystems in the face of global climate change, In: *Buying Time: a User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems*, [Hansen, L.J., J.L. Biringer, and J.R. Hoffman (eds.)]. World Wildlife Foundation, Washington, DC, pp. 1-244 as cited in: **Matson**, N., 2006: *Letter From Defenders of Wildlife to Beth Goldstein, Refuge Planner at the U.S. Fish and Wildlife Service: Comments on the Silvio O. Conte National Fish and Wildlife Refuge Comprehensive Conservation Plan*. Noah Matson, director of Defenders of Wildlife, provided this letter at the SAP 4.4 NWR Stakeholder Workshop, January 10–11, 2006.

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
			meaning that the islands and lagoon will be lost); dikes and impoundments 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.[60]		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	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		

[60] **Matson**, N., 2006: *Letter From Defenders of Wildlife to Beth Goldstein, Refuge Planner at the U.S. Fish and Wildlife Service: Comments on the Silvio O. Conte National Fish and Wildlife Refuge Comprehensive Conservation Plan*. Noah Matson, director of Defenders of Wildlife, provided this letter at the SAP 4.4 NWR Stakeholder Workshop, January 10–11, 2006.

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
	northern prairie wetland basins. Van Riper III, Sogge, and Willey discuss the effects of lower precipitation on bird communities in the southwestern United States.[61]			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; there also have been 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 affect 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					

[61] **van Riper**, C., III, M.K. Sogge, and D.W. Willey, 1997: Potential impacts of global climate change on bird communities of the Southwest. In: *Proceedings of the U.S. Global Change Research Program Conference hosted by US DOI and USGS*: Impact of Climate Change and Land Use in the Southwestern United States.

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
	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 songbirds may migrate north, which could negatively affect forests (the birds eat gypsy moths and other pests).[62] Trees will become sterile, and dying trees will become more susceptible to invasive pathogens.[63] Native species will be affected by the change in tree	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 must be changed either to focus on management of different species or thinking about the refuge boundaries.	(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: 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	Expand collaboration with other federal agencies, state agencies, private organizations to increase/share knowledge.	Need better monitoring system. Fifteen-year planning cycle may limit ability to think about long-term implications. Managers need adaptation tools. Cannot deal with this issue in a piecemeal

[62] **Matson**, N., 2006: *Letter From Defenders of Wildlife to Beth Goldstein, Refuge Planner at the U.S. Fish and Wildlife Service: Comments on the Silvio O. Conte National Fish and Wildlife Refuge Comprehensive Conservation Plan*. Noah Matson, director of Defenders of Wildlife, provided this letter at the SAP 4.4 NWR Stakeholder Workshop, January 10-11, 2006.
[63] **Matson**, N., 2006: *Letter From Defenders of Wildlife to Beth Goldstein, Refuge Planner at the U.S. Fish and Wildlife Service: Comments on the Silvio O. Conte National Fish and Wildlife Refuge Comprehensive Conservation Plan*. Noah Matson, director of Defenders of Wildlife, provided this letter at the SAP 4.4 NWR Stakeholder Workshop, January 10-11, 2006.

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
	species.[64] Warmer conditions can lead to food spoiling prematurely for species that rely on freezing winter temperatures to keep food fresh until spring.[65] Prolonged autumns can also delay breeding, which can lead to lower reproductive success. See also Hannah *et al.* (2005).			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.		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 are 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 to do that.
More frequent and extreme storm events	Debris from human settlements may be blown in or washed into refuges, and may include hazardous substances.	It is uncertain what the refuge system can		Space populations widely apart; if a catastrophic weather event occurs, population loss may be less.[67]		Hulme (2005): Species translocation can lead to

[64] **Matson**, N., 2006: *Letter From Defenders of Wildlife to Beth Goldstein, Refuge Planner at the U.S. Fish and Wildlife Service: Comments on the Silvio O. Conte National Fish and Wildlife Refuge Comprehensive Conservation Plan*. Noah Matson, director of Defenders of Wildlife, provided this letter at the SAP 4.4 NWR Stakeholder Workshop, January 10-11, 2006.

[65] **Waite**, T. and D. Strickland, 2006: Climate change and the demographic demise of a hoarding bird living on the edge. In: *Proceedings of the Royal Society B: Biological Sciences*, **273(1603)**, 2809-2813 as cited in:**Matson**, N., 2006: *Letter From Defenders of Wildlife to Beth Goldstein, Refuge Planner at the U.S. Fish and Wildlife Service: Comments on the Silvio O. Conte National Fish and Wildlife Refuge Comprehensive Conservation Plan.* Noah Matson, director of Defenders of Wildlife, provided this letter at the SAP 4.4 NWR Stakeholder Workshop, January 10-11, 2006.

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
	Eutrophication due to excess nutrients coming in from flood events could stimulate excessive plant growth and negatively affect habitats.[66] 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.	do to manage for this issue.				unpredictable consequences, so should only be used in extreme situations.

[66] **Matson**, N., 2006: *Letter From Defenders of Wildlife to Beth Goldstein, Refuge Planner at the U.S. Fish and Wildlife Service: Comments on the Silvio O. Conte National Fish and Wildlife Refuge Comprehensive Conservation Plan*. Noah Matson, director of Defenders of Wildlife, provided this letter at the SAP 4.4 NWR Stakeholder Workshop, January 10-11, 2006.

[67] **Matson**, N., 2006: *Letter From Defenders of Wildlife to Beth Goldstein, Refuge Planner at the U.S. Fish and Wildlife Service: Comments on the Silvio O. Conte National Fish and Wildlife Refuge Comprehensive Conservation Plan*. Noah Matson, director of Defenders of Wildlife, provided this letter at the SAP 4.4 NWR Stakeholder Workshop, January 10-11, 2006.

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 (see Case Study Summary 5.1): 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.

5.9 Text Boxes

Box 5.1. USFWS Goals for the NWRS (601 FW1)[68]

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.

[68] U.S. Fish and Wildlife Service manual 601 FW 1 - FW 6.

Box 5.3. National Wildlife Refuges: Adaptation Options for Resource Managers

- Manage risk of catastrophic fires through prescribed burns.
- Reduce or eliminate stressors on conservation target species.
- 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.
- 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.
- Provide redundant refuge types to reduce risk to trust species.
- Restore and increase habitat availability, and reduce stressors, in order to capture the full geographical, geophysical, and ecological ranges of species on as many refuges as possible.
- Facilitate interim propagation and sheltering or feeding of mistimed migrants, holding them until suitable habitat becomes available.

5.10 Case Study Summaries

The summary below provides an overview of the case study prepared for this chapter. The case study is available in Appendix A5.

Case Study Summary 5.1

Alaska and the Central Flyway

Alaska and Central United States

Why this case study was chosen

Alaska and the Central Flyway:

- Together produce 50–80% of North American ducks, as well as a variety of other migratory waterfowl that are National Wildlife Refuge System (NWRS) trust species;
- Support migratory species that have an energetically costly and complex life history strategy, with separate breeding, migratory stopover, and wintering habitats dispersed throughout the system;
- Show strong historical and projected warming in migratory species breeding areas (most of Alaska and the Prairie Pothole Region of the Central Flyway);
- Demonstrate heterogeneity in non-climate stressors that creates substantial complexity in both documenting and developing an understanding of the potential effects of climate warming on major trust species;
- Differ in the expected relative magnitude of climate and non-climate stressors as drivers of populations; climate is expected to be the dominant driver of migratory trust species performance in Alaska, whereas pervasive non-climate stressors such as habitat conversion and fragmentation, invasive species, pollution, and competition for water are expected to complicate estimation of the net effects of climate change on migrants in the Central Flyway.

Management context

The first unit of the NWRS was established in 1903, and the system has since grown to encompass 586 units distributed throughout the continental United States, Alaska, Hawaii, and the Trust Territories. These refuges provide the seasonal habitats necessary for migratory waterfowl to complete their annual life cycles, and conditions on one seasonal habitat may affect waterfowl performance in subsequent life history stages at remote locations within the NWRS. The key mandate of the NWRS is to maintain the integrity, diversity, and health of trust species and populations of wildlife, fish and plants, and this species mandate provides the system with substantial legal and cooperative latitude to respond to conservation challenges. Individual symptomatic challenges of climate change can be addressed at the refuge level, while NWRS planning is the more appropriate level for addressing systemic challenges to the system using all legal and partnership tools that are available.

Key climate change effects

- Observed warming that is more pronounced in Alaska than in southerly regions of the United States;
- Observed earlier thaw in Alaska that increases the length of the ice-free season;
- Observed increases in summer water deficits in Alaska;
- Observed lake drying in Alaska;
- Observed shifts to later freeze-up and longer growing seasons in the Central Flyway in Canada and in the Northern United States;

- Observed increases in temperatures that account for 60% of the variation in the number of wet basins in the Prairie Pothole Region of the Central Flyway;
- Projected further increases in temperature for much of the Central Flyway, with northerly regions expected to warm more than southern regions;
- Projected drying of the Prairie Pothole Region in the Central Flyway, the single most important duck production area in North America, which may significantly affect the NWRS's ability to maintain migratory species in general and waterfowl in particular;
- Projected sea level rise and increased urbanization in southern regions of the Central Flyway, which are expected to cause reductions in refuge area and increased insularity of remaining fragments, respectively;
- Projected changes in vegetation , which suggest that most of the Central Flyway will experience a biome shift by the latter part of the 21st century while interior Alaska will remain relatively stable.

Opportunities for adaptation

- Increased emphasis on design of inventory and monitoring programs could enhance early detection of climate change effects;
- A focus on climate change in Comprehensive Plans and Biological Reviews could allow early identification of potential mechanisms for adaptation;
- Enhanced education, training, and long-term research-management partnerships could increase the likelihood that adaptive management responses to climate change will be implemented and be successful;
- Emphasis on multiple integrated-scale responses to climate change and developing enhanced formal mechanisms to increase inter- and intra- agency communication may be particularly effective for migratory species.

Conclusions

The integrity, diversity, and health of NWRS migratory trust species populations are affected by habitat conditions throughout the system. The value of seasonal refuges can be evaluated only in the context of their relative contribution to trust species populations. Breeding areas in Alaska contribute birds to all four flyways from the Pacific to the Atlantic, but the status of staging and wintering habitats throughout these flyways also influences the number and condition of birds returning to Alaska to breed. Climate change adds substantial uncertainty to the problems associated with accessing resources necessary to meet energy requirements for migration and reproduction, and this climate challenge may interact synergistically in unexpected ways with non-climate stressors. For example, depending on the migratory species, lengthened access to migratory stopover areas that is caused by climate change combined with changing agricultural crop mixes that are driven by market forces may eventually result in either reduced or increased reproduction on breeding areas. The primary climate challenge to migratory waterfowl is that resource availability may become spatially or temporally decoupled from need, and, in a warming climate, individual refuges may no longer meet the purposes for which they were established. An emphasis on the contribution of all conservation lands to the NWRS mission and strategic system growth, using all available tools, will likely provide the greatest latitude for migratory trust species and the NWRS to adapt to climate change. The unresolved complexity of understanding the net effects of variable climate and non-climate stressors throughout the NWRS represents an opportunity to focus on the importance of strong interconnections among system units, and to foster a national vision for accommodating net climate warming effects on system trust species.

5.11 Tables

Table 5.1. The most common challenges to national wildlife refuges that could be exacerbated by climate change.[69]

Challenge	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

[69] **U.S. Fish and Wildlife Service**, 2002: USFWS unpublished data.

5.12 Figures

Figure 5.1. Structure of the NWRS. Adapted from Fischman (2003), Refuge Administration Act,[70] and FWS Regulations.[71]

National Wildlife Refuge System

"... various categories of areas that are administered ... for the conservation of fish and wildlife, including species that are threatened with extinction, all lands, waters, and interests therein administered ... as wildlife refuges, areas for the protection and conservation of fish and wildlife that are threatened with extinction, wildlife ranges, game ranges, wildlife management areas, or waterfowl production areas ..."
16 USC 668dd(a)(1)

National Wildlife Refuge

The term "refuge" means a designated area of land, water, or an interest in land or water within the System but does not include Coordination Areas.
16 USC 668ee(11)
FWS Regulations - CFR 50

Other Named Refuges

586 units with seventeen types of names

524 - National Wildlife Refuges
38 - Farm Service Administration (FSA)
9 - Wildlife Management Areas
2 - Fish and Wildlife Refuge
1 - Antelope Refuge
1 - Bison Range
1 - Conservation Area
1 - Elk Refuge
1 - Game Preserve
1 - International Wildlife Refuge
1 - Key Deer Refuge
1 - Migratory Bird Refuge
1 - Refuge for Columbian White-tail Deer
1 - Research Refuge
1 - Wildlife and Fish Refuge
1 - Wildlife Range
1 - Wildlife Refuge

Waterfowl Production Areas

"...any wetland or pothole area acquired pursuant to section 4(c) of the amended Migratory Bird Hunting Stamp Act" *FWS Regulations - CFR 50*

Over 36,494 individual units consisting of waterfowl production areas, wetland easements, wildlife management areas, easements from Farm Service Administration and other properties that are grouped into counties which are further grouped into wetland management districts.
Note: not all the areas included in this category were acquired under the Migratory Bird Hunting Stamp Act.

205 Waterfowl Production Area Counties
Note: not all of these counties have approved wetland acquisition targets

37 Wetland Management Districts

Coordination Area

" ... a wildlife management area ... made available to a State by cooperative agreement ..."
16 USC 668ee(5)
FWS Regulations - CFR 50

50 units with sixteen types of names
Note: not all of the areas included in this category are managed by States.

22 - Wildlife Management Areas
5 - Game Ranges
3 - Elk Winter Pastures
3 - Public Fishing Areas
3 - Waterfowl Management Areas
2 - Elk Refuges
2 - Winter Range and Wildlife Refuges
1 - Deer-Elk Range
1 - Deer Refuge and Winter Pasture
1 - Deer Winter Pasture
1 - Game and Fish Management Unit
1 - Game Management Area
1- Migratory Bird Management Area
1 - Migratory Waterfowl and Game Management Area
1 - State Game Range
1 - Waterfowl Project
1 - Wildlife Conservation Area

Current as of 26 September 2007

[70] P. L. No. 89-669, 16 U.S.C. '668dd
[71] FWS Regulations – CFR 50

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

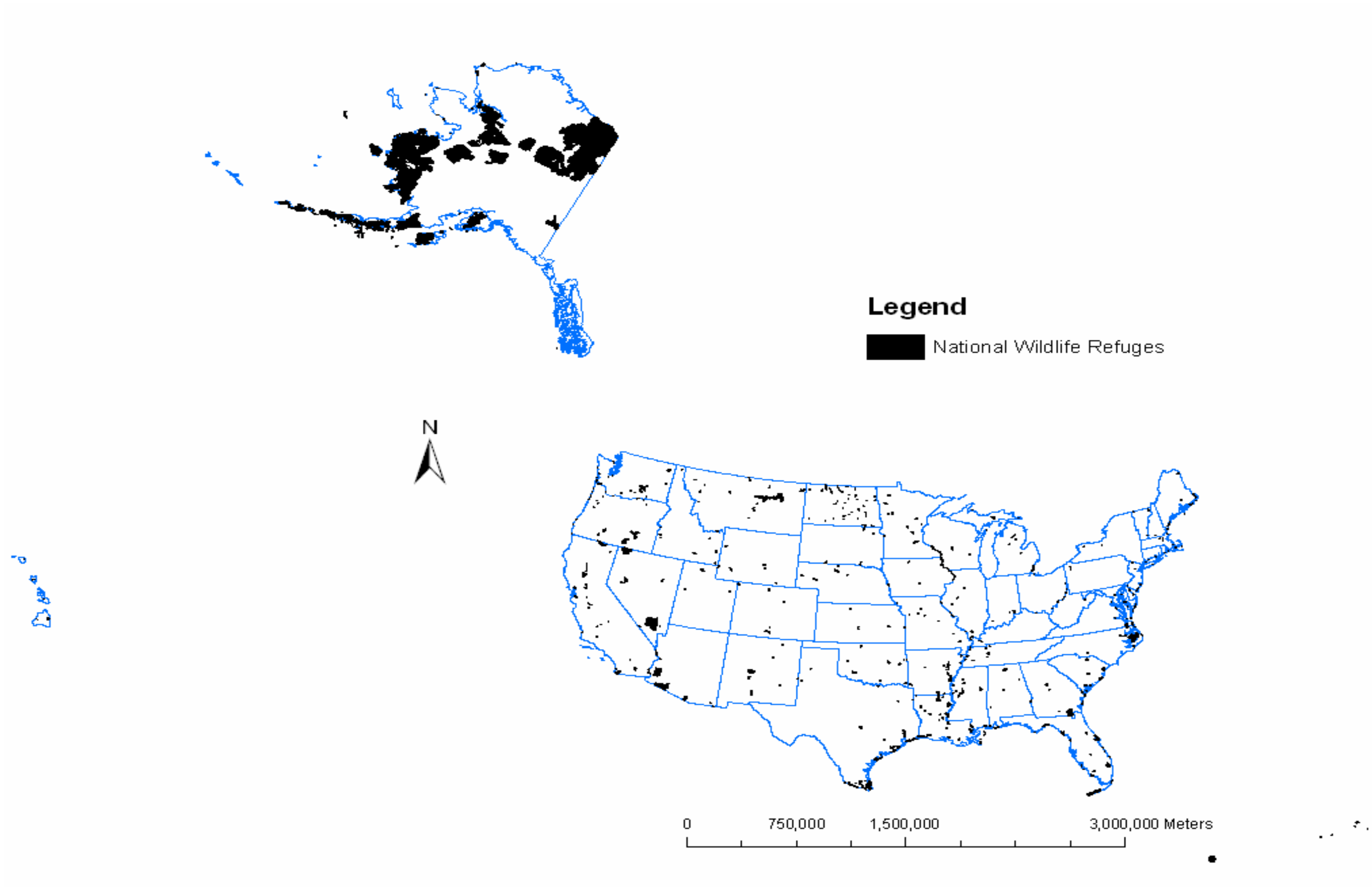


Figure 5.3a. Observed annual trends in temperature, 1901-2006, for the coterminous United States and Alaska. Data and mapping courtesy of NOAA's National Climate Data Center.

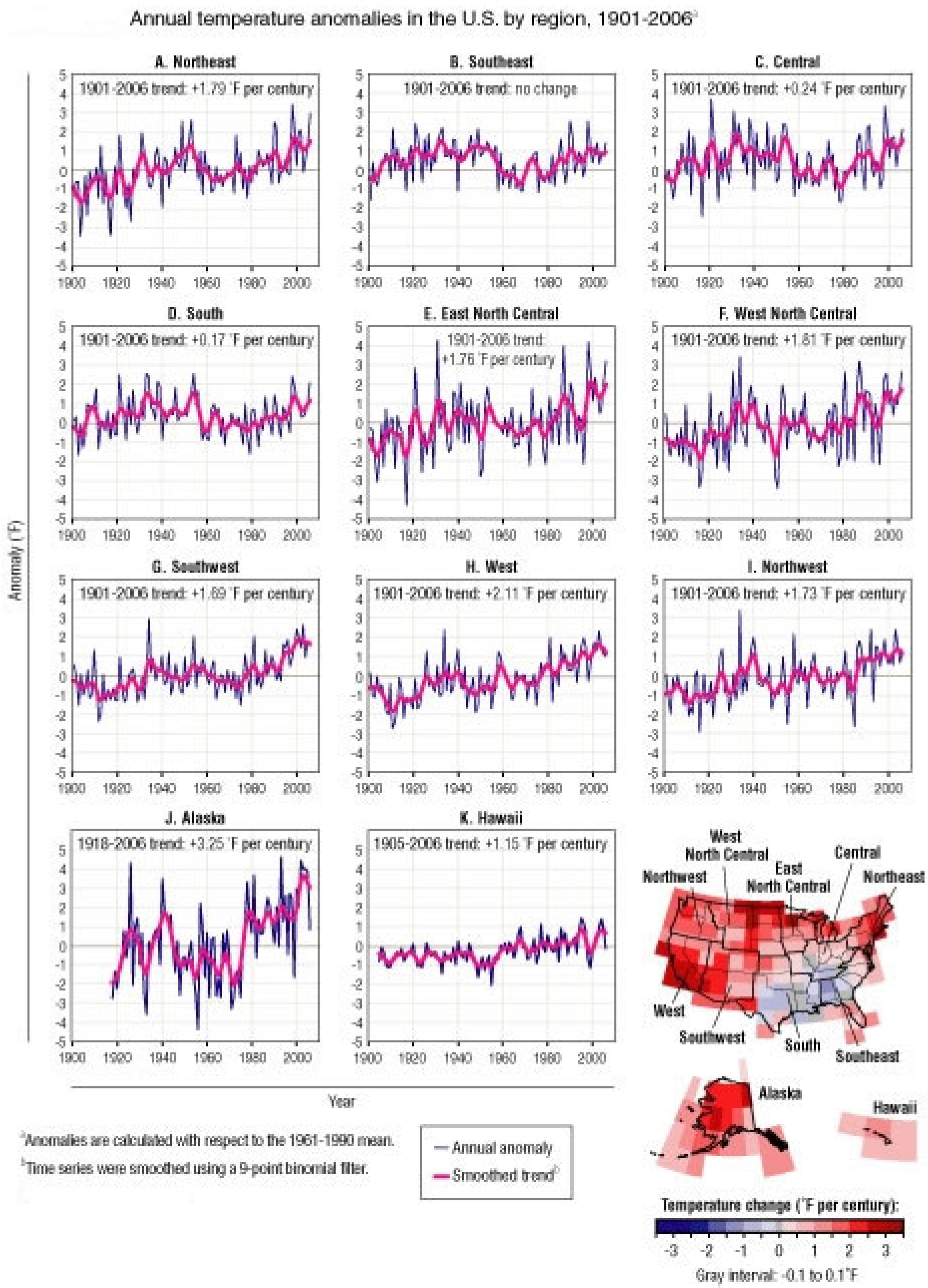


Figure 5.3b. Observed annual trends in precipitation, 1901-2006, for the coterminous United States and Alaska. Data and mapping courtesy of NOAA's National Climate Data Center.

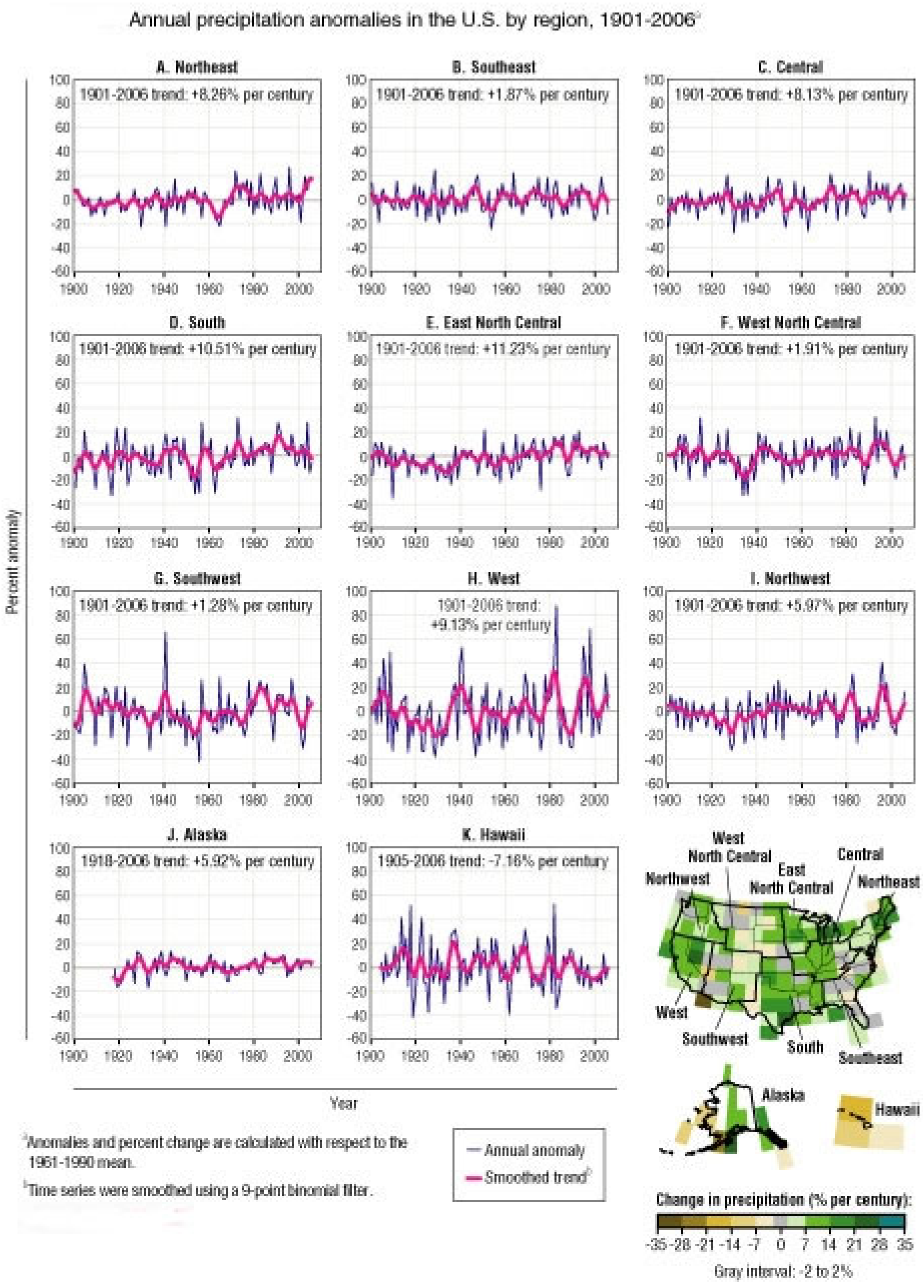
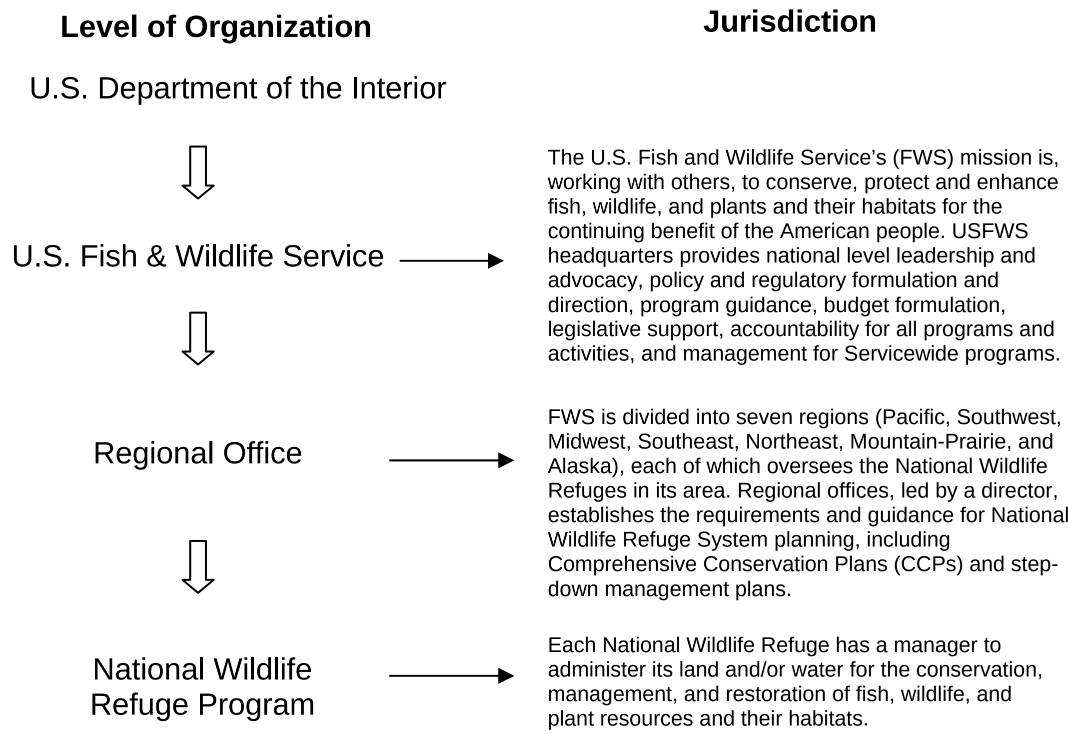
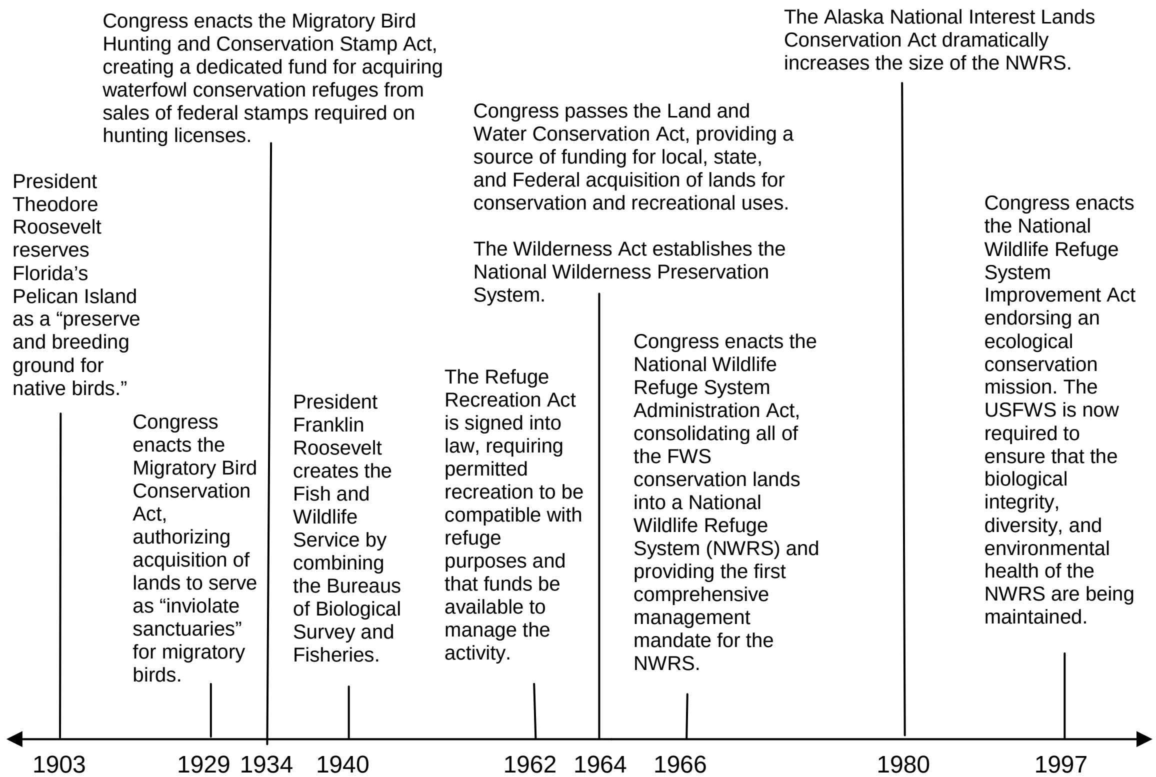


Figure 5.4. Organizational chart.[72]



[72] **U.S. Fish and Wildlife Service**, 2007: America's national wildlife refuge system. FWS Website, http://www.fws.gov/refuges, accessed on 7-18-2007.

Figure 5.5. Timeline of milestone events of the NWRS.[73]



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[73] **U.S. Fish and Wildlife Service**, 2007: History of the national wildlife refuge system. U.S. Fish and Wildlife Service Website, http://www.fws.gov/refuges/history/index.html, accessed on 7-10-2007.

Figure 5.6. Blackwater National Wildlife Refuge, Chesapeake Bay, Maryland. Current land areas and potential inundation due to climate change (Larsen *et al.*, 2004b).

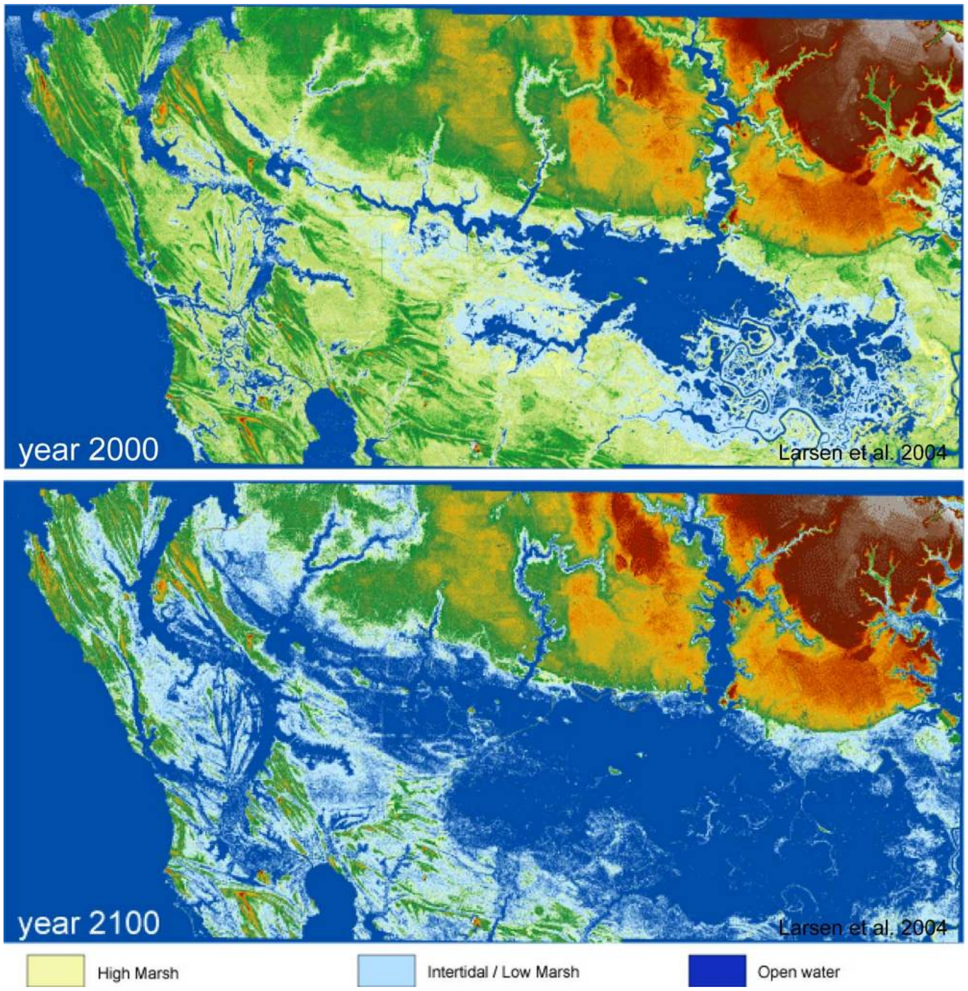
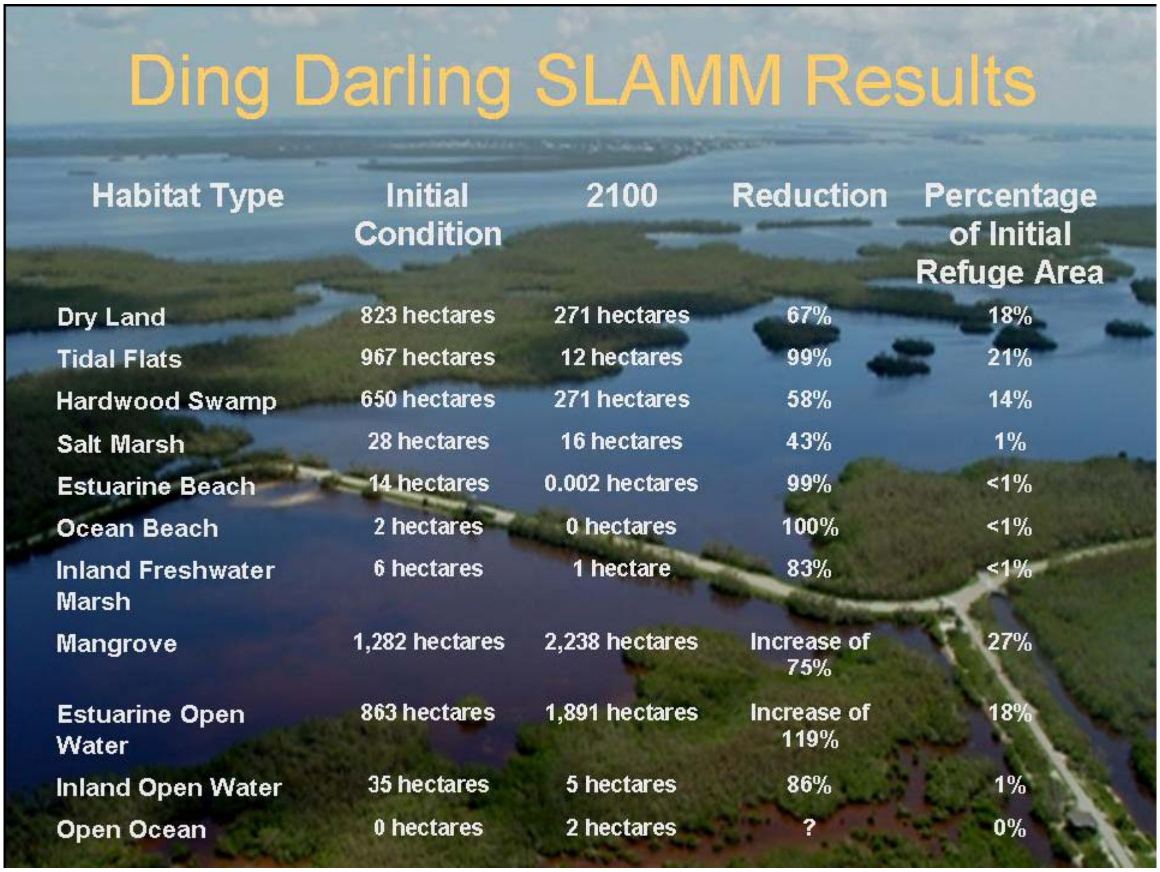


Figure 5.7. Results of the Sea Level Affecting Marshes Model (SLAMM) for Ding Darling National Wildlife Refuge. Source: USFWS unpublished data.[74]



Ding Darling SLAMM Results

Habitat Type	Initial Condition	2100	Reduction	Percentage of Initial Refuge Area
Dry Land	823 hectares	271 hectares	67%	18%
Tidal Flats	967 hectares	12 hectares	99%	21%
Hardwood Swamp	650 hectares	271 hectares	58%	14%
Salt Marsh	28 hectares	16 hectares	43%	1%
Estuarine Beach	14 hectares	0.002 hectares	99%	<1%
Ocean Beach	2 hectares	0 hectares	100%	<1%
Inland Freshwater Marsh	6 hectares	1 hectare	83%	<1%
Mangrove	1,282 hectares	2,238 hectares	Increase of 75%	27%
Estuarine Open Water	863 hectares	1,891 hectares	Increase of 119%	18%
Inland Open Water	35 hectares	5 hectares	86%	1%
Open Ocean	0 hectares	2 hectares	?	0%

[74] **McMahon**, S., Undated: USFWS unpublished data.

Figure 5.8. Ecoregions of North America (Level 1).[75]

[75] **U.S. Environmental Protection Agency**, 2007: Ecoregions of North America. Environmental Protection Agency Website, http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Level%20I, accessed on 7-12-2007.

Figure 5.9. 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).