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Climate Change Adaptation for the US National Wildlife Refuge System

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Abstract Since its establishment in 1903, the National Wildlife Refuge System (NWRS) has grown to 635 units and 37 Wetland Management Districts in the United States and its territories. These units provide the seasonal habitats necessary for migratory waterfowl and other species to complete their annual life cycles. Habitat conversion and fragmentation, invasive species, pollution, and competition for water have stressed refuges for decades, but the interaction of climate change with these stressors presents the most recent, pervasive, and complex conservation challenge to the NWRS. Geographic isolation and small unit size compound the challenges of climate change, but a combined emphasis on species that refuges were established to conserve and on maintaining biological integrity, diversity, and environmental health provides the NWRS with substantial latitude to respond. Individual symptoms of climate change can be addressed at the refuge level, but the strategic response requires system-wide planning. A dynamic vision of the NWRS in a changing climate, an explicit national strategic plan to implement that vision, and an assessment of representation, redundancy, size, and total number of units in relation to conservation targets are the first steps toward adaptation. This adaptation must begin immediately and be built on more closely integrated research and management. Rigorous projections of possible futures are required to facilitate adaptation to change. Furthermore, the effective conservation footprint of the NWRS must be increased through land acquisition, creative partnerships, and educational programs in order for the NWRS to meet its legal mandate to maintain the biological integrity, diversity, and environmental health of the system and the species and ecosystems that it supports.

Keywords Climate · Adaptation · Refuge · Conservation · Planning · Strategy

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Introduction

The US National Wildlife Refuge System (NWRS) is the largest system of protected areas in the world. It encompasses over 60 million ha and is composed of 550 refuges, 85 other units, and 37 wetland management districts, which

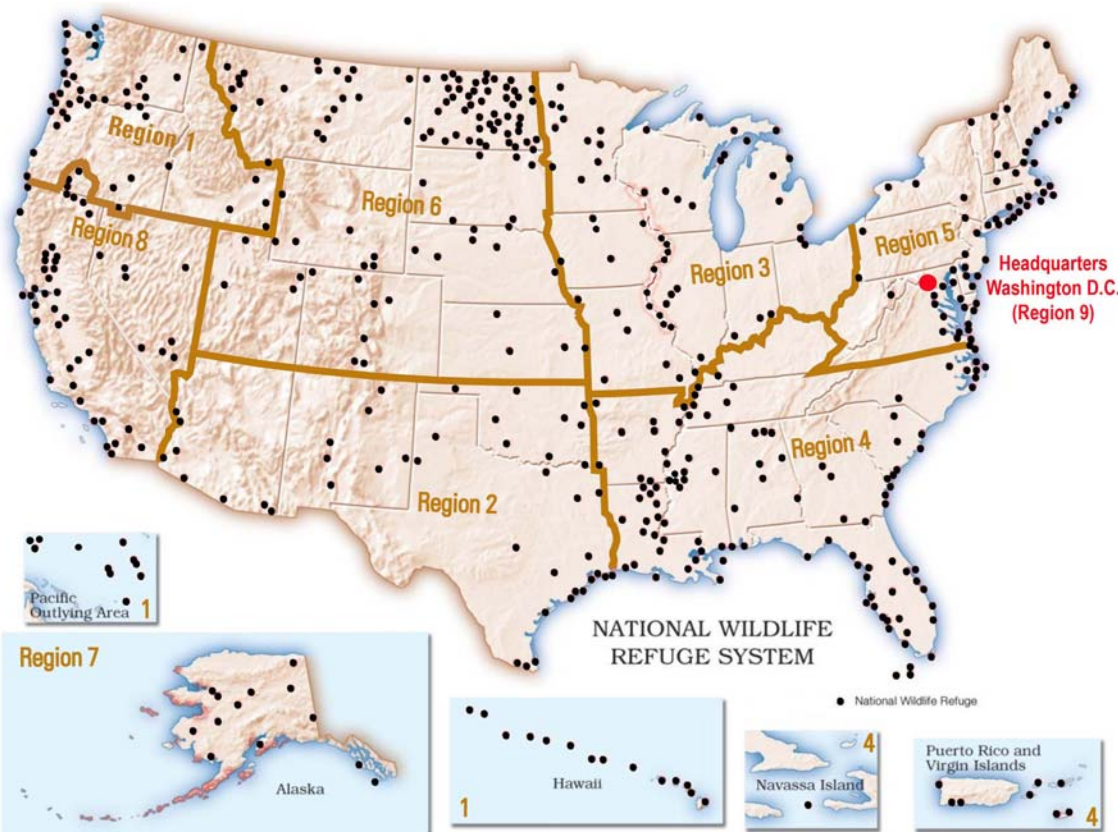

Fig. 1 The National Wildlife Refuge System. Map compiled by the US Fish and Wildlife Service, Division of Realty, Washington, DC. Base map courtesy of Tibor G. Toth (http://www.tothgraphix.com)

include waterfowl production areas in 193 counties (Fig. 1). The refuges span habitats as diverse as tundra, tropical rainforests, and coral reefs and include 161 coastal units comprising over 400,000 ha of coastal wetlands in the coterminous states.

Three characteristics distinguish the NWRS from other federal land management systems (Fischman 2004, 2005):

1) The system is characterized by an uneven geographic and ecological distribution. Most units are relatively small, typically embedded in a matrix of developed lands, situated at low elevations on productive soils; there are many coastal areas. About 3 percent of refuges are in Alaska, but they account for nearly 50% of the system area. Nearly half of the refuges are found in just 11 of the 84 ecoregions in North America (Scott and others 2004).
2) Most refuges were established to protect individual wildlife species or species groups (i.e. migratory birds, threatened and endangered species, anadromous fishes, marine mammals). Migratory birds provided the impetus for refuge system expansion in the early 1930's (US Congress 1929, US Congress 1934), while threatened and endangered species conservation drove the establishment of new refuges in the 1960's (US Congress 1966).
3) The mission of the NWRS has a clear ecological emphasis compared to other Federal land management agencies. The National Wildlife Refuge System Improvement Act (NWRSIA, US Congress 1997) set the contemporary mission of the NWRS "…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." A key mandate within this mission is to maintain the "…biological integrity, diversity, and environmental health" of NWRS. The 1997 statute envisioned the NWRS as a national network of lands and called for continued growth of NWRS "…to contribute to conservation of ecosystems of the United States."

Contemporary conservation challenges to refuges include habitat loss and fragmentation, competition for water, invasive species, urbanization, agricultural activities, natural disasters, transportation corridors, industrial development, species imbalances, pollution and disease.

All are projected to increase, and the interaction of climate change with these stressors presents a pervasive and complex challenge to the NWRS.

Expected Climate Change Effects

The climate has been warming since establishment of the first refuge. Mean global temperature has risen rapidly during the past 50 years and is projected to continue increasing throughout the 21st century (IPCC 2007). Changes in precipitation, cloudiness, diurnal temperature extremes, biome boundaries, ocean chemistry, hydrology, and sea level are expected to accompany the continued warming (IPCC 2007). These changes will have NWRS-wide effects. Scientists have already documented a coherent pattern of pole ward and upward (elevation) shifts in species distributions, advances in phenology of plants, and changes in the timing of arrival of migrants on seasonal ranges (Parmesan and Yohe 2003; Root and others 2003; Parmesan 2006; Rosenzweig and others 2008). Climate related changes in the distribution and timing of resource availability may cause species to become decoupled from their resource requirements if their breeding seasons are not flexible enough to accommodate changes in phenology (Both and others 2006).

If the spatial heterogeneity in temperature and precipitation trends of the 20th century (Mitchell and Jones 2005) persists, then different refuges and species will experience climate change effects that range from negative to positive (Peterson and Vieglais 2001; Peterson and others 2002; Peterson and others 2005; Parmesan 2006; Rosenzweig and others 2008). In addition, climate related changes may occur at scales that are relevant to individual small refuges, but are difficult to accurately forecast.

Climate Related Challenges to NWRS

The NWRS species and populations most likely to be affected by climate change include: (1) habitat specialists, (2) populations on the edges of their geographical, ecological, or geophysical ranges, (3) those species that occupy fragmented or restricted ranges, and, especially, (4) those species that are poor colonizers or dispersers. Many threatened or endangered species share one or more of these traits.

The potential vegetation for an area (the biome; e.g., boreal forest) is a function of the annual temperature and moisture regime, soil type, and fire history. Much of the NWRS lies in areas that could experience northward biome shifts by 2100 (Gonzalez and others 2005). A biome shift constitutes a regime shift, and where such 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 NWRS unit was established; e.g., Kirtland's Warbler Wildlife Management Area (Botkin 1990). Indirectly, climate may shift and hold plant communities in an earlier stage of succession without causing a biome shift. For example, increasing temperatures may enhance overwinter survival and shorten generation time for spruce beetles (*Dendroctonus rufpennis*) while stressing their host trees (*Picea* spp.). As a result, in a warming climate, endemic levels of beetles at Kenai National Wildlife Refuge may be sufficient to perennially thin spruce stands (Berg and others 2006).

Climate change will also accelerate convergence of issues (e.g., water scarcity, non-native invasive species, off-refuge land-use change, and energy development) or create such convergences where none existed before. Managing the "typical" challenges to the Refuge system requires accounting for the interaction of climate and non-climate stressors in the midst of substantial uncertainties about how stressors will interact and systems will respond.

Altered Hydrology

Water is the lifeblood of the NWRS (Satchell 2003) because much of the management of fish, migratory waterfowl, and other wildlife depends upon reliable sources of water. Climate change will alter precipitation patterns (US Climate Change Science Program 2008) and the seasonality of surface water flows in complex ways. Refuges in areas where water deficit is increasing, where demand for water already exceeds supply, and where refuges are highly dependent upon seasonal flows from snowmelt, are likely to be especially vulnerable. Climate related reductions in the number and size of lakes (Larson 1995; Sorenson and others 1998; Klein and others 2005; Riordan and others 2006) may reduce habitat quality for waterfowl (Batt and others 1989; Poiani and Johnson 1991; Inkley and others 2004; Johnson and others 2005) and reduce waterfowl populations (Johnson and others 2005) if wetland habitats are limiting. Endangered aquatic species (e.g., Devil's Hole pupfish (*Cyprinodon diabolis*) at Ash Meadows NWR in Nevada) that cannot shift their breeding ranges to wetter areas as easily as waterbirds will be especially susceptible to warming induced drying. A preview of potential future competition for water on refuges is provided by the intense conflict over water needed for endangered fish species and the demands of nearby farmers at Klamath National Wildlife Refuge (National Research Council 2005; Doremus and Tarlock 2008).

Sea Level Rise

Causes of sea level rise include land subsidence, warming related ice melt, and thermal expansion of the oceans (IPCC 2007). 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 and others 2000). Sea level rise on the mid-Atlantic coast has inundated marshes in Blackwater NWR for the past 60 years and climate related complete inundation is projected within the next 50 years (Larsen and others 2004). The Sea Level Affecting Marshes Model (SLAMM; Park and others 1989) projected significant wetland losses at four refuges in Florida (Ding Darling NWR, Egmont Key NWR, Pine Island NWR, and Pelican Island NWR) and Forsythe NWR in coastal New Jersey is losing 27% of its marshlands to open water and tidal pond expansion annually (Erwin and others 2004). More frequent extreme weather events that are projected to occur (IPCC 2007) will likely exacerbate coastal inundation problems.

Invasive Species

Invasive non-native species are currently one of the most pervasive problems for the NWRS and could become more serious with climate change (Sutherst 2000). By replacing native organisms, non-native invasive species often alter the ecological structure of natural systems by modifying predator-prey, parasite, and competitive relationships. A rise in temperatures could allow invasive non-native species to expand their ranges into habitats that previously were inaccessible to them (Westbrooks 2001). For example, purple loosestrife (*Lythrum salicari*) is a major aquatic invasive challenge to NWRS wetlands, particularly in the northeastern portion of the US. Because temperature limits the northern distribution of this invasive (Bailey and Bailey 1976) and because invasive weeds respond positively to CO_2 enrichment when not otherwise limited (Rogers and others 2008), both one of the causes of warming (CO_2 enrichment [IPCC 2007]), and the warming itself, may exacerbate invasion of NWRS units by an aquatic weed.

Disease/Parasites

Changes in temperature and moisture may shift the distribution of disease vectors and of the pathogens themselves (Harvell and others 2002; Logan and others 2003; Kutz and others 2005; Pounds and others 2006). For example, Hakalau Forest NWR, now largely free of avian malaria, harbors one of the few remaining population centers of endangered Hawaiian forest birds. Climate change may eliminate this and other such refugia by changing conditions to favor avian malaria (LaPointe and others 2005).

Interaction of Climate and Non-Climate Stressors

Because many NWRS species are migratory, their breeding, intermediate, and wintering habitats are typically dispersed throughout the system and on non-NWRS lands. The superimposition of spatially and temporally variable warming on dispersed life history events will add substantial complexity to understanding and responding to ongoing conservation challenges. The greater the stress on a refuge from existing threats, the harder it will be to adapt to climate change.

Climate change is likely to magnify the influences of other conservation challenges such as habitat loss and fragmentation, water quality degradation, and water scarcity on the NWRS. For example, increasing habitat fragmentation from transportation corridors will likely make it more difficult for species to shift their distributions to accommodate climate change. In addition, high rates of subsidence exacerbated by levees, channelization, and infrastructure development had already contributed to an annual loss of nearly 10,000 ha of wetlands along the Gulf Coast in Louisiana, even prior to Hurricane Katrina (2005) (Erwin and others 2004). Aquifer depletion, land compaction, infrastructure development, and subsidence, combined with sea level rise, are projected to result in the loss of much of the marsh and shorebird habitat in San Francisco Bay NWR within a few decades (Galbraith and others 2002).

Adaptation Issues

Adaptation is the process of changing to meet or accommodate new conditions and the term can be applied in several contexts. NWRS species can adapt to the symptoms of climate change by moving or adjusting their response to existing habitats; they may adapt in an evolutionary sense via natural selection. NWRS managers may adapt to climate change by adjusting the priorities of their actions or adding the potential effects of climate change to their assessments of refuge status and trends while the NWRS system may adapt to climate change by developing a vision of conservation targets (e.g., species, guilds, and habitats) in a dynamic future, extending budgeting and planning horizons, and by rewarding effective response to climate change. In contrast, mitigation measures are the management actions that may be used to reduce the existing negative effects of climate change. Both adaptation and mitigation will be required for an effective response by NWRS to climate change. In this treatment we focus on adaptation by the NWRS system and managers and note mitigation measures that may be employed as NWRS adapts to climate change.

One potential goal of NWRS adaptation to climate change would be to increase the resilience of the refuges to a changing climate. Resilience is the capacity of an entity to tolerate disturbance without transitioning to a different state that is controlled by a different set of processes (Holling 1973). Unfortunately, resilience, as well as the terms "biological integrity" and "environmental health" that are part of the NWRS legal mandate, are complex concepts that are difficult to quantify. Developing unambiguous, objective, performance criteria for any of these three terms in the context of climate change is nearly impossible. What is needed for effective movement toward these important concepts is simpler and quantifiable intermediate objectives.

If the NWRS increases the spatially balanced and functionally connected number and size of representative (one of each) and redundant (replicates of each) units for each conservation target, then these larger suites of representative and redundant units will meet the legal requirement to continue growth of the system (US Congress 1997) and almost certainly contribute to resilience, biological integrity, and environmental health of NWRS. This benefit would be gained, for example, because the existing NWRS cannot fully support genetically viable populations for a majority of threatened and endangered species (Czech 2005) even for those threatened and endangered species for which refuges were specifically established (Blades 2007) and because representation and redundancy are not well provided by the NWRS for species other than waterfowl and waterbirds (Pidgorna 2007).

There are three operational scales for adaptation within the NWRS: system-wide vision (strategy), eco-regional planning and coordination (tactics), and individual refuge management actions. All three scales of adaptation are essential for an effective response to the challenge of climate change and actions at individual refuges should be designed to support the NWRS strategy and regional planning efforts. Refuge level actions can occur either proactively in anticipation of climate change or in response to existing climate change effects.

Adaptation Measures

The long experience of the NWRS with intensive fish, wildlife, and habitat management techniques constitutes an important asset for the development and implementation of adaptation measures. Within refuge borders, land managers can employ prescribed burning to reduce risks of catastrophic wildfire, facilitate the growth of plant species more adapted to future climate conditions, assist in the translocation of limited-dispersal species to repositioned habitats, propagate food sources for mis-timed migrants, restore riparian forests to keep water temperatures low, and propagate heat-resistant coral. Outside refuge borders, the NWRS, its parent agency the US Fish and Wildlife Service (USFWS), and their partners can improve the configuration of conservation areas to help species adapt at landscape and regional scales. These adaptation measures include the establishment and maintenance of suitable habitat corridors, conservation of non-replaceable climate change refugia when threatened or endangered species are involved, elimination of dispersal barriers, assisted establishment of marshland vegetation where sea level rise inundates coastal land or where freshwater lake levels fall, and the restoration of natural hydrologic regimes (Scott and others 2008).

Critically, however, the NWRS needs to reassess in a collective way the value and application of established management measures in the context of the current dynamic environmental conditions. Basic inventories need to be completed because the effects of climate change cannot be assessed without robust baselines. The intensity and spatial and temporal scale of monitoring will need to be enhanced to accommodate the long-term and highly variable nature of climate change. Simply resisting the effects of continuing climate change will ultimately prove futile.

The NWRSIA of 1997 provides the NWRS with vast discretion for 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 Endangered Species Act (ESA), occasionally limit this latitude. A major legal limitation to 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. Presidential leadership will be necessary to ensure that other federal departments, including Homeland Security and Defense, coordinate with the USFWS to ensure that their actions avoid undermining the NWRS mission. In general, the USFWS has ample proprietary authority to engage in translocations, habitat engineering (including irrigation-hydrologic management), and captive breeding. However, high risk programs such as animal translocations will require cooperation with all the involved parties within the organism's current and future ranges (McLachlan and others 2007) and careful consideration of potential effects of the translocated species on the recipient plant and animal communities.

Adaptation of the Refuge System to Climate Change

Even though there have been few specific examples of adaptation principles in the past 22 years (Heller and Zavaleta 2009) immediate action is required. Perceptive and well-reasoned 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 biological integrity, diversity, and environmental health of the NWRS. Heterogeneity in climate change effects will require diverse and innovative adaptations, but application of existing management measures in a new climate change context will capitalize on decades of direct wildlife management experience available within the NWRS. Increased emphasis on rigorous modeling projections of multiple scenarios at multiple scales, effective application of adaptive management principles, and enhanced collaboration with public and private stakeholders will make most efficient use of existing research and management capabilities. However, expert opinion will need to be used in the initial responses to climate change, and mistakes will be made while new 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. New adaptations must emphasize reforms of the planning and acquisition processes, revised planning goals, and improved communication and education. For example, the Land Acquisition Priority System (LAPS, US Fish and Wildlife Service 1996) may need to develop and implement climate change based selection criteria for candidate acquisition parcels.

Reforming the Planning Process

Expected decadal persistence of climate change effects suggests that planning and budgeting horizons will need to become much longer. Also, uncertainty regarding the effects of climate change on species and habitats will require a more flexible, but more expensive, approach to planning.

The NWRS will need to build on the results of adaptive monitoring and adaptive management programs for all of its planning. Adaptive monitoring and management, as implemented by the US Department of the Interior, explicitly recognize and attempt to reduce uncertainty (Nichols and others 1995; Williams and others 2001) and provide a formal framework for conservation and management decision-making (Williams and others 2007). Adaptive monitoring programs will provide refuges with information on the frequency and intensity of monitoring required to detect specified magnitudes of climate driven changes in species and critical habitats that are important to refuges. Adaptive management programs will help elucidate mechanisms of climate change action on species and habitats. For example: (1) adaptive monitoring may be used to design the most efficient programs to detect the degree of association between climate induced habitat change and wildlife populations, and (2) adaptive management may be used to estimate whether climate induced seasonal habitat changes affect multi-annual population levels in an additive or compensatory manner.

Due to the large inter-annual variability about long term trends in climate (c.f. Oechel and others 2000), adaptive monitoring and management approaches to understanding and responding to climate change are likely to require frequent sampling, take more than one generation of managers to complete, and will be predicated on adequate baseline data. Adaptive monitoring and management are expensive propositions that will require larger annual budgets and longer budgeting cycles than conventional operations. However, these procedures may be required to obtain reliable knowledge regarding the effects of climate change. Legislation to control carbon emissions may provide a new source of funding for these expensive but critical endeavors.

Responding to ecological effects of climate change may be improved by projecting the possible futures of representative animal and plant resources, and management options at all relevant management scales. These projections should use the most rigorous scientific modeling tools, climate change scenarios, and suite of expected non-climate stressors. New projections, monitoring results, and adaptive management programs initiated under climate change can serve as catalysts to develop an increased understanding of the ecological mechanisms affecting NWRS resources.

Projecting possible futures would have several components: (1) enhancing the inventories of existing species on refuges (only birds are well represented by checklists in NWRS [Pidgorna 2007]); (2) identifying the mechanisms of climate driven effects on plants and animals; (3) identifying the species, habitats, and systems most vulnerable to climate change, in the context of other system stressors, at the refuge, regional, and national scales; (4) clearly identifying conservation targets for the coming decades; (5) evaluating scale-specific (refuge > region > NWRS) suites of management and policy responses to alternative climate change scenarios; (6) developing objective criteria for choosing among these responses; (7) proactively developing, comparing, executing, and evaluating multi-scale plans to reduce vulnerability to climate change; and (8) implementing effective and efficient monitoring programs to detect climate related system changes.

Finally, the NWRS should devise a strategic plan for adaptation to global climate change. This plan would enhance the contribution of individual refuge management toward systemic adaptation. The strategy should include management vision, research priorities, and adaptation scenarios that will guide the USFWS in its task of managing refuges. Explicit performance goals and objectives that are tied to the implementation of this strategy will be needed to assess the degree and effectiveness of NWRS response to the challenges of climate change.

Planning Goals

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. The historical concept of dynamic equilibrium must be replaced with the concept of dynamic trends that are driven by spatially and temporally variable climate forcing. This will require a revision of existing conservation targets and an emphasis on connectivity. Except in special situations, such as the sole remaining habitat for a threatened or endangered species, management for the status quo (i.e., refugia) will not be appropriate to the challenge of climate change. Because most refuges are small, fragmented, and surrounded by human altered habitats (Scott and others 2004; Pidgorna 2007), it will prove difficult for the NWRS alone 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). Currently, very few species or guilds have reasonable representation and redundancy within the NWRS (Pidgorna 2007; Rupp 2009).

As the climate changes, the species composition of communities on NWRS lands may become quite different from those present when the refuge was established. These composition changes need not imply that the biological integrity, diversity, and environmental health of refuges and the NWRS have been compromised. NWRS policy does not insist on maintenance of historical conditions that may no longer be climatically appropriate. Instead, it views historical conditions as a frame of reference for understanding shifts that may occur within ecological communities as a result of climate change. Rather than managing in order to retain species currently on refuges, the refuge system will need to manage to provide species with sufficient opportunity, in terms of well distributed, well connected, and replicate habitats, to respond to and to evolve in response to emerging selective forces.

Refuge functions may change from one species or habitat to another as a result of climate change. More northerly units may assume the current functions of southern units and it may become necessary to apply directional priorities for land acquisition and partnerships (e.g., emphasize those areas where models suggest the most valuable habitats are likely to be located in a warmer climate). It will be critically important to recognize that refuges should not be discarded when the contemporary mission is no longer achievable. Rather, the mission should be realigned to emerging conservation needs.

Because climate warming effects will persist for quite some time (IPCC 2007), the value of partnerships and collaborations for fulfilling the conservation mission of NWRS will become even more important than it is currently. Habitats and their dependent species are expected to continue to shift northward (Parmesan 2006; Rosenzweig and others 2008) as the climate warms, while administrative boundaries may remain relatively static. Refuges will need to be managed in concert with other refuges and with all public and private conservation estates, not in isolation. For example, in response to projected threats to marsh and shorebird habitat, the California State Legislature passed AB 2954, the San Francisco Bay Restoration Authority. This legislation established a multi-organizational San Francisco Bay Area Conservancy to restore, enhance, and protect wetlands and wildlife habitat in San Francisco Bay and on San Francisco Bay National Wildlife Refuge (California State Legislature 2008). This type of unified regional response will need to be used more frequently to meet the challenges of climate change.

One mechanism that could enhance such collaboration would be to establish national climate change coordination entities, such as a national interagency climate change council and a national interagency climate change information network, that facilitate information transfer and enhance the ability of all conservation agencies to collaborate, plan, and manage for the challenges of climate change. The USGS National Climate Change and Wildlife Science Center is a potential model to consider.

Renewed emphasis on collaboration must also guide the management-science relationship in order to meet the challenge of global climate change. This will be necessary to ensure that climate-related research priorities are management-relevant and conducted at scales that are ecologically relevant. Formal working groups and regional- to national-level conferences that frame management-relevant questions, identify possible funding sources, and develop collaborative relationships using the biannual Colorado Plateau Research conference as a model (van Riper, III and Mattson 2005) will increase the likelihood that critical modeling and empirical studies are conducted in a timely manner.

The NWRSIA requires system expansion and adaptation to climate change requires the NWRS to consider lands and waters outside refuge boundaries as means to expand the conservation footprint. In some instances acquisition of property for system expansion will best serve the conservation mission of the NWRS. In many 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 footprint through cooperative habitat management. On conservation matters external to the NWRS boundary, partnership and incentive programs that could be emphasized include the Partners for Fish and Wildlife Program, Refuge Partnership Programs, Safe Harbor agreements, Habitat Conservation Plans, Candidate Conservation Agreements, various Joint Ventures, Conservation Reserve Enhancement Program, and the Natural Resources Conservation Service. Increased partnerships of refuges with other Fish and Wildlife Service programs—the Endangered Species programs, in particular—could result in cost savings and increased achievement of the USFWS's goals that they could not achieve acting individually.

Communication and Education

Initiating coordinated and focused multi-scale communication, education, and training programs by all NWRS partners (management, research, and other public and private land managers) will enable more effective responses to climate change. National wildlife refuges, especially those near urban centers, can increase public awareness of climate change and the challenges facing wildlife by developing educational kiosks that provide information on the causes and effects of climate change, the effects of habitat loss and fragmentation on refuge species, and potential means to prevent and mitigate these challenges.

A clearly elucidated and formal vision of the desired state of the NWRS on the 150th anniversary of the system in 2053 would enhance 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. Refuges must be reintegrated into the American mindset and the American landscape in the context of climate change.

Conclusions

1. Climate change may be the largest challenge ever faced by the NWRS. 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, predict, and respond to.
2. Reducing uncertainty in expected climate change effects is essential to successful adaptation. Rigorous models of possible futures are required to develop a suite of appropriate adaptation responses.
3. Adaptation will be required at multiple scales (i.e., system, region, refuge). The scale of response must meet the scale of the challenge in order to meet the legal mandate of maintaining biological integrity, diversity, and environmental health of the NWRS.
4. NWRS must establish a clear vision of conservation targets (e.g., species, guilds, and habitats) necessary to fulfill the system mission. This vision should be expressed in terms of representation, redundancy, and number and size of units required under various potential climate futures. This will require exceptional leadership and discipline.
5. NWRS must conduct a gap analysis of the adequacy of existing units to meet the conservation target vision. This assessment should include the holdings of conservation partners and be repeated as uncertainty regarding possible climate futures is reduced.
6. NWRS must strategically fill gaps in the vision while reducing non-climate stressors. This activity should capitalize on enhanced communication and collaborations with its conservation partners.
7. The greatest latitude for NWRS to adapt to climate change will be provided by strategic growth and an emphasis on the contribution of surrounding, non-refuge lands to the NWRS mission. The concept of refuges as isolated conservation fortresses managed to resist change will not fulfill the promise (US Fish and Wildlife Service 1999) of the NWRSIA, nor will it meet the needs of American wildlife.

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