Strategic Plan for Inventories and Monitoring on National Wildlife Refuges: Adapting to Environmental Change

U.S. Fish and Wildlife Service, National Wildlife Refuge System

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FOREWORD

The inventory and monitoring of biological resources, ecological processes, and components of the physical environment are critical to meeting the National Wildlife Refuge System's (NWRS or Refuge System) legislated mission and mandates. The Refuge System has had a longstanding need for a more coordinated and consistent approach to collecting, analyzing, synthesizing and reporting data generated through these activities. The U.S Fish and Wildlife Service's (USFWS or Service) response to conservation in the face of climate change, as defined in the recently issued *"Rising to the Challenge: Strategic Plan for Responding to Accelerating Climate Change"* and a draft *Five-Year Action Plan to implement the Strategic Plan* (U.S. Fish and Wildlife Service, 2009a, 2009b), provides additional direction and impetus. Under this initiative, the Refuge System is to play a leadership role in developing a nationally-coordinated program of inventory and monitoring (I&M program) on Service lands.

In July 2009, two teams of NWRS biologists and managers representing all USFWS Regions were commissioned to plan the I&M program. The inventory and monitoring Core Team (I&M Core Team) and Executive Oversight Committee (EOC) met in August 2009 to define a vision for the program and set broad programmatic goals and priorities. The *Strategic Plan for Inventories and Monitoring on National Wildlife Refuges (Strategic Plan),* an *Addendum to the Strategic Plan (Addendum)* and a companion *Operational Blueprint* were developed by the Core Team from that foundation.

There was strong consensus among the I&M Core Team and the EOC that the I&M program should address the Refuge System's mission-critical information needs, in the context of its legislated mission and mandates. We also recognized that the I&M program must support the Service's landscape conservation efforts and response to climate change, working within the geographic and organizational framework defined in the Service's climate change plans. The plans call for organizing conservation planning and modeling capacity within Landscape Conservation Cooperatives (LCCs) to provide scientific leadership and work with partners within landscape units or Geographic Areas. There was strong agreement that the I&M program should engage in and embrace the principles of adaptive management since most refuges in the contiguous U.S. are managed intensively and supporting fish and wildlife adaptation to climate change will likely require the development and evaluation of new management approaches and tools throughout the Refuge System. We also discussed the potential for spatial modeling to be useful for assessing landscape-scale changes in species distributions and predicting refuge vulnerability to climate change, and the imperative of considering these issues in the design phase of baseline inventories and future monitoring. There was strong consensus that sufficient resources must be committed to a consistent approach to data management, including the development and use of data standards, a commitment to data synthesis, analysis and reporting, and the use of systems to efficiently provide data to all stakeholders. Lastly, we agreed on the importance of learning from the experiences of other national inventory and monitoring programs and collaborating with partners on integrated monitoring at multiple spatial and temporal scales, as appropriate.

The I&M Core Team and the EOC discussed the following as Refuge System-wide priorities within the context of its mission and mandates, their relevance in responding to rapid climate change, and their potential to support and complement the Service's landscape conservation efforts:

- inventories of abiotic resources and physical features (supported by assessing and utilizing existing geospatial data as appropriate);
- baseline inventories of biota, including vegetation (supported by assessing and utilizing legacy data on species occurrence on Service lands as appropriate);
- status and trends of priority fish and wildlife species;
- assessment of natural disturbance regimes, with initial emphasis on fire;
- reconnaissance-level inventories and assessments of water resources including water quality and quantity;
- status and trends of invasive species;
- support of adaptive management at refuge and landscape scales; and
- assessment of vulnerability to climate change, with initial emphasis on sea level rise modeling for coastal refuges.

Recognizing the complexity and scope of addressing these priorities, both individually and collectively, the I&M Core Team developed recommendations for initiating specific I&M program tasks, described in the Operational Blueprint, in Fiscal Years 2010 and 2011 (Phase 1), or as soon as practicable. The Operational Blueprint recommends several "pilot" approaches that could inform important programmatic decisions and help frame future monitoring needs and approaches. The Strategic Plan provides additional background and rationale for the I&M program and initial priority tasks; presents factors that should be considered as various aspects of the program are initiated; identifies key partnership opportunities, both within and outside of the Service; and identifies components that should be considered for implementation in FY 2012 and beyond (Phase 2).

In the course of its work, the Core Team was tasked with developing recommendations for an initial organizational structure for the I&M program, and later to develop operational guidance or "business guidelines." Program organization, administration, and staffing are fully described in the Addendum. The Core Team recommended an organization that included a national-level coordinating office in recognition of the following needs: 1) a cohesive, Refuge System-wide approach to inventories and monitoring in response to climate change and other stressors since many Refuge System resources and the issues affecting them transcend boundaries of administrative Regions, States and nations; 2) a consistent and coordinated approach to data management ; 3) national-level collaboration with other agencies that conduct inventories and monitoring of natural resources on Federal lands and waters, and with other conservation partners that are conducting relevant monitoring at broad geographic scales to explore opportunities for coordination that would enhance development and evaluation of climate change adaptation strategies; and 4) informing national policy decisions that depend upon concise reporting on status of the Refuge System's resources. The recommended organizational model also included staffing at the Regional Office and within Geographic Areas served by the soon-to-be established LCCs. These recommendations were reviewed by the NWRS Leadership Team in October 2009, which decided to move forward with hiring I&M program staff under the organizational model described in the Addendum. These decisions were subsequently approved by the Service Director.

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EXECUTIVE SUMMARY

This Strategic Plan summarizes and provides a long-term perspective for how the National Wildlife Refuge System will implement a nationally coordinated effort to support inventories and monitoring (I&M program) at the refuge, landscape, regional, and national scale to inform management and evaluate the effectiveness of strategies to support adaptation to climate change and other major environmental stressors. Program organization, administration, and staffing are addressed in a separate Addendum to the Strategic Plan. A companion Operational Blueprint establishes the initial structure of the I&M program and identifies priority tasks to be implemented in Phase 1 (FY 2010 - 2011). The Strategic Plan focuses more on FY 2012 and beyond (Phase 2). The Strategic Plan, Operational Blueprint, and Addendum together provide the foundation for launching the I&M program, including recommendations for the initial organizational structure, budget allocations, and hiring decisions.

The Refuge System is expected to receive $12 million in FY 2010 and another $8 million in FY 2011 ($20 million per year by FY 2011) to fund this I&M program. The I&M program will be nationally coordinated by NWRS Washington Office staff stationed in Fort Collins, CO. The program will be fully integrated with the U.S. Fish and Wildlife Service's Landscape Conservation Cooperatives (LCCs) and Geographic Areas and provide support to refuges. In FY 2010, 58 FTEs will be hired: 10 in the Washington Office, 16 associated with the eight newly-funded LCCs, eight in each of the USFWS Regional Offices, and 24 on field stations. Another four FTEs may be added in FY 2011, contingent upon funding. We envision a fully operational $100 million I&M program, supporting approximately 280 staff (of which at least 200 will be on field stations) (~$45 million) and a full range of inventory and monitoring activities (~$55 million).

The following foci are recommended for early consideration during development of the I&M program: inventories of abiotic resources; inventories and monitoring of biota (to include biological diversity; populations of priority species; vegetation inventories and mapping; genetic diversity; wildlife health; and (phenology) invasive species; water quality and quantity; fire and other landscape disturbance processes; contaminants; and Wilderness character. We recommend consideration of several approaches that are cross-cutting in nature and crucial to success. These include careful consideration of information needs in light of the uncertainties associated with climate change, and sampling designs for inventories and monitoring to address these needs to support the use of the predictive tools needed to plan and evaluate management in the face of uncertainty. Spatial modeling is advocated as a useful tool for assessing landscape-scale changes in species distributions, predicting refuge vulnerability to climate change, and stratifying I&M efforts on refuges within Geographic Areas. We recommend a strong commitment to adaptive management to evaluate climate adaptation strategies from individual refuge to appropriate landscape scales. We emphasize the importance of working collaboratively with other Service programs, Federal and State agencies, Joint Ventures, and other conservation partners in defining the questions to be answered through inventories and monitoring, and developing and refining methods.

During Phase 1, the Operational Blueprint recommends initiating abiotic resource baseline inventories; designing inventories of biological diversity; initiating vegetation inventories and mapping; assessing status and trends of priority species; developing methodologies to inventory and monitor invasive species at multiple scales; initiating reconnaissance level assessments and inventories of water quality and quantity; assessing impacts of climate change on fire regimes; completing initial sea level rise modeling for coastal refuges; and expanding support of adaptive management at refuge and landscape scales. Some of these components are promoted as “pilot studies” in the Operational Blueprint to avoid missing opportunities and creating redundancy of I&M efforts by other agencies, and to provide information to guide development and refinement of methods and future programmatic direction. Pilot testing for each of these components could occur in one or all Regions during Phase 1, providing necessary information for the further development of methods and approaches.

Lastly, but of utmost importance, the Strategic Plan recommends that a comprehensive and consistent approach to data management be an underpinning of the I&M program, and that sufficient resources be dedicated to support it. This includes the development and use of data standards, a commitment to data synthesis, analysis and reporting, and use of systems that maximize efficiency and availability of data to all stakeholders.

I. INTRODUCTION

OVERVIEW

This *Strategic Plan for Inventories and Monitoring on National Wildlife Refuges – Adapting to Environmental Change (*Strategic Plan*)* summarizes and provides a long-term perspective for how the National Wildlife Refuge System will implement a nationally coordinated effort to support inventory and monitoring (I&M program) at the refuge, landscape, regional, and national scales. The purpose of this effort is to collect and synthesize information that supports management at multiple geographic scales and informs decisions at all organizational levels. The I&M program is being designed to address the Refuge System's mission critical information needs, and to help plan and evaluate the effectiveness of conservation strategies implemented by the U.S. Fish and Wildlife Service and conservation partners in the face of accelerating climate change and growing threats from other environmental stressors. The Strategic Plan provides background and rationale for the I&M program and these initial priority tasks, presents factors needing consideration as various aspects of the program are initiated, identifies key partnership opportunities internal and external to Service, and identifies components that should be considered for implementation in 2012 and beyond (Phase 2). A companion Operational Blueprint establishes the initial structure of the I&M program and identifies priority tasks to be initiated in Phase 1 (2010 - 2011). Program organization, administration, and staffing are addressed in a separate Addendum to the Strategic Plan (Addendum). The Strategic Plan, Operational Blueprint, and Addendum together provide the foundation for launching the I&M program, including recommendations for the initial organizational structure, budget allocations, and hiring decisions.

The Service recently issued *Rising to the Challenge: Strategic Plan for Responding to Accelerating Climate Change* and a *Five-Year Action Plan* to implement the Strategic Plan (USFWS 2009a, 2009b). The plans call for organizing conservation planning and modeling capacity within Landscape Conservation Cooperatives (LCCs) to provide scientific leadership and work with partners within landscape units or Geographic Area . LCC staff will work with other agency and conservation partners to plan, design, and evaluate landscape scale conservation in the face of climate change and other stressors, using the principles of adaptive management, scientific inquiry, and a process the Service calls Strategic Habitat Conservation (SHC). The I&M program is being designed to integrate with and support the Service's landscape conservation efforts.

The Phase 1 budget for the I&M Program is expected to be $12 million in FY 2010 and $20 million in FY 2011; we expect the program to grow as it matures. We envision a fully operational $100 million I&M program, supporting 280 staff (of which at least 200 will be on field stations) (~$45 million) and inventory and monitoring activities (~$55 million). The I&M program will need staff that collectively has diverse technical as well as administrative skills, including skills in adaptive management, modeling, biometrics, structured decision making (decision analysis), hydrology, invasive species, remote sensing, and a variety of taxonomic and ecosystem expertise, such as wetland ecology, ornithology, forest ecology, grassland ecology, and fire ecology. Similarly, data managers at all levels should possess a variety of technical IT/data management skills such as programming, database design, GIS, modeling. We recognize that some of this expertise already resides within the Service and the Refuge System. Leadership will consider how best to fill the I&M program positions to fully integrate with and complement existing capacities and expertise.

We fully expect that the I&M program will co-evolve with Service efforts to better integrate landscape conservation and to respond to accelerating climate change. It is exactly because the Service is leading with several, newly-funded initiatives and because rapid climate change entails the expectation of ecological surprise that we have tried to strike a balance in this Strategic Plan between being comprehensive in scope versus clairvoyant in predicting future needs.

The Strategic Plan and Operational Blueprint focus primarily on Refuge System-wide priorities broadly shared by all or most Regions of the Service. We anticipate that each Region and/or Geographic Area will also have inventory and monitoring priorities tailored to the needs of local managers. The I&M program will evolve as staff is hired, implementation begins, and integration with monitoring priorities identified by field stations and the LCCs occurs. The I&M program is expected to provide coordination and technical support for inventories and monitoring on refuges and relevant landscapes, and the I&M program will work hand-in-hand with existing refuge, LCC and regional staffs to address these needs. We anticipate that the I&M program will provide technical and data management support for long-term (surveillance) monitoring components (e.g., water resources) as well as targeted monitoring conducted under adaptive management (e.g., invasive species management, fire effects, and other species or habitat-specific priorities defined by field stations, LCCs, or the regions and our partners).

The direction of the I&M program evolution will be determined by management priorities. A nationally-coordinated I&M program for the Refuge System will require setting priorities, clarifying the questions we want to answer, the spatial and temporal scale of those questions, and the accuracy and precision of the information we need. The Strategic Plan provides a wealth of information about possible future directions for the I&M program. The Operational Blueprint calls for a needs assessment process, which will involve broad input from refuges, the LCCs, the Regions, and partners. A process for regular review of the results of such a needs assessment and revisiting program priorities based on this information will be developed. Refuge System leadership will remain engaged in guiding program priorities and ensuring a nationally coordinated approach over the long term.

THE NATIONAL WILDLIFE REFUGE SYSTEM

The Refuge System, administered by the Service, is the world's premier system of public lands and waters set aside to conserve America's fish, wildlife, and plants. Since President Theodore Roosevelt designated Florida's Pelican Island as the first wildlife refuge in 1903, the NWRS has grown to more than 550 National Wildlife Refuges and 150 million acres. The NWRS is predominately a marine-influenced network of protected areas encompassing approximately 30,000 coastal miles across 61 million coastal land acres. In addition, refuge ocean holdings include two 1,000-mile long archipelagos, and expansive estuarine systems from above the Arctic Circle to remote coral reefs and tropical lagoons below the Equator. Coral reef ecosystems within the NWRS total almost 5 million acres. The NWRS co-manages the 89-million-acre Papahānaumokuākea Marine National Monument in Hawaii; NWRS holdings within the Pacific Remote Islands, Rose Atoll, and Marianas Trench Marine National Monuments include 53 million acres of submerged lands in the central and western Pacific. The NWRS includes 37 Wetland Management Districts and more than 30,000 Waterfowl Production Areas, encompassing 677,000 acres of wetlands and grasslands primarily in the prairie potholes of the Dakotas, Minnesota, and Montana. Congressionally-designated Wilderness makes up 20 percent of refuge lands, most of which is in Alaska.

The NWRS helps sustain more than 700 bird, 220 mammal, 250 reptile and amphibian, and more than 200 fish species. More than 200 refuges were specifically established for the conservation of migratory birds. Fifty-nine refuges were established for the primary purpose of conserving threatened or endangered species. Indeed, about 280 of the nearly 1,375 Federally-listed threatened or endangered species are found within the Refuge System.

The NWRS is characterized by an uneven geographic and size distribution. Larger refuge units are mostly in Alaska, with the 16 Alaska refuges contributing 87 percent of the total land area in the NWRS. The median and mean refuge is 5,550 acres and 20,186 acres, respectively. In contrast, the median area of Alaska refuges is 2.7 million acres (Scott et al., 2004). Nearly 20 percent of refuges are less than 1,000 acres, and effectively even smaller because more than half of refuges consist of two or more parcels.

More than 40 million people visit the Refuge System each year. Visitors enjoy many outdoor activities that are compatible with the mission of the NWRS, including hunting, fishing, wildlife observation, photography, interpretation, and environmental education. Visitor spending generates almost $1.7 billion in sales for regional economies, which includes nearly 27,000 people in private sector jobs and $542.8 million in employment income (Carver and Caudill 2007).

WHAT'S THE PROBLEM?

Although the Refuge System is more than a century old, the National Wildlife Refuge System Administration Act (16 U.S.C. 668dd–668ee), as amended by the 1997 National Wildlife Refuge System Improvement Act (NWRSIA) (Public Law 105-57), legislatively established its mission: "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 NWRSIA was the Refuge System's first true organic legislation; it has been referred to as one of the most emphatic conservation directives ever written by Congress (Meretsky et al. 2006). Under it, the Secretary of the Interior is charged with specific responsibilities, including the following biological directives:

- Provide for the conservation of fish, wildlife, and plants and their habitats;
- Ensure the biological integrity, diversity, and environmental health of the System are maintained for the benefit of present and future generations of Americans;
- Plan for the continued growth of the System;
- Assist in the maintenance of adequate water quantity and quality to fulfill the mission of the System and the purposes of refuges;
- Acquire, under state law, water rights that are needed for refuge purposes; and
- Monitor the status and trends of fish, wildlife, and plants in each refuge.

Inventories and monitoring play critical roles in implementing these directives. In fact, they are critical to effective planning and management of refuges and the Refuge System. However, unlike other Federal land management agencies, such as the National Park Service (http://science.nature.nps.gov/im/index.cfm) , and the Forest Service (http://fhm.fs.fed.us/), the Refuge System does not have a nationally-coordinated inventory and monitoring program. Inventories and monitoring comprise a large part of the work done on stations of the NWRS, but these efforts are largely uncoordinated among refuges and Regions; no synthesis of the information derived from these efforts is currently available to Regional or Washington Office managers.

The Refuge System is unique among Federal lands in having legislative mandates to maintain and restore biological integrity, biological diversity and environmental health, and to monitor the status and trends of fish, wildlife, and plant resources. Refuges have traditionally focused on the purposes for which each was established, primarily migratory birds, threatened and endangered species, marine mammals, and interjurisdictional fish. The NWRSIA requires a more comprehensive approach to managing the natural resources of the Refuge System, and to conducting the inventories and monitoring needed to inform management.

Concern about the conservation of species and ecosystems in the face of shrinking and degraded habitats is widespread (Sutherland et al. 2009). Climate change is predicted to magnify the threat and greatly increase species extinction rates across the globe (McLaughlin et al. 2002; Massot et al. 2008; Sekercioglu et al. 2008). The following is a summary of the primary threats to the integrity of North American ecosystems posed by climate change (CCSP 2009; Karl et al. 2009; Scott et al. 2009; U.S. DOI 2009b; USFWS 2008).

- **Changes in water quality and quantity** will occur. Adequate water quantity and quality are essential for managing fish, wildlife, plants, and their habitats on refuges. Climate change has the potential to decrease supply and increase demand for water, creating new water scarcity problems and exacerbating existing ones. Water temperatures will increase and high intensity storms will increase erosion and transport of contaminants into water bodies. These changes will cause direct changes in riparian habitats and fish and wildlife dependent on them as well as ecosystem-wide changes in flora. Local changes in precipitation, higher water temperatures, increased frequency of high-intensity precipitation events, and longer periods of low flows will exacerbate existing problems. Not only can we expect regional shortages, but we can also anticipate increased erosion and runoff rates during flood events that may carry pollutants in soils into water bodies. Low flows during droughts will degrade water quality by concentrating pollutants. Conversely, high water events on coastal and other refuges can damage levies and affect flood control and water management capabilities.

- **Large-scale shifts in species ranges** and timing of the seasons and animal migration will occur. Climate change will cause shifts in species ranges, in many cases away from refuges and other Department of the Interior (DOI) lands. Phenological mismatches may occur between migrating species and their available food resources. **.** One of the more pronounced effects of rapid climate change is total "regime shift," where entire ecological communities are transformed from their "natural" state to conditions that are not only degraded, but also may be novel and of anthropogenic origin. Such shifts occur as a result of changing temperature regimes and rainfall patterns, exacerbated by invasive species and wildfire, as is already being seen in the black spruce forests of southern Alaska and the coastal shrub lands of central and southern California. In other locales, such as the Midwest, wetlands such as the prairie potholes may be lost, or new wetlands may be created in previously dry areas. Where such regime shifts occur on refuges, it may no longer be possible to achieve existing wildlife and habitat management objectives and, in extreme cases, their establishment purposes.

- **The numbers of threatened and endangered (T&E) species will increase** as a result of climate change. Refuges play a unique role in conservation, protection and recovery of T&E species through the maintenance and restoration of habitats (including critical habitat). More than 50 percent of all Federally-listed mammals, birds, and reptiles use refuges for at least part of their life-history needs. Yet, climate change is expected to place 20-30 percent of extant species at high risk of extinction by 2100. Species inhabiting salt marshes, mangroves, and coral reefs are likely to be particularly vulnerable. The landscapes surrounding much of the 59 refuges established for listed species are already highly degraded, which climate change impacts will only exacerbate. Refuges will need to conserve and manage habitats for species vulnerable to climate change, even as some refuges established for that purpose may be unable to achieve their mandate because of regime shifts.

- **Fire, insect pests, disease pathogens, and invasive weed species will increase**. Dry conditions and changes in forest health will change the duration, frequency, intensity, and extent of wildland fires. Pest species are already the greatest resource management challenge within the NWRS. As of 2008, 2.43 million acres were infested with invasive plants; 4,387 pest animal populations are on refuge lands. As local microhabitats change, native plant communities already degraded by external stressors may well be outcompeted by invasive plants, many of which are hardy generalists better suited to environmental conditions of a warming world. As they spread, invasive plants will continue causing loss of existing native habitat and out-compete the establishment of new natives trying to expand their ranges or otherwise adapt to altered conditions. Climate change is already triggering forest insect outbreaks (e.g., pine bark and spruce bark beetles), which are outside the frequency and magnitude experienced in recent history. Warmer temperatures and changes in precipitation patterns will affect survival, distribution, and ontogeny of disease vectors, parasites, and pathogens. Vectors already appear to be occupying more northerly latitudes and causing outbreaks such as Lyme disease and bluetongue virus in new areas. Since the ranges and population densities of native species also will change unpredictably, we can expect new disease agent-host interactions with unknown effects. Risk of animal disease transmission to humans is also expected to increase in some locales. The international Wildlife Conservation Society recently identified 12 such diseases likely to expand and change distributions, including highly pathogenic avian influenza (HPAI) and tuberculosis in large wild mammals. Outbreaks of mosquito-borne diseases (e.g., West Nile virus, encephalitis) in humans, domestic animals, and wildlife will increase as mosquito populations proliferate in warmer, wetter locales. Disease risk on refuges increases local public sentiment against wildlife and pressure to control animals or vectors.

- **Deserts and dry lands will likely become hotter and drier**, feeding a self-reinforcing cycle of invasive plants, fire, and erosion. Climate change is already contributing to more frequent and intense fires on and off refuge lands. Plants stressed from drought or insects provide increased fuel loads, often in hot, dry areas. At the same time, vegetation communities dominated by invasive plants can alter the historical fire regime. Yet higher minimum temperatures in North America are expected to lengthen the growing season, resulting in increased primary productivity and potentially even greater fuel loads. An expanding urban interface along refuge boundaries has already increased the ecological, economic, and social risks of wildfire; the added pressure to control wildfires and conduct more prescribed burns in a warming climate can only increase for refuges.

- **Coastal, near-shore and marine ecosystems** are already under multiple stresses. Climate change will exacerbate these stresses. Expected sea level rise, combined with storm surge effects, will have a profound effect on coastal systems, including coastal refuges, with the most dramatic effects being wetland loss, lower productivity of estuaries, loss of barrier islands, and increased coastal erosion and flooding. Possible increases in coastal storms will increase these effects. Ocean warming and acidification are impacting coral ecosystems, and threaten major disruptions in ecological functions affecting marine resources worldwide. Sea levels are predicted to rise 4-8 inches by 2025, and 15-38 inches by 2100. An increase of 20 inches in sea level could cause an estimated 50 percent loss of North American coastal freshwater wetlands. Because nearly one-third of the nation's refuges are situated in coastal areas, sea-level rise will significantly impact the NWRS. Major effects of sea-level rise on coastal refuges include beach erosion from high wave energy events; barrier island migration and shoreline recession; loss of salt marsh; saltwater intrusion into near-inland freshwater wetlands; movement of the saltwater-freshwater barrier upstream in coastal streams and rivers; and degradation of coastal aquifers.

- **Arctic and subarctic ecosystems are currently experiencing the most rapid and profound effects of climate change.** Sea ice ecosystems are already being adversely affected by the serious reduction in the amount and seasonal duration of sea ice and further changes are expected. Warmer temperatures have already reduced the sea ice used by seals and walruses to rest between foraging bouts. Polar bears in some Arctic regions appear to be experiencing shorter feeding periods and decreased accessibility to the seals they hunt because of reduced sea ice. Sea ice off the Arctic coast of Alaska is thawing and retreating, having widespread effects on marine ecosystems, human settlements, and native subsistence activities. Finally, loss of permafrost is already having profound effects on localized ecosystems and threatening much more, putting the ecological integrity of Alaskan refuges at risk.

Climate change and other stressors resulting in rapid environmental change emphasize the need for a more coordinated approach to conservation. The Department of the Interior (DOI) views the threat of climate change to its public lands and waters as the most serious environmental threat since the dustbowl of the 1930s. The Service recognizes that meeting its conservation mission in the face of climate change will require a coordinated effort involving all parties interested in our natural heritage of fish and wildlife. The Service's "Rising to the Challenge: Strategic Plan for Responding to Accelerating Climate Change" and a Five-Year Action Plan to implement the strategic plan (USFWS 2009a, 2009b) call for organizing conservation planning and modeling capacity within Landscape Conservation Cooperatives (LCCs) to provide scientific leadership and work with partners within landscape units or Geographic Areas

The USFWS created a national geographic framework for the purpose of conservation planning and delivery. This framework consists of 22 Geographic Areas: 16 in the contiguous 48 states, five in Alaska and one in Hawaii (Fig. 1). With the exception of Alaska, the framework integrated Bird Conservation Regions (based on Omernik Level II ecoregions) with Freshwater Ecoregions of the World (FEOW). Bird Conservation Regions are the units developed by the North American Bird Conservation Initiative as a common ecological planning unit for birds. FEOW is a global classification of freshwater systems adopted for use in National Fish Habitat Action Plans. Existing Migratory Bird Joint Venture boundaries were used as a tertiary consideration because they represent landscape partnerships that have already developed biological planning and conservation design capacity. Geographic Areas will be served by Landscape Conservation Cooperatives and will be the regionally-scaled planning units for the NWRS I&M program. However, there are significant NWRS holdings in the Pacific Ocean that are not within established Geographic Areas (Fig. 2).

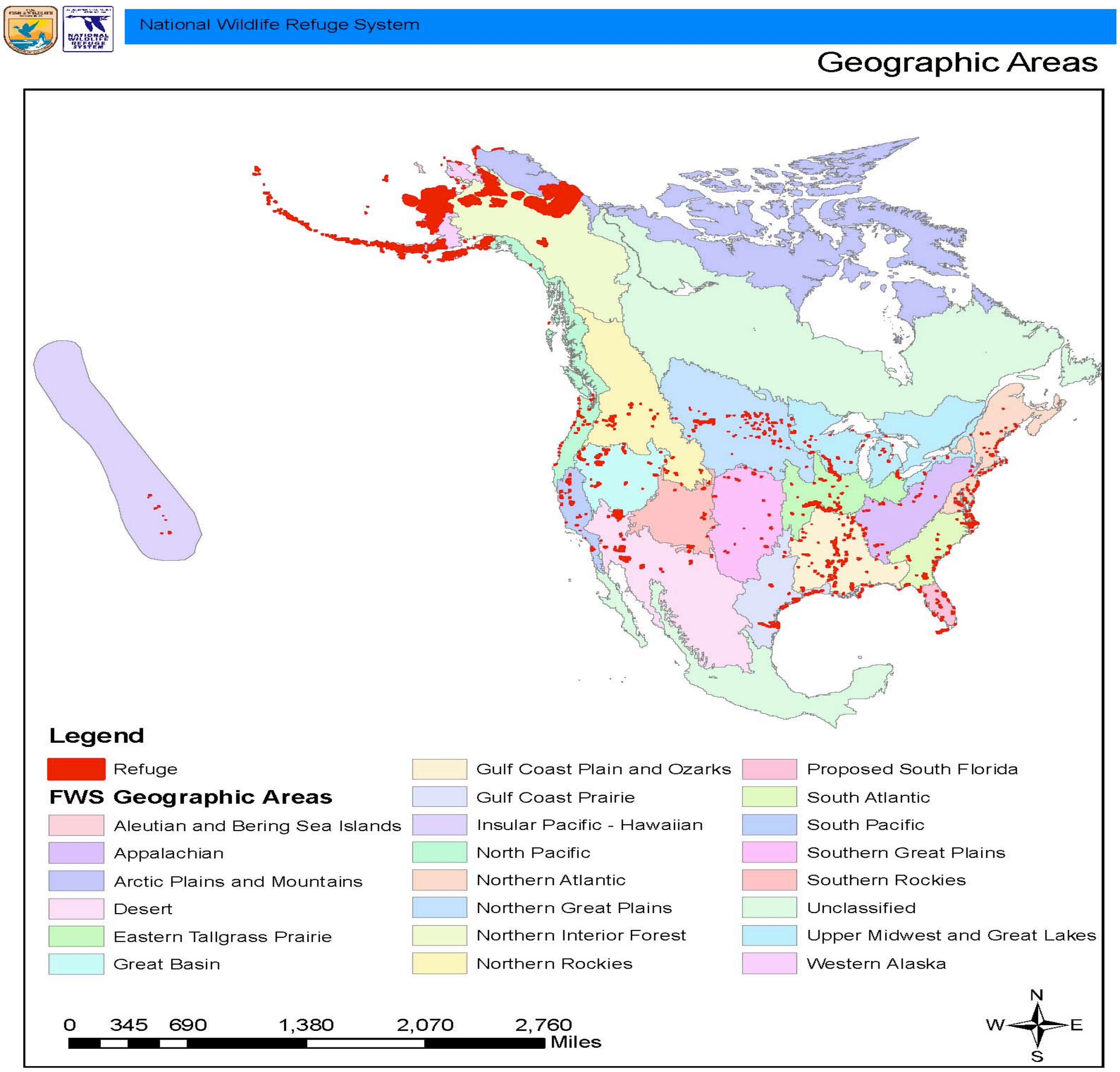

Figure 1. Distribution of national wildlife refuges within the 22 Geographic Areas delineated by the Service for biological planning and design.

(Figure 1). LCC staff will work with other agency and conservation partners to plan, design, and evaluate landscape scale conservation in the face of climate change and other stressors, using the principles of adaptive management, scientific inquiry, and a process the Service calls Strategic Habitat Conservation (SHC). The goals of the FWS Strategic and Action climate change plans were reinforced under Secretarial Order 3289, issued on September 14, 2009, tasking the DOI Regional Climate Change Response Centers (USGS) and the LCCs with developing adaptation strategies to respond to climate change (US DOI 2009a).

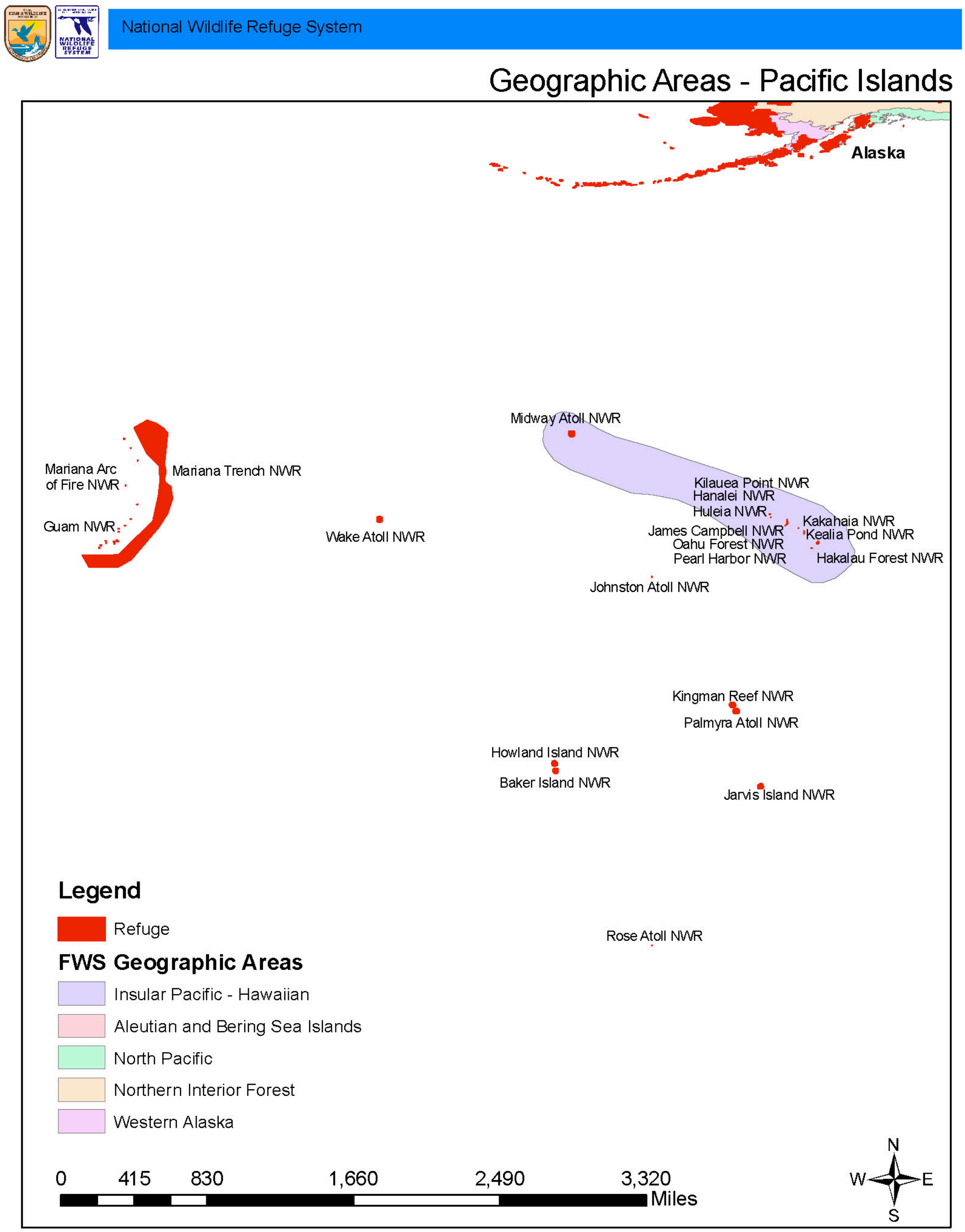

Figure 2. National wildlife refuges in the Pacific Ocean that are outside Geographic Areas currently established by the Service.

Inventories and monitoring must be incorporated into this coordinated conservation approach. The DOI Task Force on Climate Change (US DOI 2009b) has summarized the role of inventories and monitoring in the face of climate change as follows:

> *"Managing for climate change requires a thorough understanding of what species and habitats make up the ecological landscape of a park, refuge, or other management unit. Without an inventory of species and natural communities, we cannot begin to predict the ecosystem response to a changing climate, or to develop actions to deal with those responses. Adaptive management requires monitoring to determine the success of individual management actions in order to learn from them and adjust the course for subsequent actions. Throughout this report, the Subcommittee emphasizes the need to increase local and regional ecological inventory and monitoring activities through cooperative partnerships in order to improve cost effectiveness and overall efficacy of monitoring actions. "*

The Service and Refuge System must embrace a larger vision of inventories and monitoring because rapid climate change will result in 20-40 percent of existing species being on a trajectory for extinction within 50 years (IPCC 2007, Thomas et al. 2004). Environmental changes associated with climate will result in: new species assemblages before we fully understand or have documented the composition of our current communities; many coastal refuges being inundated by rising seas or surges from increased cyclonic activity; and many refuges in landscapes for which they were not established. Much of Alaska, the Pacific Northwest, and the Mississippi and Missouri River systems are expected to experience novel biomes within the next century (Figure 3), suggesting that our already incomplete knowledge of current species distributions and assemblages will be increasingly outdated. Rapid climate change demands that we expect surprises beyond our current experience with generating management-driven objectives (Burke et al. 2005, Williams and Jackson 2007).

The Service specifically addressed inventories and monitoring in its Strategic and Five-Year Action climate change plans. Goal 3 calls for the development of "monitoring and research partnerships that make available complete and objective information to plan, deliver, evaluate, and improve actions that facilitate fish and wildlife adaptations to accelerating climate change". To accomplish this goal, Objective 3.1 calls for the development of a National Biological Inventory and Monitoring Partnership with the active participation of the Refuge System:

> *Action 3.1.2 --The Assistant Director for the National Wildlife Refuge System will develop and implement a pilot inventory and monitoring program on National Wildlife Refuge System lands; I&M program will be modeled on existing programs with proven track records (e.g., U.S. Forest Service's Forest Inventory and Analysis Program and the National Park Service's Inventory and Monitoring Program).*

The Service's strategic climate change plan further defined the scope of this effort on Service lands:

> *"We will incorporate new inventory and monitoring approaches as necessary and practical, with the ambitious goal of having within 10 years complete plant and vertebrate species inventories, and inventories of select subsets of invertebrate species for all Service lands."*

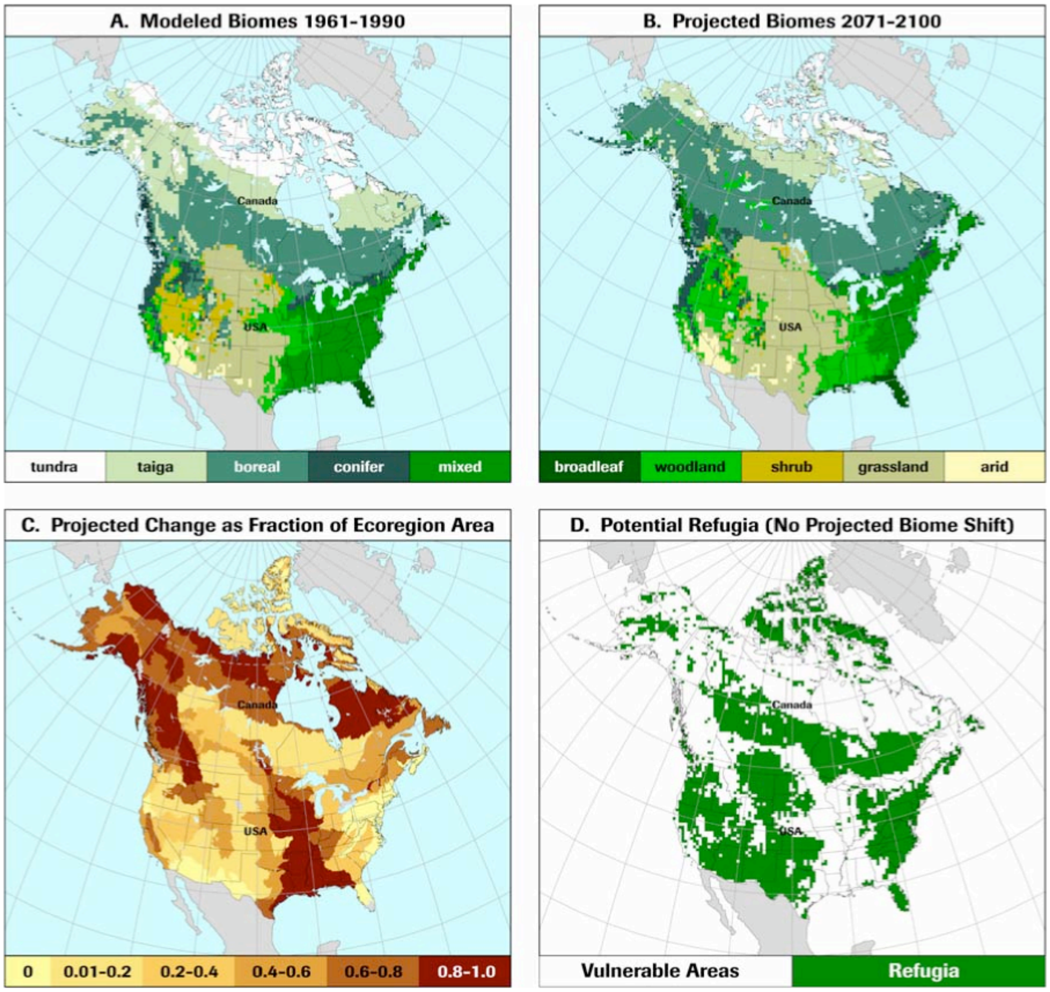

Figure 3. Spatial models of current and future distributions of North American biomes as a result of climate change (Scott et al. 2008).

HOW WILL THE SERVICE AND NWRS RESPOND?

FACILITATING CLIMATE CHANGE ADAPTATION

Facilitating the adaptation of fish, wildlife, and plants to rapid climate change is a huge undertaking and represents an enormous intellectual and ecological challenge to the Service, the Refuge System, and the conservation community as a whole. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities." A 2009 review summarized the adaptation strategies available for sustaining wildlife and biodiversity in the face of climate change by major types of actions (Mawdsley et al. 2009; Table 1). The conservation community has experience with some of the strategies; others will require new tools and approaches; none are simple. Many of the strategies do not lend themselves to experimentation. They involve landscape scale efforts that are difficult to replicate in a controlled setting. A number of the adaptation options involve reducing non-climate stressors and improving ecosystem resilience, representation, and redundancy; this is a low-risk approach, one we should be doing anyway.

Table 1. Climate change adaptation strategies available to land managers (Mawdsley et al. 2009).

Type	**Strategy**
Land and water protection	Increase extent of protected areas
	Improve representation and replication within protected-area networks
	Improve management and restoration of existing protected areas to facilitate resilience
	Design new natural areas and restoration sites to maximize resilience
	Protect movement corridors, stepping stones, and refugia
	Manage and restore ecosystem function rather than focusing on specific components (species or assemblages)
	Improve the matrix by increasing landscape permeability to species movement
Direct species management	Focus conservation resources on species that might become extinct
	Translocate species at risk of extinction
	Establish captive populations of species that would otherwise go extinct
	Reduce pressures on species from sources other than climate change
Monitoring and planning	Evaluate and enhance monitoring programs for wildlife and ecosystems
	Incorporate predicted climate-change impacts into species and land-management plans, programs, and activities
	Develop dynamic landscape conservation plans
	Ensure wildlife and biodiversity needs are considered as part of the broader societal adaptation process
Law and policy	Review and modify existing laws, regulations, and policies regarding wildlife and natural resource management

Scott et al. (2009) identified the following techniques and approaches that could be employed specifically within the Refuge System to facilitate adaptation to climate change:

- Use prescribed burning to reduce risk of catastrophic wildfire;
- Facilitate growth of plant species more adapted to future climate conditions;
- Assist species with limited dispersal abilities;
- Provide interim food propagation for mis-timed migrants;
- Reforest riparian habitats;
- Propagate and transplant heat-resistant coral;
- Apply the full range of land use planning tools (acquisition, easements, inter-agency partnerships, water right acquisition) to acquire buffers, establish corridors, and eliminate dispersal barriers;
- Conserve projected climate change refugia;
- Improve compatible land uses in lands surrounding the conservation areas;
- Restore existing and establish new marshland vegetation as sea levels rise;

- Establish other marshland vegetation where freshwater lake levels fall;
- Restore historic hydrologic regimes and retain adequate water to sustain aquatic species and wildlife;
- Restore historic fire regimes to sustain fire-dependent or fire-adapted species and ecosystem functions;
- Consider use of levees and engineering works to meet critical habitat needs; and
- Reduce or eliminate non-climate stressors on conservation targets (e.g., predator control, nest parasite control, control of non-native competitors).

In the past, management decisions have generally been directed toward maintaining or restoring historic conditions. Adaptation may now mean managing towards less certain future conditions, rather than aiming for historical or current conditions (Choi 2007, Harris et al. 2006). Consistent with the IPCC, the Service recognizes that adaptation strategies can be anticipatory or reactive (USFWS 2009a). Anticipatory adaptation works with climate change trajectories; reactive adaptation works against climate change, towards historic conditions. The former approach manages the system towards a new climate change-induced equilibrium; the latter abates the impact by trying to maintain the current condition despite climate change (Johnson et al. 2008).

It will be essential to learn quickly what works -- and what doesn't -- when it comes to helping species and ecosystems adapt. Managing toward future conditions involves a degree of uncertainty and reliance on model projections that may involve work outside the scope and definition of current legislation or policy. Efforts to reduce uncertainty are important, but uncertainty will always remain. This dictates an adaptive management approach, or the adjustment of management actions as the response to previous management is evaluated through monitoring (Johnson et al. 2008).

The Service has committed to an intensive, multi-year collaboration with Federal, State, Tribal, private, and international organizations to support the development of a National Fish and Wildlife Adaptation Strategy (USFWS 2009a). The Refuge System can contribute significantly to this effort by demonstrating how land management agencies can coordinate their collective response to climate change based on a larger landscape context while accounting for other ecological stressors. For example, Magness (2009) developed a national-scale, strategic rationale for organizing the management of individual refuges to provide a coordinated response to ecosystem vulnerability within the Refuge System. Ecosystem vulnerability to climate change depends on the rate of climatic change and the resilience of the surrounding landscape, both of which vary at multiple spatial scales. Using GIS analyses, refuges were placed into an ecosystem vulnerability framework that was used to define four broad management categories: facilitated transitions, experiments in natural adaptation, ecosystem maintenance, and refugia (Figure 4). Conceivably, this approach could be refined and formalized to provide overall guidance to refuges as their Comprehensive Conservation Plans (CCPs) are developed or revised.

There is a need to collect the kind of field data that will move the Refuge System towards a more cohesive and strategic response to a rapidly changing landscape. We have proposed in the Operational Blueprint that one selection criterion for the placement of I&M pilot studies within the NWRS be based on a similar vulnerability assessment of individual refuges within their surrounding landscape. The I&M program should evolve to contribute information needed to help plan and evaluate, in a truly adaptive approach, this national climate adaptation strategy; help define the future role of the Refuge System in its implementation; and promote coordination and collaboration with partners in the conservation estate.

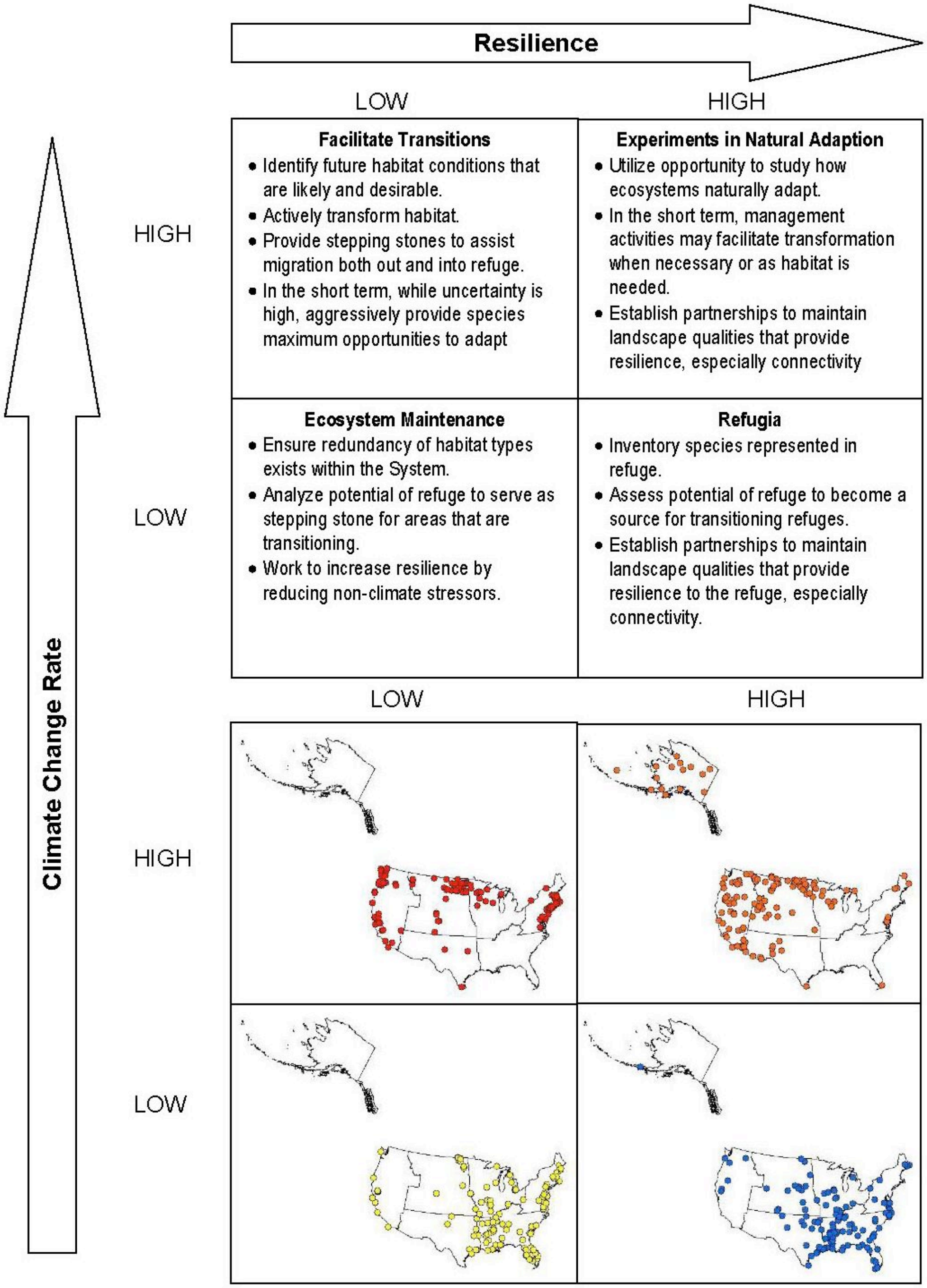

Figure 4. Management options to facilitate climate change adaptation on 550+ national wildlife refuges with varying ecosystem vulnerabilities (Magness 2009). Climate change rate was based on models of temperature change, precipitation change and sea level rise. Resilience was based on refuge size, its elevational range, and the surrounding road density.

ROLE OF THE I&M PROGRAM – AN OPPORTUNITY FOR LEADERSHIP

The I&M program is designed to address the long-term data needs of the NWRS to meet refuge purposes and the Refuge System's legislated mission and mandates, and to support the Service's landscape approach to conservation, taking climate change implications into full account.

This program is a milestone for the Refuge System. For the first time, inventory and monitoring of natural resources on refuges will be conducted across the entire Refuge System, targeting nationally- and regionally-scaled objectives. As a result, program leadership will more fully appreciate the mission of the Refuge System and the challenges that accompany accelerating climate change, as well as the long-standing information needs of refuges. Program leadership will recognize the need for collaboration with other national I&M programs to coordinate inventory and monitoring activities across the Federal, State and private conservation estate and promote data sharing among all stakeholders. Program leadership will recognize that refuges are islands in a rapidly changing landscape and work closely with LCCs and partners to provide relevant landscape context to conservation design, biological planning, outcome-based monitoring, and management.

The I&M program will serve a key role in support of the LCCs by focusing on the evaluation of landscape scale conservation delivery, providing and managing data on species occurrence on refuges, quantifying impacts of non-climate stressors, and working cooperatively with LCC staff and the USGS Climate Change Response Centers on vulnerability assessments and modeling of present and projected species distributions. The I&M program's primary role under SHC will be monitoring the effects of management on populations and refuge habitats doing so with conservation partners across the landscape. The I&M program will also provide leadership in designing and implementing surveys to assess the current state of species populations and identifying limiting factors (Biological Planning). Major components of the I&M program are directed at assessing status and trends of limiting factors already identified as important across the NWRS (water quality and quantity, and invasive species). I&M program staff will participate in other elements of the SHC process and provide leadership for monitoring at spatial scales beyond refuge boundaries.

This landscape context is critical for conservation design, biological planning and, ultimately, conservation delivery because refuges constitute only 5 percent of the contiguous U.S.; many stressors originate from outside refuge boundaries. In particular, as we consider strategic growth of the Refuge System, species translocations, habitat restoration and creation, and other tools for facilitating adaptation to climate change, it will be critical that this program be developed so it contributes to understanding ecological change within the Refuge System in regional, national, and even continental contexts.

This program will be nationally coordinated by Washington Office staff, based in Fort Collins, Colorado, to ensure that inventory and monitoring addresses national needs (Figure 5). This office will be staffed by scientists from disciplines relevant to conducting inventories and monitoring of both biotic and abiotic resources including wildlife and fisheries biology, landscape ecology, marine ecology, hydrology, remote sensing, biometry, and spatial modeling. Data management, data access, and product delivery will be significant components of this office. Data management capacity will constitute approximately one-third of the annual budget for the overall I&M program.

NWRS I&M staff in Regional Offices, associated with LCCs and assigned to field stations, will work collectively to meet the information needs unique to refuges within Geographic Areas and required by the LCCs (Figure 5). Data will be collected and summarized by Geographic Areas. NWRS I&M coordinators will work with LCCs to ensure that information collected contributes to conservation design and biological planning at landscape scales. NWRS I&M data managers will ensure that data standards and data management systems integrate well with those of the LCCs, while nesting within the I&M program's national-level data management infrastructure. I&M program staff assigned to field stations will provide additional coordination of program initiatives, including facilitation of monitoring to support regionally-scaled adaptive management projects.

The I&M program will address long-standing information needs in support of planning and management of refuges at the local scale. At a minimum, the I&M program will honor the recommendations of the WH8.1 Baseline Inventory Team (Byrd et al. 2004) that all refuges should have basic information on biotic and abiotic resources. These include inventories, maps, and geospatial databases of topography, hydrography, soils, boundaries, man-made structures, vegetation communities, vertebrate fauna, and vascular flora. With rare exceptions, refuge field staff will not be burdened by additional field work associated with subsequent monitoring. However, refuge staff will always be consulted and their active participation welcomed in regional- and national-scale monitoring efforts.

Recognizing that potential partnerships vary across the U.S. and at different scales, we are proposing an I&M program that is nationally-coordinated but allows for regional variance to address issues that may be more significant in one part of the country than another. For example, Scott et al. (2008) point out that the absolute and relative impacts of rapid climate change on waterfowl resources in the Central Flyway vary from the Alaska subarctic to the Prairie Pothole Region to the Lower Mississippi River, as does the contribution of non-climate stressors. Similarly, the logistical and fiscal hardships of conducting field work in Alaska or in marine systems will require that some Geographic Areas design I&M components that are unique.

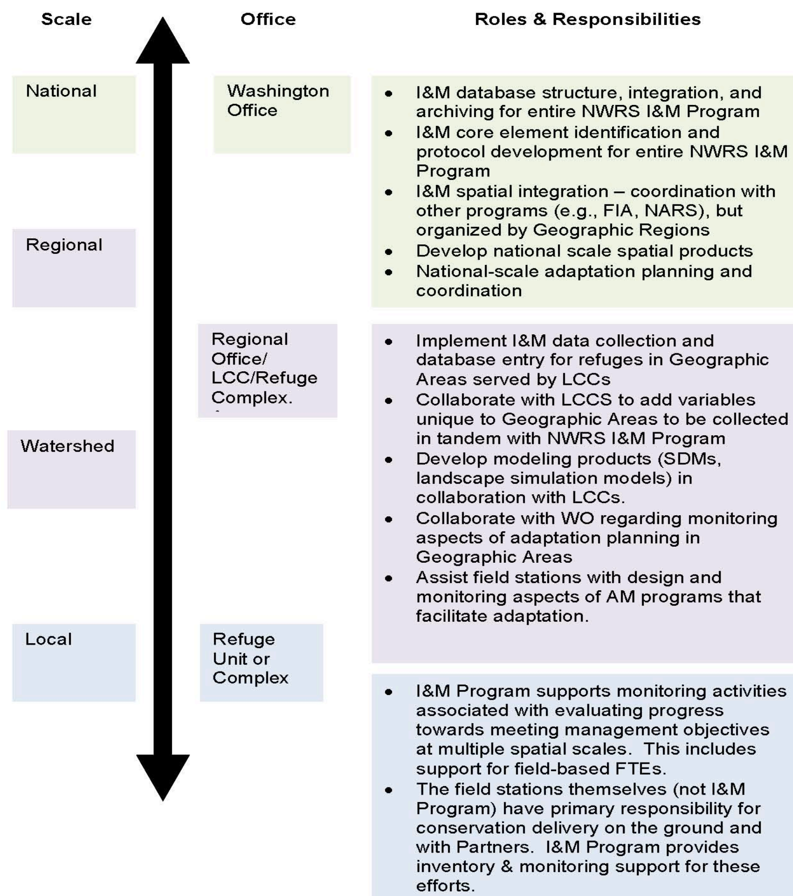

Figure 5. The roles and responsibilities of the National and Regional offices of the NWRS I&M program in relation to those of refuges.

This operational flexibility fits with the operating history and strong regional structure of the Refuge System, but successful implementation of the I&M program will require strong cooperation and communication among the national, regional, LCC, and field level I&M staff. It will require integration and leveraging of existing biological and technical capacity within the Refuge System, the Service, and conservation partners. A nationally-coordinated program will derive from good communication, adoption of standard operating procedures and data standards, an integrated data management structure, and consistent reporting requirements.

*Th*e I&M program will ensure that all survey design, data storage and analysis, and reporting is consistent with the draft 701FW2 Inventory and Monitoring Policy (USFWS 2009). This policy provides guidance for developing an Inventory and Monitoring Plan for a station of the NWRS. However, it accommodates all levels of natural resource surveys, from the station level on up to participation in national and international survey programs, both internal and external to the USFWS. Such surveys may include long-term monitoring programs (e.g., sea-level rise, climate change, biological integrity, diversity and environmental health of refuges) of regional, national, or international scale, and implement protocols developed by other Service programs or conservation partners. Overall, this policy promotes consistency in the planning and implementation of inventories and monitoring throughout the Refuge System.

PROGRAM STAFFING AND FUNDING

Current science capacity of the NWRS. As of August 2009, the Refuge System had 626 refuge managers, assistant refuge managers, or refuge operation specialists, (GS-0485); 686 professional biologists (GS-0401, -0486); and 1,010 biology, range science, or forestry technicians (GS-0404, -0455, -0462). Conspicuously absent or scarce are professional positions within biometry, Geographic Information Systems (GIS) management, data management, spatial modeling, and the physical sciences, including remote sensing. For example, the Refuge System currently has only one remote sensing scientist (Region 2), one biometrician (Region 7), and one wildlife veterinarian (Region 6). Although many biologists have strong, interdisciplinary technical skill sets, the Refuge System does not have the technical specialists to develop and implement an I&M program to meet the demands of climate change and other landscape stressors, engage with and contribute to LCCs, partner with other national I&M programs, and provide support for adaptive management.

Future science capacity of the NWRS. The Refuge System has been appropriated $12 million in FY10 to initiate development and implementation of a climate change-focused I&M program; it may receive $8 million in FY11 for the same purpose. In FY10, 58 FTEs will be funded: 10 in the Fort Collins office and 48 in the regions, with six in each of the eight regions. The latter includes one Regional NWRS I&M Coordinator, two FTEs per LCC, and three at field stations. In FY11, contingent upon funding, 45 FTEs may be added: five FTEs in the WO and 40 FTEs in the regions (LCCs and field stations). More details are provided in the Operational Blueprint and Addendum to the Strategic Plan.

Beyond the initial 23 National and Regional Office staff, the I&M program must strategically grow within Geographic Areas and at field stations in response to the information needs of the Refuge System and the LCCs. A fully operational I&M program will require funding of $100 million annually, supporting 280 FTEs ($45 million), at least 200 of which will be located on field stations. Operational costs of conducting inventories and monitoring are estimated to be $55 million per year Refuge System-wide. Completing baseline inventories alone (e.g., vegetation mapping, biota, water resources) will require approximately $25 million per year over 10 years to cover operational costs.

Alaska will require special consideration. The 16 refuges in Alaska comprise 87 percent of the land base within the NWRS, ranging in size from one to 22 million acres. Even as climate change is dramatically impacting high arctic and subarctic Alaska, the logistical and fiscal costs of inventorying and monitoring continue to be significantly greater in Alaska than elsewhere in the U.S. Indeed, national directors of both the USDA FIA and EPA NARS programs have expressed explicit interest in cooperating with the NWRS to complete biological inventories in Alaska. The National Park Service has also recognized the I&M challenge that Alaska represents and provided specific details on how to address those information gaps in the NPS Strategic Plan for Natural Resource Inventories: FY 2008 – FY 2012. The NWRS will need to partner with other agencies and other I&M programs to fully address the information needs in Alaska.

Marine ecosystems will require special consideration. Marine holdings within the Refuge System include ~30,000 coastal miles across 61 million coastal acres, with tidally-influenced lands totaling 7 million acres. Coral reefs within the NWRS encompass almost 5 million acres. The NWRS co-manages the 89-million acre Papahānaumokuākea Marine National Monument in Hawaii. Refuge System holdings within the recently-designated Pacific Remote Islands, Rose Atoll, and Marianas Trench Marine National Monuments include 53 million acres of submerged lands in the central and western Pacific (Figure 2). These tropical marine and oceanic ecosystems remain poorly understood or mainly unexplored, especially in the vast, remote central Pacific Ocean.

The magnitude of this recent growth in the Refuge System and the extensive scale of monitoring sea level rise, polar ice cap melt, ocean acidification, and changes in ocean currents demand resources and expertise beyond the Refuge System. The NWRS will need to partner and integrate with agencies such as NOAA and EPA which already have well-developed I&M capacity for marine resources, and with international initiatives such as the Global Coral Reef Monitoring Network and ReefBase. Other recommendations include close cooperation with non-DOI agencies, including NOAA, DOD, NASA, USCG, Smithsonian Institution and others, to provide satellite and remote surveillance technology to discourage unauthorized access and harvesting, enforce protection, and assess the effects of specific intrusions; expansion of the existing fledgling coral reef inventory and monitoring program to cover all remote islands, coral reefs, deep reefs, sea floor, and localized oceanic and atmospheric characteristics; and assist neighboring nations and territories that have established protected lands and marine areas to improve the overall effectiveness and efficiency of the I & M program and operation effectiveness of all protected lands and waters.

II. THE NWRS INVENTORY AND MONITORING PROGRAM

VISION

A nationally coordinated program of inventory and monitoring on the National Wildlife Refuge System will generate information critical to the System's ongoing contributions to the conservation of the nation's fish, wildlife and plant resources in the face of climate change and other environmental stressors. Collaboration with other Service programs and State, Federal and private partners will lead to the effective integration of inventory and monitoring data needed to advance conservation at landscape scales.

The inventory and monitoring program will document the status, assess the condition, and detect changes in the Refuge System's diverse fish, wildlife and plant communities, physical resources -- including water, air and soils -- and ecological processes to support science-based conservation planning and management at multiple spatial scales. The information generated will be scientifically credible, relevant, and valued by the Service, its partners in the conservation community, and the public. The program's protocols and standards will provide the basis for consistent data collection and data management throughout the Refuge System, ensuring the timeliness, availability, and long-term integrity of the information collected.

PROGRAM GOALS

1. Meet the Refuge System's legal mandate to monitor the status and trends of fish, wildlife, and plant populations on refuges, preserve wilderness character, and collect and manage information needed to maintain biological integrity, biological diversity, and environmental health and preserve the character of designated wilderness within the System.
2. Advance fish and wildlife conservation at refuge and broader landscape scales in an adaptive management cycle by providing scientific information that supports conservation planning and design, guides learning through evaluation of conservation delivery, and provides a basis for assumption-driven research.
3. Implement monitoring of fish, wildlife and plants, physical resources, and ecological processes to reduce uncertainty related to impacts of climate change and other stressors; provide early warning of changing conditions; and guide development of management actions that facilitate adaptation to climate change.
4. Synthesize, interpret, and report on the condition of fish, wildlife, plants, and habitats conserved by the Refuge System in a manner that documents the contributions of the System within the context of the larger conservation estate and clearly communicates its value to the American public.
5. Enhance effectiveness and reduce costs by coordinating and integrating monitoring of natural resources at landscape scales through collaboration with other Service programs, agencies, and organizations.

PROGRAM FOCI AT NATIONAL AND REGIONAL SCALES

SETTING PRIORITIES

A nationally-coordinated I&M program will require setting priorities, not only for Phase 1 of the program, but for the long-term as well. No matter how well-funded, this I&M program cannot address all needs; a quality program will require focus. The priorities of the NWRS I&M program should be driven by the most pressing information needs of the Service and the Refuge System. Information derived from this I&M program should inform the most important decisions made by managers at all levels of the organization. The National and Regional office staffs of the I&M program, once hired, will refine and prioritize long-term goals and objectives.

During Phase 1 or until such time as the fledging program is better developed, initial objectives are:

1. Collect, synthesize, and manage information needed to increase the resilience of existing protected areas by informing refuge planning and management and the future growth of the Refuge System. Support and evaluate adaptation strategies at multiple spatial scales.
2. Collect, synthesize, and manage information needed to assess the vulnerability of the Refuge System as related to broad-scale climate and non-climate stressors: water shortages, changes in

precipitation and disturbance patterns, changes in fire risk, contaminants, and land use changes. Support and evaluate adaptation strategies at multiple spatial scales.

3. Collect, synthesize, and manage information needed to assess the vulnerability of the NWRS to increases in weed species and changes in insect pests and disease pathogens. Support and evaluate adaptation strategies at multiple spatial scales.
4. Collect, synthesize, and manage information needed to detect shifts in biomes and species ranges, elevated extinction rates, and changes in the timing of migrations and other phenological phenomena. Support and evaluate adaptation strategies at multiple spatial scales.
5. Collect, synthesize, and manage information needed to assess the vulnerability of the Refuge System's coastal and marine resources to sea-level rise, rising ocean temperatures, and ocean acidification. Support and evaluate adaptation strategies at multiple spatial scales.
6. Collect, synthesize, and manage information needed to assess the vulnerability of the Refuge System's Arctic and other high-latitude resources, including ice-dependent species. Support and evaluate adaptation strategies at multiple spatial scales.

Nonetheless, the Refuge System cannot assume that it fully recognizes knowledge gaps or management needs when faced with accelerating climate change.

> *Many biological, hydrological, and geological processes are interactively linked in ecosystems. These ecological phenomena normally vary within bounded ranges, but rapid, nonlinear changes to markedly different conditions can be triggered by even small differences if threshold values are exceeded. Intrinsic and extrinsic ecological thresholds can lead to effects that cascade among systems, precluding accurate modeling and prediction of system response to climate change. Understanding and anticipating nonlinear dynamics are important aspects of adaptation planning since responses of biological resources to changes in the physical climate system are not necessarily proportional and sometimes, as in the case of complex ecological systems, inherently nonlinear* (Burkett et al. 2005*).*

Therefore, even as the Refuge System prioritizes and implements Phase 1 of this program, it will need to ensure constant feedback in a truly adaptive management context, not only to refine the program objectives, but perhaps even its goals. The imperative -- articulated both here and in the Operational Blueprint -- is to move forward quickly but prudently, designing inventories and pilot studies to better frame and refine the monitoring objectives, metrics, and protocols. Just as importantly, the Refuge System needs to be aware of monitoring for non-target impacts even as it considers facilitated migration and other forms of anticipatory adaptation to climate change.

The following program foci are recommended for early consideration during development of the I&M program: abiotic resources, biological diversity, populations of priority species, invasive species, vegetation mapping, phenology, genetic diversity, wildlife health, water quality and quantity, fire and other landscape disturbance processes, contaminants, and Wilderness character. Many of these program foci contribute to more than one of the I&M program's initial objectives. We have promoted some of these components as pilot studies during Phase 1 of the Operational Blueprint to avoid missed opportunities and redundancy of I&M by other agencies. Pilot testing for each of these components will occur in one or all Regions during Phase 1, while methods are being developed. These Regions will work cooperatively to design methods and tools with the ultimate goal of expanding their use nationwide. During Phase 2, some of these pilot efforts will be revised, refined, and expanded to more Regions or nationwide.

ABIOTIC RESOURCES

Abiotic factors such as soils, hydrology, and geomorphology provide the foundation for ecological processes and ecosystem restoration. Biological resources cannot be successfully managed without knowledge of the underlying abiotic resources upon which they ultimately depend and inhabit. Local-scale knowledge of soils, hydrography, topography, and geomorphology take on new significance as the Service considers translocating species to places where they may not have occurred in the past. While changing climatic conditions may support new species of fish, wildlife, and plants, local conditions (e.g., soil type, the presence of permafrost, or water chemistry) may inhibit their viability.

Abiotic baseline data are typically assembled by refuges during development of their Comprehensive Conservation Plans (CCPs). However, some refuges still lack access to these baseline data. Furthermore, there is no central location for storing this information so that it is available and/or efficiently served to Regional or National NWRS managers. The I&M program will honor the recommendations of the WH8.1 Baseline Inventory Team (Byrd et al. 2004) that all refuges should have basic information on abiotic resources.

Hydrogeomorphic analysis (HGM) is a method of assessing ecosystem condition and ecological processes at a site to evaluate departure from historic conditions, identify restoration and management options, and identify ecological attributes needed to restore specific habitats. Note that the term "HGM" as used here refers to an analysis tool in a management context, and differs from the related Hydrogeomorphic (HGM) Approach used to assess and classify wetland function in a regulatory framework. HGM provides a science-based approach to understanding the physical and ecological attributes of landscapes and specific areas within them, such as refuges. HGM utilizes historic condition and ecological processes (soils hydrology, topography, geomorphology, vegetation), identifies changes to physical condition and ecological process, and generates restoration and management options for a given landscape. An HGM analysis helps refuge stations clarify their management objectives and respond to climate change by creating a better understanding of the potential for a refuge to support wildlife and plant communities. Restoration options will need to be informed by climate models; for example, restoration of ecosystem function may be more feasible than restoration of specific plant communities. HGM analyses have been completed for some refuges in Region 6. The Operational Blueprint recommends expanding the use of this tool on additional refuges.

Some abiotic data needed to respond effectively to climate change have yet to be collected. These include soil and wetland types over most refuge lands in Alaska, and high-resolution digital elevation models to better project the impacts of sea-level rise on coastal refuges at the local scale. Working with partners, the I&M program should support acquisition of these data.

BIOTIC RESOURCES

BIOLOGICAL DIVERSITY

The Refuge System cannot be expected to adapt strategically to climate change impacts without a better sense of in situ biological diversity. Floral and faunal inventories are critical for benchmarking extant species assemblages before accelerated climate change and non-climate stressors cause extinctions, species redistributions, and novel assemblages. Inventories also set the stage for reasoned and deliberate development of monitoring objectives and a well-designed monitoring program. New data resulting from comprehensive inventories may also redirect current management priorities and assist with assessments of species vulnerability to climate change.

However, Federal agencies are generally ill-prepared to address climate change because of inadequate knowledge of the species that occur on lands they manage. The U.S. Government Accountability Office, after studying the effects of climate change on Federal agencies and lands in 2007, concluded that, "resource managers do not have sufficient site-specific information to plan for and manage the effects of climate change on the Federal resources they oversee. [They] generally lack detailed inventories and monitoring systems to provide them with an adequate baseline understanding of the plant and animal species that currently exist on the resources they manage." The Department of Interior's Climate Change Task Force similarly concluded in 2008 that, "few DOI land management units have complete biological inventories of species. Additionally, DOI has no cohesive, systematic program for monitoring change over time in the distribution of species and communities. Inventories will be critical to assessing climate change impacts and to developing management responses to those impacts." Lastly, as part of the U.S. Climate Change Program's review of adaptation options for climate-sensitive ecosystems and resources, the Synthesis and Assessment Product 4.4 recommended that the NWRS facilitate the identification of species that occur on refuges and develop detailed inventories of species, communities, and unique ecological features (Scott et al. 2008). Without these data, Scott et al. (2008) emphasized that it will be impossible to monitor changes and to determine how to allocate resources to protect the biota of the Refuge System.

The inherent value of knowing which species occur on a refuge is predicated on the certainty of that knowledge, the rigor with which data were collected, and the spatial distribution of the sampling efforts. These attributes dictate the potential for using inventory data as baseline values for plot-based monitoring, for input into spatial modeling at local scales including the development of vegetation and wildlife species distribution maps, for developing statistical models of species-habitat relationships, for inputs into remote sensing-based models, ground-truthing remotely-sensed data, or as validation data sets for spatially-explicit models. More specifically, an inventory can be a one-time event that simply generates an aspatial species list with an unknown level of certainty about its completeness, or it can be T_1 of a time series in a statistically-rigorous, spatially-comprehensive monitoring design. The trade-off is that even as the collateral benefits increase with increasing statistical rigor and spatial comprehensiveness, so does the financial cost of conducting the inventory. The Refuge System will need to consider the merits of inventory and monitoring in a way that data can be integrated by others on public and private lands outside the NWRS. Consequently, in the Operational Blueprint, development and implementation of pilot studies have been recommended to help the Refuge System better understand these methodological trade-offs while concurrently developing protocols for field sampling, curation and vouchering, and DNA barcoding. In addition, the trade-offs of leveraging data by partnering with other national I&M programs -- such as USDA's Forest Inventory and Analysis program, NRCS's Natural Resource Inventory, or EPA's National Aquatic Resource Surveys -- could also be explored (see Part III. Crosscutting Considerations and Approaches).

The documentation of species occurrences from existing data -- i.e., legacy data -- is recommended as a first step. Legacy data include existing data sets, annual narratives, reports, theses, museum voucher specimens, and species checklists. Most refuge bird checklists are compiled from legacy data. The National Park Service has developed several databases and protocols for inventorying legacy data, compiling legacy data on species occurrence within National Parks in a national database (NP_Species database) and other legacy data into a natural resource bibliography database for each park. In a world with rapid climate change, legacy data only represent historic, not necessarily current, species occurrence. However, they can serve as a benchmark against which future changes can be contrasted. As a caution, these data sources often have serious limitations; the value of the information must be weighed against the cost of acquisition and compilation before proceeding.

POPULATIONS OF PRIORITY SPECIES

As the I&M program develops, the Refuge System will consider incorporating the monitoring of populations of priority species that have a significant presence on refuges at Regional and National scales. The Refuge System will need to coordinate within the Service to ensure that relevant migratory bird species, Federally-listed species, anadromous fish, and marine mammals are given due consideration.

The I&M Program will work with LCCs, Joint Ventures and the two Habitat and Population Assessment Team (HAPET) offices to identify target bird species within Geographic Areas for monitoring. Joint Ventures are regionally-focused, public-private partnerships that implement and evaluate conservation actions in support of the four major North American bird conservation initiatives (i.e., waterfowl, shorebirds, waterbirds, landbirds). The Refuge System is a vital partner to the Joint Ventures, representing an important element in each U.S. Joint Venture's implementation infrastructure. As such, the NWRS has a role both in delivering targeted conservation actions for birds and fostering an improved understanding of the effects of conservation actions in achieving bird population objectives. Implementation of NWRS conservation actions within an adaptive framework at either the individual refuge level or as a part of coordinated regional efforts will help ensure that actions are robust to existing uncertainties and that monitoring programs are targeted to reduce key uncertainties over time, including uncertainties exacerbated by climate change. Refuge monitoring can be an important link in broader, multi-scale bird monitoring efforts designed to identify factors driving population and distributional change and to effective allocation of bird conservation resources. The Integrated Waterbird Project (http://www.acjv.org/waterbird_project.htm), which involves Regions 3, 4, and 5, is one project that attempts to deal with the complexities of migration monitoring. It is an example of adaptive management applied at the scale of two flyways (Atlantic and Mississippi flyways) and several bird taxa (waterfowl, shorebirds, marsh birds), with a focus on providing high quality migration habitat. Projects in other regions may have similar goals.

The Refue System will also seek collaboration with established programs, such as the North American Amphibian Monitoring Program or the Terrestrial Wetland Global Change Research Network, which brings focus to amphibians, a taxonomic group that is highly vulnerable to climate change. In fact, we are already dealing with declining worldwide populations, widely cited as a harbinger of a changing climate. Because of their permeable skin, biphasic lifecycles and unshelled eggs, amphibians are extremely sensitive to small changes in temperature and moisture (Carey and Alexander 2003).

Pollination is crucial to the reproduction of many plants, thus to maintenance of functioning ecosystems and biodiversity. Many pollinators are also highly climate-sensitive and declines in their populations have cascading effects on entire ecosystems. The principal mode of pollination of many plant species is by insects. Worldwide, an estimated 400 crop species are pollinated by bees and more than 30 other animal genera; possible crop loss in some species would be more than 90 percent in the absence of bees (Southwick, 1992; Buchmann and Nabhan, 1996). The Refuge System will consider participation and collaboration in new I&M programs, such as the bee monitoring initiative hosted by the USGS at Patuxent Wildlife Research Center in Maryland.

VEGETATION INVENTORIES AND MAPPING

Detailed and meaningful vegetation/habitat inventory and mapping are fundamental elements to all inventory and monitoring programs, but have not been completed for the vast majority of national wildlife refuges. Indeed, the WH8.1 Baseline Inventory Team (Byrd et al. 2004) specifically recommended the development of vegetation community maps for all refuges. Commonly following the National Vegetation Classification System, vegetation inventories conducted on field stations are developed at a floristic or floristic/physiographic scale. Required sample design and field data collection need to be rigorous and intensive to ensure a statistically defensible and accurate inventory, which can include invasive plant species. The ancillary data required to develop vegetation inventories will vary from high resolution multi-spectral airborne sensors to mid- and coarse-resolution satellite sensors such as Landsat TM and MODIS, depending on the needs of the project. Region 2 has developed and published the NWR Spatial Vegetation Inventory and Monitoring Handbook (Donnelly 2006), which documents the remote sensing methods, field protocol, sample design and statistical analysis used in their mapping procedures.

In addition, the capacity to detect change (not just a static map) over time can be incorporated through analyses of spectral (continuous) or thematic (classified) data. In scenarios where archived data are available, such as Landsat TM or historic aerial photography, change detection can be applied to quantify shifts in landscape metrics over time, historic to present. It is also useful when quantifying changes resulting from landscape disturbances such as wildland fires or hurricanes.

In spite of its acceptance as an effective landscape inventory and monitoring tool, remote sensing capacity and application within the Refuge System has been limited. There has been no programmatic support to develop the capacity to initiate a remote sensing program capable of sustaining comprehensive vegetation mapping inventory program or related remote sensing applications at National or Regional levels. Both the National Ecological Assessment Team (USFWS 2006) and the Climate Change Strategic Planning Team (USFWS 2009) have identified the need for increased capacity and utilization of remote sensing in support landscape conservation and monitoring. The Operational Blueprint specifically added the need for remote sensing capacity within the Washington Office to ensure that vegetation inventories and mapping of all refuges begin early in implementation of the I&M program. Partnerships with NASA, NOAA, and USGS will provide the I&M program with access to new sources of remotely-sensed imagery as well as significant technical expertise to incorporate cutting-edge remote sensed data products and associated models.

PHENOLOGY

The inventory of current phenology and monitoring temporal changes that result from climate change can serve as critical components of an "early warning system" for threats to both species occurrence and abundance (i.e. species vulnerability). Recent literature suggests that species that show relatively great phenological change are more resilient and therefore less likely to be locally extirpated as climate changes. Phenological data are also critical for understanding some of the underlying proximate mechanisms (e.g. trophic mismatch, parasite-host relationships, growing season) that may be driving species redistributions, population extirpations, and species extinctions in a world with rapid climate change. The USGS launched the USA National Phenology Network (NPN) in March 2009 with the goal of having 100,000 observation locations across the US monitored by citizens, universities, agencies, and other organizations. With the biological expertise and the on-the-ground eyes of refuge staff, as well as "eyes in the sky" from remotely-sensed imagery, the opportunity exists not only to contribute to the USA NPN, but also to ensure that the

NPN serves the Refuge System. By collaborating during the early development of NPN, the Refuge System can ensure that species or events relevant to it are incorporated as monitoring metrics and that data collected by NWRS staff on refuge lands are retrievable.

GENETIC DIVERSITY

Incorporation of genetic sampling into the I&M program can provide detailed information on gene flow, both interspecific (hybridization or introgression) and intraspecific (through migration and successful reproduction). At a broad level, genetics can be used to identify individual samples to species. Genetic identification is often more reliable than morphological field identification and does not require taxonomic experts in the field. On a finer scale, genetic analysis is the most realistic way to identify divergence or isolation among morphologically similar groups of individuals; it is the most absolute and reliable way to identify true populations and quantify intraspecific diversity.

Climate change is altering current landscapes, which highlights the need to understand species use and interactions across the landscape. Changing habitats resulting from changing temperature and precipitation alters species distributions and movement. Populations may become isolated over time or migration corridors may no longer be sufficient to connect seasonal habitats. Persistence of species in currently occupied habitats may be constrained by the species ability to adapt to their changing environment. Genetic assessment tools allow managers to monitor and understand when species are not adapting and, perhaps, have significant genetic constraints (e.g., inbreeding). Application of genetic techniques helps to understand adaptation of species or populations, especially for those populations that exist on the edge of the species range or are geographically isolated, and therefore are most vulnerable to the effects of climate change.

Climate change is already increasing the risk of isolation for some populations. Populations that are isolated and become small over time are exposed to increased risks of inbreeding and loss of genetic diversity, which can negatively affect fitness and further threaten their persistence or recovery. Genetic techniques can be used to monitor estimates of genetic diversity, allowing for assessment of the potential threats of inbreeding and loss of diversity resulting from low population sizes. For example, genetic techniques are often applied to captive propagation programs including those of threatened and endangered species in an effort to maintain genetic diversity. In addition, monitoring and assessment of genetic diversity can also be used to provide genetic-based surrogate estimates for demographic data, such as effective populations, or for mark-recapture studies.

Genetic tools and techniques can be widely applied to inform management and conservation actions. A variety of laboratory techniques exist that can provide different scales of resolution for estimates of genetic diversity. Critical to the application and interpretation of genetic information is the methods in which genetic samples were collected. For example, factors such as the life stage sampled, the time of year samples were collected (which may bias the life stage, sex ratio, or population of origin sampled), number of samples obtained, and the biological material obtained for genetic analysis can all significantly influence the ability to make conclusions about the species or population being analyzed. Integration of a genetic component to a large-scale inventory and monitoring program should carefully evaluate the specific management or conservation question being asked of the genetic data to best inform the appropriate sampling scheme for biological materials for genetic analysis.

WILDLIFE HEALTH

Expansion of the human-wildlife interface associated with global human population growth and food requirement, development of rapid global transport systems, the interdependent global economy, global wildlife migratory patterns, increased wildlife concentrations as wildland habitats shrink, and emergence of human infectious zoonotic diseases (many linked to wildlife reservoirs) have sparked acknowledgement and acceptance of the "One Health" concept -- the interrelatedness of human, wildlife and domestic animal health around the world. In the past two years, the World Organization for Animal Health and the World Health Organization have recognized the importance of wildlife diseases. Assessing (inventorying), monitoring and addressing wildlife health issues have emerged as priorities for wildlife, human and domestic animal health. In the next century, many factors will elevate wildlife health as a priority for the USFWS:

- Global climate change is expected to affect the type, prevalence and distribution of wildlife diseases on Refuges. The complex interaction among host, agent and environment will lead to modified and in many cases unpredictable alterations in disease expression. Increased temperatures, changes in precipitation patterns (amount, duration and seasonal distribution), and water quality will directly affect survival, distribution and development of vector organisms and pathogens. "The Deadly Dozen" (Wildlife Conservation Society 2008) outlines 12 zoonotic pathogens of wildlife that are likely to spread to new regions as a result of changing temperatures and precipitation levels expected from climate change.
- Expanded public use on refuges and other public lands will increase disease agent transmission risk between wildlife and humans. Humans play a leading role in the dynamics of disease transmission and spread.
- The emergence and persistence of diseases resistant to archetypical therapeutic solutions will require integrated ecological solutions; solutions based on holistic sound management of wildlife and habitats.

Wildlife disease is often a consequence of the implementation of landscape management decisions. Management decisions affecting ecological interactions, habitat quality and quantity, wildlife distribution, and wildlife abundance all affect disease expression. Avian botulism, brucellosis, and tuberculosis are examples of diseases greatly affected by management actions. Highly pathogenic avian influenza and foot-and-mouth disease are representative of diseases absent in the western hemisphere that would have significant human, wildlife and economic impact should they be introduced. Inventory and monitoring of wildlife resources and habitat conditions are an integral part of the Service's resource management responsibility. The I&M program should ultimately include a national emphasis on wildlife health surveillance. Specific measures of disease presence, diversity, risk of spread, and impact to wildlife and humans need to be developed. In the near future, we will consider establishing formalized wildlife health monitoring under the I&M program, including the development of a baseline database that can be used to detect changes in disease expression induced by climate change; identifying high risk areas likely to experience significant impact from climate change with likely changes in pathogen and/or vector populations; and train NWRS employees to enhance wildlife disease knowledge and surveillance, minimize the potential for disease transmission to other sites, and prevent the transmission of zoonotic agents.

INVASIVE SPECIES

Despite the importance of migratory birds, amphibians, and pollinators, we have chosen to focus on invasive species during Phase 1 of the I&M program (see Operational Blueprint). This issue demands immediate attention as a festering problem within the Refuge System that will clearly be exacerbated by rapid climate change. According to refuge managers and their partners, invasive species are one of the most pervasive threats to habitat management in the Refuge System (GAO Report, Conservation in Action Summit). In FY 2008, the NWRS reported spending $15.3 million on invasive species management activities. Rapidly changing climate will only exacerbate the issue. Pests and diseases are likely to move North, and temperature and moisture stresses will weaken native species and make them more susceptible to diseases. We will have to remove or mitigate the stress that invasive species put on Refuge ecosystems so that our fish, wildlife and plants will have the best opportunity to adapt to rapid climate change. Moreover, invasive species do not respect property boundaries. They are a landscape-scale problem and require landscape-scale solutions.

Because the Refuge System has not had the resources to strategically plan invasive species management actions, invasive species have become an overwhelming issue for many individual refuges. Management efforts commonly focus on controlling large, well established infestations rather than the early detection and complete eradication of smaller incipient infestations. This process is the opposite of what the NWRS Invasive Species Strategic Plan (2003) recommends. If we can prevent a species from entering the refuge or eliminate a small patch before it spreads, we are saving future dollars that would be spent to fight the species once it becomes established and fully entrenched.

A standardized I&M approach is critical to improving our understanding of, confronting, and deterring the invasive species threat. Without inventory data, we do not know what the problem is, where it is, and we do not understand patterns of spread. At a refuge scale, we need to be able to quantify the extent of the problem. Inventory and monitoring data at a larger landscape or watershed scale are critical for working with partners to control invasive species, and are especially crucial for the early detection of new invaders on NWRS lands. It will be necessary to share I&M protocols and databases with sister agencies and non-governmental partners through LCCs or other collaborative data sharing platforms or venues. Our vision is to address invasive species management needs through the I&M program, working closely with partners, to provide real-time, science-based inventory and monitoring data and models at multiple spatial and temporal scales that improve our understanding of the spread and distribution of invasive species and help guide management decisions on refuges and adjacent lands. This will require a national conversation with staff throughout the NWRS and with partners to determine long-term objectives. Short term steps are outlined in the *Operational Blueprint.*

WATER QUANTITY AND QUALITY

The long-term goal of a coordinated approach to water resources inventories and monitoring through the I&M program will be to provide up-to-date, accurate data on Refuge System water quantity and quality in order to acquire, manage, and protect adequate supplies of clean water. The Refuge System has a legislative mandate, under the NWRSAA, as amended in 1997 by the NWRSIA, to "assist in the maintenance of adequate water quantity and water quality to fulfill the mission of the System and the purposes of each refuge", and to "acquire, under State law, water rights that are needed for refuge purposes". The challenge for the Service in light of climate change and growing competition for water is to ensure that sufficient quantities of good quality water are available for fish, wildlife and plants.

We currently lack System-wide, baseline information on Refuge water bodies, groundwater supplies, infrastructure, water rights, water quality impairments, threats to water supplies, and needs. Lack of these data makes it difficult to manage Refuge System water supplies, prioritize field studies and water rights acquisitions, and develop efficient, informative water monitoring strategies. Also, there is currently an inconsistent effort in monitoring water resources across the NWRS. Water quantity monitoring is currently undertaken at some Refuges, particularly in States with prior-appropriation water laws, to record flow and water use. However, water quantity monitoring is rare at most Refuges in the eastern U.S., but needed to establish baseline data of a station's water use and needs. Water quality monitoring is inadequate System-wide, but needed in order to ensure maintenance of environmental health. In addition, monitoring is needed to detect climate-induced changes to NWRS surface and ground water supplies.

The initial focus of water inventory and monitoring will be to complete a baseline, reconnaissance-level inventory and assessment of water resources quantity and quality at all refuges. This will take approximately 5 years to complete. We will collect standardized information on refuge water quantity and quality, including physical descriptions of surface water and groundwater features, water rights, infrastructure, and water quality issues. When this fact-based inventory is completed, a hydrologist and water quality specialist will review and provide a professional assessment of the station's water resource issues, current and future threats and needs, and make recommendations for management actions, including recommendations for more detailed assessments where appropriate. Data collected within this inventory and assessment process will help us meet the water resource mandates described in the NWRSIA.

The water resources inventories and assessments will primarily collect existing data from multiple sources into a relational and standard database structure. The water quantity component of this inventory will include description of physical characteristics of a station's water bodies, hydrography, and water-related infrastructure, as attributes relatable to GIS layers, and include both surface and groundwater resources. The inventory will also describe each station's water rights, water resource needs, and threats. Water resource staff will work with individual refuges to populate the database. Field station staff will fill in the information they have available, and water resource staff check this data for accuracy and complete the database fields.

The water quality assessment component will look at multiple sources for existing water quality data, beginning with EPA's 303(d)-listed impaired waters database. The Service, in collaboration with the EPA and USGS, has developed an Impaired Waters Project for Refuges and Hatcheries. This project combines 2002 EPA 303(d)-listed impaired water database information with NWR boundaries and Fish Hatchery locations and delineates impaired waters in or near Refuge and Hatchery boundaries. The location, extent, and type of impairment are identified. Despite some limitations, the impaired waters database is a valuable tool and is a useful first step in assessing water quality issues in the Refuge System. We will also need to examine additional sources of information on water quality, including the USFWS Contaminants Assessment Program (CAP) database, EPA and State impaired waters databases from 2004 and later, State bio-assessment data, EPA STORET database (includes data from many different governmental and non-governmental sources), USGS National Water Quality Assessment (NAWQA) program reports, and any station-specific "legacy" data.

While the Refuge System currently engages in monitoring some water resources, particularly in the western regions, development of a monitoring program will be primarily an outgrowth of the inventory and assessment phase. Water resource inventories and assessments will allow the Refuge System to prioritize its monitoring efforts, in both water quantity and quality. However, the Refuge System may be able to identify some key monitoring needs in the initial stages of the inventory and assessment phase, such as initiating long-term monitoring of water temperature at key locations within the Refuge System, or monitoring water quality based on a specific threat.

A national water quality monitoring program for refuges should be designed to accommodate national-level assessments (status and trends for some constituents) for large scale (global) stressors such as climate change and atmospheric mercury deposition, as well as provide meaningful information to address site-specific water quality issues. Flexibility at the I&M administrative unit level in prioritizing water quality monitoring efforts and determining what to monitor will be important. The Refuge System will need to identify a network of national wildlife refuges for monitoring, using protocols developed by EPA National Aquatic Resources Survey (NARS). This will allow the Refuge System to contribute to the landscape-level assessments being conducted by the NARS program, and also allow us to make some comparisons/contrasts of water quality between the NWRS and national-level data (i.e., how do trends in water quality for NWRS wetlands compare to trends in water quality for wetlands at the national level?).

Both water quantity and quality can also be measured as responses to a changing climate. In order to adequately evaluate climate-induced impacts to NWRS water resources, water quantity and quality should ideally be assessed and monitored at both refuge level and landscape/watershed level scales. Such larger scale signals will be invaluable in detecting potential impacts to Refuge resources and identifying remediation opportunities. Again, identifying partners, particularly at the local watershed level in conjunction with the National Fish Habitat Action Plan, will be important in this regard. Some possible attributes/parameters to consider for monitoring refuge water resources to detect climate-induced changes (at key locations within the Refuge System, as selected by water resource programs) include water temperature, stream discharge and velocity, flow regimes, water table depth, water chemistry, and other constituents as determined by water quality specialists.

FIRE AND OTHER LANDSCAPE DISTURBANCE PROCESSES

Landscape responses to rapid climate change will be driven by “natural” disturbance processes including changes in the hydrologic regime (discussed above) and evapotranspiration, forest pest outbreaks (e.g., spruce bark beetle, gypsy moth), storm magnitude and frequency, and fire regime. Because fire (wild or prescribed) is one of the more significant habitat management tools in use across the Refuge System, we have promoted this change agent as one of the early foci during the early development of the I&M program.

Although the NWRSIA makes no specific reference to fire, it is undeniable that fire is essential ecological process and tool for managing the majority of the lands under NWRS stewardship. Fire at the wrong time and place also has a destructive side that plays out annually in local and national media coverage. The Refuge System now protects more than 75 million burnable acres (on more individual land management units than any other Federal agency) along with the associated NWRS facilities, surrounding communities and natural resource values. Many of these burnable acres are in small coastal and urban tracts along the East, West, and Gulf Coasts and in the Midwest, with extensive wildland-urban interface areas. Others are extensive, remote and difficult to access natural landscapes where few people live. The propensity for spreading fires to ignore ownership and jurisdictional boundaries despite active suppression efforts and to therefore conduct its ecological work on landscape and larger scales requires that refuge fire management be undertaken in a collaborative, inter-agency manner.

This long-standing interagency approach to wildland fire management was formalized in 1995 (and reaffirmed in 2001 and 2008) in the inter-agency Federal Wildland Fire Policy. Department of the Interior (620 DM 1) and Fish and Wildlife Service Policy (621 FW 1) further direct full use of wildland fire as a natural process and as a tool within the Refuge System. The Wildland Fire Leadership Council (WFLC) monitoring framework for National Fire Plan (NFP) implementation strategy (Module 2.1) identified the need to assess the environmental impacts of large wildland fires and identify trends in burn severity on all lands across the United States. In 2004, the GAO recommended that the Federal fire agencies collaborate to develop and implement comprehensive assessments of burn severity, to provide consistent summary information characterizing the environmental effects of wildland fires and meet the requirements of WFLC.

According to the Quadrennial [National] Fire Review (2009), the effects of climate change will continue to result in greater probability of longer and bigger fire seasons, in more regions in the nation. Already we have realized within the past five years: Shorter, wetter winters; warmer drier summers; and more extensive fires on the landscape.

> *"The future, under continued or accelerating climate change, holds more large wildfires persisting and possibly escalating in an irregular pattern termed "asymmetric fire". There is an expectation of potentially burning 10-12 million wildfire acres annually, nationwide over the next five years. Cumulative drought effects will further moisture-stress accumulating fuels, with the current drought cycle expected to last for another twenty years. Competition for water in ecosystems, continued problems with exotic invasive and insect kill, and faster drying of vegetation will make fuels more flammable and drive fire behavior."*

The Refuge System faces challenging decisions as climate changes, sea level rises and human development expands. Decisions about how to manage unplanned ignitions, and which vegetation treatments to apply where and when to best achieve habitat objectives, ecosystem health and services, and reduce hazardous fuels are costly and among the most mission-critical decisions refuge managers make. At some point, every refuge manager with burnable vegetation, confronted with warmer temperatures, lower fuel moistures, longer and more severe fire seasons will face difficult fire and fuels management decisions. Managers must consider many factors in deciding how to manage vegetative fuels and fire events. Monitoring to evaluate whether or not management decisions had the expected results is imperative.

Inventory and monitoring on refuges and their surrounding landscapes subject to periodic fire events, regardless of whether natural or anthropogenic in origin, requires sampling many attributes of both biotic (flora and fauna) and abiotic (soil, water, and air) environments across time and space, as well as observations about the fire (disturbance) events themselves. Therefore, the I&M program will need to include means for assessing biomass (fuel) quantity and distribution on refuge lands and the larger landscapes they are part of. Fortunately, several tools for describing or classifying fuels, and rapidly estimating fuel quantities (loading) in forms useful for predictive fire behavior and emissions models are already available and in use within the interagency wildland fire community. The I&M program will need to provide accurate recurring monitoring of current and historic fire regime attributes, fuel loading, structure and moisture, weather and climate, fire occurrence and characteristics, refuge facilities and surrounding communities and infrastructure, and to biotic and abiotic values at risk is essential to prioritize issues and tasks, and to take prescriptive actions.

Targeted monitoring of the fire environment (fuels, weather and topography) responsible for fire behavior is integral to all fire suppression (appropriate management response), and prescribed fire activities. In addition, through cooperation among Service programs and with the help of other natural resource managers, NWRS fire managers rely on fire-effects monitoring and research to help conduct on-going assessment and improvement of firefighting and fuels treatment effectiveness. Monitoring plant growth before and after fire occurrence or mechanical/chemical fuels treatment is necessary to assess the response of specific invasive species, as well as threatened and endangered plants, and adjust fire management activities to meet desired land management objectives. With the help of its partners, the Service is expanding the practice of monitoring and research within its fire management program.

Just as the NWRS has developed and integrated a fire program component, so to must fire and fuels inventory and monitoring goals, objectives, skills and capacity be integrated into the broader I&M program. The same spirit of inter-agency collaboration that was the hallmark of the wildland fire community provides a model for collaborating with partners for inventories and monitoring beyond the NWRS boundaries. Integrating fire ecology and management skills and elements into the program will provide valuable, sometimes life-saving information for a variety of audiences, from the field station level to the Department, and to partners in landscape conservation. Fire regime, fuels, and fire effects inventories, monitoring and assessments will be useful in all regions to identify threats and needs, prioritize work, and plan for future impacts to Refuge System resources.

CONTAMINANTS

Contaminant Assessment Process. The Contaminants Assessment Process (CAP) is a national program that provides a standardized approach for the Service to assess potential threats posed by environmental contaminants without and within the NWRS. CAP enables the Service to inventory point and non-point contaminant sources, identify areas of concern, and describe pathways of contaminant movement that might affect a refuge's natural resources. The CAP information can contribute to the refuge planning process, including Comprehensive Conservation Plan development.

CAP findings can provide the basis for management actions (such as more detailed investigations, cleanup actions or public outreach, including fish consumption advisories) that refuge managers can take to reduce contaminant impacts on the species and lands under their stewardship. These actions can also enhance health and safety for employees and visitors.

The CAP identifies potential pollution sources in the watersheds and airsheds of the Refuge System. These sources include transportation corridors such as highways, railways, or navigation channels that may be vulnerable to oil spills or releases of hazardous substances. This site-specific CAP information can support spill response planning, cleanup actions, and natural resource damage assessment, and restoration activities.

Other contaminant sources known to impact refuges include urban and suburban development, landfills, former military sites, mining sites, oil and gas operations, industrial discharges, shooting ranges, and confined animal feeding operations. Knowing the potential pollution sources, and types of contaminants associated with these sources, can provide a sound foundation for new Service monitoring efforts. In particular, this information should help shape I&M program decisions regarding sampling for contaminants and water quality parameters to ensure that the approach is germane to refuges with specific, known contaminant issues.

In 1996, the Service's Division of Environmental Quality and the USGS Biomonitoring of Environmental Status and Trends (BEST) Program developed a data management system to house CAP information, using readily available (but now dated) information technology. Region 3 recently conducted a retrospective evaluation of CAPs for its refuges. The overall conclusion was that, while CAP provides refuge managers with valuable information, there are some significant limitations due to the outdated data management system. In addition, Region 3 found that due to a static budget for Refuge Contaminant activities, there was little funding available to do follow-up studies and monitoring. Also, the data generally are narrative rather than quantitative, and the database is not designed to allow Regional or National searches. An informal survey of the other Service Regions yielded similar conclusions.

In 2010, the CAP database is scheduled for significant update and revision, including developing geospatial and search capability. This update is critical, as changes are needed to improve the database's function and utility for system users, including refuge managers and staff. During this process, the Refuge System should consider how CAP can integrate with other databases being developed for the I&M program in order for data to be useful for identifying refuge contaminant monitoring needs at the refuge, Regional, and National levels. The Refuge System might also consider investing some funding to enhance the capabilities of CAP. Once the suite of I&M databases are created, further CAP database development may be necessary to ensure proper integration among these systems.

Air Quality Biomonitoring. Atmospheric heavy metals are of increasing concern because they are widely dispersed, easily transported, and might cause chronic damage or stress to sensitive habitats or ecosystems. It is important to monitor and predict the change of atmospheric heavy metals by way of some handy and practical techniques. One of the most common methods to monitor atmospheric pollutants of heavy metals is via biomonitoring, especially using mosses and lichens as bio-indicators since they absorb pollutants through free ion exchange.

Biomonitoring methods can be divided into two groups: active and passive. Active monitoring includes the exposure of well-defined species under controlled conditions; passive monitoring refers to the observation or chemical analysis of indigenous plants. The ''moss bag'' technique is one of the active bio-monitoring methods. The absence of well-suited moss and lichen species living in arid or urban-influenced environments and the difficulty of choosing ideal sampling conditions for convenient area distribution encourage the use of moss-bag techniques to monitor trace metal deposition over large areas. Although the "moss-bag" method is not definitively standardized as regards the amount of plant material, exposure time, correlation to airborne depositions and form of uptake, it has the advantage of collecting information integrated over the whole exposure time, without being influenced by momentary changes in pollutants and is relatively inexpensive. The moss-bag method is based on two principles: (1) dead dried moss thallus preserves the capacity of absorbing metals and (2) concentrations of heavy metals in the moss bags correlate well with their atmospheric levels. Examples of recent investigations with moss bags are a study in Naples, Italy, (Giorgdano et al. 2005) and Shanghai, China, (Cao et al. 2009) where evaluations of spatial distribution of heavy metals were performed.

Implementation of a coordinated active-based air quality biomonitoring (AQB) effort on refuge lands could provide assistance in prioritizing management of limited Service resources and enhance legal and policy-making decisions in light of climate change issues. AQB efforts could also complement existing monitoring efforts underway on DOI lands by the Service's Bureau of Air Quality and be coordinated with its partners. Proposed AQB efforts on refuge lands could use the moss-bag techniques exposed at specific locations designated as high priority (i.e., Landscape Conservation Cooperatives or climate change vulnerable). Data collected from moss bags placed on refuge lands would need to be placed in a biological context to evaluate their significance. Ultimately, it is the magnitude of the impact, whether reduction in nest success, development of fish consumption advisories, or damage to an ecosystem, that determines whether a given pollution level is significant.

Monitoring of toxic air pollutants is needed to understand their spatial and temporal distribution and ultimately to minimize their harmful effects to refuge lands, particularly in light of exacerbations resulting from climate change. The task of monitoring airborne trace element pollution over large areas is somewhat arduous, since the concentrations of pollutants are variable in space and time. In addition, data from automatic devices are punctual and limited in number to describe spatio-temporal trends of pollutants. Furthermore, automatic devices generally only detect a limited number of pollutants (mainly CO, SO_x, N_xO_y, PAH and dust). In addition to direct physical and chemical methods of air pollution monitoring currently being conducted by the Service's Bureau of Air Quality and its partners, implementation of AQB can be used to evaluate and complement air pollution risks on Service lands, but on a larger scale to address more refuge lands.

WILDERNESS

The Wilderness Act of 1964 established the National Wilderness Preservation System and a process for Federal land agencies to recommend wilderness areas to Congress. Wilderness, as defined by the Wilderness Act, is relatively untrammeled (free from man's control), undeveloped, natural, and offers outstanding opportunities for solitude or primitive recreation. The Refuge System manages more than 21 million acres of Wilderness; about 22 percent of the National Wilderness Preservation System (NPWS) (106 million acres). Congressionally-designated Wilderness makes up 20 percent of refuge lands, including 75 areas on 63 units of the NWRS in 26 states. About 90 percent of Wilderness within the NWRS is in Alaska. The Refuge System administers the NWPS to secure an enduring resource of wilderness in coordination with the Bureau of Land Management, the National Park Service, and the Forest Service.

The Wilderness Act directs the Service to preserve wilderness character. Wilderness character encompasses biophysical, experiential, and symbolic components.   The Refuge System preserves wilderness character not only by maintaining and, where appropriate, restoring, biological integrity, diversity, and environmental health, but also by maintaining natural soundscapes. Furthermore, the Refuge System provides opportunities for risk, adventure, and a sense of connection to nature while also exhibiting appropriate management restraint.

In the near future, the Refuge System will determine how to incorporate the monitoring of Wilderness character into the I&M program, using Landres et al. (2005) as a guide. We will consider how to assess the provision of ecosystem services, ecological integrity, and the ecological role of Wilderness in sustaining ecological system in the surrounding landscape. Additionally, the Refuge System will consider using designated Wilderness areas to track environmental changes that result from climate change (Scott et al. 2008). Selected wilderness areas should be considered as priority locations to institute baseline inventory work and long-term monitoring. The larger, more intact wilderness tracts would be key elements in the 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.

Research Natural Areas. Wilderness designation can also be a constraint on many types of monitoring because of the Minimum Requirements Analysis (e.g., helicopter access). The more intrusive types of monitoring (and research), particularly of disturbance processes such a fire, may best be measured at Research Natural Areas (RNAs). RNAs are part of a national network of reserved areas (but not designated Wilderness) under various Federal ownerships where "natural processes are allowed to dominate and management is designed to preserve a given ecosystem or feature." They are cataloged by the Federal Committee on Ecological Reserves. RNAs receive no special legislative protection other than that which the agency provides. NWRS policy (8 RM 10.1) states that, "RNAs must be reasonably protected from any influence that could alter or disrupt the characteristic phenomena for which the area was established." Activities on RNAs are limited to research study observations, monitoring, and educational activities that are non-destructive, non-manipulative, and maintain unmodified conditions. There are 207 RNAs on 97 national wildlife refuges in 43 states, totaling 800,000 hectares.

Research Natural Areas (RNAs) may be a useful mechanism for establishing living vouchers. The WH8.1 Baseline Inventory Team specifically recommended the establishment of living vouchers:

> *On each refuge, permanent representative (i.e., "living voucher") plots need to be established and maintained within each Alliance. A national botanical team representing each Region should develop a standard protocol for identifying, mapping, and maintaining the "voucher plots" and determining the number appropriate for each Alliance. Identification of these plots would be done concurrently with the vegetative mapping.*

The recognition of rapid climate change makes this recommendation even more salient. However, given the expectations of species redistributions in response to rapid climate change, it may not be necessary or even possible for every refuge to maintain a living voucher. Rather, representative plots of each Alliance that occurs within the Refuge System should be identified within predicted climate refugia on refuges. Furthermore, RNAs could be "re-created" to serve as sites to measure and monitor disturbance regimes, establish baseline conditions for archetypal plots representative of habits within ecoregions, to conduct complete (exhaustive) species inventories, and conduct integrated research. In a rapidly changing climate, RNAs could be distributed among refuge units over two strata: areas that are predicted to remain the same (i.e., refugia) and those that are predicted to have extremely dynamic climatic niches with uncertain outcomes.

III. CROSSCUTTING CONSIDERATIONS AND APPROACHES

CLIMATE UNCERTAINTIES – IMPLICATIONS FOR THE NWRS I&M PROGRAM

BIOLOGICAL INTEGRITY, DIVERSITY AND ENVIRONMENTAL HEALTH

The I&M program should be truly national in scope, of the highest scientific caliber, and help the Service lead in developing approaches to inventory and monitoring biological integrity, biological diversity, and environmental health. There is a strong potential to develop a partnered program that leverages the sampling efforts of three existing Federal monitoring programs that have national sample frames. The USDA Forest Inventory & Analysis Program (FIA), EPA National Aquatic Resource Surveys (NARS), and the NRCS Natural Resource Inventory (NRI) employ national sampling frames that are nested within our

Geographic Areas and could be extended to embrace the Refuge System. We recommend that I&M program staff consider such a framework, and salient attributes of the existing Federal I&M programs are summarized below.

The NRCS NRI, EPA NARS, and USDA FIA all employ hierarchal grid-based designs that are truly national in scope (Magness et al. 2010), but are restricted to the resources they are mandated to monitor. The FIA samples only forested (albeit some rangelands) P2 and P3 plots; the NARS samples 1,000 plots each in wetlands, coastal, lakes, and stream/rivers; and the NRI samples non-Federal lands that are mostly agricultural. However, the three programs cumulatively invest ~$100 million annually to monitor multiple metrics of multiple resources nationwide. A creative, well-designed I&M program for the Refuge System could leverage the data already being acquired by one or all of these programs. Indeed, the Bureau of Land Management has partnered with the NRI and FIA in their Assessment, Inventory, & Monitoring (AIM) project to monitor terrestrial indicators, and the Kenai National Wildlife Refuge has partnered with the FIA to complete perhaps the most comprehensive and rigorous inventory of species occurrence in the Refuge System (Morton et al. 2009, Bowser et al. 2009). We would restrict more intensive sampling of ground plots to within refuge boundaries. However, by ensuring that our sampling design can be nested within, and field protocols are consistent with, other national programs, the Refuge System could demonstrate how other conservation agencies could similarly partner, leading the way to assessing change in species distributions and richness at the continental scale.

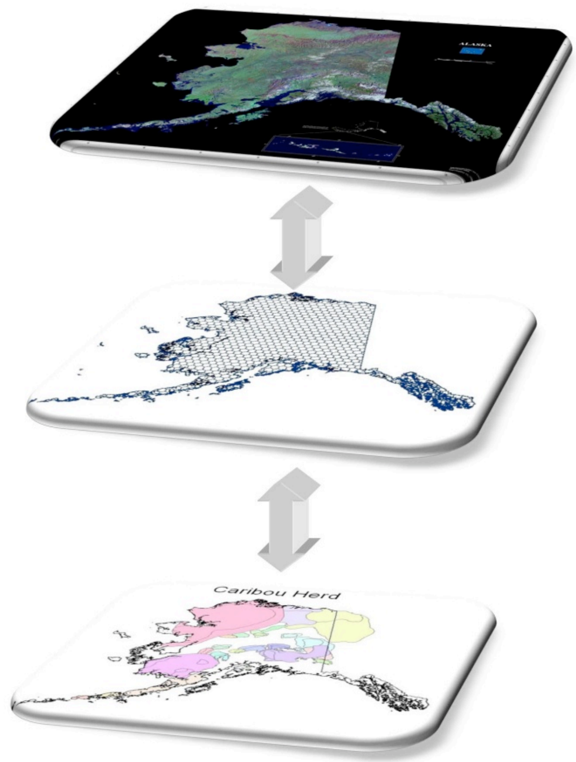

Figure 6. Conceptualization of the relationships among I&M components at different spatial scales using Alaska as an example: (1) at the most extensive spatial level, remote sensing is the primary I&M tool; (2) a spatially-based national sample frame provides estimates of occupancy for selected assemblages of vertebrate, vascular plant, and invertebrate species; and (3) at the local scale, telemetry and aerial surveys are used to estimate caribou abundance and demographic parameters, as well as key environmental factors.

The primary field-based monitoring metrics would be the (1) distribution and composition of selected assemblages of vertebrate, vascular plant, and invertebrate species (including invasive species) in terrestrial and freshwater systems; and (2) water quality and quantity. The monitoring objectives (and subsequent sampling design) would be scaled to detect changes in the NWRS at System-wide and Geographic Area scales, while ensuring that we account for the contribution of the Refuge System to the condition of resources at a truly national scale (as measured by NARS, FIA or NRI and through the application of NASA, NOAA and USGS remote-sensed imagery).

Conversely, individual refuges could choose to scale down I&M to the local level, either by increasing sample plot density or by employing similar field protocols when surveying off the national sampling frame. Species assemblages and other metrics would be selected based on criteria as indicators of biological integrity, diversity, and environmental health. We would consider the use of ecological indicators to justify management actions and to measure and communicate progress; and the use of composite or multi-metric indexes and other methods to assess ecosystem condition (Meretsky et al. 2006). This design option would ensure that the I&M program has the potential to collect relevant and comparable data at refuge, Geographic Area, and Refuge System scales.

SPECIES DISTRIBUTION MODELS

Species distribution models describe a relationship between species occurrence and environmental layers in order to extrapolate across unsampled portions of the landscape. These models provide the landscape context for adaptation planning. Within the past decade, the number of tools available to develop species distribution models has rapidly grown. Traditional statistical approaches are useful to test conceptual models of the factors that influence species distributions. New algorithmic approaches adopted from data-mining and machine learning applications in other disciplines produce models with outstanding predictive capability. In the context of climate change, species distribution models, whether produced from data model or algorithmic approaches, can greatly inform both planning and ecological monitoring by providing:

- accurate predictions of current single- and multi-species distributions with accuracy assessments, which are necessary to understand landscape context for adaptation planning;
- exploratory analysis of landscape drivers as a first step to formulating well-designed studies of mechanisms needed to develop effective adaptation plans;
- confirmatory analysis of landscape drivers that can reduce uncertainty in proposed adaptation plans;
- future projections of multi-species distributions under climate change scenarios, which are useful for developing hypotheses about future conditions and design adaptation strategies;
- vulnerability assessments based on current distributions and potential distributional change, which can help prioritize areas and species to target for facilitated adaptation, or to guide strategic growth of the Refuge System ;
- identification (even monitoring) of range expansions or contractions for multiple species using species occurrence data collected at future time steps; and
- information for developing future monitoring priorities (where, when, and how to survey).

However, making on-the-ground management or even planning decisions based on species distribution models requires a high degree of confidence in those model outputs. Good spatial models can only be built with relevant empirical data that are collected rigorously at appropriate spatial scales.

SEA-LEVEL RISE MODELING

Sea-level rise is one of the most pressing climate change issues facing coastal and some insular national wildlife refuges. Sea levels in the next 100 years will likely rise 0.18-0.59 meters above current levels (IPCC 2007). The Refuge System includes two 1,000-mile long archipelagos, expansive estuarine systems from above the Arctic Circle to remote, coral reefs and tropical lagoons below the Equator. Coastal and marine holdings within the Refuge System include ~30,000 coastal miles across 61 million coastal acres, with tidally-influenced lands totaling 7 million acres. Coral reefs within the Refuge system encompass almost 5 million acres. The Refuge System co-manages the 89-million-acre Papahānaumokuākea Marine National Monument in Hawaii; Refuge System holdings within the recently-designated Pacific Remote Islands, Rose Atoll, and Marianas Trench Marine National Monuments include 53 million acres of submerged lands in the central and western Pacific .

Understanding the potential impacts of sea-level rise to coastal, estuarine, and insular habitats is essential to management and long-term planning for the affected refuges and for the Refuge System as a whole. The Sea Levels Affecting Marshes Model (SLAMM) was developed to help predict the possible effects of various levels of sea rise on coastal marshes and adjacent lowland areas. This model uses National Wetland Inventory (NWI) data plus information on local topography, accretion and erosion rates, dikes, and development in making these predictions. SLAMM has been run for a few large estuaries, including Puget Sound, Chesapeake Bay, and Delaware Bay, and for numerous national wildlife refuges along the Atlantic, Gulf, and Pacific Coasts.

Several reasonable sea-level rise models have been developed; SLAMM has been completed for approximately 80 coastal refuges to date. Consequently, we advocate completion of SLAMM for the remaining 60 or so refuges for comparative purposes; the Operational Blueprint includes recommendations for completing this task as an initial priority. This may require updating the NWI and obtaining high-resolution digital elevation data for some refuges. The I&M program should coordinate with the other Service programs and partners to address these needs. Lastly, refinement of sea-level rise models, including SLAMM, is needed and ongoing work to do so should be supported.

ADAPTIVE MANAGEMENT

Adaptive management (AM), in which systems are closely monitored and management strategies altered to address expected and ongoing changes, is one of the most important tools for managing ecological systems in the face of climate change and other stressors. The I&M program will need to embrace AM and provide the support and training needed at the field, geographic area, Regional, and National levels to employ it. The I&M program must be relevant to the management needs of the Refuge System. AM is an essential tool for managers; thus it is the link between monitoring and management that the I&M program will need to be successful.

Recent scientific and agency white papers that evaluate the risks to species and ecosystems from climate change all call for AM as a primary tool for evaluating climate change adaptation efforts (Mawdsley et al. 2009; Scott et al. 2009; U.S. Department of the Interior 2009b). Strategic Habitat Conservation (SHC), which will be implemented by the LCCs, is landscape scale AM, with a focus on conservation design. Therefore, the basic steps of AM have already been embraced by the Service leadership and AM will be a central tool for the LCCs in implementing SHC.

Conservation design is only one type of management issue; there are many other issues that a land management agency like the Refuge System needs to address to help it adapt to climate change, including evaluating the efficacy of alternative management strategies. Nearly all forms of adaptation to climate change involve setting management objectives, delivering management on the ground, and evaluating progress towards meeting those objectives, e.g. AM. The monitoring component of AM, usually referred to as targeted monitoring, is perhaps the most frequent type of monitoring conducted by NWRS field stations and is the most resource-intensive component of the AM process (Holthausen et al. 2005; Nichols and Williams 2006; Sauer and Knutson 2008). All but the simplest forms of monitoring require protocols, sampling designs, documentation, data management, and reporting (Laskowski et al. 2008). If widely employed across the Refuge System, targeted monitoring under AM has the potential to improve the quality, efficiency, and transparency of management decisions.

AM will be an essential tool in addressing any issues arising from other I&M Program components (water resources problems, declines in plant and animal populations, invasive species problems). AM will help the Refuge System conserve species and ecosystems across the nation, minimize species extinctions, and help the System and its partners learn as rapidly as possible which adaptation strategies are most effective and efficient. Through targeted monitoring of species and ecosystems, the Refuge System can contribute to vulnerability assessments and provide an early warning of impending ecosystem changes and effects on high priority resources (Lawler et al. 2009).

A workforce must be developed with the technical skills to implement AM along with the associated monitoring. Such staff should be stationed in proximity to the field stations they will support. The I&M program can play an important role in making this happen. Currently, the Refuge System has little infrastructure for supporting stations engaged in targeted monitoring and AM, other than training through the National Conservation Training Center (NCTC) and a small pilot effort in R3 and R5 (Biological Monitoring Team). Work by the Regional refuge biologists, staff from the various Joint Ventures, National air and water quality specialists, and Regional fire ecologists to help stations identify priority CCP and HMP objectives has laid the foundation for AM across the Refuge System. Partner and interagency programs (e.g. interagency fire community, NPS Vital Signs Network, NRCS CP33 program, etc.) have AM tools and resources to share, but these are underutilized by most field stations. The I&M program will support the monitoring component of AM on Refuge System units as well as summarize and report how the Refuge System and partners are using AM to help species and ecosystems adapt to the threat of climate change and other stressors.

Targeted monitoring under AM is flexible in terms of the resources and expertise needed to implement it. Three tiers of AM that cover the full spectrum from simple to complex, which are currently employed within the Refuge System, are defined as:

- Tier 1 (Passive AM – low intensity monitoring). This is the simplest form of AM and is designed to determine if individual refuges are achieving their specific wildlife, habitat, and ecosystem objectives developed through CCPs or HMPs. Monitoring to meet these objectives documents how each refuge is meeting its purposes, maintaining biological integrity, diversity, and environmental health, and contributing to the Refuge System mission. All stations should be monitoring achievement of their CCP/HMP objectives at this basic level.
- Tier 2 (Passive AM – intensive monitoring with implications at the landscape scale). The highest priority CCP/HMP objectives require more intensive monitoring to provide definitive documentation of management outcomes. High priority objectives tend to address primary refuge purposes, management of high priority species, or the maintenance/restoration of BIDEH on Federal, State, and private lands. Monitoring at this level is highly quantitative, employs standardized protocols and databases, and involves a single refuge or a group of refuges and partners united by their need to manage similar habitats or priority species. With this level of monitoring, it is possible to evaluate effects of climate change (vulnerability) on one or more refuges and the surrounding landscape and also determine how to adapt to these effects.

- Tier 3 (Active AM – intensive monitoring). When there is high uncertainty about the outcomes of management actions, high risks to conservation targets, high costs of management, or public controversy regarding management actions, a more rigorous application of AM is needed to speed learning. At this level, AM involves one or more refuges and other conservation partners with similar conservation issues that collectively contribute to the management of high priority resources. Hallmarks of active AM include consideration of multiple models that represent different types of management uncertainty and multiple management options (Lyons et al. 2008). Tier 3 AM is being tested in a number of projects conducted in cooperation with USGS in Regions 3, 4, 5, and 6.

All forms of AM differ from simple trial and error in that each step in the AM process, including the monitoring, is clearly defined, consistently implemented, documented, and linked to the management objectives (Williams et al. 2007). The essential step in all three tiers is to use the monitoring information to learn and to adjust future management based upon this learning (Walters and Holling 1990). In Tiers 1 and 2, the focus is on management rather than on learning; in Tier 3, there is a stronger focus on learning (reducing uncertainty) while management still remains the primary focus. In contrast, research is focused primarily on learning, not on management.

Depending upon the level of uncertainty associated with management outcomes, monitoring under AM can range from simple ocular estimates and field tour evaluations (Tier 1) to intensive monitoring (Tiers 2 & 3). At a minimum, all stations should be able to accomplish passive AM (Tiers 1 & 2), given adequate staffing. Optimally, a full cadre of staff with a range of technical skills should be available in each LCC and resources provided to the field to plan, manage, collect, archive, and report the monitoring information associated with AM. Stations will need significant technical assistance with Tier 3 AM. Field-based I&M staff with skills in structured decision-making and adaptive management can help stations clarify management issues and develop the framework for targeted monitoring to reduce management uncertainty.

Documentation is an essential component of AM needed to support projects over time and help communicate the purposes and outcomes of various projects. Where appropriate and available, standard protocols and procedures for documenting project information and monitoring data, along with QA/QC procedures will be developed. Some of these tools are already available from various sources (internal and external to the Refuge System).

AM is a foundational tool needed for resource management today. The need for AM will only grow as climate change adds more uncertainty to management decisions. Monitoring, and the associated protocols, sampling designs, documentation, data management, and reporting are essential components of AM. The I&M program has a major role to play in supporting targeted monitoring under AM. The *Operational Blueprint* calls for additional staffing within the I&M program at Regional and field levels to support AM, and development of training classes at NCTC.

RELATIONSHIP TO OTHER USFWS PROGRAMS AND PARTNERS

In a world in which refuges are increasingly impacted by events and processes outside their boundaries, there is a need to coordinate and partner with other agencies and monitoring programs to address resource issues that transcend Geographic Areas, even at continental scales.

At the national level, the I&M program will work to leverage the inventorying and monitoring conducted by other DOI agencies (National Park Service, US Geological Survey, Bureau of Land Management, and Bureau of Indian Affairs), USDA agencies (Forest Service and Natural Resource Conservation Service), Environmental Protection Agency, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, and the National Science Foundation. From the onset, we will seek formal collaboration with the NPS Inventory and Monitoring Program on objectives and information needs, and to learn and benefit from this Program's many successful initiatives.

We will support other existing Service programs that collect data which contribute to the information needs of the NWRS such as the National Wetlands Inventory and Mid-Winter Waterfowl Survey. We will evaluate, and where appropriate, expand support of existing monitoring programs that have provided long-term data with proven management value such as the North American Breeding Bird Survey, North American Amphibian Monitoring Program, and Global Coral Reef Monitoring Network. New national and international monitoring programs that are being developed to specifically address climate change will also be considered including the USA National Phenology Network, Circumpolar Biodiversity Monitoring Network, ReefBase, and the National Ecological Observatory Network. New partnerships with NASA, NOAA, and USGS will bring current and past imagery and data products from the Nation's civil satellite remote sensing programs to bear on the challenge of monitoring at continental to landscape scales. Lastly, at regional and field levels, we will work closely with the LCCs, the Joint Ventures, the two HAPET offices, regional partners within the National Fish Habitat Action Plan, Partners for Fish and Wildlife, Coastal Programs, and State Natural Heritage programs. Collectively, these new partnerships will benefit refuges by providing better coordination of conservation planning and monitoring, and ensure that data collected by the I&M program have relevance at larger spatial scales than we have traditionally considered.

IV. DATA AND INFORMATION MANAGEMENT

OVERVIEW

The NWRS will ensure the long term integrity of inventory and monitoring data and provide easy to use systems for entering, retrieving, analyzing and reporting the data. A robust data management system is particularly important for the success of a nationally coordinated I&M program where the lifespan of a dataset may extend across the careers of many scientists. Our success in the face of climate change and other stressors, will be realized when we can provide timely, reliable data that meets our needs and can be understood, interpreted and helpful to our partners.

The I&M program will make a strong commitment to data management and provide the necessary resources to ensure our data assets are synthesized and turned into useful information for resource managers and partners. Data management is everyone's responsibility and not just the job for the technical staff that design and maintain database applications. The Refuge System must not allow valuable legacy data to sit isolated in file cabinets or stand alone database systems while landscape conservation cooperatives (LCCs) are assembling datasets to be used for biological planning and conservation design. We cannot afford to deliver an infinite amount of information; data must be relevant and in forms that are useful to scientists and resource managers. Refuge System information will be shared and leveraged in as many ways as possible in order to maximize its value while diminishing its overall cost.

The national I&M office will store and make available all data received in a manner which strives to meet client needs. A common task in data-analysis is "reshaping data" -- getting the data in a format necessary for analysis or summary. Often data is stored in a database that is optimized for data collection (not analysis), and usually resembles the field data collection form. These project (template) databases are an important part of the data collection, but they do not constitute data management. The data must be "melted" together to allow scientists and managers the ability to reshape it in a form they can use. At the national level, the main focus will be on developing on demand data services that can dynamically assemble various data components into usable formats for scientists and resource managers. At geographic areas, data management tasks will focus on data collection, quality control, and aggregation of data.

Efficient communication, document management and technical support strategies will be vital for success. The national office staff will design and maintain web pages with a consistent look and feel and provide templates for geographic areas to maintain their individual pages. The internet will be one of the primary communication tools for the I&M program. The national office will immediately establish and maintain an easily accessible central repository for I&M documents. It will be crucial for I&M field staff to have a "one stop shop" for accessing the most current version of user guides, I&M guidance, data standards, and field protocols. A technical support help desk will be established to provide assistance to I&M field staff and those who "consume" the information we generate.

DATA MANAGEMENT GOALS

1. Database products and associated applications sponsored by the I&M program are thoughtfully designed and meet the business needs of the Refuge System.
2. Data management systems sponsored by the I&M program are secure, transparent, and designed for interoperability to promote data sharing with others.
3. Data standards and protocols are developed, used, and shared by the I&M program.
4. Documentation (metadata) is created and maintained for all database products, models, and tools developed by the I&M program.
5. The I&M program collaborates with others in the development of data standards and efficient processes for data storage, exchange, and dissemination.
6. Data quality, ownership and accountability (governance) for data assets generated by the I&M program are established and clearly defined.

INFRASTRUCTURE AND SYSTEM DESIGN

Rapidly changing technology, bandwidth limitations, legacy systems, and the nature of our decentralized organization will present challenges in managing the information generated by the I&M program. Scalability and flexibility in system design will be important requirements as the I&M program will certainly evolve. A Service Oriented Architecture (SOA) will be the principle system design philosophy. SOA is recommended by DOI as a "best practice" and is being employed by the NPS Inventory and Monitoring Program. SOA is simply a collection of services that can communicate with each other using standard industry protocols. A service has a well defined function and is reusable, sharable, and independent in regards to the context and state of other services. These services become dynamic data building blocks that can be shared and assembled in many ways, even if their systems are substantially different. Some example services could include Corporate Master Table, Taxonomy, Endangered Species, Reference/Metadata, Voucher collections, User Identity/Security, and Biological Observations. SOA maximizes information system investments and will promote the sharing of systems and information across agencies and organizations. SOA provides set of principles or governing concepts used during phases of integration and systems development. The I&M program will embrace SOA and work with the NPS and others to identify opportunities for data exchange.

Overall management of the infrastructure (hardware/software) for the national office and LCCs will be centralized. A centralized approach will be more efficient, secure and save resources. NWRS I&M data management personnel at both the national and geographic area offices (LCCs) can spend less time maintaining hardware and more time devoted to database design, documentation and the development of data standards. Remote access capabilities will be established and available for geographic areas to use for database administration tasks and queries. Additional infrastructure capacity may eventually be necessary at geographic areas with demonstrated needs.

The location of our infrastructure will be at the Denver Federal Center. The Denver Federal Center data center is one of only two places in DOI that offers a direct connection to all other DOI bureaus. This site is at the edge of the network which enables high-speed access to other agency servers like NOAA, USDA, and EPA. Because it's also a remote access hub for DOI, it's where internet service provider (ISP) connected Service field offices and remote access users "land" and access our network. Systems in this data center enjoy the benefits of common physical and system security controls resulting in less paperwork and easier Security Certification and Accreditation (C&A). Support agreements will be established with the Division of Information Resources & Technology Management (IRTM) to maintain our information technology (IT) investments.

The national I&M office data management staff with assistance from the geographic area data managers will assess existing national, regional and LCC infrastructure and IT capacity and leverage resources where appropriate. Looking outside the Service is also critical. The NPS has devoted significant resources to the development of an integrated data management system using SOA. The NPS Integration of Resource Management Applications (IRMA) project provides an example of a similar data management effort. We may greatly benefit from products developed by IRMA as well as lessons learned from system designers. It will be important for the I&M program to establish functional application development teams which will include data managers, business or functional analysts, application developers, programmers and user acceptance teams to fully account for user needs. The data managers will assess the scope of each I&M project and determine exactly what data will be produced and how it will be incorporated into the various services. The business or functional analysts identify user needs and translate these into system requirements. The developers and programmers then focus on building applications and interfaces that meet the user requirements. User acceptance teams will independently and objectively test applications, report bugs and identify problems that need attention.

The DOI has established software standards and enterprise licensing agreements in place for Microsoft and Environmental Systems Research Institute (ESRI) software products. Therefore, the initial recommended database management system (DBMS) is Microsoft SQLServer 2008. For application development the use of .NET Visual Studio environment using C# as the programming language is recommended (used by the NPS IRMA project for application development). ESRI software products are compatible with this robust DBMS and will provide the required geospatial requirements demanded by I&M tasks.

DATA STANDARDS

Data standards are formal agreements on the representation, format, and definition of data. They are fundamental to the seamless exchange of data. Standards enable us to share information with our partners and allow them to understand, interpret and use these data appropriately. It is imperative that standardized, peer-reviewed, approved field collection protocols and data standards are determined before any major I&M data collection efforts begin. Having standardized datasets makes it much easier to generate metadata, automate processes, perform analysis and rapidly develop applications.

The I&M program is not going to reinvent the wheel and will look internally and externally for standardize practices in the data and information management arena. Existing data standards developed by the Service and others such as the Federal Geographic Data Committee (FGDC) metadata standards, Global Biodiversity Information Facility (GBIF; www.gbif.org), and the Integrated Taxonomic Information System (ITIS) will be used. A list of existing data standards required by the Service can be found at (https://intranet.fws.gov/region9/data/standards/index.html).

The recent effort by the USFWS Cadastral Working Group is an example of how the development of data standards facilitated sharing of waterfowl production area (WPA) boundaries to the public. This team comprised of individuals from each region worked together to identify standards for developing NWRS boundary data layers. Each region was responsible for producing these geospatial datasets independently and, once completed, the standardized data were then able to be merged together and dynamically displayed in landscape level web mapping application.

A team approach to data standards which includes participation from all regions is vital for I&M program success. Therefore, data management staff from the national office and geographic areas will immediately form a National I&M Data Standards Team to identify and develop standards for I&M project priorities. This team will use internet based collaboration tools along with periodic face to face meetings to accomplish their tasks. As data standards are developed and adopted by the I&M program, national office staff will formally submit the standards using IRTM guidelines.

Simply establishing data standards aren't a guarantee of success. The standards must be incorporated into the database design and need to be enforced through "chains of accountability" with "ownership" of data clearly established. Data governance must be employed to ensure the important data assets we generate are consistent, accurate, complete, accessible, protected and efficiently managed. A Data Governance Team will be established to provide the framework necessary to promote confidence in the use of our data for decision making purposes. Establishing and implementing data governance will require active participation from key national and regional technical staff and will include membership from NWRS leadership and at least one biometrician.

V. SUMMARY

The Refuge System has a unique opportunity to develop a nationally-coordinated I&M program to not only serve traditional refuge needs, but to help lead the way in providing information that is relevant to adapting to climate change. With an infusion of $12 million in FY2010 and the potential for another $8 million in FY2011, we have outlined the organizational structure and initial staffing with 58 FTEs in FY2010, with details articulated in the Addendum to the Strategic Plan. Data management is recognized as a significant component of this program from the onset. We recognize both the need and the potential for ultimately growing this program to 280 FTEs with a $100 million annual budget.

We identified the following foci for early consideration during development of the I&M program: abiotic resources, biotic resources (including biological diversity, populations of priority species, vegetation inventories and mapping, genetic diversity, wildlife health, and phenology), invasive species, water quality and quantity, fire and other landscape disturbance processes, contaminants, and Wilderness character. The Operational Blueprint, a companion to this document, further recommends initiating (during the first two years: 2010-2011) abiotic resource inventories; design of inventories of biological diversity, assessing status and trends of priority species, invasive species, and water quality and quantity; assessing impacts of climate change on fire regimes; and assessing vulnerability of coastal refuges to sea level rise. Some of these components are promoted as "pilot studies" in the Operational Blueprint to avoid missed opportunities and redundancy of I&M efforts by other agencies and to provide information needed to guide development and refinement of methods and future programmatic direction. Resources of NWRS lands and waters in Alaska and in the Pacific Ocean are recognized as particularly difficult to inventory and monitor for logistical and, consequently, financial reasons.

In addition, we identified several considerations and approaches which are crosscutting in nature and crucial to the long-term success of the I&M program. Through pilot studies, we recommend a cost-benefit analysis of potentially partnering with three national I&M programs (USDA FIA, NRCS NRI, and EPA NRCS) to leverage their data as a means for assessing biological integrity, diversity and environmental health of the Refuge System. Spatial modeling is advocated as a useful tool for assessing landscape-scale changes in species distributions, predicting refuge vulnerability to climate change, and stratifying I&M efforts on refuges within Geographic Areas. We recommend a strong commitment to adaptive management to evaluate climate adaptation strategies from individual refuge to appropriate landscape scales. Finally, we emphasize the importance of working collaboratively with other Service programs, with other Federal and State agencies, the Joint Ventures and other conservation partners in further defining the questions to be answered through inventories and monitoring.

VI. PLAN CONTRIBUTORS

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VII. ADDITIONAL INFORMATION

The I&M Core Team produced draft white papers fully describing the rationale, need, and specific recommendations for several tasks identified in the *Operational Blueprint* (the topics include invasive species; water, abiotic, and biotic inventories; fire ecology; spatial modeling; adaptive management; and data management). These white papers are available to those interested in more information and team recommendations regarding these tasks.

[1] Environmental Protection Agency, [2]National Aeronautics and Space Administration, [3]USA National Phenology Network

VIII. GLOSSARY

Term	Definition
Adaptation	Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC 2007).
Adaptive management (AM)	Adaptive Management is a decision process that promotes flexible, informed decision making and that allows adjustment as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decision making, more efficient management and other enhanced benefits. It helps meet environmental, social, and economic goals; increases scientific knowledge; and reduces tensions among stakeholders (Williams et al. 2007).
Adaptive management, active	Active adaptive management is an approach whereby managers, when faced with uncertainty, implement more than one alternative to see which will best meet management objectives. It is characterized by "actively probing" the system in order to distinguish between competing hypotheses (where the different hypotheses suggest different "optimal" actions) (Walters 1986).
Adaptive management, passive	Passive adaptive management is an approach whereby managers, when faced with uncertainty, implement the alternative they think is 'best' with respect to meeting management objectives, and then monitor to see if they were right, making adjustments if desired objectives are not in fact met (Walters 1986).
Comprehensive Conservation Plan (CCP)	A document that describes the desired future conditions of a refuge or planning unit and provides long-range guidance and management direction to achieve the purposes of the refuge; helps fulfill the mission of the Refuge System; maintains and, where appropriate, restores the ecological integrity of each refuge and the Refuge System; helps achieve the goals of the National Wilderness Preservation System; and meets other mandates (602 FW 1, 603 FW 2, 620 FW 1).
Functional analysis	The process of identifying stakeholders, interviewing users, documenting user information needs and translating those needs into the specific requirements a system needs to meet.
Hydrogeomorphic Analysis (HGM)	A method of assessing ecosystem condition and ecological processes at a site to evaluate departure from historic conditions, identify restoration and management options, and identify ecological attributes needed to restore specific habitats.
Integrated Taxonomic Information System	Easily accessible database with reliable information on species names and their hierarchical classification. The database is reviewed periodically to ensure high quality with valid classifications, revisions, and additions of newly described species. The ITIS

Term	**Definition**
(ITIS)	includes documented taxonomic information of flora and fauna from both aquatic and terrestrial habitats
Invasive Species	Alien species whose introduction does or is likely to cause economic or environmental harm, or harm to human health. Alien species, or non-indigenous species, are species that are not native to a particular ecosystem. The Refuge System is prohibited by Executive Order, law, and policy from authorizing, funding, or carrying out actions that are likely to cause or promote the introduction or spread of invasive species in the United States or elsewhere (620 FW 1).
Inventory	A survey that documents the presence, relative abundance, status, and/or distribution of abiotic resources, species, habitats, or ecological communities at a particular time (U.S. Fish and Wildlife Service 2009).
Monitoring	A survey repeated through time to determine changes in the status and/or demographics of abiotic resources, wildlife or plants, habitats, or ecological communities. Two major types of monitoring are surveillance monitoring and targeted monitoring; they address different kinds of management objectives (U.S. Fish and Wildlife Service 2009c).
Monitoring, surveillance	Monitoring that is not tied to specific predictions of how a resource will respond to management or environmental stressors but rather is designed to document the status or change over time of a station resource. Examples include monitoring climatic parameters, species population trend over time, disease incidence, contaminants, or wilderness character (U.S. Fish and Wildlife Service 2009c).
Monitoring, targeted	Monitoring to assess whether a natural resource responds to a specific management action or system stressor in a previously specified manner ('target'). This type of monitoring involves defining the expected response, then surveying to measure the response or a closely related indicator. Comparing monitoring results with target values identified in the management objectives may indicate the need for a further management response. In this policy, it generally means monitoring in an adaptive management context to improve management or evaluate progress towards achievement of management objectives (U.S. Fish and Wildlife Service 2009c).
Priority species	Species that are the focus of management and conservation by the NWRS. These may be species identified in laws or policies (trust species) or species identified through the Strategic Habitat Conservation framework (U.S. Fish and Wildlife Service 2006, 2008).
Resilience	The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change (IPCC 2007).
Station or Refuge	Any unit of the National Wildlife Refuge System, including wetland management districts and waterfowl production areas, other than coordination areas.
Strategic Habitat Conservation (SHC)	An approach to habitat conservation focused on providing landscapes capable of sustaining trust species populations at prescribed levels. This approach is founded on a science-based, adaptive, iterative process of biological planning, conservation design, conservation delivery, and monitoring and research (U.S. Fish and Wildlife Service 2006, 2008).

Term	Definition
Structured decision making (SDM)	An approach to decomposing and analyzing decisions to identify solutions that achieve the desired objectives, in a manner that is explicit and transparent. Based in decision theory and risk analysis, SDM is a concept that encompasses a very broad set of methods, not a prescription for a rigid approach for problem solving. SDM provides clear roles for stakeholders and scientists when working on problems at the interface of science and policy. Key SDM concepts include making decisions based on clearly articulated fundamental objectives, dealing explicitly with uncertainty, and responding transparently to legal mandates and public preferences or values in decision making; thus, SDM integrates science and policy explicitly.
Survey protocol	A description of the survey method sufficiently detailed to allow someone unfamiliar with the protocol to learn why the survey is being done, what personnel and technical skills are needed to implement the survey, the timing and nature of the data collection procedures, and how the data will be analyzed, reported, and interpreted. Survey protocols assure continuity of quality data collection techniques for both the duration of the survey and between similar surveys on different stations (U.S. Fish and Wildlife Service 2009c).
Vulnerability	The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and it adaptive capacity (IPCC 2007).

IX. LITERATURE CITED

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