U.S. Fish & Wildlife Service

Planning for Climate Change on the National Wildlife Refuge System

PLANNING FOR CLIMATE CHANGE ON THE NATIONAL WILDLIFE REFUGE SYSTEM

ABOUT THIS DOCUMENT

This document originated in 2008 as a collaborative project of the U.S. Fish and Wildlife Service (FWS) and the University of Maryland's Graduate Program in Sustainable Development and Conservation Biology. The original title was *A Primer on Climate Change for the National Wildlife Refuge System.* The *Primer* has evolved into *Planning for Climate Change on the National Wildlife Refuge System* in response to DOI and FWS mandates. In particular, *Planning for Climate Change* is a *Conserving the Future* deliverable. The purpose of *Planning for Climate Change* is to help Refuge System planners and managers fulfill DOI and FWS mandates to incorporate climate change considerations into planning documents.

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Collaborators since the 2008 project have included the U.S. Geological Survey (including the National Wetlands Research Center), U.S. Forest Service (including the Rocky Mountain Research Station), USA National Phenology Network, University of Arizona, South Dakota State University, Biodiversity Research Institute, Colorado State University, and National Oceanic and Atmospheric Administration. Given the proliferation of climate change effects, issues and literature, ongoing collaboration and future editions of *Planning for Climate Change* are likely.

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I. OVERVIEW & GOALS

The Refuge System and Refuge Purposes

The mission of the U.S. Fish and Wildlife Service (FWS) is working with others to conserve, protect, and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people. The National Wildlife Refuge System (Refuge System) helps to fulfill that mission with a national network of lands and waters devoted to wildlife conservation. As of February 26, 2014, the Refuge System consisted of over 150 million acres, including 562 national wildlife refuges comprising 97% of Refuge System area. Other significant units in the Refuge System include waterfowl production areas (approximately 34,000 tracts comprising 2% of the Refuge System) and coordination areas (1% of Refuge System; managed by states).

The purpose of a particular refuge (or other unit of the Refuge System) is defined by the legislative authority or executive action through which it was acquired or established. A refuge may have multiple purposes. Nearly 300 refuges have been established for migratory birds under the Migratory Bird Conservation Act. Fifty-eight have been established to protect threatened and endangered species pursuant to the Endangered Species Act (ESA), and many other refuges include parcels purchased under the authority of the ESA or otherwise contribute to threatened and endangered species conservation. Other laws frequently used to authorize the establishment of refuges include the Fish and Wildlife Act of 1956, the Fish and Wildlife Coordination Act, and the Refuge Recreation Act. Refuge purposes may also be defined by executive orders, proclamations, secretarial orders, and public land orders. Each refuge is required to fulfill its particular purposes, as well as contribute to the mission of the entire Refuge System.

DOI and FWS Response to Climate Change

Secretarial Orders

The FWS response to climate change is rooted in Department of the Interior (DOI) Secretarial Order 3226 (January 19, 2001), which states:

> "…there is a consensus in the international community that global climate change is occurring and that it should be addressed in governmental decision making...This Order ensures that climate change impacts are taken into account in connection with Departmental planning and decision making…Each bureau and office of the Department will consider and analyze potential climate change impacts when undertaking long-range planning exercises, when setting priorities for scientific research and investigations, when developing multi-year management plans, and/or when making major decisions regarding the potential utilization of resources under the Department's purview.

Secretarial Order 3289 (September 14, 2009) reiterated the mandate of Secretarial Order 3226 with regard to climate change planning and established institutions (including Climate Science Centers and Landscape Conservation Cooperatives) to "enable the bureaus and agencies to fulfill these planning requirements."

Subsequent to these orders, FWS has played a lead role in the development of two key, national-level climate change planning documents, *Rising to the Urgent Challenge* (FWS 2010) and the *National Fish, Wildlife, and Plants Climate Adaptation Strategy* (NFWPCAS Partnership 2012). The goals of each document are listed below and should be considered in all Refuge System planning efforts.

Rising to the Urgent Challenge

Rising to the Urgent Challenge is the FWS strategic plan for responding to climate change. The key principles of this plan are setting priorities in the context of climate change, vigorous partnership and interdependence with others, use of the best available science, landscape-level conservation, using state-of-the-art technology, and taking a global approach in addressing climate change (FWS 2010:2). These principles are woven through three strategic themes: adaptation, mitigation, and engagement, and eight goals are allocated among these themes as follows:

Adaptation

Goal 1: We will work with partners to develop and implement a National Fish and Wildlife Climate Adaptation Strategy.

Goal 2: We will develop long-term capacity for biological planning and conservation design and apply it to drive conservation at broad, landscape scales.

Goal 3: We will deliver landscape conservation actions that support climate change adaptations by fish and wildlife of ecological and societal significance.

Goal 4: We will develop monitoring and research partnerships that make available complete and objective information to plan, deliver, evaluate, and improve actions that facilitate fish and wildlife adaptation to accelerating climate change.

Mitigation

Goal 5: We will change our business practices to achieve carbon neutrality by the Year 2020.

Goal 6: To conserve and restore fish and wildlife habitats at landscape scales while simultaneously sequestering atmospheric greenhouse gases, we will build our capacity to understand, apply, and share biological carbon sequestration science; and we will work with partners to implement carbon sequestration projects in strategic locations.

Engagement

Goal 7: We will engage FWS employees; our local, State, Tribal, national, and international partners in the public and private sectors; our key constituencies and stakeholders; and everyday citizens in a new era of collaborative conservation in which, together, we seek solutions to the impacts of climate change and other 21st century stressors of fish and wildlife.

<u>National Fish, Wildlife, and Plants Climate Adaptation Strategy</u>

In its FY2009 appropriations, Congress directed the Secretary of the Interior "to develop a national strategy to assist fish, wildlife, plants, and associated ecological processes in becoming more resilient, adapting to, and surviving the impacts of climate change" (U.S. House of Representatives 2010:77). Working closely with the Council on Environmental Quality, FWS (representing DOI) assembled federal, state, and tribal partners, and with input from numerous scholars the *National Fish, Wildlife and Plants Climate Adaptation Strategy* was developed. The collection of participants was called the "NFWPCAS Partnership." The national strategy was reviewed by the public and published (NFWPCAS Partnership 2012).

The primary purpose of the national strategy is "to inspire and enable natural resource professionals and other decision makers to take action to conserve the nation's fish, wildlife, plants, and ecosystem functions, as well as the human uses and values these natural systems provide, in a changing climate" (NFWPCAS Partnership 2012:16). Seven specific goals are also adopted:

Goal 1: Conserve habitat to support healthy fish, wildlife and plant populations and ecosystem functions in a changing climate.

Goal 2: Manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate.

Goal 3: Enhance capacity for effective management in a changing climate.

Goal 4: Support adaptive management in a changing climate through integrated observation and monitoring and use of decision support tools.

Goal 5: Increase knowledge and information on impacts and responses of fish, wildlife and plants to a changing climate.

Goal 6: Increase awareness and motivate action to safeguard fish, wildlife and plants in a changing climate.

Goal 7: Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate.

<u>Conserving the Future</u>

Climate change is also a significant planning issue in key Refuge System documents of broader scope, most notably *Conserving the Future: Wildlife Refuges and the Next Generation* (FWS 2011). This document comprises a vision for the Refuge System, developed over an 18-month period with partners and stakeholders. Among other things, *Conserving the Future* calls for landscape-level planning in the context of climate change. See for example Recommendations 1 and 2:

> **Recommendation 1:** "Incorporate the lessons learned from our first round of CCPs and HMPs [Habitat Management Plans] into the next generation of conservation plans, and ensure these new plans view refuges in a landscape context and describe actions to project conservation benefits beyond refuge boundaries" (FWS 2011:35).

> **Recommendation 2:** "Develop a climate change implementation plan for the National Wildlife Refuge System that dovetails with other conservation partners' climate change action plans and specifically provides guidance for conducting vulnerability assessments of climate change impacts to refuge habitats and species as well as direction for innovation in the reduction of emissions and improved energy efficiency on federal lands" (FWS 2011:39).

Common themes among the mandates, goals and recommendations issued by DOI and FWS include adaptive management, conservation design, landscape-level planning, responding to climate change in various ways, and working with partners. *Planning for Climate Change* will help planners and managers to integrate these themes in a coherent manner while providing practical guidance for incorporating climate change into planning documents.

II. CLIMATE CHANGE PLANNING CONCEPTS FOR THE REFUGE SYSTEM

Climate Change Basics

Climate change is a change in the state of the climate characterized by changes in the mean and/or the variance of its properties, persisting for an extended period, typically decades or longer (IPCC 2007a). There is consensus in the scientific community that climate change is occurring, particularly that Earth and its climate are warming and that changes in atmospheric composition are the primary drivers (Bierbaum et al. 2007, USGCRP 2009, EPA 2012). As the IPCC (2013:3) described, “Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.”

The greenhouse effect is a natural process by which greenhouse gases such as water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) absorb infrared radiation emitted by the Earth’s surface, by the atmosphere itself, and by clouds. These gases also trap heat within the surface-troposphere system (IPCC 2007a), heating the Earth’s surface and the lower atmosphere. This warming process has occurred naturally and by means of human activities, primarily economic production activities (IPCC 2007b). “It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together” (italics in original) (IPCC 2013:12).

During the 20th century atmospheric CO_2 increased at a rate of 1.7% per year, from 280 parts per million (ppm) to about 380 ppm (Feely et al. 2004, U.S. Department of State 2004). As of January 2014 atmospheric CO_2 was approximately 397.8 ppm (NOAA 2014). Atmospheric CO_2 is projected to increase by 2100 to a range between 470 and 1,000 ppm (IPCC 2011a).

The key factors determining projected CO_2 concentrations are social and economic goals and trends (IPCC 2011b). For example, the high-CO_2 scenario is a “future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology… In this world, people pursue personal wealth rather than environmental quality” (IPCC 2011b). In contrast, the low-CO_2 scenario is “A convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in materials intensity, and the introduction of clean and resource-efficient technologies” (IPCC 2011b). However, rapid or significant changes in sectoral proportions are limited by the trophic structure of the economy (Czech 2008, Czech and Richardson 2011, Czech 2013). Trophic exigencies limit the prospects for the low-CO_2 scenario and help explain why greenhouse gas emissions have increased faster than expected under most scenarios (Davis et al. 2010, Manning et al. 2010).

Projected increases in global average surface temperature range from 0.6 °C to 4 °C (1.1 °F to 7.2 °F) by 2100, relative to 1980-1999 levels (IPCC 2007a). However, the Intergovernmental Panel on Climate Change (IPCC) is considered to be a relatively conservative source of climate change projections (Watson 2010, Scherer 2012). Pursuant to the assessment of the U.S. Global Climate Research Program, global average temperature is projected to increase from 1.1 °C to 6.4 °C (2.0 °F to 11.5 °F) by 2100 and the U.S. average temperature “is very likely to rise more than the global average over this century” (USGCRP 2009:9).

With regard to post-2100 scenarios, even assuming constant emissions, global temperatures are projected to rise 0.10 °C to 0.15 °C/decade (0.18 °F to 0.27 °F/decade) for two centuries after 2100

The key factors determining projected CO_2 concentrations are social and economic goals and trends.

(Titus and Narayanan 1995, van Vuuren et al. 2003).

The intensification of the greenhouse effect has contributed to:

- 341 consecutive months (as of July 2013) with a global average above the 20th century average (for the respective month) (NOAA 2013);
- shrinking of the Greenland and Antarctic ice sheets, Arctic sea ice, and glaciers "almost worldwide" over the past two decades (IPCC 2013:5);
- an increase in global mean sea level of approximately 2.0 millimeters per year between 1971 and 2010, and an increase of approximately 3.2 millimeters per year since 1993 (IPCC 2013);
- increasing Arctic temperatures at nearly twice the global average rate since 1900 (IPCC 2007a);
- an increase in intensity and length of droughts since the 1960s (USGCRP 2009), and;
- a likely increase in the frequency or intensity of North American and European terrestrial heavy precipitation events (IPCC 2013).

Climate Change and Strategic Habitat Conservation

Responding to climate change calls for adaptation, mitigation, and engagement (FWS 2010). At the same time, Refuge System planning documents must function within the already existing cycle of strategic habitat conservation (SHC) (FWS 2008). The basic SHC components are planning, implementation, and evaluation (Figure II-1).

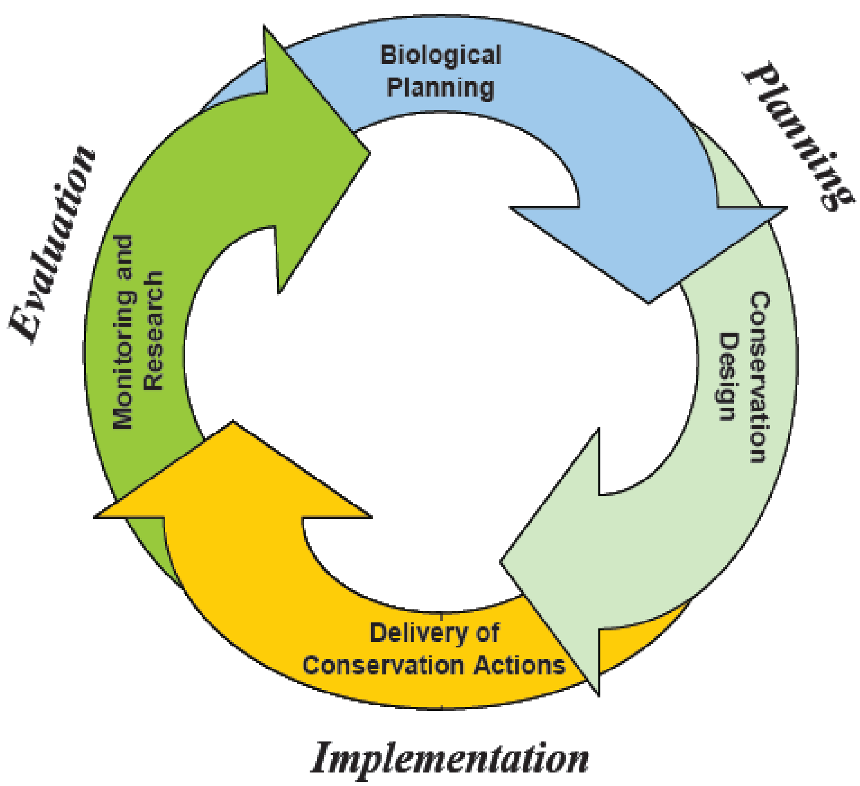

Figure II-1. The Strategic Habitat Conservation cycle (from FWS 2008).

Dovetailing adaptation, mitigation, and engagement with the basic SHC components ensures that current refuge programs and personnel are able to incorporate climate change concerns without "reinventing the wheel." Fortunately, this can be done in a straightforward manner, and the result is nine general categories of climate change responses (Table II-1).

____________________SHC Component____________________

Climate Change Responses	Planning	Implementation	Evaluation
Adaptation	Planning for adaptation	Adapting	Evaluating adaptation
Mitigation	Planning for mitigation	Mitigating	Evaluating mitigation
Engagement	Planning for engagement	Engaging	Evaluating engagement

Table II-1. Coupling of adaptation, mitigation, and engagement with SHC components, resulting in nine categories of climate change responses.

When this basic framework is supplemented with a time dimension, a more meaningful framework for climate change planning appears (Figure II-2). Planners handle the time dimension by identifying at least one action that may be taken immediately for each general category. Planners also identify actions that may be taken within the next few years and actions to commence during subsequent years (e.g., up to 15 years for CCP purposes). Some actions will be "once-and-done," such as the publication of the first educational factsheet about climate change issues on a refuge. Other actions will become long-term or ongoing exercises; e.g., installment and monitoring of tide gauges on a coastal refuge.

The time dimension of planning refers not only to how soon the action will be taken, but to the longevity of the issue. For example, engaging the public about climate change may focus on current issues (such as whether to repair a levee damaged by a hurricane) or long-run issues (such as stabilizing atmospheric carbon). Therefore, "planning now" (Figure II-2) does not preclude planning for long-term or ongoing issues. Conversely, imminent problems do call for planning now!

Refuge System plans should include specific actions falling under the general categories shown in Figure II-2. Consider the following examples:

- For adapting to climate change, specific responses may include the revision of land acquisition plans, restoration of acquired lands to enhance resilience, and subsequently conducting population surveys. These three specific responses correspond with the SHC components of planning, implementation, and evaluation, respectively.

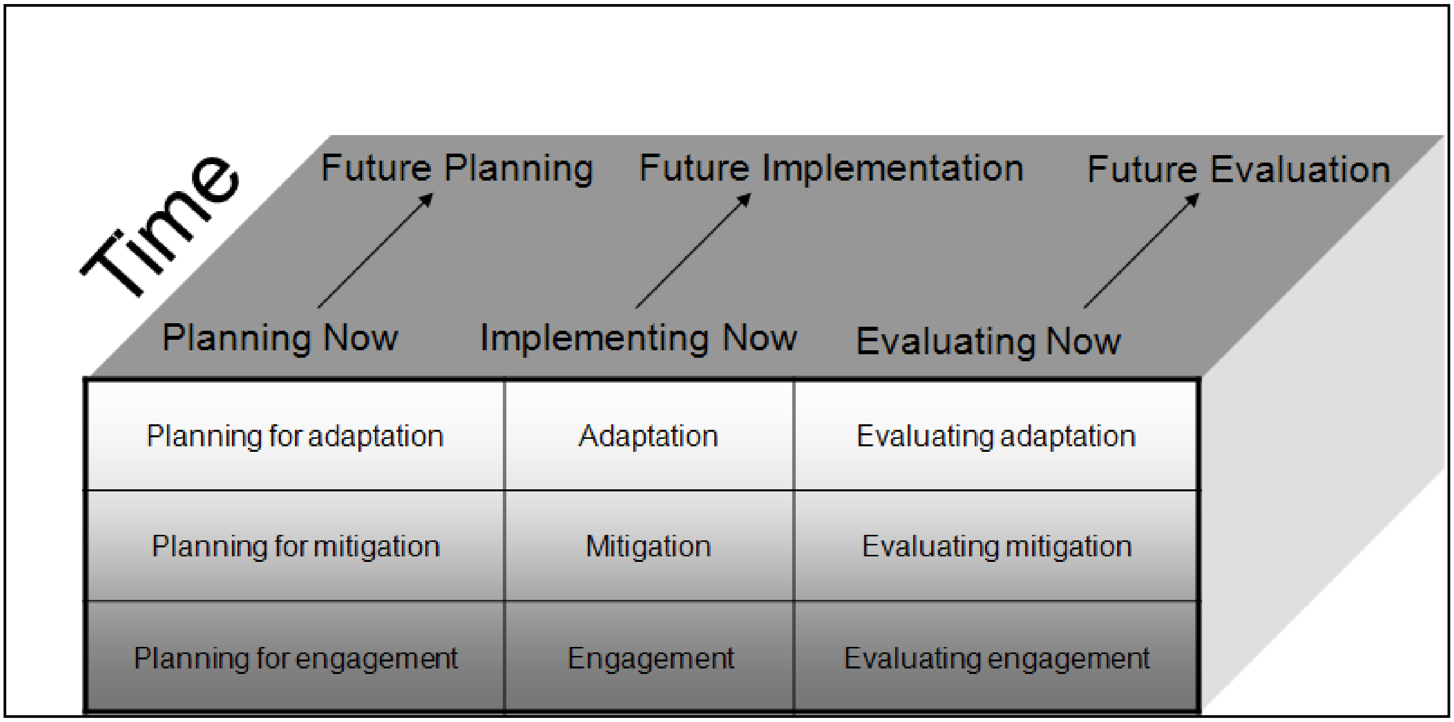

Figure II-2. Framework for climate change planning over time.

- For mitigating climate change, specific responses may include fleet management plans, transitioning to hybrid vehicles, and annual energy audits (corresponding with planning, implementation, and evaluation, respectively).
- For engagement on climate change, specific responses at a refuge might include the development of climate change outreach plans, publication of climate change fact sheets, and public opinion surveys (i.e., planning, implementation, and evaluation, respectively).

CLIMATE VULNERABILITY ASSESSMENT

Planning for climate change on the Refuge System entails assessing the vulnerability of the refuge or landscape to climate change. Vulnerability is a function of exposure, sensitivity, and adaptive capacity (Glick et al. 2011). Exposure means the degree of climate stress upon the resource or management activity in question; “it may be represented as either long-term change in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme events” (Comer et al. 2012:6). Sensitivity is the degree to which the resource or management activity will be affected by climate change. Adaptive capacity is the potential for adjusting to climate change “so as to moderate potential damages” or “cope with consequences” (Comer et al. 2012:6). Resources or management activities with high exposure, high sensitivity, and low adaptive capacity are very vulnerable to climate change.

Assessing vulnerability to climate change may or may not warrant a formal process resulting in a climate vulnerability assessment (CVA) per se. In some areas the effects of climate change may have already been studied and modeled extensively. In such cases the vulnerability of habitats and species may already be well established and valuable planning resources can be summarily devoted to climate change adaptation, mitigation, and engagement within the SHC model (Figure II-2).

However, in other cases a formal CVA will prove useful for planning purposes. In general, this will be so where the effects of climate change are subtle, doubtful, multifarious or complicated. A CVA may also be called for when numerous partners are involved in a planning effort and consensus about climate change effects must be built.

Numerous guidelines and precedents for climate vulnerability assessment are available including those of McCarthy et al. (2010), Glick et al. (2011), and Comer et al. (2012). Typically, however, the basic steps are to identify assessment targets, assemble an assessment team, select a time period or periods of concern, and analyze the aspects of vulnerability (exposure, sensitivity, and adaptive capacity) using a combination of peer-reviewed literature, expert opinion and modeling. Thought should also be given in advance to how the assessment will be used, because user needs will determine much of the assessment approach and level of detail.

Assessment targets are the foci of a CVA. They may be species, guilds, habitat types, ecosystems, or even public uses or management activities. For a refuge, the selection of assessment targets is steered by refuge purposes. For example, if the refuge is charged with conserving an endangered species, then the vulnerability of that species is likely to be the primary (and possibly the only) assessment target in the refuge's CVA. However, most refuges have more complex purposes, entailing the assessment of vulnerability for a variety of targets. This process should become wieldier with the surrogate species approach, currently under development in FWS.

A team of climatological, ecological, geological, hydrological or other relevant experts is assembled to conduct and author a CVA. (Alternatively, it is possible for one devoted scholar, such as a Ph.D. student, to conduct a detailed assessment.) The team seeks collaboration from refuge staff, conservation partners, and general stakeholders. Collaborators may contribute additional expertise and/or help refine the vision of what is needed from the assessment. A Landscape Conservation Cooperative (LCC; see Part V) is a typical starting point for finding such collaborators and in some cases may comprise the full set of collaborators.

Regarding time periods of concern, there is substantial precedent for considering the effects of climate change throughout the 21st century. This approach fits with the long-running nature of climate change and with our concern for

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"present and future generations of Americans" as specified in the Refuge System mission statement. Dates beyond 2100 are less frequently mentioned, but it is generally assumed that planning out to 2100 connotes very long-range considerations as well.

There is also some precedent for considering representative decades of the 21st century, such as the 2020s, 2050s, and 2080s (NASA 2012). This approach clarifies the meaning of short-, mid-, and long-term planning horizons. It also works well with climate models that produce time-series output data such as mean annual temperature, which may be averaged by decade.

Models play a major role in climate vulnerability assessment (Wilsey et al. 2013). The two broad categories of the most relevant models are climate models and ecological response models. Climate models range from global climate models (GCMs) to regional climate models (RCMs) of variable resolution. "GCM" may also refer to general circulation model, a major building block of a global climate model (Figure II-3). The two terms – general circulation model and global climate model – are sometimes used interchangeably. (Yet a third term, "global circulation model," typically connotes an intermediate category between general circulation models and global climate models and is also often used interchangeably.)

GCMs are typically named for the organizations or laboratories where they originated, then acquire shorter names for general usage. For example, a well-known GCM developed by the Met Office Hadley Centre for Climate Change is called the "Hadley Model." Meanwhile, Version 2.X of a GCM developed by the Geophysical Fluid Dynamics Laboratory is called "GFDL CM2.X."

Typically Refuge System staff will not be direct users of climate models, but ideally some expertise in climate modeling per se is available on the assessment team. This is especially helpful if downscaling from GCMs is required for functionality in RCMs or ecological response models. Downscaling is not necessarily required for some types of landscape-level planning. However, RCMs and ecological response models are typically downscaled and derived with inputs from several GCMs for purposes of spreading the risks of uncertainty.

An RCM may be nothing more than the application of finer-scale mathematics and/or the incorporation of finer-scale data in an existing GCM, but for a limited portion of the Earth's surface. An RCM may also incorporate a more complex conceptual model and additional variables, equations and algorithms than what are found in the "host" GCM.

To clarify, almost all CVA at the refuge or landscape level requires some type or level of downscaling from GCMs, which are global in scope, but in many cases modelers in academia or government agencies have already conducted downscaling into RCMs.

The outputs from these RCMs may serve as inputs to ecological response models. However, if there is a lack of useful RCM outputs in an area where CVA is to be performed, one of the first steps may be the downscaling of climate projections from GCMs.

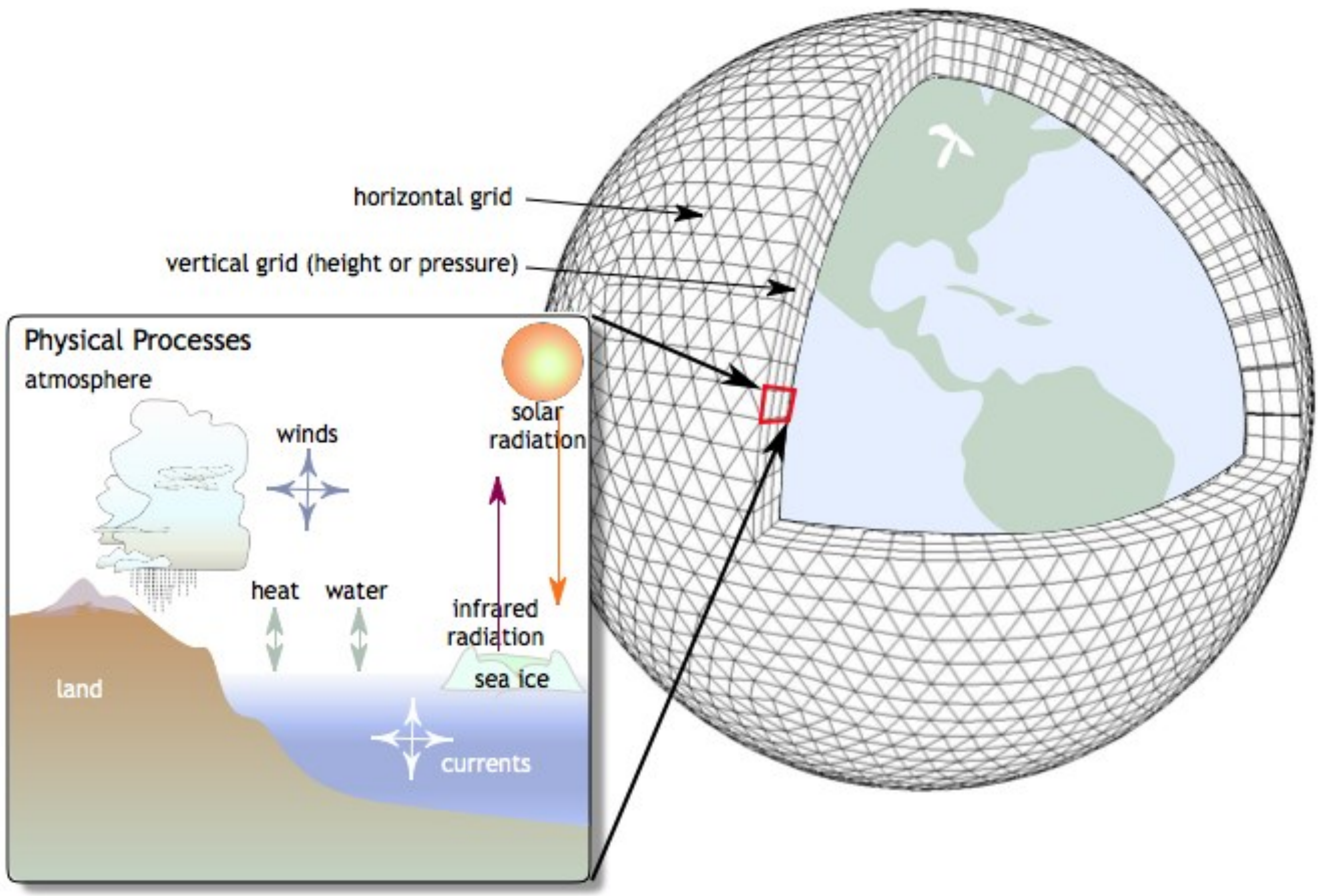


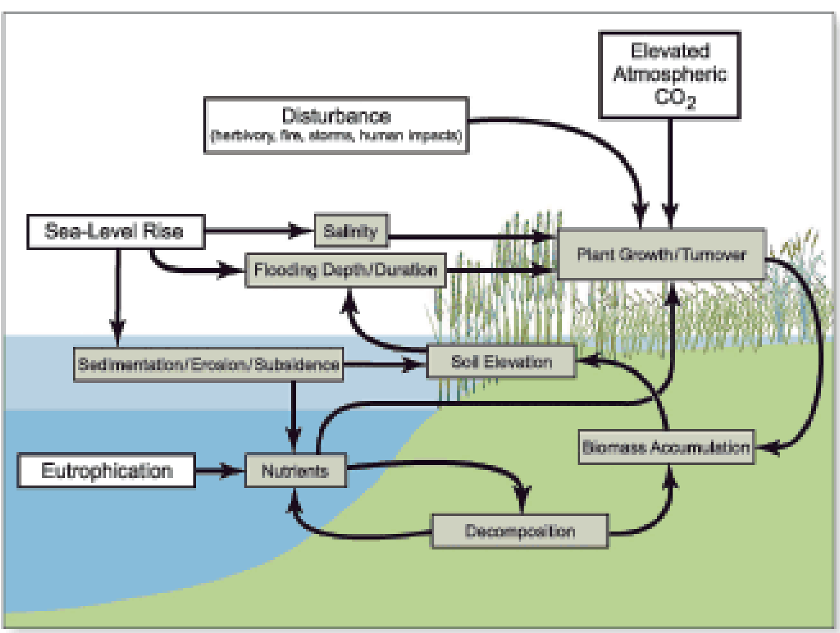
Figure II-3.
Schematic diagram of a global climate model (GCM), its cells, and some of the physical processes modeled. The schematic is simple enough that it represents primarily the general circulation modeling aspects of a global climate model.
(Credits: Colorado State University)

Ecological response models vary widely in their construction, maintenance and utility, but these are the models that will typically be most directly useful to Refuge System planners. They are difficult to classify, but Glick et al. (2011) labeled the types of ecological response models most relevant to CVA as conceptual, general characterization, expert opinion, habitat and occupancy, vegetation/habitat response, and ecological. These are generally listed in order of complexity, and key aspects of the models are identified with the labels. Otherwise there is no unifying theme to the classification. For example, expert opinion models are distinguished primarily by how they are constructed, whereas habitat and occupancy models are distinguished by what they produce.

Conceptual models are qualitative and typically manifested in diagrams showing the relationships among climatic trends and ecological responses. General characterization models deal with the effects of climate change on broad (generalized) taxa or ecological groups, such as a vertebrate family or guild, respectively. Expert opinion models are usually detailed conceptual models derived in a structured environment with the benefit of substantial expertise on the assessment targets; these models are sometimes built upon to produce data-driven, quantitative models. Habitat and occupancy models describe the development or evolution of wildlife habitats (and/or the presence of species associated with those habitats) as a function of climatic trends. Vegetation/habitat response models are much like habitat and occupancy models, except focused on responses of plant species and the evolution of plant communities. The latter two categories of models are sometimes combined into complex ecological models. In fact numerous models combine elements of the basic types labeled by Glick et al. (2011) and in some cases with other biological, physical, or chemical processes such as photosynthesis, hydrology, and acidification, respectively.

Case Study: Coastal Wetland Conceptual Model

Planning for Climate Change does not include comprehensive lists of climate or ecological response models. Such lists would be difficult to procure and unwieldy to classify, but more importantly quickly dated. Climate change and ecological response models are proliferating as climate change and its effects become major topics in academic, government, and private research programs. Therefore real-time networking is a prominent feature of climate vulnerability assessment, and one role of the expert team (or certain members thereof) in climate vulnerability assessment is to provide the latest information on relevant models and/or where to go for such information. Nevertheless, several models will be encountered below and/or listed in Appendix B.



The effects of climate change on coastal marshes have been considered by many scholars. The conceptual model diagrammed here stems from USGS research in the Chesapeake Bay Ecosystem (Cahoon 2007). It highlights direct and indirect effects of increasing atmospheric CO_2 and sea-level rise on coastal marsh evolution. (Credits: U.S. Geological Survey).

Retrospective and Prospective Planning

Refuge managers are required to manage for the "biological integrity, diversity, and environmental health" of the Refuge System pursuant to the National Wildlife Refuge System Improvement Act of 1997. This mandate is a cornerstone of Refuge System philosophy and management. As Fischman (2004:1023) described, in the evolution of federal land management the Refuge Improvement Act brought the Refuge System back "to the forefront of management reforms," and "no provision in the 1997 Act better exemplifies this renaissance than the mandate to maintain biological integrity, diversity, and environmental health." It might also be said that no provision in the Refuge Improvement Act is more challenged by climate change.

The framework for fulfilling the mandate is provided in Refuge System Policy 601 FW 3, which calls for the maintenance of "historic conditions," which are defined as "Composition, structure, and functioning of ecosystems resulting from natural processes that we believe, based on sound professional judgment, were present prior to substantial human related changes to the landscape." In other words, the policy is intended to induce management for natural conditions and with natural processes, using historic conditions to help identify such conditions and processes.

For purposes of implementing 601 FW 3 and other ecological integrity policies, a particular frame of reference is necessary (Noss 2004, Oliveira and Cortes 2006). 601 FW 3 provides some guidance beyond simply historic conditions with the phrase "prior to substantial human related changes." However, even that phrase is subject to a wide range of interpretation and does not address the question of how far back in time should be considered relevant. Czech (2004) suggested the millennium 800-1800 AD to provide a firmer frame of reference and to accommodate some degree of climate change. The suggested millennium encompassed the Medieval Warm Period (approximately 950-1250 AD) as well as most of the Little Ice Age, which commenced approximately 1300 AD. Although the Little Ice Age ran until the mid-19th century, 1800 AD was proposed as a non-arbitrary endpoint for-natural conditions due to the rapid economic growth – and concomitant human-related changes – enabled by the American phase of the industrial revolution.

The philosophy of managing for ecological integrity is not to precisely replicate conditions as they existed at any particular time, but rather to remain consistent with naturally occurring evolutionary and ecological processes. A challenge to using a chronological frame of reference is that we cannot know what would have transpired in the absence of substantial human-related changes. On the other hand, we would have even less such knowledge without the frame of reference. As Oliveira and Cortes (2006:486) noted, "Historical data provides not only the knowledge of past conditions, but it becomes essential to estimate the current ecological potential." For example, if historical data indicate that javelina (*Tayassu tajacu*) were expanding their range northward prior to anthropomorphic climate change and other effects of the industrial revolution, managing for javelina somewhat northward of their pre-1800 range may be perfectly consistent with ecological integrity (Czech 2004). This example illustrates that unprecedented conditions do not automatically imply the loss of ecological integrity. 601 FW 3 called for the consideration of what may have naturally developed, ecologically, in the absence of substantial human-related changes, but the effects

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of anthropogenic climate change are not consistent with what may have naturally developed.

Some refuges have purposes that may not readily conform to the maintenance of natural conditions or ecological integrity (Schroeder et al. 2004). In that sense, such refuges may be considered less vulnerable to climate change. For example, "development of the agricultural, recreational, industrial, and related purposes" are among the purposes of Crab Orchard National Wildlife Refuge (61 Stat. 770, Aug. 5, 1947). Although particular economic sectors may be threatened by climate change, such as wheat farming in the latitudes of Crab Orchard, climate change is not thought of as threatening the existence of general sectors of economic activity such as “agricultural, recreational, and industrial.” Therefore these general purposes of Crab Orchard National Wildlife Refuge are not very vulnerable to climate change.

601 FW 3 clarifies that refuge purposes have primacy over the maintenance of natural conditions, and provides guidance for how to proceed when refuge purposes do not readily conform to the maintenance of ecological integrity. These and other nuances of managing for ecological integrity are beyond the scope of this primer, but Refuge System staff should revisit 601 FW 3 and Volume 44, Issue 4 of *Natural Resources Journal* when faced with difficult decisions about managing for ecological integrity in the context of climate change.

The concept of ecological integrity and the cohesion of ecological integrity policies are challenged and undermined by anthropogenic climate change. In the context of climate change, the term “sound professional judgment” from the Refuge Improvement Act takes on renewed importance. Sound professional judgment is defined as “a finding, determination, or decision that is consistent with principles of sound fish and wildlife management and administration, available science and resources, and adherence to the requirements of this Act and other applicable laws.” Balancing considerations among refuge purposes, the mission of the Refuge System, and maintenance of ecological integrity requires a large dose of sound professional judgment, especially in the context of climate change.

Balancing considerations among refuge purposes, the mission of the Refuge System, and maintenance of ecological integrity requires a large dose of sound professional judgment, especially in the context of climate change.

The use of sound professional judgment also affords a certain degree of latitude or flexibility in responding to climate change. For example, responding to climate change falls on a spectrum from retrospective to prospective (Magness et al. 2011). This is especially the case with adaptation responses. Prospective adaptation is proactive and designed to “fit” ecologically with climate change trajectories; retrospective adaptation is designed toward maintaining historic conditions (Magness et al. 2011). These two basic philosophies may also be reflected in engagement strategies, and to some degree even affect mitigation efforts.

Deciding when to apply retrospective or prospective strategies is challenging for managers (GAO 2007). Ecosystem response to climate change may not be simple or linear, and a transition from one ecosystem to a markedly different one may occur suddenly due to threshold effects (Burkett et al. 2005). The best approach may be to proceed “conservatively” at first; i.e., managing against climate change impacts in the short term by sustaining or even restoring historic or recent conditions (as consistent with 601 FW 3), then moving toward managing “with” climate change as the certainty of climate change effects and our knowledge of ecosystem resilience increases. In other words, planning now is retrospective and becomes more prospective over time. These contrasting approaches have effects on implementation and evaluation over time as well (Figure II-4).

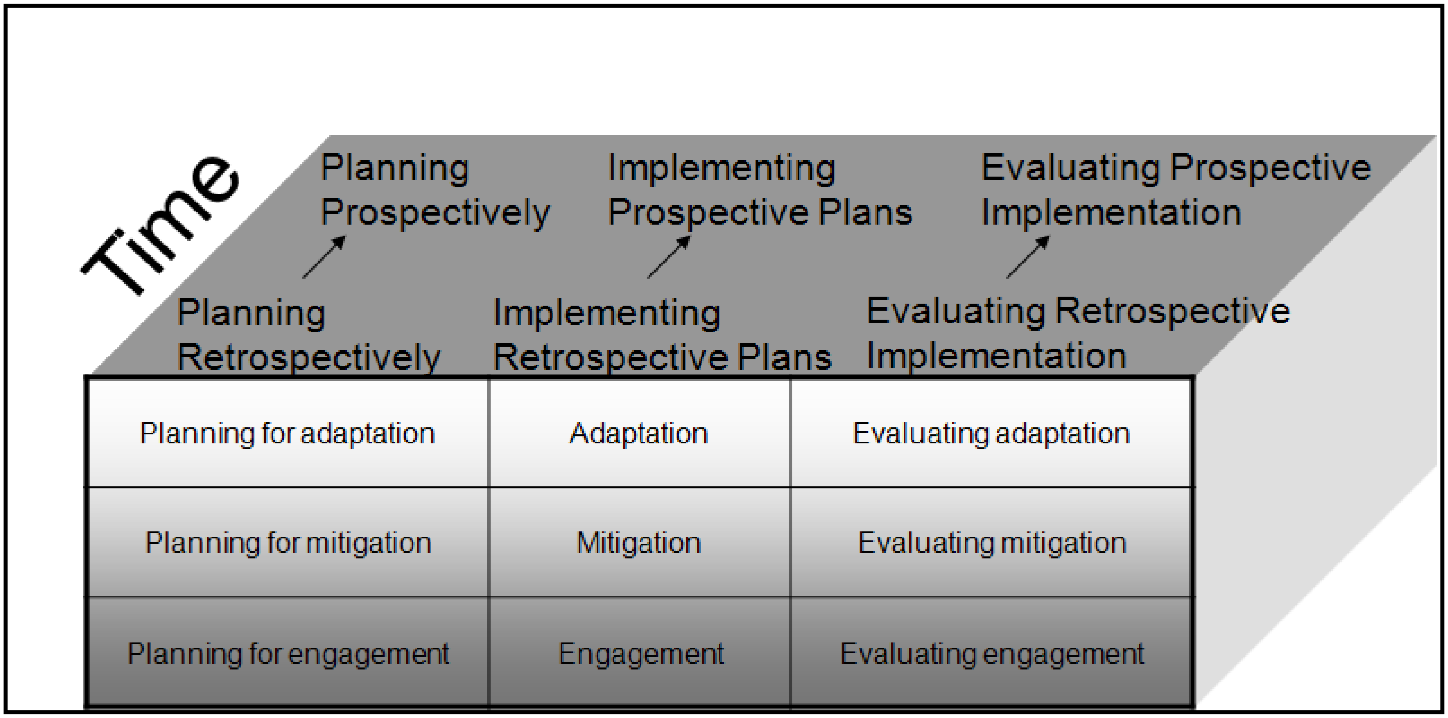

Figure II-4. Moving from retrospective to prospective approaches in planning, implementation, and evaluation.

Cautious and mixed approaches that spread the risks of planning for various potential scenarios are conducive to adaptive management. Efforts to restore or maintain historic or baseline conditions may build resilience in ecosystems and "buy time" for gaining certainty of climate change effects. Meanwhile some of the most likely and least avoidable climate change effects can immediately be planned for prospectively. Some modeling approaches are available to combine retrospective and prospective philosophies in planning for the ecological effects of climate change, such as in the case study below.

Case Study: Potential Climate Stress to Wildlife Habitats

The Issue – Complex feedbacks among climate, land use, and land cover make it difficult to predict how wildlife may respond to future climates. However, habitats are key determinants of species composition, so habitat alterations serve as leading indicators of wildlife response to climate change (Ibáñez et al. 2006). In this case study it is assumed that shifts in habitat composition under future climates can serve as a template for decision makers to evaluate potential wildlife responses to climate change.

Analysis – Researchers from the Rocky Mountain Research Station (USDA Forest Service 2012:134-135) evaluated habitat stress attributed to climate change across the conterminous U.S. based on an area's (1) historical baseline climate (retrospective), (2) future climate from GCMs (prospective), and (3) climate-induced changes in productivity and distribution of broad vegetation types (prospective). They defined the Terrestrial Climate Stress Index (TCSI) as the sum of three separate terms that reflect changes to the climate regime (shifts in temperature and precipitation), habitat quality (change in productivity), and habitat area (distribution shifts in broad vegetation types). They estimated a mean TCSI score for each grid cell across a set of alternative futures.

Findings – Areas most sensitive to climate change in the conterminous U.S. were associated with transitions between biomes and areas of high topographic relief. The areas most exposed to habitat stress occurred along the grassland-forest transition throughout the central portion of the country and the steep elevation gradients in the Intermountain West (Figure II-5). The states with the highest TCSI scores tended to be located inland where the climate is continental and less buffered by oceanic effects.

Limitation – The TCSI is limited to terrestrial habitats. Where coastal wetlands are primary ecosystems of concern, models such as the Sea Level Affecting Marshes Model (SLAMM) provide more relevant insights for coastal refuge managers and planners.

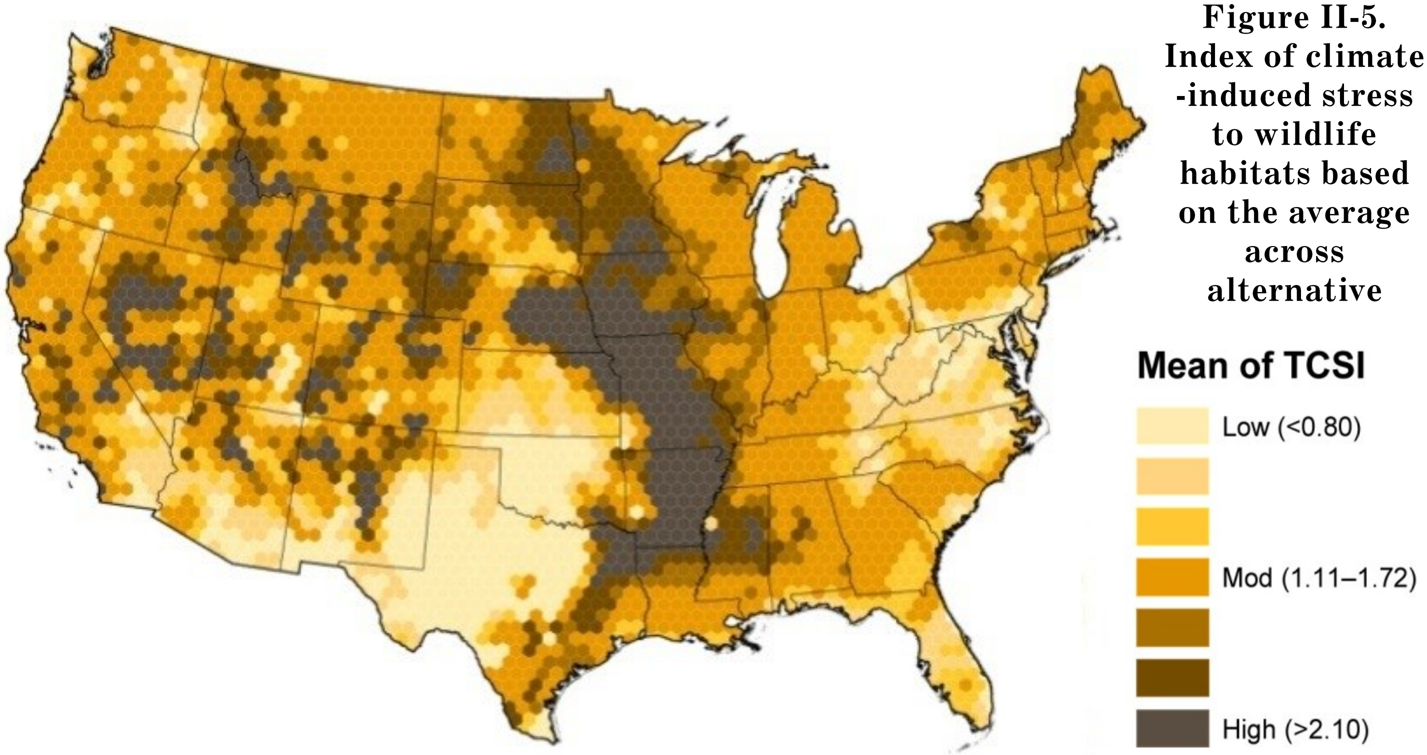

Figure II-5. Index of climate-induced stress to wildlife habitats based on the average across alternative futures (USDA Forest Service 2012:134).

As managers transition to working with climate change, taking more prospective but also more uncertain approaches, additional ecological risks can be expected. Translocation (a form of assisted migration) of species outside existing distributions (McLachlan et al. 2007), realignment of ecological processes into the range of current or expected climate, and the establishment of neo-native forests (Millar et al. 2007) are examples of prospective adaptation that may have unexpected ecological consequences.

Managers and planners should be explicit about the approach taken and the rationale used. Approaches will vary depending on the species or ecosystem affected, the resilience of the resource or activity, the scale of climate change effects, the certainty of future conditions, refuge purposes, and the intrinsic values held by refuge managers and biologists (Magness et al. 2012). With well-articulated reasoning and goals, adaptive management can then become the process by which progress is assessed and the likelihood of unexpected, negative consequences is minimized (Nichols et al. 2011)

Avoiding Maladaptation and Seeking Co-Benefits

In addition to its effects on wildlife, climate change affects economic sectors such as agriculture, logging, mining, commercial fishing, energy extraction, transportation, and the concentration of service sectors in urban areas. Many federal agencies, states, local governments, tribes, and private-sector firms are preparing to address these effects. As affected interests respond to climate change pursuant to their distinctive missions and goals, there is potential for various adaptation efforts to conflict with wildlife conservation and other goals. "Maladaptation" may occur when a response to climate change for one purpose actually increases climate change vulnerability for other purposes. For example, southwestern cities seeking additional water supplies in response to desertification may lower water availability on refuges where water is often the limiting factor for wildlife conservation.

Maladaptation is also characterized by high opportunity costs and reduced incentives for other adaptation efforts. For example, constructing seawalls in response to sea-level rise may reduce opportunities for coastal marsh development, lowering incentives to invest in wildlife conservation and marsh-related public uses on refuges.

Interdisciplinary and multi-sector planning is necessary for avoiding maladaptation, and may provide opportunities for coordinated adaptation strategies providing co-benefits for multiple sectors or parties. Wildlife conservation activities tend to protect a wide range of economically valuable ecosystem services for local communities (Tercek and Adams 2013), and in many cases this may become more relevant or evident in the context of climate change. A well-known example on the Refuge System is coastal land conservation that buffers local communities from sea-level rise, flooding and hurricanes. Another prevalent example is interior wetland restoration that increases high-quality water supplies for nearby cities.

"Maladaptation" may occur when a response to climate change for one purpose actually increases climate change vulnerability for other purposes.

The next two parts of Planning for Climate Change serve as a primer on the ecological effects of climate change most relevant to the Refuge System (Part III) and particular social, economic, and cultural effects (Part IV). Part V provides a framework and suggestions for incorporating climate change considerations into Refuge System planning documents.

Climate Change and Planning Issues on the Refuge System

The effects of climate change on the Refuge System may be classified under two broad categories: ecological effects and all other effects. Among the other effects, certain social, economic, and cultural effects stand out as especially relevant for planning purposes. The next two parts of *Planning for Climate Change* serve as a primer on the ecological effects of climate change most relevant to the Refuge System (Part III) and particular social, economic, and cultural effects (Part IV). Part V provides a framework and suggestions for incorporating climate change considerations into Refuge System planning documents.

III. ECOLOGICAL EFFECTS OF CLIMATE CHANGE ON REFUGES AND THE REFUGE SYSTEM

Sweeping changes to the American landscape are not new to the Refuge System. Intensive agriculture, widespread industrialization, the Dust Bowl, and rapid urbanization were some of the 20th-century forces that led forward-thinking American leaders to set aside refuges for future generations. Not even climate change is entirely new, but the rate and magnitude of 21st-century climate change is unprecedented. One place to look for its effects is at the ecosystem level.

Sweeping changes to the American landscape are not new to the Refuge System. Intensive agriculture, widespread industrialization, the Dust Bowl, and rapid urbanization were some of the 20th-century forces that led forward-thinking American leaders to set aside refuges for future generations. Not even climate change is entirely new, but the rate and magnitude of 21st-century climate change is unprecedented.

Figure III-1 shows Refuge System lands with respect to the major ecoregions of North America. Refuges are found in all of these ecoregions, but approximately 82.5% of Refuge System terrestrial area is in the tundra and taiga ecoregions of Alaska (Scott et al. 2004). Meanwhile there are substantial conservation deficits, as measured against the commonly cited goal of conserving 10% of an ecosystem's area, for most ecoregions in the contiguous 48 states. There, the average conservation coverage (including all conservation lands, on and off the Refuge System) is approximately 4% (Dietz and Czech 2005), underscoring the need for effective wildlife conservation on refuges of the contiguous mainland.

General Impacts on Species and Ecosystems

Ecosystems are comprised of dynamic communities of biota within unique abiotic environments. Refuge System ecosystems do and will respond to climate change in different ways and to varying extents, due in part to the heterogeneous impacts of climate change factors themselves and in part to other factors, such as the amount of stress an ecosystem may already be under and the adaptability of the species within it (Griffith et al. 2009). However, the ability of species to adapt to changes in temperature and precipitation depends on multiple factors including: mobility and motility of the species, degree of specialty, the extent to which life cycles are timed with natural events, and other characteristics. The rate of potential adaptation may or may not be sufficient to keep pace with current and future rates of climate change (Parmesan 2006).

<u>Range Shifts</u>

Paleoecological studies have shown that the distribution of vegetation is highly influenced by climate. Historically, vegetation ranges have shifted in response to glacial expansion and contraction (Lomolino et al. 2010). Meanwhile, the distributions of wildlife species are largely determined by the distributions of vegetation (McCarthy 2009). As temperatures increase, range shifts are likely. The general trends are expected to be poleward latitudinal shifts and upward elevational shifts (Zuckerberg et al. 2009). Such shifts have already occurred over a broad range of taxa (Parmesan and Yohe 2003). For example, in a study of 329 species, representing 16 taxonomic groups found in Great Britain's terrestrial and freshwater ecosystems, 275 species had experienced northward range shifts and 227 had shifted to higher elevations (Hickling et al. 2006). Parmesan et al. (1999) looked at 35 species of non-migratory European butterflies and found that 63% had northward-shifting ranges over the past century.

However, exceptions to these trends are expected. For example, Tingley et al. (2012) detected 20th century elevational range shifts among 99 avian focal species in the Sierra Nevada Mountains (California). Rather than exhibiting a strong trend, responses among these species were highly variable because rising temperatures tended to "push" species upward while rising precipitation "pulled" them downward. Tingley et al. (2012:3279) noted, "While 84% of species shifted their elevational distribution, only 51% of upper or lower range boundary shifts were upslope."

For species ranges that expand poleward or upward, the low-latitude and low-elevation boundaries of these ranges may be expected to retract. It can be challenging to attribute losses at the southern or lower boundaries to climate change, given the variety of other threats facing wildlife (e.g., invasive species and habitat loss). However, retracting ranges and extirpations have been linked to climate change in some butterfly species (Franco et al. 2006, Thomas et al. 2006). Meanwhile some ranges have expanded in area, with southern range boundaries remaining stable, so far, as northern boundaries shifted further north (Parmesan et al. 1999).

Movements and range shifts will likely be species-specific; i.e., species that comprise a given community are not expected to shift together (Gitay et al. 2002). Historic climate change events resulted in the reassembling of communities into compositions that were taxonomically similar to those that existed before the event (Parmesan et al. 2000). This type of outcome is less likely in the 21st century due to the synergistic effects of climate change and other stressors such as invasive species, modified fire regimes, and habitat fragmentation. Urbanization, economic infrastructure, built capital, land uses, and housing have blocked many species from moving or moving efficiently (Czech et al. 2000).

Movements and range shifts will likely be species-specific; i.e., species that comprise a given community are not expected to shift together.

Species Extinctions

Evidence suggests that climate change will result in the loss of species (Gitay et al. 2002), and it already appears to have played a role in some extirpations and extinctions. For example, two populations of the Bay checkerspot butterfly (*Euphydryas editha bayensis*) have been extirpated due to climate change (most notably increased precipitation) combined with habitat loss (McLaughlin et al. 2002). Loss of some amphibian populations and species has been linked to climate-related events (Carey and Alexander 2003). Table III-1 lists some of the characteristics of vulnerable species.

Also relevant from a taxonomic standpoint, at least among animal species, is the "molecular clock," or the rate at which genetic mutations occur (Gibbs et al. 1998:552). All else equal, large-bodied, K-selected species (i.e., long-lived species with low reproductive rates) have slower molecular clocks and therefore evolve less quickly, putting them at a disadvantage in the context of environmental perturbations (Czech and Krausman 1998). Small-bodied, "r-selected" species (i.e., short-lived species with high reproductive rates) are able to evolve more quickly, producing complex phylogenies fitting multiple types of environments. This also suggests an advantage of invasive species, which frequently are small-bodied species, partly because smallness of body size is conducive to inadvertent, undetected transport as well as relatively rapid evolution.

Phenological Changes

Climate change alters the timing, or phenology, of biological events of species (Root et al. 2003). Studies examining long-term records have found that many plants and animals have shifted

Figure III-1. Refuge System lands by ecoregion (Ecoregion map credits: Commission for Environmental Cooperation.)

spring activities earlier. For example, breeding is occurring earlier for some birds in North America, as well as in Latin America and Europe (Gitay et al. 2002). Other species have experienced delays or no changes in their phenology (Parmesan 2006, Cleland et al. 2007). Such patterns are a result of species-specific responses to environmental cues, such as temperature thresholds and chilling requirements (Cook et al. 2012). These patterns have been confirmed across taxa including birds, plants, butterflies, and mammals (e.g., Sparks and Carey 1995, Inouye et al. 2000, Both et al. 2006, Inouye 2008).

Phenological change has major implications for wildlife management. For example, the earlier spring documented in many areas is leading to a longer growing season, which increases the number of broods or generations that animals may produce in a single year (Monroe et al. 2009, Jönsson et al. 2009). Increases in productivity have been documented in forests and lakes as a function of longer growing seasons (Shuter and Ing 1997, Richardson et al. 2009). Phenology also affects the magnitude of disease outbreaks, wildfire risk, and the activity of invasive species (Westerling et al. 2006, Willis et al. 2010, Grulke 2011, Ziska et al. 2011). The timing of visitation to public lands is affected by climate and phenology, too (Buckley and Foushee 2011).

The magnitude and direction of changes in phenology varies by region and latitude due to differing driving forces, sometimes with counterintuitive results. For example, the southeastern U.S. has experienced a general delay in spring phenology. Shortened winter chilling days associated with recent warmer winters have been insufficient for fulfilling many plants' chilling requirements, leading to a slower, more gradual spring green-up (Zhang et al. 2007, Schwartz and Hanes 2010). Arid and

Factor	Highly Vulnerable Species	Less Vulnerable Species
Population Size	Small	Large
Dispersal Mechanisms	Limited, slow	Various, rapid
Range Extent	Restricted or patchy	Wide and contiguous
Elevation	High or low	Intermediate areas
Habitat Requirements	Narrow or specific	Broad or general
Climatic Range	Limited	Extensive

Adapted from Gitay et al. 2002

Table III-1. Some Vulnerability Characteristics of Species. .

semi-arid ecosystems have complex phenological responses to climate change because these systems are generally water-limited rather than temperature-limited (Beatley 1974, Crimmins et al. 2010, Kimball et al. 2010). Because temperature increases are more pronounced at higher latitudes, phenological changes may be stronger in those areas (Root et al. 2003).

A challenging consequence of changing phenology is the potential for mismatching of key events among species in a community (Memmot et al. 2007, Willmer 2012). For example, plants and pollinators may respond differently to climate change, leading to a temporal mismatch in their interdependent activities (Miller-Rushing et al. 2010). Other interactions that could be affected are competition, pathogen-host interactions, and the seed dispersal resulting from animal movements (Warren et al. 2011). Such disruptions of synchrony among species could cause cascading ecosystem effects, affecting reproduction, mortality, and distributions of species (Chuine 2010). We may see the development of new types of communities and interactions.

Some recent studies suggest that plants and pollinators are responding similarly to climate change (e.g., Bartomeus et al. 2011, Forrest and Thompson 2011), while others researchers have clearly documented unequal changes in phenology among interacting species, with dramatic impacts to community composition, structure, and functioning (Winder and Schindler 2004, Pearce-Higgins et al. 2005, Memmott et al. 2007, Both et al. 2009). Whether interacting species were precisely synchronized prior to anthropogenic global warming influences the degree to which they are affected by climate change-induced shifts in phenology (Singer and Parmesan 2010).

Monitoring phenology is one of the simplest ways to track species' and ecosystems' responses to climate change (IPCC 2007c). The Refuge System's I&M Initiative provides an opportunity to monitor phenology in direct collaboration with the USA National Phenology Network (USA-NPN). At the web-based "Phenology Hub" (http://www.usanpn.org/fws/), planners, managers, and biologists can learn more about phenology, network with other Refuge System personnel in monitoring phenology, and access *Nature's Notebook,* the USA-NPN online monitoring program. Phenological observations may be entered for over 800 species, contributing to a growing National Phenology database. Users of *Nature's Notebook* can take advantage of visualization tools and mobile phone applications to facilitate observation entry and phenology project development. Phenology monitoring can also be carried out using automated digital tools, such as picture posts (http://picturepost.unh.edu/) and repeat photography (e.g., Ahrends et al. 2008).

Primary Productivity

Net primary production (NPP) is declining due to large-scale, intensive economic activity on the Earth's surface (Haberl et al. 2007), but global primary productivity (a rate) seems to be rising (Gitay et al. 2002). Increasing CO_2 and temperature can lead to an increase in photosynthesis up to threshold levels that vary among different types of plants (TWS 2004). Most notably, C3 and C4 plants respond differently to increasing CO_2 and climate change.

"C3" and "C4" refer to nuances of photosynthesis. In C3 plants, an enzymatic reaction results in a three-carbon compound as the first stable product of carbon fixation (FAO 2009). More than 95% of plant biomass on Earth is of C3 plants, which include trees and large proportions of other plant taxa (Flexas et al. 2012). As a group, C3 plants do best in relatively cool, moist, cloudy climates. With adequate water, the stomata stay open, allowing intake of more carbon dioxide. Conversely, carbon losses through photorespiration are high.

C4 plants have more recently evolved mechanisms to increase carbon dioxide concentration at the site of fixation (Monson and Collatz 2012). This reduces carbon loss by photorespiration. C4 plants do best in hot dry environments and use water efficiently, "allowing up to twice as much photosynthesis per gram of water as in C3 plants" (FAO 2009:6). However, C4 metabolism is inefficient in cool or shaded areas. Only a few percent of the earth's plant species can be classified as C4, although their biomass and productivity comprise somewhat higher percentages because they include widely distributed, dominant grass (*Poaceae*) species and cultivated varieties such as corn, sugar cane, millet and sorghum (Monson and Collatz 2012).

The most relevant difference vis-à-vis climate change in North America is that photosynthesis in C3 species increases more rapidly with rising levels of CO_2 and may continue increasing to higher CO_2 levels than is possible with C4 plants. On the other hand C4 plants are likely to benefit more from higher temperatures than C3 plants, and C4 plants do better in drier conditions (IPCC 2007b, von Fischer et al. 2008). In either case, water and soil nutrients may be limiting factors for primary productivity. The complex and uncertain potential for differential adaptation to climate change by C3 and C4 plants prompted von Fischer et al. (2008:13) to write, "Under such swift and drastic environmental changes, ecological and evolutionary surprises are almost sure to happen."

A challenging consequence of changing phenology is the potential for mismatching of key events among species in a community.

One certain trend is that the growing season is getting longer in higher latitudes and largely due to increasing minimum temperatures (NOAA 2012). This, combined with increases in primary productivity, may result in greater accumulation of biomass, which could increase the risk of wildfires (NAST 2001). It is also likely in some areas that the growing season of predominant vegetation may be shortened as a function of climate change due to drought (Hatfield and Singer 2011).

The chemical and nutrient composition of plants may also change in response to increasing CO_2 levels. For example, protein content may decline in some grains (IPCC 2001b) and nitrogen content has been shown to decline in herbaceous plants (Nowak et al. 2004).

Hydrological Effects

Altered Precipitation and Water Resources

Climate change affects the magnitude, timing, distribution, and type of precipitation, with corresponding effects on surface and groundwater resources. Both drought and heavy precipitation events are anticipated to increase in frequency (IPCC 2007c). The certainty of these outcomes increases during the 21st century (IPCC 2013).

Changes in precipitation affect the timing and magnitude of floods and droughts, shift runoff regimes, and alter groundwater recharge characteristics (Gleick 2000, van der Molen and Hildering 2005). Groundwater discharges, as well as surface water runoff from precipitation and snowmelt, provide water flows that maintain habitats and species (Haney 2007). These processes have complementary ecological functions. The variable surface runoff regime is essential for mobilizing sediments, revitalizing certain habitats, and recharging alluvial aquifers. The relatively stable base-flow regime, reflecting groundwater discharge, supports the aquatic and riparian habitats between runoff events. The life-cycle needs of aquatic and riparian plants and animals are tied to these natural patterns (Rodriguez-Iturbe and Porporato 2004).

Droughts are expected to be more severe in the 21st century and will correspond additionally with La Niña events (Seager et al. 2007). Droughts affect ecosystems in numerous ways. The water flow and level in rivers can decrease to critical thresholds due to decreased precipitation in the summer and increased evaporation, increasing the exposure of fishes to predators, decreasing the availability of habitats, and diminishing water quality (Matthews 1998). Water quality can decline due to reduced oxygen levels and increased water temperatures; these effects can be fatal to aquatic species.

Droughts reduce the natural recharge of aquifers, resulting in lower water tables and reductions in base flows to streams (Kuhn 2005). The reduction in natural recharge could adversely affect ecosystems dependent on shallow aquifers and subsurface flows, such as springs and riparian communities, particularly where these aquifers are already stressed from withdrawals for human use (Scott et al. 1999, Loáiciga 2003). Lower water tables are of particular concern with regard to spring ecosystems that support endemic species (Sada 1990, Williams et al. 2005).

In the Southwest, droughts affect aquatic ecosystems such as the Colorado River Basin and the Rio Grande Basin, which have some of the highest rates of endemism on the continent (Mac et al. 1998). In the Colorado River Basin, 35% of all native genera and 64% of the 36 fish species are endemic (Carlson and Muth 1989 as cited in Mac et al. 1998). In the Rio Grande Basin, 30% of the species are endemic. Species such as the pikeminnow (*Ptychocheilus lucius*), catfish (*Ictalurus lupus*), and spikedace (*Meda fulgida*) are susceptible to droughts because of declines in habitat and water quality (Probst 1999).

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Droughts directly reduce water supplies in the desert and indirectly affect the health of wildlife populations by decreasing vegetation quantity and quality (CLIMAS 2007). Species such as the bighorn sheep (*Ovis canadensis*) have been indirectly affected by severe droughts in Kofa National Wildlife Refuge (Arizona) (McKinney et al. 2006). Suitable habitat for amphibians such as the Chiricahua leopard frog (*Rana chiricahuensis*) and waterfowl may be greatly reduced, affecting the viability of these species in the Southwest (TWS 2004).

Droughts and water scarcity in the Southwest and elsewhere diminish supplies of surface water and groundwater. Meanwhile human populations and economic activity have risen rapidly in several regions, increasing demands for water (Figure III-2). Water is an essential factor of production (Gatto and Lanzafame 2005), such that economic growth requires increasing water withdrawals from the ecosystem. As Barbier (2004:15) noted, "there is inevitably a trade-off between maintenance and protection of [ecological services] and the increasing allocation of water for use in the economy."

In Arizona, for example, GDP grew 7.4% in the 1990s (BEA 2013), reflecting a 40% increase in population (Carter 2003) and a 3.8% increase in per capita GDP (BEA 2013). The high growth rates of the 1990's were the culmination of a century of water-dependent growth (Kupel 2006). By the end of the 20th century 33% of Arizona's original wetlands had been lost (EPA 2013) and less than 1% of Arizona was comprised of wetlands (USGS 1999). The limited wetlands in Arizona are crucial to waterfowl and other migratory birds, which use the wetlands as rest stops (Ducks Unlimited 2007). Nevertheless, the eight-county "Arizona Sun Corridor" is one of 11 "megaregions" – connected clusters of metropolitan areas – in which rapid rates of population and economic growth are planned through at least the middle of the 21st century (Hagler 2009) (Figure III-3). To the extent this occurs, less water will be available for fish and wildlife, especially in the megaregions, exacerbating the effects of drought.

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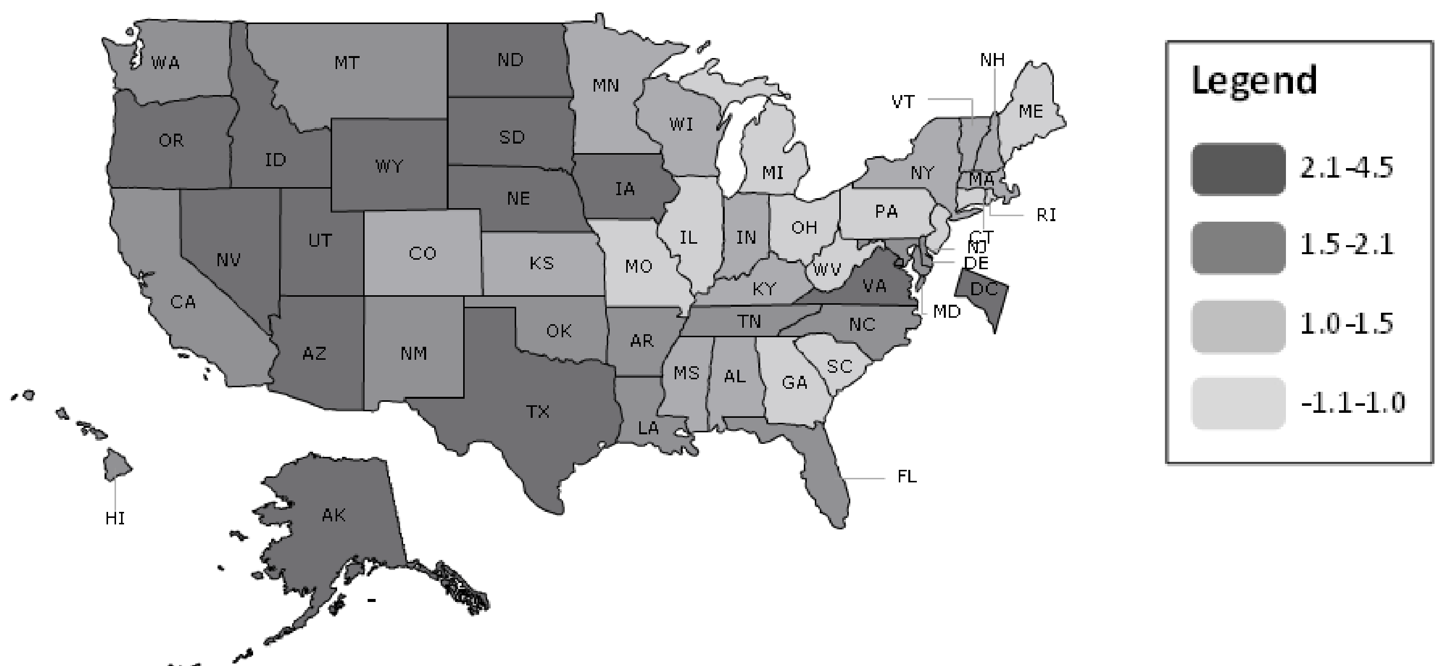


Figure III-2. Percentage Real GDP Growth by State, 2001-2010. (GDP = population × per capita production and consumption of goods and services in the aggregate.) (Data and interactive mapper compliments of U.S. Bureau of Economic Analysis.)

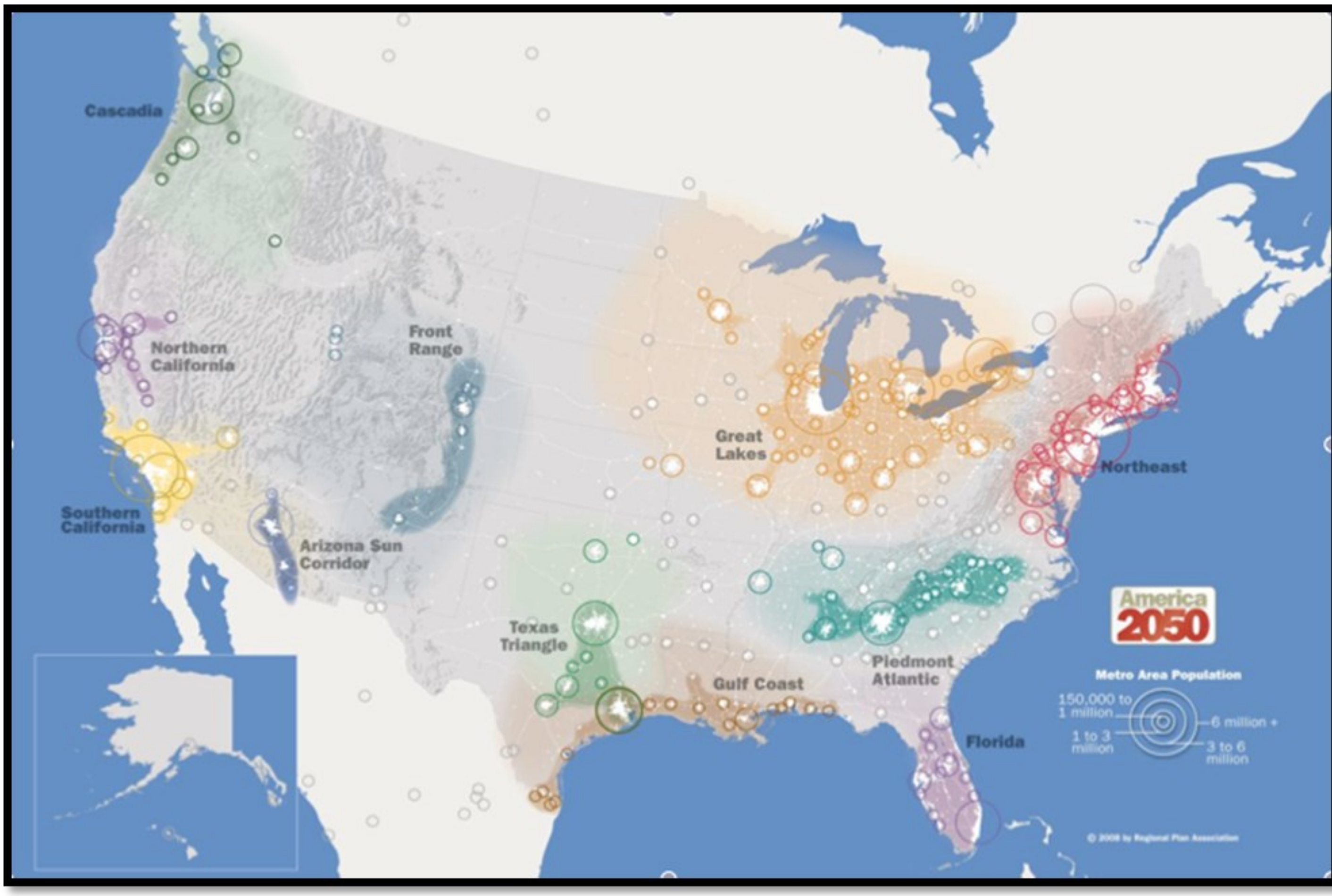


Figure III-3. "Megaregions" of Disproportionate Population and Economic Growth Planning. (Credits: America 2050, a program of Regional Plan Association.)

At the other end of the precipitation spectrum, more intense rainfall will lead to increases in the frequency, and potentially the duration, of high-magnitude flows in streams. The frequency of high-flow events helps to define the composition and relative abundance of species that make up aquatic and riparian communities; i.e., species' life histories are adapted to particular flow regimes (Poff et al. 1997). As the frequency and duration of high-magnitude events increases, the composition of associated plant communities is expected to change with more frequent disturbance/scouring of habitats and the disruption of environmental cues that trigger certain life history events such as fish spawning (Poff et al. 1997, Lytle and Poff 2004).

At the other end of the precipitation spectrum, more intense rainfall will lead to increases in the frequency, and potentially the duration, of high-magnitude flows in streams.

At higher latitudes and elevations, the type of winter precipitation is expected to shift to more rain and less snow as the climate warms. This pattern is already observable in many parts of the U.S. (Feng and Hu 2007, Miller and Piechota 2011). In addition to less snow, snowmelt is occurring earlier in the spring (Stewart et al. 2005). Both of these factors have substantial implications with regard to seasonal flows and water availability in mountain snowpack-dependent areas such as much of the western U.S. Snowpacks are natural reservoirs, storing precipitation in the winter and releasing it over a relatively predictable period during the late spring and early summer. With more rain and less snow, winter flows increase and reduced flows occur in the spring. This can adversely affect aquatic and riparian species that are adapted to flows of predictable timing and magnitude (see also the phenology chapter), as well as human communities that depend on spring runoff for agricultural and other purposes.

<u>Water Temperature</u>

Stream water temperatures are expected to rise as a consequence of increasing surface temperatures, particularly in sub-alpine locations (van Vliet et al. 2011). An increase in the relative contribution of rain versus snow in winter precipitation will also result in higher water temperatures. The extent to which water temperatures rise will vary locally, depending primarily on elevation and the relative contribution of groundwater (base flow) to total stream flow. High alpine streams fed by melting snow will remain cold. Streams that are highly dependent on groundwater input generally will not exhibit as much variation in temperature as those with little or no groundwater contribution. However, the relative contribution of groundwater is already decreasing in some snowmelt-dominated systems where earlier spring runoff has led to decreased summer base flows, thereby increasing summer stream temperatures (Mayer and Naman 2011).

An increase in water temperatures will have potentially severe consequences for cold-water fishes and the conservation efforts therefor (Mantua et al. 2010). Habitats suitable for these species will become increasingly restricted to higher elevations, and these species may disappear where such "climate refugia" are not available (Shoo et al. 2011:1, Keppel et al. 2012:398). Habitat and population fragmentation will increase accordingly. This will likely lead to regional extirpations as stochastic events such as droughts and wildfires transform the remaining habitats (Isaak et al. 2012). For species with small and non-expanding geographic ranges, such extirpations may lead to species endangerment and ultimately extinction.

Rising water temperatures also affect environmental contaminants and invasive species (addressed in separate chapters).

INVASIVE SPECIES

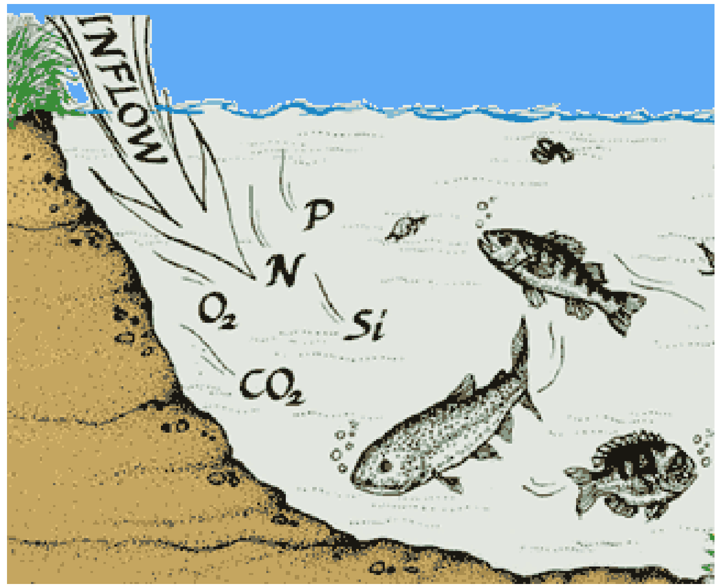
Invasive species are one of the biggest threats to biodiversity and ecosystem services. The damage from invasive species worldwide is estimated at more than $1.4 trillion annually, with impacts across a wide range of economic sectors including agriculture, forestry, aquaculture, transportation, trade, power generation and recreation (Pimentel et al. 2001, TNC 2011). Conversely, growth and trade in those same sectors is a root cause of species invasions (Ericson 2005, Kelly 2007). Invasive species are especially problematic in island ecosystems, where they have been responsible for one half to two thirds of all species extinctions in modern times (Donlan and Wilcox 2008, IUCN 2009). They are the leading cause of species endangerment in the U.S. and the sixth leading cause on the contiguous mainland (Czech et al. 2000).

The federal definition of an invasive species is "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (Executive Order 13112, February 3, 1999). The coherence of this definition is challenged by climate change. An "alien species" is defined as one "not native to that ecosystem," but there are no clear and lasting criteria for determining what is "native" in the context of climate change. Species' ranges shift as a function of climate change; are such species "non-native" in their new geographic ranges? Refuge managers will have to address these questions on a case-by-case basis. Although climate change challenges existing concepts of invasive species, few would argue with the fact that invasive species exist and are extremely challenging to wildlife conservation.

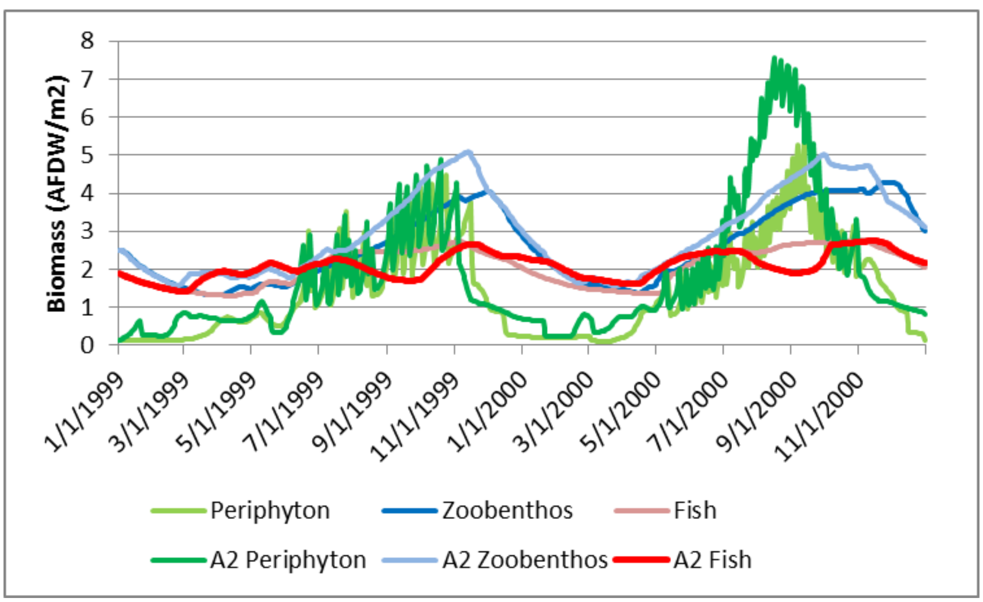
Climate change increases opportunities for invasive species because invasive species tend to be more adaptable than non-invasive species to environmental disturbance (Mächler and Altermatt 2012). With more environmental tolerance than that of native species, invasive species have a larger array of suitable habitats (Walther et al. 2009). Warmer air and water temperatures may also facilitate movement of species along previously inaccessible pathways (Burgiel and Muir, 2010). Invasive species also compete for resources that become scarcer in

Case Study: Application of AQUATOX to the Rum River near Sherburne NWR

AQUATOX is a mechanistic, aquatic ecosystem model distributed by the U.S. Environmental Protection Agency (Park et al. 2008). One of the simulation files distributed by the EPA is of a site on the Rum River within six miles of Sherburne National Wildlife Refuge (Minnesota). As an example of how the model may be used on the Refuge System, the study file for the Rum River was recalibrated slightly from the original application (Carleton et al. 2009) to better represent the fish community, including species that are potential prey for sandhill cranes (*Grus canadensis*) and bald eagles (*Haliaeetus leucocephalus*). The average annual water temperature was increased by 2.8⁰C to approximate the change for Minnesota in 2041 predicted for the high-emissions (A2) scenario using multiple climate models . Flow rate was not changed because only a 5% increase in precipitation is anticipated, with no change during the summer growing season.



Based on these parameters AQUATOX predicts that net primary productivity will increase from 346 to 382 g/m^2 year; secondary and tertiary productivity will increase from 32.2 to 36 g/m^2yr. Biomass of the periphyton and benthic invertebrates will increase. AQUATOX also predicts that bluegill (*Lepomis macrochirus*) and smallmouth bass (*Micropterus dolomieu*) will increase, northern pike (*Esox lucius*) and walleye (*Sander vitreus*) will decline slightly; and sculpin (*Cottoidea* spp.) will develop a bimodal annual response as their optimum temperature is exceeded in the summer.



Baseline data for calibrating the model run.

some areas due to climate change, such as water in the Southwest.

Evidence exists for coevolution between invasive and native species. For example, garlic mustard (*Alliaria petiolata*), not native to the U.S., produces sinigrin. Sinigrin is allelopathic to the fungi that help native plants extract nutrients from the soil. Research in the U.S. has shown that garlic mustard produces more sinigrin in areas where native plants such as clearweed (*Pilea pumila*) are present and that clearweed expresses higher levels of resistance to sinigrin in areas where the two species have a longer history of coexistence (Lankau 2012). These types of co-evolutionary adaptations may be disrupted by differential effects of climate change on species. A shift in temperature, for example, might have a significant impact on a native species, but little or slower impact on an invasive species, thereby altering the dynamic between them. Similarly, changes in precipitation patterns, CO_2 levels and nitrogen deposition may have differential effects on native and invasive plants (Richardson et al. 2000).

Changes in competitive dynamics will not be uniform globally or nationally, particularly when considering changes across tropical vs. temperate systems or low vs. high-altitude systems. Higher latitudes and altitudes will probably host shifting sets of species as temperatures increase and "new" species arrive from adjacent, previously warmer climates (Parmesan 2006). As the warmest tropical ecosystems warm even more, they will not face the same threat because there is no pool of species coming from even warmer climes. However, changes in precipitation and other climatic variables may still stress such ecosystems, thereby increasing their vulnerability to invasive species. Conversely, there may be range contraction or diminished impacts of invasive species depending on the influence of climatic and other variables (Hellman et al. 2008, Richardson et al. 2000).

Changes in flood and drought cycles, fire regimes, and permafrost stability will be advantageous to invasive species. Storms increase the disturbance of habitats already providing opportunities for invasive species. A pronounced example was after the major tsunami in Southeast Asia in 2004, when "Sri Lanka

Climate change increases opportunities for invasive species because invasive species tend to be more adaptable than non-invasive species to environmental disturbance.

witnessed a significant expansion of prickly pear cactus *(Opuntia dillennii)*, mesquite *(Prosopis juliflora)*, lantana *(Lantana camara)* and Siam weed *(Chromolaena odorata)* in degraded coastal areas, as well as of water hyacinth *(Eichhornia crassipes)* and cattails *(Typha angustifolia)* in lagoons and estuaries" (Burgiel and Muir 2010:9; see also Bambaradeniya et al. 2006). A hurricane can stir the elements of indoor and outdoor environments, too, and in the process exacerbate or cause invasive species problems. For example, lionfish (*Pterois volitans*) were evidently "introduced into Atlantic waters when a Florida aquarium was damaged during Hurricane Andrew in 1992" (Pappal 2010:3).

Climate change may also alter the physiology of plant tissue, with far-reaching effects. For example, increased CO_2 levels increase the rigidity of plant tissue and reduce the efficacy of glyphosate (Ziska et al. 2004), which is sometimes used for invasive species control (as well as in agricultural production). Another important method for invasive species management, biological control, is dependent on specific relationships of target species with control agents. As an invasive species' range shifts, so might the range of the biological control agent be expected to shift, at least to the extent that the fitness of the agent is enhanced by the host. But climate change may alter the interactions between host and agent (van Asch and Visser 2007), with unpredictable effects on population dynamics.

Some of the effects of climate change on invasive species have clear implications for human health. For example, growth rates and pollen production of ragweed (*Ambrosia sp.*) increase sharply in response to higher CO_2 concentration (Wayne et al. 2002). Meanwhile, increased nitrogen deposition (typical in and around agricultural landscapes) increases overall plant size, reduces herbivory, and also raises pollen production (Throop and Lerdau 2004). These synergistic effects on ragweed vigor and pollen contribute to respiratory problems including asthma.

New pathways for invasion and unforeseen economic developments have the potential to exacerbate the invasive-species effects of climate change. For example, receding ice is opening the Arctic to new types and levels of economic activity. Williams et al. (2011:4) described how, "Over the next 20 years, shipping, oil and gas, mining, tourism and aquaculture will be the key sectors of economic activity" in the Arctic. Meanwhile warmer water temperatures will allow invasive species to live longer in ship ballast and on ship hulls, two of the primary marine vectors for invasive species (Johnson et al. 2006). Similarly in other regions, alternative energy companies may want to use invasive plants for biofuels, and large-scale wind and solar energy projects may disturb intact ecosystems, thereby facilitating species invasions. In general, "Wider global issues such as climate change, economic growth, population increase, and an increase in food and energy demand will have a notable effect on resource-rich corners of the planet" (Williams et al. 2011:21). All of these factors are interrelated, and all are related to the spread of invasive species.

Sea-Level Rise

Eustatic and Relative Sea-Level Rise

During Earth's geological history, eustatic (i.e., global and due to the volume of oceanic water) sea level has risen and fallen many times, but is now rising at a relatively rapid and accelerating rate due to climate change (IPCC 2007a). Global warming, in particular, causes sea-level rise via thermal expansion of ocean water, melting of small glaciers, and melting of ice sheets in Greenland and Antarctica.

Global mean sea level rose approximately 19 cm from 1901-2010 (IPCC 2013), corresponding to an average of 1.7 mm per year. However, satellite altimetry measurements indicate a rate of 3.2 mm per year from 1993-2010 (IPCC 2013). Published schedules of projected sea-level rise typically call for accelerating rates throughout or during most of the 21st century (see for example Rahmstorf 2012). Eventually the rate of sea-level rise is expected to decline, partly due to the liquidation of ice stocks. However, the geophysical momentum of ice-mass melting as well as deep oceanic heating is such that sea-level rise will be ongoing for centuries, even if greenhouse gases and temperatures stabilize in the 21st or 22nd century (Meehl et al. 2012).

A well-known range of sea-level rise projections for the 21st century is 0.18-0.59 m. This range corresponds to a suite of climate scenarios described by the IPCC in its Fourth Assessment (Meehl et al. 2007a). However, peer-reviewed projections of sea-level rise have increased as more variables have been analyzed (Overpeck and Weiss 2009). Even within the Fourth Assessment, Nicholls et al. (2007:317) described an expectation of "an accelerated rise in sea level of up to 0.6 m or more by 2100." Vermeer and Rahmstorf (2009) developed a model for linking global sea-level variations to global mean temperatures. The model was corroborated with data from 1880–2000. Building on the model with IPCC global temperature scenarios, they projected sea-level increases from 0.75-1.90 m by 2100. The range in estimates results from uncertainties about future rates of economic growth (including population and per capita

New pathways for invasion and unforeseen economic developments have the potential to exacerbate the invasive-species effects of climate change. For example, receding ice is opening the Arctic to new types and levels of economic activity.

consumption growth), greenhouse gas emissions per unit of GDP, the melting of Antarctic and Greenland ice sheets, and the significance of montane glaciers in the planetary water budget (Meier et al. 2007). However, the "take-home point of the new work" (Overpeck and Weiss 2009:21461) "is that it would be wise to assume that global sea-level rise could significantly exceed 1 m by 2100 unless dramatic efforts are soon made to reduce global greenhouse gas emissions."

One of the latest efforts to assess and summarize 21st century sea-level rise scenarios was conducted by Parris et al. (2012) to assist in the development of the *National Climate Assessment* (USGCRP Draft). Parris et al. (2012:10) expressed "very high confidence (>9 in 10 chance) that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100." They also referred to a 0.5-m scenario and a 1.2-m scenario as "intermediate-low" and "intermediate-high," respectively. Parris et al. (2012:15) also recommended "that the choice of scenarios involve interdisciplinary scientific experts, as well as coastal managers and planners who understand relevant decision factors."

Based on the best available peer-reviewed science, refuge managers and planners should explicitly plan for 1-1.5 m eustatic sea-level rise by the year 2100. In addition to being scientifically defensible, this approach will ensure consistency among Refuge System planning documents and public outreach efforts. There is also precedent for using this range of planning scenarios on the Refuge System based on the use of SLAMM analysis (see below).

Numerous factors unrelated or indirectly related to eustatic sea-level rise also influence regional and local rates of sea-level rise, or "relative" sea-level rise. Such factors include subsidence due to subsurface extraction (most notably of groundwater and oil), exposure to winds and ocean currents, tidal range, sediment supply, sediment transport, localized climate, latitude, wetland drainage, deforestation, and effectiveness of artificial coastal defenses (Inman 1994, Brooks et al. 2006, IPCC 2007a). Geological processes including plate tectonics and post-glacial ("isostatic") rebound also affect sea levels over large areas.

The geophysical momentum of ice-mass melting as well as deep oceanic heating is such that sea-level rise will be ongoing for centuries, even if greenhouse gases and temperatures stabilize in the 21st or 22nd century.

The amount and extent of tectonic movement depends on the geomorphology of the coast, and the particular type of coast is an important consideration when assessing potential effects of sea-level rise. The three major types of tectonic coasts are collision, trailing edge, and marginal sea coasts (Inman 1994). Additional specific coastal types include arctic coasts and coral reef coasts. Each coastal type is represented in the U.S (Table III-2).

Post-glacial or "isostatic" rebound refers to the rising of the earth's crust after being compressed by glaciers, in this case by the Laurentide ice sheet of the Wisconsin glacial episode, the last glacial period of the Pleistocene ice ages. The rate and extent of isostatic rebound depends on the viscosity of the earth's mantle and the elasticity of the lithosphere of a particular region (Fowler 1990). In North America some of the highest rates of post-glacial rebound are in Alaska and reduce the vulnerability of some Alaskan refuges to sea-level rise. Meanwhile some of the highest rates of subsidence are along the Gulf of Mexico coast, especially in Louisiana (Tidwell 2003, National Research Council 2006).

Modeling the Effects of Sea-level Rise

A variety of models are available to help predict effects of sea-level rise on coastal refuges. Digital elevation models (DEMs) have been developed by the National Geophysical Data Center (NGDC) and the University of Arizona. Some DEMs are topographic in nature, some are bathymetric, and some have both components

(Divins and Metzger 2007). DEMs are useful for quickly identifying areas susceptible to sea-level rise and performing simple "bathtub-ring" projections of future shorelines.

Proceeding toward more complex analysis, the U.S. Geological Survey's (USGS) Coastal Vulnerability Index (CVI) is a physical model accounting for tidal range, wave height, coastal slope, shoreline change, geomorphology, and historic rate of relative sea-level rise. The six parameters are quantified and summed, and cumulative CVI scores range from 1-40 (low to high vulnerability, respectively). The USGS has calculated CVIs for the Gulf Coast region, Atlantic Coast, and Pacific Coast. Similar to bathtub models, a CVI score can provide refuge planners with a quick assessment of the relative vulnerability of long stretches of coastline, but the CVI is not an ecological index.

The most widely used sea-level rise model on the Refuge System is the Sea Level Affecting Marshes Model (SLAMM). SLAMM was developed in the 1980s by Dick Park at Butler University. Park continued developing SLAMM over the next 15 years with colleagues at Butler and Indiana University. Since then Jonathan Clough of Warren Pinnacle Consulting (Waitsfield, Vermont) has been the primary SLAMM developer and modeler through versions 5, 6, and 6.1 beta.

SLAMM is the primary tool for sea-level rise planning on the Refuge System due to a unique combination of characteristics. Most notably it is a long-tested, freely available, transparent, spatially explicit model (necessary for producing maps). It is applicable at the refuge, regional, and national level and conducive to systematic usage and economies of scale. Furthermore, it is tailored to use with the Classification of Wetlands and Deepwater Habitats of the United States, the wetland classification system that evolved from the well-known "Cowardin system" (Cowardin et al. 1979, FGDC 2005). This modified Cowardin system is used by the FWS National Wetlands Inventory (NWI) to map and monitor wetlands on (and off) refuges.

The primary processes that SLAMM models and integrates are inundation by saltwater, erosion of shoreline, vertical accretion of sediments and plant material, barrier island overwash, and saturation of uplands with fresh water resulting from rising water tables. Each of these processes is instrumental in determining the development or devolution of coastal marshes and related habitats including beaches, mudflats, and swamps. SLAMM does not account for complex hydrodynamics (such as labyrinthine channeling effects), sediment transport, differentiation of substrate, or offshore effects (such as sea-grass ecology). Details of the model's logical structure, assumptions, equations and algorithms are found in the technical documentation (Clough et al. 2010). A user's manual is also available (Warren Pinnacle Consulting 2010).

The primary outputs of SLAMM for refuge planning purposes are data tables and maps that help predict the location and extent of marshes and other coastal ecosystems. This is useful for ecosystem management and planning, but on any given refuge, more detailed planning and management may be called for because of the particular effects of sea-level rise on fish and wildlife habitats and populations. An example is salinization, which may occur through a variety of processes, including tides, storm surges, saline pollutants, and the release of marine water from geologic formations (FAO 1997). Sea-level rise exacerbates these processes as well as directly causing inundation and salinization.

Based on the best available peer-reviewed science, refuge managers and planners should explicitly plan for 1-1.5 m eustatic sea-level rise by the year 2100. In addition to being scientifically defensible, this approach will ensure consistency among Refuge System planning documents and public outreach efforts.

Salinization threatens water supplies and many aquatic species. Salinity ranges change gradually from open ocean to freshwater zones. At the interface of freshwater and saltwater, there is also seasonal variation in the degree of salinity due to seasonal freshwater runoff (Murawski 1993, Nuttle et al. 2000).

Species' responses to sea-level rise and salinization depend on their salt tolerance, inundation tolerance, nutrient availability, and other factors such as capacity for ecological reorganization. Some species may be able to move inland to avoid the presence of excessive salinity (Williams et al. 1999, Hull and Titus 1986). If a species is not able to move inland (e.g., if movement is blocked by coastal development), it may become extirpated from long stretches of coastline, endangered, and potentially driven extinct.

Status of SLAMM Modeling on the Refuge System

The Refuge System includes 173 marine coastal refuges. SLAMM is not significantly applicable to 26 of these refuges where rocky islands are the predominant feature. Also, SLAMM is not yet applicable or appropriate for the ten Alaskan coastal refuges (with some localized exceptions) or Palmyra Atoll (central Pacific Ocean) because of a lack of high-quality elevation and wetlands data. All other (136) coastal refuges possessed a SLAMM analysis as of April 2012, and 16 refuges had undergone "re-SLAMMing" by April 2013.

The large number of Refuge System SLAMM reports is, of itself, not a measure of success in sea-level rise planning or adaptation, much less mitigation. However, it ensures that each coastal refuge for which sea-level rise is a significant issue is equipped with an analysis based on sound science. A SLAMM analysis enables coastal refuge managers and planners to meet the charge of Secretarial Order 3226, Secretarial Order 3289, the FWS Climate Change Strategic Plan, and other policies calling for climate change and sea-level rise planning on the Refuge System.

Future developments in Refuge System SLAMM analysis include improvement of the model, data acquisition for Alaskan SLAMM analysis, incorporation of Sedimentation-Erosion Table (SET) data for finer and more localized accretion rate inputs, species-specific applications, and landscape-level assessments.

Czech et al. (in preparation) are developing a cumulative SLAMM analysis of Atlantic Coast refuges. Preliminary results based on a 1-m sea-level rise scenario (by 2100) are highlighted by significant gains in open water (primarily oceanic and estuarine), losses of dry land, and substantial loss of cypress swamp, tidal swamp, other low swamp forests, and brackish (irregularly flooded) marsh. Somewhat surprisingly, substantial gains of salt marsh are projected, although these gains are not projected under higher sea-level rise scenarios.

SLAMM is the primary tool for sea-level rise planning on the Refuge System due to a unique combination of characteristics. Most notably it is a long-tested, freely available, transparent, spatially explicit model (necessary for producing maps). It is applicable at the refuge, regional, and national level and conducive to systematic usage and economies of scale.

Coastal Type	Location	Features	Significance
Collision Coast	California	Narrow shelves, wave-cut cliffs, sediment from rivers	Beaches erode easily from high wave energy events, cliffs with urban infrastructure may be compromised.
Trailing-Edge Coast	Mid-Atlantic	Wide shelf with coastal plains, large estuaries, sediment from beach erosion	Relative sea-level rise causes shoreline recession and barrier islands to migrate.
Marginal Sea Coast	Mid-Atlantic	Similar to trailing-edge but less wave energy, sediment from river deltas	Similar to trailing-edge effects.
Arctic Coast	Alaska	Broad shelf with coastal plains, small tidal amplitudes, ice/water controlled by wind	Coast frozen in winter leading to ice push phenomena. Thawing in summer leads to erosion.
Coral Reef Coast	Hawaii	Dependent on latitudinal conditions and biogenics of reefs, sediment from corals, algae, foraminifera	Light, temperature, and nutrients are critical; increased depth and temperature compromise reef health.

Table III-2. Examples of Coastal Types within the U.S. (based on Inman 1994).

Case Study: Forest Retreat Along the Gulf Coast

Forest retreat due to sea-level rise depends on geomorphology and soil characteristics. Williams et al. (1999) proposed three major categories for considering the prospects of coastal forest resilience:

- Low-lying limestone coastlines such as on the west coast of Florida
- Deltaic coastlines such as in Louisiana
- Sandy coastlines

The major change to plant communities of low-lying limestone coasts is a lack of seedling regeneration due to excess salt, leading to non-viability of certain tree species. In contrast, the major stress on tree species in a deltaic system is flooding which eliminates flood-intolerant species. Soil characteristics add another layer of complexity. In this example, it is clear that although an observable response to sea-level rise is the same (i.e., forest retreat) the mechanisms are different (salinization versus inundation). Detecting and monitoring causes of forest retreat will be a key to strategic habitat conservation in coastal ecosystem.

The large number of Refuge System SLAMM reports is, of itself, not a measure of success in sea-level rise planning or adaptation, much less mitigation. However, it ensures that each coastal refuge for which sea-level rise is a significant issue is equipped with an analysis based on sound science.

Case Study: SLAMM Analysis of Swanquarter National Wildlife Refuge

One of the first FWS SLAMM analyses was of Swanquarter in 2006. Between then and 2012, projections of eustatic sea-level increased, two significant phases of SLAMM development occurred (from SLAMM 4.0 to SLAMM 6.0), LiDAR-derived elevation data became available, and the NWI layer was updated. Therefore in 2012 Swanquarter was "re-SLAMMed" with the new parameter values and with the additional sea-level rise scenarios of 1, 1.5, and 2 m by 2100.

Sample of parameter values for the 2012 Swanquarter SLAMM analysis.

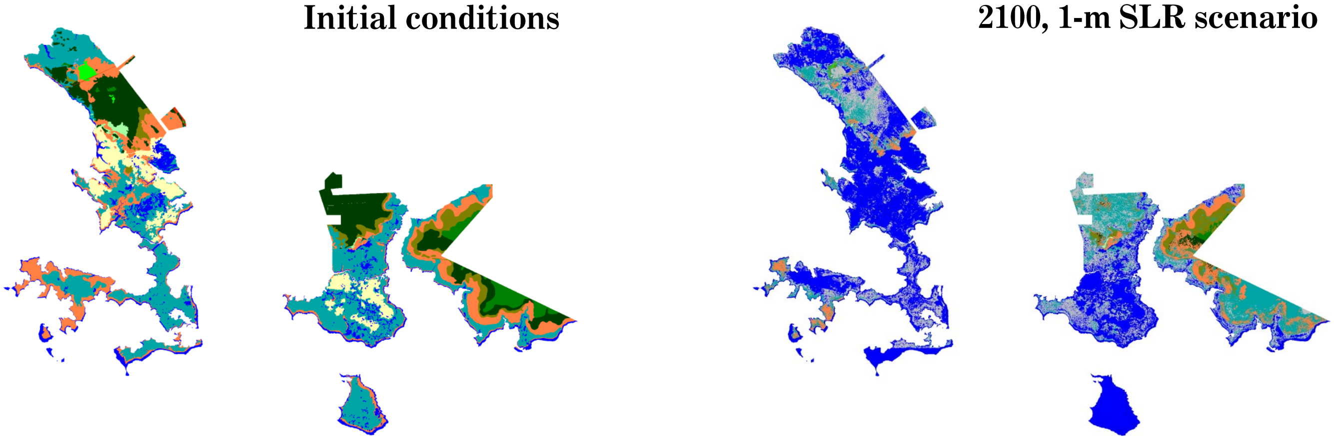
Parameter	Value	Parameter	Value
NWI Photo Date (YYYY)	2010	Marsh Erosion (horizontal m /yr)	1.8
Digital Elevation Model Date (YYYY)	2007	Tidal Flat Erosion (horizontal m /yr)	0.5
Direction Offshore [n,s,e,w]	South	Regularly Flooded Marsh Accretion (mm/yr)	3.7
Historic Trend (mm/yr)	2.66	Irregularly Flooded Marsh Accretion (mm/yr)	4.1
MTL-NAVD88 correction (m)	-0.03	Swamp Accretion (mm/yr)	0.3
Great Diurnal Tide Range (m)	0.127	Beach Sedimentation Rate (mm/yr)	0.5
Salt Elevation (m above MTL)	0.19	Frequency of Overwash (years)	25

Swanquarter is highly vulnerable to sea-level rise. Most of the tidal swamp and much of the salt marsh and brackish marsh habitats are projected to disappear by 2100.

Regularly-flooded Marsh	
Irregularly-flooded Marsh	
Tidal Swamp	
Estuarine Open Water	
Estuarine Beach	
Transitional Salt Marsh	
Swamp	
Tidal Fresh Marsh	
Inland Fresh Marsh	
Undeveloped Dry Land	
Inland Open Water	
Open Ocean	
Tidal Flat	

Land cover category (major categories only)	Initial acreage	Land cover loss by 2100, three SLR scenarios		
		0.69 m	1 m	1.5 m
Regularly-flooded Marsh	6079	20%	54%	72%
Irregularly-flooded Marsh	3299	26%	62%	97%
Tidal Swamp	2601	84%	96%	100%
Estuarine Beach	1447	79%	98%	100%
Transitional Salt Marsh	783	13%	41%	91%
Swamp	486	75%	89%	100%

Initial conditions **2100, 1-m SLR scenario**



Southwest Desertification

The United Nations Convention to Combat Desertification defined desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (United Nations 1994). The term "desertification" has connotations that pertain as much to cultural and economic welfare as to ecological processes, especially in international forums (Hutchinson 1996, Adeel et al. 2007). Perhaps for that reason, "desertification" is not a frequently used term in North America climate or ecological science. For example, it was not included in the 1193-page draft *National Climate Assessment* issued by the U.S. Global Change Research Program in January 2013 (USGCRP Draft). However, it is not uncommon in the jargon of land-management gray literature and it does have clear ecological implications.

The area covered by North American deserts – Chihuahuan, Great Basin, Sonoran, and Mojave –was approximately 1,277,000 square kilometers during the latter decades of the 20th century (MacMahon 1988 as cited in Peinado et al. 1995). Desertification had affected approximately 950,000 North American square kilometers by the beginning of the 21st century (GEF and IFAD 2002). Desertification often manifests as the replacement of somewhat homogeneous grasslands with spatially complex shrublands having little herbaceous cover (Schlesinger et al. 1990, Brown et al. 1997).

Climate change is predicted to increase desertification in the Southwest, both in the near future and in the long term (Seager et al. 2007, Manabe et al. 2004). This will affect at least six LCCs (Table III-3), especially the Desert LCC but also the Great Basin, California, Southern Rockies, Great Plains, Gulf Coast Prairie, and Great Northern LCCs, roughly in that order of desertification.

Desert	LCC
Great Basin	**Great Basin Great Northern Southern Rockies**
Sonoran	**Desert California**
Chihuahuan	**Desert Gulf Coast Prairie Great Plains**
Mojave	**Desert Southern Rockies Great Basin California**

Table III-3. Landscape Conservation Cooperatives Corresponding With North American Deserts. Prominence of deserts (in the U.S.) and LCCs is indicated by order presented in columns 1 and 2, respectively.

In addition to desertification per se (i.e., as consistent with the UN definition), the cumulative North American desert has been increasing in size and will continue to do so (Manabe et al. 2004), including as part of a poleward expansion of subtropical dry regions (Seager et al. 2007). For example, Weiss and Overpeck (2005:2065) suggested that "ecological responses may include contraction of the overall boundary of the Sonoran Desert in the south-east and expansion northward, eastward, and upward in elevation" for a net gain in Sonoran area. However, they also noted the likelihood for a different type of Sonoran Desert over at least some of its general range, given the unlikelihood of wholesale movement of the ecosystem.

Regardless of the classification of ecosystems as "desert" or the nuanced aspects of "desertification," increasing winter and spring temperatures have characterized the Southwest for several decades and the frost-free season is lengthening (Hoerling et al. 2012). Although there is more variability (geographic and temporal) associated with precipitation, the Southwest as a whole is becoming drier (Seager et al. 2007). [Note to designer: Capitalize "increasing" in the highlight box.]

Increasing winter and spring temperatures have characterized the Southwest for several decades and the frost-free season is lengthening Although there is more variability (geographic and temporal) associated with precipitation, the Southwest as a whole is becoming drier.

Southwest precipitation is characterized by a bimodal regime with rainfall peaks in summer and winter (Sprigg and Hinkley 2000). Recent modeling suggests that the summer "monsoon" season is likely to be less intense (with less rainfall) in June and July but more intense in September. The general effect is expected to be a delayed monsoon season extending somewhat into October (Cook and Seager 2013). Although there are discrepancies among models (see Seager et al. 2007, Sprigg and Hinkley 2000), some predict an increase in winter precipitation (IPCC 2001b, Felzer and Heard 1999). Unusually wet winters in the Southwest have contributed to the expansion of shrub vegetation, with cascading ecological effects (Turner et al. 2003).

Increasing temperatures coupled with recent drought have been implicated in desertification and related effects including the modification of vegetative communities (Weiss and Overpeck 2005), tree mortality (Allen et al. 2010), increasing fire frequency (Westerling et al. 2006), insect outbreaks (Bentz et al. 2010), and effects on wildlife distribution and abundance. Grasslands in the Sonoran and Chihuahuan deserts have been shifting to a shrubbier coverage (Dick-Peddie 1993) due to the advantage of C3 over C4 plants under higher CO_2 levels (Wilson et al. 2001 as cited in Webb et al. 2002). For example, the woody C3 honey mesquite (*Prosopis glandulosa*) has increased substantially on C4 grasslands dominated by little bluestem (*Schizachyrium scoparium*) in the last 150 years (Polley et al. 1994). Bare soil area is also increasing while the surface litter cover decreases (Asner and Heidebrecht 2005), diminishing habitat suitability for the species adapted to the erstwhile environment.

Grassland species such as the banner-tailed kangaroo rat (*Dipodomys spectabilis*) have been extirpated from some areas, whereas shrubland species such as Bailey's pocket mouse (*Chaetodipus baileyi*) have become more abundant. With the decline of some rodents, predators such as the Mojave green rattlesnake (*Crotalus scutulatus*) and burrowing owl (*Athene cuniculria*) have also declined.

Resident and migratory grassland species will continue to be negatively affected by desertification. Grassland birds such as the aplomado falcon (*Falco femoralis*), reptiles such as the sand dune lizard (*Sceloporus graciosus arenicolous*), mammals like the pronghorn antelope (*Antilocapra americana*), white-sided jackrabbit (*Lepus callotis*), and kit fox (*Vulpes macrotis*), as well as other wildlife characteristic of the Chihuahuan desert (Desmond and Montoya 2006) are some of the species likely to be impacted by grassland loss. Many species endemic to the Southwest, such as the white-sided jackrabbit, are fairly dependent on desert grassland (Desmond 2004).

Soil moisture is also expected to decrease in the Southwest (IPCC 2001b), as is surface runoff (Seager et al. 2012). These expectations are due to decreased annual precipitation and increased evaporation and evapotranspiration, especially in the summer and due to higher temperatures (Manabe et al. 2004). Dryland vegetation depends on soil moisture to sustain growth through dry periods (USGS 2006a).

Reduced soil moisture and runoff will affect many species in the Southwest, including threatened species such as the endemic Pecos sunflower (*Helianthus paradoxus*) (Bush 2006). The sunflower grows in wet alkaline soils along spring seeps, wet meadows, and pond margins of New Mexico and Texas (FWS 2005). It also grows in riparian ecosystems including Sonoran riparian *Populus-Salix* forests (Stromberg et al. 1996), which are characterized by species richness and habitat for other endangered species including the willow flycatcher (*Empidonax traillii*) (van Riper III et al. 2004). Impacts of desertification on riparian vegetation could also affect migratory birds such as the bald eagle (*Haliaeetus leucocephalus*), which congregates in riparian areas through the Southwest in winter for feeding purposes (van Riper III et al. 2004).

Prairie Pothole Dynamics

The Prairie Pothole Region (PPR) occupies >800,000 km^2 where areas of high wetland density intersect with grasslands of the northern Great Plains (Figure III-4). Precipitation is the primary water source for prairie pothole wetlands (Winter 1989), which are generally small (< 0.5 ha) and isolated (Kantrud et al. 1989). Water loss is due mainly to evapotranspiration, which exceeds precipitation across most of the PPR, with highest deficits in the western PPR (Winter 1989).

Prairie pothole wetlands exhibit a continuum of characteristics and water permanence (Euliss et al. 2004), but are generally classified as having temporary, seasonal, semipermanent, and permanent water regimes (Cowardin et al. 1979). Short-term drying is an important aspect of prairie pothole ecology. In fact, varying wetland water levels, which can fluctuate dramatically within and among years, are major drivers of the ecological functions of wetlands, influencing primary productivity, water salinity, nutrient cycling, invertebrate communities, composition and configuration of emergent vegetation, and wildlife population dynamics (Kantrud et al. 1989, Murkin et al. 1997, van der Valk 2005a).

Prairie pothole wetlands are extremely productive because their shallow waters warm early in spring and their dynamic nature facilitates nutrient cycling and regeneration of vegetation and associated macro-invertebrates (van der Valk 2005b). High primary and secondary productivity are largely responsible for the ability of prairie potholes to attract and support large numbers of wildlife. The PPR has long been known for hosting >50% of North America's ducks (Batt et al. 1989, Zimpfer et al. 2011) and harbors similar large proportions of many species of grassland birds, shorebirds, and waterbirds (Peterjohn and Sauer 1999, Beyersbergen et al. 2004). Mammals also play an important role in the ecosystem. Muskrats (*Ondatra zibethicus*) are important wetland grazers, and meadow voles (*Microtus pennsylvanicus*) are a major prey species for carnivores (Fritzell 1989).

Prairie potholes have declined in number and quality due largely to agricultural disturbance, as agriculture is the dominant land use in the region (Doherty et al. 2013). Drainage rates vary across the region, ranging from >85% in the eastern portion of the PPR to 27% in the western PPR (Dahl 2006, Johnson et al. 2008). Agriculture has altered historic disturbance regimes, increasing sedimentation and altering the structure and species composition of wetland vegetation (Kantrud et al. 1989, Bartzen et al. 2010). In addition, runoff containing pesticides has been shown to reduce aquatic invertebrates (Grue et al. 1998). Wetlands, grasslands, and associated species in the PPR now appear to be at risk from climate change as well.

Because waterfowl population size, nesting propensity, and clutch size are positively related to wetland numbers (Sorenson et al. 1998, Pietz et al. 2000), declines in the number and distribution of wetland basins containing water during the breeding season would reduce the ability of the PPR to attract and produce waterfowl. Because nesting success of upland-nesting waterfowl is positively related to the amount of grass in the landscape (Bethke and Nudds 1995, Stephens et al. 2005, Reynolds et al. 2006), declines in the amount of grassland in the landscape would also reduce waterfowl production in the PPR.

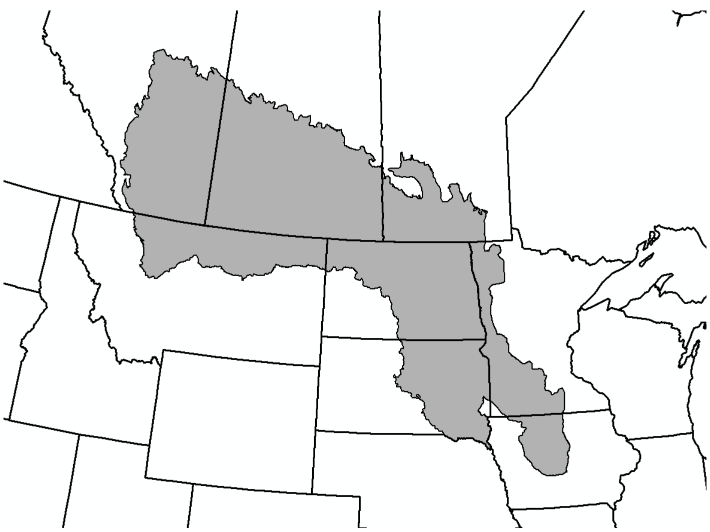


Figure III-4. The Prairie Pothole Region (PPR). The PPR is where high wetland densities intersect with grasslands of the northern Great Plains. (Credit: U.S. Fish and Wildlife Service, Habitat and Population Evaluation Team Office, Bismarck, North Dakota.)

Predicted Changes in Temperature and Precipitation

A variety of models project that future temperatures and precipitation in the PPR will be higher than historic levels, although models recognized by the IPCC are highly variable with regard to precipitation estimates (Ojima and Lackett 2002, Christensen et al. 2007, Meehl et al. 2007b). The general projections are supported by recent trends, as temperatures and precipitation have increased in the PPR since the early to mid-1900s (Zhang et al. 2000, Karl et al. 2009, Millett et al. 2009), although patterns differ between measures and among regions, timeframes, and studies.

Impacts on Prairie Pothole and Waterfowl Numbers

Wetlands in the PPR may be particularly vulnerable to drying caused by increased temperatures associated with climate change because of their tenuous water balance and dynamic nature. This is a long-standing concern in the ecology of climate change (see for example Poiani and Johnson 1991). Statistical and simulation models developed to assess potential effects of climate change on prairie pothole wetlands suggest that increased temperatures will reduce wetland numbers and hydroperiod, with subsequent reductions in waterfowl populations (Poiani and Johnson 1991, Larson 1995, Sorenson et al. 1998, Johnson et al. 2005, Johnson et al. 2010). However, increased precipitation could offset some effects of higher temperatures on pond numbers and hydroperiod (Larson 1995, Sorenson et al. 1998, Johnson et al. 2010).

Simulating a 3°C (5.4°F) temperature increase and a 10-percent increase in precipitation resulted in a 12% decline of wet basins (Larson 1995). A simulated 3°C (5.4°F) temperature increase resulted in a 28-percent decrease in the number of wet basins, while a 6°C (10.8°F) temperature increase led to a 56-percent decrease (Larson 1995). Based on simulations that incorporate projected climate scenarios, the PPR is projected to experience "increased drought conditions…under nearly all global circulation model scenarios" (Johnson et al. 2005:864), with consequences for waterfowl

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predicted to be negative in the western and central PPR due to drier conditions but positive in the eastern PPR, which is expected to become wetter (Johnson et al. 2005, Johnson et al. 2010). Subsequently, a recommendation from studies that have addressed potential effects of climate change on wetlands and waterfowl conservation in the PPR is to shift conservation efforts to the eastern portion of the PPR (Johnson et al. 2005, Ando and Mallory 2012).

However, wetland data from aerial and ground waterfowl surveys conducted each May 1974-2012 by the FWS Division of Migratory Bird Management and the Canadian Wildlife Service indicate that May wetland numbers have actually increased in six of the 20 PPR waterfowl survey strata (FWS Habitat and Population Evaluation Team, Bismarck, North Dakota, personal communication). Wetland data collected during 1974-2003 indicate that July pond numbers in one stratum in Canada declined significantly, whereas wetland numbers in seven strata increased significantly. Also during the 1974-2003 time period, three strata showed significant increasing trends in an index of wetland hydroperiod, and none of the 20 strata showed significant decreasing trends. These results suggest that increases in precipitation have been sufficient thus far to offset effects of increased temperatures on numbers of May and July ponds across most of the PPR.

Trends in pond numbers suggest that the primary conservation strategy in the US PPR of protecting grasslands and wetlands in areas of high waterfowl density (Reynolds et al. 2006, Niemuth et al. 2008) is not presently jeopardized by long-term drying of wetlands. However, increased temperatures and precipitation in recent decades have likely contributed to intensification of land use in the PPR, in conjunction with the availability of drought-resistant hybrids and genetically modified crops (Krapu et al. 2004, Karl et al. 2009, Laingen 2012, Doherty et al. 2013). In addition, growing human populations and demands for food have increased crop prices, which drive conversion of grasslands in the PPR to row crop fields (Rashford et al. 2011). Regardless of the mechanism, trends suggest that the more intensive agriculture typical of the traditional corn belt of the U.S. may be shifting northwest into the core of the PPR (Laingen 2012). The consequences of increasingly intensive agriculture to waterfowl include direct habitat loss, reduced population size, reduced nesting success, and decreased availability of preferred, high-energy foods (Bethke and Nudds 1995, Krapu et al. 2004).

More information is needed before substantial changes are made to conservation strategies in the PPR, but this should not be construed as inaction. Competing hypotheses about how climate change is impacting waterfowl in the PPR should be tested, wetland change monitored, and waterfowl response measured, enabling sound adaptive management.

Increased precipitation will also increase the desire of farmers to drain wetlands in crop fields, resulting in a permanent loss of those wetlands. Requests to the U.S. Department of Agriculture, Natural Resources Conservation Service for wetland determinations on cropland parcels, which typically precede installation of drainage tile, increased from about 500 in 2007 to >4,710 in 2011 in the PPR portion of eastern South Dakota (Jeff Zimprich, Natural Resources Conservation Service, Huron, South Dakota, personal communication). Wetland drainage remains a major threat to waterfowl populations regardless of the effects of climate change. If wetlands partially or totally embedded in cropland, not protected for conservation purposes, of temporary or seasonal class or < 0.4 ha were drained, the PPR of North Dakota and South Dakota could experience a 37% reduction in populations of five primary species of waterfowl (Reynolds et al. 2006).

If future conditions do lead to long-term drying, conservation strategies may need to evolve. For example, if hydroperiods decrease, as suggested by stable May pond numbers followed by decreasing July ponds in the northwestern PPR, the construction of deep wetlands with longer hydroperiods may be necessary to provide brood habitat in areas with large numbers of paired waterfowl on smaller ponds with a shorter hydroperiod. Management of refuges in the area, many of which are on river systems that are less prone to drying than small potholes, should be to maintain high ecological function including wetland productivity (Euliss and Smith 2010).

Given the magnitude of conservation efforts in the PPR and the potential impact of climate change on waterfowl and other wetland-dependent species, recommendations to shift conservation efforts to the eastern portion of the PPR need to be carefully considered because of complex interactions among climate, biological systems, socio-economic factors, and conservation costs (Niemuth et al. 2010, Loesch et al. 2012, Doherty et al. 2013).

More information is needed before substantial changes are made to conservation strategies in the PPR, but this should not be construed as inaction. Competing hypotheses about how climate change is impacting waterfowl in the PPR should be tested, wetland change monitored, and waterfowl response measured, enabling sound adaptive management.

Case Study: National Wetlands Inventory (NWI) and the Refuge System, Partners in Climate Change Adaptation

Wetlands, refuges, and species of special concern – Wetlands provide crucial habitats in virtually every unit of the Refuge System. Many refuges were established precisely because of their wetlands and associated wildlife. Wetlands provide habitats for numerous species of special concern, including a large proportion of North American breeding birds and federally listed threatened and endangered species. Many fish species use wetlands for breeding and rearing, while other aquatic species are wetland obligates for entire life cycles. Even marine mammals use wetlands during some portions of their life cycles. Yet among broad categories of ecosystems, wetlands are expected to be most impacted by climate change (IPCC 2007b).

NWI and the Refuge System – Geospatial data produced by the NWI are readily available to refuge managers and planners. New NWI products show where the wetlands are, and NWI records show where the wetlands were. As such, NWI is a *de facto* tool in helping monitor the effects of climate change as well as the numerous other stressors to wetland health and existence. On the Refuge System, NWI maps are especially useful for:

- land acquisition planning for new or existing refuges;
- SLAMM analysis on coastal refuges;
- planning of infrastructure development in the context of climate change;
- calculating performance pursuant to the FWS Operational Plan, and;
- monitoring of wetland status as part of the SHC cycle.

Refuge Boundaries and the Wetlands Mapper – To support these and other uses, NWI works closely with the Refuge System to dovetail updates with refuge manager needs. As part of this collaboration, NWI has added a refuge boundary layer to the Wetlands Mapper.[1] When you click on a wetland polygon within refuge boundaries (or elsewhere), a pop-up box provides the wetland classification code and a hot link to a decoder and metadata such as acreage, date of the imagery used to circumscribe the wetland, type of imagery used, etc. Using the Wetlands Mapper, refuge personnel who are more intimately familiar with a refuge can also overlay wetland imagery with USGS topo maps for fine-tuning purposes.

Strengthening the Collaboration – Widespread use of the Mapper is encouraged, as is regular input of refuge personnel to regional NWI coordinators. Such input is useful for prioritizing NWI updates, refining the wetlands layer as needed and, over time, will provide a piece of the climate change puzzle, helping FWS and partners to better understand the effects of climate change on wetlands of the Refuge System and beyond.

[1] *http://www.fws.gov/wetlands/Data/Mapper.html*

PERMAFROST THAWING

Alaska is one of the most vulnerable regions in the U.S. to climate change, with thawing of permafrost one of the most challenging issues. Permafrost, or permanently frozen soil, ranges in thickness from centimeters to more than 600 meters (Nelson et al. 1999). It underlies approximately 85% of Alaska, absent only from a small portion of the southern coast (NAST 2001). It is an extremely important ecological variable because of the degree to which it provides physical support to ecosystems, regulates surface and subsurface temperatures, and restricts drainage, affecting hydrology, root zones, microtopography and habitats (Woo 1992).

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Climate change can alter permafrost directly through changes in air temperatures and soil heat conduction, or indirectly through changes in wildfire frequencies leading to changes in the soil thermal regime (Osterkamp et al. 2000). The temperature of permafrost is an important indicator of its stability (Chapin III et al. 2006). The closer the temperature gets to 0 °C (32 °F), the more susceptible permafrost is to thawing. Permanency of snow cover and site wetness are additional factors involved in permafrost warming.

Mean temperatures of Alaskan permafrost have increased approximately 2.8 °C (5 °F) in the past three decades (Romanovsky et al. 2010). Substantial thawing has already transpired in southern and interior Alaska, where permafrost temperatures are near the thaw point (Romanovsky et al. 2010). Permafrost thawing will continue in Alaska (Lawrence and Slater 2008, Avis et al. 2011), with some models projecting the loss of near-surface permafrost from large areas during the 21st century (Marchenko et al. 2012).

Thawing leads to the loss of wetlands, ponds and lakes in which water is impounded by permafrost. Lakes have generally decreased in size in the last 50 years in central and southern Alaska due to a combination of permafrost thaw, drainage, and the increased rates of evaporation that accompany warmer temperatures (Rover et al. 2012). Conversely, in some cases lakes are growing in area due to lateral permafrost thawing (Roach et al. 2011).

In the coming decades permafrost thaw will probably increase the cumulative areal extent of lakes in areas of continuous permafrost and decrease areal extent in the discontinuous permafrost zone (Avis et al. 2011). Meanwhile the ratio of continuous:discontinuous permafrost is itself decreasing as a function of permafrost thawing such that the ratio of decreasing areal effects to increasing areal effects will also increase (with a net effect of exacerbated decreasing areal extent of lakes) until some landscape-scale threshold or equilibrium is reached. Large landscape-drying effects are possible over much of Alaska and have already transpired on the Kenai Peninsula (Klein et al. 2005).

Permafrost thawing and the associated drying of Alaskan lakes and wetlands will have major effects on Refuge System habitats and populations, most notably pertaining to waterfowl and other migratory birds. Alaskan refuges provide breeding habitats for millions of migratory birds (Griffith and McGuire 2008); these habitats are declining and will decline as a function of permafrost thawing. The waterfowl harvest will likely be impacted accordingly.

Meanwhile fire ecology is altered in Alaska by permafrost thawing. Tundra, the primary biome typified by permafrost, was usually too cold and wet to support extensive fires in Alaska for approximately the past 5,000 years (Hu et al. 2010). Wetland drying, warmer drier summers, and associated thunderstorms contributed to the occurrence of more large fires in the first decade of the 21st century than in any other decade since record keeping began in the 1940s (Kasischke et al. 2010). (See "Increased Wildfire Frequency and Severity" below for more details.)

Coral Bleaching and Other Effects on Coral Reefs

Coral reefs, hotspots of marine biodiversity, suffered significant declines in abundance and biodiversity during the 20th century due primarily to economic activities such as overfishing and byproducts such as pollution (Pandolfi et al. 2003). By the beginning of the 21st century, approximately 27% of coral reefs had been permanently lost and the rate of degradation remained high (Cesar et al. 2003). Also by then, climate change was recognized as a significant and growing threat (Hoegh-Guldberg 1999). The most-known effects of climate change on coral reefs are coral bleaching, sea-level rise and ocean acidification – these are covered below – but reefs are also increasingly susceptible to the more frequent and intense tropical storms associated with climate change (Emanuel 2005, Ostrander et al. 2000). Given their sensitivity to environmental change, coral reefs are sometimes called the "canaries of the sea."

The Refuge System includes fourteen refuges that represent the most widespread collection of protected coral reefs on the planet under a single country's jurisdiction. Because of their relatively pristine conditions, distance from human-related stresses, and legal protections, these refuges serve as natural laboratories for scientific study of climate change impacts on coral reefs (Sandin et al. 2008). Protected coral reefs are more resilient and adaptable to climate change, possibly helping to counteract global trends in coral reef decline (Hughes et al. 2003). Refuges may also provide a source of corals and coral-dependent species for recolonizing reefs damaged by economic activities and climate change.

Coral Bleaching

One of the biggest threats to coral reefs is bleaching and mortality associated with increasing ocean temperatures (McClanahan et al. 2009, Hoegh-Guldberg and Bruno 2010). Corals are dependent upon a symbiotic relationship with specialized unicellular algae, zooxanthellae, located within their tissue. Outside of a narrow temperature range (typically 25-29 °C, or 77-84 °F), corals become stressed and may expel their zooxanthellae (Manzello 2010). Coral bleaching results when the loss of the pigmented zooxanthellae leaves the coral's white skeleton visible through the clear tissue.

Global coral bleaching events have resulted, in part, from the temperature fluctuations associated with El Niño (McClanahan et al. 2007). In 1998 a single bleaching event led to the loss of almost 20% of the world's living coral (Hoegh-Guldberg 1999). Considering the projected rate of ocean warming over the next century (i.e., approximately 1-2 °C, or 1.8-3.6 °F), many corals may be unable to adapt to the cumulative effects of climate change and other major stressors (Knowlton 2001, Hoegh-Guldberg and Bruno 2010). Reducing these stressors can bolster reef resilience to bleaching and other climate change effects (Hughes et al. 2010, Anthony et al. 2011). For example, water quality improvements such as the control of nutrient inputs can ameliorate effects of climate change (Wooldridge and Done 2009).

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Sea-level Rise

Sea-level rise can influence coral reefs directly and indirectly. The zooxanthellae within coral polyps are dependent on ample light to maintain growth. Therefore coral reefs form only in clear shallow waters, typically 100 m or less, where reef growth exceeds reef erosion. The rate of sea-level rise over the next century may exceed that of potential reef growth in some areas, endangering corals and reef communities (Buddemeier and Smith 1988).

Corals are also extremely vulnerable to declines in water quality caused by coastal runoff (Fabricius 2005). Coastal erosion and inundation due to sea-level rise may result in increased runoff of sediment, nutrients, and chemicals into off-shore waters. Declines in coral reef density and growth have been documented in areas where mangroves and other coastal ecosystems have been purposely altered (Rogers 1990).

Ocean Acidification

The effect of increased atmospheric CO_2 on ocean chemistry is a growing concern (Caldeira and Wickett 2003, Doney et al. 2009). Approximately one third of the CO_2 emitted from the burning of fossil fuels is absorbed by the oceans and as a result the partial pressure of CO_2 in ocean surface water is expected to double over its pre-industrial value by the middle of this century (Sabine et al. 2004). Currently, seawater is slightly alkaline with a pH of approximately 8.06. However, CO_2 reacts with seawater, forming carbonic acid (H_2CO_3) and lowering pH (Caldeira and Wickett 2003). Since the beginning of the industrial revolution, the pH of the surface ocean waters has decreased approximately 0.1 units, corresponding to a 30% increase in acidity (Hoegh-Guldberg et al. 2007).

By 2100, increases in atmospheric CO_2 concentration are projected to correspond with a decline in pH of 0.3-0.4 from pre-industrial levels to a range of 7.76-7.86 (IPCC 2007a). Although not actually causing seawater to become acidic per se (i.e., pH < 7), ocean acidification is expected to significantly affect many marine organisms. At current pH, the surface ocean is saturated with respect to calcium carbonate, the mineral required by all calcifying marine organisms including corals. As pH decreases, the additional hydrogen ions combine with carbonate ions to form bicarbonate thus reducing the concentration of calcium carbonate in the water. As a consequence, the growth rate of many marine calcifying organisms, including corals and coralline algae, may become carbonate-limited (Caldeira and Wickett 2003, Pandolfi et al. 2011). Although geological evidence suggests that ocean pH has fluctuated over the past 300 million years, the current rate of acidification may be too fast for coral ecosystems to adapt to (Cicerone et al. 2004). The effects of ocean acidification will lower the resilience of coral reefs to other stressors (Veron et al 2009, Anthony et al. 2011). An example is overfishing, which has a nuanced relationship to the health of corals (see case study below).

Coral Reef Protection

The cumulative effects of human disturbance and climate change are increasing at rates that challenge the natural evolutionary capacities of coral and zooxanthellae to adapt (Hughes et al. 2010, Anthony et al. 2011). The emerging field of coral genetics is demonstrating the importance of maintaining biodiversity in coral reefs (Baums 2008). An intact reef with full biotic diversity is more resilient to disturbance and climate change than coral reef ecosystems that have been overfished or otherwise degraded (Bellwood et al. 2004). The global decline of coral reef ecosystems has inspired calls for creating marine protected areas, implementing sustainable fishing practices, and reducing pollution and other land-based threats (Graham et al. 2008).

The cumulative effects of human disturbance and climate change are increasing at rates that challenge the natural evolutionary capacities of coral and zooxanthellae to adapt.

With fourteen coral-reef refuges in the Florida Keys, Caribbean, and across the central Pacific Ocean, the Refuge System plays a major role in conserving the global diversity of coral reefs. A conservation advantage of the coral-reef refuges is that their boundaries extend across the land-sea interface protecting the entire continuum of interconnected ecosystems. Coral reefs are intricately connected with other nearshore ecosystems including seagrass meadows, mangrove forests, and tropical atoll forests (Nagelkerken et al. 2000).

Seagrass Response

Extensive coastal seagrass meadows range from the tropics to the Arctic and are some of the most productive ecosystems in the world, rivaling even agricultural crops in some cases (Hemminga and Duarte 2000). Seagrasses act as a vital linkage between terrestrial and marine ecosystems, performing many important ecological functions such as providing habitats, facilitating nutrient cycling, stabilizing sediments, and providing a substantial energy base for higher trophic levels. The importance of these ecosystems to local economies is emphasized where development and urbanization of the coastal zone results in deterioration of water quality and rapid loss of seagrasses (Waycott et al. 2009).

Seagrass ecosystems are not as well-studied and understood as many others (Hemminga and Duarte 2000), making it even more difficult to plan for the effects of climate change. However, basic ecology provides some guidance. For example, increased water temperature can increase growth rates, lengthen growing seasons, and expand areas for seagrasses to colonize (Short and Neckles 1999).

However, the higher ecosystem respiration rates conduced by warmer water could also cause problems for seagrasses in some areas. Seagrasses pump photosynthetically derived oxygen into sediments (Hemminga and Duarte 2000). During peak growing season, when sunlight is highest, seagrass photosynthesis produces enough oxygen to offset respiratory and other oxygen demands above and in the benthos. During an unseasonably warm fall or winter, respiration can remain high while less sunlight results in lower rates of photosynthesis. The result is decreased dissolved oxygen concentration in the submerged sediments. These sediments can become anoxic, leading to toxic sulfide production and seagrass mortality (Borum et al. 2005).

The loss of seagrass meadows can expose sediments that were previously held in place by the extensive below-ground root-rhizome structure and lead to increased water column turbidity. The decrease in light penetration then leads to lower seagrass photosynthesis, which leads to more seagrass mortality. This positive feedback loop can result in extensive die-off of seagrass meadows.

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The effect of sea-level rise on seagrasses is also difficult to predict, but all else equal, a deeper water column results in less light reaching the seagrass leaves, resulting in lower plant productivity where they are light-limited (Shaughnessy et al. 2012). On the other hand, flooding of coastal zones can open up new areas for colonization. However, rising sea levels will also adversely affect salt marshes and other intertidal vegetation. In many situations the loss of coastal marshes results in shoreline erosion which then increases turbidity and lowers light availability for seagrasses (Duarte 2002).

The geographic range of mangrove forests in southern North America is expected to expand, especially northward and including via the replacement of saltmarshes.

The possible effects of ocean acidification on seagrasses are not straightforward. Seagrasses are often carbon-limited, so increased CO_2 concentration in the water would boost productivity. Some research suggests dense seagrass meadows could provide a buffering effect from ocean acidification in surrounding waters because of the high amount of CO_2 used in the photosynthesis of seagrass (Semesi et al. 2009).

A remarkable attribute of seagrasses is their ability to store large portions of the carbon fixed during photosynthesis in their roots and soil and to continue accumulating carbon for centuries (Fourqurean et al. 2012). Researchers estimate that seagrasses store approximately 10% of the carbon in the world's ocean. Unfortunately, approximately 29% of historic seagrass meadows have been destroyed and an estimated 58% of remaining meadows are in decline (Waycott et al. 2009).

Mangrove Range Expansion

Coastal wetlands of the southeastern U.S. are responsive to changes in climate and freshwater outflow resulting from varying patterns and frequencies of freeze, drought, storm, sea-level, and runoff events. Salt marshes and mangroves thrive in the intertidal zone between land and sea. Therefore, these ecosystems are subject to the cumulative effects of marine influence (e.g., sea-level rise, salinity), freshwater drainage (e.g., flooding, nutrients, pollutants), and extreme climate events such as hurricanes.

Tidal freshwater forests of the Gulf Coast are retreating from sea-level rise, and this trend is expected to continue and accelerate (Doyle et al. 2010). Meanwhile saltmarshes are adapted to salinity regimes of coastal fringe ecosystems and are expected to persist and replace tidal freshwater ecosystems under moderate rates of relative sea-level rise (Morris et al. 2002). However, the "migration" of salt marshes may not keep up with higher rates of relative sea-level rise, and salt marshes are susceptible to coastal erosion, whereas mangroves have unique root structures that may help stabilize coastal areas from erosion. For these and other reasons, the geographic range of mangrove forests in southern North America is expected to expand, especially northward and including via the replacement of saltmarshes (Comeaux et al. 2011, Osland et al. 2013).

Mangroves are halophytes that thrive along tropical coastlines, reaching their latitudinal limits in the subtropics. Mangrove expansion is a relatively new and unexplored aspect of the ecology of climate change, but apparently some climate-related mangrove expansion has already occurred in Texas (Tresaugue 2012), Louisiana (Michot et al. 2010), and Florida above the tropical Everglades where mangroves dominate the coastal land margin (Doyle et al. 2010).

Fire regimes are strongly coupled with broad-scale climate patterns (e.g., El Niño–Southern Oscillation) that influence fire potential, timing, frequency, duration, size, and severity…Increasing wildfire frequency and severity is related to the combined influence of climate change and accumulation of fuels from decades of fire suppression.

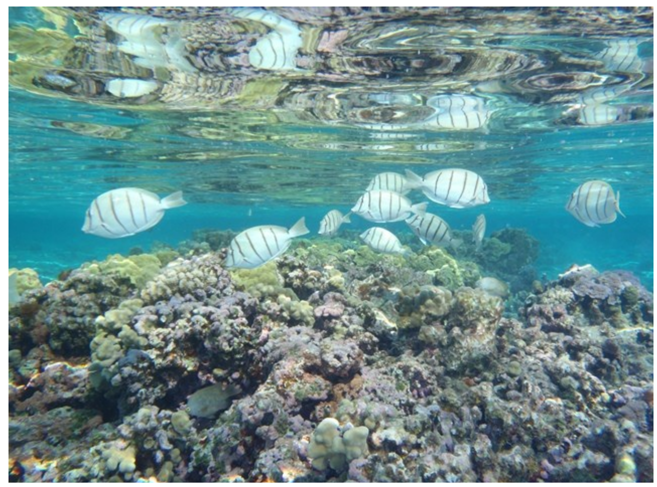
Mangroves are limited by latitude across the northern Gulf of Mexico in relation to chill tolerance (Sherrod and McMillan 1985, Osland et al. 2013). The new records of the northerly spread of mangrove species documented in recent years appear to be related to reductions in chilling frequency and intensity. For example, black mangrove (*Avicennia* spp.) in coastal Louisiana

Case Study: The Balance of Nature and Coral Reef Resilience

Ecosystem resilience is the ability to tolerate stresses and recover from disturbance without losing ecological structure, function or services (Carpenter et al. 2001). For example, a resilient coral reef can recuperate relatively soon after a bleaching event (Hughes et al. 2010). Resilience of reefs throughout the world has declined due to chronic human impacts including pollution, overfishing, climate change, and ocean acidification (Hughes et al. 2010).

Coral reefs depend on a diverse biotic community in ecological balance (Burkepile and Hay 2010). Without herbivorous fish, reefs can be overtaken by algae that compete for light, nutrients, and space (Burkepile and Hay 2010). Some species, such as tangs and surgeon fish (Acanthuridaeare spp.) graze algae off the surface of corals. Others such as parrot fish (Scaridae spp.) eat coral whole (to optimize algae intake). Therefore, a healthy predator population is also needed to maintain balance in a coral ecosystem (Ruttenberg et al. 2011).

We should seek to protect diversity and balance among reef fish populations as a strategy to maintain resilience of coral reefs in the context of increasing anthropogenic disturbance (Rasher et al. 2011). Remote and relatively pristine coral reefs with fully intact biotic communities, like those found in the Pacific Reefs National Wildlife Refuge Complex, show greater resilience to climate change than those found in areas where overfishing has occurred (Hughes et al. 2007).



Convict tangs (*Acanthurus triostegus*) at Midway Atoll NWR. Credit: Pete Leary

has expanded since the last damaging freeze in 1989 (Michot et al. 2010). To the extent that periods between freeze events lengthen, mangrove expansion is expected landward and poleward along the northern Gulf Coast, increasing the ratio of mangrove to salt marsh (Krauss et al. 2011).

Recent field and mapping studies of the northern Everglades have documented upslope migration of mangroves into tidal freshwater wetlands over the last century concomitant with sea-level rise (Doyle et al. 2010, Krauss et al. 2011). Landscape simulation models of coastal wetlands of the Everglades and northern Gulf Coast have been applied to reconstruct historical migration and to forecast potential expansion of mangrove ecosystems in relation to tropical storms and sea-level rise (Doyle et al. 2010, Osland et al. 2013).

Mangrove expansion throughout the Gulf region would have many and major implications for fish and wildlife. For example, a change from salt marsh to mangroves would be highly conducive to increasing brown pelican (*Pelecanus occidentalis*) populations (Visser et al. 2005). Other species (among many) likely to benefit from mangrove expansion are mangrove snapper (*Lutjanus griseus*), roseate spoonbill (*Ajajia ajaia*), and spiny lobster (*Panulirus argus*).

Increased Wildfire Frequency and Severity

Changing fire regimes have been implicated as one of the top ten causes of species endangerment in the U.S., ahead of stressors such as logging, road construction, and wildlife diseases (Czech et al. 2000). Yet fire is a fundamental ecological process and under the right conditions can contribute to future adaptive capacities (Driscoll et al. 2010, Fischer et al. 2006).

Fire regimes are strongly coupled with broad-scale climate patterns (e.g., El Niño–Southern Oscillation) that influence fire potential, timing, frequency, duration, size, and severity (Schoennagel et al. 2004). Major climate factors that influence fire regimes include inter-annual and seasonal variation in global atmospheric circulation patterns, precipitation, atmospheric stability, lightning, temperature, relative humidity, and winds (Baker 2009, MacKenzie et al. 2011). Increasing wildfire frequency and severity is related to the combined influence of climate change and accumulation of fuels from decades of fire suppression (Swetnam and Baisan 1996). Land management practices (e.g., grazing, logging, fire suppression) and invasive species have also altered historic fire regimes, for the most part decreasing fire frequency and causing the build-up of unsustainable accumulations of hazardous fuels (Czech 1996, Czech et al. 2000, Hunter et al. 2007).

Marlon et al. (2012) found a “fire deficit” in the western U.S. attributable to the combined effects of managerial and economic activities (e.g., suppression and fuel alteration from livestock grazing, respectively), and ecological and climate changes. They concluded that large wildfires in the late 20th and early 21st centuries have begun to lower the fire deficit. The frequency and severity of wildfires >250 acres has increased in the western U.S. including Alaska (USGS 2006b). Westerling et al. (2006) attributed these trends to dryer winters, warmer springs, earlier snow melt, dryer soils in early summer, and longer dry seasons. Miller et al. (2009) also found evidence of increasing area burned and fire severity in the Sierra Nevada and Southern Cascades. Fire regimes have also changed during recent decades in the North American Boreal Region including Alaska (Kasischke and Turetsky 2006). Increased temperature, changes in precipitation patterns, and longer snow-free periods have allowed fires to grow faster and burn over longer periods of time (Kasischke et al. 2010).

Severe fires cause ecosystem fragmentation and affect wildlife habitat availability, increasing erosion rates and diminishing water quality. They impact post-fire ecological recovery, seedling recruitment, carbon sequestration, and other ecosystem processes related to adaptive capacities (Miller et al. 2009). Changes in seasonal distribution and sizes of fires may result in an increase in depth of peat burning and seasonal thawing of permafrost. Deeper burning of surface organic layers accelerates changes in ecosystem characteristics and processes, such as soil respiration, nutrient cycling, species composition, and vegetation recruitment and growth rates (Bergner et al. 2004).

Although many wildfires have benefited various native species, the recent escalation in fire size and severity could be a warning sign of rapid climate change and may foreshadow widespread ecological degradation. For example, increased fire severity in boreal forests may increase mercury emissions, presenting a growing threat to aquatic habitats and food chains.

Although many wildfires have benefited various native species, the recent escalation in fire size and severity could be a warning sign of rapid climate change and may foreshadow widespread ecological degradation. For example, increased fire severity in boreal forests may increase mercury emissions, presenting a growing threat to aquatic habitats and food chains (Turetsky et al. 2006). Friedli et al. (2009) suggested that a warming climate in boreal regions, which contain large carbon and mercury pools, will increasingly contribute to local and global mercury emissions due to more frequent and larger, more intense wildfires. The deep organic soils found at these latitudes are predicted to become increasingly vulnerable to extensive carbon losses given these trends (Turetsky et al. 2006). (See also Environmental Contamination below.)

Case Study: Fire, the Mexican Spotted Owl, and Strategic Habitat Conservation

In Southwest forests, fires are increasing in frequency and severity to levels not found in the paleoecological record (Allen et al. 2008, Fulé et al. 2004). The endangered Mexican spotted owl (*Strix occidentalis lucida*) is an example of a species threatened by the new fire regime. The owls are found in old-growth forests that have been substantially altered by a century of fire suppression. Heavy surface and ladder fuels have made these forests and owl habitats prone to large, stand-replacing fires.

Owl habitat degradation is likely to accelerate as a function of climate change. The recently revised recovery plan calls for strategic habitat conservation, including strategic placement of fuel and restoration treatments in up to 10% of critical habitat outside of nesting and roosting sites (FWS 2012). The plan also calls for evaluating and monitoring of the effects of these fire management adjustments. This approach will help researchers and managers learn about the effects of fuel and fire treatments, assisting with owl recovery and delisting. The sequence of planning, implementation and evaluation comprises an SHC cycle (Figure II-1).

In temperate systems, both the long-term exclusion of fire and the reintroduction of fire may combine with the effects of global warming to reduce densities of large-diameter trees (Lutz et al. 2009).

Managers and planners should avoid generalizing too much based on current trends. Fire regimes in some areas may stabilize while, in others, may fluctuate for long periods of time with shifts in climatic and vegetative variables. In some locales, fire regimes may shift toward less frequency and severity during the 21st century as precipitation patterns shift. Nevertheless, the overall trend over much of the U.S. is toward more frequent, larger, and severe wildfires (Finco et al. 2012).

Researchers have been called to assess multiple aspects of fire, tracking at least the numbers, areas, and severities (Lutz et al. 2011). Fire behavior in any one year can then be compared against the long-term averages to investigate trends or uncharacteristic behavior. Effective fire management for wildlife purposes also depends on understanding what fires do not burn; i.e., the habitat refugia within fire perimeters (Kolden et al. 2012).

Marlon et al. (2012) observed that current fire suppression is taking place under conditions that are warmer and drier than those that occurred during the Medieval Warm Period (ca. 950–1250 AD). Meanwhile the annual costs (tangible and intangible; economic and ecological) of suppression and post-fire restoration are high relative to other land management activities and show little sign of declining (DOI 2012). This calls into question the long-term efficacy and sustainability of the traditional fire management approach. Strategic fire management, which includes fuels management, silvicultural treatments, prescribed fire, and managed wildfire as well as suppression, may enhance ecosystem resilience and adaptive capacities (Johnstone et al. 2010, Miller et al. 2012).

Climate change alters physical and chemical environmental conditions such as temperature, humidity, pH, salinity, and dilution rates. In the process the availability and toxicity of pollutants changes along with the exposure and sensitivity of species to pollutants.

In other words, strategic wildfire management is an example of climate change adaptation.

Environmental Contamination

Climate change alters physical and chemical environmental conditions such as temperature, humidity, pH, salinity, and dilution rates. In the process the availability and toxicity of pollutants changes along with the exposure and sensitivity of species to pollutants (Noyes et al. 2009, Gouin et al. 2013, Hooper et al. 2013). For example, increasingly humid conditions may result in the increased use of fungicides while lowered pH can increase the availability of metals (Reddy et al. 1995). In the first case, a greater quantity of a contaminant is introduced to the environment; in the second, the existing contaminant is more biologically available to harm organisms.

All chemical reactions, whether environmental or physiological, are fundamentally temperature-dependent. Among the many potential implications, as water temperatures rise the protectiveness of water quality standards may decline and stricter standards may be required to maintain current levels of water quality for fish and aquatic wildlife. For example, increasing temperature can increase exposure to metals and other contaminants by increasing respiration rates of many ectotherms such as fish (Ficke et al. 2007, Schiedek et al. 2007).

Generally, climate-induced toxicant sensitivity can be due to metabolic stress wrought by environmental change or inhibition of physiological processes that govern detoxification. Alternatively, pollutant exposure can result in climate sensitivity (Hooper et al. 2013). For example, exposure to certain organic contaminants can lower temperature tolerance in fish (Patra et al. 2007).

A prominent and illustrative contaminant that is likely to be more problematic in the context of climate change is mercury. More frequent and extreme wetting and drying cycles in wetlands will likely increase the conversion of mercury to the more biologically available methylmercury (Rudd 1995, Bates and Hall 2012). Methylmercury is more toxic and persistent than inorganic forms of mercury. Methylation processes result in significantly lower reproductive success for estuary obligates such as the saltmarsh sparrow (*Ammodramus caudacutus*) along the Atlantic Coast (Lane et al. 2011, Evers et al. 2012) and the California clapper rail (*Rallus longirostris obsoletris*) along the Pacific Coast (Schwarzbach et al. 2006).

Erosion of contaminated sediments from rising sea levels may also contribute to increased exposure to mercury and other contaminants from legacy sources. Mercury can also be deposited in an ecosystem from the atmosphere. Biological samples can be used for tracking the location and source of mercury using isotope fractionation techniques (Gehrke et al. 2011).

Climate change can affect transport patterns of pollutants, which may reach and accumulate in new places, exposing different biota. For example, intensified precipitation events may cause scouring of sediments and vegetation, redistribution of sediment, and re-suspension of contaminated sediments, as well as increased pollutant exposure due to concurrent events such as sewer overflow. Flooding, severe winds, increased erosion, and/or sea level rise may damage infrastructure, manufacturing plants, and waste storage facilities, releasing contaminants (e.g., oil from above-ground storage tanks and pipelines; toxic chemicals from landfills, pest control businesses, dry cleaners, service stations and Superfund Sites) that can affect coastal marshes as well as homes and businesses, as happened during Hurricane Katrina and with subsequent flooding (Pine 2006, Esworthy et al. 2005).

On regulated watersheds, increased erosion associated with intense storms and high flows may decrease reservoir lifespan because of increased sediment inputs, further amplifying flood risks. If reservoirs are near capacity, increased flooding and sediment transport could exacerbate the potential risk of dam breaches or failure (Palmer et al. 2008), threatening downstream infrastructure potentially including (but not limited to) fuel storage facilities and pipelines, sewage treatment plants, and hazardous materials storage areas. Also, transport of sediments may mobilize contaminants found therein.

Conversely, atypically intense or prolonged drought can have profound contaminant impacts via the exposure of friable sediments from desiccated lentic water bodies, particularly terminal sink water bodies. Sediments of lentic water bodies are the primary natural storage sites for many toxic salts (e.g., sulfates), pesticides, and other contaminants. When those sediments become exposed, friable, and subject to wind transport, the ecological consequences can be substantive at the landscape level. For example, desiccation of the Aral Sea (an inland lake) in central Asia resulted in profound human health impacts and damage to agricultural crops as far as 500 km away via aerial deposition of pesticides and sulfate salts from the newly exposed sediments (Micklin 1988, Ellis 1990, Precoda 1991).

Climate Change and Environmental Contaminants in Northern Ecosystems

Melting of glaciers can release stored persistent organic pollutants (e.g., pesticides and industrial chemicals such as PCBs) deposited during the 20th century into freshwater systems (Blais et al. 2001, Bogdal et al. 2009), with subsequent uptake by biota (Bettinetti et al. 2008, Bizzotto et al. 2009).

As diets and food webs change as a function of climate change, contaminant composition and concentrations may also change, particularly in apex predators subject to biomagnification. For example, earlier sea ice breakup has been linked to polar bear (*Ursus maritimus*) dietary changes in western Hudson Bay, Canada, with an inferred increase in consumption of open-water marine mammals such as harp and harbor seals (*Pagophilus groenlandicus* and *Phoca vitulina*, respectively) relative to ice-associated seals (particularly bearded seals, *Erignathus barbatus*). Dietary changes were in turn related to an increase in contaminants such as PCBs, PBDEs and chlordanes, but a decrease in DDT concentrations (McKinney et al. 2009).

Reduced sea ice will also lead to increases in marine shipping and transport, access to energy resources and various minerals, and commercial fishing (ACIA 2005, AMSA 2009). Among the likely impacts are increased noise pollution, higher levels of marine debris, and various types of pollution incidents (AMSA 2009).

Reduced sea ice will also lead to increases in marine shipping and transport, access to energy resources and various minerals, and commercial fishing. Among the likely impacts are increased noise pollution, higher levels of marine debris, and various types of pollution incidents.

Peatlands throughout the Arctic and subarctic regions have accumulated carbon and trace elements such as mercury for thousands of years (Rydberg et al. 2010). Increased permafrost melt and erosive processes may enhance transport of mercury to Arctic lakes and coastal zones (Macdonald et al. 2003). Thawing of permafrost and the subsequent export of carbon and mercury to freshwater systems has been documented in Sweden and is thought to present a growing threat throughout the circumpolar region (Rydberg et al. 2010).

Increasing Arctic lake primary productivity stemming from global warming has been suggested as a mechanism for increased mercury concentrations in lake sediments (Outridge et al. 2007, Stern et al. 2009) and subsequently in fish (Carrie et al. 2010). Changes in Arctic lake productivity have also been related to zooplankton community structure which in turn influences mercury bioaccumulation (Chételat and Amyot 2009).

Loss of permafrost and/or erosion may also affect the mobilization of other pollutants from historical waste disposal sites, sewage lagoons, former military sites, mine tailings storage areas, and oil storage pits (Macdonald et al. 2003).

A well-known aspect of wildlife disease ecology is that short-term fluctuations in seasonality can alter the spread and persistence characteristics of infectious diseases. Less understood is how infectious diseases will be affected by enduring shifts in seasons and phenology associated with climate change.

Wildlife Diseases

Climate change and disease ecology are themselves complex, and linking the two to forecast disease outcomes is prone to uncertainty (Rohr et al. 2011). However, it is clear that wild mammals, birds, fish, amphibians, and reptiles have co-evolved with invertebrate vectors and pathogens, and that the balance between wildlife health and disease is sometimes maintained precariously under severe seasonal and environmental constraints (Hudson et al. 2002). Even slight alterations to temperature, humidity, and rainfall patterns can disrupt this delicate balance, changing disease transmission dynamics and increasing infection pressure on wildlife. Unsurprisingly then, an empirical linkage of wildlife disease to climate change is already clear in some ecosystems and species (Walther et al. 2002). Climate interacts with and affects the complex ecological relationships underlying infectious disease transmission patterns (Relman et al. 2008). As Harvell et al. (2002:2158) described, for example, "Climate warming can increase pathogen development and survival rates, disease transmission, and host susceptibility." Nevertheless, Harvell et al. (2009) later acknowledged that the implications of such basic disease ecology were complicated by numerous other (i.e., non-climatic) factors and that, thus far, the increase in wildlife infectious diseases wasn't as pronounced as could be expected given the relatively rapid rates of climate change. Lafferty (2009:888) found, "While initial projections suggested dramatic future increases in the geographic range of infectious diseases, recent models predict range shifts in disease distributions, with little net increase in area."

In any event, it is early in the era of pronounced anthropogenic climate change and the ongoing and future effects on wildlife diseases are of considerable concern. A well-known aspect of wildlife disease ecology is that short-term fluctuations in seasonality can alter the spread and persistence characteristics of infectious diseases. Less understood is how infectious diseases will be affected by enduring shifts in seasons and phenology associated with climate change (Altizer et al, 2006). Disease emergence is typically the result of a suite of interacting factors beyond the presence or introduction of diseases and their vectors, including climate change, habitat degradation, and invasive species (Atkinson and LaPointe 2009).

Storm Intensification

There is much uncertainty about the pace and extent of storm intensification as a function of climate change. As Emanuel (2005:686) noted, "Theory and modeling predict that hurricane intensity should increase with increasing global mean temperatures, but work on the detection of trends in hurricane activity has focused mostly on their frequency and shows no trend." He pointed out that frequency and intensity are different variables, both of which contribute to cumulative effects. Similarly, Knutson et al. (2010:157) stated, "it remains uncertain whether

"Future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms" (Knutson et al. 2010).

past changes in tropical cyclone activity have exceeded the variability expected from natural causes. However, future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100."

Detecting trends in tropical storm and hurricane intensity is difficult due to high natural variability (Moran 2010). Variability along the Gulf Coast is especially high, due largely to the El Niño Southern Oscillation (ENSO) (Latif and Keenlyside 2009). However, patterns of change in some regions have been detected (Henderson-Sellers et al. 1998, Trenberth 2011). Recent analyses reveal an increase in both hurricane intensity and duration since the 1970s, which is thought to be correlated with the increased sea surface temperature (Emanuel 2005, IPCC 2007a).

Changes in the methods by which severe thunderstorms – those with large hail, high winds, and/or tornadoes – are reported make it nearly impossible to detect trends in occurrence and intensity. If the weakest tornadoes (which are most susceptible to changes in reporting) are ignored, there appears to be no long-term trend in the occurrence of tornadoes (Verbout et al. 2006, Doswell III et al. 2009). Brooks and Dotzek (2008) considered the effects of reporting methods while analyzing the records of very large hail (≥3" diameter) and found evidence for an increase in occurrence from the early 1970s until the late 1990s, but estimated that 93% of

Case Study: Avian malaria and avian poxvirus in Hawaii

The population levels, diversity, and distributions of native Hawaiian birds have changed substantially since the introduction of avian malaria, avian poxvirus, and their mosquito vectors (van Riper et al. 1986, van Riper et al. 2002). Avian malaria is caused by protozoan parasites of the genus *Plasmodium*, is transmitted to birds by mosquitoes, and results in acute anemia (Lapointe et al. 2012). Avian poxvirus is caused by a virus, is transmitted through contact with infected objects or by biting flies, and results in tumor-like swellings on exposed skin or diphtheritic lesions in the oral cavity and esophagus. Both diseases can be fatal; native honeycreepers (*Fringillidae* family) are particularly susceptible to both diseases.

The ecology of avian pox and malaria is based on climatic conditions that drive vector populations and affect the adaptability of host avian species (Atkinson and LaPointe 2009). High elevations (>1500 m) where mosquitoes are not present provide a pox and malaria-free refuge for native Hawaiian birds. Global warming threatens these bird species as it facilitates an upward expansion of the mosquito zone. Management strategies include mosquito control and potential vaccination and drug treatment campaigns in critical avian populations.

To lessen the likelihood of disease emergence in the context of climate change, refuge managers should attempt to: 1) minimize other ecosystem stressors to increase species resilience to climate change and disease; 2) lessen the vulnerability of wildlife to disease presence, amplification, and transmission; and, 3) maintain situational awareness through baseline health assessments and long-term disease monitoring, surveillance, and appropriate response.

Buffering species from the threat of disease entails: 1) maintaining genetic diversity, 2) conserving habitats and lowering rates of degradation and fragmentation, and; 3) protecting the integrity of food and water sources. Refuge managers may also lower rates of disease transmission by limiting interactions of wildlife with domestic animals and humans, and by controlling invasive species. Tighter regulation of wildlife trade is also important (although this is not often directly within the purview of refuge managers).

the change was attributable to non-meteorological factors.

Given the limitations of severe thunderstorm reporting for determining trends in occurrence, Brooks et al. (2003) developed a conceptual model of the "ingredients" in the atmosphere associated with the most severe thunderstorms; i.e., those storms of roughly the upper 10 percentile in hail size and wind speed. They assessed the relationship between the ingredients and storm events using reports from the U.S. east of the Rockies in the 1990s, a decade in which storms were reported relatively consistently. To the extent that the ingredients data represent the real distribution of ingredients in which storms form, they can be used to estimate the "true" distribution of events. Because the ingredients are observed much more consistently over time and in space, this technique can be applied globally. The most important ingredients are convective available potential energy (CAPE), a thermodynamic measure that estimates the energy that storms can use, and wind shear, the difference between the winds (speed and direction) near the surface and roughly 6 km above the ground (Brooks 2013). Storms that form in environments with high wind shear tend to be better organized and more likely to rotate strongly than storms that form in low values of wind shear. As a result, they are more likely to produce large hail and tornadoes.

Brooks et al. (2003) produced a map of the expected global distribution of severe thunderstorms and tornadoes using the ingredients-based approach. Cecil and Blankenship (2012) used satellite-derived estimates of large hailstorms to infer a distribution of large hail falls. Qualitatively, the two approaches concur in large part, indicating that the most favored locations for large hail on the planet are southern Brazil and eastern Argentina, the central U.S., southeastern South Africa, the Sahel, eastern Australia, and regions near the Himalayas. Given the very different datasets and approaches used to create these estimates, the similarity gives us some confidence that the environmental conditions explain a large part of the variability in severe thunderstorm occurrence, and that severe thunderstorms and tornadoes are trending upward in the central U.S.

The ingredients approach also has the advantage that it can be applied to output from climate models. Numerous researchers (e.g., Del Genio et al. 2007, Trapp et al. 2007, Trapp et al. 2009, Van Klooster and Roebber 2009) have analyzed climate simulations to assess the effects of greenhouse gas changes on the distribution of severe storm ingredients in North America. In general, they have reported similar results, with CAPE increasing and wind shear decreasing. Increases in CAPE tend to outweigh decreases in shear, leading to an overall increase in the number of environments conducive to severe thunderstorms. In general, this is forecast to occur over all regions of the U.S. east of the Rockies, although the strength of the signal varies from region to region and, given high interannual variability of the parameters, it takes a century for the changes that are modeled to become statistically significant (Trapp et al. 2009).

IV. REFUGE SYSTEM SOCIAL, ECONOMIC, AND CULTURAL ISSUES RELATED TO CLIMATE CHANGE

PUBLIC USES

Climate change will affect the type, quantity, and quality of outdoor recreation opportunities. For example, extended warm seasons may reduce skiing and snowboarding opportunities, earlier spring runoff may reduce freshwater fishing and boating, and forest die-off reduces the use of campgrounds, trails, and picnic areas (Morris and Walls 2009). Climate-change impacts on wildlife-dependent recreation, including hunting, fishing, wildlife observation, wildlife photography, and environmental interpretation and education will be especially important to the Refuge System and its users.

Climate change is already affecting hunters. Waterfowl hunters are noticing changes in migration patterns of waterfowl making it challenging to determine when and where quality hunting opportunities exist (WMI 2008). Warming temperatures and changes in precipitation both directly and indirectly lead to the alteration of traditional waterfowl and big game habitats including especially water and food sources. These changes will likely result in a decrease in waterfowl and other hunting opportunities in some areas. For example, moose (*Alces alces*) hunting in Minnesota is on the verge of being phased out as moose populations have declined precipitously; state researchers point to climate change as the primary factor (Cusick 2012, Smith Barnum 2012).

Anglers will also experience effects on their traditional fishing opportunities (Glick and Clough 2006, WMI 2008). Rising water temperatures and changes in precipitation are predicted to have major consequences for freshwater fish, such as trout (Salmonidae species), walleye (*Sander vitreus*), and black basses (*Micropterus* spp.), causing anglers to travel farther for these traditional target species or forcing them to shift to target species more resilient to warmer temperatures (WMI 2008). Similar problems await saltwater anglers in coming decades. Researchers conducting SLAMM analysis for the National Wildlife Federation and Florida Wildlife Federation found that "results for nine sites along Florida's coasts project that sea level rise would dramatically alter the extent and composition of important coastal habitats throughout the region… In addition, global warming is expected to lead to an increase in marine diseases, harmful algal blooms, more-extreme rainfall patterns and stronger hurricanes, all of which would have a significant impact on the state's prime fisheries" (Glick and Clough 2006:3).

These impacts on traditional hunting and fishing opportunities will result in new challenges for refuges. For example, refuges may have to lower bag limits, compress hunting and fishing seasons, or change the species allowed to be hunted or fished on the refuge accordingly.

Changes in migratory patterns will also affect non-consumptive public uses that depend on wildlife, including wildlife observation activities such as birding and photography. Birders may be particularly concerned because nearly 60% of the 305 species of birds found in North America in winter are on the move, having already shifted their early-winter ranges northward by an average of 35 miles (Audubon 2009). Birders and other wildlife observers could play an important role in "citizen science" programs, helping natural resource agencies and organizations collect information about changes in wildlife migratory patterns, range shifts, and plant phenology.

Climate change presents new opportunities as well as the need for environmental education and interpretation. A survey of refuge visitors revealed that most are concerned about climate change effects on fish, wildlife, and habitats, but just over half feel well-informed about the issue (Sexton et al. 2012). In another study, incorporating visitor surveys and interviews, 68% of respondents expressed a desire to learn more about the effects of climate change on refuges. For example, when asked if interested in learning about climate change at Nisqually National Wildlife Refuge one visitor

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replied, "Yeah… people who come here… are interested in taking care of our world, so I think it's a proper place to teach" (Schweizer et al. 2013:56). Clearly there is an opportunity on the Refuge System for education and interpretation about climate change.

Interpretation often entails the art of story-telling, and few stories pertaining to the environment are more sweeping and profound than that of climate change. Refuge managers and planners have a unique opportunity to tell the story of climate change and its ongoing and future effects on wildlife, plants, and ecosystems while also engaging the public in behavioral changes that could mitigate the effects of economic activities on our climate. In the Schweizer et al. (2013) study, 78% of respondents felt that informing visitors of actions they could take was particularly salient and important. As one visitor explained, "I guess the whole thing about climate change is that it feels so overwhelming… what am I suppose[d] to do about it? It's easier to do nothing. So tying things that you can do that people feel are doable [is a good idea]… (Schweizer et al. 2013:57)."

Visitors recognize that sometimes the effects of one's mitigation efforts cannot be directly perceived, so it is important for them to know or learn how their collective behavior affects the climate and, in turn, the places that are important to them such as wildlife refuges (Beard and Thompson 2012). FWS, the National Park Service, and NASA have developed training tools and materials to prepare interpreters for informal conversations with their visitors. See for example the Earth to Sky "Arrange for Change" toolkit.

Meanwhile the EPA has worked with a coalition of federal agencies to develop toolkits for formal and informal educators that are grounded in government-approved, current information on climate science and impacts on wildlife and their habitats in specific ecoregions. One toolkit also includes information on how students can become "climate stewards" and engage in behaviors that contribute to the mitigation of climate change.

Learning objectives for environmental education programs on the Refuge System should include a basic understanding of climate change and its ecological effects. Interpretive and educational materials about climate change should be tailored as much as possible to the landscape and community in which the refuge exists. For example, coastal and marine refuges should incorporate materials and stories about sea-level rise, while refuges with glacial-dependent water systems would focus on glacial melt. As the local impacts of climate change become evident to communities using refuges, the Refuge System will play an increasingly important role in environmental education and interpretation of the effects of climate change.

Transportation

Most conventional transportation produces greenhouse gas emissions (GGEs) that contribute to climate change, which in turn is a threat to transportation infrastructure. Refuge staff and visitors use, predominantly, fossil-fueled vehicles to travel to and within refuges. Within FWS, use of motorized vehicles accounts for approximately 17% of our carbon footprint (FWS 2009), and this figure is probably higher on the Refuge System where long distances are routinely traveled.

Transportation is a major concern for many refuge managers and planners tasked with addressing vulnerability to climate change. DOI and FWS are seeking to better understand how anticipated climate change effects might impact transportation facilities within Service units and what might be done to adapt. Transportation personnel are investigating tools for determining vulnerability, identifying ways to safeguard priority facilities, and developing transportation options to reduce GGEs. For example, DOI has partnered with the U.S. Department of Transportation to develop an approach to planning for the effects of climate change on transportation assets on national parks and wildlife refuges.

Climate change impacts that could affect transportation infrastructure include sea-level rise; increased frequency, intensity, and duration of precipitation; increased wind speeds; and higher average temperatures. Affected infrastructure includes paved and unpaved roads, bridges, trails, boardwalks, docks and boat launches, parking lots, and air strips.

<u>Impacts of Climate Change on Transportation Infrastructure</u>

Climate change impacts that could affect transportation infrastructure include sea-level rise; increased frequency, intensity, and duration of precipitation; increased wind speeds; and higher average temperatures. Affected infrastructure includes paved and unpaved roads, bridges, trails, boardwalks, docks and boat launches, parking lots, and air strips. Following are some particular aspects of climate change and likely effects on transportation infrastructure (ICF International 2010):

- Sea-level rise, storms, and increased precipitation can lead to the flooding or washout of roads, bridges, parking lots, and trails. Mudslides can also block passage.
- Higher average temperatures can lead to more extreme freeze/thaw cycles or changes in permafrost patterns (especially for unpaved infrastructure).
- Increased precipitation and storm surges can increase the erosion of unpaved roads, paved road bases, and bridge supports.
- Bridge joints and paved surfaces are vulnerable to thermal expansion caused by extreme temperatures or temperature variations, accelerating structural degradation.
- High winds may destroy or damage gates, signs, and other transportation-supportive infrastructure.

<u>Planning Tools for Transportation on Refuges</u>

There are four basic strategies for reducing transportation-related GGEs: 1) improving fuel efficiency of vehicles; 2) reducing carbon content of fuel; 3) reducing the vehicle miles traveled or shifting those miles to more efficient modes, and; 4) improving the efficiency of the transportation network (Cambridge Systematics 2009). Refuges can plan to lower their transportation GGEs by improving the efficiency of the vehicle fleet; use of alternative fuels, reducing congestion within and near the refuge, and; encouraging staff and visitors to reduce their vehicular use by walking and bicycling, using public transit, and carpooling.

FWS developed a Climate Leadership in Service Units (CLIR) tool with the Federal Highway Administration to help refuges and other FWS units estimate GGEs from building and fleet energy consumption, as well as from visitor travel to and within units (O'Brian 2012). The tool is also useful for developing strategies to reduce GGEs. FWS has held workshops and piloted the CLIR tool at four refuges. Each workshop included an assessment of GGEs (see for example ICF International 2011). Visitor travel to these refuges accounted for 85-98% of GGEs associated with the refuges. Visitor travel within the refuges was the second-largest source of emissions. However, travel behavior of FWS personnel is important symbolism that affects public attitudes and eventually behavior.

CLIR workshop participants suggested the following for reducing GGEs:

- Strategically employ transit on site, considering carrying capacity, interpretation, alternative fuels, and local school bus fleets.
- Conduct a fleet vehicle analysis to plan for a more fuel-efficient fleet.
- Reduce staff vehicular use through trip sharing, carpooling, and incentives for commuting via alternative modes.
- Lighten vehicle loads to remove excess by season or task.
- Provide incentives to visitors for high-occupancy or fuel-efficient vehicles or carpooling.

To plan for the transportation impacts of climate change, refuge managers must first identify the vulnerable infrastructure on their refuges. Various tools are helpful for identifying such vulnerabilities, including:

- Climate Change Vulnerability Assessment. FWS is developing a transportation-focused vulnerability assessment tool in partnership with the National Park Service and Federal Highway Administration to identify anticipated impacts of climate change on transportation infrastructure. The tool should be available in 2013 (Steve Suder, Refuge System Transportation Coordinator, Arlington, Virginia, personal communication).
- Coastal Vulnerability Index (CVI). The CVI provides a rough measure of vulnerability to sea-level rise and other coastal dynamics, and may be useful for broad-scale or first-step transportation planning.

> ***Once refuge managers have identified vulnerable transportation infrastructure, they need adaptation strategies. There are five basic adaptation approaches for transportation: repair and maintenance, reconstruction/ strengthening, relocation, abandonment, and redundancy.***

- Sea Level Affecting Marshes Model (SLAMM). SLAMM is used primarily for modeling the ecological effects of sea-level rise but in 2013 a roads module was developed to help managers identify which roads or portions thereof are most vulnerable to sea-level rise.

Once refuge managers have identified vulnerable transportation infrastructure, they need adaptation strategies. There are five basic adaptation approaches for transportation: repair and maintenance, reconstruction/strengthening, relocation, abandonment, and redundancy. Many of the specific methods currently available for transportation infrastructure management may be used for climate change adaptation. For example, drainage can be improved to obviate severe flooding, roads may be elevated, and roads may be closed during seasons of high vulnerability.

Buildings

Refuge System buildings include visitor centers, offices, meeting halls, educational facilities, maintenance and storage facilities, laboratories, and staff housing, among others. Buildings are integral to the mission of the Refuge System and provide for the health and safety of employees, volunteers and visitors.

Buildings also contribute to climate change due to their usual reliance upon fossil fuels for heating, cooling, and other energy-intensive functions. Building design, construction, renovation and maintenance has a substantial effect on the Service's carbon footprint and therefore climate change mitigation.

Conversely, buildings are subject to the ongoing and future effects *of* climate change. The vulnerability of buildings to more severe or otherwise different weather calls for adaptive measures in the design, construction and maintenance of buildings.

<u>Climate Change Mitigation</u>

Numerous laws, codes and regulations are in place to guide and assist federal planners when designing and constructing new buildings or rehabilitating existing buildings. Design and alteration of federal buildings is guided by *Facilities Standards for the Public Buildings Service* (GSA 2005). The Federal Emergency Management Agency (FEMA) defines minimum building standards for flood damage protection in Special Flood Hazard Areas. Engineering and construction of Refuge System buildings must also comply with Part 360 of the Service Manual. In general, all construction (new and retrofit) must comply with or exceed applicable life-safety building codes.

Other federal guidance especially relevant to climate change mitigation includes:

- The Federal Leadership in High-Performance and Sustainable Buildings Memorandum of Understanding (MOU) of 2006. DOI joined 16 other departments and agencies in signing the MOU that outlines five "guiding principles" to be followed when leasing, designing, constructing, operating, and maintaining high-performance and sustainable buildings. The principles are:
  1. Employ integrated assessment, operation, and management principles.
  2. Optimize energy performance.
  3. Protect and conserve water.
  4. Enhance indoor environmental quality.
  5. Reduce environmental impact of materials.
- Executive Order 13423 (2007), "Strengthening Federal Environmental, Energy, and Transportation Management," formalized the requirement to follow the principles listed above.
- Executive Order 13514 (2009), "Federal Leadership in Environmental, Energy, and Economic Performance," set sustainability goals for federal agencies and focused on making improvements in their environmental, energy and economic performance.

Pursuant to Executive Order 13514 the Service committed to become carbon neutral by 2020. To assist in meeting this goal, all new building and major renovation completed after 2020 must be "net zero" meaning that buildings must use no more energy than they convert for use on-site. (Such buildings are said to "consume" no more energy than they "produce.") They are often off the grid or independent of it. If on the grid, net-zero buildings return as much energy to the grid as they draw. Ideally, net-zero buildings emit no carbon and require no grid-based fossil-fueling. At the least, energy use by net-zero buildings results in no net gain in carbon emissions.

There are thirteen common strategies for accomplishing net-zero energy use:

- Highly efficient building envelopes
- Cool roofs
- High thermal resistance (R-value), low-emissivity window glazing
- Daylighting
- Highly efficient lighting including occupancy controls
- Minimized plug loads
- Natural ventilation
- Under-floor or displacement ventilation (rarely used on the Refuge System)
- Highly efficient HVAC systems
- Heat recovery
- Radiant heating/cooling systems
- Geothermal (ground source) heat pumps
- Renewable energy systems, such as solar photovoltaic arrays

To assist in meeting federal sustainability goals and objectives, Service policy requires that all new construction and major renovations exceeding 5,000 square feet earn a Leadership in Energy and Environmental Design (LEED) Silver certification by the U.S. Green Building Council. In addition, all new buildings must be at least 30% more energy efficient than relevant code.

Standards and codes frequently change. Furthermore, climate change mitigation and adaptation often entails building "beyond code." Refuge System staff considering new building construction or major renovation should contact the licensed professional architects and engineers in the appropriate Regional Engineering Office for advice and assistance.

CASE STUDY: CLIMATE CHANGE MITIGATION AT THE ENVIRONMENTAL DISCOVERY EDUCATIONAL CENTER, BRAZORIA NATIONAL WILDLIFE REFUGE

Brazoria National Wildlife Refuge (Texas) received a Federal Energy and Water Management Award and a Department of the Interior Environmental Achievement Award in 2005 for completion of the Service's first 100% solar energy-powered building. The 2,065 square-foot Brazoria Environmental Discovery Educational Center in Freeport is used by over 5,000 students, grades 4-9, to conduct experiments in biology and environmental science, and has over 15,000 visitors per year. The complex consists of an education building with an open classroom and visitor displays, a restroom building, a pump house, and a nature trail. The Center generates 100% of its own electrical power using two separate solar photovoltaic arrays. A 2 kW solar array operates two direct-current pumps. A 5.4 kW solar array on the roof of the educational building maintains the charge on deep-cycle batteries, the DC electrical power from which is converted to single-phase AC power by two inverters that serve the building's light, receptacles, and ventilation systems. The solar system is backed up by an 8.5 kW electric generator. Approximately two dozen major energy conservation measures are built in including superinsulation, clerestories, low-E windows, sun shades, reflective metal roofing, natural ventilation, T-8 lighting, and an energy-efficient HVAC system.

Protecting Buildings and People from Multi-Hazards

The ongoing and future meteorological effects of climate change have implications for the design, construction and maintenance of buildings, too. We must be concerned with occupant safety and protection of buildings from severe or otherwise unexpected weather. Some measures to address these concerns entail moderate expenditures on preventive maintenance, while other measures require considerable investment.

The conditions and functions of Refuge System buildings should be assessed with the projected effects of climate change in mind. Templates for risk assessment are provided by NOAA (2010) and FEMA (2013). In general, climate change increases the risks of building devastation, especially due to wildfire, flooding, and severe winds.

Fire provisions are especially important in areas of increasing drought and ecosystem stress. "Firewise" design criteria are outlined in Bueche et al. (2012) and CFRO (2008). Many state and university extension offices offer suggestions for minimizing the risk of fire damage to buildings, as do other organizations that specialize in particular ecosystems (e.g., California Chaparral Institute). The refuge manager has the additional advantage of the Refuge System's Fire Management Program, and may consult with the Zone Fire Management Officer for purposes of fire risk reduction and building protection.

Flooding may be coastal, riverine, or indeterminate in path (typical of mountain river systems entering alluvial plains). Precipitating events include hurricanes, coastal storms, winter storms, early snowmelt, and severe or extended rain, as well as dam, levee or water system failures. Major flood protection strategies for new buildings and retrofits include relocation, elevation, and floodproofing. Historic buildings present special cases in which floodproofing is often the only acceptable option (FEMA 2008). Various model regulations and technical requirements for flood design are summarized in ACSE (2006) and Watson and Adams (2011), with FEMA regulations being the most relevant for Refuge System purposes.

Planning for sea-level rise is similar to planning for coastal flooding, but the design criteria and safety factoring cannot be based on historic data. Design decisions must rely upon modeling with the best available data and the interpretation and judgment of refuge managers and others responsible. Sea-level rise threatens buildings with increasing frequency and severity of flooding, erosion (horizontal and vertical), and fetch, and ultimately with inundation as well as saltwater intrusion into water supplies. The two major planning responses to sea-level rise are relocation and elevation (Watson and Adams 2011), not including demolition or abandonment.

Hurricanes bring the multi-hazards of storm surge and severe winds (Figure IV-2). Wind-bracing of structures is relatively inexpensive, but requires particular attention to proper installation, nailing, and strapping connections from roofs to foundations. Guidance is provided in the International Code Council's *Standard for Construction in High-Wind Regions*, which is updated every few years (ICC 2008).

<u>Shelter Provision and Survivability</u>

Buildings are often sought for shelter during natural disasters. Warning times vary from seconds (e.g., earthquake) or minutes (e.g., tornado) to hours (e.g., forest fire) or days (e.g., hurricane). Multi-hazards should be anticipated. For example, in the context of drought and increasing storm severity, fire and flooding can occur in short succession.

Refuge System buildings should be "survivable" during extended power outages (Watson and Adams 2011: 210). For starters, such buildings are functional without reliance upon a central power grid. They have ample natural lighting (such as with sky-lights), passive solar-heating with sun-facing windows, sunrooms, and perhaps with on -site solar power, and are naturally cooled with ventilation and thermal mass. Survivable buildings tend to serve the dual purposes of climate change mitigation and adaptation to climate change effects.

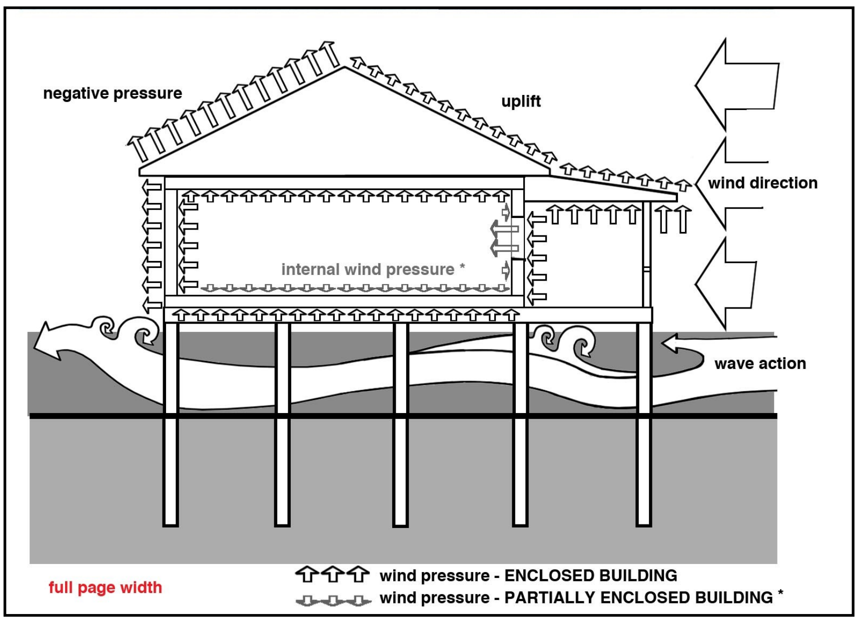

Figure IV-2. Exposure of coastal buildings to wind and waves. (Courtesy of Donald Watson and Earthrise Design).

Cultural Resources

Cultural resources in the field range from landscapes to artifacts, prehistoric to historic, buried to exposed, but are always considered fragile remnants of the past. They have long been threatened by vandalism, economic activities, and public land management activities that, while authorized, do not sufficiently consider the impacts on cultural resources. For example, chert, obsidian, bone, ceramics, metals, and glass can be altered by the high surface (and sometimes subsurface) temperatures associated with wild and prescribed fire (Buenger 2003).

Climate change is recognized as another challenge to the conservation of cultural resources. A 2009 report to Congress cites climate change as a growing threat to archaeological sites on federal lands (NPS 2009). Sea-level rise, especially, threatens all types of historic properties and artifacts along the coasts (National Research Council 2012). For example, defense works from World War II are succumbing to sea-level rise (Figure IV-1).

Zooarchaeological materials are prevalent among FWS collections and, with exposure and proper management, can become important data sets for climate change modeling and planning.

Among FWS cultural resources staff, the consensus is that increased erosion, the result of increasing temperature and drought-reduced vegetation, is and will continue to expose archaeological sites to damage. Sites will either completely erode or will be exposed for longer periods of time, making them more susceptible to damage and looting. In either case, information useful for Refuge System planning will be lost. For example, archeological information, especially from the period encompassing approximately a millennium prior to the Industrial Revolution, is highly relevant for implementing the Biological Integrity, Diversity, and Environmental Health Policy (601 FW 3) (Czech 2004).

Archaeological sites offer a unique understanding not only about human history but about ecological and evolutionary history. For example, examination of faunal remains from archaeological sites (which FWS curates as museum property) can illustrate how the presence of a species or set of species has changed in a given area over time. Hightower et al. (1996) and Finch et al. (1999) considered archaeological specimens and historic documents in their conservation research.

Ecologically oriented archeological research often provides climatological insights. Moore and Huntington (2008) considered 12,000 years of prehistory in their analysis of climate change impacts on Arctic mammals. Murray (2008) cited some recent work using zooarchaeological samples to examine past and present species' ranges. Zooarchaeological materials are prevalent among FWS collections and, with exposure and proper management, can become important data sets for climate change modeling and planning.

Archaeological sites also offer an understanding about past landscape uses, past impacts on the land, and human accommodation to these impacts. Many archeological sites on the Refuge System are

Figure IV-1. Historic structure at Midway Atoll vulnerable to sea-level rise.

culturally important to Tribes, too. Tribes have longstanding (and current) connections to their ancestral lands, and climatological impacts may greatly affect their ability to maintain traditional lifeways. Reduced lifeway opportunities could strain consultation efforts with FWS over the nature, availability, and use of cultural resources in the future.

Consulting with Tribes is important for refuge managers and the Refuge System not only from the standpoint of cultural resource preservation, but also to incorporate traditional ecological knowledge (TEK) (Menzies 2006). Such knowledge, held by tribal members about their ancestral environment and the cultural practices that built on that environment, may provide crucial insights about climate change, its ecological effects, and our potential for adaptation (Pettenger 2013). Tribes should be invited to participate in Comprehensive Conservation Planning, and even more so in the context of climate change. (See Tribal Affairs below.)

Education and Outreach

Success in planning for climate change on a refuge or landscape usually hinges upon the acceptance and support of the local public and various partners from outside the conservation professions such as towns, businesses, and industry groups. Ultimately, atmospheric and ecological stability requires widespread public knowledge of the causes and consequences of climate change. Therefore, planning for climate change entails education and outreach, which largely comprise the "engagement" response to climate change (Table II-1). Furthermore, such planning for education and outreach may be viewed along a spectrum from short-term to long-term (Figure II-2).

Short-term education and outreach may be designed to address immediate concerns such as the need for prescribed fire, invasive species control, or land acquisition inland of coastal marshes threatened by sea-level rise. Long-term education and outreach is designed to provide the public with a broad, holistic knowledge of climate change and its drivers to enable an effective societal response to climate change (U.S. Department of State 2010, Gough 2011). Typically a combination of short- and long-term education and outreach may be provided within the same document, program or presentation.

Ultimately, atmospheric and ecological stability requires widespread public knowledge of the causes and consequences of climate change.

Education and outreach may not require separate, formal documents, which may be difficult to author or procure given limited resources. For example, an "Education and Outreach Plan," per se, may not be needed. At the most basic level, planning for climate change education and outreach can simply entail a decision (a mental or conceptual plan) to include climate change educational material in existing Refuge System plans.

All CCPs and landscape-level plans are *de facto* opportunities for climate change education and outreach. Merely noting the existence and effects of climate change on a refuge or landscape helps to perform such education and outreach, and numerous examples of doing so are provided in Part V (see for example Table V-3.)

Climate change considerations may also be incorporated in interpretive materials such as brochures, visitor center displays, and trail signs. Brochures and visitor center displays are particularly conducive to big-picture education and outreach geared toward long-term solutions. These types of outreach products should describe the basics of climate change, including the greenhouse effect and anthropogenic drivers of climate change (Part II). These products should also "incorporate and more clearly communicate biological, social, and economic science… at all scales" (PIT 2013:1).

Social and political sensitivity is important in climate change outreach. Therefore it will help to cite the work of well-established climate science entities such as the IPCC, NASA, and the USGCRP. Regarding education on the drivers of climate change, the most authoritative and widely cited document is the IPCC's *Special Report: Emissions Scenarios*. The full report is available as a 570-page book published by Cambridge University Press (Nakicenovic et al. 2000), but the *Summary for Policymakers* is web-accessible as noted in Appendix B.

The IPCC states, "the main driving forces of future greenhouse gas trajectories will continue to be demographic change, social and economic development, and the rate and direction of technological change" (IPCC 2000:5). The level of economic activity, which reflects the size of the population and its affluence (per capita consumption), is directly linked to climate change because national and global economies are primarily fossil-fueled (Hannesson 2009). As Glick et al. (2011) pointed out, the IPCC's high-range scenarios (A1F1 group of scenarios) and low-range scenarios (B1 scenarios) both assume substantial economic growth. So do the mid-range scenarios of the A1B group. In other words, the major differences in projected emissions pertain to assumptions about technological change, most notably pertaining to alternative sources of energy and the energy intensity of economic activity.

Education and outreach should be designed to raise public awareness of the causes of climate change in a manner that is neither too alarming nor unreasonably optimistic. We want to inspire hope and action to avert catastrophic climate change without leading the public to think that climate change will be solved simply through new technologies and with no change in the level of economic activity. There is no evidence that alternatives to fossil fuels will be sufficient for further growth of national and global economies (Pimentel in press). To the contrary, thermodynamic science indicates that more intensive use of fossil fuels is required for further economic expansion (Hall and Klitgaard 2011). Evidence for this may be seen in the dramatic increase in coal mining (Chadwick and Higgins 2006), hydro-fracturing for natural gas (Pless 2012) and the extraction of "heavy oil" from tar sands and oil shale (Maugeri 2012). Education and outreach should help clarify these relationships among economic activity, energy requirements, fossil fuel combustion, and climate change.

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We should also avoid advancing hypotheses of re-structuring the economy such that growth may continuously result from ever more and "lighter" services relative to goods comprised of natural resources. The belief in perpetual growth via re-structuring is inconsistent with the physical and economic sciences (Daly and Farley 2010) as well as ecological theory and evidence (Czech 2013) and again is belied by current trends in resource extraction and conflict (Klare 2002). Given the limitations of technological and restructuring approaches to stabilizing greenhouse gas emissions and atmospheric concentrations, it may be more appropriate to assist in identifying lifestyle choices that can help lower rates of greenhouse gas emissions and climate change (U.S. Department of State 2010). This may be especially appropriate in regions where significant concern about climate change already exists.

Meanwhile interpretive signs on nature trails are especially conducive to addressing immediate or short-term climate change concerns. For example, a sign overlooking a degraded coastal marsh may be used for education and outreach on the effects of sea-level rise. SLAMM "before and after" maps are useful for this purpose, as well as diagrams displaying the basic processes (including sea-level rise) affecting the evolution of coastal marshes. Similarly, signs overlooking prairie potholes, Alaskan spruce forests, Arctic tundra, or mangrove forest may provide the relevant information on climate change effects. If enough space and resources are available for large signs or kiosks, these facilities may be used for education and outreach on the greenhouse effect and anthropogenic drivers of climate change as well.

Although formal education and outreach plans are not necessary for developing a refuge or landscape approach to climate change education and outreach, there may be circumstances that warrant such formal planning. For example, urban or suburban refuges with high rates of visitation offer exceptional outreach opportunities. Typically, a climate change education and outreach plan would constitute a portion of a Visitor Services Plan and would lay out a balanced approach to addressing short-term and long-term, local and global climate change challenges and solutions. Additional considerations on climate change education and outreach are found in the Climate Change Communications and Engagement Strategy for the National Wildlife Refuge System (FWS 2014).

TRIBAL AFFAIRS

Secretarial Order 3289, "Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources" (September 14, 2009) states:

> Climate change may disproportionately affect tribes and their lands because they are heavily dependent on their natural resources for economic and cultural identity. As the Department has the primary trust responsibility for the Federal government for American Indians, Alaska Natives, and tribal lands and resources, the Department will ensure consistent and in-depth government-to-government consultation with tribes and Alaska Natives on the Department's climate change initiatives. Tribal values are critical to determining what is to be protected, why, and how to protect the interests of their communities. The Department will support the use of the best available science, including traditional ecological knowledge, in formulating policy pertaining to climate change. The Department will also support substantive participation by tribes in deliberations on climate-related mechanisms, agreements, rules, and regulations.

The fact that climate change "may disproportionately affect tribes and their lands" was corroborated by the National Wildlife Federation, which also noted that "Traditional Tribal natural resource management practices are inherently place-based, time-tested, climate-resilient, collectively managed, cost-effective, and sustainable" (NWF 2011:24).

Refuge managers regularly engage neighbors and local stakeholders as partners in planning and management. Such neighbors and stakeholders may include individual Native Americans and Tribes. Meanwhile federally recognized Indian Tribes have a unique status entitling them to a special government-to-government relationship with the United States based on their status as sovereign nations as set forth in the Constitution of the United States, treaties, statutes, and court decisions (Wilkins 1997). In matters of wildlife conservation, this government-to-government relationship was reinvigorated by the U.S. Supreme Court in *New Mexico v. Mescalero Apache Tribe*, which ensured tribal fish and wildlife jurisdiction on large reservations in the West (Czech 1995). Tribes have responded with some of the most progressive wildlife management programs in the U.S., balancing subsistence harvesting, cultural preservation, and recreational opportunities for non-tribal members.

Secretarial Order 3317, *Department of the Interior Policy on Consultation with Indian Tribes*, provides guidance for achieving a standard for engaging tribal governments through the lens of the government-to-government relationship. The order describes consultation as a deliberative process that aims to create effective collaboration and informed federal decision-making and is built upon the exchange of information. Proper consultation promotes enhanced communication that emphasizes trust, respect, and shared responsibility regarding departmental actions with tribal implications. Efficiencies derived from the inclusion of Indian Tribes in climate change planning help ensure that future federal

To help ensure that refuges are able to meet the required level of tribal engagement in matters relevant to potentially affected Tribes, refuge managers and planners should seek out and create opportunities to meet with tribal representatives about climate change and strategic habitat conservation.

action is achievable, comprehensive, long-lasting, and reflective of tribal input.

Subsequent to Secretarial Order 3317, DOI developed a more thorough policy on consultation with tribes, which was published in the *Federal Register* for public review (*Federal Register* Document Number 2011-11971). Although the policy awaits final adoption, the approach taken by DOI, and as modified here to be more specific to the Refuge System, is that an action warranting consultation is any regulation, rulemaking, policy, guidance, or operational activity that may have a substantial direct effect on an Indian tribe on matters including, but not limited to:

- Tribal cultural practices, lands, resources, or access to traditional areas of cultural or religious importance on federally managed lands;
- The ability of an Indian Tribe to govern or provide services to its members;
- An Indian Tribe's formal relationship with the Refuge System; or
- The consideration of our trust responsibilities to Indian Tribes. (This, however, does not include matters that are in litigation or in settlement negotiations, or matters for which a court order limits our discretion to engage in consultation.)

When considering an action with tribal implications, refuge managers must notify the appropriate Indian Tribe(s) of the opportunity to consult and ensure that notice is given at least 30 -days prior to scheduling. If exceptional circumstances prohibit early notice, an explanation must be provided in the invitation letter.

Tribes evolved and developed with an intimate connection to particular climatological regimes and associated ecological characteristics including fish and wildlife populations. Tribes are often keenly interested in activities that are not in their immediate, current locale, because many Tribes were relocated pursuant to federal removal policies or otherwise occupied vast areas beyond their present locale (Anderson 2006). Tribal interest in activities on ancestral lands is especially applicable to fish and wildlife management; e.g., hunting and fishing pursuant to treaties (McCorquodale 1999, Czech 2000). These aspects of tribal culture are now threatened not only by socioeconomic displacement but also due to climate change.

To help ensure that refuges are able to meet the required level of tribal engagement in matters relevant to potentially affected Tribes, refuge managers and planners should seek out and create opportunities to meet with tribal representatives about climate change and strategic habitat conservation. The Service's Office of the Native American Liaison in Regional or National Headquarters can facilitate refuge efforts to communicate with tribal governments and ensure that the appropriate Tribes are included.

Land Acquisition

Some of the clearest implications of climate change to the Refuge System pertain to land acquisition. Obvious implications occur where wholesale ecosystem transformation is occurring or projected. However, there are nuanced implications where lesser ecological impacts are forecast. Nuances also stem from the diversity of refuge purposes.

Sea-Level Rise

The clearest land acquisition implications of climate change occur along the coasts where sea-level rise threatens coastal wetlands and related terrestrial ecosystems or ecosystem components such as beaches and dunes (Czech 2002). If a refuge's purposes are to conserve these types of ecosystems, then two land acquisition responses are especially pertinent.

First, land acquisition should be designed to mitigate for the loss of ecosystem types to sea-level rise. For example, if a refuge is expected to have a net loss of 10,000 acres of salt marsh, and refuge purposes are specifically focused on salt-marsh species such as black ducks (*Anas rubripes*), then land acquisition should be designed to expand refuge areas where salt marsh is expected to develop as a function of sea-level rise. Such land acquisition may occur on the refuge, on a nearby refuge, or as part of a new project.

Second, land acquisition already planned in low-lying coastal ecosystems should be reconsidered and revised – potentially abandoned – if new information indicates that the area intended for acquisition is highly vulnerable to sea-level rise.

Several factors in addition to sea-level rise must also be considered in developing a prudent land acquisition response to climate change: 1) land prices; 2) urgency of species conservation; 3) compensating ecological effects. If land prices are low, then the loss of an area to sea-level rise is less costly. Conversely if land prices are high and the land will be lost to sea-level rise, then land acquisition would have a lower benefit: cost ratio. This is not only poor strategy for conservation (Naidoo et al. 2006) but may reduce the confidence of policy makers and the public in the Refuge System's vision of strategic habitat conservation.

Short-term conservation of a habitat may be justified if the species in question is imperiled. For example, if nesting sites are the limiting factor for an endangered sea turtle species, then land acquisition may be justified even if the nesting sites are highly vulnerable to sea-level rise. The strategy may be to "buy time" while other nesting sites can be procured or developed.

The clearest land acquisition implications of climate change occur along the coasts where sea -level rise threatens coastal wetlands and related terrestrial ecosystems or ecosystem components such as beaches and dunes.

In some areas, substantial habitat loss is expected, but there is also an expectation that other habitats consistent with refuge purposes will be gained. For example, Alligator River National Wildlife Refuge is expected to undergo substantial loss of swamps to sea-level rise, impacting its conservation value for a variety of species including the red wolf (*Canis lupus rufus*) and wood duck (*Aix sponsa*). However, the refuge is also expected to gain salt marsh (at least during the 21st century), helping to mitigate the loss of salt marshes at nearby refuges such as Swanquarter. This transformation will benefit numerous species including black ducks (*Anas rubripes*) and saltmarsh sparrows (*Ammodramus caudacutus*). It is also consistent with the refuge's general conservation purposes (pursuant to the Fish and Wildlife Act of 1956, the Refuge Recreation Act of 1962, and the Emergency Wetlands Resources Act of 1986).

Interior Refuges

The land acquisition implications of climate change for interior refuges are seldom as obvious as the implications of sea-level rise for coastal refuges. As with coastal refuges, however, refuge purposes are key in

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determining the potential impacts of climate change. In a sense, refuge purposes describe the administrative vulnerability of a refuge to climate change.

For example, the Driftless Area National Wildlife Refuge was established for the purposes of conserving the endangered Iowa Pleistocene snail (*Discus macclintocki*) and the threatened Northern monkshood (*Aconitum noveboracense*). If, due to climate change, the talus slopes of the refuge lose their algific (conducive to the maintenance of cold) properties, then the refuge may no longer serve its purposes. Land acquisition might help to solve the problem, but probably not in the immediate vicinity of the existing refuge. A strategy of land acquisition or protection in a generally northward path may be the best available option for conservation of these species in the U.S., assuming other relic populations of the two species are discovered.

For interior refuges having general purposes, such as Kirwin National Wildlife Refuge (Kansas), the implications of climate change are less relevant to land acquisition. As the climate of Kansas changes and different species and ecosystems become prominent at and around Kirwin, land acquisition goals and objectives may change, but the refuge will always have a role to play in "the conservation, maintenance, and management of wildlife" as specified in the Fish and Wildlife Coordination Act (the establishing legislation for Kirwin).

It follows that one of the key land acquisition implications of climate change is adaptation of habitat and population goals and objectives, at least to the extent that such adaptation is consistent with refuge purposes. Meanwhile climate change may become a threat to the viability of refuges with very specific purposes. Refuge System policy may need to be developed to address these circumstances, but refuge managers may also use sound professional judgment in seeking to expand refuge purposes where appropriate and feasible (based partly on climate vulnerability assessment and modeling). Such judgment should be informed and facilitated by LCCs and LCDs (see Landscape Conservation Designs in Part V).

Oil, Gas, and Other Energy Infrastructure

The effects of climate change will include impacts on energy exploration, production and distribution. These activities may also become more challenging for the Refuge System in the context of climate change. For both of these reasons, careful planning of energy development is called for to avoid maladaptation and negative impacts to natural systems.

The Refuge System has a variety of energy-related infrastructure, such as natural gas pipelines and oil wells (GAO 2003), that may be impacted by climate change. Sea-level rise, floods, and increased periods of extreme heat and drought have adverse effects on energy-related infrastructure. For example, sea-level rise may inundate coastal refuges that have well heads and tank batteries.

Most wellheads and supporting infrastructure on the Refuge System were not designed for prolonged use under water. When infrastructure becomes submerged or continuously exposed to tidal systems and inundation events, the risk of leaks and spills increases. In these circumstances electrical distribution to energy infrastructure will also be inundated, adding to the difficulty of responding onsite with electrical equipment (Wilbanks et al. 2012). Therefore, where sea-level rise is expected (e.g., based on SLAMM analysis), wellheads and supporting infrastructure should be retrofitted, plugged, or moved to higher elevations. This is an expensive activity that causes ecological disturbance, but

One of the key land acquisition implications of climate change is adaptation of habitat and population goals and objectives, at least to the extent that such adaptation is consistent with refuge purposes.

waiting until inundation leads to a more difficult, expensive, and ecologically damaging outcome.

On inland refuges, flooding can damage oil and gas developments, especially on abandoned sites or sites in disrepair. If flood debris damages wellheads, leaks can drain into streams when floods occur. Also, extreme drought can exacerbate these problems because dry soils soak up spill materials, which are then liberated when infrequent torrential rains fall.

In general, extreme weather events have major implications for energy supply systems on and off the Refuge System, including indirect adverse impacts on fish and wildlife and ecosystems. For example, alteration in runoff patterns affects hydropower production. Reduced stream flows stemming from drought may lead to disputes over water resources necessary for wildlife conservation. Changes in precipitation patterns alter river flows and snow deposition. This can result in the mis-timing of water availability vis-à-vis water needs (Aizen et al. 1997, Krasovskaia and Gottchhalk 2002). For example, dam management authorities may withhold water for agricultural and other economic purposes, with effects on fish spawning and wildlife migrations. Some refuges have already experienced these challenges; climate change is expected to increase the frequency of such situations. Planning with hydroelectricity providers, dam operators, water authorities, agricultural interests and others should be done accordingly.

A more recent problem involves hydraulic fracturing, especially in arid areas or areas experiencing drought. Hydraulic fracturing requires large volumes of water (estimates range from 1.7 to 3.9 million gallons/well), so acquisition and disposal of water creates problems (Andrews et al. 2009, DOE 2009). For example, many refuges rely on spring- or stream-fed surface waters for managing waterfowl. With or without climate change, drought is a challenge, but the challenge is multiplied if upstream withdrawals for hydro-fracturing are sought simultaneously. Managers and planners need to foresee these types of conflicts and plan accordingly.

Efforts to mitigate climate change with alternative energy production also have adverse impacts on refuge resources and purposes. For example, biofuels production as an alternative to petroleum products is pushing up corn and other grain prices, as well as the land prices where grains are produced (Hill et al. 2006). Agricultural interests seek to reduce CRP acreage caps substantially to make room for biofuel and other commodity production (Knight 2012). The expansion of the agricultural economy to incorporate biofuels places additional stress on refuges in key waterfowl production areas, especially in the prairie pothole region (Wright and Wimberly 2013). Ironically, the conversion of CRP easements to biofuel production typically results in a long-lasting net increase in carbon emission, with the duration of this "carbon debt" depending primarily upon the conversion performed (e.g., to corn vs. soybeans) and details of production (e.g., tillage vs. no-till methods) (Gelfand et al. 2011:13864).

It is a daunting challenge for the refuge manager and planner when wildlife conservation is pitted against fuel production, agriculture, and other economic activities, and planning options are limited at the refuge level. Ultimately, planning must also occur at the national level if fish and wildlife in the "economy of nature" are to be maintained in balance with the human economy (TWS 2003). Meanwhile refuge managers, planners and other personnel will need to adapt their habitat and population

It is a daunting challenge for the refuge manager and planner when wildlife conservation is pitted against fuel production, agriculture, and other economic activities, and planning options are limited at the refuge level. Ultimately, planning must also occur at the national level.

Case Studies: Refuges with Specific Species Conservation Purposes and Climate Change Concerns (modified from Van Metter 2008).

Refuge	Species	Current Threats	Potential Climate Change Challenges
Driftless Area (Iowa)	Iowa Pleistocene snail (*Discus macclintocki*)	Invasive species including mustard grass Pesticides	Increased flooding, causing removal of soil from talus layer Warming of algific talus slopes, creating a thermally unsuitable environment
Buenos Aires (Arizona)	Masked bobwhite (*Colinus virginianus ridgwayi*)	Habitat loss due to overgrazing Desertification Summer droughts decrease egg hatching success	Drought leading to both reduced vegetation and decreased water availability Increased occurrence of invasive grasses reducing available cover and increasing exposure to aerial predators
Blowing Wind Cave, Logan Cave (Alabama, Arkansas, respectively)	Indiana bat (*Myotis sodalis*)	Habitat loss and habitat fragmentation Human disturbance of hibernacula White-nose syndrome	Increased temperatures leading to increased winter mortality
Mortenson (Wyoming)	Wyoming toad (*Bufo hemiphys baxteri*)	Pesticides Fungal infections	Reduced immunological response – increased susceptibility to chytrid fungus; vulnerability to disease Changes in daily and seasonal activity due to air and water temperature changes
Watercress Darter (Alabama)	Watercress darter (*Etheostoma nuchale*)	Urbanization Reduced ground water supply	Loss of thermal niche to exotics Decreased dissolved oxygen Increased toxic & nutrient concentrations

goals, objectives, and management plans to the exigencies imposed by economic pressures and climate change.

Wilderness Preservation

Wilderness preservation allows refuge managers to hedge their bets against the possibilities of inaccurate climate change projections and experimental management techniques that could lead to unintended consequences. Wilderness is “a strategy for spreading the risk of failing to find the right adaptation options for non-wilderness lands” (Watson 2009a:67) as well as a “critical scientific yardstick” for measuring climate change effects (Watson 2009b:65). The yardstick metaphor is especially relevant to the Refuge System where the maintenance of biological integrity, diversity, and environmental health is mandated by the Refuge Improvement Act. The Refuge System policy for implementing this mandate, 601 FW 3, calls for the maintenance of natural and historic conditions unless such conditions interfere with refuge purposes. Of all the categories of refuge purposes (e.g., migratory bird conservation, endangered species conservation, outdoor recreation, etc.), wilderness

Larger, more intact wilderness areas provide the best "scientific yardstick" for measuring landscape-level ecological changes stemming from climate change. All else equal, observed ecological change in wilderness areas could more reliably be attributed to climate change than to the complex mix of anthropogenic variables that operate outside of wilderness.

preservation is the refuge purpose most congruent with the maintenance of ecological integrity. Therefore, wilderness areas comprise a portion of the Refuge System where 601 FW 3 is especially applicable. Wilderness is intended to represent natural conditions, *de facto*.

However, the congruence of wilderness preservation and ecological integrity is not always perfect or absolute, because in designated wilderness there is also the need to avoid manipulative management to the extent possible (Landres 2010). This is challenging to managers who attempt to maintain natural species assemblages for purposes of ecological integrity, but find it difficult to accomplish without hands-on management. Most controversial wildlife management activities result from the need to balance the ideals of natural and non-manipulated conditions. This controversy has been well-documented in the Southwest (Czech and Krausman 1999) and appears as a common theme throughout the Wilderness Preservation System.

However, in the context of climate change, the non-manipulation ideal of wilderness offers one distinct advantage over the natural conditions ideal. The non-manipulation ideal is stable and clear in any context, whereas anthropogenic climate change results in confusion about the appropriateness and techniques for maintaining natural conditions (see also "Retrospective and Prospective Planning" in Part II). For example, in some cases it is becoming difficult to determine what constitutes an invasive species as climate change alters the ecological parameters that determine the fitness of a species to its environment. In such cases, the non-manipulation ideal tilts the scales toward leaving species and community evolution to take its own course. Obvious exceptions unrelated to climate change may still occur, however. For example, the introduction of rats on a wilderness island due to a shipwreck or trespass may call for short-term manipulation for purposes of rat eradication.

Larger, more intact wilderness areas provide the best "scientific yardstick" for measuring landscape-level ecological changes stemming from climate change. All else equal, observed ecological change in wilderness areas could more reliably be attributed to climate change than to the complex mix of anthropogenic variables that operate outside of wilderness. Therefore, some wilderness areas may be considered optimal for establishing baseline inventories and long-term monitoring. They can also function as control areas in experimental designs for assessing the effectiveness of restoration efforts conducted outside wilderness.

V. INCORPORATING CLIMATE CHANGE CONSIDERATIONS INTO REFUGE SYSTEM PLANS

LANDSCAPE CONSERVATION DESIGNS

A Refuge System Planning Implementation Team (PIT) was assembled pursuant to Recommendation 1 of *Conserving the Future*, which was to "incorporate the lessons learned from our first round of CCPs and HMPs into the next generation of conservation plans, and ensure these new plans view refuges in a landscape context and describe actions to project conservation benefits beyond refuge boundaries" (FWS 2011:35). The PIT was especially concerned with developing an approach to landscape-level planning, and called for the development of landscape conservation designs (LCDs) "as part of the preplanning phase of every refuge-specific CCP and LPP" (PIT 2013:3).

Climate change was central to the thinking of the PIT, which noted, "Our charge was to investigate how Refuge System planning will address large-scale conservation challenges such as climate change, while maintaining the integrity of management and conservation delivery within our boundaries" (PIT 2013:1). While LCDs will be a valuable addition to Refuge System planning for numerous reasons, they are particularly suited to responding to climate change in the near and foreseeable future. As suitable climates for species "move" across the landscape, LCDs will provide a mechanism for us to determine where to focus conservation efforts in the future.

Furthermore, by definition LCDs must be concerned with climate change, because an LCD "is an assessment of the landscape's current and potential future condition, a description of a desired future condition, and a suite of preliminary, coarse-scale management strategies that are developed by the greater conservation community" (PIT 2013:5). The "potential future condition" of a landscape is a function of climate change, and the feasibility of a "desired future condition" is determined, in part, by climate change. The Planning Implementation Team envisioned "climate modeling" and "vulnerability assessments" as components of LCDs (PIT 2013:6).

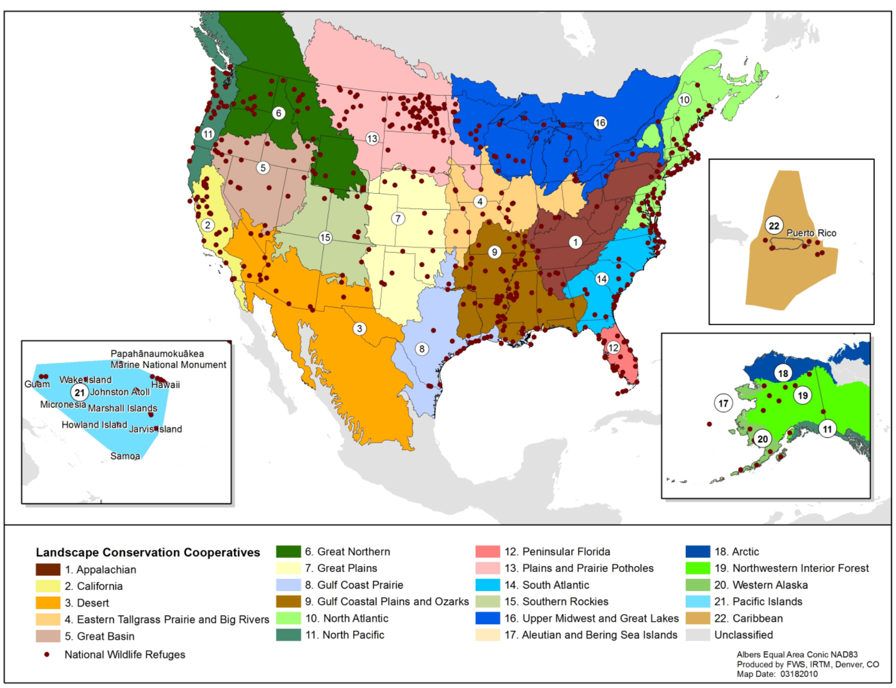


Figure V.I. Landscape Conservation Cooperatives (http://www.doi.gov/lcc/index.cfm) overlain by national wildlife refuges. (Credits: Douglas Steinshouer and Ron Salz, FWS).

LCDs are likely to be established as subunits of Landscape Conservation Cooperatives (LCCs) (Figure V.1). Procedurally, LCCs are appropriate for leading or hosting LCD efforts because they are, by definition, existing landscape-scale conservation partnerships. LCD boundaries will be based upon conservation features such as such as species ranges, watersheds, vegetation, or ecoregions (Figure V.2).

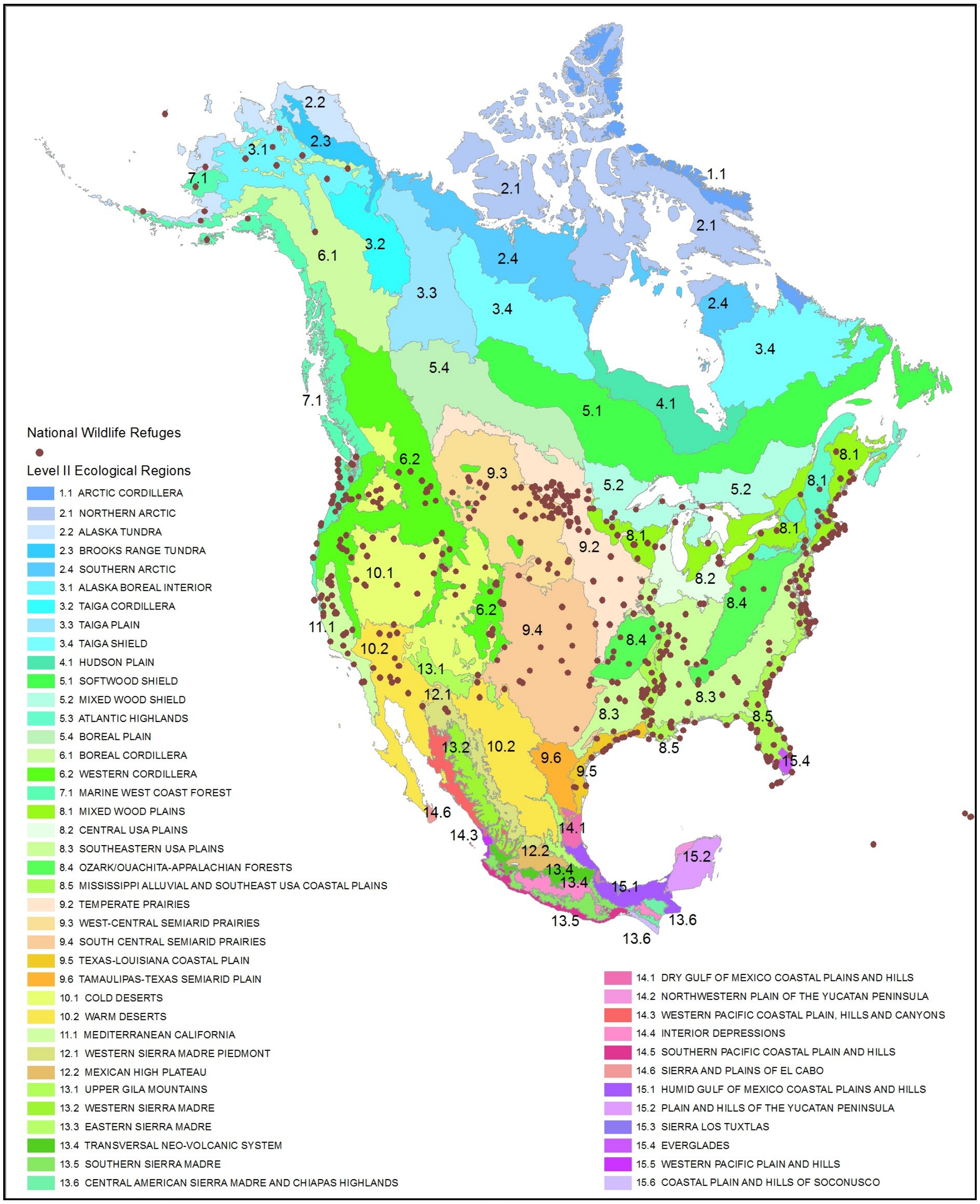
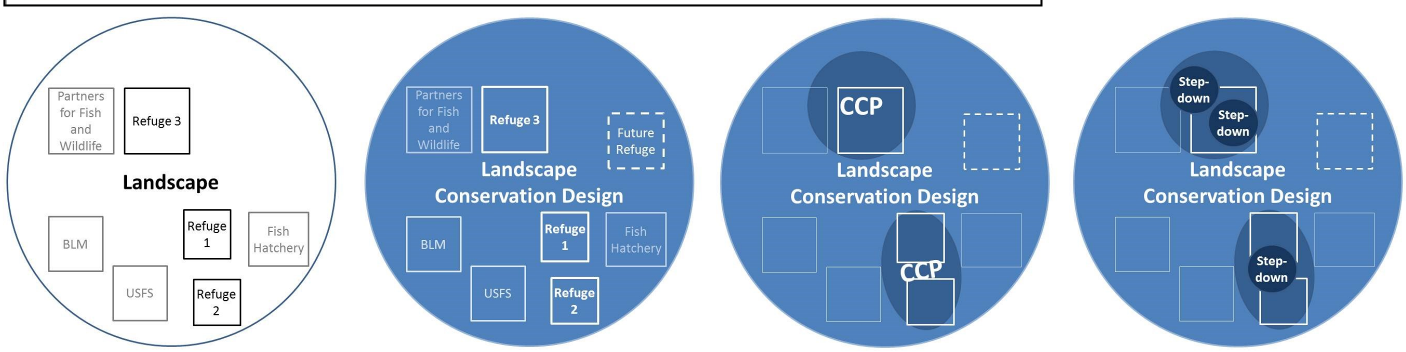


Figure V.2. Level 2 ecoregions as designated by the Commission for Environmental Cooperation (often called "Omernik Level 2 ecoregions") overlain by national wildlife refuges. (Credits: Glenn Griffin, Environmental Protection Agency and Ron Salz, FWS).



Multiple refuges, fish hatcheries, and partner conservation lands may be found within a landscape. Additionally, other conservation efforts (e.g. Joint Ventures) may be actively working to conserve this area. This landscape may be an entire Landscape Conservation Cooperative or a smaller area, such as an ecoregion.

To be more consistent in our planning, we can set goals at this scale through a Landscape Conservation Design. This can include outlining the need for new refuges to increase connectivity or to secure specific habitat.

Comprehensive Conservation Plans (CCPs) should be written in the context of the broader Landscape Conservation Design. In theory, a CCP could encompass multiple refuges.

Just as the CCPs should tier to the larger goals in the Landscape Conservation Design, the step-down plans (including Habitat Management and Visitor Services Plans) should be directly related to their corresponding CCP. In some instances, a step-down plan may fit the needs of multiple refuges.

Figure V.3. Hypothetical Landscape Conservation Design (LCD) (from PIT 2013).

An LCD is likely to encompass several refuges as well as other units of the broader conservation estate, such as fish hatcheries, state wildlife management areas, national parks, national forests, BLM districts, county forests, and private conservation lands such as TNC holdings (Figure V.3). Within the framework of an LCD, LCCs and the broader conservation community will prioritize the location and type of actions necessary for fish and wildlife conservation in the context of climate change.

Once the boundaries of an LCD are established, conservation planning – including climate change planning – may commence in earnest. While LCCs are expected to provide primary leadership in the development of LCDs, leadership may also come from various Refuge System personnel, states, tribes, NGOs, or academia depending on the circumstances. An LCD, informed by other efforts such as downscaled climate modeling, CVA, dynamic vegetation modeling, and species distribution modeling, will identify where and how the conservation community can take action to conserve fish and wildlife in the context of climate change. Such action may include land acquisition, protection of climate refugia, and identification of key areas for protection or restoration such that species may disperse to areas of suitable climate. The potential for assisted migration may also be planned for, as well as the need to redirect refuge management in light of altered hydrology, newly established invasive species, or other effects of climate change.

An LCD is not a final, operational plan. It is "neither an individual partner's management plan nor a decision-document that requires National Environmental Policy Act (NEPA) compliance" (PIT 2013:5). Rather, it will serve as an umbrella to guide or inform the development of operational plans such as CCPs and the various step-down plans such as habitat management plans, visitor services plans, and fire management plans. Climate change considerations must be central to the development of LCDs to help ensure that operational plans will be successful in the context of climate change.

In the remainder of *Planning for Climate Change*, more specific examples of climate change planning are provided in the context of CCPs. These examples correspond with the ecological and other climate change effects described in Parts III and IV.

Comprehensive Conservation Plans

With the benefit of context provided by LCDs, all refuges must be yet managed in accordance with an approved 15-year Comprehensive Conservation Plan (CCP) pursuant to the National Wildlife Refuge System Improvement Act of 1997. However, this does not mean "one refuge – one CCP." As the PIT (2013:4) noted, "Within each LCD, if feasible, the Service should complete a single CCP that encompasses all the refuge units." In general, smaller refuges with relatively similar purposes and issues are more conducive to multi-refuge CCPs than large refuges with unique and complex issues.

CCPs describe the desired future conditions of a refuge and provide long-range guidance and management direction to achieve refuge purposes, help fulfill the Refuge System mission, maintain the ecological integrity of the refuge and Refuge System, help achieve the goals of the National Wilderness Preservation System, and meet other mandates (FWS 2000a). Going forward, new CCPs and CCP revisions will also be designed to incorporate climate change considerations in a landscape context. Also recall from the Education and Outreach chapter that every CCP is an opportunity for

An LCD, informed by other efforts such as downscaled climate modeling, CVA, dynamic vegetation modeling, and species distribution modeling, will identify where and how the conservation community can take action to conserve fish and wildlife in the context of climate change.

raising awareness of climate change, its causes, and its effects on the Refuge System.

The first round of CCPs (for refuges existing at the time the Refuge Improvement Act was passed) was scheduled for completion by the end of 2012. As of February 14, 2014, 499 CCPs were completed, 79 were being drafted, and 22 of the completed CCPs were being revised.

Early CCPs seldom addressed climate change. The incidence of addressing climate change has increased but remains unsatisfactory. Fischman et al. (2013:26) found that "only 73 of 185 CCPs (39%) written between 2005 and 2011 contained one or more prescriptions for addressing climate-change impacts to refuge resources," although an additional 42 refuges at least identified climate change as an issue. Fischman et al. (2013:26) stated, "Without question, revisions of CCPs will need to significantly increase attention to craft management responses to climate change."

Going forward, all CCPs should identify climate change as an issue affecting resources on and around the refuge. A large majority of CCPs should also call for actions, plans, studies, monitoring, modeling, outreach, or related efforts toward climate change adaptation, mitigation, and engagement. The CCPs yet being drafted or revised may help set the standard for climate change planning on the Refuge System.

Appendix A provides a checklist of climate change issues for refuge managers, planners, and other authors to consider at the beginning of

All CCPs should identify climate change as an issue affecting resources on and around the refuge. A large majority of CCPs should also call for actions, plans, studies, monitoring, modeling, outreach, or related efforts toward climate change adaptation, mitigation, and engagement.

While the starter language provided here is designed specifically with CCPs in mind, it may be readily adapted to LCDs, LPPs, a wide range of step-down management plans, and other Refuge System documents concerned with climate change.

CCP development or revision. Use Appendix A to help ensure that no significant climate change effects or issues are overlooked. The Appendix A checklist corresponds with chapters from Parts III and IV, so if an issue is identified that may be relevant to the refuge, the corresponding chapter may be useful for CCP development.

Appendix A is not a comprehensive list of climate change effects and issues, although it covers the primary effects and issues that pertain to large portions of the Refuge System. Sound professional judgment is required to identify other climate change effects or issues that may be relevant to a particular refuge or landscape.

Table V-1 reproduces the "Refuge Comprehensive Conservation Plan Recommended Outline" (FWS 2000b) and with bold font identifies CCP sections most relevant for addressing climate change. Following the table are short sub-chapters providing "starter language" for addressing climate change; that is, language to start with, borrow from, elaborate on, or simply as food for thought in developing a CCP.

Starter language is provided only for CCP sections that will include climate change considerations in all or nearly all CCPs. That is, each CCP section in bold font in Table V-1 has a corresponding subchapter below.

Here are a few tips to keep in mind for using the climate change starter language:

- Starter language is not intended to comprise an entire example of what may be written in a CCP for the section in question. For example, the relevance of climate change should be noted or at least alluded to in a refuge's vision statement, but all refuge vision statements will be concerned with more than climate change. The starter language provided below pertains only to climate change aspects.

- While the starter language provided here is designed specifically with CCPs in mind, it may be readily adapted to LCDs, LPPs, a wide range of step-down management plans, and other Refuge System documents concerned with climate change. *Planning for Climate Change* is intended to assist with climate change planning in virtually any Refuge System context as well as with the planning activities of other FWS programs and partners.
- Much of the starter language below is documented with literature citations. Given the burgeoning of climate change literature, citations may become quickly dated. (One easy starting point for finding updated references is entering the literature citation in an online search engine.)
- It bears reiterating that "starter language" is language to start with, borrow from, elaborate on, or to simply consider as food for thought.

CASE STUDY: USING SLAMM ANALYSIS IN ATLANTIC COAST LCDS.

The ranges and flyways of North American migratory birds are generally moving north. Atlantic coastal LCDs and refuges should expect gradual northward movement of black ducks, brant, mallards, greater and lesser scaup, pintails, redheads, canvasbacks, ring-necked ducks, wood ducks, etc. At the same time, coastal wetlands are being lost to sea-level rise, and our land acquisition efforts are designed partly to offset these losses.

Combining the range-shifting effects of climate change with the wetland-loss effects of sea-level rise, pre-planning in a coastal LCD will entail gradually identifying coastal wetlands further north and further inland for protection in an effort to maintain populations of particular waterfowl species. Refuge System and other conservation personnel will find SLAMM analyses useful for such pre-planning and should include SLAMM maps and tables in coastal LCDs.

Due to northward movements, some waterfowl species may cease to exist on particular refuges and along larger coastal stretches. It may become appropriate to pass along the pre-planning for some species to the next LCD to the north. Meanwhile, the southward LCD may adapt its pre-planning to the new suite of species arriving from the south. This type of pre-planning will be needed not only for waterfowl but also for shorebirds and passerines (migratory and non-migratory) as well as mammals, reptiles, amphibians, fish, invertebrates, and plants.

Table V-1. Refuge Comprehensive Conservation Plan recommended outline. CCP sections in bold font should include climate change considerations in all or nearly all CCPs. Other CCP sections may include climate change considerations on a case-by-case basis.

I. Introduction/Background
- Refuge Overview: History of Refuge Establishment, Acquisition, and Management
- **Purpose of and Need for Plan**
- NWRS Mission, Goals, and Guiding Principles
- Refuge Purpose(s)
- **Refuge Vision Statement**
- **Legal and Policy Guidance**
- Existing Partnerships

II. Planning Process
- Description of Planning Process
- **Planning Issues**

III. Summary Refuge and Resource Descriptions
- **Geographic/Ecosystem Setting**
- **Refuge Resources, Cultural Resources, and Public Uses**
- Special Management Areas

IV. Management Direction
- **Refuge Management Direction: Goals, Objectives, and Strategies**
- Refuge Management Policies and Guidelines

V. Implementation and Monitoring
- Funding and Personnel
- **Step-Down Management Plans**
- Partnership Opportunities
- **Monitoring and Evaluation**
- **Plan Amendment and Revision**

Appendices
- **Glossary**
- **Bibliography**
- RONS List
- MMS list
- Compatibility Determinations
- **Habitat/Land Protection Plan(s)**
- Compliance Requirements
- **NEPA Documentation**
- Summary of Public Involvement/Comments and Consultation/Coordination
- Mailing List
- List of Preparers
- Others, as appropriate

Climate Change Starter Language for CCP Section I: Introduction and Background

Purpose of and Need for a Plan

CCPs are designed to help refuges realize their purposes and goals. CCPs should account for the effects of climate change on those purposes and goals.

> Starter language for CCP:
>
> The CCP is also needed to ensure that the refuge continues to conserve fish, wildlife, and ecosystems [or paraphrase other refuge purpose] in the context of climate change, which affects all units of the National Wildlife Refuge System.

Vision Statement

The refuge vision statement is intended to be future-oriented and give a broad sense of purpose to the refuge. It should be formulated to reflect climate trends and expectations for ongoing climate change. For purposes of identifying the most locally relevant challenges of climate change, refuge managers and other CCP authors may start by using Appendix A, Climate Change Effects Checklist.

> Starter language for CCP:
>
> The refuge will serve as a resilient source of evolving habitats and ecosystem processes even as structure and composition are altered due to climate changes. Such changes may include [significant climate change effects occurring or likely to occur on the refuge].

In some cases, vision statements may also include a basic strategy for adaptation, mitigation, and engagement.

Legal and Policy Guidelines

The implementation of several existing FWS policies (e.g., the Biological Integrity, Diversity, and Environmental Health Policy) will be complicated by climate change, and planners may note that on a case-by-case basis. However, Secretarial Order 3226 is the most directly relevant and important policy related to climate change planning and should be cited in this section of the CCP.

> Starter language for CCP:
>
> Department of the Interior Secretarial Order 3226 (January 19, 2001) states that “there is a consensus in the international community that global climate change is occurring and that it should be addressed in governmental decision making…This Order ensures that climate change impacts are taken into account in connection with Departmental planning and decision making”. Additionally, it calls for the incorporation of climate change into long-term planning documents such as the CCP: “Each bureau and office of the Department will consider and analyze potential climate change impacts when undertaking long-range planning exercises, when setting priorities for research and investigations, when developing multi-year management plans, and /or when making major decisions regarding the potential utilization of resources under the Department’s purview. Departmental activities covered by this Order include, but are not limited to, programmatic and long-term environmental reviews undertaken by the Department, management plans and activities developed for public lands, planning and management activities associated with oil, gas and mineral development of public lands, and planning and management activities of water projects and water resources.”
>
> Secretarial Order 3289 (September 14, 2009) reiterated the mandate provided in Secretarial Order 3226. Also, the FWS strategic plan for climate change states, “We will consider actual and projected climate change impacts to fish and wildlife populations and their habitats in Service planning, decisionmaking, consultation and evaluation, management, and restoration efforts” (FWS 2010:22). CCPs are explicitly listed as plans subject to this directive.

Climate Change Starter Language for CCP Section II: Planning Process

Planning Issues

The ecological effects of climate change require attention in CCPs. They are distinct challenges and they exacerbate already-existing issues such as invasive species, environmental contamination, and wildlife diseases. Secretarial Order 3226 and the FWS climate change strategic plan require us to plan for the effects of climate change.

Planning issues as identified in CCPs also derive from public forums in which the general public and specific stakeholders are present. On refuges where local effects of climate change are evident and observable, the public may initiate dialog on the effects of climate change. In other cases, refuge staff may need to bring climate change to the public's attention.

Some of the ecological effects of climate change effects are ubiquitous or nearly so. Therefore, they should be addressed in all (or nearly all) CCPs. These effects include general ecosystem impacts, hydrological effects, invasive species, and exacerbated environmental contamination. All coastal refuge CCPs should address the issue of sea-level rise, although some (i.e., refuges with predominantly steep rocky shorelines) may treat the issue very briefly.

Table V-2 provides a list of climate change ecological issues that are less ubiquitous. These issues are broken down by the FWS Regions most affected. For example, Table V-2 indicates that all or nearly all CCPs in Region 2 should address the issues of desertification and increased wildfire frequency and severity (in addition to the ubiquitous issues noted above). Similarly, many CCPs in Region 3 should address the issue of prairie pothole drying, some in Region 4 should address the issue of coral bleaching, etc.

Table V-2. Major (but non-ubiquitous) ecological issues related to climate change, by Region.

Table V-2 is a *quick guide* for considering which non-ubiquitous climate change effects to consider in CCPs. It should not be relied upon to identify all such effects or issues, especially for a particular refuge. (CCP authors should use Appendix A, Climate Change Effects Checklist, to help ensure that no significant climate change issues are overlooked.) Nevertheless, Table V-2 is useful for constructing Table V-3, "Starter language for CCPs regarding major ecological issues related to climate change."

Region	Sea-Level Rise	Desertification	Prairie Pothole Dynamics	Permafrost Thawing	Coral Effects	Seagrass Response	Mangrove Expansion
Pacific (1)	X				X	X	
Southwest (2)	X	X				X	X
Midwest (3)			X				
Southeast (4)	X				X	X	X
Northeast (5)	X					X	
Mountain-Prairie (6)		X	X				
Alaska (7)				X		X	
Pacific-Southwest (8)	X	X				X	

Table V-3. Starter language for CCPs regarding major ecological issues related to climate change.

General Impacts on Species and Ecosystems: Climate change is expected to impact species and ecosystems in a variety of ways (Griffith et al. 2009). These impacts may include species range shifts (Zuckerberg et al. 2009), species extinctions (Gitay et al. 2002), phenological changes (IPCC 2007c), and increases in primary productivity (TWS 2004). Because the refuge goals and objectives call for the conservation of fish and wildlife resources [may elaborate on refuge goals and objectives here] and such impacts may compromise these goals and objectives, ecosystem impacts due to climate change constitute a significant planning issue.

Hydrological Effects: Climate change affects the magnitude, timing, distribution, and type of precipitation, with corresponding effects on surface and groundwater resources (Gleick 2000, van der Molen and Hildering 2005). Nationwide, both drought and heavy precipitation events are anticipated to increase in frequency (IPCC 2007c). In this region [Southwest for example] the frequency and severity of drought has increased and is expected to continue doing so as a function of global warming and cyclically in response to La Niña (Seager et al. 2007). Water flow and level is expected to decrease due to decreased precipitation in the summer and increased evaporation. This will increase exposure of fishes to predators and have negative impacts on water quality, affecting numerous aquatic species (Matthews 1998).

Invasive Species: Invasive species are generally more adaptable than naturally occurring (native) species to environmental disturbances including climate change (Walther et al. 2009). Because the refuge goals and objectives call for the conservation of (native) fish and wildlife resources [may elaborate on refuge goals and objectives here] and invasive species compromise these goals and objectives, the additional introduction and spread of invasive species due to climate change constitutes a significant planning issue.

Sea-Level Rise: Rising sea levels due to thermal expansion and melting glaciers, both the result of the greenhouse gas emissions associated with human economic activity (IPCC 2007a), are important considerations for a coastal refuge. Impacts of sea-level rise can include inundation of coastal wetlands, increased salinity of coastal wetlands, increased flooding or storm surges, and beach erosion (Craft et al. 2009). Because the refuge goals and objectives call for the conservation of coastal wetlands [may elaborate on refuge goals and objectives here] and sea-level rise compromises these goals and objectives, sea-level rise constitutes a significant planning issue.

Desertification: Desertification due to climate change is an important consideration for a refuge in the Southwest. Desertification replaces relatively homogeneous grassland in arid, semi-arid, and dry sub-humid areas with shrublands having little herbaceous material (Brown et al. 1997). This process can degrade the habitat on which many species depend (Desmond and Montoya 2006). As the refuge goals and objectives call for the conservation of fish and wildlife resources [may elaborate on refuge goals and objectives here] and desertification compromises these goals and objectives, desertification constitutes a significant planning issue.

Prairie Pothole Dynamics: The refuge goals and objectives call for the conservation of migratory birds and other wildlife dependent on the prairie pothole wetlands on and near the refuge. Therefore prairie pothole dynamics constitute a significant planning issue for the refuge as well as many other refuges in the Prairie Pothole Region. A variety of climate models project that future temperatures and precipitation in the region will be higher than historic levels (Ojima and Lackett 2002, Christensen et al. 2007, Meehl et al. 2007b). These projections are supported by recent trends, as temperatures and precipitation have [if this is the case] increased on the refuge and in the region since the early to mid-1900s. Thus far total wetland area [has or has not] held fairly constant since the refuge was established, although [if this is the case] seasonal wetlands have been drying up earlier in the summer.

Permafrost Thawing: Permafrost thawing, due to increased air temperatures and soil heat conduction, is an important consideration for most refuges in Alaska (Lawrence and Slater 2008, Avis et al. 2011). Impacts of permafrost thawing include erosion, ground subsidence, landslides, disruption and damage to forests, and conversion of ecosystems from terrestrial to aquatic or wetland systems (Schaefer et al. 2012). Because the goals and objectives of the refuge include the conservation of fish and wildlife [may elaborate on refuge goals and objectives here] and permafrost thawing compromises these goals and objectives, permafrost thawing constitutes a significant planning issue.

Coral Bleaching and Other Effects on Coral Reefs: Coral bleaching, sea-level rise, and ocean acidification are major threats of climate change to coral ecosystems (Hoegh-Guldberg and Bruno 2010, Buddemeier and Smith 1988, Cicerone et al. 2004, respectively). The added pressures of pollution, overfishing, and other anthropogenic stressors make it difficult for these ecosystems to recover from climate-related disturbance and degradation (Anthony et al. 2011). Consequently, coral reefs and the biodiversity they support are experiencing national and global declines (Pandolfi et al. 2003). Because the goals and objectives of the refuge entail the maintenance of coral ecosystems [may elaborate on refuge goals and objectives here] coral bleaching and other climate-related threats constitute a significant planning issue.

Seagrass Response: Seagrass meadows are important coastal ecosystems in the region. Because of their high biological productivity and their ability to store carbon in below-ground tissue and sediments, seagrasses are significant carbon-sequestering ecosystems (Fourqurean et al. 2012) as well as key habitats for numerous coastal wildlife species. Climate change has positive and negative effects on seagrasses. Although seagrasses may benefit from warmer waters (Short and Neckles 1999), degradation of other coastal ecosystems adversely affects water quality and light availability (Borum et al. 2005). Because the goals and objectives of the refuge entail the maintenance of coastal (including near-shore) ecosystems [may elaborate on refuge goals and objectives here], altered seagrass dynamics constitutes a significant planning issue.

Mangrove Range Expansion: The range of mangrove forests is expected to expand in the region (Comeaux et al. 2011, Osland et al. 2013). This is a promising trend in the sense of providing rootstock and shoreline structure that is relatively resilient to sea-level rise. However, mangrove expansion typically comes “at the expense” of salt marshes, substantially altering habitat parameters for fish and wildlife (see for example Visser et al. 2005). Because the goals and objectives of the refuge include the conservation of fish and wildlife [may elaborate on refuge goals and objectives here] and mangrove expansion alters the suitability of habitats for numerous species, mangrove expansion constitutes a significant planning issue.

Increased Wildfire Frequency and Severity: One of the effects of climate change in the region is increased wildfire frequency and severity (Kasischke et al. 2010). Wildfire regimes have also changed due to long periods of fire suppression, forestry practices, and other land management trends, but higher temperatures and decreased precipitation are fundamental to wildfire intensification (Westerling et al. 2006). Intensified fire regimes modify fish and wildlife habitats, benefiting some species while harming others. However, the risk of catastrophic fire that causes widespread and permanent damage to current ecosystems increases in warmer and drier conditions (Miller et al. 2009). Because the goals and objectives of the refuge include the conservation of certain fish and wildlife species [may elaborate on refuge goals and objectives here] and intensified fire regimes threaten habitats for numerous species, increased wildfire frequency and severity constitutes a significant planning issue.

Environmental Contamination: Environmental contamination – ongoing or potential – is a major concern on all refuges, especially in the context of climate change. Alterations to temperature and rainfall patterns may result in changes in availability, uptake, and toxicity of contaminants, as well as increased sensitivity of fish and wildlife to contaminants (Gouin et al. 2013, Hooper et al. 2013) . Additionally [specify climate change effects relevant to the refuge such as extreme rain events, sea-level rise, melting of glaciers and permafrost, etc.], expected with climate change, may mobilize contaminants that would otherwise remain sequestered. Because the refuge goals and objectives include the maintenance of ecological integrity [may elaborate on refuge goals and objectives here] and environmental contamination compromises ecological integrity, the threat posed by environmental contamination constitutes a significant planning issue.

Wildlife Diseases: Wildlife health is an important consideration for all refuges, and may be readily impacted by climate change. Even slight alterations to temperature, humidity, and rainfall patterns will result in changes to disease transmission dynamics and increase infection pressure on wildlife populations. Because the refuge goals and objectives call for wildlife conservation [may elaborate on refuge goals and objectives here] and the impacts of wildlife disease compromise these goals and objectives, the threats to wildlife health posed by climate change constitute a significant planning issue.

Storm Intensification: There is growing evidence that the frequency of severe storms in North America is increasing (IPCC 2013). This relationship is difficult to establish because many years of data are needed for a solid case. However, basic precaution calls for considering the potential effects of severe storms [which have increased in the region]. Because the refuge goals and objectives entail conservation of specific ecosystems and habitats [may elaborate on refuge goals and objectives here] and severe storms can transform these habitats in an instant, storm intensification constitutes a significant planning issue to consider.

Not all planning issues stemming from climate change will be focused on the ecological effects. Part IV of *Planning for Climate Change* describes some of the more common social, economic, and cultural issues related to climate change on the Refuge System. A few examples help to show how these issues may be addressed in Section II of a CCP (Table V-4).

Table V-4. Starter language for CCPs with regard to social, economic and cultural issues affected by climate change.

Public Uses: Climate change is gradually modifying fish, wildlife, and vegetative communities of the [name of refuge]. Such modification has been noted and described in many areas of the U.S., including at other refuges (Griffith et al. 2009). This has affected a variety of public uses (Morris and Walls 2009) and will continue to do so, probably noticeably so over the 15 years covered by the CCP. Refuge managers and biologists will be challenged to adapt population and habitat objectives in the context of climate change [some elaboration could be provided here, such as modified waterfowl wintering objectives on refuges where some species are no longer wintering in numbers accustomed to] and avoid maladaptive activities. Public uses will be a significant consideration in the adoption of new population and habitat objectives. Refuge personnel are keenly aware that regular, long-time hunters, anglers, birders, and others using the refuge for wildlife-dependent recreation are likely to encounter first-hand these ecological and managerial changes. Refuge staff welcome their input, including observations about ecological change as well as desired management practices. Some visitors may be interested in regularly providing feedback about ecological change, either through refuge staff or through the National Phenology Network (www.usanpn.org).

Transportation [with language included for interior and coastal refuges]: The meteorological effects of climate change can damage or destroy roads, bridges, trails, and other transportation infrastructure (Nemry and Demirel 2012). Rising sea levels, increased precipitation, and storm surges can flood or wash out infrastructure, rendering them impassable and cutting off access to the refuge. Storms, high winds, and variable water levels can increase erosion to roads and trails, leading to more frequent need for maintenance and repair (ICF International 2010). Eventually or possibly quickly (especially with severe storm events), infrastructure along coastlines may be entirely submerged seasonally or permanently. Transportation infrastructure on the refuge that may be especially vulnerable to climate change includes [elaborate]. Basic adaptation methods include repair and maintenance, reconstruction/strengthening, relocation, abandonment, and route redundancy. [The relevant activities] will be carefully planned to avoid negative impacts to refuge purposes and the ecological integrity of the refuge.

Cultural Resources: Higher temperatures [and perhaps greater precipitation, depending on the refuge] due to climate change, as well as severe weather events that are also consistent with climate change, may cause a reduction in vegetative coverage and seasonal exposure and cracking of soils, resulting in increasing erosion rates on the refuge (Nearing et al. 2004). This in turn may impact cultural resources such as [elaborate on refuge archaeological sites or other cultural resources]. Impacts may include site degradation and exposure, which if prolonged could adversely affect the integrity of the site and/or open the site to unauthorized collecting, compromising the cultural, historical, and scientific significance of the site. Careful planning will help in protecting the cultural resources of the refuge [and perhaps contingency plans for curating may be called for].

Education and Outreach: Climate change is a major planning issue for [name of refuge] and a threat to fish and wildlife conservation at the national and global levels (TWS 2004). Widespread public understanding of the causes and consequences of climate change is required to address the mix of short-term and long-term challenges of climate change (U.S. Department of State 2010). Climate change in the 21st century is largely “anthropogenic” or human-caused (IPCC 2013). Basically, as the human economy grows (whether from more people or more per capita consumption) it requires more fossil fuel combustion, resulting in higher atmospheric concentrations of CO_2 and other gases that intensify the greenhouse effect that warms the planet. Society at large and individual consumers face serious decisions about the trade-offs between economic activity and climate stability (U.S. Department of State 2010). Meanwhile the refuge will continue to feature talks and other interpretive programs about the ongoing effects of climate change and what these effects mean for the residents of [local town(s) and county (or counties)] in the short term and in the long run.

Tribal Affairs: The [name of refuge] is [adjacent to, within the traditional hunting/fishing territory of, etc.] the [name of Tribe]. The refuge has a mutual interest with the tribe in monitoring, adapting to, and mitigating the effects of climate change. Refuge personnel realize that the ecosystem of and around the refuge is a key element of tribal identity, culture, and [specify here if, for example, tribal subsistence harvesting, ceremonies, or other activities occur on or adjacent to the refuge]. We will consult with tribal fish and wildlife personnel and other tribal government representatives who may have special concerns about the effects of climate change on traditional and customary tribal activities on and around the refuge. We welcome input from non-governmental tribal members as well, and some may be interested in regularly providing feedback about ecological change, either through refuge staff or through the National Phenology Network (www.usanpn.org). We are also interested in learning about traditional knowledge pertaining to fish, wildlife, and plants on and near the refuge, especially as it may help in detecting the effects of climate change.

Land Acquisition: The goals of [name of refuge] are [list the goals]. Due to climate change and the resulting [note the problematic effect(s)] some of these goals have become more difficult to accomplish on the existing refuge. In particular, for [species X], the area [further north, higher in elevation, inland of sea] holds more potential for maintaining viable populations well into the 21st century. Therefore we are working with the local community, county officials and other partners to explore the option of expanding the refuge to include that area.

Oil, Gas, and Other Energy Infrastructure: Built capital is another type of resource that exists on the refuge, not all of it public property. In the [name the area of the refuge], X oil wells [or other type of energy extraction facilities] are located, along with related infrastructure such as pumps, pipelines, and storage tanks [or other types of infrastructure]. There may be special challenges posed by climate change to the maintenance of these facilities, due to the [elaborate on the particulars; e.g., permafrost melting, sea-level rise]. Refuge personnel will be diligent in monitoring the condition of these facilities, working with [name the energy company or other proprietor] to ensure that extraction, transportation and storage activities do not compromise the ecological integrity of the refuge as a result of climate change.

<u>Climate Change Starter Language for CCP Section III: Summary Refuge and Resource Descriptions</u>

Geoographic/Ecosystem Setting

Local climate is an important ecological aspect of a refuge *and* should be briefly described in the CCP in order to provide context for the issue of climate change. Some refuges are already collecting data on temperature, precipitation and other climate variables. If these data are not available at the refuge level, data collected from nearby stations may be used to document historic conditions, current conditions, and trends.

Starter language for CCP:

The average annual temperature is [X] degrees Celsius, or [XX] degrees Fahrenheit. This is an increase [or decrease] of [Y] degrees Celsius, or [YY] degrees Fahrenheit, since [year]. The annual average precipitation is [A] centimeters, or [AA] inches. This is an increase [or decrease] of [B] centimeters, or [BB] inches, since [year]. These trends are [or are not] consistent with global and regional models of climate change and are expected to continue [or are not] as the concentration of greenhouse gases in the atmosphere continues to increase for the foreseeable future and beyond that due to thermal inertia.

Local climate is an important ecological aspect of a refuge and should be briefly described in the CCP in order to provide context for the issue of climate change.

New management direction may be required for adapting to climate change. These new direction(s) will depend on the purposes and vision of the refuge in the context of the Refuge System mission.

The geographic scope of the plan should take into account wildlife species and habitat range shifts and novel communities and ecosystems that may appear due to these shifts. For example, a landscape -scale analysis that is not limited to political/administrative boundaries is warranted in the context of climate change. Such analysis will be facilitated by the relevant LCD(s), or perhaps even comprised thereby.

Similarly, the plan should address wildlife species and habitats that are not currently in the geographic area but are likely to occur there in the future. The planning team should consider

<u>Climate Change Starter Language for CCP Section IV: Management Direction</u>

Refuge Management Direction: Goals, Objectives, and Strategies

New management direction may be required for adapting to climate change. These new direction(s) will depend on the purposes and vision of the refuge in the context of the Refuge System mission. For example, a decision to conserve the species and ecosystems that have historically been important at a refuge will require different goals, objectives, and strategies than a decision to manage habitat for a new suite of species more suited to a changing climate.

Starter language for CCP:

Goal 1: Identify future scenarios for refuge ecosystems.

Objective 1: Within [X] years of the plan's approval, identify likely changes in climate variables over the next [Y] years.

Objective 2: Within [X] years of the plan's approval, identify potential impacts of the projected climate changes on abiotic and biotic components of the refuge's existing ecosystems.

Objective 3: Within [X] years of the plan's approval, identify species and communities outside the refuge's existing boundaries that may be suited to the projected climatic conditions of the future.

Goal 2: Reduce the carbon footprint of the refuge.

Objective 1: Within [X] years of the plan's approval, reduce carbon emissions from transportation by [Y]%.

Objective 2: Within [X] years of the plan's approval, reduce carbon emissions from administrative operations by [Y]%.

A complementary or alternative approach to developing new management directions would be to incorporate climate change into existing goals. Some existing goals may be impracticable due to climate change. For example, a goal of protecting a historic assemblage of species will likely need to be broadened as climate change forces those species to move beyond the refuge's boundaries. Such a goal could be revised as follows: "Provide new habitats for wildlife while maintaining elements of ecological integrity that are not precluded by climate change." (This is an example of mixing retrospective and prospective adaptation philosophies.)

Refuge goals may already be sufficiently broad to encompass the refuge's approach to climate change, in which case climate change-related objectives and strategies may fit more appropriately under existing goals.

Starter language for CCP:
Visitor Services Goal
Existing Goal: Visitors appreciate the importance of the refuge to migratory waterfowl [or other wildlife species or group] and support its conservation efforts.

New Objective: Within [X] years of the plan's approval, at least [Y]% of visitors will be informed of the major climate change issues affecting migratory waterfowl [or other wildlife species or group] at the refuge.

New Strategy: Develop interpretive exhibits in proximity to wetlands [or other habitat type] that focus on climate change issues affecting migratory waterfowl [or other wildlife species or group].

Biological Goal
Existing Goal: Maintain viable population levels of resident amphibians [or other wildlife species or group].

New Objective: Within [X] years of the plan's approval, protect [Y acres] of potential suitable habitats and corridors situated within the expected path of amphibian [or other wildlife species or group] movement in response to climate change.

New Strategy: Contact local landowners who own property with suitable habitat.

New Strategy: Identify corridor properties for acquisition.

New Objective: Within [X] years of the plan's approval, conduct [Y] surveys in wetland habitats [or other habitat type] to monitor responses of resident amphibians [or other wildlife species or group] to climate change.

New Strategy: Monitor temperature and precipitation data.

New Strategy: Monitor changes in population size, behavior, and morphology of resident amphibians [or other wildlife species or group] using call surveys and traps [or other techniques].

Climate Change Starter Language for CCP Section V: Implementation and Monitoring

Step-Down Management Plans

A step-down management plan is a document in which detailed plans to accomplish particular CCP goals and objectives are formulated (FWS 2000c). Along with LCDs, the development of step-down management plans is a Refuge System priority. The production of management plans has been prioritized over CCP revision while LCDs are being developed (PIT 2013).

Of the potential step-down management plans outlined in 602 FW 4, several are especially conducive to incorporating climate change issues. For most step-down plans, climate change is at least moderately relevant. Ascertaining relevancy is a subjective endeavor, but for two types of step-down management plans, climate change should not be particularly relevant (Table V-5).

Table V-5. Step-down management plans and relevance of climate change. List of plans compiled from FWS (2000d).

Step-Down Management Plan	Climate Change Relevance
Occupational Safety and Health	Low
Water Rights	High
Law Enforcement	Low
Pollution Control	Moderate
Compliance Requirements	Moderate
Pesticide Use and Disposal	High
External Threats to FWS Facilities	Moderate
National Wildlife Refuge System (NWRS) Uses	Moderate
Priority Wildlife-Dependent Recreation	Moderate
Wilderness Management	Moderate
Special Area Management	Moderate
Minerals Management	Moderate
Cultural Resources Management	Moderate
Habitat Management Planning	High
Fire Management	High
Population Management	High
Fishery Resources Management	High
Exotic Species	High

Monitoring and Evaluation

Monitoring and evaluating are central to SHC, allowing managers to adjust their strategies to more effectively achieve their goals (as well as for purposes of documenting performance). This is particularly helpful in the context of climate change because managers are unlikely to have experienced the projected types and levels of impacts.

Starter language for CCP:

Traditional fish and wildlife management goals, objectives, and management activities may become difficult or even impossible to accomplish in the context of climate change. Monitoring and evaluation includes efforts to assess the effects of climate change identified in Planning Issues (above). Monitoring the relevant variables enables evaluation, which builds upon data obtained via monitoring by describing the relationships among variables. Adaptive management – including if necessary reformulation of goals and objectives – is made possible given adequate monitoring and evaluation.

For example, on [name of Refuge], increasing temperatures are known to affect the acreage of suitable habitat for species [X]. During the past [Y] years, mean annual temperatures have increased [Z] °F. Meanwhile suitable habitat for species [X] has decreased from [A] acres to [B] acres. The implications of these trends for Refuge goals, objectives, and management practices are…

Plan Amendment and Revision

Each CCP must be revised every 15 years or when significant new information becomes available or ecological conditions change (U.S. Fish and Wildlife Service 2000a). The annual review process required for CCPs provides an opportunity to determine whether new information or changing conditions warrant revisions of purposes (if feasible), visions, or management goals. (In general, however, most CCP revisions should not occur before a geographically encompassing LCD has been adopted (PIT 2013).)

> Starter language for CCP:
>
> The annual plan review process will include an evaluation of ecological conditions related to climate change. If significant changes are identified and compromise the refuge's purpose, vision, goals or objectives, then the CCP will be revised.

Climate Change Starter Language for CCP Appendices

Glossary

Some terms related to climate change may be unfamiliar or confusing. The following are examples of terms and definitions associated with major climate change issues that may be useful additions to the CCP glossary.

- **Bathymetry**: underwater contours of lake or ocean floors; the underwater equivalent to topography.
- **C3 plants**: plants that initially assimilate carbon into a molecule of three carbon atoms.
- **C4 plants**: plants that initially assimilate carbon into a molecule of four carbon atoms.
- **Climate change**: A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, such as decades or more. Climate change may be due to natural processes or to human economic activity, which affects atmospheric composition.
- **Climate change vulnerability**: a function of exposure to climate change, sensitivity to climate change, and adaptive capacity.
- **Climate refugium**: an area where the ecological effects of climate change will be less pronounced. (Plural: climate refugia; sometimes used interchangeably with "habitat refugia." See NCCARF 2011).
- **Eustatic sea-level rise**: global sea-level rise resulting from increased volume of oceans, largely resulting from increased water temperatures (cold water is denser) and runoff from melting glaciers and ice sheets. An underlying variable influencing localized, relative sea-level rise.
- **Evapotranspiration:** the combined processes of evaporation and transpiration by which water is transferred from the earth's surface to the atmosphere.
- **GCM:** global climate model, global circulation model, or general circulation model. A general circulation model is often a major building block of a global climate model. A global circulation model typically connotes an intermediate category between general circulation models and global climate models. However, the three terms are often used interchangeably.
- **Isostatic rebound**: rising of Earth's crust in response to the removal of glacial units from past millennia; a regional phenomenon.
- **Permafrost:** soil or rock that remains $\leq$ 0 °C (32 °F) for at least two continuous years.
- **Phenology:** timing of biological events such as flowering, mating, migration, nesting, hibernation, etc.
- **Range shift:** change in the distribution of a population or a species' geographic distribution in

which net extirpation occurs at one boundary and/or net colonization occurs at the opposite boundary.

- **Relative sea-level rise:** sea-level rise relative to local land surface; includes effects of eustatic sea-level rise and regional or local processes such as plate tectonics, isostatic rebound, land subsidence, sedimentation, etc.
- **Sedimentation-erosion table (SET):** used to measure elevation dynamics (most notably vertical accretion) in wetlands; alternatively referred to as "surface elevation table."
- **Synergistic effects (of climate change):** the combined effects of climate change and other stressors (e.g. invasive species); "synergistic" implies that the effects are greater than a simple summation of the two distinct effects (e.g., due to positive feedback mechanisms).
- **Thermal inertia:** the degree of slowness with which the temperature of a body approaches that of its surroundings and which is dependent upon its absorptivity, specific heat, thermal conductivity, dimensions, and other factors.

Bibliography

CCP authors choosing to develop a bibliography as a CCP appendix may select from the 500-plus references found at the end of *Planning for Climate Change*. A suggested approach is to decide which subject(s) are most appropriate for the bibliography (e.g., prairie pothole dynamics), go to the corresponding chapter, and select from the relevant references.

Habitat/Land Protection Plan(s)

If a land protection plan (LPP) is to be included as a CCP appendix, it must incorporate climate change considerations pursuant to Secretarial Order 3226, Secretarial Order 3289, the FWS climate change strategic plan (*Rising to the Urgent Challenge*) and other relevant policies and guidelines on climate change planning. A good place to start in developing an LPP with climate change considerations is with the chapter "Land Acquisition" above. Starter language is also provided below.

Starter language for CCP:

Coastal Refuge: The purposes of [refuge name] are to [list purposes, which on the majority of coastal refuges include migratory bird conservation]. One of the most daunting challenges to fulfilling these purposes is climate change and associated sea-level rise. Sea-level rise impacts on the refuge and surrounding areas were modeled with the Sea Level Affecting Marshes Model (SLAMM) in [year of analysis] and the results are summarized below [insert SLAMM maps and tables]. The analysis indicates that the refuge is subject to ongoing losses of [list SLAMM categories such as tidal forest, brackish marsh, etc.] throughout the 21st century. [Perhaps language may be added here, if appropriate, about environmental and economic challenges of sea-level rise facing nearby communities as well.] Therefore, the refuge is considering the acquisition, from willing sellers, of lands that are more likely to comprise productive waterfowl habitats in coming decades than areas that are inundated, degraded, and lost due to sea-level rise. These areas are found largely in the [describe appropriate area projected by SLAMM analysis].

Interior Refuge: The purposes of [refuge name] are to [list purposes]. One of the most daunting challenges to fulfilling these purposes is climate change and associated [list effects most relevant to the refuge]. Recent research indicates a [high, moderate, low] degree of vulnerability to climate change in the area of the refuge. [Use the Terrestrial Climate Stress Index, preferably with a score downscaled to the refuge or its immediate vicinity, or use another climate vulnerability assessment, to elaborate on the vulnerability of the refuge.] Therefore, the refuge is considering the acquisition, from willing sellers, of [adjacent or nearby] lands that are more likely to contribute to refuge purposes in coming decades. These areas are found [perhaps higher in elevation, closer to water, along a movement corridor, etc.].

Appendix A. Climate Change Effects Checklist

Instructions: Check those effects that are – or are likely to be – significant or secondary. Note that "general impacts on species and ecosystems" is checked at the "significant" level because climate change significantly affects all species and ecosystems. Hydrological effects and invasive species are almost certain to also be checked, although they may be secondary issues at some refuges. Education and outreach is checked, too. Other relatively ubiquitous effects include environmental contamination, and to a lesser degree increased wildfire and wildlife diseases. Other effects are regional.

Name of Refuge: ____

	Effect of Climate Change	Significant and current	Secondary and current	Significant and projected	Secondary and projected
Ecological Effects	General impacts on species and ecosystems	✓		✓	
	Hydrological effects	(probably)	(possibly)	(probably)	(possibly)
	Invasive species	(probably)	(possibly)	(probably)	(possibly)
	Sea-Level rise				
	Southwest desertification				
	Prairie pothole dynamics				
	Permafrost thawing				
	Coral bleaching and other coral reef effects				
	Seagrass response				
	Mangrove range expansion				
	Increased wildfire frequency and severity				
	Environmental contamination				
	Wildlife diseases				
Social, Economic, and Cultural Effects	Storm intensification				
	Public Uses				
	Transportation				
	Buildings				
	Cultural resources				
	Education and outreach	✓		✓	
	Tribal affairs				
	Land acquisition				
	Oil, gas, and other energy infrastructure				
	Wilderness preservation				

Appendix B. Links to Climate Change Planning Resources

Climate Change Overview

IPCC's Climate Change 2013: The Physical Science Basis (Summary For Policymakers).
http://www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved27Sep2013.pdf

IPCC's Climate Change 2007: Synthesis Report.
http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm

IPCC's Special Report: Emissions Scenarios: Summary for Policymakers.
http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

USGCRP 2009 Global Climate Change Impacts in the United States.
http://nca2009.globalchange.gov/
http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

Center for Climate and Energy Solutions (C2ES)
http://www.pewclimate.org/global-warming-basics/climate_change_101

Ecological Impacts of Climate Change, National Academies of Sciences
http://dels-old.nas.edu/climatechange/

Climate Literacy: The Essential Principles of Climate Sciences, A Guide for Individuals and Communities.
http://www.climatescience.gov/Library/Literacy/

United States Global Change Research Program
http://www.globalchange.gov/

DOI

Department of Interior Climate Change Website.
http://www.doi.gov/whatwedo/climate/index.cfm

FWS

FWS climate change homepage
http://www.fws.gov/home/climatechange/

FWS Climate Change intranet site: https://inside.fws.gov/index.cfm/go/post/Climate-Change-Intranet?

FWS monthly Climate Change Update (newsletter – submit articles to David Eisenhauer)
http://www.fws.gov/home/climatechange/climatechangeupdate.html

NCTC Climate Change Learning Center http://training.fws.gov/CSP/Resources/climate_change/home.html

Science Excellence
http://www.fws.gov/science/index.html

NCTC Climate Resource Center – includes links to publications, videos and literature
http://training.fws.gov/CSP/Resources/climate_change/resources.html

Selected Scientific Journal publications related to climate change – internal FWS site with citations and links to climate change reports, selected journal articles, etc.
https://inside.fws.gov/index.cfm/go/post/Climate-Change-Resources?

Region 1 – Climate Change Resources
https://inside.fws.gov/index.cfm/ceshandler/entry?id=A794FDFE-B0CE-11D5-65180894144A9976

FWS Climate Change Facebook page – mostly links to news articles about climate change
http://www.facebook.com/usfwsclimatechange?sk=wall

NPS

Climate Response Program
http://www.nature.nps.gov/climatechange/index.cfm

USFS

USFS Climate Change Resource Center - http://www.fs.fed.us/ccrc/index.shtml

USFS Climate Change Primer for Land Managers: An example from Sierra Nevada http://www.fs.fed.us/ccrc/primers/climate-change-primer.shtml

USGS

USGS Climate Centers - https://nccwsc.usgs.gov/

Assessing the Vulnerability of Species and Ecosystems to Projected Future Climate Change in the Pacific Northwest
http://esp.cr.usgs.gov/projects/effects/vulnerability/products.html

Modeling Sea-Level Rise in San Francisco Bay Estuary.
http://www.werc.usgs.gov/ProjectSubWebPage.aspx?SubWebPageID=2&ProjectID=238

USGS Climate and Land Use Change - http://www.usgs.gov/climate_landuse/

NOAA

NOAA Climate
http://www.noaa.gov/climate.html

EPA

EPA Climate Change
http://www.epa.gov/climatechange/

FWS Climate Change Publications (including with partners)

Strategic Plan: *Rising to the Urgent Challenge*
http://www.fws.gov/home/climatechange/pdf/CCStrategicPlan.pdf

Strategic Plan Fact Sheets:
http://www.fws.gov/home/climatechange/pdf/ClimatePlanOverview.pdf
http://www.fws.gov/home/climatechange/pdf/ClimatePlanFAQ.pdf
http://www.fws.gov/home/climatechange/pdf/ClimateChangeKeyPoints.pdf
http://www.fws.gov/home/climatechange/pdf/PriorityActions10.pdf
http://www.fws.gov/home/climatechange/pdf/ClimateIPCC.pdf

National Fish, Wildlife and Plants Climate Adaptation Strategy
http://www.wildlifeadaptationstrategy.gov/pdf/NFWPCAS-Final.pdf

Strategic Habitat Conservation http://training.fws.gov/CSP/Resources/SHC/shc_finalrpt.pdf

Webinars

NCTC webinar series on Safeguarding Wildlife from Climate Change (ongoing series): http://training.fws.gov/CSP/Resources/climate_change/safeguarding_bc.html

NCTC Climate Change Webinar Series: http://training.fws.gov/CSP/Resources/climate_change/webinars.html

Workshops and Training

Region 1, Climate Change Workshops http://www.fws.gov/pacific/Climatechange/meetings.html

Region 2, Climate Change Workshop http://www.fws.gov/southwest/Climatechange/08CCWorkshop/workshop.html

Region 5, Workshop presentations from Adapting to Climate Change in the Mid-Atlantic http://www.fws.gov/northeast/climatechange/conference/conferences.html

Region 7, Talks from ongoing "Climate Change Lecture Series" http://alaska.fws.gov/climate/lecture.htm

NCTC course Resource Management Implications of Climate Change http://distancelearning.fws.gov/courses/csp/csp3181/

Adaptive Management Courses http://www.doi.gov/initiatives/AdaptiveManagement/training.html

Tools

FWS Climate Change Information Toolkit – toolkit for communicating about climate change http://www.fws.gov/home/climatechange/toolkit.html

The Nature Conservancy – Climate Wizard http://www.climatewizard.org/

EPA Climate Change, Wildlife, and Wildlands Toolkit http://www.epa.gov/climatechange/wycd/CCWKit.html

Climate Change Adaptation Knowledge Exchange – includes tools, library, case studies, directory, and a listing of events, all related to climate adaptation http://www.cakex.org

Models

Sea Level Affecting Marshes Model (SLAMM) on the Refuge System - http://www.fws.gov/refuges/planning/seaLevelRise.html

SLAMM-View. http://www.fws.gov/slamm/

NOAA Climate Models http://www.oar.noaa.gov/climate/t_modeling.html

USFS – Landscape Analysis - http://www.fs.fed.us/ccrc/topics/landscape-analysis.shtml

AQUATOX - http://water.epa.gov/scitech/datait/models/aquatox/index.cfm

Modeling Climate Change Bird Atlas -http://www.nrs.fs.fed.us/atlas/bird/index.html

Modeling Climate Change Tree Atlas -http://www.nrs.fs.fed.us/atlas/tree/tree_atlas.html

Climate Vulnerability Assessment

Refuge Resource Vulnerability Assessments – Partnership with Natureserve http://www.fws.gov/refuges/whm/refugeResourceVulnerabilityAssessments.html

NWF- Safeguarding Wildlife from Climate Change: Quick Guide to VA http://www.nwf.org/~/media/PDFs/Global-Warming/Climate-Smart-Conservation/NWF%20vulnerability_assessment_QuickGuide.ashx

Scanning the Conservation Horizon - Guide to conducting Vulnerability Assessments http://www.nwf.org/vulnerabilityguide and http://training.fws.gov/CSP/Resources/vulnerability/index.html (click on picture of cover)

Climate Change Vulnerability Assessment and Adaptation Tools – excel sheet w/ descriptions and links http://www.ebmtoolsdatabase.org/resource/climate-change-vulnerability-assessment-and-adaptation-tools (last modified Dec. 29, 2011)

NPS – Appraising the Vulnerability of Park Resources http://www.nature.nps.gov/climatechange/docs/VulnerabilityAssessmentBrief.pdf

Adaptive Management

Climate Adaptation Strategy: http://www.wildlifeadaptationstrategy.gov/ or for the report http://www.wildlifeadaptationstrategy.gov/pdf/NFWPCAS-Final.pdf

Appraising Adaptive Management: http://www.ecologyandsociety.org/vol3/iss2/art3/

Martin Nie Decision Making Triggers in Adaptive Mgmt. http://www.cas.umt.edu/facultydatabase/FILES_Faculty/1126/Triggers%20Final%20Report%20Nov%202011.pdf

Adaptive Management in Use http://www.doi.gov/initiatives/AdaptiveManagement/casestudies.html

Terrestrial Forest Management Plan for Palmyra Atoll http://pubs.usgs.gov/of/2011/1007/pdf/ofr20111007.pdf

Adaptive Management of Natural Resources: Theory, Concepts, and Management Institutions http://www.treesearch.fs.fed.us/pubs/20657

Climate Change Adaptation Across the Landscape: survey of federal and state agencies, conservation organizations and academic institutions in the United States (Defenders of Wildlife) http://www.defendersofwildlife.org/resources/publications/programs_and_policy/gw/climate_change_adaptation_across_the_landscape.pdf

Respond-ing to climate change in national forests: a guidebook for developing adaptation options. http://www.fs.fed.us/pnw/pubs/pnw_gtr855.pdf Template web page: http://www.taccimo.sgcp.ncsu.edu/

California Climate Adaptation Strategy 2009 (public review draft) http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-D.PDF

Füssel, H.M. 2007. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. Sustainability Science. 2: 265–275. http://www.pik-potsdam.de/~fuessel/download/sust07_published.pdf

Inventory and Monitoring

NPS Inventory and Monitoring Program http://science.nature.nps.gov/im/index.cfm

Refuge CCP's

Refuge planning documents online:
http://library.fws.gov/RefugePlanningDocuments.html

Examples of Refuge CCPs with Climate Change Considerations:

J.N. "Ding" Darling NWR CCP (2010) http://www.fws.gov/southeast/planning/PDFdocuments/DingDarlingFinal/JN%20Ding%20Darling%20NWR%20Final%20CCP.pdf

Texas Chenier Plain Refuge Complex (Table of Contents; click on chapter titles) (2008)
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U.S. Fish and Wildlife Service
National Wildlife Refuge System

www.fws.gov/refuges

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CONSERVING THE FUTURE

Recommendation 2: *Develop a climate change implementation plan for the National Wildlife Refuge System that dovetails with other conservation partners' climate change action plans and specifically provides guidance for conducting vulnerability assessments of climate change impacts to refuge habitats and species as well as direction for innovation in the reduction of emissions and improved energy efficiency on federal lands.*