Planning for Adaptation to Climate Change: Lessons from the US National Wildlife Refuge System

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US national wildlife refuges have recent, detailed management plans illustrating the state of planning for climate-change adaptation in protected areas. Discussion of and prescriptions for addressing climate change increased in refuge plans between 2005 and 2010 but decreased in 2011. The plans respond to some climate-change impacts on biodiversity and call for monitoring but with little clarity regarding how to act on monitoring results and scant attention to future changes in phenology and community composition. The threats posed by sea-level rise generated the best-developed plan prescriptions. Examples of excellent prescriptions provide models for future planning. Some decision-support tools, such as vulnerability assessments, will improve future planning as they become more available. However, research better targeted at management information gaps is also needed. Region-level coordination, such as through landscape conservation design, offers opportunities for enlarging conservation footprints and improving information generation and sharing.

Keywords: adaptation, conservation, protected areas, biodiversity, climate change

Generalized advice to land managers about how to plan for climate change is plentiful (e.g., Groves et al. 2012), but evaluations of the actual practice of adapting to climate change through conservation planning are scarce (Bottrill and Pressey 2012). We begin with a detailed examination of unit-level planning for climate change in the US national wildlife refuges. We compare our findings with published results for other large protected-area systems and with general recommendations for addressing climate change in conservation planning. Our overview offers lessons for both scientists and practitioners of nature conservation in four broad areas: planning tools, adaptive management, landscape-scale strategies, and information gathering. Although we offer specific suggestions tailored to the refuges' adaptive responses to climate change, most of our recommendations apply generally to conservation planning and research.

The refuge system

If any system of nature reserves in the United States could demonstrate best practices for climate-change adaptation, it would be the National Wildlife Refuge System (NWRS), managed by the US Fish and Wildlife Service (USFWS). The 58 million hectares of the NWRS represent the world's largest system of lands and waters dedicated to wildlife and plant protection (USFWS 2009). The NWRS has a legal mandate to orchestrate the management of individual refuges into a connected "national network of lands and waters for the conservation… [of] fish, wildlife, and plant resources and their habitats" (16 U.S.C. § 668dd(a)(2)). Furthermore, Congress mandated that the USFWS ensure the maintenance of "the biological integrity, diversity, and environmental health of the System" (16 U.S.C. § 668dd(a)(4)(B)). No other US public land system has a stronger legislative mandate for ecological integrity (Fischman 2003). The USFWS implemented its conservation mandate for the refuges by prohibiting uses that "reasonably may… reduce the quality or quantity or fragment habitats" (603 FW 2.5).

The refuge system undertakes unit-level planning through comprehensive conservation plans (CCPs), which typically establish management objectives for 15 years (16 U.S.C. § 668dd(e)(1)). USFWS regulations explicitly endorse adaptive management, an approach universally promoted for responding to climate change (Lawler et al. 2010). Agency guidance (Adamcik et al. 2004) calls for CCPs to include specific, measurable goals and monitoring to ensure that goals are being met—also common recommendations in the climate-change adaptation literature (Hilty and Groves 2009). The USFWS strategies provide a general framework for incorporating climate-change adaptation in plans (USDOI 2009, USFWS 2010, AFWA et al. 2012). Hence, recent CCPs have been created pursuant to policies and guidelines well matched to the scholarly recommendations

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for responding to climate change (Griffith et al. 2009). A recent survey reports higher levels of adaptation implementation for the NWRS than for other US land systems (Archie et al. 2012). Among US land-management plans, the CCPs tend to be more current than plans for other public lands systems and are therefore more likely to address climate change. Earlier surveys of other US land systems show no systematic work to address climate change. A 2006 sample of national forest plans showed that 15 of 121 referenced climate change (Joyce et al. 2008), roughly on par with refuge planning at the time. A 2008 study of national park planning documents stated that "only a few individual parks address climate change" (Baron et al. 2008, p. 19). A 2010 survey of employees of the US Forest Service and the US Bureau of Land Management revealed that managers were aware of potential problems arising from climate change and wanted more information but rarely considered climate-change issues in their daily decisions (Ellenwood et al. 2012).

The USFWS announced as part of its 2013 strategic plan that it will undertake CCP revisions within the same ecoregion together, as a group, under a common vision for regional conservation called a landscape conservation design (LCD; USFWS 2013). The LCDs will be the foundation for future planning.

The comprehensive conservation plans

We reviewed each CCP completed between 1 January 2005 and 1 January 2012 that included at least one named national wildlife refuge. The 185 CCPs cover planning for 324 (58%) of the 555 national wildlife refuges that existed in 2012. We excluded CCPs prepared prior to 2005 because they were unlikely to have addressed climate change.

Although descriptions of species, ecosystems, and threats to them dominate the content of CCPs, our study was focused on the prescriptions (whether those were classified as goals, objectives, or implementation strategies) that the CCPs established to steer management. We categorized all CCP climate-change discussions into nine impact categories selected to address both common areas of concern (e.g., sea-level rise and species' range shifts) and major emerging issues (e.g., the spread of pests and pathogens) for the refuge system's main responsibilities of wildlife and habitat conservation (table 1). We determined whether the CCPs merely described a given impact as a general or regional problem or tied the impact specifically to a refuge and whether an impact, once it had been described, was addressed by a prescription for study or action. Some of these impacts, such as the spread of undesirable plants, are happening regardless of climate change. We coded an impact only if the CCP explicitly related it to climate change.

Among the 185 CCPs, 115 (62%) discussed at least one of the nine climate-change impacts in some way (table 1). Descriptions of climate-change impacts linked to specific refuge resources appeared in 101 CCPs; an additional 14 CCPs described climate-change issues as general or regional, without tying them directly to refuges. Overall, of the 115 CCPs discussing climate change in some way, 73 (38% of 185 CCPs and 63% of the 115 discussing climate change) contained prescriptions.

The proportion of CCPs reporting climate-change impacts increased consistently for all nine categories from 2006 to 2010 (table 1). The proportion of CCPs mentioning at least one climate-change impact increased throughout the period from 25% in 2005 to 100% in 2011. However, from 2010 to 2011, the proportion of CCPs reporting climate-change issues declined for five of the nine impact categories. The proportion of CCPs providing prescriptions addressing climate-change impacts on refuge resources increased from 6.3% in 2005 to 79.3% in 2010 and then fell to 65% in 2011 (table 1). The average number of climate-change issues addressed with prescriptions fell between 2010 and 2011 for five of the six regions with at least one CCP in each of those years (see supplemental table S1). Alaska was the only region that did not, on average, address fewer climate-change issues in 2011 than in 2010. The sample sizes were too small to permit analysis across regions.

The climate-change prescriptions favored studies or plans over actions or modeling, and actions outside the refuge were recommended in nine CCPs (figure 1). Whereas sea-level rise was the fourth most mentioned climate-change issue, it ranked second in the CCPs that included prescriptions (figure 1). It also generated better-developed prescriptions than other climate-change threats. Approximately one-third of the CCPs incorporated modeling, often using the sea-level-rise model SLAMM (Craft et al. 2009) or GIS; the CCPs for coastal and estuarine refuges were more likely to include one or more climate-change prescriptions than were those in other settings. Although the majority of plans prescribed monitoring, much less than half indicated an intent to act on the results of monitoring or described specific actions that should follow from monitoring results. Quantitative goals or thresholds of any kind for monitoring were rare.

The CCPs containing climate-change objectives did not consistently integrate other land-use plans or address other conservation issues better than the CCPs that failed to address climate change. Neither did the recognition of refuge roles in ecological connectivity or as sites important to migratory species increase the likelihood that a CCP would address climate change.

The climate-change prescriptions generally did not score well against the so-called SMART criteria explicitly adopted by the USFWS for CCPs (prescriptions should be specific, measurable, achievable, results-oriented, and time-fixed; Adamcik et al. 2004, 602 FW 3). For each of the 73 CCPs with one or more prescriptions for climate change, we assigned a score from 0 to 3 for each of the five SMART criteria (for a perfect overall score of 15; see the supplemental material). The scores for specificity, achievability, and results-orientation reflect the best-written prescription within each CCP and, so, show a best-case picture (tables 2a, 2c, 2d). The CCPs scored highest in these best-case categories, with the top score for the achievable criterion (mean [M] = 2.2), followed

Table 1. Proportions of the year's comprehensive conservation plans (CCPs) with prescriptions addressing climate-change (CC) impacts, by threat and year, ordered by average proportion over time.

								The percentage of 185 CCPs examined		The percentage of 115 CCPs discussing climate change	
Climate-change impacts	2005	2006	2007	2008	2009	2010	2011	Discuss CC threat	Contain prescription for CC threat	Discuss CC threat	Contain prescription for CC threat
Habitat or plant community	(6.3)	5.4	8.0	29.0	48.1	69.0	60.0	53.5	31.9	86.1	51.3
Sea-level rise	0	0	16.0	25.8	18.5	41.4	35.0	42.7	19.5	68.7	31.3
Desirable (nonfish) wildlife	(6.3)	0	(4.0)	16.1	33.3	44.8	25.0	38.9	18.4	62.6	29.6
Freshwater availability	(6.3)	0	0	6.5	25.9	27.6	35.0	38.9	13.5	62.6	21.7
Desirable fish	(6.3)	0	0	6.5	14.8	31.0	25.0	34.6	11.4	55.7	18.3
Undesirable plants or animals	0	0	(4.0)	(3.2)	11.1	27.6	20.0	26.5	9.2	42.6	14.8
Changes in extreme weather	(6.3)	0	0	(3.2)	25.9	20.7	(5.0)	23.2	8.6	37.4	13.9
Changes in fire regime	0	0	0	(3.2)	11.1	17.2	(5.0)	16.8	5.4	27.0	8.7
Spread or arrival of diseases and parasites	0	0	0	(3.2)	0	17.2	0.0	14.6	3.2	23.5	5.2
Total number of CCPs for the year	16	37	25	31	27	29	20	185	185	115	115
The percentage of the year's CCPs discussing CC	25.0	27.0	48.0	58.1	92.6	93.1	100	–	–	–	–
The percentage of the year's CCPs with CC prescriptions	6.3	5.4	16.0	38.7	66.7	79.3	65.0	–	–	–	–

Note: The parenthetical entries represent data from only a single CCP.

by results-oriented (M = 2.1), and specific (M = 2.0). The CCPs scored lowest on the time-fixed (M = 1.5) and measurable (M = 1.3) criteria, categories in which we scored the prescriptions as a whole rather than taking just the best ones in the CCP (tables 2b, 2e). The mean total SMART score for the 73 CCPs was 9.1, and the SMART scores showed no clear trend over time.

Planning tools

Many of the CCPs that we reviewed were written too early to take advantage of climate-related planning support tools. Even the most recent CCPs rarely employed modeling, with the exception of the sea-level-rise predictor SLAMM (Craft et al. 2009). In the realm of conservation planning, modeling forecasts climate changes, predicts impacts on and assesses the vulnerability of species and ecosystems, and optimizes outcomes of management actions.

Climate predictions. The general circulation models (GCMs) used to predict climate changes are typically not used directly by conservation managers; rather, their outputs feed into other models. The Nature Conservancy's Climate Wizard (*www.climatewizard.org*) provides graphical and downloadable climate data from 28 individual GCMs, as well as averages and various percentiles, allowing users to see the variability among the predictions. Regionally downscaled GCM output is sometimes presented as a more relevant form of GCM prediction for unit-level planning, but the improvement in prediction accuracy may be illusory (Pielke and Wilby 2012).

Impact, threat, and vulnerability assessments. Planning for climate change requires some idea of the expected impacts and the area's capacity to cope with them. Threat assessments determine the risk of potentially harmful events. Impact assessments, in turn, inventory the potential effects on managed resources from threats. Guidelines for climate-change impact assessment have been available for some time (e.g., Glick et al. 2011). Vulnerability assessments build on threat and impact assessments by adding information regarding the capacity of a resource to withstand or adapt to predicted impacts. For instance, ecosystems vary in their vulnerability to altered timing and quantity of precipitation.

CCPs and other conservation plans often refer simply to "assessments." Only 3 of the 185 CCPs that we examined discussed refuge-specific assessments; 5 alluded to existing regional assessments, and 30 mentioned or planned future

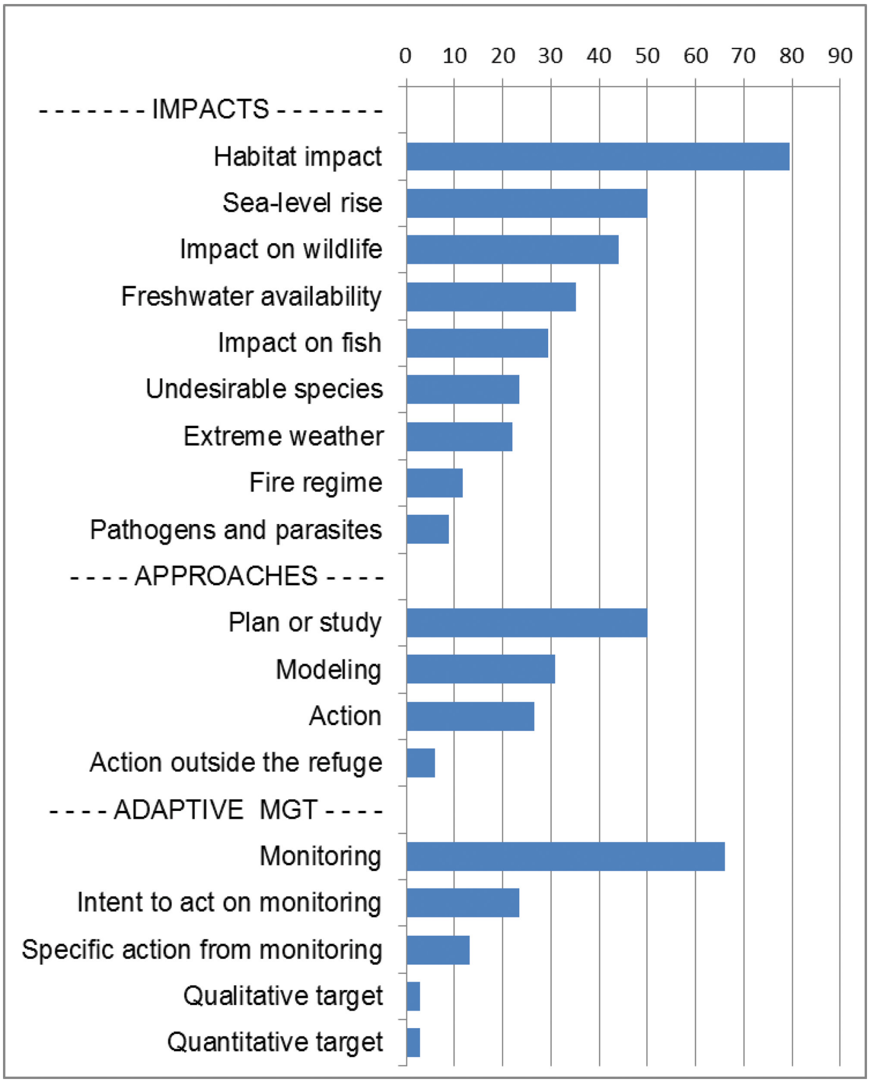

Figure 1. The percentage of 73 comprehensive conservation plans with prescriptions for climate change that address specific climate-change impacts, employ specific approaches to address climate change, and employ specific aspects of adaptive management. The figure shows data across all regions for 2005–2011.

assessments. The CCPs increasingly recognized threats from major classes of climate-change impacts over the period of our study, even without formal threat assessment (table 1), but some threats (e.g., phenological changes, compositional changes in vegetation) deserve attention from all refuges, not the bare majorities that we observed. Even in the most recent years, the CCPs scarcely mentioned some threats, such as the spread of diseases and parasites, despite their potential adverse impacts on wildlife (AFWA et al. 2012). The NWRS can build on recent efforts, such as the northern prairie project, which identifies metrics that encapsulate prairie responses to actions intended to enhance native plans currently under invasion from introduced grasses, weedy forbs, and woody vegetation (Grant et al. 2009).

Vulnerability assessments are rapidly becoming more available for conservation planners. Magness and colleagues (2011) provided an initial GIS-based vulnerability assessment for almost all of the national wildlife refuges. US Forest Service researchers are conducting climate-change vulnerability assessments of forests at the level of ecological provinces (*http://climateframework.org*), and NatureServe has piloted a vulnerability and adaptation strategy for the Mojave and Sonoran deserts (Comer et al. 2012). A vulnerability assessment for the Kenai Peninsula will assist the refuge there to adapt to relatively rapid climate change (AFWA et al. 2012). A comparison of vulnerability assessments showed that they can vary substantially in their predictions and recommended that users clearly understand the inputs and methods of assessments that they consult (Lankford et al. 2014).

The USFWS strategy for preparing the statutorily required revisions to CCPs promises better use of vulnerability assessments (USFWS 2013). By grouping refuges together and preparing LCDs, the USFWS plans to coordinate CCP revisions for ecologically similar refuges. That will help unit-level planners as they tailor ecosystem-level vulnerability assessments to their resource prescriptions. The NWRS can enhance the benefits of assessments if it integrates the results into its land acquisition prioritization system, which steers the spending of scarce acquisition funds.

Decision analysis. Despite the uncertainty of site-specific climate-change impacts, the literature emphasizes the enduring importance of planning (e.g., Lawler et al. 2010). Uncertainty accumulates from data gaps, variability in model formulations and predictions, and an imperfect understanding of natural and social processes and capacities. Decision analysis is a set of tools for formally evaluating decisions to make them more robust.

Users with strong mathematical skills or user support can take advantage of tools that model uncertainty (e.g., Probert et al. 2011), which is particularly appropriate for decisionmaking under climate change. However, the level of modeling in the CCPs suggests that less intensively mathematical tools may be more approachable and practical for managers faced with many decisions and few support staff.

Two common decision analysis approaches are structured decisionmaking and scenario planning. Both are

Table 2a. Examples of prescriptions for the specific *SMART criterion.*

Illustrative prescription text	Comprehensive conservation plan source	Example of	Explanation
A GIS specialist is needed to track changes in the barrier island ecosystem and analyze climate-change impacts and to assist in land acquisition planning and conservation design modeling for species impacted by [climate change (CC)].	Cape Romain	Who	Specifically states who will be undertaking the task: GIS specialist.
Seek funding and partners for dedicated dredge disposal projects to create 809 hectares of restored sandy beach and bayside emergent habitat.	Delta and Breton	What	States what project is: dredge disposal.
Assess saltwater intrusion (i.e., effects on plants, wildlife) for Harkins Slough as a result of sea-level rise.	Ellicott Slough	Where	Identifies where saltwater intrusion assessment will occur.
Within three years of the plan, assess potential impacts of climate change to refuge resources, develop adaptive strategies, and prioritize management to address… [CC] impacts (e.g., erosion, flooding).	San Pablo Bay	When	Provides specific timeline for this project: within 3 years.
Within the life of this plan, assess the feasibility of developing a hydrologic model for the refuge's principal watersheds.… Such a model would allow the refuge to track and predict changes in water resources and evaluate the effect of these changes on fish, wildlife, plants, and people. For example, climate change could lead to changes in precipitation patterns that could affect flooding regimes and water quantity, melting of permafrost with alteration of drainage patterns, and changes in water temperature that could affect the survival of fish, aquatic plants, and invertebrates.	Innoko	Why	Explains why a model would help the refuge.

Note: The ideal prescriptions answer all five of the *who, what, where, when*, and *why* questions about prescribed studies or actions.

Table 2b. Examples of prescriptions for the measurable *SMART criterion.*

Illustrative prescription text	Comprehensive conservation plan source	Example of	Explanation
Protect and enhance… habitats associated with the Lake Mattamuskeet environment in the context of climate change and rising sea levels.	Mattamuskeet	Quality	Provides only qualitative goal for project: protection and enhancement.
Continue to work with the partners to monitor and maintain the 34 kilometers of beaches and nearshore habitats of the larger Archie Carr national wildlife refuge partnership to support annual nesting goals of at least 10,000 loggerhead nests and a biennial goal of at least 3000 green sea turtle nests and 50 leatherback nests to support sea turtle recovery efforts.	Archie Carr	Quantity	Provides quantitative, measurable goals for project: length of beach to monitor and maintain, and number of sea turtle nests.

Note: The ideal prescriptions provide quantitative measures against which to judge prescribed studies or actions.

recommended for decisionmaking under climate-change (Lyons et al. 2008, AFWA et al. 2012, Comer et al. 2012, NPS 2013). USFWS training material indicates that structured decisionmaking underlies the CCP process (USFWS 2014). Structured decisionmaking requires managers to specify goals, actions, and hypotheses for the expected outcomes and uncertainty in outcomes (Conroy and Peterson 2013). This transparency improves both the efficiency and the effectiveness of management decisions. The Conservation Measures Partnership, a group of conservation organizations working to improve conservation practices, now shares structured-planning tools such as the Miradi program (Conservation Measures Partnership 2013).

Scenario planning is a means of describing plausible futures using quantitative or qualitative data (Peterson et al. 2003). Usually, it is a participatory process involving a wide range of stakeholders; it works well when decisions are taken without any preliminary experimentation with the outcomes of possible actions. The use of scenarios may organize uncertainty somewhat, but it does not necessarily reduce it.

Scenario planning was not evident in the CCPs, despite a wealth of materials on practical applications for climate-change adaptation. The LCD model for revising the CCPs calls for scenario planning (USFWS 2013). Although assessments can be prepared by experts and used by many planning units, scenario planning requires greater local involvement. The USFWS can make the best use of structured decisionmaking and scenario planning by engaging partners and stakeholders in discussions of the trade-offs associated with different management approaches (Tompkins et al. 2008).

Table 2c. Examples of prescriptions for the **achievable** *SMART criterion.*

Illustrative prescription text	Comprehensive conservation plan source	Example of	Explanation
Plant tree seedlings to reduce the number of fragmented forest gaps by 50%.	Canaan Valley	General	No resources discussed.
Seek partnerships to understand impacts of global climate change.… Develop partnerships with agencies or institutions to conduct baseline global climate-change investigations.	Guam	Resources discussed	Specific partner not indicated, but partnerships desired: with agencies or institutions.
Conduct long-term habitat and wildlife monitoring on 26,000 hectares of forested and wetland habitats on Cache River National Wildlife Refuge and adapt management activities based on analysis and interpretation of results.… This could be a joint effort with state universities, Lower Mississippi Valley Joint Venture Office, Arkansas Game and Fish Commission, Migratory Bird Office, The Nature Conservancy, Audubon, Arkansas Natural Heritage Commission, and possibly other federal agencies. The ecologist also will serve the needs of the other refuges in the Complex in ecosystem and landscape planning, strategic habitat conservation, climate-change initiatives, and coordination with conservation partners. Estimated cost $114,439.	Central Arkansas Complex	Resources identified	Resources identified, along with plan for obtaining them (funding source and amount, specific staff positions, or specific partners).

Note: The ideal prescriptions identify the resources needed to complete the prescribed study or action, and indicate how the resources will be obtained.

Table 2d. Examples of prescriptions for the **results-oriented** *SMART criterion.*

Illustrative Prescription Text	Comprehensive conservation plan (CCP) source	Example of	Explanation
Explore ways to study the potential impacts of [climate change] on algific talus.	Driftless Area	No action	No stated intention to do anything.
Within 15 years of CCP approval, monitor: coral species density, diversity, and size and spatial distribution; fish species presence or absence and habitat associations; turtle species presence or absence; marine mammal species presence or absence; and oceanographic conditions in relation to climate-change effects.	Baker Island	Start or continue monitoring	Stated intention to start or continue monitoring.
Within 15 years of the plan completion, seek to acquire 25%–50% of the remaining private lands within the current acquisition boundary from willing sellers… land acquisition is a key adaptive response to climate change.	Klamath Marsh	Specific results described	On-the-ground objective to do something beyond monitoring: acquiring land.

Note: The ideal prescriptions indicate the specific result desired.

Table 2e. Examples of prescriptions for the **time-fixed** *SMART criterion.*

Illustrative Prescription Text	Comprehensive conservation plan (CCP) source	Example of	Explanation
Develop adaptive management approaches to priority habitats that mitigate the long-term effects of climate change and sea-level rise. Within 15 years of CCP approval, monitor: coral species density, diversity, and size and spatial distribution; fish species presence or absence and habitat associations; turtle species presence or absence; marine mammal species presence/absence; and oceanographic conditions in relation to climate-change effects.	Savannah Coastal Complex, Baker Island	Full period of CCP	Provides no time frame, or one equal to duration of the plan (15 years) for fulfillment of objective.
Within 10 years of the date of the CCP, work with the research partners to assess the changes to refuge resources associated with climate change. Within 5 years of the date of this CCP, identify important habitat areas surrounding the refuge that are less susceptible to the effects of sea-level rise for potential addition to the refuge.	Banks Lake, Cape Romain	Deadlines shorter than CCP time frame	Provides a time frame of less than 15 years, shorter than the duration of the plan.

Note: The ideal prescriptions provide interim deadlines for all intermediate steps as well as an indication of the overall timeframe for the proposed study or action.

Adaptive management

Whereas decision analysis can help managers choose among competing objectives and priorities, adaptive management is the consensus choice for implementing them (Williams et al. 2009, Williams and Brown 2012). As an aspect of ecosystem-based management and an approach best suited to situations in which multiple paths may lead to desired outcomes, adaptive management has become a fixture in natural-resource administration. Its iterative cycle of planning, acting, observing, and finally modifying plans acknowledges that management actions are experiments whose outcomes are never fully known, a situation that climate change exacerbates (Conroy et al. 2011, Williams and Brown 2012).

In reviewing the CCPs, we assessed the intent to develop baselines, to take actions, to monitor, and to act on the monitoring's results. Program evaluation, which is beyond the scope of this review, would be needed in order to assess the plans' implementation and effectiveness.

All but one of the CCPs that we examined called for monitoring some aspect of refuges. However, both in general and with respect to climate change specifically, the CCPs were much less likely to indicate how monitoring results would be used to assess and adjust management actions. Among all of the CCP biological prescriptions calling for monitoring, habitat management had the highest percentage (62%) of targets (Meretsky and Fischman 2014). In contrast, 8.9% of the CCPs calling for monitoring of some aspect of climate change included at least one related target. This relatively high use of monitoring but low specification of targets is consistent with a growing literature documenting how agencies and nongovernment organizations employ monitoring (e.g., Westgate et al. 2013). Our SMART assessment demonstrates that the most important elements of prescriptions with room for improvement in the CCPs are providing quantitative goals (measurability) and breaking down actions into short-term steps (time-fixed). Without specific criteria for evaluating success, refuge managers will have difficulty knowing whether and how to adjust activities on the basis of monitoring (Schroeder 2009, Moore et al. 2011). In order to adjust activities, managers will need at least conceptual—and likely quantitative—models that relate actions to outcomes.

The conservation literature is particularly adamant that measurable objectives improve planning (Kareiva et al. 1998), and that failure to establish rigorous quantitative objectives is a chronic problem (Ruhl and Fischman 2010). The Archie Carr CCP (table 2b) illustrates how planners coping with sea-level rise can advance their goals—in this case, for sea turtle conservation. The CCP establishes quantitative objectives for the length of beaches supporting a specific number of turtle nests. The addition of a time frame would ensure appropriate deadlines for action and better meet guidelines for adaptive-management efforts. The Archie Carr CCP does add a time frame in prescribing a reduction in nest predation from 10% to 5% in the first year of plan adoption.

The plans that incorporate the SMART criteria more clearly reflect management priorities (Schroeder 2009) and may even spur deeper engagement with adaptation issues. For example, to fulfill an objective to monitor and maintain island habitat in an area of rising sea levels along the Gulf coast, the Delta and Breton NWRs CCP calls for managers to seek funding and partners for dedicated dredge disposal projects to create 809 hectares of restored sandy beach and bayside emergent habitat (table 2a), with specific goals for sand fencing and the number and species of plants to be established. The CCP objective includes a list of potential private, nongovernmental organization, and public partners who might be able to help achieve the objective. The CCP clearly lays out its line of reasoning for the prescription, citing the lessons for previous storm-related losses of islands and the futility of small-scale restoration projects. By starting with well-defined, measurable, and achievable goals, the Breton NWR has improved its chances of success with a new, landscape-scale approach to an important conservation problem in the Gulf of Mexico.

The plans that avoid specifying clear criteria often result from a desire to retain management flexibility (Schroeder 2009). When funding opportunities and partnerships may be unpredictable, some flexibility is desirable. However, specificity, like prioritization, strengthens managers' positions by insulating them somewhat from political pressures and expediency. Broad, vague language is an easy response to high levels of uncertainty and is therefore a common reaction to the wide confidence intervals around climate-change predictions. However, a growing library of climate-change planning shows how adaptive management's experimental approach allows managers to prescribe management actions as experiments and corresponding goals without knowing the exact shape of the future (Moore et al. 2011, Williams and Brown 2012, Conservation Measures Partnership 2013). Some CCP climate-change prescriptions illustrate the specific, measurable, achievable, results-oriented, or time-fixed elements that best support adaptive management (tables 2a–2e). Because adaptive management integrates decision-making and learning, it benefits from close collaboration between managers and scientists in developing these design criteria (Grant et al. 2009).

Despite recommendations in the literature, managers are often reluctant to commit to specifics in conservation plans in the face of uncertainty (NRC 2009); few of the CCP climate-change prescriptions included monitoring thresholds or specific actions to be triggered when thresholds are crossed (figure 1). However, further research into climate processes may result in no useful increase in certainty and may actually increase uncertainty over the next decade or two (USCCSP 2009). Therefore, rather than waiting for future certainty, managers can most effectively pursue their goals by developing no-regrets strategies that provide benefits under a wide range of future conditions (e.g., reducing nonclimate stressors) and limiting their use of approaches that resist climate change (e.g., irrigating to offset climate-change drought or attempting to enforce a fire regime that a changed climate no longer supports). This would result in more-agile management as the focus of plans shifts from present species assemblages to landscapes and ecosystem services (Lawler 2009, Fischman and Adamcik 2011). The approach can also sustain evolutionary processes by providing more-secure habitats in which organisms can adapt to changing conditions (Aycrigg et al. 2013).

In the CCPs, and in climate-change strategies generally, planners typically fail to overtly address the unavoidable loss of existing species and natural communities. In the no-analog future, triage will be necessary (Lawler 2009). Planning for such a future will require rethinking management priorities well ahead of the anticipated changes in order to change course when that is appropriate (Poiani et al. 2011). Leadership in agencies, organizations, and even legislatures will be necessary to support major alterations in priorities and triage, especially when reserves have been established for goals no longer feasible in new climate regimes. Refuge managers will require strong support to expressly abandon a species or habitat that has a long association with local identities, recreational activities, or businesses.

Conservation plans should reflect a consideration of priorities, not recommend such reflection. Prioritization is a key aspect of conservation planning (Hilty and Groves 2009), given time and funding constraints. The vagaries of funding and collaborative opportunities mean that reserve managers will not be able to accomplish all of their planning objectives. However, clearly written priorities can support managers' choosing carefully among competing claims. The LCD approach promises to highlight opportunities for both cost sharing and collaboration (USFWS 2013). This is another reason why plans should provide clear, scientifically supported justifications for priorities and strategies related to climate change. The sources of information and the lines of reasoning should be well documented. Plan revisions will be most easily undertaken if new information can be seen as supporting, augmenting, or opposing previous justifications. Many of the CCPs paired strategies with well-crafted justifications (although most of these did not relate to climate change; Meretsky and Fischman 2014); we recommend that this practice be continued and enhanced.

Many of the CCPs deferred much of the planning and related adaptive management processes to step-down plans (the USFWS term for implementation plans) that will deal most commonly with habitat management, fire management, and monitoring. Step-down planning can be effective if the comprehensive plans justify and specify objectives. Step-down plans can then sketch out predictive models that management will test. Subsidiary documents should be strategic and should not usurp the goal-setting role of the main planning documents (Grantham et al. 2010, 602 FW 3, 4). Compared with step-down plans, the comprehensive unit-level plan is likely to receive far wider scrutiny and feedback. Step-down plans alone cannot support the fundamental changes in conservation approaches required to adapt successfully to climate change.

Climate change complicates adaptive management because learning that takes place in one cycle may be obsolete in the next because of changes resulting from nonstationary climate alterations, such as continually increasing temperature. Nevertheless, scientists and policymakers alike continue to support the use of adaptive management for planning under climate change (Nichols et al. 2011, Haasnoot et al. 2013). One approach to dealing with nonstationarity is to apply adaptive management through CCPs across sets of refuges dealing with similar issues, particularly if these are somewhat offset from each other in time. The LCD framework is well suited to structure adaptive management in this way.

Landscape-scale strategies

Recommendations for conservation management actions under climate change have converged, in part, on a suite of consensus practices (Heller and Zavaleta 2009). Most rely on the flexibility afforded by long-range, landscape-scale strategies that facilitate trade-offs, experiments, and collaboration (e.g., USFWS 2010). The USFWS has already committed its resources to landscape-scale strategies for its next round of unit-level planning (USFWS 2013), which will aid the implementation of the following recommendations.

Enlarging protected-area footprints. Only nine of the CCPs in our study prescribed acting outside the refuge to address climate-change impacts. This is particularly surprising because CCPs overall show high rates of prescriptions for acting outside of refuge boundaries, especially to reduce water pollution, habitat loss, and invasive species problems (Meretsky and Fischman 2014). These actions are also useful in combating climate-change impacts through a reduction in stressors and improvements in connectivity (Lawler 2009, AFWA et al. 2012) but were not presented as such in CCPs. For instance, CCP prescriptions often employ Farm Bill programs (e.g., conservation reserve, wetland reserve, and environmental quality incentives) designed to encourage private land conservation through direct government payments and cost sharing (e.g., the Savannah Coastal Refuges Complex CCP, *www.fws.gov/savannah/pdfs/finalccp.pdf*). However, most of the CCPs failed to link this work to climate change. Where the CCPs did prescribe acting outside of existing boundaries expressly for climate-change adaptation, they overwhelmingly sought to identify outside parcels for acquisition on the basis of expected coastal marsh habitat migration (e.g., the Ellicott Slough NWR CCP, *www.fws.gov/cno/refuges/ellicott/EllicottSloughNWRFinalCCP.pdf*).

It seems likely that planners working with familiar approaches to biodiversity conservation overlook their applicability to climate change and therefore use them less effectively than they could. For example, protected area managers often participate in collaborations aimed at establishing connecting corridors and protective buffers. The Willamette Valley NWRs CCP calls for restoring riparian habitat to provide wildlife corridors and to assist in lowering water temperatures (*www.fws.gov/pacific/planning/main/docs/OR/Willamette%20Valley/WillValleyFinalCCPforWeb.pdf*). This illustrates how a refuge can simultaneously improve habitat, reduce existing stressors, and enhance resilience through a corridor project. Such projects may be precluded in the future because of the increasing residential development around and between many refuge units in the eastern and southern United States. Securing corridors and buffers today for short-term goals would retain opportunities for more effective adaptation in the coming decades (AFWA et al. 2012, Hamilton et al. 2013), especially if the projects were designed with long-term impacts of climate change in mind. Land-use changes affecting connectivity may, themselves, be driven by climate change.

Effective biodiversity conservation in the face of climate change is beyond the scope of even the largest protected areas (Magness et al. 2011). Collaborative efforts are needed to ensure the level of redundancy, connectivity, and overall system resilience necessary to conserve species and ecosystem functions (Griffith et al. 2009, AFWA et al. 2012). The landscape conservation cooperatives (LCCs; *www.doi.gov/lcc/index.cfm*), a network of collaborative teams, can serve as leaders in creating regional coalitions and LCDs if they can overcome important challenges of funding and durability (Moore et al. 2011, Meretsky et al. 2012, Aycrigg et al. 2013).

Examples of promising USFWS landscape initiatives include conservation coordination for the Nebraska sandhills (USFWS 2012), restoring native vegetation in the Dakota prairie portions of the NWRS (Grant et al. 2009), and identifying strategies to restore aquatic connectivity for native fish migrations in the Great Lakes Basin (Januchowski-Hartley et al. 2013). Three national forests in the Pacific Northwest have already undertaken a similar coordinated planning effort (Joyce et al. 2008).

Climate change is a global conservation issue, and effective solutions require coordinated responses within and among nations in order to facilitate range shifts and species movements. The US national climate strategy reflects this reality in its call for a coordinating body, yet to be identified (AFWA et al. 2012). However, the strategy neglects to assign responsibility for monitoring range-wide impacts of climate change to assure that species are not falling through the cracks between different planning jurisdictions. Ultimately, LCDs will need to link together different conservation systems in addition to different refuge units.

Conserving refugia. Climate-change refugia are areas that, by virtue of their high resilience or adaptive capacity (often owing to a well-protected, cool, or moist local climate), are likely to suffer fewer impacts of climate change than are nearby areas, at least in the short term. The literature on identifying climate refugia is maturing, and refugia are widely recommended as high-priority conservation targets (e.g., Groves et al. 2012). Only 2 CCPs out of the 185 in our study explicitly addressed climate-change refugia. For reserves whose missions include conserving less mobile or endemic species, identifying and protecting climate-change refugia will be useful (Keppel et al. 2012). For reserve systems with explicit mandates to protect existing ecosystems, refugia may provide breathing room before policies must be modified to acknowledge changing community composition and transitions to novel communities (Hobbs et al. 2013). As with many of the climate-change prescriptions, addressing sea-level rise provides the best example of a refuge objective for conserving refugia. The Cape Romain NWR CCP calls for the identification of habitat surrounding the refuge that is less susceptible to the effects of sea-level rise for land acquisition (table 2e). The CCP helpfully provides a time-fixed deadline of 5 years for the task.

Resistance, resilience, transformation. In general, adaptation actions may be understood as responses to climate change that include resistance (ecosystem remains unaltered as climate changes), enhanced resilience, and transformation (ecosystem composition or function changes; AFWA et al. 2012). Where the CCP prescriptions explicitly responded to climate change, they overwhelming chose resistance strategies. This provides baselines of existing conditions, and these CCPs scored well on measurability as a result. For example, refuges might seek to maintain a certain length of beach as habitat or a certain number of breeding pairs of some species (e.g., Archie Carr CCP; also see table 2b). Such strategies may buy time to maintain valued resources and services. However, resistance, in the long term, is futile (Magness et al. 2011).

Improving landscape-scale connectivity and reducing biodiversity stressors are commonly recommended no-regrets strategies for enhancing resilience that appear in many CCPs without being expressly connected to climate-change adaptation. The CCPs could better coordinate many of their activities for adaptation by defining connectivity, as US national forests do, to include ecological conditions facilitating range shifts in response to climate change (36 C.F.R. § 219.19). The example of the Willamette Valley NWRs CCP corridor project illustrates how conventional habitat objectives can be advanced through actions that also improve resiliency. But most of the prescriptions for outreach to key private landowners or new partners are uncoordinated (Aycrigg et al. 2013). One danger in low levels of coordination is that the weakest link in an area's conservation network may undermine an adaptation plan. The LCD approach for revising CCPs should alleviate this problem. However, resilience strategies, insofar as they seek to allow species to remain in their present locations, will often fail in the long term.

In time, the CCPs will need to move beyond promoting resilience and monitoring compositional changes in biological communities to consider the facilitation of ecosystem transformation to novel assemblages (Hobbs et al. 2013). Managing reserves undergoing these changes may require new tools to enhance adaptation, such as managed relocation to conserve species or ecosystem function (Williams and Brown 2012). Discussions of managed relocation either of ecotypes or of species are still controversial, however, and do not provide strong guidance for managers. Recent suggestions that such relocations should be considered within a framework of ecosystem function may be helpful (Lunt et al. 2013). Future plans should more thoroughly investigate tipping points and triggers for major changes in ecosystems (e.g., from forest to savannah or from herbaceous tundra to shrubby tundra) and consider the likely timeframe for such transitions.

Gathering and sharing information

Climate change increases the burden on land managers to understand as much as possible the strength and direction of anticipated changes and the nature of the resulting impacts. Strong baseline inventories resist creeping expectations that can develop when incremental changes occur slowly enough to avoid clear perception, and subsequent targeted monitoring can help document change. Conservation reserve managers rarely have the luxury of research. Their decision-making may be best served by judicious partnering with scientists and by leveraging available research syntheses. Managers also have an important role to play in sharing the results of their efforts.

Monitoring and reporting. Climate-change strategies invariably recommend general monitoring of protected area ecosystems and of management results (e.g., AFWA et al. 2012). In addressing climate change, the CCPs call for monitoring more than any other action (figure 1). The literature on monitoring argues for care in undertaking these programs (Lindenmayer and Likens 2009), beginning with a clear information need and a sampling design that can provide statistically robust answers. Step-down plans defining monitoring programs will affect the success of many prescriptions.

Some questions, such as whether an easily identified advancing species has arrived in number in the vicinity of a protected area, will be more easily addressed than others that may require statistically complex analysis or very accurate information. For instance, it is difficult to untangle climate-change effects from among a set of interacting forces to explain population trends, especially for cryptic or rare species.

Existing citizen-science monitoring efforts, such as the Christmas Bird Count, the North American Breeding Bird Survey, eBird, and the North American Amphibian Monitoring Program, may provide information responsive to management-relevant questions. Managers are equipped to handle some monitoring issues but may need to join a larger monitoring network or design monitoring activities with the help of research partners to obtain needed information. Research partnerships could test cost-effective sampling strategies to probe how various population parameters (e.g., size, health, behavior) are related to aspects of climate change.

Managers of protected areas are potentially valuable participants in monitoring programs designed to provide standardized data for climate-change research. Refuges can play a leadership role in building collaborations to develop common metrics, such as those identifying prairie vegetation responses to management (Grant et al. 2009). The results of comparable monitoring projects support synthesis without recourse to conversions and the attendant loss of resolution and accuracy that occur when combining data collected by disparate methods.

To take full advantage of standardized practices, protected-area managers should report the monitoring of management experiments to existing forums (e.g., CAKEX, *www.cakex.org*; CASES Adaptation Library, *cses.washington.edu/cig/cases/library*). Where no forum or database exists, managers should support efforts to create them. Reserve management cannot be judged in isolation when climate change affects virtually all aspects of conservation.

More important than the centralized storage of monitoring data is the synthesis of those data to facilitate collaboration at all necessary scales (Kareiva et al. 1998). Without regional, national, and international data synthesis, the role of protected areas in conservation will be unclear, and the success of adaptive actions will be difficult to assess. In the United States, government centers involved in climate-change research have proliferated to the point that states and other stakeholders begin to find interfacing with them to be burdensome (Ryder 2011). Data storage, data synthesis, and capacity building need not be undertaken by the same organization, but all conservation actors would benefit from national-level coordination (Meretsky et al. 2012).

Research needs. Support for climate-change planning should include supplying or coordinating vulnerability assessments and related research syntheses. These are currently produced piecemeal, by public and nonprofit organizations (e.g., Comer et al. 2012). A strategic plan could prioritize the regions for which climate-change planning is particularly urgent and could arrange for the necessary forecasts and assessments. The LCDs that will serve as hubs for USFWS regional planning will be peer-reviewed documents that will bring researchers and planners together (USFWS 2013). LCDs, along with collaborative adaptive management (Moore et al. 2011), can better educate research scientists about management problems and spur more management-oriented research.

Although the conservation literature emphasizes the importance of planning for climate change and largely agrees on general approaches, researchers have offered few on-the-ground prescriptions (Cook et al. 2013). Proposals for or case studies of excellent on-the-ground adaptive-management efforts could clarify what prescriptions work and how (e.g. Cross et al. 2013). For example, the collaborative Climate Change Response Framework supports an incipient database of demonstration projects integrating climate considerations into planning (*http://forestadaptation.org/demonstration-projects*).

The high-priority information needs of managers have been identified (Fleishman et al. 2011), and methods to identify key issues have been described (Sutherland et al. 2011). Research to address these would support improved CCPs. The LCCs can build on existing partnerships through cooperative research units to provide more geographically and ecologically focused forums for convening researchers and managers.

Finally, effective climate-change adaptation for nature reserves requires support from social scientists (Fleishman et al. 2011). Fruitful conservation efforts often trace their success to strong relationships and communication among scientists, managers, and other key stakeholders (Raymond and Knight 2013). Collaborative conservation requires an in-depth understanding of the social nuances involved in a project (Lauber et al. 2011). Such understanding can contribute to social–ecological resilience in landscapes that include protected areas (Folke 2006). By contributing to the overall knowledge of a particular region, these studies help scientists and managers identify key collaborators, communicate effectively with local (human) communities, and build a consensus for adaptation actions based on the concerns and information available to all (Jacobson et al. 2006). For example, refuge plans need to grapple with the cultural disruptions of climate change as people modify traditional knowledge and practices surrounding hunting and fishing (Adger et al. 2013). Boreal reserves, such as the Alaska NWRs, and island nations, such as Kiribati, may provide testing grounds and blueprints for grappling with such problems.

Social scientists can also make valuable contributions in developing the capacity to employ adaptive-management techniques within institutions. Conservation agencies are complex and are often managed with a top-down approach poorly suited to the flexibility that adaptive management demands; adaptive management often fails for institutional reasons (Walters 1997). Adaptive strategies require that institutions be capable of experimenting with and modifying longstanding practices (Stankey et al. 2005). Scholars of business management can help institutions acquire the necessary skills (Rogers et al. 2000). In particular, the regional institutions supporting LCDs will need to be nimble, effective, and durable in the face of changing administrations.

Conclusions

The 2005–2011 CCPs steadily increased in the extent to which they described climate-change impacts but less consistently responded to those impacts with prescriptions for studies, actions, monitoring, or adaptive responses to monitoring results. The threats posed by sea-level rise generated the best-developed plan prescriptions. Although the specific actions needed to adapt resiliently in a given refuge or in a given region may be difficult to determine, some basic principles of early preparation for climate change are well established. Protecting climate refugia, extending the effective conservation footprint of a reserve, strengthening ecological connectivity, and developing effective monitoring programs are all feasible steps.

Of these steps, the CCP prescriptions most commonly promoted connectivity. However, the connectivity objectives often predated climate-change concerns and, therefore, may not provide the connections that are most suitable for species moving in response to climate change. In responding to climate change, the CCPs sometimes neglected to consider the usefulness of actions already being taken that reduce stress on species and ecosystems. As a result, implementation may fail to employ these actions effectively. Resistance to climate change may be appropriate in the short term for some areas, but, as species assemblages change, plans should consider longer-term strategies to support biodiversity, ecosystem function, and ecosystem services. Unfortunately, unit-level planners are unlikely ever to have the resources necessary to devise all such strategies themselves.

The proposed LCD framework for the next generation of CCPs should help refuge units connect and collaborate with larger-area plans and programs (e.g., Farm Bill programs). Although CCPs will always focus on refuge issues, the LCDs will provide a platform for other public lands, land trusts, and private enterprises to work together in identifying conservation targets and contributions to landscape-level conservation that each participant is willing to make (USFWS 2013). Many existing planning tools, such as vulnerability assessments, can help refine priorities. The LCDs can identify opportunities to undertake climate-related assessments and analyses unaffordable at the unit level.

Ultimately, integrating unit-level plans into a broad, landscape-scale endeavor allows reserve managers to make a greater contribution to climate-change adaptation than they can by acting independently. This will require refuges to reach out beyond their boundaries and engage with other resource managers who have objectives unrelated to conservation. This is a challenge familiar to the refuge system, which has struggled for decades to coordinate management across hundreds of units, each with its own establishment purposes, in order to achieve continent-scale objectives. Coordinating the actions of a disparate collection of reserves so that they achieve more together than each can independently is, after all, the whole point of having a conservation system. Climate-change adaptation requires a similarly systemic approach of coordinating responses across a wide range of land management regimes.

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Supplemental material

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