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Adaptive management in the U.S. National Wildlife Refuge System: Science-management partnerships for conservation delivery

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ABSTRACT

Adaptive management is an approach to recurrent decision making in which uncertainty about the decision is reduced over time through comparison of outcomes predicted by competing models against observed values of those outcomes. The National Wildlife Refuge System (NWRS) of the U.S. Fish and Wildlife Service is a large land management program charged with making natural resource management decisions, which often are made under considerable uncertainty, severe operational constraints, and conditions that limit ability to precisely carry out actions as intended. The NWRS presents outstanding opportunities for the application of adaptive management, but also difficult challenges. We describe two cooperative programs between the Fish and Wildlife Service and the U.S. Geological Survey to implement adaptive management at scales ranging from small, single refuge applications to large, multi-refuge, multi-region projects. Our experience to date suggests three important attributes common to successful implementation: a vigorous multi-partner *collaboration*, practical and informative decision framework *components*, and a sustained *commitment* to the process. Administrators in both agencies should consider these attributes when developing programs to promote the use and acceptance of adaptive management in the NWRS.

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1. Introduction

The management of public lands entails an aggregation of decision making at all levels of the managing agency: from the programmatic level where strategic decisions are made about agency priorities and allocation of resources, to the field level where a manager decides how to treat a specific unit of land. Common to nearly all of these decision settings is uncertainty as to whether a proposed action will bring about intended results. It is fortunate, however, that for many of these settings – particularly those at the level of the land manager – decisions occur in a sequence (or can be arranged to do so) such that insight gained from any one decision can be exploited to improve the quality of subsequent decisions. That is, many of these settings lend themselves to an approach in which a manager's understanding about the relationship between action and outcome evolves through time, and future actions adapt to that gain in understanding.

1.1. The National Wildlife Refuge System

One U.S. federal entity charged with the management of a large public land base is the National Wildlife Refuge System (NWRS) of the U.S. Fish and Wildlife Service ("Service"). The U.S. government first formally set aside land for wildlife conservation in 1903, with the designation of Florida's 1.2-ha Pelican Island as a Federal Bird Reservation (Gabrielson, 1943). The Migratory Bird Conservation Act of 1929 established the legal authority for a national system of wildlife refuges (Gabrielson, 1943; Curtin, 1993). The NWRS has been a component of the Service since the agency was formed in 1940 (Curtin, 1993). The mission of the NWRS is to administer a network of lands and waters for the conservation of fish, wildlife, and plant resources and their habitats for the present and future benefit of Americans (U.S. Code, 1997). In 2008, this network exceeded 60 million hectares contained in 550 National Wildlife Refuges in all 50 states and over 36,000 Waterfowl Production Areas in the Prairie Pothole Region of the northcentral U.S. (U.S. Fish and Wildlife Service, 2008; Griffith et al.,

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2009). Managers within much of the NWRS pursue their mission through active forms of managing animal and plant populations, their habitats, and the human users of these resources.

However, NWRS managers face daunting uncertainties as they make decisions about the lands under their care, and almost always under severe constraints of cost (Smiley, 2008). What is the best strategy for limiting forest damage due to an invasive tree borer? How should the hydrology of a network of wetlands be manipulated to increase diversity of amphibians? Is it possible to bring desired changes in the songbird community through control of the deer herd? For these and many other management scenarios, adaptive management is an effective means for making transparent, defensible decisions in the face of uncertainty, with the ultimate aim of improving decision making and resource delivery over time (Lyons et al., 2008).

1.2. A natural fit for adaptive management

By "adaptive management," we mean a decision-theoretic approach to making a sequence of decisions by which uncertainty about decision making is reduced over time through comparison of predictions of outcomes by competing models against observed values of those outcomes (Williams, 1997; Kendall, 2001; Moore and Conroy, 2006; McCarthy and Possingham, 2007; Conroy et al., 2008). Development of the idea traces back to operations research in the 1950s (Bellman, 1957, 1961); Walters and Hilborn (1978) and Walters (1986) described its use in natural resource applications. The Department of the Interior, the parent organization of the Service, developed guidance for the appropriate setting and use of adaptive management within its agencies (Williams et al., 2009). The use of competing models is a defining element of adaptive management (Conroy and Moore, 2002) because the most efficient path to the desired outcome is unknown to the manager but dependent on model choice (Pascual et al., 1997). Models that generate more reliable predictions of outcome earn greater influence in determining the direction of future decision making (Kendall, 2001), and adaptive management provides a precise blueprint for how this learning is to be accumulated and focused on achieving the management objective (Williams et al., 2002). Because of this blueprint, adaptive management is a forward-looking process that unfolds in an anticipated manner; it is not an ad hoc, trial-and-error, or wait-and-see approach to management.

Adaptive management is a specific form of structured decision making (Williams et al., 2009; Lyons et al., 2008). As such, an adaptive decision framework has several requisite components (Nichols et al., 1995; Kendall, 2001), many of which are already in place throughout the NWRS as part of conventional practices.

1. A recurrent decision is to be made, one that either affects a resource in its entirety (e.g., harvest management of an animal population) or in subunits treated in turn over time (e.g., management compartments of a large wetland). In some settings, it is possible to consider one-time decisions (e.g., dam removals or wetland restorations) made in different locations over time as recurrent decisions.
2. The decision is selected from a fixed set or range of clearly defined decision alternatives.
3. A clear statement of measurable objectives drives the selection of a decision. Objectives reflect core conservation goals of the decision maker and characterize the essential reason for interest in the resource problem. These *fundamental* objectives are distinguished from *means* objectives, which establish the means or waypoints for achieving the fundamental objectives (Keeney, 1992). For example, "complete a prescribed burn of 100 ha" or "achieve a population of 100 fertile individuals" may serve as means to the fundamental objective of "establish a self-sustaining milkweed population". An objectives hierarchy is an important device for mapping the linkages between fundamental and means objectives (Keeney, 1992). However, reliance on means objectives without ever identifying fundamental objectives or examining their relationships to fundamental objectives carries some risk of overly prescriptive management (Failing and Gregory, 2003).
4. Management uncertainty is represented through a set of competing models, which make distinct predictions of outcome for a given management decision. It is through the evaluation of predictions generated under different beliefs about system behavior that insight is gained about management of the system.
5. A system of monitoring is in place to inform the decision maker about current system state and to provide feedback on the relative performance of the competing models. The suite of monitoring metrics is judiciously chosen to inform progress toward the management objective and to meet the information requirements of the models. Adaptive management firmly establishes a purpose for monitoring and sharply distinguishes relevant monitoring metrics from those less relevant (Nichols and Williams, 2006; Lyons et al., 2008).

The focus of adaptive management is not research: the primary objective is the accumulation of knowledge for the aim of improving decision making (Lancia et al., 1996). Adaptive management abandons the traditional science-management relationship in which managers express a research need, scientists work separately on the problem and furnish results, and managers implement the findings. Instead, adaptive management integrates the decision making and learning processes, so that decision making can proceed even as uncertainty is being resolved (Lyons et al., 2008). As in other forms of structured decision making, a model informs the decision maker and guides the selection of a management action. The key aspect of adaptive management is that competing models reflect management uncertainties, and each influences the decision. Over time, management performance is improved by the recurrent assessment of these models through iterative monitoring of the system. Adaptive management thus provides the means to make defensible decisions that are informative, even if the management application does not offer the degrees of control, randomization, and replication that are sought in a conventional research application. To illustrate an extreme case, the adaptive harvest management of North American waterfowl (Johnson and Williams, 1999) is an example of resource management that employs a single replicate (the continental waterfowl population) and no experimental control or randomization whatsoever; yet managers learn about this system as they make decisions, and a formal process applies that learning to future decisions.

In our interpretation of the process, adaptive management is scalable, meaning that the approach may be appropriately sized to scales ranging from a single management unit to entire ecosystems (Williams et al., 2009). For example, the process can be tailored to the management of a group of water control structures on a portion of a management area or to the management of land units across an entire biome (see examples in Appendix 1). As the NWRS is charged with making efficient and scientifically-defensible decisions for conservation objectives, an adaptive approach seems well-suited for application to land management problems occurring across different scales and fraught with uncertainty.

2. Opportunities and challenges of working within the NWRS

In many ways, the NWRS offers an ideal environment for adaptive approaches to decision making. The NWRS has a strong tradition of manipulating habitats to meet the annual life cycle requirements of many target wildlife species or species guilds. Many of the required elements of adaptive management are already found in the customary operations on refuges. Refuges have on-site capability to perform a variety of management actions and associated monitoring. However, a system-wide assessment revealed that 25% of 66,000 staff days spent on annual monitoring activities was devoted to monitoring for which little use is made of the data or to which no decision is attached (H. P. Laskowski; internal USFWS survey of NWRS managers and presentation to Senior NWRS Leadership Team, Salt Lake City, 2003); thus there may be opportunities to direct monitoring effort more productively through adaptive management (Nichols and Williams, 2006). Our Service coauthors have also observed that managers are beginning to identify uncertainties relative to the effectiveness and efficiency of some of their more traditional management actions toward achieving conservation targets, providing further motivation to implement adaptive management.

The large land base of the NWRS provides a unique and significant advantage for applications of adaptive management. The accumulation of knowledge to improve management can be greatly accelerated if a decision framework can be established across the units of a single refuge or across multiple refuges. Furthermore, spatial variability in management response can be observed and captured in predictive models; the information can then be usefully applied in a novel setting where management uncertainty exists.

Despite the many advantages and potential of adaptive management, there are considerable challenges to its implementation within the NWRS, and we believe these challenges are likely to be universal among national, state, provincial, and private organizations that manage large land holdings (Lee, 1993; Allan and Curtis, 2005). Refuge managers have many responsibilities and face a host of immediate demands that deter intense or long-term focus on any single project. Financial resources may be so severely limiting that managers typically cannot afford to assign personnel for adaptive management projects that involve an experimental component. Unanticipated environmental disruptions, logistical complications, or diversions of resources may cause management actions to fall outside of control guidelines, or not be implemented at all.

Traditions of the NWRS can make implementation of adaptive management difficult in some settings, particularly those in which multiple refuges face a common management problem. Refuges enjoy a high degree of autonomy to address natural resource problems, and while inter-refuge cooperation is not discouraged, it has been an uncommon management tactic. Furthermore, the Service is structured into geographic regions in which much management authority and autonomy is vested. Therefore, refuges that occur in the same ecosystem and that face similar resource management challenges may be separated by a regional boundary that creates distinct – if not competitive – environments for available resources and program priorities, making collaboration across the boundary difficult.

Misunderstandings about adaptive management among land managers can also impede its implementation. A reluctance to consider adaptive management may be rooted in a belief that adaptive management takes away a manager's decision making flexibility, or that departing from a long-established traditional management practice will compromise past management achievements. Some managers may believe that traditional management is already as effective as it can be, despite the lack of evidence in the form of data or documentation to demonstrate the claim. Other managers who hear the term 'model' may be distrustful of anything associated with it. The term 'adaptive management' is defined in various ways in the literature and it is sometimes difficult to see how it differs from trial-and-error. Therefore, those who use trial-and-error or who may be responding to a changing resource condition may contend that they are already using adaptive management (Williams et al., 2009).

Last, refuges may lack sufficient expertise needed to construct adaptive decision frameworks that conform to the constraints and logistical realities of refuge management. Many parts of the process – elicitation of objectives and decision alternatives, constructing decision models, designing effective monitoring, and linking outcomes to learning – could be facilitated by experienced managers or additional experts with skills in modeling, sample design, and human dimensions. In many instances, decision frameworks are not necessarily complicated, and indeed, a computer spreadsheet is sufficient for many applications.

3. Cooperative efforts to implement adaptive management in the NWRS

Recognizing both the great potential of adaptive management to address resource management needs within the NWRS and the opportunity to combine management and scientific expertise to establish such systems, the Service partnered with the U.S. Geological Survey (USGS) in two cooperative efforts to implement adaptive management on Service-owned lands. Both efforts were similar in that they built in a high and ongoing degree of interaction between NWRS managers and their scientific collaborators, and they strove to develop decision approaches that adhered closely to conventional practices and resource constraints of the NWRS.

The two efforts differed along lines of scale, complexity, and comprehensiveness of effort. Under the *Adaptive Management Consultancy* ("Consultancy"), the focus was on a narrowly defined resource issue contained within a single refuge or shared among a small number of refuges (Appendix 1). From both agencies and other partnering organizations, the Consultancy brought together refuge biological and management personnel, resource specialists, a programmer, a specialist in decision analysis, and a facilitator. In a 2–3 day workshop, the group developed the initial draft of a decision structure. The structure was revisited and revised in further rounds of discussion; in other words, each Consultancy was intended to initiate cycles of "rapid prototyping" (Nicolson et al., 2002). Under this effort, relatively modest Service funding was used to support workshops, and monitoring and treatment activities were designed to be sustained within the existing resources of participating refuges. Because of the narrow scope and compressed time frame for the work, the resulting decision framework was usually simple and often could be portrayed in a computer spreadsheet.

In contrast, the *Refuge Cooperative Research Program* (RCRP) was initiated to address problems larger in scope and resource investment, allowing more time and resources to be committed to developing decision frameworks (Appendix 1). Multiple-year funding provided through USGS supported the work of a team of scientists to develop an adaptive decision structure for an ecosystem-scale resource issue identified by NWRS staff. NWRS provided funding to refuges to enable participation in the design and implementation of the study. Requirements for RCRP funding included the involvement of multiple refuges in at least two Service administrative regions, necessitating cooperation across refuge and regional boundaries. RCRP funding also required inclusion of Service personnel on science teams to assure that the product would meet Service needs and priorities and would ensure program continuity by the Service at the end of the setup phase. Because of the large scale and dispersed nature of this program, projects funded under the RCRP often involved complex, spatially-referenced models and advanced methods for collecting and organizing data and for reaching optimal decisions.

Refuge participation in these efforts was voluntary, if not initiated by the refuge itself. In all cases, the refuge manager or a staff member served as the decision maker for the management problem. The decision framework provided a lens through which monitoring data were interpreted and translated into a decision action. However, actions were not mandated or "prescriptive" in any way, i.e., the manager ultimately decided the action on the basis of monitoring data or external considerations. The decision framework was designed to accommodate this decision flexibility and remain informative as long as action and monitoring protocols are followed. Ultimately, the aim of these efforts was to improve management decision making within the NWRS. As these projects move toward implementation, they will begin to provide the stream of information that will measure how well conservation goals are being reached.

4. Attributes of success

Although the Consultancy and RCRP projects are still in various phases of development, our experiences to date suggest that projects have specific attributes and employ certain heuristics that lead to success (Nicolson et al., 2002). Because the NWRS is reflective of other land management entities, we suspect that these attributes apply broadly. The attributes can be considered under the general headings of collaboration, components, and commitment.

4.1. Collaboration

Project success depends on a well-structured collaboration between team members who contribute toward all aspects of the effort. Ultimately, the project is driven by refuge information needs for informing management decisions; therefore, clear articulation by refuge staff of management objectives, decisions, and uncertainties is vital. Success also depends on identification of feasible management alternatives and potential logistical constraints to management treatments during the design phase of the project. Participating scientists work to incorporate these constraints into the adaptive management framework.

RCRP project teams generally comprise refuge personnel and scientists from USGS and other organizations (universities, NGOs, Service) who are experts in the area of management interest. Consultancies included a similar complement of expertise and backgrounds. The context of the project determines the specific roles to be taken on by team members, but we see three roles as vital to the success of any project.

The first role is a team leader (or co-leaders) from the Service who serves as a coordinator through the establishment phase and into the implementation phase of the project. The key skills of the coordinator are organization and communication. The coordinator provides project focus and overall vision for the project team and refuge cooperators. The coordinator serves as the main communication conduit among refuge cooperators and between the NWRS and USGS members of the team. The coordinator monitors all aspects of refuge participation and performance (e.g., timely and proper data collection, follow-through on treatment application, consistency of procedures), and takes the lead on resolving logistical problems that arise. The coordinator uses various means (site visits, conference calls, workshops, internet resources) to communicate and to assure procedural quality. The coordinator has a vested interest in the outcome of the project and thus is involved each step of the way from project conception to operational roll-out. In particular, the coordinator plays a critical role during the transition from design phase to implementation phase, as the decision framework is handed off to the NWRS and the project team is dissolved.

The second role is an expert in decision structuring and process modeling. This person (or team of persons) leads the collaborating group through the processes of developing the framework, eliciting management objectives and decision alternatives, designing monitoring to inform management, and formulating the models to inform decision making. This person has a clear view of what pieces are required and how they fit together in an adaptive framework, so that guidance can be given to other specialists to develop the specific technical components (e.g., database development). This role was well exemplified in the Consultancy projects, which featured productive interactions between the decision analysis expert and the programmer. While each was a specialist in his area, each could converse with the other, but most importantly, each could communicate with the stakeholder group to extract the needed elements and to ultimately lead the group toward a decision framework.

The third role is a facilitator who is familiar with the problem scope and basic tenets of structured decision making, but who is not invested in the decision or the outcome. The facilitation role is vital in short-term workshop settings, such as the Consultancy, where communication and exchange of ideas must occur in a compressed time frame. In the RCRP setting, the facilitator role can be critical during annual coordination meetings where the project team and refuge cooperators often face tactical and strategic decisions about the project.

Successful collaboration depends on inclusive and regular communication among members of the project team and between the team and cooperators. Participants in the project educate one another in a process that continues throughout the entire project: non-NWRS team members learn about the objectives, capabilities, and constraints of management, and Service personnel learn about principles of structured decision making, modeling, and monitoring design. Frequent workshops, webinars, and teleconferences provide the project team the critical input needed to structure the decision making process: objectives of management, decision alternatives, logistics of carrying out treatments and monitoring, and key uncertainties. For example, the native prairies RCRP group (Appendix 1) makes routine use of live, web-based collaboration tools to explore the behavior of models, to demonstrate data management systems, and to consider alternative expressions of the objective function. Timely communications provide feedback to project participants to maintain their interest and engagement.

A successful collaboration also depends on a common understanding of roles and responsibilities among team members and the products and services to be supplied by each cooperating agency. For example, the guidance language of the RCRP assigns responsibilities to the Service and to USGS regarding the conduct of design, management, research, data collection, reporting, and coordination tasks.

4.2. Components

The customary practices, operational constraints, management "surprises", and spatial dispersion of units that characterize the NWRS present specific challenges in developing adaptive management components, i.e., the decision framework, the prediction models, and the monitoring system. A typical challenge is the representation of treatment alternatives in the decision framework and predictive models. For example, in many management applications, there are several treatments available and many possible options for application of each (e.g., timing, duration, intensity, treatment combinations). Their permutations may yield innumerable decision alternatives that cannot all be accommodated in a decision framework. Furthermore, events that are not possible to predict, such as inclement weather or availability of labor, may prevent an action from being implemented in the way it was intended, if at all. These real circumstances are two sources of "partial controllability" (Nichols et al., 1995) that makes prediction of a planned action difficult but which the project team must nevertheless anticipate.

As mentioned, managers may share an aversion to the use of models, challenging the project team to find ways to convey their utility. In our experience, we find greater acceptance for the use of models when it is pointed out that all decision making is based on some kind of model, even if the model is simply a manager's opinion about the response to a specific action. We also make the point that even simple models are effective for decision making, particularly if a set of those models can be formulated to represent alternative 'hunches' (hypotheses) about system response to management. While a manager initially may be reluctant to have his or her thought process exposed in a model, a degree of confidence is built among all the collaborators when it becomes apparent that adaptive management provides a means for alternative views to be recognized and used to guide decision making.

Because of time and staffing constraints, time-intensive activities such as monitoring and data management are likely to be the primary limiting factors in terms of new tasks that a refuge can undertake for participating in an adaptive management project. Therefore, a common challenge for the project team is to design a monitoring program that is informative for assessing progress towards the management objective, evaluating model performance, and portraying current state of the system, yet is efficient and simple to conduct. Implicit in the design is a trade-off between inference strength of the monitoring program (which is determined by resources available for monitoring) and rate of improvement in management performance (i.e., learning). The project team may also consider the design of an intuitive interface for rapid data entry, with capabilities to catch errors and generate simple reports.

If decision making is distributed among multiple refuges, the project team may design a central data processing mechanism to manage the assembly of monitoring data, the update of the predictive models, and the distribution of information back to cooperating units in the form of revised decision guidance. For example, data obtained from cooperators could be uploaded to a central database, where they are used to assess decision models. Updated decision tables or other forms of decision guidance could then be posted on a central site accessible to cooperators. A commercial web-based collaboration tool is used by the reed canary grass RCRP project team (Appendix 1) primarily for communication among different sets of team members (science team, Service coordinators, cooperators), but it is also used to upload monitoring data from cooperators and to distribute field protocols and instructions. Project cooperators have found the system intuitive and easy to use, and other RCRP and Consultancy teams have begun using similar tools to manage data exchange in a dispersed system.

The interacting dynamics of the resource, its measurement, and its management may require considerable effort by the project team to design the iterative scheme of decision, action, and monitoring. For example, time windows for treatment application and monitoring may overlap, phenological differences among refuges may complicate the scheduling of actions, and certain actions (e.g., prescribed burning, seeding) may require substantial planning between the time that the decision is made and the action is implemented. These situations present challenges to the planning of a "just-in-time" decision process (Conteh and Forgionne, 2003), where data from monitoring arrive just in time to inform the next decision, and where each action can be "pulled off the shelf" and readily implemented. Building the decision structure in such a context almost certainly requires simplifying assumptions be made in the model and negotiation with managers for consensus on timing protocols. These discussions may result in a delicate but tight choreography of actions, responsibilities, and products that defines the decision cycle.

Because adaptive management is a process defined over long, indeterminate time frames, a plan for project documentation ensures that actions, outcomes, and project modifications are recorded and that the project is easily communicated to new cooperators and survives staff turnover. Such documentation would include templates or protocols that describe in sufficient detail all procedural elements of the decision cycle; i.e., the timetable of actions, responsibilities of each project participant, how data are to be collected and managed, how treatments are to be implemented, contingencies, etc. The body of documentation would also include the scientific reports and publications that describe the models, monitoring design, knowledge updating approaches, and other elements designed in the project setup phase.

4.3. Commitment

Adaptive management is a difficult process to sustain in program environments that operate in budgetary and priority-setting horizons of 2–3 years. For this reason, adaptive management may be feasible only for resource decision problems that are most pressing, for example, decisions characterized by greatest uncertainty, controversy, highest risk of resource loss, or potential to affect a refuge's focal species or ecosystem. Here, commitment of time and resources are most convincingly demonstrated, and the requisite long-term commitment to the process at the station, coordinator, and administrative levels may be more likely to obtain.

A focus on high-priority management issues is key to ensuring station commitment. When the issue is of high importance to a refuge, managers are more willing to alter routine management actions, to follow defined protocols, and to devote time toward collaboration with scientists and other managers. When multiple refuges are involved in a project that addresses a high-priority issue, the successful pursuit of better management practices relies on a tight interdependency of refuges. Understanding this, managers then act in their own best interests and in the interests of their cooperating peers by following through with their commitments and adhering to established protocols. The endpoint of adaptive management is defined relative to the time frame for response by the resource being managed, which may range from only a few years for some ecosystems to potentially decades for others. However, even if uncertainties are resolved over time so that "adaptation" of management formally ends, resource decision making will certainly continue, and there may remain a role for monitoring to inform decision making based on current resource state.

As described above, the involvement of a Service project coordinator from inception through implementation is a characteristic of effective projects. In light of current workloads on Service biologists, coordination may only be possible through a reassignment of duties. Because work progress vitally depends on information sharing, managing cooperator commitment, and ceaseless vigilance of the process, effective projects will have actively involved coordinators and cooperators, rather than ones who observe passively.

Such sustained commitments of time are possible only through support at the upper levels of administration. Of course, administrators have no desire to commit to an endless endeavor of experimentation and data collection, which is how adaptive management is sometimes perceived. Commitment is easier to secure when the purpose of adaptive management – transparent decision support that improves decision making through time – is demonstrated to cooperators and program administrators alike.

5. Moving forward with adaptive management in the NWRS

Because the Consultancy and RCRP efforts involve a collaboration and sharing of resources between the Service and USGS, both agencies have a vested interest in the ultimate outcome of these efforts; namely, a clear process for making defensible decisions and for using science to improve management through time. Furthermore, because adaptive management is a process defined over time, the commitment of resources by an agency over any project development time frame – whether 3 days or 3 years – is an implicit expression of confidence that the process can be institutionally supported beyond the development endpoint. However, inadequate institutional support is a widely acknowledged cause of adaptive management failures (Schreiber et al., 2004; Gregory et al., 2006). Therefore, because investments in project development cannot be considered apart from the institutional capacity to carry them forward, we offer general program suggestions for the partnering agencies.

First, we suggest the formation of a biological team within the NWRS to provide design and logistical support for adaptive management projects within the system and to assist refuge biologists in their coordination. When a new project is conceived, a team member is placed on the development team, assuring that the project receives Service guidance and input from inception through implementation. As no adaptive management project is likely to require full-time attention, a team member's support could be distributed over multiple projects. Team members would assume (or assist a refuge biologist in) all the coordination responsibilities outlined above; including meeting regularly with the development team; organizing meetings of cooperators; overseeing monitoring, decision action, and data management efforts; and updating and distributing the decision support information to cooperators. At least two models analogous to an adaptive management support team exist within the Service, and both occur within the Division of Migratory Bird Management: the Branch of Population and Habitat Assessment and the Habitat and Population Evaluation Team.

Second, concurrent with the formation of a team to support adaptive management projects, we suggest the NWRS increase its capacity to design and implement structured decision making efforts in general and adaptive management in particular. This could be accomplished through training in a range of technical areas, including decision modeling, monitoring design, statistical analysis, database development, GIS, optimization, and human dimensions, either through the Service's National Conservation Training Center or through outside means. In this regard, USGS could provide incentives (promotion or award-based) for its scientists to engage in the provision of training, in both workshop and classroom settings. Capacity building can also be accomplished through the hiring of biologists with these technical backgrounds. While there will always be need to seek science expertise outside of the Service to address specific needs, much of the structuring of adaptive management follows a technical blueprint that can be learned and adopted by NWRS personnel.

Third, we see tremendous value in the continuation of support for collaborative work between the NWRS and USGS for the development of adaptive management projects. Both partners receive great benefit from the collaboration: NWRS biologists and managers gain experience in the process of structured decision making and build technical capacity, and USGS scientists are challenged to provide science that directly supports management in the form of tools that acknowledge real system complexities and constraints. Most importantly, though, we believe that the collaboration may more effectively achieve conservation delivery than traditional approaches which separate the research and management enterprises.

6. Conclusions

Adaptive management is a structured process for making recurrent decisions that offers great potential for achieving conservation outcomes in the face of daunting biological uncertainty. In many ways, the National Wildlife Refuge System is ideally situated to exploit the principles of adaptive management to carry out its mission. However, implementation of adaptive management is difficult without attention given to three key attributes: a vigorous multi-partner collaboration, practical and informative decision framework components, and a sustained commitment to the process. By building certain institutional and technical capacities and sustaining its collaborations with science partners such as the USGS, the NWRS can be better poised to apply the principles of adaptive management as part of its science-based approach to reach habitat conservation goals.

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Appendix 1

National Wildlife Refuge System[1] management projects addressed under the Adaptive Management Consultancy and the Refuge Cooperative Research Program.

Adaptive Management Consultancy

Restoring native plant diversity in native grasslands

An interagency working group is evaluating alternative management practices and designing monitoring tools to restore and maintain high quality native grasslands in Minnesota. This project guides decision making about application of disturbance treatments (fire, grazing, haying) while uncertainties about their use and temporal patterns of application are being resolved.

- Two stations and non-federal partners in Service Region 3 (MN)

Managing temporary wetlands for waterfowl

Temporary wetlands lose their habitat value for waterfowl if they become choked with vegetation; however, managers are uncertain whether small wetlands can be managed to improve their value for breeding waterfowl. This project evaluates waterfowl use among several low-cost practices designed to alter the habitat structure.

- Five stations in Service Region 3 (MN and WI)

Fire as a management tool in coastal salt marshes

Salt marshes at Blackwater National Wildlife Refuge in Maryland have been managed with fire for decades, but managers are uncertain about the effect of fire on the ecological community and what frequency of fire maximizes salt marsh stability. This project evaluates the effects of different burn frequencies on vegetation, amount of open water, and marsh elevation.

- Blackwater NWR and adjacent public lands in Service Region 5 (MD)

Habitat management on coastal islands for nesting seabirds

Island units of the Maine Coastal Islands NWR have been under various forms of intensive management for many years. Managers are uncertain which habitat management practices are most effective in supporting seabird nesting. This project guides decision making for habitat management under these uncertainties, with knowledge gained applied to other units not currently managed.

- Maine Coastal Islands NWR and adjacent partner units in Service Region 5 (ME)

Restoration of native shrublands for migrating landbirds and New England cottontail rabbit

Invasive shrubs complicate efforts to restore and maintain native shrub communities in the northeast U.S., which provide important habitat for the New England cottontail rabbit and for fall migrating landbirds. Managers are uncertain about which restoration practices are most cost-effective for restoring northeastern U.S. native shrub habitats.

- Four stations in Service Region 5 (ME, MA, RI)

Use of sediment excavation in wetland restorations

A set of customary practices for restoring small wetlands are in place. However, some evidence indicates that removing sediment from a basin, although costly, greatly increases quality of the restored wetland. This project evaluates alternative restoration approaches in the face of uncertainty about the trade-off between cost and outcome.

- Two stations and private lands in Service Region 3 (MN)

Impact of sea-level rise on coastal wetland impoundment management decisions

Freshwater impoundments on some eastern U.S. coastal refuges support a diversity of wildlife, but they require expensive maintenance. Uncertainties about the rate of sea-level rise and about the nature of the replacement biological community confront the manager who must choose at each decision cycle whether an impoundment should be maintained or abandoned to return to a natural salt marsh community. This project guides recurrent decision making under these uncertainties, where a decision made to abandon an impoundment is followed by a decision about the type of approach taken to restore the natural community.

- Six stations in Service Region 5

Refuge Cooperative Research Program

Management of native prairies in the northern Great Plains

Service-owned native prairies in the northern Great Plains have become invaded to varying degrees by introduced grasses and woody vegetation over decades of management that de-emphasized vegetation disturbance. Reintroduction of forms of defoliation disturbance is now desired, but managers are uncertain about what disturbance treatments to apply and in what manner to achieve desired states of native grass and forb composition at least cost. This project will provide a decision tool for making recurrent habitat management decisions under uncertainty about response.

- Over 100 management units on 19 stations in Service Regions 3 and 6

An ecological integrity index for coastal salt marshes

Salt marsh ecosystems on NWRS lands face threats to integrity from local to global scales, and managers are challenged with making habitat decisions under uncertainty to restore and maintain system integrity. This project focuses on the development of tools for monitoring the ecological integrity of salt marshes that are effective across a range of scales, responsive to a hierarchy of threats, and are informative about effects of management.

- 11 stations in Service Regions 1 and 5

Impoundment management to support migratory waterbird use

Impoundments on Service-owned lands in the U.S. northeast and midwest provide important stopover habitat for migratory waterbirds (shorebirds, wading birds, waterfowl). Managers may manipulate impoundment levels and drawdown schedules for benefit of migratory birds, but bird use response is uncertain, as are the trade-offs of these actions among the vegetation, invertebrate, and bird communities. This management study evaluates seasonal timing and across-year effects of alternative impoundment drawdown strategies on migratory waterbird use.

- 22 stations in Service Regions 3 and 5

Cattail control through prescribed fire

Cattail growth on emergent wetlands is a concern on some Service-owned lands in the U.S. northeast and midwest. The use of fire in wetland management is common, but managers are uncertain about parameters of its use and its interactions with biotic and abiotic conditions of the site. The objective of this management study is to provide information that will improve fire planning and will lead to the development of models and monitoring protocols as part of an adaptive decision support system for control of cattail.

- Five stations in Service Regions 3 and 5

(*continued on next page*)

Appendix 1 (*continued*)

Reed canary grass control and transition to wetland forests and meadows

Native wet forests and meadows on many Service-owned lands in the northcentral U.S. are invaded to varying degrees by reed canary grass (*Phalaris arundinacea*). Decision making for its control and eventual replacement by native communities is difficult because managers are uncertain about relative effectiveness of alternative treatments and ability of the species to outcompete re-establishing native vegetation. The objective of this project is to create a tool to support recurrent decision making about control of reed canary grass and revegetation efforts under these biological uncertainties.

- Nine stations in Service Regions 3 and 6

Implications of climate variability for optimal monitoring and adaptive management in wetland systems

The implications of climate change on wetland habitats and on the waterfowl and shorebirds that depend on them are unknown, but adaptive approaches will be increasingly used to learn about managed system behavior in the face of uncertainty. However, climate variability over the typical temporal and spatial scales at which management and monitoring is conducted can obscure learning. This project seeks to assess this variability and discover spatial and temporal scales of monitoring effort that are efficient yet informative under expected climate variability.

- Stations in Service Regions 6 and 7

[1] Service regions: (1) Pacific, (2) Southwest, (3) Great Lakes - Big Rivers, (4) Southeast, (5) Northeast, (6) Mountain-Prairie, (7) Alaska, (8) Pacific Southwest.

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