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Ecosystems, Adaptive Management

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Article Outline

Glossary

Adaptive governance Institutional and political frameworks designed to adapt to changing relationships between society and ecosystems, institutional frameworks that enable adaptive management, and the facilitation of learning from adaptive management to policy.

Adaptive management A systematic process of natural resource management whereby management actions are treated as experiments to increase learning and improve subsequent management.

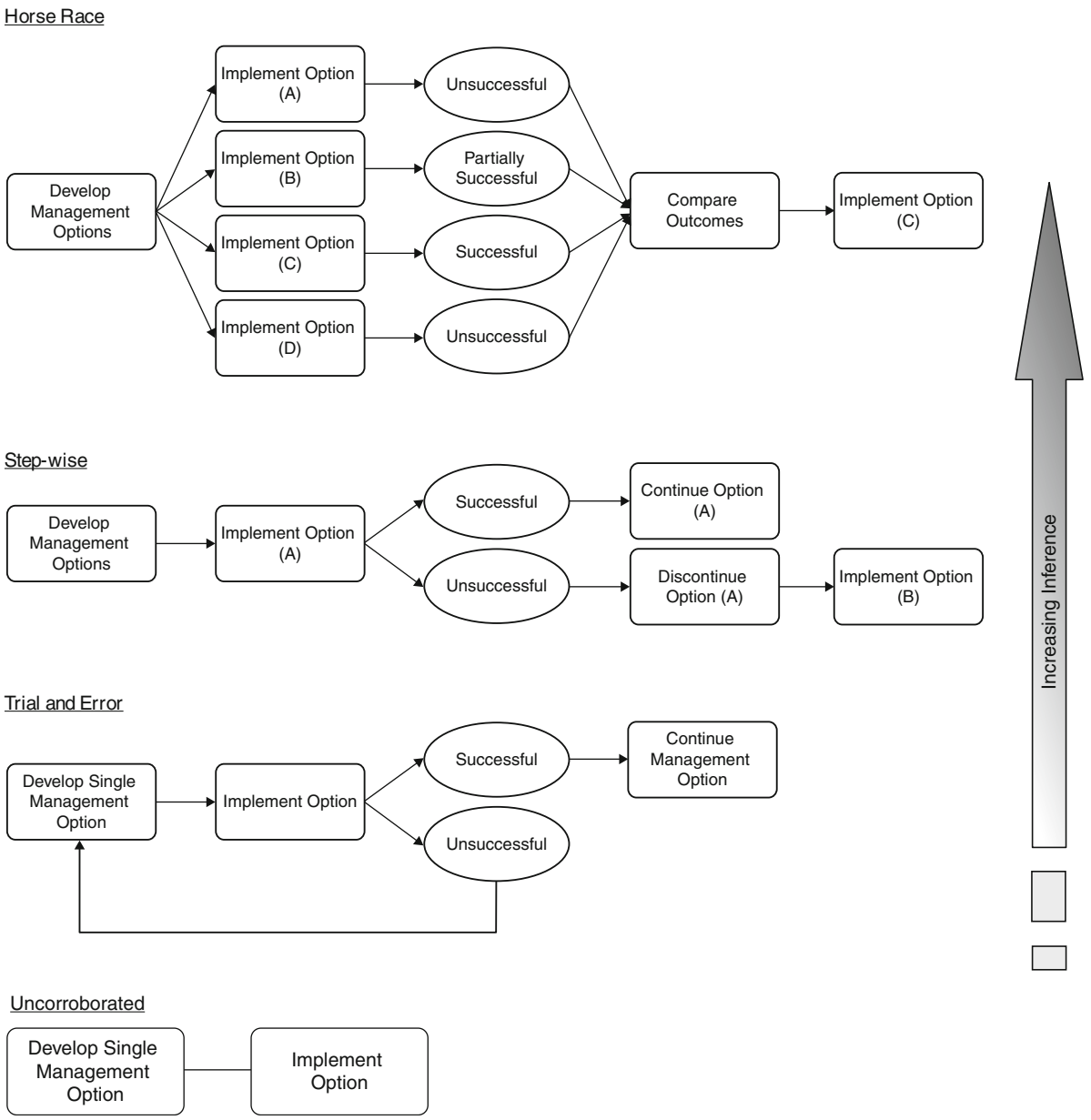
Natural resource management The management of natural resources including land, water, plants, and animals to meet societal goals, including conservation and exploitation.

Resilience The capacity of a system to absorb disturbance without altering states (undergoing a regime shift); a measure of the amount of disturbance a system can tolerate before collapsing.

Structured decision making A general term for a framework of analysis of problems to reach decisions based on evidence to meet stated goals.

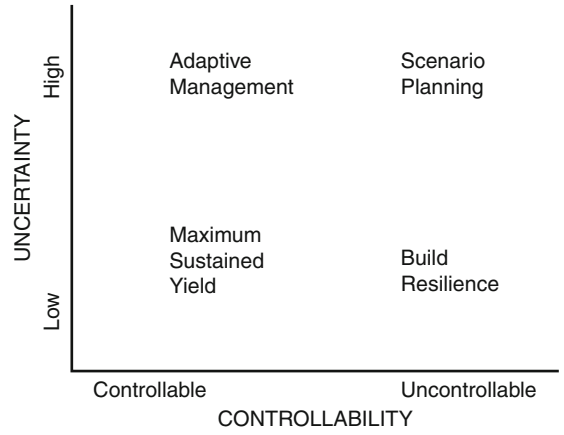
Definition of Adaptive Management

Adaptive management is an approach to natural resource management that emphasizes learning through management based upon the philosophy that knowledge is incomplete and much of what is thought to be known is actually wrong, but despite uncertainty, managers and policymakers must act [1]. Although the concept of adaptive management has resonated with resource management scientists and practitioners following its formal introduction in 1978 [2], it has and continues to remain little practiced and much misunderstood. Misunderstanding is largely based upon the belief that adaptive management is what management has always been, a trial and error attempt to improve management outcomes. But unlike a trial and error approach, adaptive management has explicit structure, including a careful elucidation of goals, identification of alternative management objectives and hypotheses of causation, and procedures for the collection of data followed by evaluation and reiteration. Since its initial introduction and description, adaptive management has been hailed as a solution to endless trial and error approaches to complex natural resource management challenges and recently, it has become increasingly referenced under various forms (please refer to following sections) (Fig. 1). Regardless of the particular definition of adaptive management used, and there are many, adaptive management emphasizes learning and subsequent adaptation of management based upon that learning. The process is iterative, and



Ecosystems, Adaptive Management. Figure 1
Generalization of the different approaches to natural resource management

serves to reduce uncertainty, build knowledge, and improve management over time in a goal-oriented and structured process. However, adaptive management is not a panacea for the navigation of "wicked problems" [3, 4] as it does not produce easy answers, and is appropriate in only a subset of natural resource management problems where both uncertainty and controllability are high (Fig. 2) [5]. Where uncertainty is high but controllability is low, scenarios are a more appropriate approach. Adaptive management is a poor fit for solving problems of intricate complexity, high external influences, long time spans, high structural uncertainty, and with low confidence in assessments [5] (e.g., climate change). However, even in such



Ecosystems, Adaptive Management. Figure 2
Adaptive management and scenarios are complementary approaches to understanding complex systems. Adaptive management functions best when both uncertainty and controllability are high, which means the potential for learning is high, and the system can be manipulated (Adapted from [60])

situations, adaptive management may be the preferred alternative, and can be utilized to resolve or reduce structural uncertainty.

Clearly, adaptive management has matured, but it has also reached a crossroads. Its application is now common to a variety of complex resource management issues, and while practitioners and scientists have developed adaptive management and structured decision-making techniques, and mathematicians have developed approaches to reducing the uncertainties encountered in resource management, there continues to be misapplication of the method, and misunderstanding of its purpose.

Introduction

Adaptive management of natural resources did not spontaneously appear, but represents an evolving approach to natural resource management in particular, and structured decision making in general. Founded in the decision approaches of other fields [6] including business [7], experimental science [8], systems theory [9], and industrial ecology [10], the first reference to adaptive management philosophies in natural resource management may be traced back to Beverton and Holt [11] in fisheries management, though the term "adaptive management" was yet to be used (reviewed in [6]). The term "adaptive management" would not become a common vernacular until C.S. Holling, widely recognized as the "father" of adaptive management, produced his edited volume on the subject "Adaptive Environmental Assessment and Management" in 1978 [2]. The work was spawned by the experiences of Holling and colleagues at the University of British Columbia following from the development of resilience theory [12]. The concept of resilience, predicated upon the existence of more than one alternative stable state for ecosystems, had several ramifications. For one, it meant that managers should be very careful not to exceed a threshold that might change the state of the system being managed, and the location of those thresholds is unknown. Second, for ecological systems in a favorable state, management should focus on maintaining that state, and its resilience. Adaptive management, then, was a method to probe the dynamics and resilience of systems while continuing with "management," whereby management experiments were developed to enhance learning and reduce uncertainty, in a fail-safe manner. According to Holling (http://www.resalliance.org/2561.php):

- The resilience research led us to mobilize a series of studies of large scale ecosystems subject to management- terrestrial, fresh water and marine. All this was done with the key scientists and, in some cases, policy people who "owned" the systems and the data. So the process encouraged two major advances. One advance developed a sequence of workshop techniques so that we could work with experts to develop alternative explanatory models and suggestive policies. We learned an immense amount from the first experiment. That focused on the beautiful Gulf Islands, an archipelago off the coast of Vancouver. We chose to develop a recreational land simulation of recreational property. I knew little about speculation, but we made up a marvelous scheme that used the predation equations as the foundation- the land of various classes were the "prey," speculators were the "predators" and a highest bidder auction cleared the market each year. The equations were modifications of the general predation equations. The predictions were astonishingly effective and persisted so for at least a decade. As much as anything, it reinforced the earlier conclusion that

these equations were powerful and general. But the important conclusion concerned the workshop process and the people.

Eventually Carl Walters [1] built upon Holling's foundational contribution [12] and further developed the ideas, especially in the realm of mathematical modeling. Whereas Holling's original emphasis was in bridging the gap between science and practice, Walters emphasized treating management activities as designed experiments meant to reduce uncertainty. Both scientists sought an approach that allowed resource management and exploitation to continue while explicitly embracing uncertainties and seeking to reduce them through management. Walters [1] described the process of adaptive management as beginning "with the central tenet that management involves a continual learning process that cannot conveniently be separated into functions like research and ongoing regulatory activities, and probably never converges to a state of blissful equilibrium involving full knowledge and optimum productivity." He characterized adaptive management as the process of defining and bounding the management problem, identifying and representing what is known through models of dynamics that identify assumptions and predictions so experience can further learning, identifying possible sources of uncertainty and identifying alternate hypotheses, and finally the design of policies to allow continued resource management or production while enhancing learning.

A key focus of adaptive management is the identification and reduction, where possible, of uncertainty. Uncertainty is reduced through management experiments which enhance learning. Williams [6] describes four critical sources of uncertainty:

1. *Environmental variation* is often the most common source of uncertainty, and is largely uncontrollable. It may have a dominating influence on natural resource systems, through such factors as random variability in climate.
2. *Partial observability* refers to uncertainty about resource status. An example of this is the sampling variation that arises in resource monitoring.
3. *Partial controllability* arises when indirect means (e.g., regulations) are used to implement an action (e.g., setting a harvest rate), and it can lead to the misrepresentation of management interventions and thus to an inadequate accounting of their influence on resource behavior.
4. *Structural or process uncertainty* arises from a lack of understanding or agreement regarding the structure of biological and ecological relationships that drive resource dynamics.

Adaptive Management Today

Adaptive management has been referenced either implicitly [11] or explicitly [2, 13] for more than 50 years, but despite an illustrious theoretical history, there has remained imperfect realization of adaptive management in real world natural resource management decisions. The limited implementation of adaptive management stems from three fundamental problems: (1) a lack of clarity in definition and approach, (2) a paucity of success stories upon which to build [14–18], and (3) management, policy, and funding paradigms that favor reactive rather than proactive approaches to natural resource management [19, 20]. Each of these challenges has slowed the development of adaptive management as a paradigm for natural resource management and resulted in incomplete, inefficient, and even inappropriate implementation of adaptive management.

Although semantic arguments may seem the realm of ivory-towered professors, inconsistent and even contradictory approaches and definitions of adaptive management have resulted in confusion and limited the ability of management organizations to develop consistent and repeatable comprehensive adaptive management programs. Ironically, the confusion over the term "adaptive management" may stem from the flexibility inherent in the approach which has resulted in multiple interpretations of "adaptive management" that fall upon a continuum of complexity and *a priori* design, starting from the simple (e.g., "learning by doing") and progressing to the more explicit (e.g., "a rigorous process that should include sound planning and experimental design with a systematic evaluation process that links monitoring to management") [2, 21, 22]. Obviously, there is a clear distinction in intent, investment, and success between approaches that propose to learn from prior management decisions and those that outline a concise feedback mechanism dependent upon sound scientific principles on which

future management decisions will be made. The definition of "adaptive management" is further confused because one of the powerful attributes of adaptive management is the ability to simultaneously address multiple needs of managers, scientists, and stakeholders. The result has been published reports of adaptive management that emphasize definitions that focus on the needs of the authors and the ability of adaptive management to meet those needs (e.g., experimentation [14], uncertainty [23], changing management actions [24], monitoring [25], and stakeholder involvement [26]).

Despite the challenges in defining adaptive management, momentum and interest in the subject and its application continue to grow. The recent development by the United States Department of Interior of an adaptive management technical guide (http://www.doi.gov/initiatives/AdaptiveManagement/TechGuide.pdf) and the policies developed around this manual to:

- Incorporate adaptive management principles, as appropriate, into policies, plans, guidance, agreements, and other instruments for the management of resources under the Department's jurisdiction. – Department of Interior Manual (522 DM 1)

are an indication of the growing movement in natural resource management toward taking a more proactive role in management decisions. Unfortunately, this movement has little to build upon with one clear exception, the U.S. Fish and Wildlife Service (USFWS) Adaptive Harvest Management Plan (AHM) for mid-continent mallards. Worldwide, AHM is one of the few successful efforts to apply the principles of adaptive management and demonstrate how to successfully manage natural resources by improving the understanding of natural systems through management actions. The adaptive management processes of AHM have greatly improved the understanding of the harvest potential of waterfowl populations, the ability of managers to regulate harvest, and the importance of monitoring and assessment programs to support the decision-making process.

So why has AHM succeeded while so many other attempts to implement adaptive management have stalled? First, AHM developed a clear and concise objective: maximize long-term waterfowl harvest while ensuring long-term viability of waterfowl populations. The development and agreement by stakeholders to a concise set of fundamental objectives is paramount to ensuring the success of any adaptive management program. Failure to agree upon fundamental objectives and unwarranted attempts to alter objectives will ensure any attempt to manage, whether adaptive or not, will fail. The second key to the AHM success was due to simultaneous support for management, research, and monitoring. Waterfowl research and management in North America are nearly unequaled by almost any natural resource management program in terms of history, scope, and investment [27]. The enormity of historical and current data and the availability of resources for researchers and managers to utilize that data have facilitated the development of innumerable research and management activities all of which have fed back into the AHM process. In addition, the AHM program has arguably one of the most comprehensive monitoring programs for any ecological system currently under study. The combination of well-supported management, research, and monitoring programs has resulted in a clear reduction in the uncertainty of how waterfowl populations respond to management and enabled managers and policy makers to more effectively meet their stated objectives. Unfortunately, too often, attempts to implement adaptive management fail to address all of the requirements. In particular, resources for monitoring and research are often undervalued with the resultant outcome being a series of management actions with no understanding of their implications.

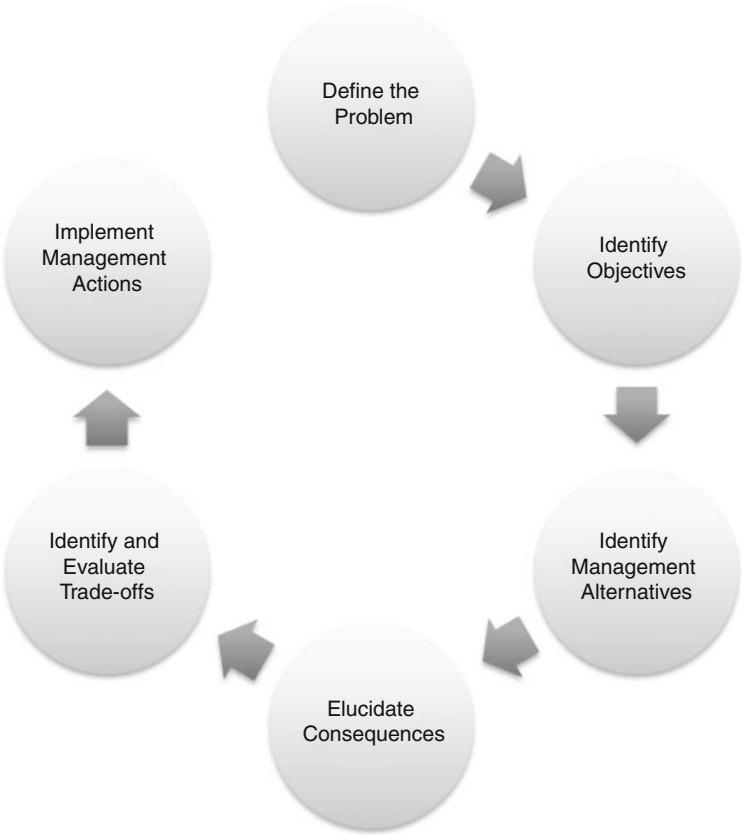
The final key to the success of AHM has been the ability to implement management and policy decisions based on the best information available. In many historical and current attempts to implement adaptive management, the regulatory body charged with implementation of management recommendations either is unable, or worse, is unwilling to implement actions proposed by the outcome of the adaptive management process. The body in charge of regulatory control is too often a stakeholder in the process of adaptive management with an agenda independent of regulating the resource alone. There may even be, and often are, several regulatory agencies controlling resources, each an independent stakeholder, each with an independent agenda. Such a situation can make implementation of a management

recommendation challenging, especially if it contradicts long-standing dogma. Consider for example, the management of Glen Canyon Dam and the waters of the Colorado River. Heralded by Congress as an adaptive management success story, the Colorado River Adaptive Management Program has fallen short of success because despite 13 years of work, the ecological status of the Colorado River and the conflict inherent to the development of an adaptive management program continue to worsen [28]. This is because the regulatory agency that controls the flow of water throughout the Colorado River Basin, the Bureau of Reclamation, is also one of the major stakeholders in the adaptive management process with an agenda (water storage) that conflicts with several other stakeholders and regulatory agencies that manage people and wildlife along the Colorado River (e.g., California Department of Water Resources, Mexican National Water Commission, USFWS). In contrast to the management of the Colorado River, there is a single centralized regulatory body governing waterfowl harvest in the United States (USFWS), and although there are many stakeholders that play a role in setting harvest management regulations, ultimately, decisions are made by the USFWS. Equally important, the interests of the USFWS parallel those of the other stakeholders. For the Colorado River, stakeholder interests are almost directly at odds. So from these examples is one to conclude that adaptive management is an unattainable mandate for the management of resources where various stakeholders and regulators are at odds? No, implementation of adaptive management is appropriate in both examples, possibly even more so for the management of the Colorado River. What the Colorado River example highlights is the importance of collaboration, the benefits of a single or superregulatory body, and the need to agree upon *a priori* objectives that guide long-term management decisions despite short-term political, societal, economic, or even environmental impacts.

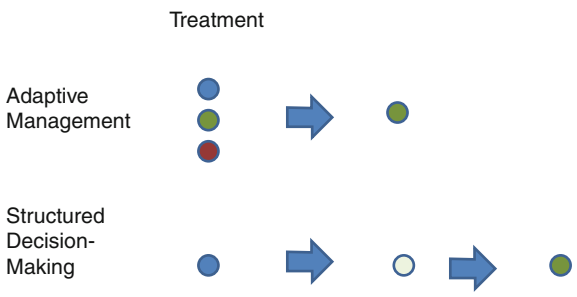
Structured Decision Making

A key component of any management approach, whether it is adaptive or not, is deciding on the objectives, goals, and ultimately management options that may best achieve the desired goals (Fig. 3). Unfortunately, as with many decisions, deciding upon a proper set of objectives and the means to reach those objectives can prove challenging. Resource management decisions are further complicated because social-ecological systems are complex (e.g., multiple objectives and stakeholders, overlapping jurisdictions, short- and long-term effects) and are characterized by a high degree of uncertainty (e.g., appropriate management action or monitoring protocols, future economic or ecological conditions) and therefore present decision makers with challenging judgments (e.g., predicted consequences of proposed alternatives, value-based judgments about priorities, preferences, and risk tolerances) often under enormous pressure (economic, environmental, social, and political) and with limited resources to ensure success. The resulting outcome of such conditions too often leads to management paralysis, or continuation of the status quo, as managers and policy makers become overwhelmed by the process of the decision and lose track of the desired social-ecological conditions they are charged with achieving. Indeed, the process of resource management can be arduous and even controversial, particularly if there are a variety of stakeholders vying to push the agenda. Fortunately, there are methods to overcome these pitfalls and maximize the potential for success.

One method to overcome management paralysis and mediate multiple stakeholder interests is structured decision making. Borrowed from the sociological fields, structured decision making is an organized approach to identify and evaluate alternative resource management options by engaging stakeholders, experts, and decision makers in the decision process and addressing the complexity and uncertainty inherent in resource management in a proactive and transparent manner. Structured decision making uses a simple set of steps (Fig. 3) to evaluate a problem and integrate planning, analysis, and management into a transparent process that provides a roadmap focused on achieving the fundamental objectives of the program. It differs somewhat from "active" adaptive management in that it does not emphasize replicated management experiments (Fig. 4). Central to the success of the structured decision making process is the requirement to clearly articulate fundamental objectives, explicitly acknowledge uncertainty, and respond



Ecosystems, Adaptive Management. Figure 3
The minimum steps necessary to implement a structured decision-making process: More complex integration of individual steps may be necessary if future steps clarify the process or if the decision is iterative over time



Ecosystems, Adaptive Management. Figure 4
Structured decision making and adaptive management differ somewhat, especially in that active adaptive management emphasizes the utilization of multiple replicated management experiments. As such, learning may be faster when such experiments are possible. However, adaptive management and structured decision making are terms often used interchangeably

transparently to all stakeholders' interests in the decision process. The conceptual simplicity inherent in structured decision making makes the process useful for all decisions from minor decisions to complex problems involving multiple stakeholders.

Structured Decision Making Steps

1. *Define the Problem* – The first step in a structured decision making process is a clear and concise evaluation and articulation of the problem being addressed and the motivation underlying the need to address the problem. Although identifying the problem may seem self-evident, failure to clearly articulate the problem to all stakeholders and subsequent agreement by stakeholders as to the nature of the problem is often cited as the primary reason management and policy actions fail, or worse, face

future litigation. To facilitate this process, decision makers need to ask:

(a) What specific decision(s) have to be made?
(b) What is scope of the decision (e.g., geographic, temporal)?
(c) Will the decision be iterated over time?
(d) What are the constraints within which the decision will be made (e.g., logistical, ecological, legal, temporal, financial)?
(e) What stakeholders should be involved in the decision process and what are their respective roles?

2. *Identify the Objectives* – The centerpiece of the structured decision making process is a set of clearly elucidated objectives. Together they define the "why do we care" about the decision and thereby facilitate the search for alternatives, and become the metric for comparing and evaluating management outcomes. When defining objectives, there are many considerations to ensure that decision makers can adequately evaluate alternatives. Ideally, objectives are stated in quantitative terms that relate to parameters that can be measured and thus evaluated. More importantly, objectives are meant to focus efforts on the importance of the decision in a consistent and transparent manner that exposes key trade-offs and uncertainties so decision makers can generate creative and proactive alternatives. Objectives should be complete, controllable, concise, measurable, and understandable [29]. To achieve this end requires "brainstorming" with stakeholders to identify what is important about the decision at hand. The outcome of such an effort may produce a wide variety and often extensive list of objectives that will need to be simplified to focus on things that matter and the direction they need to move (e.g., maximize deer harvest or minimize erosion). It is important to note, that unlike goals or targets, objectives do not have specific quantitative outcomes (e.g., 50% increase), but are meant to define the preferred ends and the direction of change to meet that ends.

   Once a list of objectives has been defined, it is important to separate the objectives into fundamental objectives (which reflect the ultimate goals) and means objectives (which are ways of achieving the ends) to ensure that management actions really effect the defined problem. For example, "maximize sandbars" may be an important objective for the management of a river like the Missouri or Platte, but if the river system is being managed for wildlife, sandbars are primarily important because they increase breeding habitat for threatened and endangered terns and plovers. "Maximize sandbars" is thus a means objective toward reaching the fundamental objective of "maximize tern and plover population size." Clearly, there are other means objectives that would also facilitate this fundamental objective (e.g., minimize nest predation, maximized food availability, etc.). The benefit of the process of distinguishing objectives is that the identification of means objectives can help lead to alternative management actions (e.g., build sandbars, release reservoir water), while the identification of fundamental objectives gives a basis for evaluating and comparing alternatives (annual tern and plover population size). Keep in mind, however, that the status of fundamental or means is not an innate quality of an objective, but rather is highly context dependent. Thus, what was a means objective for one decision, in the example "maximize sandbars," may be a fundamental objective for another if the decision problems shifts from say "wildlife management" to "aesthetics" or "flow."

   After developing a careful list of objectives, it can be useful to develop a hierarchy or means-ends diagram to group similar objectives and clarify the links and relationships between means and fundamental objectives. An objectives hierarchy can help clarify the context of each fundamental objective by identifying all the important elements that are affected by the decision process and demonstrate to stakeholders the importance of all objectives even those that are not "fundamental objectives."

3. *Identify Management Alternatives* – Management success is only as likely as the creativity and diversity of possible management alternatives. Unfortunately, management paralysis, "pet" management actions, and staying with the status quo too often limit managers and policy makers to few options and thereby impede management success. The process of identifying management alternatives, like the process of identifying objectives, starts with

brainstorming. Identifying alternative management actions is a process that should be addressed iteratively, as knowledge of best practices and the creativity to develop novel ideas should not be expected to develop instantaneously. The key is bringing the "right" people together. It is important to have a group with a set of interdisciplinary backgrounds that represent the larger decision to ensure that the needs of stakeholders are not overlooked. This is not to say that the stakeholders involved in identifying alternative management actions are the same as the larger stakeholder group, usually they are not. This is primarily due to the technical knowledge necessary to present plausible alternatives. Still there are opportunities where the benefit of being naive may present novel actions that might not otherwise be considered.

The brainstorming process should begin by identifying alternatives for individual objectives, but always be looking for opportunities when one action may fulfill the needs of multiple objectives. Identifying alternatives also means being mindful of those actions that must be done (e.g., standing policy), constraints (real or perceived) and potential trade-offs between objectives and various management actions. In developing alternatives, it is important that the "brainstorming" process focus on developing high-quality management actions that are: (1) explicitly designed to address the outlined objectives, (2) technically sound in that they build on the best known practices, (3) concise yet comprehensive enough to include the technical understanding for implementation, (4) designed to expose trade-offs between the decision process by having mutually exclusive strategies, and (5) developed to achieve the greatest good for the stakeholders involved.

Once an extensive list of alternatives has been identified, it can be useful to group them into strategies or portfolios based on general similarities in what they aim to achieve. Sometimes these portfolios can represent the needs of specific stakeholder groups or specific conditions that could be achieved. For example, management actions on a river system may be grouped together into portfolios that meet the needs of sport-fishery, endangered species, or irrigation; alternatively, they may be grouped based on their ability to return the river to 50%, 75%, or 95% of historical flows. Both methods have merit, the first in that it is generally clear to the stakeholders what objectives are being met and then where trade-offs must be considered, and the second in that the inherent interests of any particular group are not the driving factor and thus the process can be less contentious.

4. *Elucidate Consequences* – The list of alternative management actions is only effective if it creates an opportunity to evaluate and compare actions in light of the objectives before implementation. It is important to realize that the process of identifying management consequences is not a value judgment, but an analytical assessment of the most likely outcome of the action(s). Using the best scientific knowledge available, this process is a modeling exercise focused on predicting the likely outcomes of each alternative and thus the likelihood that each achieves the desired objective. Depending upon our knowledge of the system, this process can be highly quantitative where extensive data are modeled and probabilities assigned to each outcome or as is often the case, if little or nothing is known about the system, this process can depend heavily on expert opinion or comparisons to similar systems. In both cases, there is a degree of uncertainty associated with predicted outcomes as well as the parameters included in the modeling process. Indeed, because system function is rarely precisely understood, the effects of management actions are never certain and the future states are unknown, decisions are almost always made in the face of uncertainty. Uncertainty can make differentiating among alternatives difficult, but because uncertainty is an inherent part of the decision process, it must not be ignored. It is important that uncertainty be confronted throughout the decision process and that the uncertainties are identified and the possible impacts on the system and the ability to achieve stated objectives documented.

Once the modeling process has predicted the likely outcomes of each management action and the corresponding ability to address each objective, the next step is to develop a consequence table. The purpose of a consequence table is to produce

a visual summary of the consequences of each potential management action on each of the objectives in a table or matrix. A consequence table can take a variety of forms, from a simple rating system (e.g., consumer report 5-star rating) to a complex table with specific probabilities of outcomes and subsequent likelihoods of achieving each objective. Independent of the complexity of the underlying models that populate the matrix, the purpose of the consequence table is to ease and facilitate direct comparison of each management actions' ability to achieve each objective.

5. *Identify and Evaluate Tradeoffs* – Ideally the structured decision making process would lead to a clear management alternative that achieves the objectives of all interested parties; unfortunately, this is rarely the case. Generally, the process of developing a consequence table will clearly elucidate which options are the least likely to be effective, but if there are multiple stakeholders and thus multiple objectives, most decisions will require a trade-off between the ability of the remaining options to achieve each objective. The process of identifying where these trade-offs arise is analytical, but the decision process itself is highly value laden and thus dependent upon stakeholders. In most complex decisions, this will involve stakeholders choosing between less-than-perfect alternatives. There are a variety of methods to facilitate highly value-laden decisions by weighing options based on the values of the stakeholders and then comparing alternatives to find the "best" compromise solutions. However, trade-offs are real and it is unlikely that all parties will be totally satisfied with the eventual outcome. Indeed, although consensus is ideal, it is not necessary and is often unachievable; however, the benefit of the structured decision-making process is that even if there is disagreement, the process makes the disagreement transparent and enables stakeholders to re-evaluate using new knowledge and/or perspectives.
6. *Implement Management Action* – The final step in the structured decision-making process is implementation. Although this may always seem to be the desired outcome of a decision process, unfortunately, social and political pressures to reach "perfection" often impede implementation and leave decisions in a continuous state of inaction. To ensure success, managers, policy makers, and stakeholders must work together to move through the decision process in a timely manner to ensure action can be taken. Failure to take action is a decision, whether it is made passively or actively.

Participatory Active Adaptive Management

Panarchy is a useful model for characterizing ecological systems and the formal institutions that manage these systems [30]. One of the most critical aspects in the panarchy appears to be a bridging organization that can monitor the status of the social-ecological system, and manifest rapid change, if conditions are deteriorating [31]. Monitoring will allow for management to set new target levels, and modify policy to reach those target levels, as new information is generated on scale-specific system attributes [32]. In order for management entities operating at discrete scales to improve communication channels and create opportunities for collaboration, intermediate level entities may serve to facilitate these cross-scale linkages. Bridging organizations have the capacity to fulfill this role and organize cooperation between stakeholders across scales [33], but to do so successfully, one must formulate strategies, coordinate joint action, address uncertainty, and link diverse stakeholders in a world of increasing complexity. Brown [33] investigated bridging organizations from across the world, and from a variety of scopes (e.g., regional economic policy in the USA; small-scale irrigation projects in Indonesia; agricultural productivity in Zimbabwe) found that bridging organizations are independent of stakeholders in a social-ecological system, which allows them to negotiate with stakeholders and advocate multiple positions. This unique role in the management of social-ecological systems affords bridging organizations the capacity to catalyze the formation of policies that are flexible and reflective of the panarchy of ecosystems and institutions [33]. In addition, bridging organizations have the capacity to reduce transaction costs, and provide a mechanism to enforce adherence to desired policies, despite their lack of regulatory authority [34].

Examples of bridging organizations include: (1) assessment teams, which are made up of actors across sectors in a social-ecological system;

(2) nongovernmental organizations, which create an arena for trust-building, learning, conflict resolution, and adaptive co-management; and (3) the scientific community, which acts as a "watchdog," as well as a facilitator, for adaptive management. For purposes of environmental management, an example of a successful bridging organization is that of Ekomuseum Kristianstads Vattenrike (EKV), a small, municipal organization that facilitated progressive ecosystem management in southern Sweden [34]. EKV was tasked with managing water resources at a regional scale in Sweden, and was successful largely because it employed organizational flexibility that allowed for EKV to respond quickly to "surprise." This was achieved through leadership, a core interdisciplinary staff, and the facilitation of connections between individuals and organizations (i.e., the panarchy of institutions) in the social-ecological system. EKV was able to improve the social capacity to respond to "surprises" and create the trust necessary to push the social-ecological system toward improved adaptive management of resources.

The formal management institutions in place are likely to persist barring a large-scale perturbation to social-ecological systems. So, managers must operate within the limitations of these institutions, which complicates matters, but does not make the situation intractable. One possible option for improving environmental management, as highlighted in this section, appears to be in developing bridging organizations that catalyze cross-scale communication across the panarchy of institutions and ecosystems, and explicit recognition of the underlying cross-scale structure and nonlinear interactions of these linked systems, by both policy and policy makers. The lack of communication and cooperation between institutions at even small scales further illuminates that bridging organizations may help bring about effective management of natural resources at multiple scales [35]. Thus, bridging organizations should act as mini think tanks that facilitate communication between institutions, incubate new ideas for environmental management, and provide a forum for coming to agreements on contentious issues [36].

Bridging organizations play a critical role in facilitating adaptive comanagement and governance, and are essential to managing for resilience in social-ecological systems [37]. Perception of a particular policy can play a significant role in whether it is accepted by critical stakeholders in a social-ecological system [38]. Engaging stakeholders, implementing change at a suitable rate, and providing outreach to keep the public informed are all important for new environmental policy to be perceived of as positive and for a successful transition to a new policy regime [38]. This environmental management framework, which incorporates panarchy, adaptive management, and bridging organizations, could serve as one scenario in the suite of policy options for actualizing sustainability [30].

Adaptive Governance

Administrative agencies typically change incrementally [39], and as such, changes in policy are small because there is not enough information to make large overhauls of organization policy. Standard operating procedures are another mechanism that contributes to organizational inertia, as they slow the bureaucratic process [40]. Further, the lack of institutions matched to the appropriate scale is a significant barrier for sound environmental management [41]. Within this context, adaptive governance can help with this scale mismatch via collaboration of a diverse set of stakeholders at multiple scales [42]. Adaptive governance is a form of governance that incorporates formal institutions, informal groups/networks, and individuals at multiple scales for purposes of collaborative environmental management [43]. Bridging organizations, enabling legislation and government policies can also contribute to the success of an adaptive governance framework; governance creates a vision and management actualizes the vision [43].

Adaptive governance works via sharing of management power and responsibilities, and promotes a collaborative, participatory process, but is dependent upon adaptive comanagement, and adaptive comanagement is dependent upon social networks for success. Social networks have the capacity to allow for development of new ideas, to facilitate communication between entities, and to create the flexibility necessary for the interplay of the fluid (ecological systems) and the rigid (institutions) to be successful for environmental management [43]. Leadership has been well established as a critical factor in facilitating good environmental management. Leaders develop and facilitate a vision for

environmental management, incorporating local knowledge and information from social networks [43].

Olsson et al. [44] studied adaptive comanagement in Sweden and Canada and concluded that this form of management of ecological systems was most effective when there was: leadership with vision for the system of interest; legislation that created the environment for adaptive management; funds for adaptive management; monitoring of the ecological system; information flow (i.e., cross-scale linkages); combination of a variety of sources knowledge; and venue for collaboration. Olsson et al. [44] contend that these factors are critical to building resilience in social-ecological systems, as they help to protect the system from the failure of management decisions under uncertainty (i.e., imperfect information). Further, they assert that adaptive comanagement is necessary to facilitate adaptive governance. In turn, adaptive governance is facilitated by informal networks and leadership, which creates the capacity for development of novel ideas for environmental management [43]. These informal networks have the capacity to generate political, financial, and legal support for novel environmental management [43]. Further, adaptive governance is dependent upon polycentric institutions that are redundant (e.g., scale-specific) and are quasi-autonomous [45]. Olsson et al. [45] compared five case studies from around the world and concluded that in order for a social-ecological system to transition to adaptive governance, it must undergo a preparation and a transformation phase, linked by a window of opportunity.

In a well-cited example (Kristianstads Vattenrike) from Sweden, Olsson et al. [45] report the transition to adaptive governance was preceded by the development of a social network of parties interested in the management of the social-ecological system. The network consisted of members from local groups (environmental groups, farmers' associations), local government (municipality of Kristianstad, the County Administrative Board), and national scale (World Wildlife Fund, National Museum of Natural History, National Research Council). In case studies that have not resulted in a successful transition to adaptive governance, the social networks needed to help facilitate the transition were not well developed, and this hindered the changes needed for good environmental management [45].

The role of leadership has also been cited as critical to a transition to adaptive governance, and Olsson et al. [45] provide an example of leadership from Kristianstads Vattenrike. A key individual acted as a catalyst to social network formation, setting the research agenda, and mobilizing support at multiple scales for "new" environmental management. Critical to setting an agenda is defining how an issue becomes perceived as a "public problem because if most individuals accept a particular condition, negative feedback works to maintain public opinion in that particular regime" [46]. However, if the individuals in the regime develop a "critical mass" of distaste for a particular issue, public opinion can cross a threshold and reorganize into an alternative regime. Importantly, interest groups, the media, and other agents can have an effect on agenda setting and creating the "climate" necessary for a shift in public opinion [46]. There are critical roles to be played by individual actors in shifting policy from one regime to an alternate regime. For instance, social networkers that share information freely; individuals that have numerous, diverse connections; and individuals with powerful ability to persuade play key roles in policy change [47]. These individuals can interact to create the conditions necessary for regime shifts in public policy. In particular, the director of a municipal organization (Ekomuseum Kristianstads Vattenrike) filled this leadership role and served as a bridging organization that also was a significant factor in the transition to adaptive governance [45]. The leadership needed to foster a transition to adaptive governance is not necessarily the work of one individual, but rather is often encompassed by several individuals and entities [48].

There are two types of policy windows: a problem-driven window and a politically driven window [49]. A problem-driven window opens when a policymaker believes that a policy is necessary for a specific issue. A politically driven window is driven by a particular theme adopted by a policymaker, in which the policymaker looks for problems that fit within the theme. Significant changes in policy occur when conditions (e.g., problems, solutions, and politics) converge at the same time, which creates the window of opportunity for change [49]. In the Kristianstads Vattenrike example, social and ecological change at one scale triggered cross-scale effects which resulted in a window of opportunity for the transition to

adaptive governance [45]. In adaptive governance, decision making is not top-down but rather emerges from outreach and group meetings with stakeholders [50]. In order for adaptive governance to be effective, the policy requires strong leadership, communication, and incorporation of uncertainty, which allows for adaptation to changing circumstances [50].

Adaptive Management and Law

Legal certainty is an aspect of law that does not mesh well with environmental unpredictability. One of the most significant barriers for managing linked social-ecological systems is that often the aspects of a society that make it free (e.g., certainty of law) are not in concert with ecological realities (e.g., multi-regimes, nonlinear systems, and responses) [51]. The certainty of law and institutional rigidity often limit experimentation that is necessary for adaptive management [30]. This point is critical, as some scholars contend that environmental governance of the commons can only succeed if rules evolve with the system of interest [41].

Ecosystem management has been applied within the outdated framework of the Endangered Species Act (ESA), but ecosystem management is best implemented via adaptive management [52]. In its current form, the ESA does not have the necessary flexibility in its regulatory language to effectively implement adaptive responses to changing environmental conditions [52]. The legal constraints upon adaptive management in the American system of law do not stop there. The fundamental constraint to adaptive management is the current state of administrative law [53]. As the law now stands, the procedural rules require a vast amount of work before an agency promulgates a rule or issues a permit [54]. This "pre-decision" activity allows for public input and prepares agencies for judicial review. Ruhl [54] contends that "agencies will find that interest groups and courts relentlessly will erode adaptive agency behavior, using all the tools conventional administrative law puts at their disposal." Having to operate in an atmosphere where each policy is evaluated on the "front-end," in anticipation of public and legal scrutiny, has squelched agencies' appetite for adaptive management.

US administrative law is a two-step process, in which the first step allows for public comment on draft documents and alternative options [55]. The second step is final agency action, which creates "certainty" to the process and makes the decision subject to judicial review. This process is based on the assumption that agencies have the capacity to predict the consequences of a "final agency action" [55]. Thus, there is a fundamental conflict between linear legal processes (i.e., administrative law) based on "stationarity," versus environmental management frameworks (i.e., adaptive management) based on the realization of dynamic systems characterized by "surprise" [55]. Given this inherent conflict, adaptive management may not be possible under the current administrative law framework [54].

The adversarial character of administrative law, combined with the need for certainty (e.g., procedural rules) in the larger realm of American law, is likely incompatible with adaptive management [56]. Thus, environmental law is at odds with science, as the certainty required for socio-political stability makes it very difficult to apply a novel approach to ecosystem management (e.g., adaptive management) that requires institutional flexibility. Thus, if adaptive management is necessary for good environmental management, environmental law must be "adapted" to fit with adaptive management [54]. Karkkainen [56] argues that administrative law should proceed on two trajectories: (1) a fixed rule track that will apply unless an agency can justify otherwise; and (2) an adaptive management track, where a new set of administrative law standards specific to adaptive management would hold precedence, in order to actualize adaptive management as a tool for environmental policy.

Thus, some in the law community argue that adaptive management is not possible under the current administrative law framework [54]. The National Environmental Policy Act (NEPA) may act as a barrier to implementation of adaptive management (sensu Holling) [57]. NEPA could possibly be modified to an iterative process that could accommodate adaptive management [57]. Ruhl [54] contends that adaptive management is necessary for good environmental management, which in turn means that environmental law must be "adapted" to fit with adaptive management.

In effect, administrative agencies in the USA do not conduct adaptive management as it was originally conceived [55]. Rather, agencies conduct adaptive

management "lite," as the courts have provided some leeway to adaptive management projects, provided they have requirements that are legally enforceable [55]. The primary problem with adaptive management "lite" is that it does not measure up to the standards of adaptive management theory, nor does it hold up under the scrutiny of substantive and procedural law. Adaptive management (sensu Holling) is not likely until Congress provides more funding for adaptive management and clear standards for the adaptive management process [55].

Conclusions

The conceptual underpinnings for adaptive management are simple; there will always be inherent uncertainty and unpredictability in the dynamics and behavior of complex ecological systems as a result of nonlinear interactions among components and emergence, yet management decisions must still be made. The strength of adaptive management is in the recognition and confrontation of such uncertainty. Rather than ignore uncertainty, or use it to preclude management actions, adaptive management can foster resilience and flexibility to cope with an uncertain future, and develop safe-to-fail management approaches that acknowledge inevitable changes and surprises. Since its initial introduction, adaptive management has been hailed as a solution to endless trial and error approaches to complex natural resource management challenges. However, it does not produce easy answers, and it is appropriate in only a subset of natural resource management problems. Clearly adaptive management has great potential when applied appropriately.

Future Directions

Adaptive management is increasingly heralded as the future of natural resource management and has been adopted by many governmental and nongovernmental agencies. Institutions adopting adaptive management have utilized different definitions often focusing on a single strength of the process (i.e., experimentation, reducing uncertainty, involving stakeholders) and thus operationalize the practice uniquely. Some, like the U.S. Department of Interior, are highly focused on the decision process and the incorporation of structured decision making while others, such as the US Army Corps of Engineers, have embraced stakeholder involvement. Each approach has merit but adaptive management has failed to live up to its expectations [58]. The reasons for failure are many, and likely to be repeated, yet the great potential of adaptive management remains; unfortunately, it remains largely untapped. Translation of adaptive management approaches to "on-the-ground" natural resource managers is a critical step that has largely failed. Most natural resource managers are still unable to define adaptive management, let alone incorporate it into their normal management activities. The next decade will be critical: Will adaptive management remain in the domain of ivory towers, or will it become a tool for the trenches? Taking adaptive management to the practitioners will require the communication of adaptive management techniques in a clear, simple, and most importantly applicable manner. Currently, adaptive management fails because of an adherence to mathematical modeling above all else, its application to situations that are not conducive to replication or the measurement of success (e.g., large rivers such as the Missouri or the Colorado), and because adaptive management has not been adequately incorporated into natural resources management via appropriate legal mechanisms [59]. If the future of natural resource management is to be proactive and address the increasing uncertainties facing our world, adaptive approaches to resource management will require communication of the methodology and merits in a clear and simple manner.

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Ecotones and Ecological Gradients

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Article Outline

Glossary

Beta-diversity Also termed species turnover, beta-diversity refers to the change in species as one moves between habitats, communities, or ecosystems.

Divergence-with-gene-flow model of speciation A model explaining the process of species formation (speciation) in which new species diverge in the face of gene flow; the movement of genes within a group that results from mating with immigrant individuals.