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Craig R. Allen
University of Nebraska-Lincoln, callen3@unl.edu

Joseph J. Fontaine
University of Nebraska-Lincoln, jfontaine2@unl.edu

Kevin L. Pope
University of Nebraska-Lincoln, kpope2@unl.edu

Ahjond S. Garmestani
National Risk Management Research Laboratory, garmestani.ahjond@epa.gov

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Adaptive management for a turbulent future

Craig R. Allen [a,*], Joseph J. Fontaine [a], Kevin L. Pope [a], Ahjond S. Garmestani [b]

[a] U.S. Geological Survey, Nebraska Cooperative Fish and Wildlife Research Unit, School of Natural Resources, University of Nebraska, Lincoln, NE, USA
[b] U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH, USA

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ABSTRACT

The challenges that face humanity today differ from the past because as the scale of human influence has increased, our biggest challenges have become global in nature, and formerly local problems that could be addressed by shifting populations or switching resources, now aggregate (i.e., "scale up") limiting potential management options. Adaptive management is an approach to natural resource management that emphasizes learning through management based on the philosophy that knowledge is incomplete and much of what we think we know is actually wrong. Adaptive management has explicit structure, including 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. It is evident that adaptive management has matured, but it has also reached a crossroads. Practitioners and scientists have developed adaptive management and structured decision making techniques, and mathematicians have developed methods to reduce the uncertainties encountered in resource management, yet there continues to be misapplication of the method and misunderstanding of its purpose. 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 along a continuum of complexity and *a priori* design. Adaptive management is not a panacea for the navigation of 'wicked problems' as it does not produce easy answers, and is only appropriate in a subset of natural resource management problems where both uncertainty and controllability are high. Nonetheless, the conceptual underpinnings of adaptive management are simple; there will always be inherent uncertainty and unpredictability in the dynamics and behavior of complex social-ecological systems, but management decisions must still be made, and whenever possible, we should incorporate learning into management.

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1. Introduction

Adaptive management is an approach to natural resource management that emphasizes learning through management based on the philosophy that knowledge is incomplete and much of what we think we know is actually wrong, but despite uncertainty managers and policy makers must act (Walters, 1986). Although the concept of adaptive management has resonated with resource management scientists and practitioners following its formal introduction in 1978 (Holling, 1978), it has been and continues to remain relatively little practiced and much misunderstood. Misunderstanding is largely based on the belief that adaptive management is what management has always been, a trial and error attempt to improve management outcomes. However, unlike a traditional trial and error approach, adaptive management has explicit structure, including 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 (Fig. 1). Since its 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, as discussed later, it has become increasingly referenced under various forms (Fig. 2). Regardless of the particular definition of adaptive management used, and there are many, adaptive management emphasizes learning and subsequent adaptation of management based on that learning. The process is iterative, and serves to reduce uncertainty, build knowledge and improve management over time in a goal-oriented and structured process.

It is evident that adaptive management has matured, but it has also reached a crossroads. This field of study has matured through two primary schools of thought: the Resilience-Experimentalist School (with high emphasis on stakeholder involvement, resilience, and highly complex models) and the Decision-Theoretic School (which results in relatively simple models by emphasizing stakeholder involvement for identifying management objectives)

* Corresponding author.
E-mail address: allencr@unl.edu (C.R. Allen).

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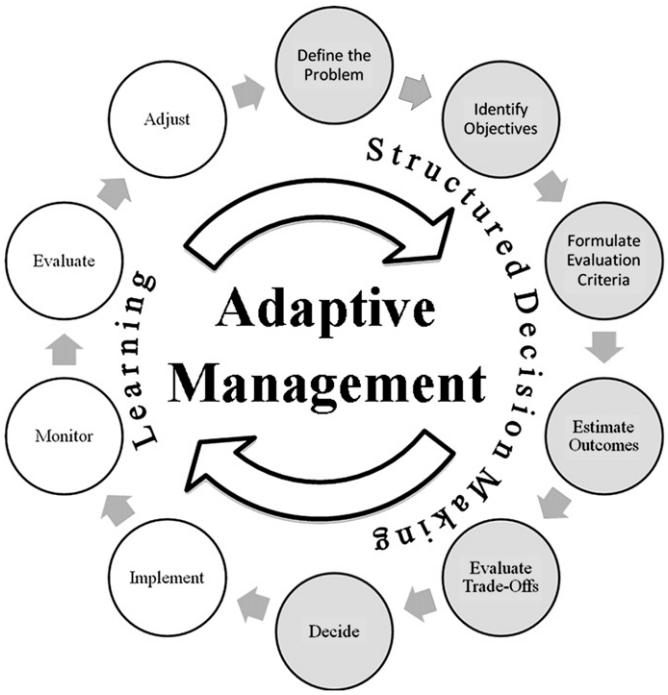

Fig. 1. Adaptive management, often characterized as 'learning by doing', is a formal iterative process of resource management that acknowledges uncertainty and achieves management objectives by increasing system knowledge through a structured feedback process. As illustrated, integral to the adaptive management process is both a decision component and an opportunity to learn. Structured decision making (gray circles), a term often confused with adaptive management, is an organized and transparent approach to the decision process for identifying and evaluating alternatives and justifying complex decisions; however, structured decision making does not necessitate the iteration and consequential higher order learning (white circles) inherent in adaptive management.

(McFadden et al., 2011). Application of adaptive management 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 methods to reduce the uncertainties encountered in resource management, there continues to be misapplication of the method, and misunderstanding of its purpose.

Obviously, adaptive management is a term that carries with it unknown potential and irrevocable misunderstanding, a paradox that simultaneously explains the inherent interest and discomfort in its implementation. In an effort to address this paradox and assist in the evolution of natural resource management, here we outline the process of adaptive management, its characteristics and its utility. To this end, we start in the beginning with a description of the history and foundations underlying adaptive management, how it is currently used, and how misconceptions, legal and social constraints and over exuberance of its potential have led to discontent and misuse. Through this process we are careful to articulate the conditions favoring adaptive management and how it relates to the associated topics of structured decision making, adaptive governance, and adaptive co-management for which it is often confused, yet is integrally tied. In reintroducing adaptive management, here and more generally within this special issue, we hope to reinvigorate the discussion of proactive management approaches that may best facilitate the increasing global and highly uncertain environmental challenges facing natural resource managers, researchers, and policy makers today, and into the future.

2. A brief history

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 (Williams, 2011a), including business (Senge, 1990), experimental science (Popper, 1968), systems theory (Ashworth, 1982) and industrial ecology (Allenby and Richards, 1994), the first reference to adaptive management philosophies in natural resource management may be traced back to the work of Beverton and Holt (1957) in fisheries management (reviewed in Williams, 2011a). The term adaptive management would not become 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 (Holling, 1978). The work was spawned by the experiences of Holling and colleagues at the University of British Columbia following the development of resilience theory (Holling, 1973). The concept of resilience, predicated on the existence of more than one alternative stable state for ecosystems, had several ramifications. First, 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 locations of those thresholds are often difficult to detect. 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' via management experiments developed to enhance learning and reduce uncertainty.

Eventually Carl Walters (1986) followed up on Holling's original book (1978) 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 (1986) 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 we know 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 designing 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 that enhance learning. Williams (2011a) 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

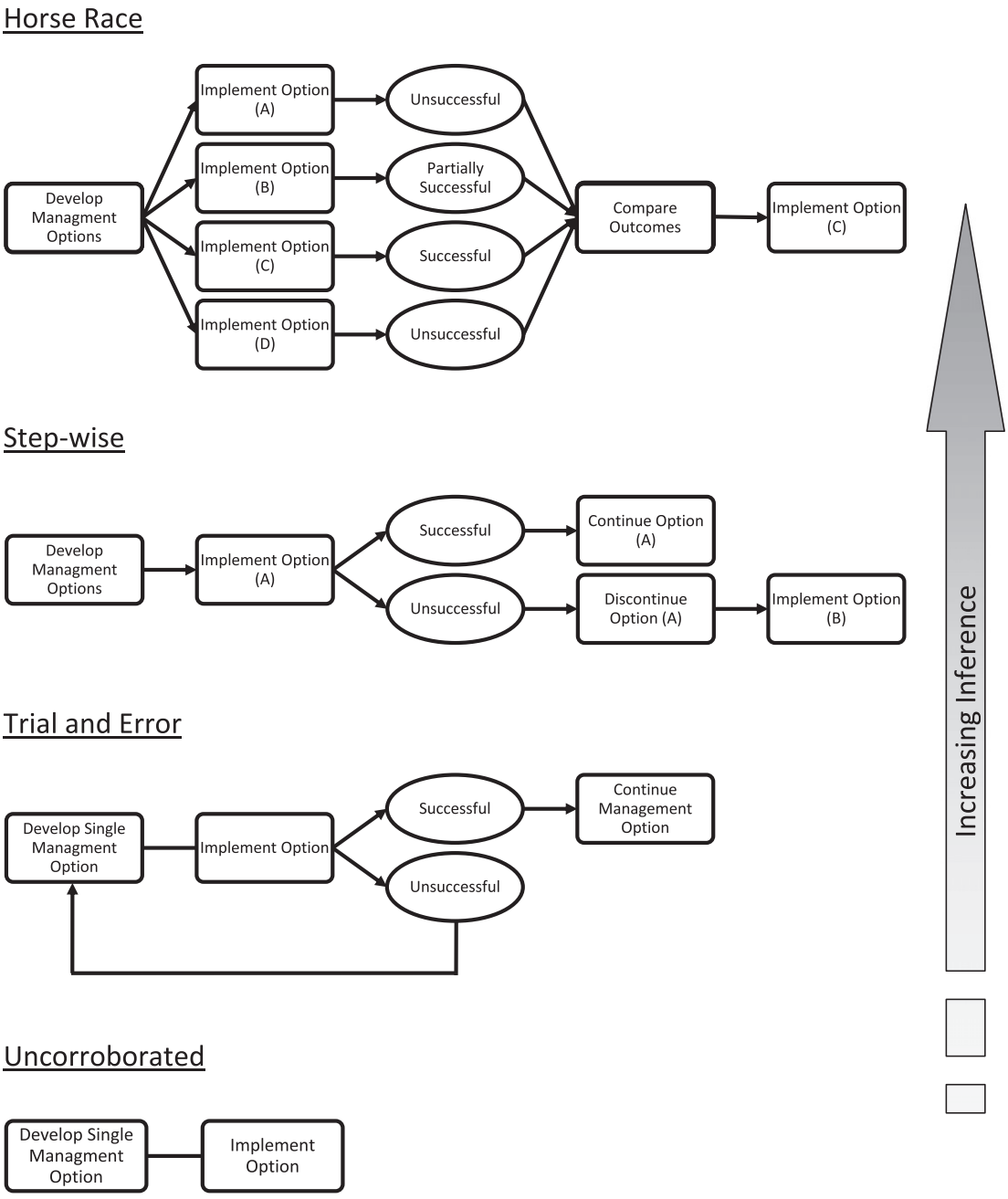

Fig. 2. The learning and inference possible among approaches to natural resource management varies, increasing from little or none in uncorroborated learning to much in the horse race approach (active adaptive management).

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.

3. Adaptive management today

Adaptive management has been referenced either implicitly (Beverton and Holt, 1957) or explicitly (Holling, 1978; Walters and Hilborn, 1978) for more than fifty years, but despite an illustrious theoretical history there has remained imperfect realization of adaptive management in real world natural resource management decisions. The challenge of implementing adaptive management stems from: 1) a lack of clarity in definition and approach (Fontaine, 2011), 2) a paucity of success stories on which to build (Lee, 1993; McLain and Lee, 1996; Lee, 1999; Moir and Block, 2001; Walters, 2007), 3) management, policy, and funding paradigms that favor reactive rather than proactive approaches to natural resource management (Walters, 1997; Ascher, 2001; Schreiber et al., 2004), 4) failure to recognize the potential for shifting objectives (Tyre and Michaels, 2011), and 5) failure to acknowledge the social source of

uncertainty, and hence increased risk of surprise (Tyre and Michaels, 2011). 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 to be in 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 along 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") (Holling, 1978; Wilhere, 2002; Aldridge et al., 2004). 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 on sound scientific principles necessary for future management decisions. 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 (Williams, 2011a,b). 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 (Lee, 1993), uncertainty (Williams and Johnson, 1995), changing management actions (Rauscher, 1999), monitoring (Bormann et al., 2007), and stakeholder involvement (Norton, 1995)).

Despite the challenges in defining adaptive management, interest in the subject and its application continue to grow. Adaptive management is an ideal method to resolve uncertainty when research results in weak inference (Rehme et al., 2011). The recent development of an adaptive management technical guide by the U.S. Department of Interior (Williams et al., 2009) is an indication of the growing movement in natural resource management toward taking a more proactive role in management decisions. The policies developed in this manual are intended 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."

3.1. Structured decision making

One method to overcome management paralysis and mediate multiple stakeholder interests is structured decision making. Structured decision making is a term often used in conjunction with or as a synonym for adaptive management, but in actuality it is a problem solving approach borrowed from the sociological fields, and is best used 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. As such, the framework of structured decision making is an ideal template to facilitate the decision making process inherent in adaptive management (Fig. 1). To achieve this goal, structured decision making uses a simple set of steps 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. Central to the success of the structured decision making process is the requirement to clearly articulate fundamental objectives, explicitly acknowledge uncertainty, and respond transparently to all stakeholder interests in the decision process. The conceptual simplicity inherent in structured decision making makes the process useful for minor decisions as well as complex problems involving multiple stakeholders.

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. Unfortunately, as with many decisions, deciding on 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 (Allen and Gunderson, 2011) and maximize the potential for success.

3.2. Bridging organizations for participatory adaptive management

One method for improving environmental management is the development of bridging organizations that catalyze cross-scale communication across institutions and ecosystems, and explicitly recognizes the underlying cross-scale structure and non-linear 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 (Roy et al., 2008). Bridging organizations play a critical role in facilitating adaptive co-management and governance, and are essential to managing for resilience in social-ecological systems (Olsson et al., 2007). Perception of a particular policy can play a significant role in whether it is accepted by critical stakeholders (Marshall, 2007). 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 as positive and for a successful transition to a new policy regime (Marshall, 2007).

Monitoring allows 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 (Karkkainen, 2002). 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 (Brown, 1993), but to do so successfully they must formulate strategies, coordinate joint action, address uncertainty, and link diverse stakeholders in a world of increasing complexity. Being independent of stakeholders in a social-ecological system,

bridging organizations are able to negotiate with stakeholders and advocate multiple positions (Brown, 1993). 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 (Brown, 1993). 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 (Hahn et al., 2006). Examples of bridging organizations include: (1) assessment teams, which are made up of actors across sectors in a social-ecological system; (2) non-governmental 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. 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 (Brown et al., 2001).

3.3. Adaptive governance

Administrative agencies typically change incrementally (Lindblom, 1959), and as such changes in policy are small because there is not enough information to make large overhauls of organizational policy. Standard operating procedures are another mechanism that contributes to organizational inertia, as they slow the bureaucratic process (Allison, 1969). Further, the lack of institutions matched to the appropriate scale is a significant barrier for sound environmental management (Dietz et al., 2003). Within this context, adaptive governance can help with this scale mismatch via collaboration of a diverse set of stakeholders at multiple scales (Hughes et al., 2005). 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 (Folke et al., 2005). Bridging organizations, enabling legislation and government policies can also contribute to the success of an adaptive governance framework, whereby governance creates a vision and management actualizes the vision (Folke et al., 2005).

Adaptive governance works via sharing of management power and responsibilities, and promotes a collaborative, participatory process (Folke et al., 2005), but is dependent on adaptive co-management, and adaptive co-management is most effective when there is: leadership with vision for the system of interest; legislation favoring adaptive management; funds for adaptive management; monitoring of the ecological system; information flow (i.e., cross-scale linkages); a variety of sources of knowledge; and a venue for collaboration (Olsson et al., 2004). Ultimately, these factors are critical in 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). Underlying adaptive governance and adaptive co-management is an inherent dependence on social networks which have the capacity for innovation, communication, and the flexibility necessary for the interplay of the fluid (e.g., ecological systems) and the rigid (e.g., institutions) (Folke et al., 2005). Successful social networks can generate the political, financial and legal support for novel environmental management, but they depend upon leadership to facilitate good environmental management (Folke et al., 2005). Leaders develop and facilitate a vision for environmental management, incorporating local knowledge and information from social networks (Folke et al., 2005).

3.4. Law

Legal certainty 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., multiple regimes and non-linear systems and responses) (Folke et al., 2007). The certainty of law and institutional rigidity often limit the experimentation that is necessary for adaptive management (Garmestani et al., 2009). 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 (Dietz et al., 2003).

U.S. administrative law is a two-step process, in which the first step allows for public comment on draft documents and alternative options (Ruhl and Fischman, 2010). The second step is final agency action, which creates "certainty" to the process and makes the decision subject to judicial review (Ruhl and Fischman, 2010). This process is based on the assumption that agencies have the capacity to predict the consequences of a "final agency action" (Ruhl and Fischman, 2010). Thus, we see the fundamental conflict between a linear legal process (i.e., administrative law) based on "stationarity" versus an environmental management framework (i.e., adaptive management) based on the realization of dynamic systems characterized by "surprise" (Ruhl and Fischman, 2010). Given this inherent conflict, adaptive management may not be possible under the current administrative law framework (Ruhl, 2008).

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 (Karkkainen, 2005). Thus, environmental law can be 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, especially because sustainability likely must occur via the institutions we have in place (Benson and Garmestani, 2011).

In effect, administrative agencies in the USA do not conduct adaptive management as it was originally conceived (Ruhl and Fischman, 2010). Rather, agencies conduct "adaptive management-lite", as the courts have provided some leeway for adaptive management projects, provided they have requirements that are legally enforceable (Ruhl and Fischman, 2010). 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 (Ruhl and Fischman, 2010). Thus if adaptive management is necessary for good environmental management, environmental law must be "adapted" to fit with adaptive management (Ruhl, 2008). Karkkainen (2005) argues that administrative law should proceed on a fixed rule track that will apply unless an agency can justify 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. We likely will not see adaptive management (*sensu* Holling) by U.S. agencies until Congress provides more funding for adaptive management and clear standards for the adaptive management process (Ruhl and Fischman, 2010).

4. Global challenges for the current millennia: when is adaptive management appropriate?

Humanity faces unprecedented global challenges. Increasing human populations and affluence has translated to a human population that sequesters a large proportion of global productivity. This resource use, and current population and energy use trends

are probably unsustainable. Although Malthusian predictions of doom have failed in the past because of ever more efficient resource use and technological advances, it is inconceivable that there are no limits to human consumption of renewable and non-renewable natural resources.

The challenges that face humanity today are different from past challenges in that few are wholly local; our biggest environmental challenges are global in nature, and the influence of humans has managed to scale up in just a few centuries, such that formerly local problems, that could be fixed by shifting populations or switching resources (e.g., fishing down the food chain), now aggregate and options for local solutions are limited. These challenges include climate change, global land-cover and land-use change, ocean chemistry and circulation patterns, and fossil energy and water shortages. Adaptive management can help mitigate anthropogenic impacts resulting from several of these global changes. This includes species decline and habitat loss (Fontaine, 2011; Smith, 2011), recreational harvest of animals that migrate across political boundaries (Johnson, 2011) and other transboundary resource management issues, regulation of human participation in natural resource-based recreational activities (Martin and Pope, 2011), and management of competing interests on public lands with limited resources (Moore et al., 2011).

However, adaptive management is not a panacea for the navigation of many of the 'wicked problems' (Rittel and Webber, 1973; Ludwig, 2001) humanity faces in this new millennia, because it does not produce easy answers, and is only appropriate in a subset of natural resource management problems where both uncertainty and controllability are high (Fig. 3; Gregory et al., 2006). Where uncertainty is high but controllability is low, developing and analyzing scenarios is a more appropriate approach. However, even in such situations where controllability is low (e.g., climate change), adaptive management can help us mitigate some of the impacts that may occur, such as shifting distributions of plants and animals, or changes in water availability. Adaptive management is predicated on the idea that resources will respond to management. If there is little ability to affect resources through management (controllability), there is no reason to engage in adaptive management. Likewise, if we already know what the resource response will be, that is if uncertainty is low, there is no reason for management experiments. Further, some of the challenges facing humanity today are so large in spatial extent (global) and so slow in response, that they are inappropriate for adaptive management. Political time spans that rarely extend more than five years make long-term monitoring rare. However, many natural resource management challenges are appropriately, and best, addressed through the process of adaptive management.

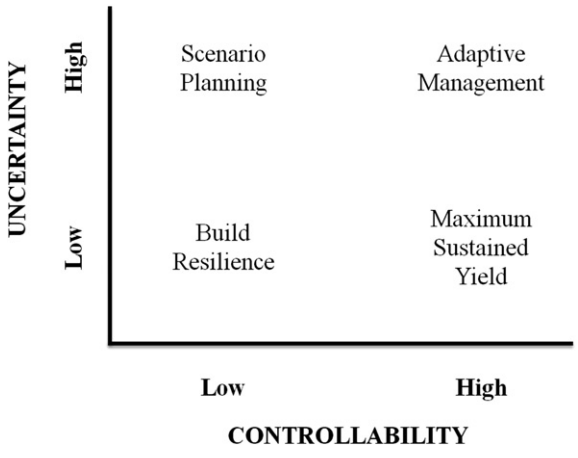

Fig. 3. Adaptive management and scenarios are complementary approaches to understanding complex systems. Adaptive management functions best when both uncertainty and controllability are high, which means the potential for learning is high, and the system can be manipulated (adapted from Peterson et al., 2003).

5. Conclusions

The conceptual underpinnings for adaptive management are simple; there will always be inherent uncertainty and unpredictability in the dynamics and behavior of complex social-ecological systems as a result of non-linear 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 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. Nonetheless, adaptive management has great potential when applied appropriately.

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