Adaptive Management and the Future of Science in the Sacramento-San Joaquin Delta

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Abstract

Adaptive management is a concept with great potential but a lackluster track record. We contend that policy-makers, resource managers, and scientists are more likely to realize the potential of adaptive management if it is implemented as a step-wise, structured approach to incorporating scientific information into decision-making. In the Sacramento-San Joaquin Delta, the contemporary blueprint for adaptive management is set forth in the Delta Plan. Here, we build upon the Delta Plan's nine-step framework by articulating a structured approach by which best available scientific information guides selection of defensible management actions, allows for assessment of the effectiveness and efficacy of those actions, and is used to reconsider conceptual models, to recalibrate quantitative models, and to adjust or refine conservation actions in support of adaptive management.

Keywords: adaptive management, structured decision-making, best available science

The role of science in conservation planning poses challenges to policy-makers, resource managers, and scientists alike. Impediments to well-informed management actions include insufficient data regarding many of the factors that affect survival and reproduction of imperiled species and the absence of analytical tools tailored to those species' life histories. These shortcomings are often compounded by a lack of critical analysis of scientific information, incomplete presentation of information, or misinterpretation or misrepresentation of information (Murphy and Weiland 2011). Attempts to meet these challenges often have failed to produce effective management actions (Susskind et al. 2012, Gunderson and Light 2006). More concerning than past failures is the fact that resource managers and scientists – daunted by the task of making scientifically defensible decisions – are in the habit of defaulting from engaging the "best available science," and instead falling back on informed intuition (Ruckelshaus et al. 2002).

A contributing factor to over-reliance on intuition has been the invocation of adaptive management in lieu of a step-wise, structured process for acquiring scientific information and integrating it into resource management decisions. At this point, more than 30 years after the term adaptive management began appear in the scientific literature (for example, Holling 1978), many federal and state resource agencies nominally have integrated adaptive management with their other core functions. In the Sacramento-San Joaquin Delta, adaptive management has become the institutional template for addressing the conservation of a highly altered ecosystem. A *Delta Plan* has been issued by the state's Delta Stewardship Council, the Council's Delta Science Program has drafted a Science Plan that details many of the elements in the Delta Plan's implementation, and the ambitious Bay-Delta Conservation Plan appears to be nearing completion – all call for resources management in an adaptive framework (Delta Stewardship Council 2013, Delta Science Program 2013, California Resources Agency 2013). Each of these initiatives recognizes that an initial management action frequently will not produce the exact desired conservation outcome, but that adapting or adjusting the action might well provide the palliative. Not explicitly recognized with that attractive notion is that a misinformed or misdirected management action will not fit into an adaptive framework, and that attempts to remedy that circumstance can come with high societal costs and dubious ecological benefits.

To avoid this undesirable outcome, it is essential to implement adaptive management as a step-wise, structured approach to incorporate scientific information into decision-making (consider Walters 1997, National Research Council 2009, Gregory et al. 2012). While the operative term in adaptive management is "management," for the term "adaptive" to apply, the best available scientific information must serve as the basis for all management decisions. It has been long recognized that a structured approach is essential to adaptive management (Holling 1978, Walters and Holling 1990); however, there has been a propensity to dispense with such an approach in conservation planning, particularly during the process of developing initial management actions. Adaptive management, typically represented in a simplified circular figure composed of as few as three or as many as nine or more steps, has introduced structure into conservation planning (for example, Stankey et al. 2005, Delta Stewardship Council 2013), but it has often done so after – rather than before – an initial decision has been made to pursue one or more management actions. Almost without exception adaptive management plans and programs have given relatively little attention to the structured process that is necessary to identify programmatic management actions.

In the Delta, the most recent and thorough blueprint for adaptive management is set forth in the *Delta Plan*, a document issued pursuant to the Delta Reform Act of 2009. The Act defines adaptive management as "a framework and flexible decision making process for ongoing knowledge acquisition, monitoring, and evaluation leading to continuous improvements in management planning and implementation of a project to achieve specified objectives." The *Delta Plan* sets forth a nine-step adaptive management framework (Figure 1), further refined by clustering the steps into three distinct phases labeled "Plan," "Do," and "Evaluate and respond." The Plan phase includes three steps that precede selection of a management action – defining the problem to be addressed, establishing goals and objectives, and modeling linkages between objectives and the management action. While this adaptive management graphic identifies appropriate prerequisites for informed selection of one or more management actions, the steps presented do not fully articulate the structured approach that is necessary to capture the process by which the best available scientific information guides selection of defensible management actions.

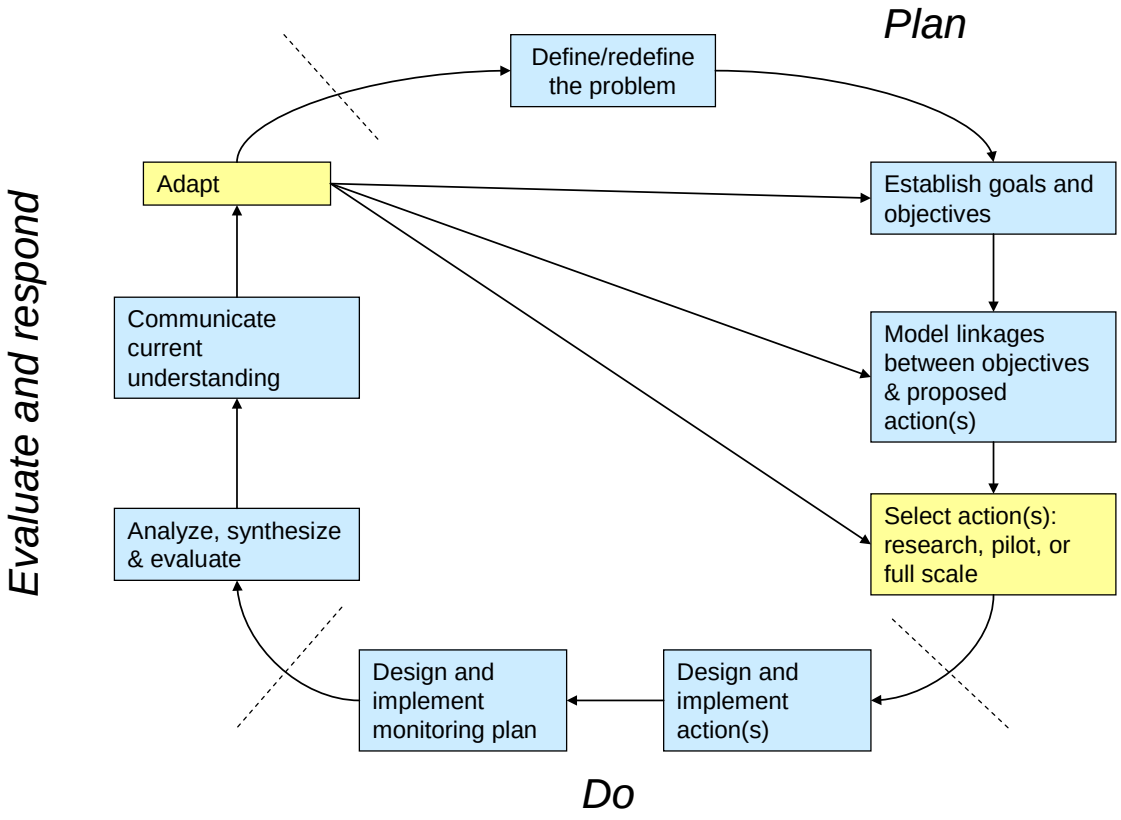

Figure 1. *The adaptive management cycle as illustrated in the* Delta Plan*. The process is initiated with the identification and definition of the management problem. The boxes that are colored blue identify steps informed by best available scientific information. The yellow boxes include decisions made by policy makers and implementation of those decisions by resource managers.*

A number of approaches to decision-making set in the context of natural resources management advocate a structured, transparent process (EPA 2003, National Research Council 2009, Murphy and Weiland 2011). Use of a structured process may yield more defensible and efficacious decisions by assuring pertinent scientific information is gathered, critically assessed, and integrated into the process of making decisions using conceptual and operational models. Where such a process is not utilized to arrive at initial management actions, those actions are liable to fail to achieve desired outcomes, and subsequent efforts to adhere to an adaptive management framework also will fail to meet expectations. As the federal wildlife agencies have indicated, "adaptive management should not be used in place of developing good up-front conservation measures or to postpone difficult issues" (FWS and NOAA 2000). For instance, if a management action is premised on the supposition that a specific environmental indicator well

represents the response of a target species to management, and that supposition is not tested or validated, both the action and subsequent efforts to monitor its effectiveness will be compromised.

A structured adaptive management process is initiated with a problem-formulation exercise, and proceeds through the selection and implementation of (initial) management actions together with the design of an associated monitoring scheme (Figure 2). The first nine steps in that process lay the groundwork for evaluation of alternative management actions and the selection of an action from among them. This collection of steps must be informed by the best available science; it will yield suboptimal results if either the steps are not taken in sequence or if one or more of the steps is not carried out in a technically rigorous manner by analysts with adequate training, time, and resources.

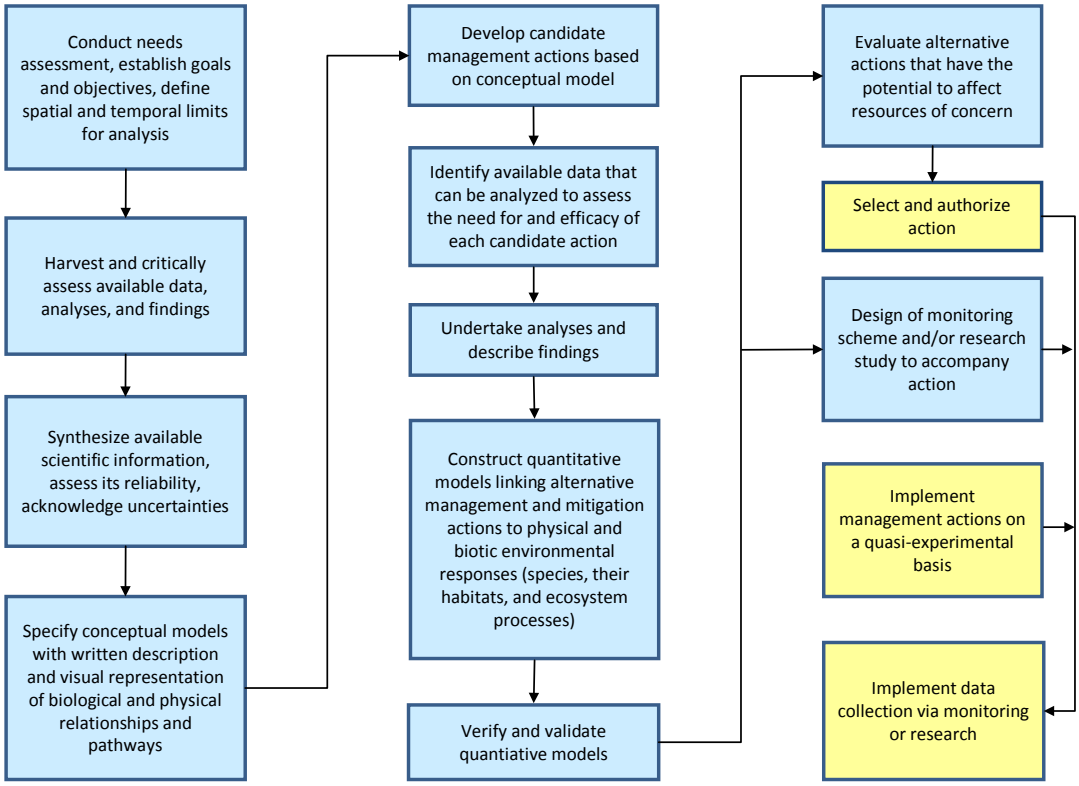

Figure 2. *Requisite steps in the selection of management actions to be carried out in an adaptive framework. The first 11 process steps correspond with the "Plan" phase in Figure 1.*

The science-informed process of selecting from among candidate management actions is often presumed to have been carried out, rather than explicitly described as a requisite set of steps in most adaptive management graphics (it is integrated into a single "modeling linkages between objectives and proposed action(s)" step in Figure 1). The multi-step process of selecting a management action to be implemented in an adaptive framework can involve the testing of basic hypotheses that address cause and effect relationships between targeted species and environmental stressors, as well as applying sophisticated analytical and modeling techniques in the field of population biology.

The selection of the management action does not terminate the input of scientists into the adaptive management process (Figure 3). It is at this point that the "Do" and "Evaluate and respond" phases of the adaptive management cycle are pertinent. The implementation of the management action is coupled with initiation of monitoring -- the gathering of data on pertinent ecological factors in an experimental or quasi-experimental framework in order to allow for assessment of the effectiveness and efficacy of the management action. Data from monitoring, its analysis, and its interpretation by technical experts may lead decision-makers to reconsider the

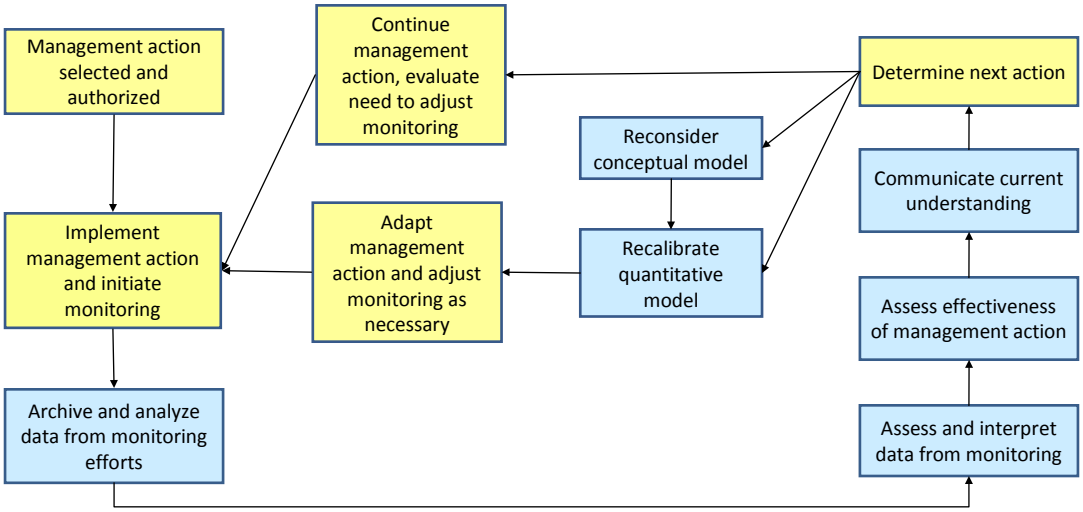

Figure 3. *Adaptive management as implemented after selection of a management action. These process steps correspond with those in the "Do" and "Evaluate and respond" phases in Figure 1.*

conceptual model that links the species and other targeted resources, baseline environmental conditions, and management opportunities, recalibrate the operational model that quantifies their relationships, or continue to implement the management action.

Within the framework set forth in Figures 2 and 3, there are five essential points of engagement where science guides adaptive management.

Developing conceptual ecological models

After an agency has engaged stakeholders in the process of conducting a needs assessment and developing goals and objectives, and has gathered, critically assessed, and synthesized available scientific information, it must specify conceptual models that it will use to inform the development and analysis of alternative management actions (EPA 2003). Conceptual ecological models are essential in informing all conservation-planning efforts, the development of assessment and monitoring programs, the design of research agendas, and serve as a fundamental step in the implementation of an effective adaptive management program. Conceptual ecological models document the human perception of how ecological systems function by describing in graphical or narrative form the structure of the ecosystem and linkages between the species and other biotic and physical elements in the system (DiGennaro et al. 2012). To assure that a conceptual model contributes to the identification of the environmental factors that need to be targeted by resource managers, it must be structured to incorporate explicitly the environmental factors that are affected by ongoing resource management and it should describe how management actions manifest as impacts on target species and their habitats.

Confronting management prescriptions with available data

Adaptive management is an effective way to fine tune a management action that has *a priori* been recognized as an effective means of mitigating harm to targeted resources, which may include species, their habitats, and ecological processes that affect them. Unless adaptive management incorporates the structured process set forth in figure 2 above, it is not a competent

or an efficient way to identify appropriate management actions from among alternatives, or to validate an action that lacks empirical support (Doremus et al. 2011). Because ecological systems are incompletely understood, all management actions are accompanied by uncertainties regarding their probable outcomes. Accordingly, proposed management actions that are intended to be implemented in an adaptive framework must be confronted with available data in a sequential hypothesis-testing exercise to establish by inference their likely benefit to the resources targeted by the actions. Such hypotheses are structured, for example, to differentiate between environmental stressors that appear to be causative agents affecting the status and trends of target species, and those that may simply be correlated with demographic changes. Hypotheses are designed to rigorously consider hierarchies of environmental stressor effects, mechanistic pathways linking management actions and expected environmental outcomes, variable specification, and spatial and temporal aspects of the costs and benefits of alternative actions. A management action that is not falsified through the hypothesis-testing process, that is, is "supported" by available data, can be considered to be a reasonable candidate management action for implementation in the adaptive framework portrayed in Figure 3.

Building quantitative models

Conceptual models serve as the blueprints for the development of quantitative (or operational) models. The quantification process allows for population viability analysis, or some demographic-modeling equivalent, to be used to assess the effects of alternative operational regimes and mitigation activity scenarios on target species. The construction of quantitative models requires formulation of unambiguous physical (in the context of the Delta, hydrological) and ecological relationships that describe mathematically the interaction between model components. The operational model should be a computational manifestation of the conceptual model; however, some evolution in modeling directives and model form will likely occur as new data and understanding become available, as data limitations are realized, or as species objectives are refined or revised during implementation of management actions or environmental restoration efforts. It is essential to employ a group of expert scientists to carry out this essential modeling activity, while a second group in turn verifies and validates the model(s) to confirm that they produce results that are consistent with the current understanding of the affected

ecosystems and species. That process step is necessary to assure that quantitative models exhibit behavior that is consistent with that intended by those who constructed the model, and, using sensitivity analyses, to identify the variables (or parameters) that have a potentially significant impact on model outputs.

Designing monitoring schemes

Monitoring is reasonably described as environmental surveillance; it is a form of applied research, which is approached much as a laboratory experiment is approached, with a rigorous design and application of the scientific method. A monitoring scheme must clearly articulate programmatic goals and objectives, gather data in a framework adequate to detect meaningful changes in the conditions of ecological resources, and develop reliable, scientifically defensible indicators for measuring change. Development of a monitoring scheme must include identification and characterization of the full complement of environmental attributes, including the water-quality, physical landscape, and biotic factors that are believed to affect the status and population trends of target species, the extent and quality of their habitats, and the pertinent ecological processes that directly and indirectly affect both. Direct measures and environmental-condition indicators that are efficient at detecting effects on target species and their essential resources (in other words, validated prior to use) must be identified. In addition, it is necessary to establish detection limits for those measured variables and condition indicators determined, and contingent decision values (thresholds or trigger points) for indicators.

Interpreting returns from monitoring

Adaptive management proceeds, not just by adjusting management actions and protocols to make them more effective and efficient over time; but, by drawing lessons from incoming data and contemporary analysis used to adjust the monitoring design and its implementation. Real-time adjustments to data collection must consider (or reconsider) whether the monitoring scheme's limits in time and boundaries in space are appropriately captured in the allocation of sample locations and temporal sampling frame (including the time intervals between samples). To confirm their value to the monitoring effort, indicator variables need to be re-evaluated

periodically to address the precision with which they can reject null management hypotheses and, where applicable, to confirm that surrogates are sufficiently congruent with the targets they are being used to track. Monitoring schemes must be queried on an ongoing basis to establish whether spatial heterogeneity has been appropriately stratified within sampling designs, units of measure for indicators are effective, and trade offs between marginal gains in precision and statistical power are addressed.

Conclusion

Successful implementation of adaptive management has a mixed track record at best (Allen and Gunderson 2011). Two conclusions can be drawn from this fact: either the concept itself is flawed and should be abandoned, or the concept is sound, but there is a frequent failure to implement it properly. In our view, the latter is true. Structured adaptive management offers a most-promising framework for integrating guidance from science, in the forms of research, monitoring, and modeling, into resource management and policy in the Delta. Given the enormity of the challenge California faces as it attempts to meet the co-equal goals of a more reliable water supply and protecting, restoring, and enhancing the Delta ecosystem, a new and different framework for integrating science into resource management and policy is an imperative in the Delta.

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