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Research article

# Adaptive management of large aquatic ecosystem recovery programs in the United States

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## ABSTRACT

Adaptive management (AM) is being employed in a number of programs in the United States to guide actions to restore aquatic ecosystems because these programs are both expensive and are faced with significant uncertainties. Many of these uncertainties are associated with prioritizing when, where, and what kind of actions are needed to meet the objectives of enhancing ecosystem services and recovering threatened and endangered species. We interviewed nine large-scale aquatic ecosystem restoration programs across the United States to document the lessons learned from implementing AM. In addition, we recorded information on ecological drivers (e.g., endangered fish species) for the program, and inferred how these drivers reflected more generic ecosystem services. Ecosystem services (e.g., genetic diversity, cultural heritage), albeit not explicit drivers, were either important to the recovery or enhancement of the drivers, or were additional benefits associated with actions to recover or enhance the program drivers. Implementing programs using AM lessons learned has apparently helped achieve better results regarding enhancing ecosystem services and restoring target species populations. The interviews yielded several recommendations. The science and AM program must be integrated into how the overall restoration program operates in order to gain understanding and support, and effectively inform management decision-making. Governance and decision-making varied based on its particular circumstances. Open communication within and among agency and stakeholder groups and extensive vetting lead up to decisions. It was important to have an internal agency staff member to implement the AM plan, and a clear designation of roles and responsibilities, and long-term commitment of other involved parties. The most important management questions and information needs must be identified up front. It was imperative to clearly identify, link and continually reinforce the essential components of an AM plan, including objectives, constraints, uncertainties, hypotheses, management actions, decision criteria and triggers, monitoring, and research. Some employed predictive models and the results of research on uncertainties to vet options for actions. Many relied on best available science and professional judgment to decide if adjustments to actions were needed. All programs emphasized the need to be nimble enough to be responsive to new information and make necessary adjustments to management action implementation. We recommend that ecosystem services be explicit drivers of restoration programs to facilitate needed funding and communicate to the general public and with the global efforts on restoring and conserving ecosystems.

## 1. Introduction

Large-scale aquatic ecosystem restoration programs have been initiated worldwide in an effort to recover impaired ecosystem services as well as species diversity (Doyle and Drew, 2008; Palmer et al., 2014). Many programs are turning to adaptive management (AM) because of the enormous cost and effort involved to realize the goals of the programs, and the oftentimes-significant uncertainty associated with restoration actions (Allen and Gunderson, 2011; McFadden et al., 2011; NRC, 2004). AM provides a framework for dealing with uncertainty and ultimately reducing costs by

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maximizing the effectiveness of the actions (Thom, 2000; Thom et al., 2005). Although AM guidance has been developed by the U.S. Department of the Interior (Williams et al., 2009; Williams and Brown, 2012), programs wishing to initiate an AM program can find it difficult to apply AM procedures for their specific case. Variation in stakeholders, goals of the program, unique conditions of the system, governance and funding uncertainty can present formidable barriers for development of the appropriate AM framework (Allen and Curtis, 2005; Allen and Gunderson, 2011; Greig et al., 2013; Levine, 2004; Walters, 1997, 2007). Further, the actual effect of an AM program in improving outcomes as compared with programs conducted under other frameworks is poorly documented (Gregory et al., 2006; McLain and Lee, 1996; Rist et al., 2013; Westgate et al., 2013; Williams, 2011).

Recovery of habitats and associated endangered and threatened species in aquatic ecosystems often encounter similar issues. For example, sediment supply available for shallow water and emergent vegetated habitats is limited by levees, and flow regulation by dams, meant to reduce flood risk and provide navigation benefits, affects the ability of habitats to form naturally. These purposes can conflict, and resolving conflicts involves focused efforts to implement actions with good certainty that authorized purposes are maintained and recovery of ecosystem services are promoted (i.e., MEA, 2005). For example, the National Research Council (NRC, 2011) concluded that success of the Missouri River Recovery Program in recovering endangered and threatened species depended on the sediment supply and dynamics in this heavily managed river system and that the recovery actions represent significant challenges because of competing uses of the system. The NRC recommended a structured approach to decision-making that considered all uses. Runge (2011) has recommended that structured decision making be applied when developing an AM plan to organize the understanding of the system, and tie program goals to decisions by clarifying hypotheses and risks associated with decisions.

Our primary purpose was to synthesize lessons learned on how large-scale aquatic ecosystem restoration and species recovery programs are utilizing AM. Our secondary purpose was to assess the nexus between specific *drivers* for these programs relative to more generic ecosystem services. We suggest that the current program drivers, albeit reasonable, could be used to extend the intended outcomes of programs to broader implications on ecosystem condition. Several flow-related AM programs (e.g., Glen Canyon Dam, Vernalis, and San Joaquin River) were identified as initial examples, and in September 2013, we conducted a literature review to summarize and compare how each program implements key processes such as decision making, monitoring and reporting, and stakeholder engagement (USACE et al., 2013). Though many resources are available from program websites, including goals, science questions, hypotheses and models, we sought a synthesis specific topics of governance and administration from AM practitioners from a wider array of AM programs that would provide helpful guidance to emerging aquatic recovery programs. The application of AM to natural resource recovery programs in large aquatic systems has received criticism for not working. Allen and Gunderson (2011) outlined nine ‘pathologies’ leading to AM failure, and provide suggestions on how these can be avoided. Finally, LoSchiavo et al. (2013) documented five key lessons learned during a decade-long development and implementation of AM within the Comprehensive Everglades Restoration Program.

## 2. Methods

We selected the nine programs to survey based primarily on their aquatic ecosystem recovery and species recovery focus, relatively large scale, status (i.e., AM program approved and under way), and ability of program staff to participate in the process (Fig. 1). The main goals of the interviews were to identify commonly applied best practices and identify specific elements of the AM plans that would help guide AM plan governance and administration. Each interview began with a discussion of the program background, including drivers, goals and services to be generated, and funding, followed by a discussion of the three focus areas. We used detailed notes from the interviews to compose three-page draft summaries, which we distributed to each participant to review for accuracy.

We developed a list of questions (see Supplemental Material

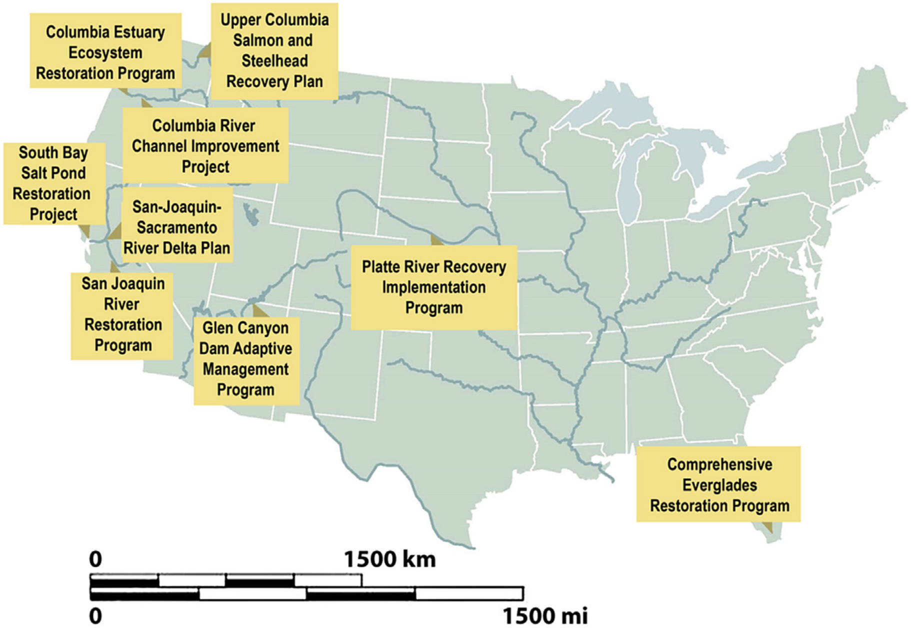

**Fig. 1.** Locations of nine programs interviewed in the contiguous continental United States. Approximate horizontal distance between west and east coastlines is 4100 km.

Questions), related to the three focus areas, to guide conversations with AM program representatives during the phone interviews:

1. **Administration** (e.g., who administers the overall AM process? Who is responsible for decision-making?).
2. **Monitoring and Assessment** (e.g., How are monitoring and research activities selected? Who is responsible for synthesizing and evaluating data?).
3. **Implementation** (e.g., Have decision criteria been established? How are National Environmental Policy Act [NEPA] requirements satisfied?).

## 3. Results and discussion

Although all nine programs differed in scale, scope, and approach, the overall goals were similar: to promote species recovery through protection of critical species, to restore ecosystem services or habitats, and/or to manage a project to mitigate impacts on resources (Table 1).

Each program was unique in how it applied the AM process because of the specific natural resource issues it was meant to address; however, numerous common themes emerged. The *program drivers* were classified into (1) recovery of threatened and endangered species primarily including fish and birds; (2) ecosystem restoration; (3) jeopardy avoidance (i.e., do not harm) for threatened and endangered species; and, (4) mitigation for dam operations. It was obvious that adherence to federal regulations were central to these programs. However, the ecosystem services mentioned in the interviews, and derived by us, were broader. These services were either important to the recovery or enhancement of the drivers, or were additional benefits associated with actions to recover or enhance the program drivers. For example, the Columbia Estuary Ecosystem Restoration Program is directed at restoring native runs of salmonid fisheries stocks to partially mitigate the effects of dams and dam operations. The approach utilized in the program is focused on restoring tidal floodplain habitats where the juvenile fish feed and find refuge during their outmigration to the North Pacific Ocean. Reconnecting and restoring the floodplain not only provides access to refuge and highly productive feeding area, thus increasing the carrying capacity of the system, but also provides organic matter and prey export to the broader ecosystem thus restoring the food web long damaged by dams and diking (Diefenderfer et al., 2016).

Linking effects of management actions to generic ecosystem services is clear in this program. The actions taken in the Columbia River estuary benefit a greater of diversity of life history strategies of salmonids throughout the river basin; some of which have been suppressed for decades or longer (Jones et al., 2014). Thus the actions affect the service of enhancing expression of *genetic diversity* offering high resilience of salmonid populations to variations in climatic conditions and other sources of stress. Salmon are central to the culture of Northwest Native American Tribes, thus restoring habitat for salmon serves to preserve this important element their *cultural heritage*. The economic benefit for communities through *recreation* and *tourism* is also substantial in the region.

The performance measurement for the management actions centers on the benefit to the survival of juvenile salmon. However, this example illustrates where a focus on a single driver provides a nexus for enhancing several ecosystem services. In fact, all of the programs, although focused on one or a few drivers, were taking actions to benefit a variety of ecosystem services. Because aquatic restoration programs are juggling ecosystem or natural resource enhancement under situations where water resources are overallocated, or physically restricted, *water provisioning* becomes an operational element in evaluating restoration alternatives.

Every program we interviewed utilized conceptual and/or numerical models to guide their actions, as well as to reveal critical uncertainties, generate hypotheses, and generate performance measures. In the Columbia estuary example, flows that historically inundated the floodplain have been highly altered by hydroelectric dams. Understanding how to provide hydrological reconnections to the floodplains under altered flow regimes has required both field assessments and modeling (e.g., Jay et al., 2016).

Based on personal assessment by with practitioners, and our assessment, *most of the programs primarily employed passive AM*. Following Gregory et al. (2006), active AM is where managers define competing hypotheses about the ecological outcomes of actions and use experiments to test the hypotheses. In contrast, in passive AM, managers develop a single ‘best’ hypothesis and implement actions according to that hypothesis, while monitoring the effectiveness of the actions. New information is then used to update the hypothesis and actions. In discussions, most of the practitioners argued that active AM applied to large ecosystems could become rapidly more complicated and expensive than passive AM (Gregory et al., 2006). Active AM experiments were carried out by several programs typically in representative areas of the ecosystem and the results extrapolated to actions in the entire system (e.g., Comprehensive Everglades Restoration Plan).

Gregory et al. (2006) developed a set of 15 criteria, posed as questions, for deciding whether to use AM or what type of AM to employ in environmental management problems. They parsed the criteria into the four topic areas of spatial and temporal scale, dimensions of uncertainty, costs, benefits and risks, and stakeholder and institutional support. Although we do not specifically link the criteria with findings from the interviews here, there was very strong concordance between the two. For example, the criterion “Is there policy guidance and leadership support for AM?” was addressed in responses regarding planning, governance, and challenges from our interviews summarized below.

Planning was not one of the original focus areas in the list of questions; however, during the interviews many lessons learned emerged about aspects to consider during initial planning for an AM program. The programs reported that it was important to obtain an authority and mandate to fund and support AM, and buy-in from upper management levels, in addition to other stakeholders, throughout the process so that there is understanding, support, and a sense of shared ownership. It was also critical to identify the most important management questions decision makers need to know up front so that monitoring and research can effectively inform decision-making. To do this, some programs used “big questions” stated in common language to capture management-relevant information needs and communicate program progress. Defining the set of decisions, decision-making processes, and roles and responsibilities at the outset of the AM program ensured an orderly process. Finally, a key factor in a successful program was to identify a single point of contact (e.g., AM Coordinator) that is responsible for day-to-day facilitation and implementation of the overall AM program, as well as individuals and/or groups responsible for each step of the AM process.

Governance is used to describe both the organizational structure and the decision-making process. Defining the governance structure and decision-making process early on as part of the AM Plan is critical (Williams and Brown, 2012). To accomplish this, programs weaved the AM process into agency programs and standard business practices so that AM was central to overall program implementation rather than being a stand-alone program on the side. All programs had active formal communication systems, which included frequent meetings (e.g., monthly) to maintain communication between scientists and decision makers. They

**Table 1**
Summary of key elements of each program. See Supplementary Material Responses for a complete summary of the information from the interviews. (T&E = threatened and endangered species).

| Program | Program funding (approx.) | Program driver | Ecosystem services expected | Program lead(s) | AM approach | Establishment of decision targets or triggers? | Stakeholder engagement approach |
|---|---|---|---|---|---|---|---|
| Platte River Recovery Implementation Program | $157M (for 13-yr. first increment: 2006 to 2019) | Recovery of T&E species | Food, genetic resources, recreation, ecotourism, aesthetic, cultural heritage | Governance Committee composed of signatory (federal and state agencies) and non-signatory (water users and environmental groups) | Passive | No, used qualitative positive, negative or no response of metrics | Organized stakeholder advisory groups with charter tasked with making consensus recommendations to Governance Committee for decision-making |
| Comprehensive Everglades Restoration Plan | $14 billion over 30 years | Ecosystem restoration | Primary production, fresh water, recreation, ecotourism, aesthetic | Two implementing agencies: USACE Jacksonville District and South Florida Water Management District | Passive with Active AM flow experiment | Yes, many are qualitative (based on professional judgment) | Governmental stakeholders are members of interagency project teams; non-governmental stakeholders participate via traditional public review and comment |
| Upper Columbia Salmon and Steelhead Recovery Plan | $125M | Recovery of T&E species | Food, genetic resources, recreation, ecotourism, cultural heritage | Upper Columbia River Salmon Recovery Board, UCSRB, (non-profit organization) | Passive | No, using a trajectory approach as opposed to a target-based approach | No organized group for stakeholders not included on UCSRB; primarily use traditional methods for public/stakeholder input. Public can participate in local recovery forums (watershed action teams) and individual projects |
| Columbia Estuary Ecosystem Restoration Program | $20M/year for restoration, $4M/year for research | Recovery of T&E species and ecosystem restoration | Food, genetic resources, recreation, ecotourism, cultural heritage | Jointly managed by program managers from two funding agencies: USACE Portland District and BPA | Passive | Yes, targets established for survival benefit units of juvenile salmon | Several independent organizations that each have an organized stakeholder group use traditional methods for public/stakeholder input |
| Columbia River Channel Improvement Project | $200,000 - $500,000/year over 10 years | Jeopardy avoidance for T&E species | Genetic resources | AM Team composed of representatives from federal and state agencies and Port of Portland | Passive | No, risk endpoints | No organized group for stakeholders not on AM Team; use traditional methods for public/stakeholder input |
| Glen Canyon Dam Adaptive Management Program | $11M/year | Mitigation for dam operations | Fresh water, recreation, ecotourism, cultural heritage | AM Work Group (FACA committee of 25 stakeholders and agency representatives) | Passive with active AM experimental flow releases | No | Organized stakeholder groups tasked with achieving unanimous consensus with voting and non-voting members |
| South Bay Salt Pond Restoration Project | $8M for Phase I studies and monitoring | Ecosystem restoration | Water purification, recreation, ecotourism, educational | Executive Leadership Group and Project Management Team (PMT) composed of federal and state agencies and local entities | Passive with active AM experiments to address key uncertainties | Yes, initial restoration targets are primarily qualitative/directional | Organized stakeholder group (Stakeholder Forum) that makes recommendations |

(*continued on next page*)

**Table 1** (*continued*)

| Program | Program funding (approx.) | Program driver | Ecosystem services expected | Program lead(s) | AM approach | Establishment of decision targets or triggers? | Stakeholder engagement approach |
|---|---|---|---|---|---|---|---|
| San Joaquin River Restoration Program | $3–4M reduced to <$1M to keep focus on infra-structure projects | Recovery of T&E species and ecosystem restoration | Fresh water, genetic resources, water purification, recreation, ecotourism | Five implementing agencies: three federal and two state | No formal approach, have incorporated some AM components | Yes, have specific numerical goals for fish (i.e., 500 returning adults by 2024) | Stakeholders primarily represented by settling parties; other stakeholders organized into group which provides input to decision makers, but most engagement done one-on-one |
| Sacramento-San Joaquin River Delta Plan | $11M/year, excluding federal and state reimbursement; 2/3 for Delta Science Program | Ecosystem restoration | Food, fresh water, genetic resources, water purification, cultural heritage | Delta Stewardship Council composed seven members representing different areas of California | Primarily passive, but encouraging active AM experiments | No | No organized group for stakeholders; use traditional methods for public/stakeholder input |

Note: 'Ecosystem services expected' are our interpretations of the services inferred by program goals, using the categories provided in the Millennium Ecosystem Assessment (MEA, 2005).

mentioned that clear and frequent communication built trust among all groups involved in the AM process and maintained a foundation of trust and integrity.

One of the strongest recommendations from the programs was the need for a science program that is focused on achieving three key attributes: credibility, relevance (must be relevant to decisions), and legitimacy. Further, stakeholders must be involved throughout the process to understand why the research is needed, and how decisions will be affected by the research findings.

The programs stated the importance defining roles and responsibilities related to monitoring, evaluation, and communication, as well as establishing decision criteria and triggers, during development of the AM Plan (Williams and Brown, 2012). Some programs used a qualitative or directional (trajectory) approach at the outset of an AM program if knowledge gaps made it difficult to define specific quantitative targets and decision triggers, and designed the AM program so it provided information to define quantitative targets and triggers over time. They prioritized and linked research and evaluation to AM objectives and program goals, and continuously reinforced those connections through presentations and products so decision makers understand that the research being conducted is applicable to the program and can be used to make adjustments. They found that by providing the key questions to principal investigators, along with previous study results, the researchers could develop proposals that clearly linked to program goals and critical questions. Finally, some programs conducted in large basins set up a collaborative forum to coordinate and share scientific information (e.g., modeling, geographic information system [GIS] tools), provide a venue for communicating across programs, and facilitate regional and landscape-scale evaluations.

All programs faced realities and challenges to implementing a 'text book' AM program (e.g., Williams et al., 2009). One of the most often mentioned challenges was obtaining enough funding to support the AM process throughout the duration of the AM program, particularly funding for monitoring, applied research, data storage and management, and active AM experiments. In general, natural ecosystems respond over extended periods of time to manipulations, and predicting the rate and direction of change in the system toward a goal can be fraught with uncertainty. Having to adjust a large program, especially if it adds cost, creates a difficult situation for program managers who are focused on achieving goals. This situation can be mitigated to some degree by arranging for contingency funds, and alerting funders, managers and stakeholders that the nature of AM can result in higher overall program costs. Inherent in the arguments by program leads and their agencies, was the point that for large multifaceted programs AM can offer a lower cost solution over the life of the program. After analyzing studies from 235 marine coastal restoration projects, Bayraktarov et al. (2016) concluded that increasing the amount of investment in a project will not necessarily improve the changes of success, but that care in site selection and restoration technique were likely the most important factors determining success. Based on our interviews, AM was considered a useful approach to investigating these two and other factors affecting success.

## 4. Conclusions

Our study of programs applying AM essentially found results similar to those in previous studies (e.g., LoSchiavo et al., 2013; Allen and Gunderson, 2011). The programs generally adhered to procedures for AM outlined by Williams et al. (2009), but in application, nuances to the procedures emerged. Recurring problems (i.e., termed 'AM-lite') identified by Fischman and Ruhl (2015) in the application of AM, including failure to establish objectives, describe monitoring protocols, define decision thresholds or to identify specific actions that will be triggered when thresholds are crossed, were not apparent in the programs we interviewed. In programs where triggers were not used, trajectories or qualitative (e.g., positive, negative response of metrics) were enough to drive decisions (e.g., Platte River Recovery Implementation Program). That said, the programs differed in how AM is applied, which was the result of an evolution of application based on experience … essentially *learning how to do AM by doing AM within the confines of the ecosystem and necessary governance*.

Because there were species-based drivers of the programs, most with regulatory ties, there was no explicit effort on the part of the programs to express results in terms of ecosystem services. However, it was apparent to us that generic ecosystem services were linked to actions through models used to organize the work of the programs. The results available from the programs (e.g., Columbia River estuary) prove that the actions were delivering a positive response in the drivers as well as ecosystem services. That said, we suggest that ecosystem services become a more explicit aspect of restoration and recovery programs in order to provide a broader context in terms of an ecosystem-wide scope, and justifying funding for, and assessing the fundamental benefits of, these programs. The most frequently mentioned challenge we heard was securing adequate long-term funding for the program. Expressing outcomes in terms of ecosystem services also provides a link to a universal vocabulary that can be used to synthesis results globally, as well as provide a nexus for evaluating economic and social values of restoration and conservation programs (e.g., Gregory and Wellman, 2001; Ingraham and Foster, 2008).

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2016.08.001.

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