ADAPTIVE MANAGEMENT APPLIED TO AQUATIC NATURAL RESOURCES

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Abstract. Most natural resource management is conducted under conditions of considerable uncertainty; rarely do we have 100% confidence that management actions will deliver the predicted outcome. Adaptive management is a scientific approach to management that explicitly deals with this uncertainty. It involves predicting management outcomes, collecting data to test those predictions (monitoring), revising the predictions and adapting the management strategy to reflect the new knowledge. In this session, we introduce adaptive management and describe three projects where this tool is applied to aquatic resources.

INTRODUCTION

Adaptive management is a specific type of *structured decision making* (Lindley 1985), the formal process that guides the making of all kinds of decisions that have uncertain outcomes, for example, deciding whether to build a factory, approve a drug, or launch a rocket. In such applications, while any specific outcome of a decision can never be predicted with absolute certainty, its probability of occurrence is generally known. But often, these probabilities are unknown or are at the center of dispute between affected parties. For example, if the chance of rain is reported by one radio broadcaster at 70% and by a second one at 20%, is it appropriate to prepare for rain if doing so is especially cumbersome? What if getting wet is terribly unpleasant?

In settings where decision making is affected by such *structural uncertainty*, where decision opportunities are recurrent, and where the outcome of each decision can be measured, adaptive management may offer guidance in the making of good decisions while maintaining a focus on reducing this uncertainty over time (Walters 1986, Williams 1997, Gregory et al. 2006). All applications of structured decision making are model-based, meaning that a decision model is used to specify the probability of each possible outcome of any proposed decision. Likewise, adaptive management is also model-based, but structural uncertainty implies that more than one model can plausibly describe the outcome probabilities. Therefore, adaptive management utilizes a set of *competing models* to portray this uncertainty.

Adaptive management is a cyclical process of decision evaluation, prediction, measurement, and model updating (Nichols et al. 1995, Moore et al. 2005). First, each decision alternative is evaluated given the current assignment of belief or credibility to models in the model set: under profound uncertainty, each model could be assigned equal credibility. When a particular decision alternative is chosen, the outcome for that decision is predicted for each model in the set. After the decision has been implemented, the actual outcome is measured. Lastly, the share of credibility assigned to each model is updated on the basis of how well the measured outcome is matched by each prediction. With the new credibility assignments in place, the process is repeated at the next decision opportunity. The accumulation of credibility in one or more models in the set reflects reduction of structural uncertainty through time, with a consequent increase in decision quality. Thus, from a starting point of complete uncertainty where each candidate model tugs equally on the selection of a decision, information returned from the system leads to an “adaptation” in how the competing models influence the decision process.

Applying this approach to the weatherman example above, the decision whether or not to prepare for rain on any given day would take into account how well each broadcaster had historically predicted the realized outcome. Therefore, early in this process and lacking any history of forecasting performance, we would expect our decision maker to make quite a few unfortunate – but not *bad* – decisions. But as this history accumulates, the acquired information serves to refine the predictive capability of the model set, leading to more satisfying decisions.

CASE STUDIES

We describe three projects for which an adaptive management approach to conserving aquatic biological resources has been developed. These projects address broadly differing management issues: water withdrawals in southwest Georgia, hydropower management in a

Piedmont river in Alabama, and urban development in north Georgia. In each case, however, adaptive management entails the core components of model-based predictions, monitoring to test predictions, and a framework for updating models and adapting the management strategy.

Fish populations in the lower Flint River system

Stream flow regulation is one of the most important issues facing natural resource managers and planners in Georgia. In recent years, the rapidly growing population has led to increased water demands from agriculture, industry, and municipalities (Fanning 1999) and increased strain on stream ecosystems (Richter et al. 1997). Nowhere is this more evident than in the lower Flint River Basin (FRB), where the State has established the Flint River Drought Protection Act to conserve water during critical drought periods. Water conservation decisions, such as where best to conserve water, are complicated by the complexity and uncertainty associated with the response of ecological systems to changes in streamflows. Conservation efforts can be effective only if decision-makers are informed as to the effects of alternative management actions. Thus, our objectives were to build spatially-explicit decision models for evaluating the effects of water use in the lower FRB and examine the sensitivity of model predictions to various ecological assumptions.

We studied fish communities, water quality parameters, and habitat availability at 29 study sites representing the dominant geomorphologies, channel types, and stream sizes in the lower FRB. Fishes were sampled, habitat measured, and quality monitored in spring, summer, and winter from 2001- 2004. Streamflows during the study period included among the lowest and highest seasonal flows ever recorded at long-term gauges in the basin. This provided us with a unique opportunity to observe changes in fish communities, habitats, and water quality over a large range of flows. Based on our observations, we developed and evaluated the relative support of models representing hypothesized influences of streamflow on the colonization and persistence of fishes (Peterson et al 2006). The four most-plausible models, representing different biological mechanisms, then were used to create decision models for estimating changes in species-specific distribution patterns under four simulated water use scenarios.

Simulations of variation in fish distribution patterns under current or projected water use scenarios predicted losses in species distribution compared to a no water use scenario for all species considered and regardless of the biological mechanisms simulated. However, a sensitivity analysis indicated that estimates of the effects of water use on species-specific distribution were strongly influenced by the assumptions about the dynamics of the system (i.e., *structural uncertainty*). For example, assumptions about fish colonization dynamics had a profound effect on spatially-explicit changes in fish distribution patterns. To incorporate the structural uncertainty, we created composite predictions using weights representing the relative credibility of each models in the model set. The composite predictions indicated losses in species distributions of 17% and 39% in the Ichawaynochaway and Spring Creek basins, respectively. Losses also were, on average, greatest for the projected increased water use scenario and smallest for the current water use scenario.

Our evaluation demonstrated that decisions on how best to conserve water for ecological needs are complicated by the uncertainty about biological system dynamics. For example, assumptions about biological mechanisms would strongly influence estimates on where (e.g., which streams) water conservation efforts would be most effective. We believe that an adaptive approach to managing flows in the lower FRB could be incorporated into dynamic decisions situations, such as the Flint River Drought Protection Act, where decisions on when and where to conserve water depend on the current state of the system (e.g., drought conditions) and are likely to be revisited over time. Feedback, in the form of monitoring data, could be provided using existing sampling efforts by State fishery biologists. Such an approach would be used to resolve the uncertainties about the dynamics of fish populations in the lower FRB and improve water future resource decision-making.

Hydropower dam operations in the Tallapoosa River

Most major river systems in the Southeastern U.S. are managed for multiple uses including hydropower, navigation, flood control, recreation and water supply, as well as support of natural resources such as native biota. Managing river systems to meet these diverse uses, some of which are conflicting, requires innovative approaches that can incorporate competing objectives and that allow reduction in the uncertainty inherent in predictions of how river ecosystems will respond to particular changes in flow regimes. New approaches are particularly needed to support re-licensing decisions by the Federal Energy Regulatory Commission (FERC). Objectives of this work were to develop a template for incorporating adaptive management and decision support into the FERC re-licensing process (Kennedy et al. 2006, unpublished report, Alabama Cooperative Fish and Wildlife Research Unit; www.rivermanagement.org).

We used resource information for the 78 km, unimpounded reach of the Tallapoosa River downstream from R.L. Harris Dam in Alabama to develop an adaptive management template for hydropower operations. This reach of the Tallapoosa contains habitat for at least 57 native riverine fishes, including five species that are endemic to the Tallapoosa system. The dam is operated as a hydropeaking facility with water released through one or two turbines in pulses, typically of 4-6 hours duration, once or twice during weekdays.

Resource management objectives include achieving and maintaining diverse aquatic communities of native species in the regulated reach below the dam. A number of research studies (e.g., Travnichek et al. 1995; Freeman et al. 2001; Andress 2002) have provided data describing responses by fishes to various components of the regulated flow regime. However, understanding of the river ecosystem is insufficient to predict with certainty how particular species will respond to particular changes in dam operations.

A decision-support model was developed based on 10 fundamental objectives and hypothesized relations between flow and system response. Fundamental objectives were derived during a workshop for watershed stakeholders, and addressed river boater satisfaction, reservoir recreation opportunities, river landowner satisfaction, cost and flexibility for hydropower production, and condition of native riverine fauna and flora. Flow features hypothesized to affect biological responses were (1) depleted flows during non-generation periods, (2) flow instability from hydropeaking operations, and (3) thermal-regime alteration. Modeled decisions included alternative flow regimes (i.e., daily flow operations at the dam), provision of extended periods of stable flow (i.e., without hydropeaking) of differing durations and timing, and provision of enhanced October flows for recreational boaters. Relations between flow decisions and system responses were modeled based on probabilistic dependencies from long-term empirical data, from expert opinion, and from stakeholder opinion. These relations were incorporated into a Bayesian network for use as a decision support model.

Alternative flow-management decisions were evaluated by examining the expected values associated with predicted outcomes with respect to the management objectives. Importantly, the model allowed explicit quantification of the uncertainty associated with system response to management actions. The process resulted in stakeholders and management agencies agreeing on initial changes to the operations of the dam, with predictions of system responses to those changes and a monitoring program to test the predictions.

The framework of stakeholder involvement and decision-support modeling developed in this project is intended to support periodic re-evaluation of dam operations with respect to management objectives in the Tallapoosa River. This framework may also provide a useful template for managing flow-regulated rivers elsewhere.

Adaptive management in the Etowah Aquatic HCP

The Etowah River system, located to north of metropolitan Atlanta, Georgia, has been the focus of a process intended to assist county and municipal governments deal with population growth and urban development while protecting aquatic resources, including imperiled stream fishes. The resulting Etowah Aquatic Habitat Conservation Plan (HCP; www.etowahhcp.org) comprises a set of policies to be implemented by the participating governments. The policies address primary threats to imperiled stream fishes: stormwater runoff, erosion and sedimentation, road crossing design and construction, utility line crossings, riparian buffer loss, and reservoir locations. Etowah species affected by these stressors include three stream fishes that are listed as Threatened or Endangered under the federal Endangered Species Act (ESA). Actions that result in harm to listed species or their habitat (i.e., 'take') are prohibited by the ESA unless explicitly permitted. Development of an HCP is mechanism by which non-federal entities can obtain permission to engage in activities (in this case, urban development) that may result in take of listed species. Once the U.S. Fish and Wildlife Service (Service) approves the Etowah Aquatic HCP, participating jurisdictions (that implement the policies through ordinances and regulations) will receive an Incidental Take Permit that allows for the specified level of take of the species covered by the HCP.

Adaptive management is an essential component of HCP implementation. To approve an HCP, the Service must find that actions permitted by the HCP will not jeopardize the survival and recovery of the covered species. This means that it must be possible to project the status of the species under future conditions, including novel conditions (such as urbanization of the upper Etowah watershed) that the species have not yet experienced. Management decisions in these cases must be based on best-available understanding of (1) how species will respond to management actions (e.g., land use changes under specific development policies), (2) how well management actions can and will be implemented, and (3) future environmental conditions (e.g., rainfall patterns). Obviously, none of these factors can be known with certainty, and uncertainty is further compounded by the error inherent in measuring variables such as fish populations or extent of impervious cover. Adaptive implementation of an HCP allows explicit quantification of the uncertainty in future conditions and species responses, in a framework that specifies how new information will be gathered and used to adjust management, as necessary, to ensure species protection as development proceeds.

The adaptive management components of the Etowah Aquatic HCP are (1) models that predict species persistence and abundance given HCP implementation, (2) a monitoring program designed to test those predictions and provide data for improving the models, and (3) a process for using updated models to guide future development decisions. The models are spatially-explicit expressions of probabilities of species occurrence or abundance for future build-out scenarios under the HCP, and are based on observed relations between occurrences of the listed stream fishes and effective impervious area (Wenger 2006). The models are critical in allowing prediction of where species should maintain strong populations in the future, as well as where species are expected decline under assumptions of future growth patterns. After the HCP is approved and adopted by the participating jurisdictions, populations and stream habitat will be monitored at locations chosen to test model predictions and to track the status of the fish populations. Monitoring will provide new observations of species responses to development, allowing the models to be updated. Future data may show that the species covered by the HCP are less sensitive to development than current conditions indicate, in which case additional development might occur without exceeding limits established by the Service. Alternatively, if the covered species decline more than predicted under future conditions (and during the life of the HCP), the HCP allows for adjustment in policies regulating development to improve species protection.

CONCLUSIONS

Water resource managers and planners are faced with difficult decisions on how to satisfy the socio-economic needs of the public while maintaining or restoring properly functioning ecological systems. Such decisions are fraught with complexity and uncertainty associated with both ecological systems and multiple management objectives (e.g., hydropower, recreation, ecological) and alternatives under consideration (e.g., minimum flow, water use policies). In most instances, managers do not have the luxury of delaying decisions until key uncertainties are, if they even can be, resolved. Adaptive resource management provides decision makers a means to evaluate the relative value of alternative actions with respect to resource objectives, given the current level of uncertainty of system dynamics, and in anticipation that reducing uncertainty (i.e., learning) will improve decision-making through time. Here we have demonstrated that adaptive approaches to water resource management are not only feasible, but that also they can lead to greater insights into biological processes and improved decision-making.

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