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# Introducing Adaptive Management for Natural Resources: An Estuary Case Study

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**ABSTRACT** Adaptive management (AM) is a systematic process for improving environmental management policies and practices in a way that incorporates uncertainty and learning. In the realm of natural resources, AM is increasingly being used by management agencies in the United States (e.g., U.S. Fish and Wildlife Service and the National Park Service) and non-governmental organizations (e.g., The Nature Conservancy and World Wildlife Fund). As such, it is important that students in natural resources, conservation, and environmental management majors become familiar with the concepts of AM. This case study uses the real-world example of the Herring River estuary restoration project (Cape Cod, MA) to demonstrate the theoretical processes involved in adaptively managing an ecosystem governed by ecological uncertainties and a wide range of stakeholders. Through the incorporation of role-play, students gain experience with the AM framework while actively learning about the role of uncertainty and stakeholder perspectives in decision-making. The case was tested with a group of students from an introductory course on environmental conservation to gauge student interest and verify proof of concept. Following the case study, students felt that they would be able to define adaptive management and explain the concept to their classmates, despite no prior exposure to AM.

The field of natural resources conservation and management is inherently interdisciplinary and adaptive, forcing conservationists to think outside of their traditional fields and make judgements on management approaches that constantly evolve based on disciplines and value systems other than their own (e.g., Kessler et al., 1992; Vonhof, 2010). To satisfy the needs of employers and ensure that students are prepared for the workforce, universities are working to create more interdisciplinary curricula that focus on active learning strategies; students learn from a broad base of natural and social sciences in a way that encourages engagement and application of their new knowledge and skills (Vincent and Focht, 2011). It will be necessary to incorporate courses and activities that introduce students to the frameworks commonly implemented in resource management as well as offer opportunities for experiential learning (Millenbah and Millspaugh, 2003) as departments look to establish and adapt curricula to the needs of employing organizations (Millenbah and Wolter, 2009).

One particular management framework gaining utility is adaptive management (AM). As a management strategy, AM emphasizes the need to use management opportunities as learning experiences. First introduced by Holling and Walters (1978), AM has been adopted by many governmental and non-governmental organizations (NGO), including the U.S. Department of Interior (Williams et al., 2009), the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS, 2002), the U.S. Environmental Protection Agency (EPA, 2009), The Nature Conservancy (TNC, 2007), World Wildlife Fund (WWF, 2014), and the National Audubon Society (Audubon, 2014). The use of AM by these entities suggests that the skills and tools required to implement AM will be critical for those looking to enter natural resources conservation and environmental management professions. Although many organizations seek AM skills in prospective employees, few university programs provide opportunities for developing these skills. Here we offer a real-world case study of the Herring River estuary in Cape Cod, MA, to facilitate active learning of AM concepts through context-specific problem-solving featuring role-play (Ryan and Campa III, 2000) and to explore the issues surrounding a multi-stakeholder management decision within the AM framework.

## THE CASE

### History of the Estuary

The Herring River estuary encompasses nearly 400 ha and more than 10 km of waterways that were historically home to one of the largest river herring (which collectively refers to the closely related Alewife, *Alosa pseudoharengus* and Blueback Herring, *A. aestivalis*) fish runs of the region (Exhibit 1; Massachusetts Energy and Environmental Affairs, 2015). In 1909, the town of Wellfleet, MA, received funding from the Massachusetts Legislature to construct a dike at the mouth of the Herring River in order to control mosquitos and increase tourism. With the installation of the dike,

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**Abbreviations:** AM, adaptive management; HRTC, Herring River Technical Committee; NGO, Non-Governmental Organization; NPS, National Park Service.


Exhibit 1. Location of the Herring River estuary in Cape Cod, MA. Map created using Massachusetts 2008–2009 USGS Color Ortho Imagery (MassGIS, 2008) and a Mass Water Features layer (MassGIS, 2010).

the 120-m natural tidal stream was replaced with a 2-m wide pipe with unidirectional flow into the bay (Exhibit 2). By the mid-1930s, the river had also been channelized and straightened and mosquito ditches dug. The new conditions lowered water levels and decreased flooding associated with tidal flows, which allowed for residential and commercial developments in the floodplain on land that was previously unavailable, and allowed freshwater vegetation to replace the native salt marsh species (Herring River Technical Committee, 2007; NPS, 2011).

Bidirectional flow was partially restored in the 1960s when the tide gates of the dike deteriorated and became rusted in an open position. This increased tidal exchange allowed for some recovery of the salt marsh vegetation and shellfish began recolonizing areas above the dike where they had not been seen for several decades (NPS, 2011). However, the increased tidal exchange also increased the risk of flooding of private properties and roads. After several years of conflict between residents and businesses impacted by flooding and advocates for ecological restoration, the dike was rebuilt in 1974, but with an adjustable sluice gate to simulate the modest levels of tidal exchange that were occurring prior to the repair. Despite this modification, the benefits initially observed during the dike leak of the 1960s have largely been reversed and water quality in the Herring River has since declined. In the 1980s, fish kills of river herring and American eel (*Anguilla rostrate*) occurred as a result of the low levels of dissolved oxygen, low pH, and high metal concentrations in the estuary (NPS, 2011). In 2003, under the federal Clean Water Act, the Herring River was listed as impaired due to these conditions (NPS, 2011; Department of Interior, 2012).

The National Park Service (NPS, 2011) has identified a number of concerns related to the health of the Herring River estuary including restrictions to natural tidal flow, changes in plant communities from saltmarsh species to freshwater species, degradation of water quality, changes in sedimentation leading to land subsidence, increased mosquito populations, and decreased ability of river herring to migrate. Although restoring natural tidal flows may be helpful in alleviating some of these environmental impacts, the development that has occurred in low-lying areas since the dike's installation preclude simply restoring flows.

## Goals and Decision Makers

Over the past several years, local, state, and federal partners and NGOs have expressed support for restoring the Herring River estuary. In 2005, the town of Wellfleet and Cape Cod National Seashore signed a memorandum of understanding that established the Herring River Technical Committee (HRTC), which consists of town governments (Wellfleet, MA, and Truro, MA), state agencies (Massachusetts Department of Environmental Protection), federal agencies (NPS, FWS, National Oceanic and Atmospheric Administration, and U.S. Department of Agriculture), scientists from several universities and research centers (Marine Biological Laboratory in Woods Hole, MA), and local stakeholders such as anglers, businesses, country club members, and residents (NPS, 2011; HRTC, 2007).

The goals of the HRTC include: (1) restoration of the natural tidal range and salinity throughout the floodplain including all tributary stream basins; (2) reestablishment of the physical connection with the marine environment for exchange of nutrients, organic matter, and biota; (3) restoration of the natural sediment budget to counter wetland subsidence; (4) improvement of water quality realized by increased salinity, alkalinity, and pH, and decreased metals and coliform bacteria; (5) control of salt-intolerant plants including invasive species; (6) reestablishment of native saltmarsh plants and animals; (7) improvement of estuarine fish and shellfish


Exhibit 2. Locations of the current tidal structure built in 1909 and of the proposed dam in the Herring River estuary in Cape Cod, MA. Blue lines indicate the natural 120-m wide tidal outlet and red lines indicate the current 2-m wide outlet. Map created using the ESRI Imagery Basemap.

habitat; (8) improvement in the natural control of mosquitoes and other nuisance insects; and (9) improvements in recreational access including boating, finfishing, shellfishing, and bird watching (NPS, 2011; HRTC, 2007).

## The Decision

As part of the Draft Environmental Impact Statement developed by the stakeholders, four alternatives were chosen for consideration (Department of Interior, 2012). The first alternative is to take no action and continue tidal restriction. The second alternative is to remove the dike and install a new tidal control structure, which would allow limited tidal exchange. Increased tidal flow under this alternative would require addition flood prevention plans for low-lying roads and properties. The third alternative involves construction of the new tidal control structure as well as construction of a dike to exclude tidal flow to low-lying properties. The new dike would help to provide flood impact mitigation, but would require long-term maintenance. The fourth and final alternative proposed is similar to the third; however, the dike would allow partial tidal flow. This would restore tide elevations and tidal inundation to natural levels, but would also necessitate flood protection for low-lying properties.

A final decision on which alternative will be chosen has not been made at the time of this writing, but is expected in the near future. Regardless of the alternative chosen, AM will be used at the site by incrementally increasing tidal flows in the estuary. This will allow managers to monitor the impacts on both the ecosystem and surrounding homes and businesses and take appropriate actions to mitigate negative impacts, including removing or altering man-made structures (Department of Interior, 2012).

# TEACHING NOTES

## Case Goals and Objectives

The two main objectives of this case study are to (1) introduce students to the concepts and processes of AM and (2) encourage active learning by students through the use of role-playing and decision-making. The use of case studies in natural resources classes can provide students and instructors with an active-learning experience applicable to various class lengths and sizes (Villamagna and Karpanty, 2009). The hands-on experience can challenge students to think critically and reflect on real-world problems and processes. An interrupted case format (Herreid, 2005) is used to provide information to students piece-by-piece over a series of "rounds." The interrupted case study format is designed to address learning objectives by engaging students through multiple management rounds with increasing levels of information in each, as would occur in real-life management situations (Villamagna and Karpanty, 2009). For this case study, using a small-group discussion structure provides the opportunity to enforce interdisciplinary understanding of situations and concepts and allows students to practice communicating academic and management concepts to their peers.

## Introduction to Adaptive Management

There is a strong body of literature on the theory and application of different AM frameworks in natural resources. Our goal is to teach the basic principles of AM but not provide an exhaustive overview, which could warrant a stand-alone course. By introducing the conceptual underpinnings of AM early during their undergraduate careers, we hope that students can apply AM concepts and

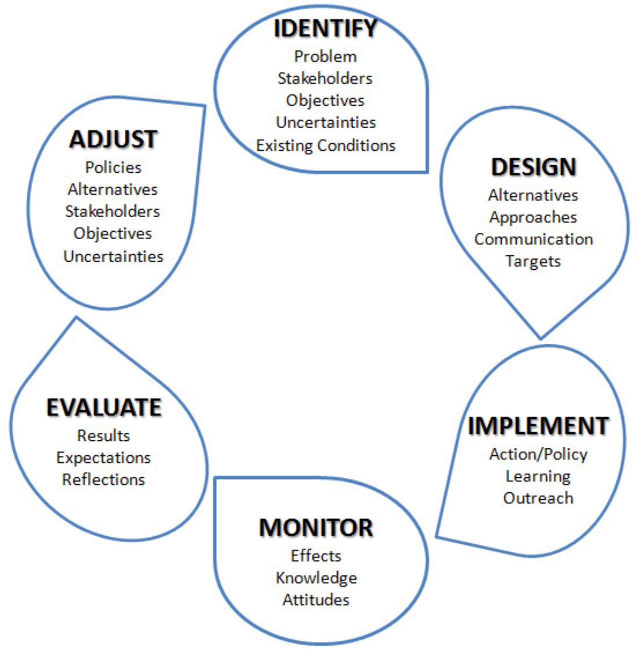



Exhibit 3. Adaptive management framework and iterative process.

processes during future coursework and think critically about future natural resources decision-making. For additional readings about AM, we suggest Holling and Walters (1978), Rist et al. (2013), Allen and Gunderson (2011), and Olsson et al. (2006), among others.

Ecological differences and uncertainties exist for every type of ecosystem, which can complicate management. Why do restoration efforts work in some locations and not others? How will climate variability and change affect habitat management? These knowledge gaps are referred to as uncertainty. Environmental decisions and management always involve some degree of uncertainty. One weakness of many conventional management strategies is that they do not explicitly address uncertainties prior to management activities (Holling and Meffe, 1996). Adaptive management actively addresses management uncertainties by facilitating learning throughout natural resources planning and management activities. In creating a management plan for the Herring River estuary, the NPS is employing an AM framework.

Learning is the insight gained from analyzing and interpreting data that can be applied to future management decisions. By incorporating learning into a management framework, management actions are treated as experiments that work to reduce uncertainty about the ecological and social systems surrounding the management area of concern. In AM, managers can use approaches to facilitate learning passively or actively. Passive and active AM describe the way in which a plan may recognize, account for, and ultimately reduce uncertainty (Williams, 2011). Passive AM is similar to conventional management in that a single optimal alternative is originally implemented. However, this strategy uses data gleaned from each phase of the management process to adjust future management in a way that reflects the dynamics of the resource or ecosystem. Active AM differs in that it incorporates experimentation into the management and learning processes. Experimental designs allow managers to implement multiple management alternatives simultaneously or sequentially, allowing the exploration of various factors or variables that may be helpful or harmful to achieving objectives, thereby maximizing learning.

There are two additional characteristics of AM that distinguish it from other management techniques. First, AM often considers perspectives from multiple stakeholders. This is not unique to AM, but it is a key element rather than an ancillary component to developing management plans. Stakeholder involvement is fostered during all parts of the management process including priority setting, planning, implementation, and evaluation stages (Davies and White, 2012). Creating an environment of collaboration among often diverse stakeholder groups builds trust and can create a more comprehensive understanding of the management issue.

Secondly, AM is an iterative process, so the decision-making and management process is repeated through several cycles with the intent of reaching a desired target, objective, or goal. The AM process includes identifying the problem, deciding on a management approach, implementing management actions, monitoring and analyzing environmental outcomes, evaluating the effectiveness of management, and, ultimately, using what has been learned to adjust future decisions (Exhibit 3). Monitoring environmental or ecosystem responses to management decisions improves knowledge about the system. Learning is achieved by analyzing the monitoring data and assessing how well the management decision addressed the objectives. Adaptive management routinely, and therefore iteratively, integrates this new knowledge and learning to improve future management decisions (Williams and Brown, 2014).

## Use of the Case

This particular case was tested with a group of 16 students from an introductory Environmental Conservation course (University of Connecticut, NRE 1235, Spring 2015). The group was predominately underclassmen, none of whom had prior exposure to AM. At the end of the 2-hour period, students were asked to evaluate the case study and provide feedback. Only half of the students claimed a major classified as natural sciences. Majors varied, ranging from natural resources and environmental science to nursing and pharmacy. One-fifth of the students planned to go into a management- or extension-related career.

We structured the case study into three rounds of management, to introduce students to the iterative nature of AM and to juxtapose this with conventional management. In its current form, this case study takes about 2 hours to conduct, but it could be modified to take either more or less time, depending on classroom constraints.

### Round 1: Conventional Management

In the first round, students are introduced to the background information from the Herring River case. Key terminology may also be reviewed as necessary, including what natural resources are, abiotic vs. biotic resources, and what constitutes management. Students are divided into groups of 4 or 5 and are asked to assume the role of the NPS, tasked with developing a management plan for the Herring River. The instructor then provides each group with management actions from which they can choose.

For the sake of simplicity, students are provided with three management alternatives: (1) no action;

Exhibit 4. Hypothetical alternatives of the Herring River Restoration Management Plan. Students choose to implement one of the following three management alternatives during the case study.

| | Management alternative | Economic cost | Ecological cost | Pros | Cons |
|---|---|---|---|---|---|
| 1. | No action | Low | High | • No flooding<br>• No change in sedimentation or disturbance of shellfish beds<br>• Continued unimpeded boat access | • Tide restriction continues<br>• Potential loss of fin and shell fisheries<br>• Increase mosquito population<br>• Loss of salt marsh |
| 2. | Widen culvert | Medium | Low | • Complete restoration of tidal flow<br>• Increase water quality/salinity<br>• Decrease mosquito population<br>• Promote salt marsh species<br>• Allow herring migration | • 2 year time frame<br>• Flooding of roads/properties<br>• Need additional flood prevention measures/plans |
| 3. | Widen culvert and build dam | High | Medium | • Flood prevention<br>• Partial restoration of tidal flow<br>• Increase in water quality/salinity | • 5 year time frame<br>• Construction damage to wetlands<br>• Not full restoration |

(2) widening the culverts of the original tidal structure; or (3) both widening the culverts of the original tidal structure and constructing a dam to protect low-lying development from expected flooding (Exhibit 4). These options and their associated outcomes are hypothetical and are constructed solely for the purpose of this case study. The three options represent a range of economic costs and ecological gains that will encourage discussion and debate among the groups in future rounds.

Within their groups, students should take some time to determine which alternative is the best option based on the goals of the NPS and the problem presented at the beginning of the session. Once they have selected a management alternative, each group randomly draws one of three plausible future scenarios that describes the consequences of their decision over the several years following the implementation of that decision. These future scenarios are specific to each alternative and incorporate a mixture of expected and unexpected management results, as well as events related to economic, social, and environmental stochasticity. As a class, each group presents their chosen management alternative and the resulting future scenario. Potential discussion questions include:

- What was your group's thought process in making this decision?
- Did your group think the management alternative you selected was successful based on your outcomes?
- After hearing from other groups, would your group have done anything differently?

During our administration of the case study, most groups (three out of four) chose Alternative 2: to widen the existing tidal structure without additional structures to prevent flooding, citing concerns about the costs and ecological damages associated with building a dam. This decision reflected the high value of environmental preservation and restoration to these students, who chose to optimize benefits to the environment and showed less concern over the associated social consequences (i.e., flooding). One group chose Alternative 3 because this option helped to mitigate flooding. Students expressed ease in coming to a management decision as a group, a benefit of the conventional management approach where top-down decisions are made by a singular entity rather than shared with stakeholders who may show opposition. Students also reflected on the outcomes of their management decisions and, in many cases, were surprised to find that the results of their decision did not reflect their intentions. Though outcomes of each management decision were randomly distributed, by chance, no two groups received the same outcome. This likely helped students visualize the uncertainty associated with management decisions and dynamic environmental systems. Based on comments from the students, they seemed to understand that although groups may have made the same management decisions, the results varied. Most groups concluded that their results were not ideal and that perhaps the management decisions they made were not the best possible choices.

Following this round of management, the important take-home message should be that uncertainty is an inherent part of any natural system, both from within the system and from external factors. The issue with conventional management is that managers are trying to achieve a desired or preferred state, but for the most part do not address or attempt to learn what is yet unknown about how the system functions (Holling and Meffe, 1996).

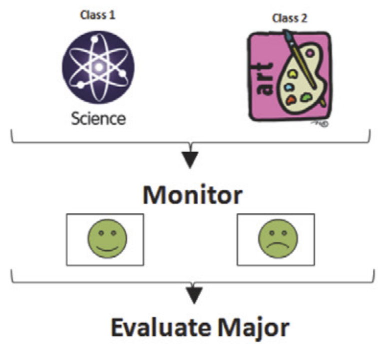
## Round 2: Adaptive Management

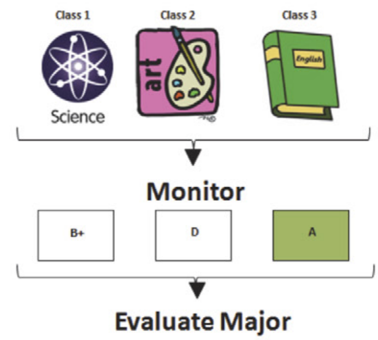
In the second round, students are introduced to the concept of adaptive natural resource management: what AM is, the different types of AM, and the roles of uncertainty and learning in implementing AM. The example of choosing a college major is used to relate the concepts to decision-making and management in the students' lives (Exhibit 5). These concepts are then reiterated using oyster bed restoration as an example which is more closely tied with natural resources management and the Herring River case. For the oyster bed restoration example, three types of artificial surfaces are introduced as options for oyster reestablishment. Conventional management would advocate for the selection and use of one surface type, while in passive AM the manager would select one, monitor reestablishment rates, and make adjustments as needed. In active AM, managers would use all three surfaces (at one site or across several sites) and determine which one performs best under the given conditions.

Following a brief lecture on the basics of AM, students have a second chance at management with all ecosystem conditions restored to their original degraded state prior to Round 1. The options remain the same, but each student within the group now takes on the role of a stakeholder and represents their interests during the decision process. These stakeholders include: the NPS, Marine Biological Laboratory, Chequesett Yacht and Country Club, Wellfleet

Exhibit 5. The scenario of choosing a major may be used to demonstrate differences in management strategies.

| Conventional Management | Passive AM | Active AM |
|---|---|---|
| Select a major. | Select a major that seems best. | Select courses from all majors of interest during first semester. |
| Only occasionally (if ever) evaluate whether it is the best major for you. | Take one elective per semester from a different major that you may or may not think you like. | Evaluate which was your favorite course and enroll in that major. |
| | Evaluate each semester whether you prefer your current major. | Continue to take 1+ elective each semester to reevaluate choice of major |


Town Council, and the Cape Cod Commercial Fishermen's Alliance (Exhibit 6). These stakeholders emphasize and/or prioritize management goals differently based on their organization's values and interests (Exhibit 6 and 7).

Additionally, students incorporate elements of AM in their decision by considering which management option may lead to the greatest amount of learning. Instructors provide students with a list of possible environmental variables to monitor (e.g., invasive plant populations, water quality and macroinvertebrates, fisheries and shellfisheries, wildlife populations, mosquitoes, tidal flow and flooding, and recreation). Due to hypothetical budget and time restrictions, they may select only three of the monitoring categories. Within their groups, students decide on a management and monitoring plan as well as discuss how their plan aligns with stakeholder objectives and why this plan is or is not different from their choice in Round 1. Some within-group discussion questions are:

- Are any stakeholders dissatisfied with the management approach chosen?
- How does your management plan incorporate AM?
- How will you learn from your management approach? What do you hope to learn from the monitoring categories you chose?
- How might you incorporate monitoring data into the next iteration of the decision-making process?

Each group shares these decisions with the class as a whole and thinks about how their choice of management action and monitoring variables compare with those chosen by other groups. Potential whole-class discussion questions include:

- In what ways did this round of management differ from the Round 1 planning?
- Did the involvement of multiple stakeholders help or hinder the decision process? What are the benefits and/or drawbacks to collaborative decision making? Do you think some stakeholders benefit more from your plan than others?
- Having heard feedback from the other groups, would your group have done anything differently? Is there anything you would add or change about your own decision?
- This is an example of passive AM because you are picking one option and seeing what happens. What could you do to make it active AM if, for example, each group was working in a different system?

The complexity of socio-ecological systems allow for many different kinds of uncertainty throughout the management process. In our use of the case study, this round added more real-world pressures of natural resources management as students faced cost constraints and dealt with opposition to their opinions on management decisions and data collection. Students were able to articulate how they got to their decisions and provide reasons for why they chose to monitor certain aspects of the environment and not others, usually based on stakeholder interests. Decisions may not have equally addressed interests of all stakeholders, but we emphasized the importance of considering all interests in order to ensure cooperation and successful implementation of a management plan.

Of the four groups, two chose the same management alternative (2) as the first round and two groups changed their decision. One group switched from Alternative 2 to Alternative 3, and the group who chose Alternative 3 in the first round chose Alternative 2 for this round. Students were given an opportunity to discuss how their priorities had shifted as they assumed the persona of a stakeholder and recognized the trade-offs of stakeholder involvement. Students recognized that the decision process became more complicated, but that the result was more likely to address the diverse concerns of the community. The small group discussion during this round was longer than for the first round, as groups needed more time to reach consensus on

Exhibit 6. Stakeholders within the Herring River estuary, the role students are asked to assume within the organization, and values and priorities of that organization.

| Organization | Role within organization | Organizational values |
|---|---|---|
| NPS | Natural Resource Manager | • Preserve the natural and cultural resources of the National Park System.<br>• Preserve parklands for the enjoyment, education, and inspiration of this and future generations.<br>• Improve recreational boat and fishing access and wildlife viewing opportunities.<br>• Provide open space for public activities such as local summer camps for children. |
| Marine Biological Laboratory | Research Scientist | • Study changes to water and environmental quality within the estuary.<br>• Restore the function of the estuary ecosystem.<br>• Maintain sustainable wildlife and shellfish populations in additional to other natural resources. |
| Chequesett Yacht and Country Club | Owner | • Provide recreational opportunities, primarily golfing, to country club members.<br>• Continue club involvement with the local community, including homeowners' associations and local charities.<br>• Protect club property from weather and flooding damage.<br>• Avoid having to pay higher taxes or high premiums for flood insurance. |
| Wellfleet Town Council | Chairperson | • Address constituent concerns.<br>• Maintain high levels of tourism revenue.<br>• Keeping town costs and taxes low.<br>• Maintain quantity and quality of public water supply. |
| Cape Code Commercial Fishermen's Alliance | Member | • Maintain maximum fish and shellfish populations to support recreational and commercial industries.<br>• Maintain healthy waterways and environment to benefit fish and shellfish populations by improving water quality and connectivity. |

a management alternative, but they were encouraged to come to a final decision within the allotted time.

Students' feedback indicated that the use of stakeholder role-play and the provision of management outcomes as the most successful aspects of the case study. One student commented, "The discussion for stakeholders illustrates how all the different issues impact the decision," while another noted, "It was challenging to come to an agreement with those in our group." We feel that this provided an important insight into the challenges of real-world decision-making with multiple stakeholders.

The take-home message at the end of this round was reflected in important differences between the decision process of this round and the previous round. Adaptive management involves the inclusion of stakeholders in the decision-making process, which might make coming to an agreement more challenging. However, the inclusion of stakeholders also provides a more holistic view of the

Exhibit 7. Management interests of each stakeholder given their organization's values and interests.

| | Stakeholders† | | | | |
|---|---|---|---|---|---|
| Management goals | NPS | Marine Biological Laboratory | Chequesett Yacht and Country Club | Wellfleet Town Council | Cape Cod Commercial Fishermen's Alliance |
| Limit flooding damage to businesses and residences. | | | + | + | |
| Limit costs of management and restoration activities. | | | | + | |
| Restore natural tidal and salinity ranges throughout the floodplain and stream basins. | | + | | | + |
| Reestablish physical connection with the marine environment for exchange of nutrients, organic matter, and biota. | | + | | | + |
| Restore natural sediment budget to counter wetland subsidence. | | + | | | + |
| Improve water quality (i.e., increase salinity, alkalinity, and pH and decrease metals and coliform bacteria). | | + | | + | + |
| Control salt-intolerant plants including invasive species. | + | + | | | |
| Reestablish native saltmarsh plants and wildlife. | + | + | | | |
| Improve estuarine fish and shellfish habitat. | + | + | | + | + |
| Improve natural control of mosquitoes and other nuisance insects. | | + | + | + | |
| Improve recreational access (e.g., boating, finfishing, shellfishing, and bird watching). | + | | + | + | + |

† + indicates where management goals for the Herring River estuary align with organizational values (see Exhibit 6).

ecosystem and its components and leads to a decision that considers the needs of all stakeholders.

### Round 3: Monitoring and Reevaluation

The third round of management emphasizes the learning component of AM by making learning a management objective and incorporating learning into future management decisions. Instructors distribute data tables and figures representing plausible monitoring outcomes that demonstrate environmental variability and are based on the group's management plan and the variables they chose to monitor. With this new information, they discuss within their groups what their data indicates, how successful their decision was, and what they may choose to do differently in the future. Potential discussion questions include:

- What data was helpful and what was not? What would you like to continue monitoring in the future? Is there anything you would stop monitoring or start monitoring now based on your management actions or outcomes?
- Do your management outcomes influence how you would make future management decisions? Why?

They may discuss the following questions as a class:

- What if all of your scientists had been working together and were able to implement all (or several) of the groups' alternatives? What more could you have learned during the process?
- How did uncertainty or unexpected events affect your management actions?
- How were you each able to incorporate learning into your future management?

With our class, some groups were satisfied with the environmental variables they chose to monitor. Others realized they had neglected important parameters that they would incorporate into the next round of monitoring once they learned what other groups had chosen to monitor and were able to learn. Students were also asked to look at this activity in a different context, one that reflects an experimental approach to management (see the first class discussion question). If each group were to be simultaneously managing different sections of the impaired ecosystem using different alternatives or techniques, then comparisons could be conducted and students could learn from the various outcomes all at once rather than over a longer timescale. This is an example of active AM. Although prior rounds provided an experience with passive AM, this allowed them to think analytically about a more active experimental approach. Students were able to correctly identify this case study as an example of passive AM because they selected one management option and waited to see what happened rather than implementing several options at once.

This round concludes the class activity, with the take-home message being: through learning we are better able to respond and adapt to uncertainty within the ecosystem. It is easier to justify past and future management decisions with monitoring data. Students should understand that they can change their minds based on new information and that data from other groups or studies can help them to learn and ultimately refine their decisions. The iterative manage–monitor–learn–manage process is a hallmark of AM. This approach helps students realize that there is no one right choice and that decisions may change depending on time, place, and other circumstances.

## Additional Resources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## Teacher Suggestions

We were pleased with the overall results and responses of students during and after administration of the case study. For future implementation of this case study in classrooms, we believe that it would be beneficial to have a second facilitator (or third, depending on the number of small groups) present for aiding group discussions and for preparing materials during whole-class discussion and lecture periods. Suggestions for improvement from student feedback included providing more management options to choose from and shortening the length of the case study activity. However, the latter is likely a result from the activity taking place outside of a regularly scheduled class period. Overall, students agreed that a case study activity, and in particular the Herring River case, was successful and more effective than lecturing as a means of presenting adaptive management concepts. Although the introduction of AM early in their academic career may help students to understand general concepts of decision-making, use of this case study activity in advanced courses may prove more efficient in reaching students who have already chosen the field of natural resources and who are more likely to go into management positions.

There are many ways in which this case study can be used as an avenue for enriched active learning. Stakeholders and background information can be modified to present a variety of issues in natural resources from restoration and conservation to decision-making. The activity may also be adapted for a variety of classroom settings and lengths. Depending on the format of the class, specific course objectives, and the time allotted to learning about AM, this exercise can be configured differently or extended/shortened. Many examples are provided below and reflect a number of ways in which the teaching and learning of AM concepts can be approached.

### For Longer or Multi-Day Class Periods

**Jigsaw Puzzle Method.** Small groups are designated as a stakeholder. Representatives of each stakeholder group are then paired up into mixed-stakeholder discussion groups to talk about management alternatives. Students independently explore pieces of the problem and then reconvene with their original stakeholder group to talk about how the whole picture fits together. This method gives participants a sense of importance and responsibility to do their part (Aronson and Patnoe, 2011).

**Active AM.** Small groups are designated a management alternative that they will implement and follow throughout the activity. Each whole-class discussion then functions as a larger active AM experiment that is going on in the study area. Students can then reflect on passive AM and active AM opportunities and outcomes.

**Management Monopoly.** To implement management decisions, managers are given a starting budget for the next 5 years. Each management action and monitoring option comes with a cost, leaving managers with very few options given the budget. However, different stakeholder groups are also allotted a certain amount of money that they may give toward managing the area. Managers are encouraged to cooperate with stakeholders to meet some of their needs in return for voluntary contributions. Students should find that, by working together, they have more options and can implement a more successful and efficient management plan.

For longer class periods or those that span multiple class periods, students can also be held responsible for generating some of the background information that is provided for them in this example including management alternatives, variables to monitor, and so forth.

### For Shorter Class Periods

**Combine Round 1 and 2.** Small discussion groups are assigned one of two sets of instructions. The first set reflects the conventional management strategy described in Round 1 and the other reflects the AM strategy. Whole-class discussion should focus on comparing and contrasting the benefits and costs of the two.

**Pre-Activity Assignment.** For shorter class periods, the instructor can ask students to do a bit of research before the activity day, similar to the case in Pierzynski and Vaillant (2006). This may include various readings or videos on AM or the case study and should include a reflective writing assignment. The written portion should demonstrate the student's knowledge of AM after the reading and incorporate some of the discussion questions in Round 1. This way students come in prepared to have a quick discussion about the assignment to set the stage for the rest of the activity.

## CONCLUSION

Case studies allow students to become more active in the learning process and gain critical skills in understanding, analyzing, and communicating ideas and concepts. The active participation of students as different stakeholders enables them to engage different viewpoints and effectively communicate and argue particular values whether or not they reflect their own. The use of this particular case study introduces students to AM, an increasingly important management framework that can provide them with real-world skills for management of natural resources as well as decision-making tools that can be used in everyday life. The integration of context-specific problem solving with general management principles and organizational theory are essential to the structure of the education of future natural resources professionals. Just as clinicians need training to practice and improve the actual work skills and behaviors required to perform on-the-job tasks and functions, future managers need to be equally equipped with the tools necessary to work toward creating a whole-system sustainable future. Teaching tools such as this case study can incorporate real-world information and issues in a format more readily retained by students and encourage the understanding of concepts that have the potential to fill the knowledge gap between post-secondary education and a successful career in natural resources management.


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## *About the authors...*

This paper came out of a graduate seminar that the authors participated in on adaptive management (AM), in which we read seminal papers on the management approach. Dr. Vokoun initially recognized a gap in the graduate education regarding AM, which needed to be addressed considering the prevalence of this approach to management in the profession. During the course, we decided that there was also a need to introduce undergraduate students early in their education to the concepts of AM in a way that was accessible to them since they will likely use the concepts in their future careers.

L.M. Driess, D.P. Kloster, M.R. Liberati, J.R. Barclay, J-M. Hessenauer, and L.R. Nathan were all Ph.D. students in the Natural Resources graduate program at the time this manuscript was accepted for publication. K.M. O'Connor was an M.S. student. Their interests include fisheries, wildlife, forest resources, water resources, and the conservation and management of socio-ecological natural resource systems. All are pursuing careers in natural resources, some in higher education, others in research, and some in management agencies. Dr. Jason Vokoun is associate professor and director of the Wildlife and Fisheries Conservation Center at the University of Connecticut. His research program is primarily focused on the conservation of freshwater fishes, both nongame and those pursued by anglers in recreational fisheries.