Solving Problems in Fisheries Management: Proof of Concept Using Structured Decision Making at the Undergraduate Level

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Abstract: Fisheries management problems are generally complex because they are socio-ecological systems encumbered by issues of scale, stakeholder conflict, and structural uncertainty with respect to the influence of management on the resource. Consequently, agencies that manage fisheries actively seek employees that can demonstrate problem-solving skills and communicate to a diverse set of stakeholders. To enhance development of critical thinking skills, problem-based learning was incorporated into an undergraduate introductory fisheries class using a structured decision making (SDM) framework. Student teams identified a problem of local, regional, or national significance, then defined the problem's scope and scale and identified decision makers and stakeholders, multiple conflicting objectives, and alternative actions designed to meet objectives. Students analyzed consequences of actions on objectives using a decision analysis tool allowing for determination of preferred management actions or portfolios and associated trade-offs. Finally, the students presented their findings in an oral group presentation and in a single-authored final report. Among other things, the SDM framework allowed students to identify and acknowledge key uncertainties related to various aspects of the problem and determine the influence of lack of information on the decision. Because state and federal natural resources agencies are increasing their use of SDM and adaptive management frameworks (i.e., the iterative form of SDM) for fisheries management problems, teaching these techniques to the next generation of managers could give our students tools to help frame, decompose and solve future complex problems.

Key words: Structured decision making, problem-based learning, undergraduate education

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Fisheries are socio-ecological systems, and management usually involves multiple-conflicting stakeholder objectives, uncertainty regarding various aspects of the system, and issues of scale (Garcia and Charles 2007, McGowan et al. 2015). Natural resource agencies have recognized the need for their workforces to be responsive to changes in the social-ecological framework of problems in the 21st century (Stummann and Gamborg 2014, Johnson et al. 2015). With an increasingly involved public (McMullin and Pert 2010) and uncertain future (i.e., changing climate and shifting land use priorities), management of natural resources, including fisheries, often involves holistic, multidisciplinary approaches. Management issues in the natural resources are often complex, involve stakeholders with diverse values, and have a high degree of uncertainty relative to the success of alternative solutions. The fisheries profession faces the challenge to address these complex problems by predicting management outcomes in order to make sound decisions that are still socially acceptable. Ultimately, this charge relies on a well-trained and educated workforce that can apply knowledge in the context of time- and space-dependent decisions with a high degree of structural uncertainty (Johnson et al. 2015).

For decades natural resource employers have ranked critical thinking, communication, and quantitative skills at the top of their qualification list for natural resource hires, expecting that those skills, knowledge, and abilities will be learned at universities (McMullin et al. 2016). Although it is well recognized that critical thinking skills are desirable to employers, imparting these skills through teaching is difficult without techniques to engage students in experiential learning and development of application of knowledge (Halpern 1998). Structured decision making (SDM) is a values-based framework that allows for problem definition and identification of preferred management alternatives based on quantitative assessments that lead to a decision (Hammond et al. 2002, Gregory et al. 2012). This framework has been applied to fisheries problems on multiple scales in North America including state, federal, and provincial arenas over many decades (Bain et al. 1987, Peterson and Evans 2003, Gregory and Long 2009, Irwin 2014, Johnson et al. 2015, McGowan et al. 2015). The SDM framework described herein engages participants in a process to define a problem, identify objectives, formulate alternatives, conduct consequence and trade-off analyses, and ultimately make a decision (Hammond et al. 2002, Gregory et al. 2012, Conroy and Peterson 2013).

Formal discussions with the Alabama Department of Conservation and Natural Resources (ADCNR) leadership, and surveys of other employers, indicated that critical thinking skills were highly valued for potential hires. Therefore, Auburn University School of Fisheries, Aquaculture, and Aquatic Sciences added an SDM project to an undergraduate course for rising juniors in order to develop critical thinking skills through an experiential team exercise. In addition, Auburn University initiated a mandate to educators to ensure that students in their classes had the opportunity to practice and hone writing skills, which are also highly regarded by employers (McMullin et al.2016). This paper describes the approach to teaching SDM principles and methods and provides insights regarding the applicability and efficacy of the SDM process in an undergraduate curriculum.

Methods

The undergraduate Introduction to Fisheries Science course (FISH 2100) at Auburn University is a five-week intensive field course taught to rising juniors during summer. Based on input from potential employers, the faculty in charge of the course decided to use an SDM framework to introduce problem-solving skills to the students. The SDM process employed was defined by Hammond et al. (2002) and is a framework that is used by the U.S. Fish and Wildlife Service (USFWS) and the U.S. Geological Survey in their coursework and experiential workshops delivered at the National Conservation Training Center (NCTC) and to stakeholder groups at-large. The textbook for the class was Hammond et al. (2002), which described the process of problem decomposition and illustrated it using the acronym PrOACT (Figure 1). This acronym represented the process: problem definition (Pr), objectives identification (O), alternatives exploration (A), consequence quantification (C), and trade-off evaluation (T) in order to find potential solutions for problems of local, regional or national significance. We have taught the SDM module over the last five years (2012–2016).

To deliver the material needed for students we followed the format used by SDM coaches who assist stakeholder groups with problem framing and analysis during one-week workshops at NCTC (e.g., ALC3159; https://training.fws.gov/). After a formal introductory lecture on SDM, students were assigned to teams of 3–5 members and were presented with current or emerging problems related to fisheries management, aquatic conservation, or aquatic disease pathology (see Table 1 for examples). The instructors and/or a graduate student took on the role of team coach, leading the process and providing avenues toward gaining knowledge and data to inform the decision making. Teams selected their problem topic and additional lecture material was presented that covered individual elements of the PrOACT process. After each lecture the student teams worked through the individual SDM steps and completed assignments that included written or diagrammatic display of the steps (Table 2). Two

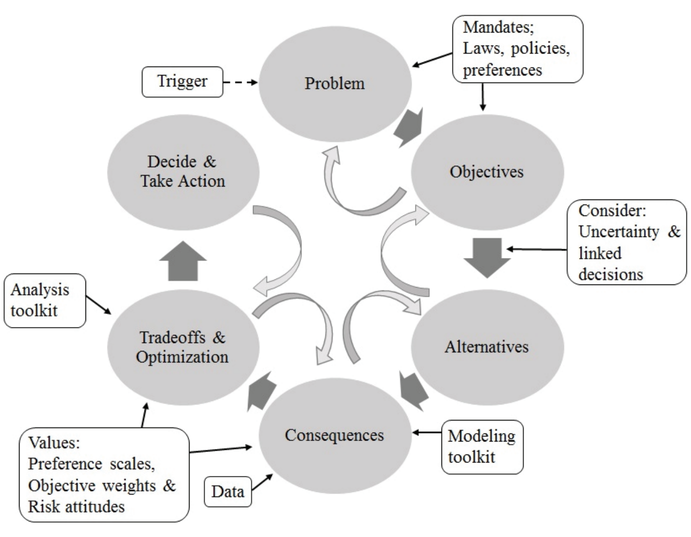

Figure 1. PrOACT process represented by the main steps (ovals) and related information and other inputs to the steps (rectangles). Constructed by J. Cochrane (personal comm.) and used with permission of the U.S. Fish and Wildlife Service.

Table 1. Examples of problems for the FISH 2100 teams. Problems are introduced in a broad sense and student teams draft a problem statement that defines the scope of the problem.

Problem example	Description
Lionfish (*Pterois* spp.) invasion	Invasive marine species with no known predators. Solutions are needed to minimize impacts on fisheries.
Alabama Department of Conservation and Natural Resources (ADCNR) State Lakes Program Evaluation	Evaluation of strategies to maximize the program that provides affordable fishing for the public.
Elk River boulder darter (*Percina wapiti*) conservation	Federally endangered species extant in a regulated river. A trout fishery is also present creating conflict between conservation objectives and angling objectives.
Red snapper (*Lutjanus campechanu*) management in the Gulf of Mexico	Fisheries are highly regulated in the Gulf of Mexico. Evaluated available management strategies to maximize angling satisfaction while protecting spawning stocks.

Table 2. Steps for a structured decision making framework taught to undergraduates (PrOACT). Students worked on a real-world issue and practiced problem framing, objective setting, alternatives development, consequences prediction and trade-off evaluation. Assignments were completed by the group for each of the PrOACT steps.

PrOACT Step	Detail of Assignment
Problem	Describe the problem. Why do we have a problem? What is the trigger? Who is the decision maker? How urgent is the decision? What is the regulatory and legal background? Who else needs to be involved (stakeholders)? Write a problem statement with all the applicable information about the problem.
Objectives	What are the values of decision maker? What would be the best outcome? Who are the stakeholders and what do they care about? What are the most important values (fundamental)? How are we going to meet the objectives (means)? Each objective must have measurable attributes, direction, and scale. Are all the objectives weighted equally in the decision context? Construct an objectives hierarchy to illustrate the relations among fundamental and means objectives.
Alternatives	List all the alternatives that might help meet the objectives. Think out of the box and consider all reasonable actions that might be implemented.
Consequences	Predict the consequences of each action on the objectives. Use a consequences table to complete the assignment. Measurable attribute data from the objectives assignment will be used. Data can come from expert opinion or the published literature. Utility scores will be generated to determine how well the alternatives meet the objectives.
Tradeoffs	Assess the tradeoffs among the alternatives. Are there any irrelevant objectives or dominated alternatives? What is the final proposed decision and why?

Table 3. Generic consequences table summarizing the impacts of alternative actions on objectives related to a fish population, angler satisfaction, and cost in a hypothetical fishery management problem. Measurement attributes are electrofishing catch per effort (CPE_e; number h^{-1}), angler CPE_a (number h^{-1}), and cost ($US spent on alternatives; using a 1–5 scale). The numbers reported are normalized, weighted scores; the sum of those values for each alternative provides a utility score for individual alternatives. Note that Multiple actions strategy would have been the preferred alternative.

	Fundamental objective	Quality population	Societal satisfaction	Cost	
	Means objective	Population	Fish to catch	Dollars spent	
	Measurement attribute	CPE_e	CPE_a	US $	
	Desired direction	Maximize	Maximize	Minimize	
Alternative	**Weight**	**0.50**	**0.25**	**0.25**	**Weighted sum**
Status quo		0.10	0.13	0.20	0.43
Management strategy 1		0.17	0.12	0.17	0.46
Management strategy 2		0.20	0.17	0.20	0.57
Multiple actions strategy		0.25	0.20	0.27	0.72
Do nothing		0.04	0.08	0.10	0.22

case studies were also presented to the class to illustrate how SDM has been applied to real-world and ongoing issues (Gulf striped bass management and Harris Dam flow management) in the region. Additional case study reports were provided to the students electronically.

Based on a literature search, group discussions, and a search for potential experts on the problem, the teams delineated fundamental (i.e., what the decision maker cared about the most) and means objectives (i.e., potential avenues to achieve outcomes). For each objective the teams identified measurable attributes (this helped determine data needed), direction of response (maximize or minimize), and scale (i.e., suitable ranges of values for achieving stated objectives). They then listed potential management actions that might be linked to the objectives. In terms of data used to inform the decisions, we encouraged the teams to elicit expert opinion from professionals in the field who were knowledgeable regarding the problem and/or use data from the published literature. Data related to identified measurable attributes were compiled in a consequences table which was a spreadsheet that tabulated the utility of each alternative relative to all the weighted objectives (see Table 3 for a generic example). Technically, the consequences table that we used applied a linear value model to aggregate weighted and normalized consequence scores for each attributed objective (Gregory et al. 2012). The scores were first normalized to account for different scales and the teams assigned weights to objectives (some were more important than others) to mimic real-world decision making (Table 3). Finally, the weighted aggregate scores were ranked for each objective to begin to evaluate trade-offs. The coaches worked with the students to ensure that all the formulas and tabulations in the consequences table were correct.

Over the course of the SDM process, teams orally presented updates to the rest of the class to generate discussion and ideas about the different problems. To enhance transparency, the teams presented their final problem to the rest of the class and visitors (e.g., school director, graduate students, other faculty) using visual graphics of all the PrOACT steps. In addition, students graded their team members on participation. Final papers followed an outline set forth by the USFWS NCTC curricula for SDM (http://training.fws.gov/courses/ALC/ALC3159/reports). Final papers were sole-authored by individual students in order to meet University writing requirements. The SDM module constituted 50%–60% of the final grade; the other 40%–50% consisted of two exams.

Results

Over the five years that we have offered SDM training and practice to students ($n = 63$), 15 management issues have been analyzed by student teams. Course evaluations were always high for the course (average >4.0 on a 5.0 scale) and this trend did not change after the SDM module was initiated. During the five years, students offered 27 written comments in their final course assessment and only three were related to the SDM portion of the class. They were: "Not enough time for SDM," "SDM was too hard," and "Drop the SDM part of the class." Because the full course was intensive (taught in five weeks) it was acknowledged after the second year that the students needed additional time to prepare their presentations and write their final paper. Since the 2014 offering, the course has been extended to cover both summer sessions allowing for more time to prepare the two final products; all of the SDM assignments related to PrOACT were completed within the first 5 weeks. The instructors also modified various timelines for completing assignments so that the students were not burdened with multiple assignments due at the same time. Grades were high and yearly means were between 86% and 93% on the SDM portion of the course; 86% of students received an "A" or a "B" for their project. There was no apparent relation between the complexity of the management issue and grades earned, nor were there temporal trends in grades earned that might have been related to the various course changes enacted by the instructors.

In general, the problem solving projects were well executed by the team, which was reflected by the student's ability to communicate the elements of SDM both orally and in writing along with delivery of a final set of solutions. In addition, high student grades were reflective of students' grasp of the process and their competencies on the various assignments. Typically, the challenges were complex and evaluated various aspects (e.g., social, political, biological, scale in time or space) of the problem (Table 1). All of the topics had fairly clear objectives, such as to "maximize conservation/harvest population" or "minimize introduced/exotic nuisance species". Often the objectives were conflicting (e.g., to "maximize a sport fishery and increase endangered species populations"), typical of many problems in natural resources. To identify the objectives, students sometimes contacted professionals in the field and discussed with them issues surrounding their assigned problem. This was not a requirement because many of the assigned issues were well addressed in the primary literature and other available on-line resources. However, when the objectives were more obscure and data were limited, the coaches assisted the students with finding contact individuals, and this usually aided the objectives identification portion of the exercise.

Students were routinely coached toward working through a sub-set of the problem where they focused only on a few objectives or a finer spatial scale due to problem complexity or lack of data or expert knowledge on the topic. Developing measureable attributes for objectives and identifying data to use in the consequences tables was a challenging aspect of SDM for the students, but all the teams populated their tables with some type of data such as Likert scales (e.g., 1–5), likelihood percentages, or actual values from the literature.

Team-work was an important aspect of the SDM project. In early years the instructors were informed that not all students were contributing to the various team products needed to complete the assignments. The instructors implemented a process by which each individual graded the participation of their team mates. Oral presentations by teams followed the PrOACT outline and visuals were placed in slide show formats; each individual was required to verbally deliver some part of the presentation. Coincident with this change, the instructors changed the SDM portion of the course to account for 60% of their grade (increased from 50%) where the team participation was 10% of the total grade. The instructors and visitors graded presentations with a rubric used in the School's exit seminar series. Similarly, papers were graded with a rubric to ensure that all the PrOACT elements were covered and that the consequences model was logical and useful for informing a decision. In general, papers were well-written and students easily followed the format for reporting about their SDM project.

Discussion

Inclusion of experiential learning and critical thinking in natural resources curricula and post-graduate training is effective for imparting decision making and problem solving skills to students and professionals (Millenbah and Millspaugh 2003, Johnson et al. 2015). Undergraduate curricula should be designed to prepare students for employment (including advanced degree assistantships); critical-thinking skills are highly desired by employers of natural resource professionals (McMullin et al. 2016). Including formal instruction in SDM processes along with realistic problem solving will give our students an additional assessment framework for situations encountered in the workplace or even during advanced education opportunities (Halpern 1998, Powell et al. 2011, Colvin and Peterson 2016). Teaching SDM principles and requiring the decomposition of a real-world problem in the FISH 2100 class provided an introduction of how these issues may be addressed by integrating human dimensions, ecological and economical aspects, and legal and regulatory contexts (Powell et al. 2011). In fact, our SDM module provided practice for four of the five most desired job skills deemed important by employers for success of entry level hires: critical thinking skills, oral communication, writing, and teamwork (McMullin et al. 2016).

Johnson et al. (2015) advocated a two-step approach of lecturing basic steps and theory for SDM and then practicing the application with a real-world problem and this seems to be working well in our class. Based on personal experience by the instructors, many of the student teams executed the SDM process better than employed resource professionals and stakeholders in workshop settings. One explanation for this was that the students were presented more SDM lecture material than is typical in an SDM workshop offering. Course evaluations have been high every year, attesting to the notion that the students valued the opportunity to integrate management goals with basic information to arrive at a set of best management alternatives. Because of the complex nature of the assigned problems, quantitative assessment using a decision tool (i.e., consequences table) enhanced students' ability to assess trade-offs among management alternatives through manipulation of objective weights. The benefit of using a decision tool, such as a consequences table, illustrates the explicit, visual, and transparent presentation of the analysis.

In many presentations and papers, the teams and individual students acknowledged that they had formed a solution to the problem before they conducted the step-by-step SDM. A very common response to the assignment by the students was initial skepticism followed by an articulated realization that SDM was relevant for problem solving (e.g., "I thought this was really worthless at first"). One of the first steps in the SDM process is to do basic research to frame a broad problem topic. The students were instructed regarding appropriate sources for the information as well as how to integrate data to inform the decision making. Often student comments considered the uncertainty in the data, the complexity of the problem, and the fact that the identified "preferred" alternatives were not those that they would have selected early in the process. For example, one team was surprised that the value of a trout fishery did not play heavily into the ranking of alternatives and discussed the uncertainty in the existing data and its potential impact on decision making.

The principles of biology and ecology are presented in courses as knowledge (i.e., facts, concepts) needed for management, but social and economic aspects of resource management (e.g., stakeholders, decision-makers, economic impact, or budgeting) are not as well covered in most natural resources curricula (Millenbah and Millspaugh 2003, McMullin and Pert 2010). Given that our class is usually the first fisheries class that students take in the curriculum, their knowledge base for informing the problems assigned to them was lacking. Therefore, the final problem assessment using PrOACT as the structure was intended to be a rapid prototype of the actual problem (Johnson et al. 2015). However, in real life, the problem decomposition process is explicit in identifying decision makers, stakeholders, and legal frameworks. By minimizing the time spent on any one part of the problem (i.e., problem framing), the students were able to complete the full PrOACT process and conduct a final tradeoff analysis toward a decision. A total of six lecture hours and 12 hours of in-class working time (~3 h per step) with coaches was allotted during the course. Coaches routinely met with teams during their office hours, but the total time that teams spent on the problems outside of class is unknown. However, based on the quality of products delivered to the instructors, we believe most teams worked diligently outside the classroom.

There are other excellent examples of curricula using SDM or other decision analysis frameworks to develop critical thinking skills for students (Johnson et al. 2015, Colvin and Peterson 2016). Although we used Hammond et al. (2002) as a text book, other more comprehensive and natural resource specific texts are available (e.g., Gregory et al. 2012, Conroy and Peterson 2013). Powell et al. (2011) proposed that adding SDM to curricula in various courses should be deliberate and enacted early in the undergraduate program so that students can practice the application of structure for decision analysis over time. Addition of a capstone course for seniors that would employ SDM and knowledge learned in formal classes could be considered the next step for curriculum development; however, waiting until the final course in a curriculum to introduce concepts for enhancing critical-thinking and problem solving skills would not be as effective as developing options for multiple exposures to the components over the entire curriculum (Powell et al. 2011).

Graduates of fisheries programs are increasingly faced with complex problems where simple solutions and management tools do not apply (Jentoft and Chuenpagdee 2009). Problem decomposition, transparency, and alternative development that are linked explicitly to objectives and placed in a structured process lead to efficiency in implementing strategies especially in challenging fiscal contexts. Teaching these skills to the next generation will enable transparency in the workforce, better allocation of resources, and better communication even among colleagues. Unfortunately, we have not conducted formal assessment regarding the impact of teaching SDM to the 63 students that have received the instruction and practice in FISH 2100. However, in teaching critical thinking skills, "structural training" allows for "capacity to code and manipulate relational knowledge" (Hummel and Holyoak 1997). Using SDM as the scaffolding to provide cues for retrieval (i.e. structural training) of specific aspects of a problem gives way to monitoring of the thinking process such that thinking and learning is improved (Halpern 1999). The experience gained from the FISH 2100 classes over the years supports a positive influence of adding structured problem solving exercises to fisheries classes. It is hoped that the students' experiential learning will be useful when encountering the complex problems that they will face in the future.

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