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Implementation of a framework for multi-species, multi-objective adaptive management in Delaware Bay

Conor P. McGowan [a,*], David R. Smith [b], James D. Nichols [c], James E. Lyons [d], John Sweka [e], Kevin Kalasz [f], Lawrence J. Niles [g], Richard Wong [f], Jeffrey Brust [h], Michelle Davis [i], Braddock Spear [j]

[a] U.S. Geological Survey, Alabama Cooperative Fish and Wildlife Research Unit, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36845, United States
[b] U.S. Geological Survey, Leetown Science Center, Kearneysville, WV 25430, United States
[c] U.S. Geological Survey, Patuxent Wildlife Research Center, 12100 Beech Forest Rd., Laurel, MD 20708, United States
[d] U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Patuxent Wildlife Research Center, 11510 American Holly Drive, Laurel, MD 20708, United States
[e] U.S. Fish and wildlife Service, Northeast Fishery Center, P.O. Box 75, Lamar, PA 16848, United States
[f] Delaware Department of Natural Resources and Environmental Control, Delaware Division of Fish and Wildlife, Smyrna, DE 19977, United States
[g] Conserve Wildlife Foundation of New Jersey, Bordenton, NJ, 08505, United States
[h] New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Port Republic, NJ 08241, United States
[i] Virginia Tech University, Department of Fisheries and Wildlife Sciences, Blacksburg, VA 24061, United States
[j] Atlantic States Marine Fisheries Commission, Washington D.C. 20005, United States

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ABSTRACT

Decision analytic approaches have been widely recommended as well suited to solving disputed and ecologically complex natural resource management problems with multiple objectives and high uncertainty. However, the difference between theory and practice is substantial, as there are very few actual resource management programs that represent formal applications of decision analysis. We applied the process of structured decision making to Atlantic horseshoe crab harvest decisions in the Delaware Bay region to develop a multispecies adaptive management (AM) plan, which is currently being implemented. Horseshoe crab harvest has been a controversial management issue since the late 1990s. A largely unregulated horseshoe crab harvest caused a decline in crab spawning abundance. That decline coincided with a major decline in migratory shorebird populations that consume horseshoe crab eggs on the sandy beaches of Delaware Bay during spring migration. Our approach incorporated multiple stakeholders, including fishery and shorebird conservation advocates, to account for diverse management objectives and varied opinions on ecosystem function. Through consensus building, we devised an objective statement and quantitative objective function to evaluate alternative crab harvest policies. We developed a set of competing ecological models accounting for the leading hypotheses on the interaction between shorebirds and horseshoe crabs. The models were initially weighted based on stakeholder confidence in these hypotheses, but weights will be adjusted based on monitoring and Bayesian model weight updating. These models were used together to predict the effects of management actions on the crab and shorebird populations. Finally, we used a dynamic optimization routine to identify the state dependent optimal harvest policy for horseshoe crabs, given the possible actions, the stated objectives and our competing hypotheses about system function. The AM plan was reviewed, accepted and implemented by the Atlantic States Marine Fisheries Commission in 2012 and 2013. While disagreements among stakeholders persist, structured decision making enabled unprecedented progress towards a transparent and consensus driven management plan for crabs and shorebirds in Delaware Bay.

* Corresponding author.
E-mail addresses: cmcgowan@usgs.gov (C.P. McGowan), drsmith@usgs.gov (D.R. Smith), jnichols@usgs.gov (J.D. Nichols), James_Lyons@fws.gov (J.E. Lyons), John_Sweka@usgs.gov (J. Sweka), Kevin.Kalasz@state.de.us (K. Kalasz), larry.niles@gmail.com (L.J. Niles), Richard.wong@state.de.us (R. Wong), Jeffrey.Brust@dep.state.nj.us (J. Brust), midavis1@vt.edu (M. Davis), braddock.spear@gmail.com (B. Spear).

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Decision analytic approaches to problem solving are increasingly recommended for the management of natural resource systems, especially management problems characterized by complexity and uncertainty (Williams et al., 2007; McFadden et al., 2011; Runge, 2011; Gregory et al., 2012; Nichols, 2012). The conservation literature of the last 2 decades contains many examples of decision analyses applied to abstractions of real-world conservation problems (e.g., Martin et al., 2010; McGowan, 2013). However, these example analyses have seldom led to formal adoption and implementation by conservation agencies, such that full use of decision-analytic approaches in natural resource management is still extremely rare in practice (e.g., Rist et al., 2013; Westgate et al., 2013). The few existing applications by conservation agencies of full decision-analytic approaches to problems in resource management are for single populations (e.g., Johnson et al., 1997; Martin et al., 2011; U.S. Fish and Wildlife Service, 2013). Applications of decision analysis to problems involving ecological systems and multiple species are virtually nonexistent, for reasons that include scientific uncertainty, administrative problems and the complexity of trade-offs among system components (Hilborn, 2011).

Here, we describe our efforts to fully engage a fisheries management agency, and its associated group of stakeholders, to develop a formal decision-analytic approach to management of a regional fishery. The management problem included the complexity of a non-fishery species believed to be influenced by the population status of the harvested species. We applied basic concepts of decision analysis to develop an adaptive management (AM; e.g., Walters, 1986; Williams et al., 2007; Nichols, 2012) program for horseshoe crab (*Limulus polyphemus*) harvest in the Delaware Bay region. Horseshoe crab harvest policy has been a longstanding and highly controversial management problem, as past unregulated horseshoe crab harvest has been identified by some as the cause for a substantial decline in abundance of Red Knots (*Calidrius canutus rufa*) and other migratory shorebirds, which eat horseshoe crab eggs on the beaches of Delaware Bay during their spring migration (Berkson and Shuster, 1999; Baker et al., 2004; Niles et al., 2008; Niles et al., 2009; Millard et al., 2015). Our horseshoe crab harvest framework explicitly incorporates multiple competing objectives derived from stakeholder values. Multispecies or ecosystem based approaches to fisheries management have been advocated in the scientific literature (e.g., Worm et al., 2009; Hilborn, 2011), yet are seldom implemented for a variety of reasons that include institutional and ecological complexity (Hilborn, 2011). We hoped that decision analysis would provide a useful framework to transparently incorporate potentially competing objectives and ecological complexities inherent in multispecies management (Hammond et al., 2002; Gregory and Keeney, 2002; Williams et al., 2007).

Our primary motivation for writing this paper is to add to the small number of natural resource management problems in which structured decision making (SDM)-AM approaches have been developed fully and adopted institutionally (also see Williams and Brown, 2012). We also wanted to demonstrate the utility of decision processes for dealing with problems involving multiple species and associated trade-offs. We doubt that there is a single blueprint for developing a management program based on SDM, but another motivation is to provide the details of the process that we used as an example. We make no claims that our process was optimal or even “good”, but it worked for a difficult and controversial management problem and may provide techniques that others will find useful in development of similar processes for other similarly difficult problems.

In this paper we summarize the development of a group decision making process that resulted in formal institutional adoption of an AM framework for horseshoe crab harvest in the Delaware Bay region. Specifically, we describe the deliberative or set-up phase of AM (Williams et al., 2007) in which we first defined the problem and then developed the requisite components of an AM approach: objectives, management actions, predictive modeling (consequences), decision algorithm (e.g., optimization) and monitoring (Fig. 1). We also highlight aspects of program development for which the SDM and AM approaches were especially important, if not essential, as a means of trying to motivate others to engage in such approaches.

1. Adaptive management

Our claim that full development of AM programs is very rare is conditional on our definition of AM. Indeed there are so many different views about what constitutes AM (Nichols and Williams, 2013), that it comes as no surprise that many programs claiming to have adopted

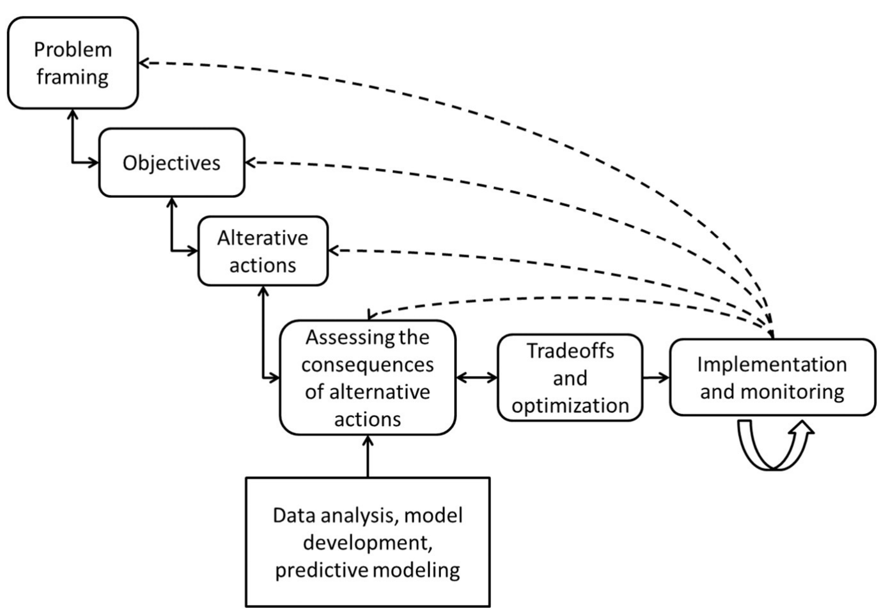

Fig. 1. Schematic of a structured decision making and adaptive management decision process showing the step by step advancement through a decision analysis. The figure is based on previously published figures (e.g., Williams et al., 2007; Runge, 2011). We note the bi-directional arrows indicating the potential for continual reassessment of previous steps throughout a problem solving effort, and the dashed arrows indicating the potential for reassessing all components of an AM plan after implementation (i.e., double loop learning from Williams et al., 2007).