Structured decision making as a conservation tool for recovery planning of two endangered salamanders

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Abstract: At least one-third of all amphibian species face the threat of extinction, and current amphibian extinction rates are four orders of magnitude greater than background rates. Preventing extirpation often requires both ex situ (i.e., conservation breeding programs) and in situ strategies (i.e., protecting natural habitats). Flatwoods salamanders (*Ambystoma bishopi* and *A. cingulatum*) are protected under the U.S. Endangered Species Act. The two species have decreased from 476 historical locations to 63 recently extant locations (86.8% loss). We suggest that recovery efforts are needed to increase populations and prevent extinction, but uncertainty regarding optimal actions in both ex situ and in situ realms hinders recovery planning. We used structured decision making (SDM) to address key uncertainties regarding both captive breeding and habitat restoration, and we developed short-, medium-, and long-term goals to achieve recovery objectives. By promoting a transparent, logical approach, SDM has proven vital to recovery plan development for flatwoods salamanders. The SDM approach has clear advantages over other previous approaches to recovery efforts, and we suggest that it should be considered for other complex decisions regarding endangered species.

Keywords: adaptive management, *Ambystoma*, amphibians, captive breeding, decision analysis, habitat restoration

Globally, amphibians are among the most imperiled taxa—at least one-third of all species face the threat of extinction (Stuart et al., 2004; Wake & Vredenburg, 2008). Scientists conservatively estimate that current amphibian extinction rates are four orders of magnitude greater than background rates, supporting the hypothesis that a sixth mass extinction is underway (Alroy, 2015; Wake & Vredenburg, 2008). There are currently 35 amphibian species or populations listed as threatened ($n = 15$) or endangered ($n = 20$) in the United States by the U.S. Fish and Wildlife Service (USFWS) under the Endangered Species Act (ESA); 22 of these have active recovery plans (USFWS, 2016a), though some have not been updated to reflect current knowledge (Walls et al., 2017). These plans are developed by the USFWS to provide guidance regarding management actions needed to achieve recovery of protected species. Preventing the extinction of endangered species often requires both in situ actions (i.e., protecting species in their natural habitats) and ex situ strategies (i.e., establishing conservation breeding programs). The decision to establish ex situ populations requires careful thought—as a last resort, captive breeding may be necessary to prevent extinction, but its ultimate success depends on having high quality habitat into which captive-bred individuals can be reintroduced (Dolman, Collar, Scotland, & Burnside, 2015). Decisions about in situ and ex situ actions for federally-protected species are especially complex because managers must address regulatory burdens in addition to complicated biological issues (Runge, 2011). Thus, effectively evaluating the costs, risks, and benefits of both in situ and ex situ approaches requires input from various types of stakeholders, including scientists, zoo collaborators, agency personnel, non-governmental organizations, and land managers.

The flatwoods salamanders (*Ambystoma cingulatum* and *A. bishopi*; Fig. 1) are federally-protected species native to the southeastern United States, but these species lack complete recovery plans. In 2013, the informal Flatwoods Salamander Working Group was established to coordinate conservation actions among research and management groups (see author affiliations). For flatwoods salamanders, substantial uncertainty regarding the effectiveness of possible conservation actions in both in situ and ex situ realms is a hindrance to recovery planning. Uncertainty concerning in situ actions stems from an inadequate understanding of necessary habitat characteristics, as well as the particular management

actions required to properly restore flatwoods salamander habitat. On the ex situ front, considerable uncertainty remains about the capacity to establish captive breeding populations, because there has been very little success thus far in breeding bi-phasic (i.e., those with both aquatic and terrestrial life history stages) ambystomatid salamanders in captivity—in some cases, efforts have failed due to unknown diseases.

In general, recovery plans have faced criticism for their static nature, lack of scientific rigor, and failure to adequately address threats (Clark, Hoekstra, Boersma, & Kareiva, 2002; Wolf, Hartl, Carroll, Neel, & Greenwald, 2015). Additionally, recovery planning processes may stall due to data deficiencies and disagreements about optimal management actions (Gregory, Long, Colligan, Geiger, & Laser, 2012). Leaders within the Flatwoods Salamander Working Group opted to formally confront the complexity and uncertainty about potential recovery actions using decision analysis. Structured decision making (SDM) is a process that decomposes a decision into key components: problem identification, management objectives, potential actions, system models that project consequences of actions, and optimization processes that reconcile tradeoffs (Gregory et al., 2012; Williams, Szaro, & Shapiro, 2007; Fig. 2). Here, we present our approach to addressing both in situ and ex situ efforts through two related SDM workshops, discuss the major decision outcomes, and highlight current efforts toward recovery planning. First, however, we illustrate the motivation for the decision processes with a description of flatwoods salamander declines.

Flatwoods salamander declines

Flatwoods salamanders (Fig. 1) occurred historically throughout the Coastal Plain of the southeastern U.S., across South Carolina, Georgia, Alabama, and the panhandle of Florida (Lannoo, 2005; Fig. 3). The species was initially designated as threatened in 1999, but in 2007, it was split into the federally-threatened frosted flatwoods salamander, *A. cingulatum*, and the federally-endangered reticulated flatwoods salamander, *A. bishopi* (Pauly, Piskurek, & Shaffer, 2007). Both species have complex life cycles—they depend on seasonal ponds for breeding and larval development, and juveniles metamorphose

and disperse into terrestrial habitats. In other ambystomatid species, most juvenile salamanders are recruited into natal populations, but some disperse to new breeding sites (Gamble, McGarigal, & Compton, 2007; Semlitsch, 2008). Like many other amphibians with complex life cycles, detection of larval flatwoods salamanders requires appropriate rainfall in a given year (to provide suitable breeding conditions), intense and standardized effort to sample aquatic larvae, and coordination among researchers, natural resource managers, and regulatory agencies.

We used museum, natural heritage (Florida [FL] Natural Areas Inventory, Georgia Department of Natural Resources [GA DNR], South Carolina DNR), and metacrawler databases (Global Biodiversity Information Facility, VertNet, HerpNet) to compile all historic locality data for flatwoods salamanders. We georeferenced records with missing coordinate information using GEOLocate and Google Earth, and plotted Cartesian coordinates (in ArcGIS 10.3.1) to validate records and eliminate duplicates. We found 476 unique known historic locations of flatwoods salamanders (Semlitsch, Walls, Barichivich, & O'Donnell, 2017). Despite extensive efforts to survey historical locations and find new populations, the combined range of these two species decreased to only 63 recently extant locations (occupied at some point in 2010 – 2015), which represents an 86.8% population loss (Fig. 3; Semlitsch, Walls, Barichivich, & O'Donnell, 2017). Subsequent surveys in 2015 – 2016 detected previously unknown *A. bishopi* breeding wetlands (2 in GA, 3 in FL; J. Jensen, Georgia DNR; M. Winland, Florida Fish and Wildlife Conservation Commission, pers. comm.) and several *A. cingulatum* breeding wetlands (St. Marks National Wildlife Refuge [SMNWR] and Apalachicola National Forest, FL), but the difficulty of discovering newly identified populations limits our ability to completely assess the magnitude of declines. Though we lack empirical information regarding the cause of population losses, particularly on private lands, experts have identified several primary threats – habitat loss due to land use change and development, habitat degradation of longleaf pine flatwoods and savannas, and fire suppression – which have presumably led to decreased suitability of wetland habitat for larvae and terrestrial habitat for juveniles and adults (Bishop & Haas, 2005; Means, Palis, & Baggett, 1996; Fig. 1b-c). Despite continued surveys of historical and extant populations and the modification of fire management regimes in some

protected areas (Gorman, Haas, & Himes, 2013; Fig. 1e), flatwoods salamanders have continued to decline, and many remaining populations are vulnerable to extinction.

As figure 3 indicates, many populations across these species' ranges have likely been extirpated, which threatens the sustainability of larger metapopulations (Gamble et al., 2007; Marsh & Trenham, 2001; Semlitsch, 2008). These losses have decreased the representation and redundancy of flatwoods salamanders – two principles which indicate viable species (Shaffer & Stein, 2000; Wolf et al., 2015). Representation “requires the protection of populations across the full range of ecological settings of a species' range” (Wolf et al., 2015). Redundancy “requires establishing multiple populations in each ecological setting to spread extinction risk and to increase species' viability” (Wolf et al., 2015). New assessment methodologies being developed by the USFWS encourage recovery plan developers to specify the ecological needs for representation and redundancy for federally-protected species (USFWS, 2015; S. Blomquist, pers. comm.). By compiling the locality data shown in Figure 3, we have begun the process of identifying criteria for representation and redundancy of these species.

Captive breeding decision process

We held our first SDM workshop in August 2014 to address the potential use of ex situ population supplementation for the recovery of flatwoods salamanders (Walls et al., 2015). Attendees included conservation breeding experts, biologists, and the ultimate decision-maker—the USFWS recovery coordinator for flatwoods salamanders. For many critically imperiled species, establishing captive assurance colonies and controlled propagation programs is necessary to prevent complete extinction. However, USFWS policy requires decision makers to evaluate potential risks, benefits, and less intrusive alternatives before pursuing controlled propagation efforts (USFWS, 2000). Other considerations include financial costs, detrimental effects on source populations, and public communication challenges for agencies conducting reintroductions (Converse, Moore, & Armstrong, 2013).

We employed a formal, structured decision process to evaluate the use of captive breeding, as well as reintroductions or translocations of individuals to suitable habitat. We specified four fundamental

objectives: maximize (1) persistence (time to extinction), (2) viability (no. of populations), and (3) land steward cooperation; and (4) minimize costs. We developed a number of alternative actions designed to achieve these objectives (see Appendix A); then, we grouped the actions into several strategies (“portfolios”): (A) a “do nothing” option; (B) in situ translocations only; (C) establishing three captive populations (no animals released); (D) establishing 2 captive populations plus reintroducing captive-bred larvae into 3–5 ecologically-suitable, unoccupied historic sites; and (E) establishing 3 captive populations, conducting reintroductions at 6–8 sites, including 3–5 sites restored/constructed for purposes of reintroduction. We used a stochastic population viability model to estimate long- and short-term extinction probabilities under each alternative scenario (McGowan, Catlin, Shaffer, Gratto-Trevor, & Aron, 2014). Under the assumption that captive breeding will be successful, we projected that a “realistic maximum number of animals” (50 breeding pairs per facility, generating 2500 offspring per year) could be produced in just five years. We evaluated the five alternative strategies against our four objectives using a consequence table and found that alternative D was preferred because it provided the same persistence probability and only slightly lower population viability than alternative E for approximately 60% of the cost of the next best alternative (Walls et al., 2015).

Uncertainties— Many of our uncertainties regarding ex situ efforts arise from environmental stochasticity, enigmatic causes of decline, and a lack of basic demographic data. However, the pivotal uncertainty is whether these species can be bred successfully in captivity. Peer-reviewed studies regarding salamander conservation breeding techniques and successes are sorely lacking (Dodd, 2005). To our knowledge, besides the fully aquatic Mexican Axolotl (*Ambystoma mexicanum*), there have been only small scale efforts to rear ambystomatid salamanders for reintroduction in a captive environment, and neither of the flatwoods salamander species has been successfully bred. The climatic and microhabitat conditions under which flatwoods salamanders breed in nature are highly specialized and will likely be difficult to replicate in captivity. Even if captive breeding is successful, we remain uncertain about the number of individuals needed to sustain viable populations in nature. Additionally, it is difficult to predict

short-term survival rates of released individuals, how individuals will acclimate to a reintroduction area, and which life stage (larval, metamorphosed subadult, or adult) would be optimal for reintroductions.

Successful population reintroductions of imperiled species are, in general, rare: for other herpetofauna, only 42% of published translocation efforts have been deemed successful (though another 29% were uncertain; Germano & Bishop, 2009). Effective procedures for the reintroduction of pond-breeding salamanders are poorly understood and “success” criteria have not been formally established. Assessing the potential success of ex situ efforts is also difficult due to environmental stochasticity, which could be especially pivotal for flatwoods salamanders. For example, an adequate hydroperiod is critical for the reproductive success of ambystomatid salamanders, but increased drought frequency due to projected climate change may increase the probability of early pond drying in the future (Chandler, Rypel, Jiao, Haas, & Gorman, 2016; Walls, Barichivich, & Brown, 2013; Westervelt, Sperry, Burton, & Palis, 2013). During the SDM workshop, we simulated the impacts of drought on population viability using our preliminary model, but found that varying climate scenarios did not change the identity of the optimal decision (Walls et al., 2015).

Our primary intent in conducting this SDM workshop was to provide the USFWS flatwoods salamander recovery coordinator with a decision support tool to use in recovery planning. A plan to initiate and synchronize a multi-partner sampling and monitoring effort of wild populations is already underway, and conservation breeding partners are working to identify necessary components of a successful captive breeding program for these species. Because the ultimate success of ex situ conservation is persistence in the wild, we identified a linked decision: how to approach habitat restoration and maintenance to ensure long-term species persistence and successful relocation and translocation efforts. Thus, we held a second SDM workshop to confront this problem.

Adaptive habitat management decision process

In February 2015, we addressed how to restore wetland and upland habitat to minimize the extinction risk of *A. cingulatum* at a focal site – SMNWR – that represents one of two remaining strongholds for *A. cingulatum* (Fig. 3; O’Donnell et al., 2015). We specified six primary objectives to guide our decision: to maximize (1) likelihood of population persistence, (2) ecosystem integrity, (3) public support, and (4) human safety; and to minimize (5) cost and (6) impacts to other at-risk species. Collectively, we developed a list of more than 40 alternative management actions to address these objectives, and we separated participants into three sub-groups – (A) scientists only, (B) a mix of scientists and land managers, and (C) land managers only – to identify the five actions that each would prioritize, given a five-year time span. We expected this exercise to generate three divergent management portfolios, representing a range of opinions, which we would subsequently discuss and evaluate. However, all three groups identified very similar priorities – growing season burns of wetlands and mechanical restoration (as needed) to restore pond edges (see Appendix B).

Upon realizing that all workshop participants agreed about how to address the original decision problem, we shifted focus to a more immediate need. Because it will likely take several years to restore habitat at SMNWR, we concentrated on how to keep *A. cingulatum* on the landscape in the interim. We converged on what we dubbed “assisted metamorphosis,” in which we would head-start *A. cingulatum* larvae in large, in situ mesocosms to increase survival to metamorphosis (an approach widely used in experimental contexts; Semlitsch & Boone, 2009; Wilbur, 1987).

We developed a state-dependent adaptive management framework to encompass all possible management actions. We considered each pond to be either suitable or unsuitable habitat, and to be either occupied or unoccupied, resulting in four states: suitable//occupied, suitable//unoccupied, unsuitable//occupied, or unsuitable//unoccupied. Restoration actions would only be taken on unsuitable sites, assisted metamorphosis would only occur at occupied sites, and translocation would only occur at suitable//unoccupied sites (Table 1). To generate transition probabilities (i.e., the chance of a site in one state remaining in that state or transitioning to a different state in the next year), we elicited values from experts at the workshop (Morgan, 2014). In our follow-on analysis, we use these transition probabilities

in a category count model (Fackler, 2012) to predict the proportion of ponds within each state under two management scenarios: (1) the future status quo (FSQ), in which the same management strategy (i.e., frequent growing-season burns) is applied to all ponds, and (2) an all-of-the-above (AOTA) strategy, in which additional actions (Table 1) are taken at each pond. We use a Markov decision process to project the proportion of sites in each category at future time intervals, and to identify the suite of actions that would lead to the optimal solution. We combine the utility (i.e., relative desirability of each state) and monetary cost values in a reward function, which represents the trade-offs between taking more aggressive management actions and increasing costs (O'Donnell et al., 2015). The final optimal decision policy will determine the best management strategy to take in each state (O'Donnell et al., unpub. data).

Uncertainties— A natural degree of uncertainty exists due to inherent variability in ecosystem processes (environmental stochasticity) and random variation in population dynamics (demographic stochasticity), as well as our ability to observe those population changes (Williams, 1997). The inability to completely control the timing of management actions is another source of uncertainty, especially when dealing with weather-dependent actions like prescribed fire. Perhaps the greatest source of uncertainty in our decision is structural – we do not know exactly how the habitat or salamander populations will respond to our various proposed actions. To address these uncertainties, we outlined an adaptive management approach to systematically reduce uncertainty over time (O'Donnell et al., 2015). Decisions about management actions will be made each year, and we will monitor the system to evaluate the effects of the actions (Fig. 4). By comparing our predictions to observed management responses, we will be able to reduce the uncertainty of actions and make better decisions over time.

Current and future actions

We have begun to implement numerous in situ and ex situ recovery actions, as determined at the SDM workshops. Ex situ teams are working to develop captive breeding protocols, and two locations (The Amphibian Foundation [Atlanta], San Antonio Zoo) currently have flatwoods salamanders in captivity. Research and management teams at Eglin Air Force Base and SMNWR have implemented in situ assisted

metamorphosis and will evaluate success of the 2015-2016 efforts. Fire managers at SMNWR conducted growing season prescribed burns in several flatwoods salamander management units in July 2015 and plan to burn remaining management units in the 2016 growing season (Fig. 1e). Importantly, SMNWR secured substantial funding for executing necessary management actions through the USFWS Cooperative Recovery Initiative program in early 2016 (USFWS, 2016b). The proposal was successful due to the partnerships formed through the SDM process and the decisions made therein.

As a result of workshop discussions, we identified numerous data needs and areas for further development. Assessing genetic structure among current flatwoods salamander populations is important for informing captive breeding and reintroduction efforts, and for identifying effects of management on population persistence. We also need better estimates of life history characteristics to improve population viability analyses (PVA). Working Group members from both SDM workshops are currently refining predictive models and will continue to update them as we learn more about the systems. Various partners will also continue coordinated survey efforts to monitor flatwoods salamander persistence and attempt to identify previously unknown breeding sites.

Shortly after the second SDM workshop, we held a meeting of the larger Working Group to discuss the results of the workshops with other stakeholders. In summer 2015, the Flatwoods Salamander Recovery Team was restructured, and the first team meeting was held in October 2015. This team is tasked with developing recovery criteria, along with conservation actions designed to meet those criteria. The SDM workshops proved to be valuable steps for informing recovery planning, by developing short-, medium-, and long-term goals. Through these workshops, we came to realize the necessity of keeping flatwoods salamanders on the landscape in the short-term (i.e., assisted metamorphosis) because of uncertainties and time-lags in longer-term captive breeding and habitat restoration goals. Given the dire situation of flatwoods salamanders, we suggest that continued coordination and swift action is necessary to prevent extinction. As a result of the SDM workshops, we are well-situated to develop comprehensive recovery plans and execute the proposed actions.

Value of SDM

Three essential elements to decision structuring are: (1) defining the decision problem, (2) specifying a set of objectives, and (3) generating alternatives (Fig. 2; Keeney, 2004). By explicitly defining these components at each workshop, our group was able to assess the linked problems in an organized, tractable manner. The objectives we specified provided the structure we needed to work toward a common goal, and the SDM process encouraged transparent, methodical communication among biologists and stakeholders. Because we mutually agreed on objectives, we ensured that the eventual decision would be endorsed by all participants. We also believed that it was extremely valuable to meet face-to-face, to convene in a neutral location (e.g., the USFWS National Conservation Training Center), and to dedicate five days to the SDM process.

At the second SDM workshop, structuring the decision allowed us to quickly realize that – to our surprise – all participants generally agreed on how to restore habitat at SMNWR. However, we also recognized that we had not fully captured the complexity of the situation in our initial decision problem. Structuring the decision made it clear that we agreed on a long-term approach to habitat restoration, but that developing a short-term solution was a more important decision. Overall, SDM provided distinct advantages over previous attempts to tackle these decisions.

We believe that many similar amphibian conservation efforts could have been more successful had SDM been the decision-making process. For example, SDM could have aided recovery efforts for Houston toads (*Bufo houstonensis*), which suffered due to complex local politics and failed reintroduction efforts (Brown & Mesrobian, 2005; Dodd & Seigel, 1991). Adaptive management could also have improved recovery efforts for the Wyoming toad (*Bufo baxteri*), in which captive-bred toads were reintroduced, but subsequent monitoring was insufficient to evaluate the efforts (Dreitz, 2006). Miscommunication among management agencies also hampered conservation efforts, but may have been avoided if SDM was in use (Dreitz, 2006). There are several recent examples of SDM applications for amphibian conservation, including decisions about ex situ conservation (Canessa et al., 2015; Grant, Zipkin, Nichols, & Campbell, 2013; Robinson, McGowan, & Apodaca, 2016). The Flatwoods

Salamander Working Group is, to our knowledge, the first to use two related SDM workshops to address different aspects of imperiled species recovery. We believe this model could improve recovery efforts of many other protected species. There are usually many roadblocks when developing recovery plans, and often each roadblock is of appropriate scope for an SDM workshop. Because we sought to keep the number of workshop attendees relatively small, holding separate workshops allowed a greater diversity of expertise to be represented at each workshop.

SDM has proven vital to our process of developing recovery plans and implementing recovery actions for flatwoods salamanders. Given the complexity of decisions regarding imperiled species and the demonstrated value of SDM, we believe that SDM should be integral to those decision processes. Most federal natural resource agencies (including USFWS) employ SDM (Williams et al., 2007), but it is applied with varying levels of rigor and effectiveness (Fischman & Ruhl, 2015). Overall, however, SDM remains underutilized – especially for amphibians. We hope that this case study provides further support for its application.

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Table 1. State-dependent management actions for four possible wetland conditions.

System state	Potential Alternative Actions
suitable//occupied	Rescue (“assisted metamorphosis”)
suitable//unoccupied	Translocation
unsuitable//occupied	Restore (mechanical, herbicide, pond burns) + Rescue (“assisted metamorphosis”)
unsuitable//unoccupied	Restore (mechanical, herbicide, pond burns)

Figure 1. Flatwoods salamander life stages and habitat: (a) reticulated flatwoods salamander larva, (b) suitable flatwoods upland habitat, (c) adult frosted flatwoods salamander in wiregrass, (d) adult frosted flatwoods salamander, and (e) prescribed burning to restore flatwoods salamander habitat. [Photos a, c, d: P. Hill; b, e: KMO]

Figure 2. Stages of the structured decision making (SDM) process, illustrated with examples from adaptive habitat management SDM workshop.

Figure 3. Geographic distribution of flatwoods salamanders (frosted flatwoods salamander, *Ambystoma cingulatum*, and reticulated flatwoods salamander, *A. bishopi*) in the southeastern U.S.A. Black squares indicate all known records. Yellow triangles indicate locations which were extant in ≥ 1 year between 2011 – 2016. Shaded counties indicate the range of each species. Arrow indicates St. Marks National Wildlife Refuge (SMNWR).

Figure 4. Key steps of adaptive management process, which is used to reduce uncertainty regarding management actions and improve decision-making.

Figure 1

Figure 2

STRUCTURED DECISION MAKING

PrOACT steps

salamander case study

PROBLEM

Identify decision maker, decision scope, potential linked decisions

How to restore wetland and upland habitat to minimize extinction risk of *Ambystoma cingulatum* at SMNWR

OBJECTIVES

Driven by values; will be used to assess alternatives

Maximize population persistence, ecosystem integrity, public support, human safety; minimize costs, impacts to other species

ALTERNATIVES

Develop management actions to achieve objectives; creativity is key at this step

(1) Future status quo strategy vs. (2) all-of-the-above strategy (i.e., rescue, restore, translocation)

CONSEQUENCES

Models predict how alternatives will achieve objectives

Use elicited transition probabilities to predict pond occupancy under the two alternative strategies

TRADE-OFFS

Evaluate relative importance of objectives to choose among alternatives

Combine relative desirability of each state + monetary costs in a reward function to represent trade-offs

DECISION

Make decision and take action

Optimal policy indicates best management strategy to take in each state

Figure 3

Figure 4