Strategic Decision Planning for Endangered Species Recovery in Puerto Rico: Final Report

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Introduction

In Puerto Rico, the Caribbean Ecological Services Field Office of the United States Fish and Wildlife Service (USFWS) currently bears the responsibility to manage, with the goal of recovery, 77 listed species (J. Cruz-Burgos, Endangered Species Program Coordinator, pers. comm.). The staff of the Caribbean Field Office Endangered Species Program performs diverse tasks (hereafter, recovery actions) to protect and recover these listed species (http://www.fws.gov/caribbean/es/Endangered-Main.html), as well as additional at-risk species. With many endangered species, uncertain knowledge, and limited resources, there is a risk of inefficient resource allocation (reducing the rate of species recovery) or inadequate resource allocation (leading to species extinction). There is a need to develop a strategy to prioritize among possible recovery actions in a manner that maximizes the benefit to listed species over the long term while simultaneously protecting species at risk of imminent extinction. Planning the allocation of limited resources and effort is difficult, not only due to knowledge gaps, but also due to the inherent challenges of managing complex, dynamic systems under stress. However, formal analysis of management practices and decision alternatives can improve the planning process, reducing risks despite uncertainty and maximizing the chance of successful outcomes (Conroy et al. 2008; Gregory & Failing 2012; Martin et al. 2009).

In January 2015, we led the Caribbean Field Office staff and partners from the Puerto Rico Department of Environment and Natural Resources (DENR) through a Structured Decision Making workshop (Gregory & Failing 2012) to identify the principles and information which guide their endangered species recovery decisions. The ultimate goal of this workshop was breakdown the decision process into its components and then construct a Recovery Action Prioritization tool from these components. The vision for this project described a simple, transparent tool that would incorporate information regarding costs, expected benefits of action, expected risks of inaction, sources of uncertainty, and probability of success, among other factors. The anticipated functionality of the tool included the abilities to simultaneously evaluate all possible decisions (within the set contained in the decision database) and to explore alternative decision scenarios (e.g., different budgets, decision values, or recovery action data). Some of the anticipated benefits of such analyses would be improved transparency of the decision process, greater confidence in the decisions selected (and not selected), increased ability to explore potential conflicts (due to differences in either information or values), increased ability to present impacts of any proposed budget changes, and reduced burden of pending legal issues.

The workshop was also attended by supervisors from the Field Office and from DENR (decision makers). In the workshop, we identified and characterized the criteria by which FWS staff make decisions when they act to recover endangered species. We worked to clarify both their objectives (i.e., what they hoped to achieve) and their justifications (e.g., cost, response time, collaboration, probability of success, etc.) driving them to select one decision above another. As part of this process, we worked with the workshop participants to formally define objective functions by which they evaluate decisions. We used the information gathered in the workshop to develop a tool to help prioritize decisions as defined by the participants. We delivered this tool to the FWS via webinar in March 2015.

This report outlines the workshop outcomes and the resulting Recovery Action Prioritization tool. The associated documents deliver the model underlying the prioritization tool (written in the program R; R Core Team 2014) along with a sample database, instructions, and definitions. The FWS has responsibility to complete the database, explore the decision weighting system, and ultimately, prepare an Endangered Species Program plan. Through the workshop and this report, we have introduced FWS and partner staff to formal decision-making procedures that can serve as a template for other programmatic units.

Methods and Results

Workshop

The workshop had two primary objectives: (1) familiarize all field office staff with formal decision analysis and strategies to define and then optimize management outcomes, and (2) gather the necessary information to produce a tool to prioritize recovery actions that the Caribbean Field Office Endangered Species Program could apply to better leverage limited resources, and to more efficiently and effectively recover listed species. Eleven staff and supervisors from the Caribbean Field Office and five from the DENR participated in the workshop. The first day provided an overview of the project objectives and discussion of the Endangered Species program current management framework. This included discussion of the agency's mandate and procedures, such as budget strategies (e.g., whether recovery money is distinct from administration costs), current measures of success (e.g., annual and 5-year review procedures), and how recovery actions have been selected (versus delayed) in the past.

A novel aspect of our project, compared to past discussions of endangered species recovery decisions, was the incorporation of estimated costs, probability of success, and risks associated with inaction. Several recent projects have demonstrated that including costs and probability of success is critical to developing effective conservation plans generally (DoF 2013; Joseph et al. 2008; McCarthy et al 2008; Scott et al. 2005), and for endangered species specifically. Workshop participants reviewed the case study of New Zealand which recently increased their rate of species recovery by incorporating costs and probability of success (Joseph et al. 2008). We used this project as a launching point to discuss FWS definitions of success. Previous projects have not always considered the risk of delayed action (e.g., if three of ten decisions are prioritized for action based on cost and probability of success, then seven actions are delayed). Therefore, we also devoted workshop time to discuss whether FWS considered risk of delayed action when making decisions. Specifically, we asked if there were any situations (e.g., high cost, low probability of success) under which the FWS could knowingly delay action if best available science and best professional judgement predicted a high risk of species extinction due to delay.

We constructed the prototype models in real-time collaboratively with the workshop participants. The ability to gather information (model parameters, variable definitions, decision objectives, etc.) and immediately demonstrate how these parameters combined to affect decision priority was critical to the success of the workshop. This procedure (developing the prototype model within the workshop) maintained a high level of engagement and momentum as products could be reviewed and modified immediately. A significant portion of the first day required clarifying fundamental versus means objectives. Initially, FWS staff more easily identified means objectives (e.g., protect land, reduce poaching, control predation, acquire knowledge) than fundamental objectives (e.g., recover species, prevent extinction, etc.). Significant discussion also focused on deciding whether the annual decisions addressed only the Endangered Species Act mandate to recovery species or if other factors also influenced their day-to-day decisions. Through our iterative approach, FWS staff could immediately see the implications of their various ideas and we could test if ranking actions by expected contribution to recovery, for example, matched with the actions they would recommend. Discrepancies indicated the possibility of additional decision criteria or exceptions for "special cases" that required further investigation.

To illustrate, some of the special cases that participants identified and discussed included:

(1) Species with unknown population status. These are species that require research to determine appropriate recover actions. Thus the action of research arguably does not immediately or directly contribute to recovery. In fact, research could result in determining a species is at even more risk than previously suspected. Yet effort to acquire knowledge is sometimes prioritized. Significant discussion focused on if/when FWS would ever value an action leading to transition from unknown to known status over a transition from endangered to threatened to recovered status.
(2) Species that have a very low probability of recovery. Some species might never recover, but certain actions could greatly improve the probability of long-term persistence. Effort to improve a species' long-term probability of persistence is sometimes prioritized.
(3) Actions that have a low probability of successful completion. Some actions have a really high probability of resulting in recovery if implemented but a low probability of being successfully implemented at present. Effort on such an action might be delayed (de-prioritized) until the opportunity for successful action improves.
(4) Species at imminent risk of extinction if immediate action not taken. Delayed action, in some cases, could have a high likelihood of resulting in species extinction. In such cases, action is likely to be prioritized; FWS would not knowingly act to allow a species to go extinct, even if the expected outcome of the action was population maintenance rather than recovery.

As these examples illustrate, selecting among hundreds of possible actions to manage for species recover is a complex process. However, as these same examples illustrate, FWS staff could generally identify how they would interpret their mandate and act in various scenarios. Together, evaluating these and other scenarios, we identified a set of fundamental objectives and their relative value weights to incorporate into the decision prioritization tool.

Recovery Action Prioritization Tool

The Recovery Action Prioritization Tool has three fundamental objectives. Given an expected 5-year budget estimate (input by the manager), the tool identifies sets of actions that will:

- Maximize the probability of positive reclassification
- Maximize the increase in probability of long-term persistence
- Minimize the immediate risk of extinction

The tool incorporates uncertainty due to imperfect information. In addition to estimating probabilities, the experts also characterize the quality of the information supporting their estimates. Specifically, they scored their confidence in the information on a 0 – 100% scale.

Software Requirements
The tool only requires Excel (input and output data) and R (model code), but having R Studio will help greatly. R Studio is a programming shell (IDE, integrated development environment) that will color code the R text and provide line numbers for easy reference. Both R and R Studio are free.

R (http://www.r-project.org/)
R Studio (http://www.rstudio.com/)

The model was developed in R version 3.1.2 (2014-10-31) -- "Pumpkin Helmet", Copyright (C) 2014 The R Foundation for Statistical Computing, Platform: x86_64-w64-mingw32/x64 (64-bit) using R Studio version 0.98.1102 – © 2009-2014 RStudio, Inc.

Model Code Description
First we divide the data into two tables: Candidate Actions and Non-Candidate Actions. Managers should review the Non-Candidate Action table to understand what actions have been excluded, especially for species suspected to be at high risk of immediate extinction. Candidate Actions are those actions requiring decisions for this decision cycle. These are all actions Not Yet Started (Progress = 0) and with all Prerequisites completed (Prerequisites = N). This model only considers and weights decisions available in the present; it does not account for future expectations. For example, if Step 1 has a very low value and Step 2 has a very high value (but is prerequisite on completing Step 1), the model does not look ahead to predict that you should do Step 1 because Step 2 has such a high value. Although the decision database includes some data to incorporate more complex dynamics (e.g., prerequisite structure, benefits of single actions shared across multiple species), it was beyond the scope of this pilot project to incorporate these more complex dynamic. (See the discussion for strategies to include future expectations and dynamics of decision interactions in future versions of the model.)

Next we incorporate the uncertainty into the expected benefits of action and risks of inaction. We incorporate uncertainty for the five probability variables: successful completion, 50 year baseline extinction, 50 year with action extinction, delay action 5 year extinction, reclassification probabilities. (Note: These time horizons are built into the database variable definitions, but in other applications the time horizons could easily be adjusted). We did this by treating the experts' probability estimates as mean values from a normal distribution and using their confidence score to calculate a standard deviation value for each mean. Thus, if an expert predicted a probability of 0.75 with a confidence of 0.80, we assigned a standard deviation of 0.75*(1-0.80) = 0.15. For each expected probability, we drew a value from the probability distributions defined by these means and standard deviations. The change in probability of persistence was calculated as the 50 year baseline extinction probability minus the 50 year with action extinction probability. In any case where the selection of distribution values resulted in probabilities greater than 1 or less than 0, these were adjusted to 1 or 0, respectively. Although the estimates of costs, time, benefits shared with other species, and leverage (expected percentage contribution from partners) are also best professional judgments subject to uncertainty, these variables are treated as known values in our model.

The value of an action includes both the expected contribution towards an objective and the probability of successfully completing the action within the stated budget and time frame. We calculated the single objective values for three objectives: minimize 5 year extinction risk due to delaying action, maximize increase in probability of persistence, and maximize probability of reclassification. The manager must select numeric values to indicate agency decision values at two points. First, weights must be assigned to the three possible reclassification transitions: unknown to known, endangered to threatened, and threatened to recovered. Based on correspondence with the staff of the Caribbean Field Office Endangered Species Program, default values for these transitions are currently set to 1.0, 1.5, and 3.0, respectively (Lines 144-146). For each action, the calculated reclassification objective values are multiplied by the relevant weight value. The second point where managers must assign weights is when we combine objectives within a single decision framework. Based on discussion with PR-FWS, default values for the risk, persistence, and reclassification objectives are 1.5, 1.0, and 2.0, respectively (Lines 168-170). To calculate the value of an action given all three objectives jointly, we calculated the weighted average for that action.

Once all actions have been valued for the individual and joint objective, we sort the actions (high to low) based on the value column. Managers indicate the available annual budget (Line 22) and actions are selected, starting from the top of the list (highest value towards meeting objective), until the budget has been allocated. (Note: In this calculation, we only reference the percentage of costs covered by the FWS.) Importantly, in this version of the tool, actions are considered individually. Although we gathered data on shared costs and benefits (e.g., one action, such as habitat protection, could protect multiple species) it was beyond the scope of this initial project to map and model the temporal, spatial, and taxonomic interdependencies among species. Implications and recommendations relative to this aspect of the model design are presented in the discussion.

The entire model process of drawing probability values, calculating objective values, and identifying the actions that best meet objectives within the given budget is repeated multiple times (default is 1000 simulations; Line 70). Given uncertainty on the probability estimates, the decision set can differ slightly among model runs. We report the results in two ways. First, we tabulate how many times, given a specified budget, each action was selected within any decision set given each objective function (Table 1). Second, we identify which sets of actions were most frequently selected as a group of actions within the budget constraints (Table 2).

Table 1. An illustrative example of the "individual action" output showing how many times (number of simulations out of 1000) each decision was included as part of the top priority decision set. The format has been modified for readability. These results are not representative of any FWS decision values and are merely a sample run with a subset of the data and default budget and priority value weights to illustrate output data and data interpretation. Results are tallied for each priority objective individually (minimize immediate extinction risk [Risk], maximize increase in persistence [Persist], and maximize probability of positive reclassification [Reclass]), and for the combined result from considering the three weighted objectives together [Weighted]. Referenced species are: Mona Island boa (Epicrates monensis granti), unnamed fern (Thelypteris yaucoensis), unnamed shrub (Catesbaea melanocarpa), unnamed fern (Adiantum vivesii), Monito gecko (Sphaerodactylus micropithecus), uvillo (Eugenia haematocarpa), guajón (Eleutherodactylus cooki), Mona iguana (Cyclura steinegeri).

Action	Risk	Persist	Reclass	Weighted
Protect and manage known E. monensis granti populations	685	860	861	907
Prevent T. yaucoensis habitat loss and population decline	18	936	82	857
Evaluate techniques and develop a plant propagation program for C. melanocarpa	887	946	396	824
Conduct research on A. vivesii genetics to determine if it is hybrid	706	0	352	818
Monitor for potential S. micropithecus predation	3	704	819	765
Conduct scientific research on C. melanocarpa on specific habitat requirements and population genetics	844	748	484	747
Protect existing C. melanocarpa populations from threats and limiting factors through landowner agreements and other conservation mechanisms	982	855	7	697
Determine status and trends of present S. micropithecus population	301	56	757	597
Determine the distribution and population status of C. melanocarpa throughout its present and historic range including Barbuda Antigua and Guadalupe	0	886	502	583
Define T. yaucoensis habitat requirements and reproductive biology.	0	973	0	464
Update T. yaucoensis distribution and abundance information	900	204	0	265
Gather info on E. haematocarpa distribution and abundance	0	0	748	265
Determine the distribution and population status of the E. cooki within traditional non-traditional and unoccupied habitat	0	697	952	195
Document the effect of natural and manmade disturbances on the E. cooki population	944	16	868	154
Implement conservation strategies for protection of essential habitat for the E. cooki	71	25	552	55
Determine status of present E. monensis granti populations	0	21	239	24
Determine and characterize habitat requirements E. monensis granti movements and behavior	0	25	238	18
Develop an inter-agency agreement to promote E. haematocarpa recovery	0	13	145	15
Facilitate the recovery of C. melanocarpa through public awareness and education	83	625	0	1
Prevent A. vivesii habitat loss and decline	549	0	0	0
Gather info to define A. vivesii distribution and abundance	2	0	0	0
Facilitate the recovery of the E. cooki through public awareness and education	334	26	0	0
Determine the current status of the C. steinegeri population	0	34	315	0

Table 2. An illustrative example of the "decision set" output showing all decision sets identified as the priority set in greater than 1% of the simulations (>10 of 1000) based on the weighted average of the three agency priority objectives. The format has been modified for readability. These results are not representative of any FWS decision values and are merely a sample run with a subset of the data and default budget and priority value weights to illustrate output data and data interpretation. Notice that actions 3, 9, 11, and 12 occur in all the top decision sets, therefore these are decisions we refer to as being robust to knowledge uncertainty. Actions 10, 19, 25, 27, and 28 appear substitutable given uncertainty, and these are decisions which impart a degree of flexibility given uncertainty. Similar tables are also generated for each individual objective. Referenced species are: unnamed fern (Adiantum vivesii), unnamed shrub (Catesbaea melanocarpa), unnamed fern (Thelypteris yaucoensis), Mona Island boa (Epicrates monensis granti), Monito gecko (Sphaerodactylus micropithecus), uvillo (Eugenia haematocarpa).

Decision Set	% Sims
(3) Conduct research on A. vivesii genetics to determine if it is hybrid, (9) Protect existing C. melanocarpa populations from threats and limiting factors through landowner agreements and other conservation mechanisms, (10) Determine the distribution and population status of C. melanocarpa throughout its present and historic range including Barbuda Antigua and Guadalupe, (11) Evaluate techniques and develop a plant propagation program for C. melanocarpa, (12) Conduct scientific research on C. melanocarpa on specific habitat requirements and population genetics, (19) Prevent T. yaucoensis habitat loss and population decline, (25) Protect and manage known E. monensis granti populations, (27) Determine status and trends of present S. micropithecus population	5.2
(3), (9), (10), (11), (12), (19), (25), (28) Monitor for potential S. micropithecus predation - NOT (27)	5.1
(3), (9), (10), (11), (12), (19), (25), (28) Monitor for potential S. micropithecus predation, (30) Gather info on E. haematocarpa distribution and abundance - NOT (27)	3.7
(3), (9), (10), (11), (12), (27), (28) Monitor for potential S. micropithecus predation - NOT (19), (25)	3.5
(3), (9), (11), (12), (19), (25), (28) Monitor for potential S. micropithecus predation - NOT (10), (27)	2.9
(3), (9), (11), (12), (19), (25), (27), (28) Monitor for potential S. micropithecus predation - NOT (10)	2.1

Products, Outcomes, and Next Steps
These are the products delivered with this report (RecoveryActionPrioritization_Report.pdf):

- Spreadsheet of decision data (RecoveryActions_DDMMYYYY.xlsx)
- Data quality checklist (RecoveryActions_DataCheckList.pdf)
- Definition sheet to accompany spreadsheet (Prioritization_Definitions.pdf)
- Model code, Version 1.0 (RecoveryActionPrioritization_V1.R)
- Model instructions (RecoveryActionPrioritization_Instructions.pdf)

This first version of the Recovery Action Prioritization Tool is fully functional and offers several immediate benefits over current decision processes. Specifically, our model provides:

(1) Recommendations for decisions that are robust, yet flexible in the face of various sources of uncertainty.
(2) Documentation (transparency) of agency assumptions, data, and values underlying decisions.
(3) A central location for Recovery Action information for easier data management, knowledge transfer, and outcome monitoring (Campbell et al. 2002).
(4) The means to quickly and with greater detail summarize anticipated effects of budget loss or gain in terms of anticipated ability to perform Recovery Actions.
(5) The means to quickly and with greater detail summarize anticipated effects changing recovery landscape (e.g., partners, probabilities success, costs of actions).
(6) The means to explore whether differences of opinion (e.g., regarding budget, weights, or estimated values within the model) are significant enough to alter prioritization, and thus warrant further research or discussion.

While the tool is fully functional, there are still several tasks to be undertaken by the FWS staff, as outlined in the project proposal. Specifically, they will complete data entry to populate the recovery action spreadsheet, run through a set of simulations to ensure that they understand the tool, and finally use the tool to support the development of a recovery planning document for the PR recovery program. Optionally, they may wish to develop a strategy to maintain the database and to assess the performance and value of the tool. We will remain available to provide technical support and guidance.

Discussion

With this work, the Puerto Rico FWS demonstrate a transition from a reactive to a proactive approach to selecting and implementing Recovery Actions for endangered species recovery. In the absence of a prioritization strategy, the staff expressed frustration that good recovery work was not translating to higher numbers of petitions to positively reclassify species. They cited several examples of near-complete recovery projects, where final action was delayed as other emergencies or opportunities demanded resources. Furthermore, with 77 listed species and hundreds of recommended Recovery Actions, they lacked a structured way to annually select the few projects that would best achieve their mandate. This challenge is not unique to the Puerto Rico office (DoF 2013; Joseph et al. 2008; McCarthy et al 2008; Scott et al. 2005) and Defenders of Wildlife recently recommended prioritization as the first of five strategies to improve endangered species programs: “The problem is that prioritization is not often explicit, transparent or organized, thus preventing limited resources from being used to maximize the amount of species diversity conserved (one of the underlying goals of the [Endangered Species Act])" (DoF 2013). Recent case studies in New Zealand and Australia demonstrate that prioritization generally, and the integration of cost and probability of success specifically, can dramatically improve the efficiency and effectiveness of endangered species recovery programs (Joseph et al. 2008, McCarthy et al. 2008).

There are three primary means by which this initial version of the tool could be improved. We present these in increasing order of complexity. First, the utility of the tool could be greatly improved through development of user-friendly graphic interfaces for data entry, decision analysis and reporting. This would facilitate accurate and rapid transcription of recovery actions into the tool, testing of the core decision components of the model, demonstration of how the tool can (and cannot) support recovery planning, and build understanding of the tool's functionality. Second, additional decision criteria could be developed and incorporated. These could include factors that (1) weight individual species, such as taxonomic uniqueness or endemism or factors, (2) weight shared benefits, such as actions that benefit multiple species or build strong partnerships, and (3) weight nested benefits, such as when a high cost prerequisite action could be followed by a low cost, high probability of success second action. Modeling shared and nested benefits requires more complex modeling to map the linkages between actions, but much of the required data exist within the existing data frame. Third, once data have been entered and the simpler version of the model well tested and understood, FWS might consider modifying the model to incorporate the dynamic nature of decisions through time. When a decision is made and a set of actions completed the decision environment is changed. A dynamic model will help select the best decision at present, conditional on how "states" or conditions in the future change in response to that decision. In other words, it helps minimize potential pitfalls of making decisions without anticipating how they might affect future decisions. In the present model, decisions can only evaluated within one time horizon based on the available information.

In summary, our project facilitated the design of a structured approach to a previously unstructured problem. Together, we completed a decision-making workshop and created a fully-functional decision tool to prioritize recovery actions. Importantly, this prioritization is not a panacea and model output must always be carefully weighed as no model captures all biological, social, economic, and political variables. The Defenders of Wildlife report addressed some of these concerns when they caution:

> "Despite our general support for prioritization, we also acknowledge its difficulty and weighty implications, and know that it must be done carefully. Prioritization should never be used as an excuse to limit or decrease funding for conservation. Rather, it should be tailored in a way that enhances the impact of funding for conservation by enabling wildlife managers to demonstrate greater conservation benefits and a more transparent use of public and private conservation contributions. Prioritization should also be made compatible with the conservation of keystone, umbrella and other functionally important species or guilds of species, because doing so will enable us to better conserve many other species and their shared habitats, and buttress public support for conservation." (DoF 2013)

In this tool, through application of simulation techniques to account for uncertainty in best available science and best professional judgement, managers obtain a set of priority Recovery Actions which they know to be robust to knowledge uncertainty and some aspects of administrative uncertainty. At the same time, they receive output that shows the many "runnerup" decision sets and the objective scores for each Recovery Action (individually and jointly). These supporting data ensure that they maintain the flexibility to make informed, transparent decisions in response to changing opportunities or emergencies. Furthermore, they can evaluate prioritized decisions within the broader, dynamic context of both federal and partner programs.

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