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A Decision-theory Approach to Cost-effective Population Supplementation for Imperiled Species

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ABSTRACT

Despite decades of managing endangered species, few have been successfully recovered. One option to reduce this gap is to use decision analysis to weigh alternative recovery actions. Using decision analysis, we evaluated tradeoffs between recovery actions to reduce extinction risk and financial cost for the imperiled Oregon spotted frog (*Rana pretiosa*). We simulated population supplementation via captive breeding or head-starting, and releasing offspring into the wild as larvae or young of the year. We ranked the efficacy of recovery scenarios, represented by a culmination of a series of decision points, to reduce the 10-year extinction risk below 10% while minimizing financial costs. We explored how rankings varied with respect to the extinction risk target, the endangered population size, and the reproductive output captive females. Our top-ranked pathway was to supplement with captive bred larvae, resulting in a 3% reduction in extinction risk for every $100,000 spent. In general, supplementing with captive bred larvae resulted in the biggest reduction in extinction risk per dollar invested. Additionally, we found that increasing spending does not always result in a proportional reduction in extinction risk. These results link quantitative and applied conservation by considering the biological and economic efficacy to recover endangered species.

1. Introduction

The US Endangered Species Act (ESA) and Canadian Species at Risk Act (SARA) mandate that recovery strategies be developed for endangered and threatened species. Of the 1872 species or populations listed under the ESA or SARA, two thirds (1393) have formal recovery plans (Fig. 1). Despite this large-scale effort, relatively few listed species have been sufficiently recovered as to be removed or down-listed from either the ESA or SARA. Of the 61 species delisted from the ESA, only half (32 species) have been delisted because they have met recovery goals, 10 species have been removed due to extinction, and the remainder as a result of updated information (e.g. taxonomic revisions) (https://ecos.fws.gov/tess_public/reports/delisting-report accessed 7 December, 2015), while only 3 species under SARA have been delisted because they were recovered (Favaro et al., 2014). The challenge of recovering species often stems from uncertainty in the causes of decline, mitigating or circumventing the drivers of decline, and having sufficient resources to meaningfully address these problems at the often large spatial and temporal scales required for species recovery.

Recovery decisions for endangered species are often made quickly and with limited data with which to inform recovery objectives (Martin et al., 2012; Gerber and Hatch 2002). However, reviews of ESA recovery plans found that plans with a higher number of clear quantitative recovery goals (i.e. target population sizes and number of populations) are associated with improving species status (Gerber and Hatch 2002; Himes Boor, 2014), suggesting that leveraging even limited data in a quantitative framework to inform species recovery is useful. Others have also suggested steps to improve science-based decision making that are applicable across taxa, including specifying quantitative requirements for species recovery and recovery timelines, as well as identifying the number of populations or the spatial extent to which recovery measures apply (Boersma et al., 2001; Clark et al., 2002; Gerber and Schultz, 2001; Himes Boor, 2014; Possingham et al., 1993; Scott et al., 1995; Waples et al., 2013), but such standards have yet to be adopted in a way that improves planning (Himes Boor, 2014; Doak et al., 2015; Troyer and Gerber, 2015). For instance, recent updates to the US Fish and Wildlife Service and National Marine Fisheries Service failed to make any quantitative criteria or standards mandatory (Troyer and Gerber, 2015).

Integrating quantitative measures into recovery planning can be challenging due to lack of data for rare species, uncertainties in recovery costs, and sociopolitical factors (Restani and Marzluff, 2002; Scott et al., 1995). One way to leverage limited data to support choices between alternative recovery actions is to apply decision theory, which provides a logical structure for complex problems (Keeney and Raiffa, 1976;

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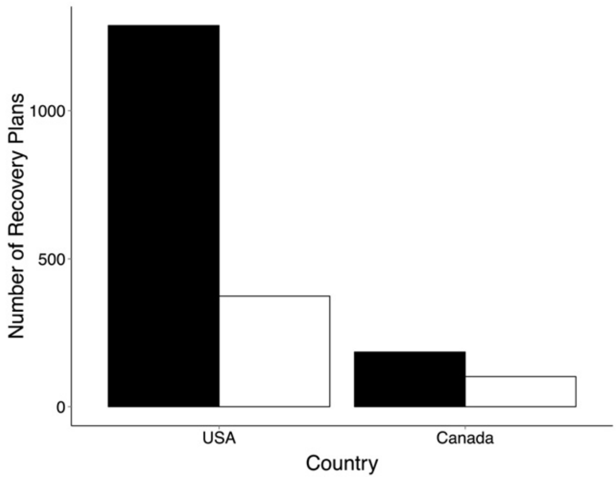

Fig. 1. The number species listed under the Endangered Species Act (USA) and Species at Risk Act (Canada) with written recovery plans. Black bars indicated endangered species and white bars indicate threatened species.

Morgan and Henrion, 1990; Peterman and Anderson, 1999). While most natural resource management decisions are ultimately made based on more than scientific data (e.g. economic, social, cultural, political factors), decision analysis can provide clear support to these decision-making processes by identifying and ranking options that meet stated objectives and provide quantitative information regarding tradeoffs among alternative actions, and can accommodate both qualitative (i.e. expert opinion) and quantitative data (i.e. models to estimate extinction risk or occupancy) in the process. A decision analysis can help to streamline decision-making processes that often involve multiple pathways to achieve an objective, and an array of different stakeholders, sometimes with competing objectives (Peterman and Anderson, 1999). The steps of a decision analysis include; 1) explicitly stating the objectives or targets, 2) outlining alternative pathways to achieve the targets, 3) identifying uncertainties or unknowns in the data (referred to as 'uncertain states of nature') and explicitly incorporating them into the analysis, 4) using a quantitative model to determine the outcomes of each potential pathway, 5) determining the 'optimal' decision by ranking the outcomes with respect to the objectives, and 6) performing sensitivity analyses on key parameters in the model to determine the robustness of the 'optimal' decision (Peterman and Anderson, 1999). Acknowledging uncertainty in the process by assigning probabilities to each identified uncertain state of nature (step 3), and performing sensitivity analyses on critical parameters (i.e. targets or key model assumptions, step 6), decreases the likelihood of choosing an ineffective recovery option by increasing the quantitative basis of the decision-making process.

Decision analysis models have been applied to numerous conservation problems, such as invasive species management (Buhle et al., 2012; Maguire, 2004), designing ecological reserves (Possingham et al., 2000), and endangered species planning (Drechsler, 2000; Pestes et al., 2008). Several studies highlight the utility of decision analysis for endangered species management (Drechsler et al., 1998; Moore et al., 2010; Possingham et al., 1993; Southwell et al., 2008; VanderWerf et al., 2006), and it can be a valuable tool for quantifying tradeoffs between the biological efficacy and economic cost of a suite of alternative recovery strategies (Canessa et al., 2014; Converse et al., 2013; Engeman et al., 2002; Fairburn et al., 2004; Martínez-Abraín et al., 2011; Rose et al., 2015).

A fundamental assumption of most recovery efforts is that increased spending will result in improvements in species status (Kerkvliet and Langpap, 2007; Male and Bean, 2005; Miller et al., 2002). However, it has been demonstrated for marine turtles that there can be a three-fold difference in the benefit-cost ratio between alternative predator removal strategies (Engeman et al., 2002), and for the kokako, an endangered bird in New Zealand, that an increase in spending for predator control does not always lead to an increase in the number of breeding pairs (Fairburn et al., 2004). These examples highlight the need to explore tradeoffs between the cost of management actions, and the resulting net benefit to the population or species. In many cases, recovery costs are not incorporated into biological analyses of recovery options (e.g. Drechsler et al., 1998; Regan et al., 2005; VanderWerf et al., 2006), but often play a large role in whether a recovery option is successfully implemented (Hughey et al., 2003) and thus it is useful to explicitly consider costs during the decision-making processes. Weighting a recovery option by its associated cost in a decision analysis framework can help identify pathways to recovery that are easier to achieve given both financial and biological constraints, and ensure that limited funds are not allocated to recovery options that are unlikely to succeed.

Here, we use decision analysis in a novel way by incorporating both the biological efficacy and monetary cost of recovery to quantitatively assess alternative population supplementation strategies, captive breeding or head-starting wild embryos, and to explore the return on investment for each potential management action while considering the initial state of the population (i.e. wild population size). Captive breeding and head-starting are two commonly proposed population supplementation tools for critically endangered populations (Fischer and Lindenmayer, 2000; Zippel and Mendelson, 2008), particularly for amphibians which are at higher risk of extinction than many other vertebrate taxa (Hoffmann et al., 2010; Stuart et al., 2004). Captive breeding and release involves establishing a population in captivity, in which individuals mate and produce offspring that are subsequently released into a separate wild population. Head-starting and release typically involves removing individuals at an early life stage (embryos or larvae) and raising individuals in captivity through sensitive life stages before releasing into a wild population. Although both options include rearing individuals in captivity for a period of time, the relative genetic and demographic consequences, as well as the economic tradeoffs between captive-breeding and head-starting are largely unknown (Griffiths and Pavajeau, 2008). In general, the effectiveness of population supplementation, regardless of method, has been difficult to assess (Dodd and Seigel, 1991; Griffiths and Pavajeau, 2008), and thus is often reserved for when other threat mitigation strategies (e.g. habitat degradation, competition with invasive species) are not feasible (Zippel and Mendelson, 2008).

We identified 24 alternative supplementation strategies using either eggs from captive females (captive breeding) or wild collected eggs (head-starting), which we compared to no supplementation (for a total of 25 alternative scenarios, Fig. 2), to aid the recovery of a critically endangered population of Oregon spotted frogs (*Rana pretiosa*). Using empirical data and an existing population demographic model (Kissel et al., 2014) we evaluated the biological efficacy of each of the 25 supplementation strategies (henceforth recovery pathway) and conducted a decision analysis from the perspective of conservation managers who wanted to choose a recovery strategy to achieve a baseline recovery target of reducing the 10-year extinction risk below 10% while minimizing cost. We calculated the cost of each alternative recovery pathway and used stochastic population viability analysis to estimate the reduction in extinction risk over 10 years of continuous implementation of each pathway. We explored uncertainties in the top ranked scenario with sensitivity analyses by relaxing model assumptions and recovery targets, which allowed us to assess the robustness of the top-ranked recovery pathway under non-static conditions. We found that decision analysis is a feasible, intuitive method for providing a quantitative basis for ranking alternative recovery actions, and can be a useful lens through which to balance tradeoffs between costs and endangered species management.