Global Ecology and Conservation 12 (2017) 119–130

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: http://www.elsevier.com/locate/gecco

Original Research Article

# Incorporating population viability models into species status assessment and listing decisions under the U.S. Endangered Species Act

Conor P. McGowan [a], [*], Nathan Allan [b], Jeff Servoss [c], Shaula Hedwall [d], Brian Wooldridge [d]

[a] U.S. Geological Survey, Alabama Cooperative Fish and Wildlife Research Unit, Auburn University, Auburn, AL 36849, United States
[b] U.S. Fish and Wildlife Service, Southwest Region, Ecological Services, Austin, TX 78613, United States
[c] U.S. Fish and Wildlife Service, Arizona Ecological Services Office, Tucson, AZ 85745, United States
[d] U.S. Fish and Wildlife Service, Arizona Ecological Services Office, Flagstaff, AZ 86001, United States

## ARTICLE INFO

*Article history:*
Received 20 March 2017
Received in revised form 27 September 2017
Accepted 27 September 2017

*Keywords:*
Climate effects on viability
Endangered species listing decisions
Parametric uncertainty
Sensitivity analysis
Sonora desert tortoise

## ABSTRACT

Assessment of a species' status is a key part of management decision making for endangered and threatened species under the U.S. Endangered Species Act. Predicting the future state of the species is an essential part of species status assessment, and projection models can play an important role in developing predictions. We built a stochastic simulation model that incorporated parametric and environmental uncertainty to predict the probable future status of the Sonoran desert tortoise in the southwestern United States and North Central Mexico. Sonoran desert tortoise was a Candidate species for listing under the Endangered Species Act, and decision makers wanted to use model predictions in their decision making process. The model accounted for future habitat loss and possible effects of climate change induced droughts to predict future population growth rates, abundances, and quasi-extinction probabilities. Our model predicts that the population will likely decline over the next few decades, but there is very low probability of quasi-extinction less than 75 years into the future. Increases in drought frequency and intensity may increase extinction risk for the species. Our model helped decision makers predict and characterize uncertainty about the future status of the species in their listing decision. We incorporated complex ecological processes (e.g., climate change effects on tortoises) in transparent and explicit ways tailored to support decision making processes related to endangered species.

Assessment of a species' biological status is a key part of U.S. Endangered Species Act decision-making by the U.S. Fish and Wildlife Service (Doremus, 1997; Regan et al., 2012; Smith et al., in review). Historically, status assessments have included current abundance estimation, recent population trends, and an accounting of past and on-going factors affecting the species (Waples et al., 2013). However, predictive modeling can play a crucial role in management decisions for protected species by incorporating qualitative information into explicit quantitative risk assessments (Smith et al., in review, McGowan and Ryan, 2009; McGowan and Ryan, 2010). Model-based predictions can project future population size and growth, present the

---

[*] Corresponding author.

*E-mail addresses:* cmcgowan@usgs.gov (C.P. McGowan), nathan_allan@fws.gov (N. Allan), jeff_servoss@fws.gov (J. Servoss), shaula_hedwall@fws.gov (S. Hedwall), brian_wooldridge@fws.gov (B. Wooldridge).

https://doi.org/10.1016/j.gecco.2017.09.004

uncertainty in those predictions, and assess the effectiveness of management actions on future population status (Morris and Doak, 2002). Explicit predictions about future outcomes, and the uncertainty associated with those predictions, allow decision makers to understand and base their decisions on the likely future status of, and risks to, a species.

Population viability models have a long history of use in assessment of species at risk of endangerment or extinction and in assessing the relative importance of demographic parameters for species viability (e.g., Boyce, 1992; Morris and Doak, 2002). More recently researchers and managers are applying population viability-type models to support specific decision contexts for species conservation (e.g., McGowan and Ryan, 2009; New et al., 2012; Converse et al., 2013; Doak et al., 2015; Wolf et al., 2015; Robinson et al., 2016). Models tailored to specific decision contexts may not allow for broad advances in population ecology theory, but they can support management decisions by evaluating uncertainties and stochastic elements that often impede decision making. One key feature to making models especially useful in decision contexts is to work directly with decision-makers to establish desired model outputs and formats to aid in decision making (Smith et al., in review).

Decisions on whether or not to list species as endangered (i.e., in danger of extinction) or threatened (i.e., likely to become endangered in the future) under the Endangered Species Act could benefit from explicit models that characterize uncertainty in predictions. Deciding to list or not list a species comes with the risk of providing a species protection that is not needed, or not providing protection to a species that might require protection to avoid extinction. The risk assessments that support these important decisions could be greatly enhanced in some cases by explicit extinction probability predictions, and the predicted range of future population status (e.g., estimated median future abundance and the 2.5 and 97.5 percentiles on future abundance). Explicit presentation of these uncertainties allows decision makers to understand the most likely future state of a population and species, and also provide an estimate of the probability that the future state of the population is lower or higher than the most likely prediction. If done effectively, a decision-maker can visualize and understand what the distribution of future population status is and use that information to determine whether protection is warranted. Tailored models can incorporate the best available demographic data, specific threats, and management benefits experienced by populations to project demographic and environmental stochasticity along with parametric uncertainty. Models specifically tailored to a decision context allow for developing scenarios that evaluate ongoing and future influences on populations and species with greater specificity than a sensitivity analysis in a traditional population viability analysis (e.g., Morris and Doak, 2002).

We built a demographic population viability model to represent Sonoran desert tortoise (*Gopherus morafkai*, hereafter SDT) populations in Arizona, U.S.A. and Sonora, Mexico. The model was based on the best available demographic data and published analyses, and it included parametric and environmental variation as sources of uncertainty in the projections (McGowan et al., 2011). The model predicts the probability of quasi-extinction (i.e., the probability of abundance declining to less than a pre-determined abundance threshold) at each time step under current habitat and environmental conditions and possible future scenarios of changing habitat and environmental conditions. Our work focused on predicting future extinction risk because the decision-makers in the U.S. Fish and Wildlife Service desired some assessment of future extinction probability and because the Endangered Species Act listing requirements are focused on imminent extinction probability. We also incorporated a framework to evaluate a wide array of future possible conditions and estimate the relationship between those varied future conditions and quasi-extinction probability through regression analysis of the model output. For the purposes of this modeling exercise and as part of the species status assessment, hereafter SSA, we are treating the species as two large populations, one in Arizona, U.S. and one in Sonora, Mexico (U.S. Fish and Wildlife Service, 2015). The Service decided to subdivide the species into two populations because of differing management practices, grazing practices, invasive grass communities and other issues in Arizona vs. Sonora. We anticipated that, though the species are genetically and ecologically indistinct, future scenarios would be different for these two portions of the range. The model was a key part of the SSA that was conducted in order to inform whether or not to list the SDT as a threatened or endangered species under the Endangered Species Act (U.S. Fish and Wildlife Service, 2015).

## 1. Methods

### 1.1. Model development

We built a female-only, stage-structured matrix model to reflect the SDT life cycle (Fig. 1). The conceptual model of the SDT's life cycle was elicited from taxon experts, based on published literature (Van Devender, 2002; Rostal et al., 2014), and Mojave desert tortoise (*Gopherus agassizii*) population models (Darst et al., 2013). The life cycle diagram presents three main life stages (Adults (A), small juveniles ($J_1$) and large juveniles ($J_2$)). Small juveniles, once hatched, can survive each year and remain in the $J_1$ age class for approximately 5 years (McCoy et al., 2014). Little is known about the habits or survival rates of $J_1$ because they are difficult to detect in the wild and, therefore, have received little study. However, given its size (<40 mm), $J_1$ is expected to be the life stage most susceptible to predation and other causes of mortality (McCoy et al., 2014), and survival rates of newly hatched tortoises in their first year are presumed to be very low. McCoy et al. (2014), suggest that, for North American tortoises in general, first year survival is as low as 10%, and it increases about 1–2% annually thereafter until the animals are in the subadult or large juvenile stage. Larger juveniles have approximately 0.77 annual survival and remain in $J_2$ for 10 or 12 years (until approximately the age of 15) and then transition into the breeding adult age class. Adults have very high survival rates, 0.93–0.98 annually (Zylstra et al., 2013), and, given these high survival rates, live for many years as adults. Approximately 52% of females will breed in any given year, and females lay small clutches of approximately 5 eggs with