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Establishing endangered species recovery criteria using predictive simulation modeling

Conor P. McGowan [a,*], Daniel H. Catlin [b], Terry L. Shaffer [c], Cheri L. Gratto-Trevor [d], Carol Aron [e]

[a] U.S. Geological Survey, Alabama Cooperative Fish and Wildlife Research Unit, Auburn University, Auburn, AL 36849, United States
[b] Department of Fish and Wildlife Conservation, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, United States
[c] U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, ND 58401, United States
[d] Environment Canada, Prairie and Northern Wildlife Research Centre, Saskatoon, SK, Canada
[e] U.S. Fish and Wildlife Service, North Dakota Field Office, Bismarck, ND 58501, United States

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ABSTRACT

Listing a species under the Endangered Species Act (ESA) and developing a recovery plan requires U.S. Fish and Wildlife Service to establish specific and measurable criteria for delisting. Generally, species are listed because they face (or are perceived to face) elevated risk of extinction due to issues such as habitat loss, invasive species, or other factors. Recovery plans identify recovery criteria that reduce extinction risk to an acceptable level. It logically follows that the recovery criteria, the defined conditions for removing a species from ESA protections, need to be closely related to extinction risk. Extinction probability is a population parameter estimated with a model that uses current demographic information to project the population into the future over a number of replicates, calculating the proportion of replicated populations that go extinct. We simulated extinction probabilities of piping plovers in the Great Plains and estimated the relationship between extinction probability and various demographic parameters. We tested the fit of regression models linking initial abundance, productivity, or population growth rate to extinction risk, and then, using the regression parameter estimates, determined the conditions required to reduce extinction probability to some pre-defined acceptable threshold. Binomial regression models with mean population growth rate and the natural log of initial abundance were the best predictors of extinction probability 50 years into the future. For example, based on our regression models, an initial abundance of approximately 2400 females with an expected mean population growth rate of 1.0 will limit extinction risk for piping plovers in the Great Plains to less than 0.048. Our method provides a straightforward way of developing specific and measurable recovery criteria linked directly to the core issue of extinction risk.

1. Introduction

The central part of any recovery planning process for endangered or threatened species is to establish criteria for recovery. Under the various endangered species protection laws (e.g., the US Endangered Species Act, the Canadian Species at Risk Act, etc.) the reason endangered species are protected is because of some elevated risk of extinction. When that risk of extinction is somehow reduced, the species is considered recovered and therefore taken off the protected species list (delisted; 16 U.S.C. 1531 et seq.). It logically follows that recovery criteria for a species should somehow be related to eliminating or greatly reducing the risk of extinction (Goodman, 2002). Setting recovery criteria is a decision in which, minimizing, eliminating or reducing the probability of extinction for the protected species is the fundamental objective of endangered species protection and recovery efforts. However extinction probability itself is not empirically measurable and therefore recovery criteria serve as the means objectives or measurable attributes of the extinction probability fundamental objective. A rational process would first identify a tolerable level of extinction risk for a species, and then use some process to identify measurable quantities that effectively represent extinction risk. Structured decision making (SDM) is an increasingly applied decision analytical approach to complex natural resource decision making and may be well suited to endangered species management (Gregory and Keeney, 2002; Gregory and Long, 2009; McGowan, 2013). In SDM it is imperative to first establish fundamental objectives and then select measurable attributes of those fundamentals that are unambiguous, understandable,

* Corresponding author.
E-mail addresses: cmcgowan@usgs.gov, cmcgowan@auburn.edu (C.P. McGowan).

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comprehensive, direct, and measurable (Keeney and Gregory, 2005; McGowan, 2013) to improve both the decision making transparency and the likelihood of achieving the fundamental objectives. The measurable attributes of extinction probability should address each of those five criteria; indeed, a thorough structured decision making process to set recovery criteria for a protected species would use the criteria established by Keeney and Gregory (2005) as objectives and also consider other fundamental objectives such as monitoring costs and efficiency. Setting recovery criteria would be a decision process that selects the best measurable attributes that maximizes the precision of the relationship to extinction probability but also minimizes costs and inefficiency.

Extinction probability is derived from a model that projects current conditions into the future, replicates that projection under demographic and environmental stochasticity with ecological and statistical uncertainty, and calculates the proportion of replicates that went extinct (Beissenger and Westphal, 1998; Morris and Doak, 2002). Population projection models (conceptual or quantitative, implicit or explicit) are key components of any effort to manage a species or population (Starfield, 1997). Making effective management decisions requires the ability to make formal predictions about the probable effects of management choices (Starfield, 1997). Measuring extinction probability is impossible with field data alone. However, models that predict extinction can be used to develop surrogate metrics that represent measures of extinction risk. Observation error associated with measuring attributes of recovery criteria further complicates the setting of recovery criteria. Inaccurate measurement could inhibit our ability to detect whether a species is recovered or has gone extinct; it could result in premature or delayed delisting. Recovery criteria should in some way account for imperfect detection either by only using metrics that can be accurately measured or by accounting for observational uncertainty of measurable attributes when setting the recovery criteria.

Piping plovers are a protected species under the U.S. Endangered Species Act (ESA) and the Canadian Species at Risk Act (SARA). Piping plovers are a small, widely distributed, migratory shorebird (Elliott-Smith and Haig, 2004). In the United States there are three separately listed populations, the Atlantic Coast (Threatened), the Great Lakes (Endangered), and the Great Plains (Threatened; U.S. Fish and Wildlife Service, 1985). Piping plovers are listed as endangered throughout Canada (Environment Canada, 2012). In 2010 the U.S. Fish and Wildlife Service (USFWS) convened a new recovery team and initiated an effort to revise the recovery plan for piping plovers in the Great Plains. The previous recovery plan for the Great Plains population was written in 1988 (USFWS, 1988) and new data and research suggested the recovery plan may need to be redrafted. The Great Plains breeding population spends the non-breeding season mainly on beaches, coastal sand flats and marshes of the Gulf Coast in the United States and Mexico (Elliott-Smith and Haig, 2004; Gratto-Trevor et al., 2012). During the breeding season, birds nest on the ground in sand and gravel substrates on river sandbars, reservoir beaches and alkali wetlands (Prindiville Gaines and Ryan, 1988; Lefer et al., 2008; Anteau et al., 2012) from Manitoba, Canada, to eastern Montana and south to Nebraska, Colorado, and rarely in northeastern Kansas, USA (Elliott-Smith and Haig, 2004).

In this paper we present an SDM-rooted, transparent process that uses population projection models and regression analysis of simulated data to directly link recovery criteria (e.g., population abundance targets, demographic parameter targets) to the probability of extinction. Our primary objective is to frame the process of setting recovery criteria as a decision in which the fundamental objective is to maximize the precision of the relationship of the metric to extinction probability. To aid in that framing we present a process for establishing and evaluating the link between measurable attributes of a population and extinction probability using simulation models and regression analysis of the simulated data. We developed a population projection model for piping plovers in the Great Plains to inform and support the recovery planning process and to link piping plover abundance and other demographic parameters to extinction probability. The model builds on previously published models (Ryan et al., 1993; Plissner and Haig, 2000; Larson et al., 2002; McGowan and Ryan, 2009) and incorporates existing data and expert opinion (i.e., consultation with the recovery team) of population dynamics and meta-population structure in the Great Plains. We used the model to predict the necessary starting population size, spatial distribution, and population growth rate needed to reduce the probability of extinction to a prescribed level. We also assessed how observation error and imprecision can affect recovery criteria. The end result is a set of tables describing the sets of conditions (combinations of initial population size and expected population growth rate) that achieve recovery (reduced extinction risk), akin to an optimal decision table (Williams et al., 2002), under perfect and imperfect observability. Though population viability models have been used in developing recovery criteria previously (e.g., Schultz and Hammond, 2003), to our knowledge, creating a decision table based on varied initial conditions and expected demographic rates is a novel approach for establishing recovery criteria. Furthermore, while extinction probability has been linked to initial population conditions and input demographic parameters (e.g., Lande and Orzack, 1988), establishing the measurable attributes of recovery criteria directly quantitatively linked to extinction probability has rarely, if ever, been carried out. Here, we are presenting a method to utilize these relationships in the decision making contexts of establishing recovery criteria and delisting a species.

2. Methods

All projection models and analyses of simulated data were developed and executed in program R (R core development team, 2011). Our process was initiated through consultation with the piping plover Northern Great Plains recovery team, which consisted of representatives from State or Federal wildlife or management (e.g., Nebraska Game and Parks Commission, the U.S. Army Corps of Engineers) agencies. The team provided species and management expertise and we relied on their input to ensure that the model we developed was ecologically and management relevant.

The model we developed included spatial structure that divided the northern Great Plains into four breeding/management regions: Southern Rivers (primarily the Platte River and Missouri River in southern South Dakota and along the Nebraska-South Dakota border), Northern Rivers (the Missouri River and its constructed reservoirs in central South Dakota north through North Dakota and Montana), alkali wetlands (i.e., along the Missouri Coteau in North Dakota and Montana), and Prairie Canada (all river, reservoir and wetland habitats in Prairie Canada; Fig. 1). The model included limited exchange of individuals between the breeding regions and can be considered a meta-population model (Hanski, 1994). These divisions of the breeding range were supported by the available banding data (see below) from multiple studies in the Great Plains. In addition to reflecting suspected regional boundaries between breeding populations, these sub-population units would likely have differing reproductive rates, different limiting factors, and would therefore require potentially different management strategies. That is, the management actions could be differentially effective among regions given the variation in ecological and physical processes.