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Prioritizing actions for the recovery of endangered species: Emergent insights from Greater Sage-grouse simulation modeling

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ABSTRACT

Urgent conservation situations require immediate action informed by existing data and information. Model-based analyses are well suited to rapidly identifying and evaluating alternative actions but often lack explicit linkages between habitat conditions and population outcomes. We provide an example of how spatially explicit population modeling can uniquely inform conservation planning by integrating changes in habitat conditions with population responses. Using a case study of the critically endangered Greater Sage-grouse in Canada, we integrated habitat selection maps, demography and demographic risk maps, movement, and behavior into a predictive individual-based modeling framework. We used this framework to simulate population dynamics, evaluate demographic sensitivities, assess source-sink dynamics, and compared the population gains from restoring different types (strengths) of sinks. Sensitivity analysis results underscored the need for multiple, simultaneous population recovery actions to stabilize the population, including improving chick and adult survival. Strong source-sink dynamics were an emergent property of simulations, driven by the maladaptive selection of habitats with low chick survival and nest success. Simulated habitat restorations improving chick survival conditions in strong sinks were more effective at increasing abundance than actions targeting all sinks, or removing sinks. Spatially explicit population modeling can be an informative means of predicting and comparing potential population responses to habitat restoration and population recovery options. Individual-based modeling can uniquely evaluate habitat-population dynamics and can be particularly useful for critically endangered species, when too few animals or time remains to conduct field experiments.

1. Introduction

Urgent conservation situations require immediate action with the best available data. For critically endangered species, there is a need to understand which conservation actions are likely to yield the best results, where those actions are best applied, and how much change or effort is needed to stabilize the species' trajectory. Yet there are often too few animals and insufficient time with which to conduct habitat restoration and population recovery experiments. In these urgent situations, conservation decisions are made in uncertain and untested circumstances (Campbell et al., 2002; Hartmann et al., 2015; Regan et al., 2005) often supported by expert opinion (Cook et al., 2010; Pullin and Knight, 2005) rather than decision-support models. Hence, investments in habitat restoration and population recovery actions are often made without estimates of their potential impact on species recovery (Hartmann et al., 2015). Even if population outcomes are monitored, the challenges of dynamic landscapes, small populations, environmental stochasticity, and other sources of variability, often make it difficult to infer the success of conservation actions. Species recovery actions and decisions also try to make sense of several sources of information, generated by different projects, with different methods, spatial extents, and times. Despite these difficulties, there is a need to understand, or at least gauge, the effects of multiple interacting habitat and population conditions to anticipate the scale and duration of needed recovery actions (Lawler et al., 2002).

In research endeavors for critically endangered species, modeling tools present an attractive alternative to field-based manipulations. Conceptual relationships, flow charts, spatial overlays (e.g., combining GIS layers), and textual or tabular syntheses of published data can help in scoping the status and threats of species at risk of decline. Further

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advanced, quantitative and inferential statistical analyses are integral to identifying relationships among ecological variables and describing habitat and population conditions. Quantitative models also offer methods for understanding uncertainty and accounting for ecological complexity (Addison et al., 2013). Yet small sample sizes can complicate inferential statistical predictions, and phenomenological evaluations are often limited in their ability to make predictions based on multiple population and habitat conditions. Phenomenological simulation models (e.g., RAMAS; Akcakaya, 2005) also lack explicit and detailed linkages among habitat conditions and population outcomes, making it difficult to connect habitat changes with population consequences.

Mechanistic simulation frameworks provide unique advantages for evaluating population responses to conservation and recovery actions. Individual-based simulation models can leverage the strengths of different types of data by creating flexible linkages among different datasets and provide a transparent means of data integration. For example, spatially explicit individual-based models like those constructed in the HexSim modeling platform (Schumaker et al., 2017), accommodate maps of fine-scale habitat conditions that can be used to modify individual outcomes through interactions with the modeled landscape. Individuals (i.e., unique hypothetical animals with their own traits and experiences) can interact with habitat through movement, habitat selection, and decisions that weigh access to resources and social needs. Simulation models can integrate temporally and spatially varying landscapes, demographic, movement, behavior, habitat selection, life history characteristics, individual traits, and spatial stressors, etc., into a common predictive framework, directly incorporating the best available information. The interaction of these multiple varying conditions can lead to emergent insights that uniquely inform conservation actions and future data needs (e.g., Schumaker et al., 2014).

We suggest that spatially explicit individual-based simulation modeling can play a valuable role in recovery planning by: 1) Assembling data and known relationships into a common framework, 2) quantitatively prioritizing threats to persistence, 3) predicting the recovery actions likely to have the greatest benefit, 3) identifying target locations associated with the greatest predicted improvements, 4) and indicating the requried magnitude and time scale of conservation actions to meet recovery goals. Despite the opportunities and advantages of simulation methods for population responses to quantifying recovery alternatives, few conservation practitioners use simulation models in conservation decisions (Addison et al., 2013; Knight and Campbell, 2008). Fewer are versed in the application of spatially explicit individual-based simulation modeling for habitat restoration and population recovery planning. In this paper, we provide an example of a spatially explicit individual-based model, developed to inform recovery planning for the critically endangered Greater Sage-grouse in Canada. We discuss the conservation insights gained by this simulation modeling approach for imperiled species, and suggest where future improvements and methodologies could further support recovery planning.

1.1. *Greater Sage-grouse case study*

Greater Sage-grouse (hereafter “Sage-grouse”) are listed in Canada as an ‘Endangered’ species under the *Species at Risk Act*. The Canadian Sage-grouse population has declined by ~82–92% in the last two decades (Environment Canada, 2014) and now consists of two small populations in southeastern Alberta (and nearly adjoining Saskatchewan range, hereafter ‘West’ population) and southwestern Saskatchewan (hereafter ‘East’ population; Fig. 1). Concerns over small population sizes have prompted the translocation of Sage-grouse from populations in the United States (total of 79 birds during the years 2011–2012, 2016; Whiklo and Nicholson, 2015) and egg collection and captive rearing efforts (Calgary Zoological Society). Although a recovery strategy has been developed and critical habitat has been identified and legally protected (Environment Canada, 2014), there is little new demographic and behavioral data available to support broad-scale conservation planning (See Appendix). Yet, additional planning and spatial prioritization of management efforts are needed to guide habitat restoration (Environment Canada, 2014).

To characterize the degree to which recovery and restoration interventions are likely to be required, we first estimated demographic rates, and then conducted a sensitivity analysis to characterize population outcomes under a range of demographic conditions. We examined demographic elasticities for East and West populations to indicate the types of population recovery approaches that are most likely to be effective in improving persistence. As other Sage-grouse populations have been found to be more sensitive to survival than reproduction (Taylor et al., 2012), we expected that survival would be a key factor shaping population responses. Specifically, we expected chick survival to be a key factor limiting population growth in Alberta, with rates reported to be < 1/3 of those reported elsewhere in the species range (Aldridge and Boyce, 2007; Taylor et al., 2012). If population outcomes are sensitive to changes in chick survival and responsive to small improvements, habitat restoration efforts that improve conditions for chick survival may be particularly effective.

Population sinks or ecological traps are expected to exist in many human-modified or otherwise altered landscapes (Battin, 2004; Bock and Jones, 2004; Donovan and Thompson, 2001). For Sage-grouse, ecological traps (hereafter referred to as ‘sinks’) can arise from the maladaptive selection of familiar nest and/or brood-rearing sites without awareness or identification of risky areas. Although Sage-grouse in larger landscapes can avoid some ecological traps (Kirol et al., 2015), there is evidence of ecological traps in disturbed areas of Wyoming (Holloran, 2005; LeBeau et al., 2014), and in the Alberta Sage-grouse population (Aldridge and Boyce, 2007). To identify potential recovery and habitat restoration locations that are informed by source-sink dynamics, we assessed and mapped likely population sources and sinks. Putative sources and sinks were previously assessed in a small focal area of Alberta using a spatial overlay of habitat selection and demographic risk maps (Aldridge and Boyce, 2007). However, source-sink dynamics have not been identified across the range in Alberta, nor from an integrative perspective that compares dynamic habitat use (movement and selection) with location-specific demography (i.e., BIDE) to predict sources and sinks through time. To evaluate and prioritize potential habitat restoration actions based on source-sink classifications, we digitally removed or restored different kinds of sinks and measured simulated long-term population responses. We expected habitat improvement scenarios that restore sinks to sources would be more effective than removing attractive or familiar sites, given the strong nesting and breeding site fidelities of Sage-grouse. Further, restoring sinks to source conditions rather than preventing the use of ecological traps was expected to augment the capacity of the landscape to support more Sage-grouse.

2. Materials and methods

2.1. *Overview*

We first estimated Canadian Sage-grouse demographic rates for use in a spatially explicit individual-based modeling framework and integrated demography with movement, behavior, habitat selection, and life history characteristics. Alternative simulations assessed demographic sensitivities and elasticities, and indicated the magnitude of possible population improvements. We tracked simulated individual movements and fates to identify sources and sinks, and assessed the impacts of removing and restoring different kinds of sinks on potential increases in population abundance.