From Mark-Resight to Management: Bayesian Hierarchical Models for Endangered Bird Populations

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A dissertation

submitted in partial fulfillment of the

requirements for the degree of

Doctor of Philosophy

University of Washington

2023

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Program Authorized to Offer Degree:

Quantitative Ecology and Resource Management, College of the Environment

University of Washington

Abstract

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Producing reliable estimates of demographic rates is critical to our understanding of wildlife population dynamics and can provide valuable information for prioritizing conservation and management efforts. Precise and unbiased estimates are challenging to obtain when monitoring data are sparse, knowledge gaps are pervasive, or model assumptions are violated. This is often the case for species of conservation concern, which may be poorly understood and difficult to monitor. Bayesian hierarchical models are particularly useful for estimating demographic rates because they separate imperfect observation processes from the underlying biological processes, especially when combined in an integrated framework that leverages multiple data sources for increased precision and parameter identifiability.

Here I present three case studies using Bayesian hierarchical models to better understand the demography of threatened birds, with particular contributions to mark-resight and integrated population modeling. In Chapter 2, I addressed a common but poorly understood problem in mark-resight studies of open populations: partial mark loss and degradation. I present a novel approach to sampling latent states in a Markov Chain Monte Carlo framework using a backtracking algorithm, and I apply this approach in the context of a multi-event model to the Oregon Vesper Sparrow (*Pooecetes gramineus affinis*) in South Puget Sound, Washington, USA. The results from this model constitute some of the first estimates of age-specific survival and dispersal rates for this species of conservation concern. In Chapter 3, I developed a novel multi-site integrated population model (IPM) to better understand the population dynamics of Streaked Horned Larks (*Eremophila alpestris strigata*) in South Puget Sound, Washington. These estimates will inform future habitat management and a planned reintroduction effort, and the multi-site framework addresses a critical gap in modeling small populations monitored over fragmented landscapes. In Chapter 4, I developed an IPM to examine the impact of a cryptic threat, bycatch in commercial fisheries, on the population dynamics of Atlantic Yellow-nosed Albatross (*Thalassarche chlororhynchos*). Results from this model will motivate ongoing monitoring of Atlantic Yellow-nosed Albatross and seabird bycatch in the South Atlantic and inform fisheries regulation decisions. Broadly, the work I present here makes contributions to the development of complex demographic models with the goal of supporting conservation and management decisions by quantifying and reducing key uncertainties in the population dynamics of threatened species.

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ACKNOWLEDGEMENTS

Writing this dissertation has been hard, but writing the acknowledgments section has been easy. In fact, throughout the last six months of my dissertation, I came back to it many times. Whenever I had writer's block, I would look to the acknowledgements I had drafted, and the words would start to flow. This is a small, but I hope meaningful, example of how the people listed below have supported me both directly and indirectly during my education. I could not have done it without them.

I have received financial support over the years from the University of Washington's Quantitative Ecology & Resource Management Program, the College of the Environment, the Washington Cooperative Fish & Wildlife Research Unit, the Northwest Climate Adaptation Science Center, and the Royal Society for the Protection of Birds.

I am so grateful to my coauthors of these chapters. In particular, I'd like to thank Steffen Oppel and Nathan Hostetter. To Steffen Oppel, who has been pushing Chapter 4 forward for over a decade. Thank you for trusting that I could contribute meaningfully to this project, and for your continued support and expertise. And to Nathan Hostetter, you're my hero. Thank you for your generosity, your brilliance, and your graciousness.

I'd also like to thank my colleagues in the Quantitative Conservation Lab and the co-op unit. To Staci Amburgey, Lisanne Petracca, Matt Farr, Hannah Sipe, Mark Sorel, Amanda Warlick, Amelia DuVall, Brielle Thompson, Liam Pendleton, Eve Hallock, Nate Redon, Kelly Mistry, Verna Blackhurst, and Sarah Romero. I have learned so much from each of you. Thanks for looking at code and drafts, and for being the sounding boards for all my best (and worst) ideas.

To my fellow QERMies, thanks for all the soup! To my cohort in particular, Martin Endress, Maria Kuruvilla, Yian Lin, and Megan Ferguson. You guys helped shoulder the challenges of that first year and even made it fun. To Tim Essington, Beth Gardner, Trevor Branch, and Erica Owens. Thanks for all you do to keep QERM the supportive professional and personal community that it is.

Thank you to my committee members, Sarah Converse, Beth Gardner, Gary Slater, Scott Pearson, and Ryan Kelly, for their mentorship. Ryan, thank you for going above and beyond as a member of my committee, for asking great questions, and for broadening my perspective on the world. Scott, thank you for your ever-thoughtful feedback and for pointing me in the right directions when I got lost. Gary, thank you for getting me out from behind the desk and trusting that a young statistician could turn into a young ecologist. Beth, you've worn several hats as a member of this committee and as the director of QERM and your contributions as both have been invaluable. Thank you for challenging me and reminding me to laugh at the same time. And to Sarah. I cannot begin to describe the impact you've had on my life as a scientist and a human being. Working with you has been an honor and a privilege.

I am grateful also for the unwavering support and understanding I have received from friends and family as near as the bedroom across the hall and as far as Norway. To my parents, Beth and Nick. Thank you for giving me space to dream. Thank you for teaching me to find joy in hard things. Thank you for making sure I know I always have a safe place to land. To Jesse, Miriam, Jens, and Maud. Time zones are generally a curse, but for me, they have been a blessing. What a joy it's been to wake up to messages from you nearly every day. I was also fortunate enough to gain some new family members over the course of this ride. To Halinka, Dalton, Izzy, and George. Thank you for keeping me company during the darkest and lightest times of the past few years. Becoming a member of your family has been the honor of a lifetime.

And to Henry. 99% of people (real statistic) think statistics is the most boring subject on the planet. I feel so fortunate to have found a partner who is so curious about the world and who asks the most insightful questions. Thank you for seeing me. Thank you for knowing when I need a hug, a laugh, a break, or a meal. You are my best distraction. I love you so much.

DEDICATION

To my grandfathers:

Charles Christopher Bratt and Lloyd William Eichhorn

Champions of conservation, lovers of poetry, advocates for a good breakfast.

Chapter 1. INTRODUCTION

1.1 BACKGROUND

Understanding population dynamics and drivers of population trends can support the conservation of threatened species. However, estimating demographic rates and their variation over space and time is challenging for small, declining, fragmented, or otherwise difficult-to-monitor populations. Knowledge gaps may impede decision making when data are sparse. Population modelers aim to leverage available data to close these knowledge gaps and identify key uncertainties for future study.

One approach to population modeling is integrated population modeling, where multiple data sources with shared underlying parameters are combined in a joint analysis. Integrated population models (IPMs; Besbeas et al., 2002; Brooks et al., 2004; Schaub & Abadi, 2011; Zipkin & Saunders, 2018) have become popular in part because they leverage all available data to provide information about both demographic states (i.e., abundance) and rates (e.g., survival, productivity). Crucially, IPMs can improve precision (Abadi et al., 2010a; Schaub et al., 2007) and produce estimates of demographic rates that are unobservable (e.g., Oppel et al., 2022) or may otherwise be unidentifiable (Abadi et al., 2010b). Though much of the preliminary work demonstrating the utility of IPMs focused on taxa with simple life histories (e.g., herons; Besbeas et al., 2002), as available computing power increases, IPMs for species with complex life histories (e.g., apex predators; Regehr et al., 2018) are becoming more common. Like other hierarchical model types, IPMs can facilitate estimation of the effects of environmental conditions or anthropogenic stressors on demographic rates (e.g., Oppel et al., 2014), which is of useful when trying to identify causes of decline for threatened or indicator species.

To be a true integrated model, IPMs need to include a dataset relevant to the estimation of abundance and at least one additional dataset that allows for the estimation of one or more demographic parameters; commonly this is a mark-recapture or mark-resight dataset. Studies of marked populations can lend insights about a number of demographic parameters, including survival (e.g., Lebreton et al., 1992), recruitment (e.g., Tucker et al., 2023), movement (e.g., Sollmann et al., 2013), and productivity (e.g., Lahoz-Monfort et al., 2013). Often these parameters are strongly correlated with population trend and therefore it is valuable to estimate these parameters precisely and to identify their drivers to inform conservation decision-making. Mark-resight models vary widely in complexity, from Cormack-Jolly-Seber models (Cormack, 1964; Jolly, 1965; Seber, 1965), to multi-state models (Nichols & Kendall, 1995), to multi-event models (Pradel, 2005) and can therefore accommodate many sampling situations, provided that model assumptions are met.

While the development of complex models and integrated models can help resolve some uncertainty in our understanding of demography, there is no substitute for a well-designed monitoring program. Underpinning all models are assumptions about the underlying observation and biological processes and when those assumptions are violated it may render results invalid. Some assumptions may matter relatively little (e.g., independence of datasets in integrated population models; Abadi et al., 2010a), where others can matter more (e.g., mark loss in mark-resight models; Chapter 2). Given that we rely on long-term monitoring programs to inform conservation decisions for endangered wildlife (Nichols & Williams, 2006), great care should be taken at the outset to design a monitoring program that has the power to produce accurate and precise estimates of demographic rates, and that are more likely to detect changes in population trends. Similarly, monitoring programs should be regularly reevaluated to ensure they are being implemented correctly and functioning as intended (Lindenmayer & Likens, 2009).

1.2 RESEARCH OBJECTIVES

The objectives of my research were twofold, including (1) advancing Bayesian hierarchical modeling of mark-resight data in the context of integrated population models, and (2) estimating vital rates for three poorly understood species of conservation concern. To this end, I developed a novel multi-state model for mark-resight data in the presence of mark loss for Oregon Vesper Sparrow (*Pooecetes gramineus affinis*) in Washington State, and IPMs for Streaked Horned Larks (*Eremophila alpestris strigata*) and Atlantic Yellow-nosed Albatross (*Thalassarche chlororhynchos*) in Washington State and on Gough Island in the South Atlantic.

The methodological advancements made here were motivated by challenges presented in the available data. For Oregon Vesper Sparrow and Streaked Horned Larks, partial mark loss is pervasive and has hindered our understanding of survival and dispersal rates for these species. Thus, in Chapter 2 I developed a novel model and approach for sampling latent states for multi-state models of mark-resight data in the presence of partial mark loss and degradation. Streaked Horned Larks are intensively monitored at numerous sites, but the region-wide population dynamics are not well understood. Thus, in Chapter 3 I built a multi-site IPM, using mark-resight data to inform movement and survival across a fragmented landscape. Atlantic Yellow-nosed Albatross are vulnerable to cryptic threats but are difficult to monitor and only observable during some life history stages. Therefore, in Chapter 4 I built an IPM around a multi-event model of mark-resight data with several unobservable states. Each challenge that I have addressed here is not unique to the case-study species. Consequently, the methodology I present is applicable to many endangered species which are monitored with through marking and resighting, over fragmented landscapes, or only during portions of their life-history.

1.3 BROADER IMPACTS

Collectively, the developed in these studies contribute new approaches for developing models of complex ecological processes and the specific case studies make contributions that will inform species conservation decisions. Ecologically, the Oregon Vesper Sparrow is a species of great conservation interest throughout the Pacific Northwest, including in Washington State, where it is listed as endangered. I present some of the first robust estimates of age-specific survival and dispersal probabilities for this subspecies, which will inform future population modeling efforts and influence conservation action. The Streaked Horned Lark is state and federally listed and is intensively monitored throughout South Puget Sound, where the model and demographic estimates I produced will be used to inform a reintroduction effort. Atlantic Yellow-nosed Albatross is endangered per the IUCN and is vulnerable to cryptic threats such as environmental change and anthropogenic stressors in the South Atlantic. Bycatch in commercial fisheries is a known threat to seabirds but the degree to which it impacts population dynamics of this species is not well understood. My work on this species identifies knowledge gaps for future study. Methodologically, I present novel model frameworks that facilitate robust estimation of vital rates in the face of common challenges with the integration of mark-resight data: mark loss or degradation, dispersal over fragmented landscapes, and multiple unobservable states.

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