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Using citizen science data in integrated population models to inform conservation

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ABSTRACT

Analysis of animal population status and change are core elements of ecological research and critical for prioritizing conservation actions for at-risk species. Traditionally, count-based data from structured surveys have been the main source of information used to estimate trends and changes in populations. In the past decade, advances in integrated population models (IPMs) have allowed these data to be combined with other data sources (e.g., observations of marked individuals). IPMs have allowed researchers to determine the direction and magnitude of population trends and to identify underlying mechanisms contributing to population change. For many species, life-history characteristics (e.g., colonial breeding, low site-fidelity), low abundance and/or low detection probability make it difficult to collect sufficient data; thus, IPMs for these species are difficult to employ. Citizen science data may be useful in such situations and enable conservation biologists to combine data from many sources into robust estimates of population trajectories. IPM's represent a possible way of combining diverse data sources, but their practicality for incorporating citizen science data has not been investigated. Here, we used count data from eBird to estimate population trends for a species of conservation concern, the tricolored blackbird (*Agelaius tricolor*). We combined estimates of relative abundance with banding and nesting data. Our joint estimation of demographic rates allowed us to evaluate their individual contributions to the population growth rate. Our analysis suggests that the California tricolored blackbird population suffered a mean decline of 34% from 2007 to 2016. Mean annual adult survival ranged from 0.28 to 0.93 for females and 0.17 to 0.78 for males. Mean juvenile survival across years was 0.21 (95% CI = 0.0007–0.49), fecundity (as nestlings per nest) ranged from 0.46 to 1.27. We suggest that investments in increasing reproductive success and recruitment are the most likely conservation strategies to increase the population. Here, the extensive survey efforts of citizen scientists aided the employment of IPMs to inform conservation efforts for tricolored blackbirds.

1. Introduction

The ability to provide information on the status and distribution of poorly known species has been a focus of recent developments in the fields of population ecology and conservation biology (Pacifici et al., 2012; Specht et al., 2017). Often, such species are rare, nomadic (Pedler et al., 2018), have irruptive or unpredictable life histories (Woinarski et al., 1992), or possess other characteristics that make counting or collecting demographic information difficult (Thompson, 2004). Count-based data across a species' range are typically collected through survey programs that use a structured design (e.g., repeated counts; Royle, 2004). This approach has worked well to characterize trends and distributions of populations at local (Keever et al., 2017) and continental scales (e.g. North American Breeding Bird Survey [BBS]; Sauer and Link, 2011) for species that have predictable movements or are faithful to specific sites at certain times of the year. However, most structured surveys are designed with a limited number of fixed sampling locations surveyed each year, which can lead to biased population trajectory/trend estimates for species with unpredictable intra- and/or inter-annual movements. That is, a high count in one year followed by a low count in the next may not be indicative of a decline, but rather that a significant number of individuals occurred at non-sampled sites during the second survey. Williams and Boyle (2018) showed that grasshopper sparrows (*Ammodramus savannarum*) changed sites, even

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within a breeding season, far more often than previously thought. This suggests that although an observer may be counting the same species at the same sites year after year, the likelihood of encountering the same individuals in successive years may be very low. As such, it may be difficult to infer population processes when using data collected in this manner.

Information on population vital rates is equally challenging to obtain relative to count data for nomadic or irruptive species, greatly limiting our ability to determine what factors influence population growth rates, or to define populations at all (Yoccoz et al., 2001). Mark-recapture studies are a widely used technique to estimate survival; however, species that do not return to the same breeding locations each year are unlikely to yield recapture rates that are high enough to allow for the robust estimation of survival and other vital rates (Marshall et al., 2004). Mark-recapture studies based on live encounters measure apparent survival; losses of marked birds may represent true mortality or permanent emigration from the study area, and the distinction between the two may not be teased apart. This is an even greater issue in birds with low site fidelity. For example, nomadic red crossbills (*Loxia curvirostra*) have low recapture probabilities and transient dynamics, which have been shown to underestimate survival (Alonso and Arizaga, 2013). High rates of transience, such as those shown by American yellow warblers (*Setophaga petechia*), also lead to estimates of survival rates that are biased low (Cilimburg et al., 2002).

Integrated population models (IPMs) are increasingly being used in population ecology and have great potential as a wildlife management and conservation tool (Zipkin and Saunders, 2018; Arnold et al., 2018). IPMs allow researchers to jointly analyze data collected by different types of population studies (Schaub and Abadi, 2011). Benefits of this joint analysis can include improved precision in the estimates of demographic parameters and population size, estimation of demographic parameters for which data are lacking, and simultaneous examination of the change in population size and the mechanisms underlying the estimated change (Kéry and Schaub, 2012). While these models may accommodate many types of data, population counts or indices are required. These data allow the integration to occur, as the change in population size or structure over time is driven by the vital rates estimated by the other data sets in the model (Schaub and Abadi, 2011). Population index data from national-scale surveys have been successfully used in IPMs to estimate large-scale population trends (e.g. Robinson et al., 2014; Ahrestani et al., 2017). However, these data come from rather strict sampling protocols conducted at fixed locations and applying them to nomadic or irruptive species may be inappropriate.

Tricolored blackbirds (*Agelaius tricolor*) are nearly endemic to California, with no > 1% of the population breeding in Washington, Oregon, Nevada, and the Mexican state of Baja California (Beedy et al., 2017). The species has declined rapidly, experiencing a 63% decline in its breeding abundance from 1935 to 1975 (Graves et al., 2013). This decline was concurrent with declines of freshwater wetlands and grasslands, their historical breeding habitats, although recent studies suggest that reproductive success may be as high or higher in alternative habitats such as Himalayan blackberry (*Rubus armeniacus*) and silage crops (Holyoak et al., 2014; Weintraub et al., 2016). The population has continued to decline since 1975, although the most recent California statewide survey (conducted in April 2017) suggests that the population may have increased slightly since 2014, or that breeding birds were uncounted previously and are now included in the breeding surveys (Beedy et al., 2017).

Tricolored blackbirds present monitoring challenges because of their unique life-history traits. They are a colonial breeding species, historically breeding in colonies as large as 200,000 individuals (Neff, 1937), and many individuals breed twice per year, typically in 2 different locations (Hamilton, 1998; Beedy et al., 2017). For species that nest in highly-dynamic wetland environments, the benefits of site fidelity to previous breeding colonies may be outweighed by annual changes in habitat quality, as has been observed in colonial nesting herons and egrets (Carrasco et al., 2017). This has also been observed in tricolored blackbirds, where most colony sites are not used in consecutive years (Beedy and Hamilton, 1997; Holyoak et al., 2014; Airola et al., 2016). This variable site occupancy can make it challenging to recapture banded birds and/or to collect yearly population count data (Marshall et al., 2004). As most surveys are conducted at fixed locations, it may be difficult to interpret year-to-year counts of a species that is not likely to be in the same count location for each subsequent sampling occasion. Early efforts for counting tricolored blackbirds have summed the number of birds across all breeding sites (Meese, 2015), however this metric was shown to be highly dependent upon the number of colony sites sampled and is not recommended (Graves et al., 2013). The current method is a coordinated range-wide survey conducted triennially (e.g., Meese, 2014) and augmented by a sampling of the statewide population in years where the larger survey does not occur. However, these efforts are focused on previously occupied sites and may miss colonies that are established in new locations.

Given the uncertainties associated with tricolored blackbird count and index data (e.g., BBS), we used data from the eBird citizen-science project (Sullivan et al., 2014) as the population index data in an IPM. These data provide comprehensive spatial coverage and are independent of species occurrence as they may be collected anywhere in a species' range. As such, they may provide the best available representation of the population trajectory over the last 10 years of this unique species. We integrated eBird data for tricolored blackbirds from the pre-breeding period with band re-capture data from 18 sites and fecundity data from 10 sites in an IPM to determine the population trajectory and to identify life-history stages that are most influential to population growth. Understanding these parameters will help to identify knowledge gaps and inform management recommendations that may ensure the persistence of the species. This study provides the first use of less structured, citizen-science data in an IPM, and emphasizes the potential for these types of rapidly growing databases to become powerful tools in the fields of applied ecology and conservation biology.

2. Methods

2.1. Mark-recapture data

Tricolored blackbirds were banded at 18 sites throughout central California using United States Geological Survey (USGS) metal bands from 2007 to 2016. Trapping occurred during the breeding season (April–July) using walk-in traps, typically baited with cracked corn and infrequently supplemented with mealworms. Recaptures were recorded each year during the breeding season. Each breeding season was considered a separate recapture occasion and data for within-season recaptures were not included in our estimates of annual survival. We used data from 64,129 tricolored blackbirds (49,668 females and 14,461 males) banded and 1460 recaptured (1336 females and 124 males) as adults in our analysis. Only 368 individuals were initially marked and then recaptured at the same site.

2.2. Fecundity data

As raw fecundity data were unavailable, we simulated the fecundity data based on the reported summary statistics for nestling (defined as 5–9 day old chicks) surveys from 1992 to 2016 (Appendix 1). This was conducted in such a way as to capture the substantial year-to-year variation expected in the underlying data. Because between 60 and 100 nests (n) were surveyed in each year (i) per site (s), we allowed the number of nests sampled in a year to be a random draw from a uniform distribution with minimum 60 and maximum 100. The number of sampled sites varied among years between two and 10, thus we allowed the number of sites to be drawn from a uniform distribution with a minimum of two and maximum of 10. We then calculated the long-term

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