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Short communication

Integrating citizen science and remotely sensed data to help inform time-sensitive policy decisions for species of conservation concern

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ABSTRACT

The United States Fish and Wildlife Service (USFWS) uses a Species Status Assessment (SSA) framework to inform Endangered Species Act (ESA) policy decisions. A major challenge for development of SSAs includes inconsistent or incomplete monitoring throughout a species' range, which can result from inadequate time and funding for data collection prior to final rulings. In 2014, the USFWS initiated an SSA for the Sprague's pipit (*Anthus spragueii*; hereafter pipit), a migratory songbird scheduled for consideration as Threatened or Endangered in fall 2015. At the time, researchers had no field data to identify the spatial distribution of habitat across the geographic extent of the pipit's wintering grounds or to forecast the species' response to probable future scenarios of environmental conditions or conservation efforts during winter. In addition, the timing of the ESA decision precluded range-wide surveys on the pipit's wintering grounds. We present an SSA case study to demonstrate how citizen science and remotely sensed data could be integrated to help inform time-sensitive policy decisions for species of conservation concern. We developed three independent estimates of potential pipit habitat, and we assumed that spatial congruence among models provided increased evidence of habitat likely to support our focal species. We do not suggest that our approach replace more robust analyses, but rather illustrate an alternative strategy to obtain baseline information for SSAs and other policy decisions when data and time are lacking.

1. Introduction

The United States Fish and Wildlife Service (USFWS) uses a Species Status Assessment (SSA) framework to inform Endangered Species Act (ESA, 1973, as amended) policy decisions (USFWS, 2016a). In brief, an SSA entails three iterative stages: (1) identification of the species' needs; (2) description of the current habitat conditions, recent demographics, and probable explanations for past and ongoing changes in abundance and distribution within the species' ecological settings; and (3) forecasting of the species' responses to scenarios of plausible future environmental conditions and conservation efforts (USFWS, 2016a). Throughout the SSA process, the USFWS and their partners use the conservation biology principles of resiliency (i.e., the ability of a species' populations to withstand stochastic disturbance events), redundancy (i.e., the ability of a species to withstand catastrophic events), and representation (i.e., the ability of a species to adapt to changing environmental conditions) to measure the health of a species (Shaffer and Stein, 2000; Waples et al., 2013; Earl et al., 2017). The result is a single "living document" that can be used to determine ESA protections, designate critical habitat, inform recovery planning, and more (USFWS, 2016a).

A major challenge for development of SSAs includes inconsistent or incomplete monitoring throughout a species' range, which can result from complex life histories, geopolitical boundaries, detectability of rare and elusive species, and inadequate time and funding to obtain such data prior to policy decisions (Culver et al., 2009; Murphy and Weiland, 2016; Earl et al., 2017). Given these constraints, tools available through Geographic Information Systems (GIS)-based technology are critical to the development of SSAs and can be used to identify potential habitat, examine wildlife-habitat relationships, describe movement patterns, and predict changes in habitat conditions over time (Starfield, 1997; Guisan and Zimmerman, 2000). Field observations can and should assist with training and verification of geospatial data and analyses (Rykiel, 1996). However, when time-sensitive policy decisions

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limit our ability to collect geographically dispersed, multiseasonal observations, incorporating citizen science data into our analyses, particularly parameterization of species distribution models (Sauermann and Franzoni, 2015), may improve baseline data necessary for SSAs and help inform future sampling efforts (Wang and Gertner, 2014).

As demonstrated in the following SSA case study, we used remotely sensed similarities in environmental conditions at detection points recorded by citizen scientists within the spatial extent of our study area to identify potential wintering habitat for a bird species of conservation concern. We created our potential habitat map by overlaying three independent models, and we assumed that spatial congruence among models (i.e., areas of overlap) provided increased evidence of habitat likely to support our focal species. We do not suggest that our approach replace more robust analyses, but rather illustrate a strategy for obtaining baseline information when data and time are lacking. Our study also highlights an important contribution of citizen science to research, conservation, and policy decisions.

2. Background

In 2014, the USFWS initiated an SSA for Sprague's pipit (*Anthus spragueii*; hereafter pipit), a migratory songbird that breeds in mixed-grass prairie of the northern United States and Canada and winters in grasslands across the southwestern United States and Mexico (Robbins and Dale, 1999). Written accounts suggest that pipits were once abundant throughout their breeding range (Coues, 1874; Seton, 1890), but pipit populations declined sharply during the 20th century as a result of human-mediated habitat loss and degradation (Sauer et al., 2012). In 2008, the USFWS received a request to list the pipit as Endangered under the ESA (USFWS, 2009), and from 2010 to 2013, the USFWS determined that legal protections for the pipit were warranted under the ESA, but precluded by higher conservation priorities (UFSWS, 2010, 2011, 2012, 2013). When the SSA was initiated in 2014, the USFWS was expected to announce an updated decision on the pipit's ESA status in fall 2015.

During the SSA process, experts from the United States and Canada met with the USFWS to discuss the pipit's habitat requirements, review current conditions on the breeding grounds, and project the future extent of breeding habitat based on plausible land trend scenarios (USFWS, 2014a, 2014b; Aron, 2015). Data from the breeding grounds suggested that pipit populations had stabilized between 1.1 and 3 million birds and that the probability of population persistence is relatively high given current and predicted conditions (Aron, 2015). Research conducted in Texas and north-central Mexico prior to the SSA indicated that pipit density in winter is positively correlated with grassland patch size and negatively correlated with shrub cover (Desmond et al., 2005; Jones, 2010; Panjabi et al., 2010; Pool et al., 2012), which is similar to the species' ecological requirements on the breeding grounds (Robbins and Dale, 1999; Davis et al., 2006). Records also suggested that pipits use a broader range of vegetative cover types on their wintering grounds than on their breeding grounds, including turf grass farms, golf courses, heavily grazed Bermuda grass (*Cyndon* spp.), right-of-ways with grass shoulders, and burned pastures (Robbins and Dale, 1999; Freeman, 1999). However, at the time of the SSA (and to date), researchers lacked field data to identify the spatial distribution of habitat across the geographic extent of the pipit's wintering grounds or to forecast the species' response to probable future scenarios of environmental conditions and conservation efforts, as outlined in the SSA framework. In addition, the timing of the ESA decision precluded range-wide surveys prior to the ruling.

In spring 2015, we initiated a project to provide baseline information on the spatial distribution of potential pipit habitat in the state of Texas, where generalized range maps suggest most of the pipit's wintering habitat occurs (Robbins and Dale, 1999). Our goal was to complete the project within six months of the start date to align with preparation and submission of the SSA. Given data and time constraints, we used remotely sensed similarities in environmental conditions at detection points recorded by citizen scientists and the rest of our study area to identify potential pipit habitat. Below, we detail our justification for use of each dataset, the vetting process we used to remove unreliable and redundant data from the bird location data, and our geoprocessing methods.

3. Bird observation data

The most popular and widely used citizen science programs for birds in North America include the North American Breeding Bird Survey (BBS; coordinated by the United States Geological Survey and the Canadian Wildlife Service; https://www.pwrc.usgs.gov/bbs/), the National Audubon Society's Christmas Bird Count (CBC; https://www.audubon.org/conservation/science/christmas-bird-count), and eBird, which is administered by the Cornell Lab of Ornithology and the National Audubon Society (https://ebird.org/home). The BBS follows a standardized sampling methodology, with all data collected from late May through early July. As such, BBS data provided no information to drive winter habitat mapping in Texas. Alternately, the CBC occurs during December of each year, but detections are aggregated from multiple observers over a 15-km radius area, and, therefore, lack locational specificity. Given these constraints, we used observation points of pipits and co-occurring species that were recorded by citizens using eBird to drive our mapping process. eBird is a real-time, online checklist program dedicated to birdwatching that allows volunteers to report observations, including the species, date, location, and number of individuals per species (Sullivan et al., 2009, 2014). To assist with data quality, eBird enlists volunteer experts who create filters for geographic regions based on the geographic coordinates and dates of the observations that automatically flag potentially problematic submissions for further review (Sullivan et al., 2009, 2014). Although eBird data are not collected using a standardized study design or sampling methodology, eBird was designed to maximize data integrity of volunteer-recorded observations (Sullivan et al., 2009, 2014) and, at the time of our study, represented the best available information on the distribution of wintering pipits and co-occurring bird species in Texas.

We obtained eBird records for pipits using the Global Biodiversity Information Facility (GBIF), an international repository for biological data (https://www.gbif.org/). We limited our observations to those recorded in Texas from 2006 to 2008 and 2011 to 2013 to coincide with United States Census of Agriculture data for a separate objective to identify the counties at greatest risk of land cover change within the pipit's potential habitat (A.M. Long *unpublished data*). We also limited our inclusion of eBird observations to points recorded from November to March in each of those years to maximize the number of training points in our remote sensing analyses while minimizing the inclusion of migratory individuals. The exported pipit dataset from GBIF included geographic coordinates for 1721 detections. We identified the associated eBird checklists for all pipit detections and created a database of all other bird species recorded on the same checklists as pipits with data separated by eight regions (i.e. Panhandle Plains, Trans-Pecos, Central Plateau, North Central, Central Prairie, Rio Grande Brushlands, East Texas Pineywoods, Gulf Coastal Prairie) to account for potential geographic differences in species assemblages. We calculated the number of checklists that included pipits and each co-occurring species within and across regions, and we retained all co-occurring bird species with ecological requirements similar to the pipit that were represented on > 30 checklists. Our final list of co-occurring species included grasshopper sparrow (*Ammodramus savannarum*), McCown's longspur (*Calcarius mccownii*), chestnut-collared longspur (*C. ornatus*), lark bunting (*Calamospiza melanocorys*), and American pipit (*A. rubescens*). We then exported from GBIF all eBird observation records for the co-occurring species within the same timeframe that we set for the pipit data, resulting in 14,714 detection points for co-occurring species.

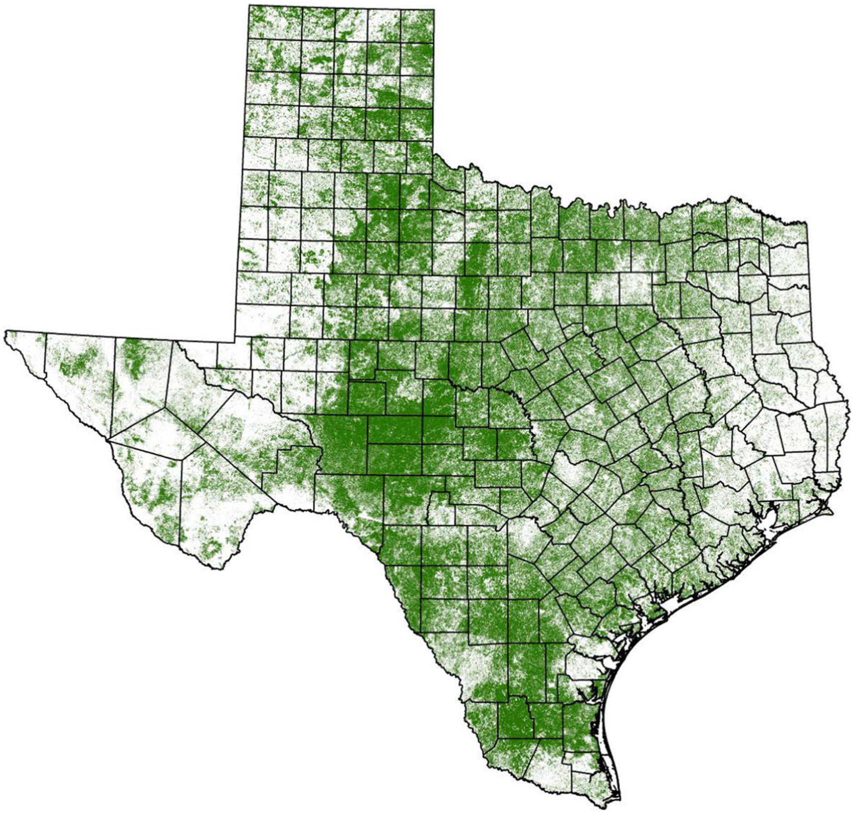

Fig. 1. Potential Sprague's pipit (*Anthus spragueii*; hereafter pipit) winter habitat in Texas delineated using eBird pipit detections and Landsat 8 imagery.

4. Geoprocessing and results

Our goal was to create three independent estimates of potential pipit habitat using (1) an image classification of habitat based on known winter sighting locations of our focal species, (2) an image classification based on known sightings of co-occurring avian species with similar autecological characteristics, and (3) an identification of homogenous grassland, grass savannah, and rangeland cover types using spatial analysis of Normalized Difference Vegetation Index (NDVI) classifications. We conducted all preprocessing steps and analyses in ArcMap 10.3 (ESRI, 2014) and used 30-m resolution Landsat 8 imagery recorded from 14 October 2014 to 10 February 2015 for image classifications. We included this relatively broad timespan to concur with the approximate dates of the pipit's winter season in Texas and to increase the likelihood of obtaining Landsat 8 scenes with minimal cloud cover. We used NDVI as an indicator of "greenness" or the amount of vegetative cover (Henebry, 1993) and calculated NDVI from Landsat 8 as ([NIR − Red] / [NIR + Red]) (Rouse et al., 1973).

Prior to geoprocessing, we deleted all redundant detections (i.e., multiple detections of the same species at the same point) from our pipit and co-occurring species datasets so that each location was only represented once. We then created a 500-m buffer around each location point and deleted all points that contained > 20% "non-habitat" land cover based on the 2011 National Land Cover Database (NLCD) classifications (i.e. water, developed, forest, and barren land cover classes) (https://catalog.data.gov/dataset/usgs-national-land-cover-dataset-nlcd-downloadable-data-collection). We chose this buffer size because pipits prefer large patches of grassland on their breeding grounds (> 29 ha; Davis, 2004), and because it allowed us to account for variability in landscape features that could affect pipit habitat use on the wintering grounds. These pre-processing steps resulted in 103 unique pipit locations and 548 unique co-occurring species locations that we used as training samples for our image classifications. We classified each pixel within the buffered areas around our training samples as "potential habitat" or "non-habitat" based on NDVI values that correspond to land cover types; "potential habitat" included NDVI values 0.15–0.60, which represent grassland and rangeland vegetation (USGS, 2018). We then used supervised maximum likelihood classification in ArcMap 10.3 (ESRI, 2014) to create one binary raster model based on the pipit locations and one binary raster model based on the co-occurring species locations. As a final step, we eliminated areas of low confidence from each model (i.e., cells with < 10% classification confidence), and we applied a smoothing filter to remove single, misclassified cells.

Our third model represented an independent estimate of potential pipit habitat as defined by areas of homogenous grassland, grass savannah, and rangeland cover in Texas. As described by Garrigues et al. (2006), differences in NDVI across landscapes can be explained by the spatial variability in reflectance values of land cover types. Empirically, agricultural fields are the most heterogeneous because NDVI values of bare soil are very different than NDVI values of the crops. Conversely, forests and grasslands are more homogenous at the landscape level. After masking all known non-habitat based on NLCD classifications (e.g., water, developed, forests), we calculated the coefficients of variation for positive NDVI values using a 100-ha pixel-based moving window analysis (Garrigues et al., 2006) and classified pixels as "potential habitat" when $\sigma^2_{\mathrm{NDVI}} > 0.49$.

We then aggregated each of the three binary models to 1 km^2 and overlaid the resulting layers to produce a final composite map. Because each model provided an independent estimate of potential habitat, we assumed that spatial congruence among models (i.e., areas of overlap) provided increased evidence of habitat likely to support our focal species, and that the strength of evidence should be weighted toward combinations containing pipit location information. Accordingly, we reassigned pixels of potential pipit habitat within the composite map to values of "Low", "Medium", and "High". We defined "Low" (5,359,213 ha) as potential winter habitat represented by the pipit model alone (Fig. 1) or by overlap between the co-occurring species

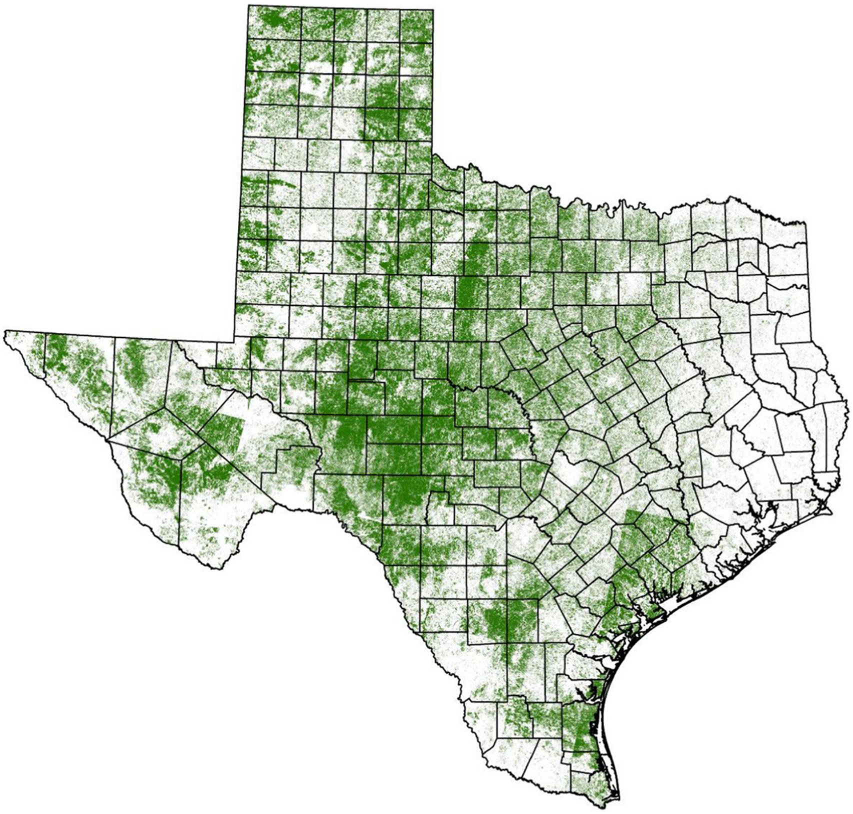

Fig. 2. Potential Sprague's pipit (*Anthus spragueii*) winter habitat in Texas delineated using eBird detections for co-occurring species and Landsat 8 imagery.

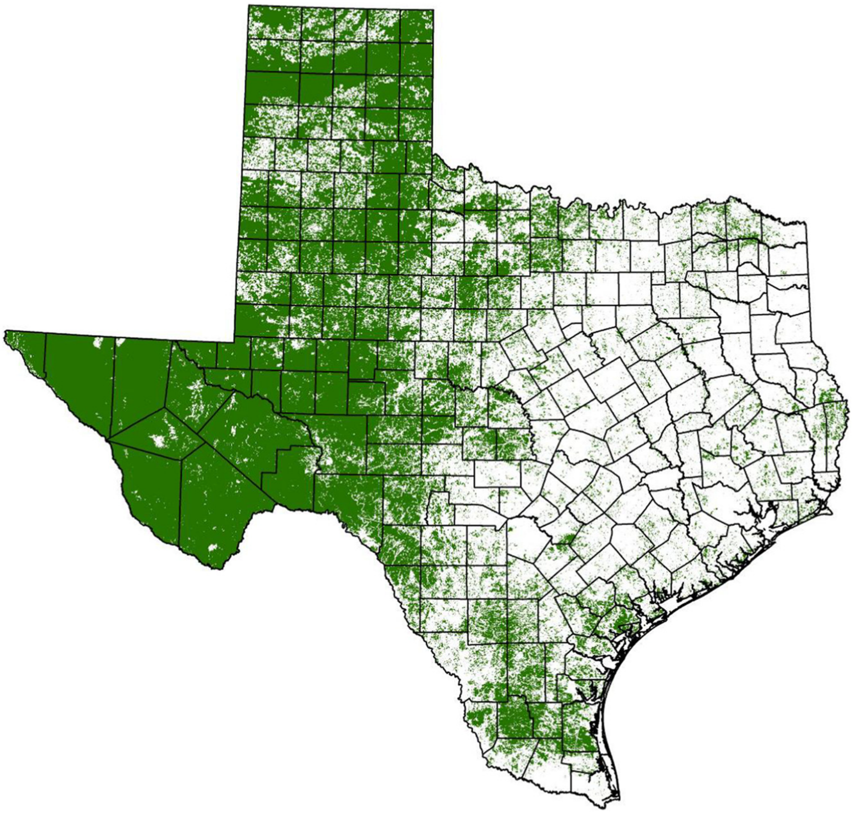

Fig. 3. Potential Sprague's pipit (*Anthus spragueii*; hereafter pipit) winter habitat in Texas delineated using variation in NDVI values.

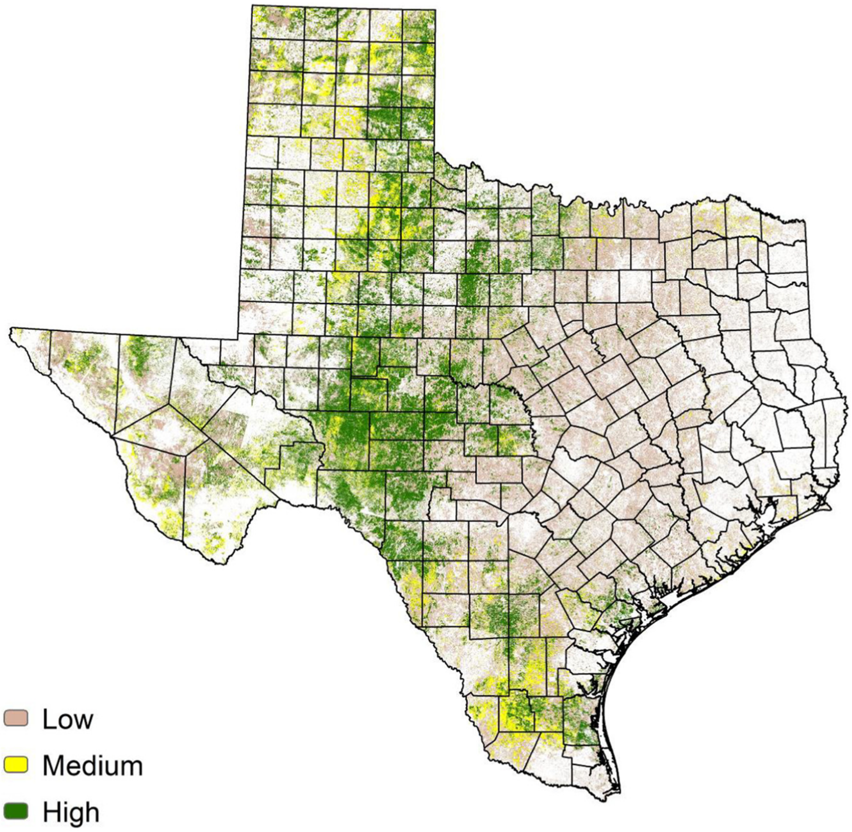

Fig. 4. Final composite of Sprague's pipit (*Anthus spragueii*; hereafter pipit) potential wintering habitat in Texas. Low, medium, and high categories represent the degree of overlap among three independent estimates.

model and the grassland model (Figs. 2 and 3), we defined "Medium" (3,101,844 ha) as overlap between the pipit model and grassland model (Figs. 1 and 3), and we defined "High" (6,401,865 ha) as overlap among all three models (Figs. 1–4).

5. Discussion

Citizen scientists have long contributed to avian research and monitoring through bird banding and resighting, nest monitoring, checklisting, collecting specimens and sound recordings, and reporting disease or deformity, among others (Colón et al., 2018). In recent years, technology has allowed citizen science observations to be used for more advanced analyses and to help inform conservation and policy actions (Sullivan et al., 2009; Dickinson et al., 2012; Sullivan et al., 2014; La Sorte et al., 2018). For example, scientists who categorize species' extinction risk for the International Union for Conservation of Nature's Red List increasingly use citizen science data to calculate population trends and species distributions, and information obtained through the Red List process is often used to develop species action plans, design reserves, and more at global and regional scales (Mace et al., 2008; Maes et al., 2015). Similarly, citizen science data can drive baseline species distribution models during an SSA.

Integrating citizen science data into any modeling environment does not occur without challenges, and there are on-going efforts to identify analytical techniques that minimize sources of uncertainty inherent to citizen science datasets (e.g., variable effort over time, lack of random sampling, informal protocols, inaccurate spatial locations, misidentified species) (Isaac et al., 2014; La Sorte et al., 2018). Depending on the application, biases caused by the use of citizen science data in model-based predictions may outweigh the benefits of data availability and quantity that are required to produce a "more complete" and reliable SSA. Also, data necessary to complete certain tasks may be unavailable given the data submission requirements of the citizen science program. In particular, it may not be possible to estimate the probability of species' occurrence at a particular site or to account for imperfect detection in estimates of species' occupancy probability using citizen science data (Guillera-Arroita et al., 2015). Given the statistical limitations associated with opportunistic data (Isaac et al., 2014), clear communication with decision makers regarding the assumptions, results, and implications of uncertainty when using citizen science data is of utmost importance during the SSA process or any other time that opportunistic data are used to help inform policy and management decisions.

Optimally, a species distribution model developed using only citizen science data would be viewed as an initial step in a much longer process to understand the conservation status of a species. To illustrate this point, our final potential pipit habitat map most certainly contains area outside the realized niche for our focal species, in part, because we had limited information on the autecological factors that drive pipit distributions on their wintering grounds. Such information can only be obtained through field studies on the bird's wintering grounds that account for detection probability under a probabilistic sampling design and allow for quantification of site-specific vegetation structure and composition used by pipits, minimum patch size requirements, patch-density estimates by habitat types, and other landscape features. Further, our geoprocessing methods at the state-wide scale did not allow us to distinguish among types of grassland (e.g., native, managed), which could also influence habitat use by this species (Robbins and Dale, 1999). The USFWS did not list the pipit as Threatened or Endangered, but they acknowledged a large data gap still occurs for this species on the wintering grounds (USFWS, 2016b). Mapping exercises that incorporate citizen science data like our multi-pronged approach and others (e.g., Muller et al., 2018), as well as site-specific research that identifies habitat associations of pipits on their wintering grounds (e.g., Stevens et al., 2013; Saalfeld et al., 2016), could provide a robust sampling framework for future studies that benefit pipits and other grassland species of conservation concern.

More broadly, integrating citizen science and remotely sensed data to help inform future survey efforts fits well with the intent of the SSA process to provide a "living document" that can be updated over time (USFWS, 2016a). And the availability of citizen science data that can be used for this purpose is increasing, as participants can now access learning materials and protocols online, upload data to real-time repositories, and view results in interactive graphs and maps using home computers, tablets, and cellular devices. Recent research suggests there are > 420 citizen science programs that support > 3600 projects, with scales of implementation ranging from global monitoring with tens of thousands of participants to specialist projects that focus on a particular taxa or local interests (Chandler et al., 2017). Citizen science records are collected at larger spatial and temporal scales than feasible during individual field studies (Sauermann and Franzoni, 2015), are available through free public repositories (e.g., eBird, Global Biodiversity Information Facility [GBIF]), and can encourage scientific literacy and public participation in policy decisions (Bonney et al., 2009, 2014). Given increasing threats to biodiversity around the world and constrained resources, our SSA case study demonstrates yet another way that we can use these valuable data to help inform time-sensitive policy decisions for species of conservation concern.

Declaration of Competing Interest

The authors of this paper are not aware of any actual or potential conflicts of interest that could inappropriately influence, or be perceived to influence, their work.

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