Biological Conservation 201 (2016) 327–335

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/bioc

Future frequencies of extreme weather events in the National Wildlife Refuges of the conterminous U.S.

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ARTICLE INFO

Article history:
Received 1 March 2016
Received in revised form 3 July 2016
Accepted 6 July 2016
Available online 1 August 2016

Keywords:
Protected areas
Climate change
Conservation planning
Droughts
Extreme heat
False springs

ABSTRACT

Climate change is a major challenge for managers of protected areas world-wide, and managers need information about future climate conditions within protected areas. Prior studies of climate change effects in protected areas have largely focused on average climatic conditions. However, extreme weather may have stronger effects on wildlife populations and habitats than changes in averages. Our goal was to quantify future changes in the frequency of extreme heat, drought, and false springs, during the avian breeding season, in 415 National Wildlife Refuges in the conterminous United States. We analyzed spatially detailed data on extreme weather frequencies during the historical period (1950–2005) and under different scenarios of future climate change by mid- and late-21st century. We found that all wildlife refuges will likely experience substantial changes in the frequencies of extreme weather, but the types of projected changes differed among refuges. Extreme heat is projected to increase dramatically in all wildlife refuges, whereas changes in droughts and false springs are projected to increase or decrease on a regional basis. Half of all wildlife refuges are projected to see increases in frequency (>20% higher than the current rate) in at least two types of weather extremes by mid-century. Wildlife refuges in the Southwest and Pacific Southwest are projected to exhibit the fastest rates of change, and may deserve extra attention. Climate change adaptation strategies in protected areas, such as the U.S. wildlife refuges, may need to seriously consider future changes in extreme weather, including the considerable spatial variation of these changes.

1. Introduction

Protected areas are a cornerstone for biodiversity conservation, and climate change represents one of the major challenges for managers of protected areas globally (Hole et al., 2009; Lawler, 2009). As climate changes, conditions within protected areas are also expected to change, potentially triggering shifts in species and changing ecosystem properties (Langdon and Lawler, 2015; Wiens et al., 2011). Conserving biodiversity into the future therefore, requires understanding future climatic conditions in protected areas (Hannah, 2008).

Most studies assessing effects of climate change on biodiversity and protected areas have focused on climate averages, e.g. changes in mean temperature or precipitation, rather than potential changes in the frequency of extreme weather such as prolonged droughts, extreme heat, or unseasonable cold periods (Garcia et al., 2014; Loarie et al., 2009; Scriven et al., 2015; Wiens et al., 2011). However, studying the changes in extremes explicitly allows for better interpretation of the consequences for protected area managers, because extreme weather events can pose stronger threats to species and ecosystems, and make habitat management more challenging, than shifts in average conditions (Reyer et al., 2013). Increased frequency or intensity of extreme heat and droughts can facilitate plant invasions (Jiménez et al., 2011), increase tree mortality (Allen et al., 2010), reduce avian breeding success and survival (Jenouvrier, 2013), and trigger species movement and range shifts, potentially changing community composition, resource availability, and ecosystem properties (Parmesan et al., 2000). For example, the Dickcissel (*Spiza americana*), a grassland bird species of the U.S. Midwest, exhibits strong abundance shifts at its range edges during drought events compared to years of average precipitation (Bateman et al., 2015). In Mediterranean forests, droughts can trigger widespread tree defoliation that disrupts insect and fungal communities and alters food webs (Carnicer et al., 2011). At times when managers are trying to initiate a restoration, flood a wetland management unit, or perform some other management action, droughts may prevent implementing the desired management action at the most beneficial time (Dale et al., 2001; Thurow and Taylor, 1999). In general, extreme heat and drought are projected to become more frequent in some

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http://dx.doi.org/10.1016/j.biocon.2016.07.007
0006-3207/

regions in the next decades (IPCC, 2012; Walsh et al., 2014) but future patterns of these extremes in protected areas are largely unknown (Monahan and Fisichelli, 2014).

In addition to extreme heat and drought, false springs can have large ecological effects. False springs, which occur when leaf-out of plants is followed by a hard freeze, typically cause severe vegetation damage (Augspurger, 2013). False springs can occur when there is a combination of premature warm temperatures followed by late freezes. Widespread vegetation damage from false springs has been observed in both natural and agricultural systems, with negative consequences for plant productivity, survival, and growth (Augspurger, 2011; Inouye, 2008). In turn, the effects from false springs can percolate through an ecosystem, as reduced plant productivity negatively affects dependent animal populations, interactions among species, and the provision of ecosystem services (Hufkens et al., 2012; Nixon and McClain, 1969). In 2010, for example, false springs reduced annual gross productivity in forest ecosystems of the northeastern United States (U.S.) by 7–14% (Hufkens et al., 2012). Projections of future climate change in places such as the U.S. indicate that false springs may become more frequent in certain regions (Allstadt et al., 2015), yet their effects on protected areas are unknown.

Assessing how droughts, extreme heat, and false springs may change across protected area networks as a result of future climate changes can provide important information about potential challenges that species and managers may face. In particular, evaluating future changes in extreme weather during the spring season can be of major importance, because plant and animal populations can be especially sensitive to extremes during those months (Bolger et al., 2005; Both and Visser, 2001; Drever et al., 2012), when many wildlife species are breeding, and plants are growing and blooming (Jenouvrier, 2013; Filewod and Thomas, 2014). Furthermore, when assessing the exposure of protected areas to different types of extreme weather, it is important to evaluate their exposure to each extreme individually, as well as to all types of extremes combined, because the interactions among multiple environmental stressors can exacerbate ecosystem responses (Albright et al., 2010; Breitburg et al., 1998). While the ultimate response of the biota will depend on other factors as well, including individual species' tolerances and interactions within and among trophic levels (Parmesan et al., 2000; Walther, 2010), knowing their exposure to future changes is a critical first step.

Patterns of climate change vary, however, especially at regional and continental scales, and that variability matters when prioritizing management actions across protected area networks (Monahan and Fisichelli, 2014). For protected area managers and governmental agencies, knowing which protected areas will be affected by multiple stressors is of major importance because those protected areas can be considered under potentially increasing threat due to climate changes, and thus may require particular attention. Furthermore, individual protected areas are typically embedded within larger administrative regions. Assessments of future climate change in protected areas are therefore more useful if they can inform both managers of individual protected areas as well as higher-level administrators, yet such assessments are rare. Finally, because of the uncertainty in predictions of future climate conditions, it is important to evaluate multiple models and scenarios of climate change (Lawler, 2009).

The goal of our study was to quantify future changes in the frequency of extreme weather events during the spring breeding season in protected areas, focusing on the National Wildlife Refuge System (NWRS) in the conterminous United States. The NWRS is one of the world's largest protected area networks designated to protect wildlife and plants, and information about future climate conditions is needed for the NWRS' climate change adaptation plans (Czech et al., 2014; Griffith et al., 2009). Our specific objectives were to: i) quantify future changes in the frequency of extreme heat, droughts, and false springs for each administrative region under different climate change scenarios, and ii) map future changes in extreme heat, droughts, and false springs at the level of individual wildlife refuges across the nation. We also identified which refuges are projected to see increases in multiple types of extremes, our main indicator of increasing threat due to future climate changes.

2. Materials and methods

2.1. Data

2.1.1. Wildlife refuges

In the conterminous U.S. alone, there are over 460 wildlife refuges aggregated in seven Fish and Wildlife Service (FWS) administrative regions. We focused on the conterminous U.S., and excluded NWRS lands not directly managed by the FWS (namely, cooperatively managed lands) or not specifically designated as refuges, as in previous studies (Hamilton et al., 2013). In addition, because the weather data used in this study are best suited for analyzing changes on continental lands, we did not consider wildlife refuges and wildlife refuge's portions in the oceans and the Great Lakes, but included river refuges. As a result, the final number of wildlife refuges that we assessed was 415, with 42 to 99 wildlife refuges in each of the seven FWS administrative regions (Fig. 1a). Wildlife refuges are relatively small in size (the median size was 2754 ha), typically embedded in a matrix of developed lands, and situated at low elevations and on productive soils (Griffith et al., 2009). Wetlands are common in the NWRS.

2.1.2. Extreme weather data

We derived focal weather variables (extreme heat, droughts, and false springs) based on daily records from the Coupled Model Intercomparison Project 5 (CMIP5) multi-model ensemble General Circulation Models (GCM) dataset. Specifically, we used data spanning from 1950 to 2100 that have been statistically downscaled to approximately 12-km resolution from the coarse-scale GCM using the Bias-Corrected Constructed Analog (BCCA) technique (Maurer et al., 2007; Reclamation, 2014). The main reason for going back to 1950 was to obtain a large sample size, which is important for analysis of extreme events. We analyzed data for 19 GCMs (Table A.1), and present here the multi-model median values, and in some cases the 25th and 75th percentile values to represent variation among GCMs. We considered two emissions scenarios that were available for each of the 19 GCMs, including the Representative Concentration Pathway 4.5, or RCP4.5 (medium-low emissions) and the RCP8.5 (high emissions). Our study variables were summarized into simulated historical (1950–2005), mid-century (2041–2070), and end of the century (2071–2100) time periods, and were based on spring season only (March, April, May), which is when birds make their settling decisions in the northern states, and in the southern U.S., includes the early breeding season. Spring precipitation, or the lack thereof, strongly affects resource availability and water levels during the avian breeding season.

2.1.2.1. Droughts. We quantified changes in spring drought by comparing the frequency of droughts with a 20-year recurrence interval observed during the simulated historical period, with the frequency of droughts of similar magnitude in the future. For example, for a certain pixel, a 20-year drought during the historical period might occur every 10 years by mid-century, which means that the frequency has doubled. We chose twenty-year events as our key metric, because they clearly represent an extreme event, and are frequent enough that managers can expect at least one of these to occur during their career.

We calculated 20-year droughts based on the Standardized Precipitation Index (SPI) (McKee et al., 1993). The SPI is a widely used drought metric (World Meteorological Association, 2009) defining drought as a probabilistic lack of precipitation in terms of a standard normal distribution (Guttman, 1999; McKee et al., 1993). That is, a 20-year drought is defined as a SPI ≤ -1.64. We calculated SPI independently for each model, and for each grid cell. In each cell, we calculated the total