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Impacts of climate change and renewable energy development on habitat of an endemic squirrel, *Xerospermophilus mohavensis*, in the Mojave Desert, USA

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ABSTRACT

Predicting changes in species distributions under a changing climate is becoming widespread with the use of species distribution models (SDMs). The resulting predictions of future potential habitat can be cast in light of planned land use changes, such as urban expansion and energy development to identify areas with potential conflict. However, SDMs rarely incorporate an understanding of dispersal capacity, and therefore assume unlimited dispersal in potential range shifts under uncertain climate futures. We use SDMs to predict future distributions of the Mojave ground squirrel, *Xerospermophilus mohavensis* Merriam, and incorporate partial dispersal models informed by field data on juvenile dispersal to assess projected impact of climate change and energy development on future distributions of *X. mohavensis*. Our models predict loss of extant habitat, but also concurrent gains of new habitat under two scenarios of future climate change. Under the B1 emissions scenario- a storyline describing a convergent world with emphasis on curbing greenhouse gas emissions- our models predicted losses of up to 64% of extant habitat by 2080, while under the increased greenhouse gas emissions of the A2 scenario, we suggest losses of 56%. New potential habitat may become available to *X. mohavensis*, thereby offsetting as much as 6330 km^2 (50%) of the current habitat lost. Habitat lost due to planned energy development was marginal compared to habitat lost from changing climates, but disproportionately affected current habitat. Future areas of overlap in potential habitat between the two climate change scenarios are identified and discussed in context of proposed energy development.

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1. Introduction

Many studies modeling the consequences of 20th–21st century climate change on species distributions suggest that the distributions of many North American flora and fauna will be reduced, altered, or eliminated if regional climate trends continue (Rosenzweig et al., 2008, Pearson et al., 2014). Changes in temperature and precipitation are likely to push some ecosystems and their species poleward or up-slope (Hickling et al., 2005, Lenoir et al., 2008), downslope (Serra-Diaz et al., 2014), cause heterogeneous range shifts (Tingley et al., 2012, Serra-Diaz et al., 2014), or contractions in their ranges (Schloss et al., 2012, HilleRisLambers et al., 2013). In particular, those with narrow niche breadth may be especially vulnerable to changing climates due to their often limited geographic range, low dispersal capacity, low reproductive output, and limited physiological tolerances (Broennimann et al., 2006, Schloss et al., 2012). Further complicating these stressors, surface-disturbing land uses (e.g., urbanization, transportation corridors, military training, agriculture, recreational activities, and energy development) have altered vast areas of terrestrial landscapes (Leu et al., 2008), fragmenting habitat and disrupting habitat corridors. This potentially restricts the ability of species to migrate to new areas (Wilson et al., 2010, Beltrán et al., 2014). The combination of these global, regional and often local stressors – in the form of climate and land use changes – can interact in unexpected ways to cause further reductions in species distributions (Mantyka-Pringle et al., 2015). These interactions have not been extensively explored for desert landscapes, especially those facing an increase in pressure from energy development.

Deserts of the southwestern United States are increasingly being recognized as having great potential for energy development given the abundant wind, solar and geothermal resources (NREL, 2013;

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Hernandez et al., 2015) and have vast expanses of public land. In recent years, federal public policy initiatives have mandated or encouraged the construction of utility scale renewable energy development (abbreviated hereafter as “energy development”). Consequently, infrastructure and energy development in the Mojave Desert have increased in recent years (Leu et al., 2008, Barrows and Allen, 2009, Lovich and Ennen, 2011). This region is home to many species of conservation concern that face increasing degradation, fragmentation, and outright losses of habitat due to growing energy infrastructure (Lovich and Ennen, 2011, Vandergast et al., 2013), invasive plants and fire (Brooks and Matchett, 2006), military training, and recreation (Berry and Aresco, 2014, DRECP, 2015).

The Mohave ground squirrel, *Xerospermophilus mohavensis* Merriam is endemic (Frank and McCoy, 1990) to the western Mojave Desert in California, USA (Best, 1995) and has one of the smallest distributions among North American ground squirrels, occupying an area of just 20,000 km^2 (Hoyt, 1972, Hall, 1981, Zeiner et al., 1988–1990). *X. mohavensis* is protected as a threatened species under the California Endangered Species Act (Fish and Game Code Section 2050) and was petitioned for listing under the federal Endangered Species Act in 2005, though the United States Fish and Wildlife Service decided that federal listing was not warranted at that time. Recent initiatives by the United States to reduce dependence on imported oil and reduce greenhouse gas emissions by pursuing solar, wind, and thermal power in the Mojave Desert have again raised concerns about the status of this species (Inman et al., 2013, DRECP, 2015). *X. mohavensis* has responded to historical changes in climate by migrating to their current range from southern refugia after the Last Glacial Maximum (Hafner and Yates, 1983), though current and future land use changes and the limited period of activity (Best, 1995) and dispersal ability of *X. mohavensis* raise concerns that a rapidly changing climate may challenge the persistence of this species. Recent research has shown that the ranges of small mammals at high elevations in California, USA, have decreased within the last century – likely due to climate change (Moritz et al., 2008). Others have predicted that the distributions of many rodent species in Texas, USA, will decrease to 60% of their current distributions under some climate change predictions (Cameron and Scheel, 2001). Although similar changes in climate may have occurred historically, broad landscape changes driven by recent human development may dramatically hinder some species' abilities to adapt to and disperse across a rapidly changing landscape (Schloss et al., 2012) resulting in precipitous range contractions and population declines.

Species distribution models (SDMs) have been widely adopted as tools for casting projections of habitat suitability under future climate scenarios (Franklin, 2010), and have been incorporated into many conservation planning strategies as tools to identify new future habitat or existing climate refugia for protection from land use changes (Jones et al., 2016). These models correlate a species' current distribution to environmental variables and infer habitat suitability at locations where a species' presence is unknown. SDMs incorporating mechanistic interactions between organisms, their environments, and fitness consequences are often referred to as ‘niche’ models, and are generally preferred over models devoid of physiological knowledge (Tracy et al., 2006, Buckley et al., 2010). Models ignoring these fundamental evolutionary processes may produce accurate representations of current geographic distributions, but can misrepresent relationships between current geographic distributions and future climates (Hijmans and Graham, 2006; Botkin et al., 2007, Williams and Jackson, 2007) or overestimate vulnerability to extinction (Schwartz, 2012). Moreover, while these models often predict substantial changes to habitat suitability under future conditions, few account for the ability (or inability) of species to relocate to new areas with suitable habitat (Bateman et al., 2013). Dispersal ability strongly influences the resilience of species to climate change – both through range shifts in response to shifting habitat suitability, and through increased gene flow between populations that can influence the rate of in situ adaptation to changing conditions (Bell and Gonzalez, 2011).

The work here builds on previous studies of *X. mohavensis* habitat and connectivity (Esque et al., 2013, Inman et al., 2013, Dilts et al., 2015) by forecasting habitat suitability under two climate scenarios across an expanded study area and by augmenting the previously developed SDM with a model of dispersal to account for potential *X. mohavensis* range expansion. Here we explore the ability of *X. mohavensis* to shift its range in response to changing climates from 2015 to 2080 and address alteration of habitat due to current land use through the use of scale factors reducing habitat suitability in areas affected by surface disturbance. Finally, we ask what impacts proposed energy development might have on future *X. mohavensis* habitat. The methods presented here can serve as a template for incorporating dispersal and land use when assessing the impacts of climate change on habitat.

2. Materials and methods

2.1. Study area

Our study area covered 131,059 km^2 of the Mojave Desert and Sierra Nevada mountains in California, including portions of Inyo, San Bernardino, Kern, and Los Angeles counties, and encompassed the entire known historical range of *X. mohavensis* (Zeiner et al., 1988–1990). This area is characterized by desert mountain ranges and plateaus separated by lower elevations with geomorphic features such as washes, outwash plains, dry lakebeds and basins, and is constrained by high elevations of the Sierra Nevada mountain range to the west. We expand the region used by Inman et al. (2013) to accommodate potential shifts in available habitat to the north and east, which were expected under future climate scenarios. Our study area included extremes in elevation, however 90% of the study area is below 2500 m. Regional precipitation ranges from 100 to 350 mm per year, with more rainfall occurring in the winter than in the summer (Hereford et al., 2004) and at higher elevations. Temperatures range from below 0 °C in the winter months to over 54 °C in the summer, with considerable daily and geographic variation (Turner, 1994).

2.2. SDM and environmental data

A previously developed SDM was chosen to represent current *X. mohavensis* habitat (Inman et al., 2013), and was used to forecast how future habitat may be altered under multiple climate change scenarios. This model, hereafter referred to as ‘current conditions model’ was developed with MaxEnt (version 3.3.3e, Phillips et al., 2006) at a spatial resolution of 1 km, and relied on 629 locality records of *X. mohavensis* from multiple sources including the California Natural Diversity Data Base (CNDDB), the Mojave Desert Ecosystem Program, as well as recent trapping and survey work in the region (P. Leitner and D. Delaney, unpublished data). Prior to use in the SDM, records were thinned to 1 per each 1 km^2 grid cell, and observations prior to 1975 were removed to minimize the effects of drastic land use changes, such as urbanization or agriculture. A bias file – realized as a density surface of all observations – was used to reduce the influence of biased sampling (Phillips and Dudik, 2008) and was created using a 4 km search radius from each cell. Environmental correlates of habitat suitability representing land surface characteristics and surface water balance were used in the current habitat model to describe the niche space of *X. mohavensis*, and were selected previously from a suite of model candidates derived from 14 environmental variables described by Inman et al. (2013). The current conditions model was selected from a suite of 86 candidate models with an information theoretic approach using a modified AICc score that was bias corrected for small sample sizes (Burnham and Anderson, 2002), and showed an Area Under the receiver operating