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Predicting the impact of fire on a vulnerable multi-species community using a dynamic vegetation model

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ABSTRACT

Conservation management under human-induced changes to disturbance requires tools that can balance the needs of multiple species with different life histories and habitat requirements. Despite this urgent conservation need, landscape management typically focuses on single species and rarely includes the influence of disturbance-dependent vegetation transitions on multiple target species. In this paper, we describe a simulation model that achieves these goals, ranking possible fire management strategies from the viewpoint of protecting endangered coastal Southern Californian wildlife. The model involves the direct and indirect effects of fire on four animal species of conservation concern (coastal cactus wren, California gnatcatcher, Stephens' kangaroo rat, and Pacific pocket mouse) and five vegetation types (grass, coastal sage scrub, obligate seeding and resprouting chaparral, resprouting-only chaparral, and woodlands). Using historical fire records for the region, we predicted spatially-explicit fire frequencies and ignition probabilities. For these predictions, we simulated the location and extent of fires. Combining fire history and vegetation transition data from 1933 to 2003, we specified vegetation change probabilities under simulated fire regimes. Fire occurrence in a location altered habitat suitability, directly for each of the animal species and indirectly by changing the vegetative community. For some open-habitat species, such as the Stephens' kangaroo rat and Pacific pocket mouse, fairly frequent fire is required to reduce the density of invasive grasses and herbs. For other species, such as the coastal cactus wren and California gnatcatcher, frequent fire destroys the mature coastal sage scrub on which these species depend. The model includes a management component, allowing us to rank fire management actions. Over a 50-year time horizon, we find that populations of California gnatcatchers and Pacific pocket mouse are highly variable, and the pocket mouse is particularly prone to decline, despite prescribed burns designed to boost population viability. California gnatcatchers were also likely to be extirpated in the model, with relatively small extirpation risks for the cactus wren and Stephens' kangaroo rat. Despite conflicting requirements with respect to fire and differing life history traits among the four animals, we identified a beneficial strategy for our four target species, namely, controlling fire in coastal sage scrub.

1. Introduction

Conservation management requires integrated approaches to address conservation objectives for multiple species experiencing myriad threats that span landscapes (Franklin, 1993). Though conservation objectives at the landscape scale usually need to encompass multiple species, formal quantitative decision support models are still largely focused on single species or biodiversity surrogates (e.g. umbrella/flagship species) (Roberge and Angelstam, 2004; Simberloff, 1998). The success of specific management strategies is contingent upon understanding trade-offs among multiple species and threats. Different species have different habitat requirements, respond to threats in different ways and possess different life history traits. These species differences can lead to conflicts when managing for the conservation of multiple species as available habitat decreases and other threats increase. Successful multi-species management will depend on a clear understanding of the trade-offs imposed when species have very different resource needs and responses to conservation actions.

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In the conservation literature, "trade-offs" are often discussed in the context of compromises between biodiversity goals and economic well-being (McShane et al., 2011; Hirsch et al., 2011), or conflicts among potential services provided by natural landscapes (Faith, 2012). Few studies look at trade-offs between species in a particular landscape context. Such analyses require considerable information, often unavailable, about individual species' responses to potential landscape threats. We address the issue of trade-offs from the viewpoint of conserving multiple species on a particular landscape.

Conservation within the California Floristic Province, a global biodiversity hotspot and one of five Mediterranean-type ecosystems, illustrates the trade-offs involved in multi-species management. In California, only 10% of the coastal sage scrub habitat remains (Rubinoff, 2001) and this study focuses on one of the few extensive areas that still exists. Coastal sage scrub is a terrestrial plant community consisting of a short somewhat open canopy of mostly soft-leaved, sometimes dry-season deciduous shrubs (Kirkpatrick and Hutchinson, 1977). Increased fire frequency is threatening coastal sage scrub ecosystems, where fire frequency above the historical rate of once every 30–40 years (Keeley and Fotheringham, 2001a,b) can shift the competitive advantage towards invasive plants (Keeley et al., 2011; Fleming et al., 2009; Talluto and Suding, 2008). Short-lived invasive annuals grow quickly, leaving behind large quantities of dry, combustible biomass for most of the year (Link et al., 2006; Lambert et al., 2010), thus further increasing fire frequency (Brooks and Chambers, 2011) and invasive plant spread. This positive feedback between fire and invasive plant spread can result in vegetation type conversion from coastal sage scrub to exotic grass (Fleming et al., 2009; Talluto and Suding, 2008). Chaparral vegetation, a shrubland that is denser, taller and more evergreen than sage scrub, is even more sensitive to repeated, frequent fires than coastal sage scrub, and is also at risk of converting to exotic grassland (Jacobsen et al., 2004; Syphard et al., 2006; Keeley and Brennan, 2012).

While the native vegetation of the California Floristic Province has important global conservation value in itself, it also serves as key habitat to a host of threatened and endangered species. Here, we focus on the federally listed (under the United States Endangered Species Act) California gnatcatcher (*Polioptila californica*), Stephens' kangaroo rat (*Dipodomys stephensii*), and Pacific pocket mouse (*Perognathus longimembris pacificus*), as well as the coastal cactus wren, a California Bird of Special Concern (*Campylorhynchus brunneicapillus*). The two bird species prefer mature coastal sage vegetation that has not recently experienced a fire (Preston and Kamada, 2012, 2009; Beyers and Wirtz, 1995), whereas the rodents prefer coastal sage scrub or grasslands that have recently burned and thus lack a dense understory of invasive grasses (O'Farrell and Uptain, 1987; Price et al., 1993, 1995; Spencer, 2005). Maintaining adequate habitat for multiple species of conservation concern with contrasting habitat requirements and life history traits is a significant challenge for land managers.

Multi-species management must account for complex processes, different habitat needs, and a range of threats, life histories, and trade-offs. Thus, integrated modeling frameworks have been promoted that coalesce available physical and ecological data into meaningful decision support tools. Examples are the landscape succession models LANDIS and LANDIS-II (Mladenoff, 2004; Scheller et al., 2007; Sturtevant et al., 2009) and MEDFIRE (De Caceres et al., 2013) that simulate vegetation succession under fire disturbance. These dynamic vegetation models can then be coupled with population models to address the joint impact of environmental stochasticity and fire on the viability of at-risk species.

Multiple species models that incorporate fire and habitat requirements for target animal species typically focus on correlating landscape features with species presence or absence. For example, vegetation type, climate change, and fire disturbance can be used in a standard species distribution model that describes habitat suitability for multiple focal taxa (White et al., 2011; De Caceres et al., 2013). Models that include the effects of disturbances, such as fire and succession, go beyond traditional species distribution models that estimate habitat suitability based on topographic and climatic conditions (Beltrán et al., 2014; Pompe et al., 2008; Thuiller et al., 2006). However, neither of these types of models typically include dynamic, disturbance-dependent vegetation transitions that affect species occurrence and resulting conservation management decisions.

Because of the difficulties in obtaining adequate data for parameterization, models rarely consider multiple species, habitat types, threats, and management options together in one framework. An exception is the Across Trophic Level System Simulation (ATLSS) model for the Florida everglades (DeAngelis et al., 1998). This model uses topographic, vegetation, and hydrology inputs to model energy flow through three trophic levels. The model was designed to allow managers to make hydrological decisions while managing multiple focal species. Adopting this strategy for fire management in Southern California, we developed a dynamic vegetation and occupancy model with the functionality to accommodate multiple species interacting with a landscape under threat from frequent fire. We use data on the frequency of fire-induced changes in vegetation type (Fleming et al., 2009; Callaway and Davis, 1993) to model vegetation transitions among grasslands, coastal sage scrub, chaparral, and woodlands (open tree canopies dominated by live oaks) under different fire regimes. Our model addresses ecosystem threats common to Mediterranean ecosystems and allows for conservation decision-making where trade-offs between habitat requirements and altered natural disturbance regimes can stymie a clear course of action.

Although wildfire is a natural process in Southern California and other Mediterranean-climate regions, altered fire regimes may threaten wildlife directly or indirectly through vegetation transitions. We model these direct and indirect threats for the vegetation types and for the four species that rely on them. Our aim is to use available data on the locations and extent of different vegetation types, transitions between vegetation types, fire size and frequency, and species locations to create a model that simulates the dynamic tradeoffs in habitat requirements for four threatened species. We will then use the model to identify the best plausible fire management scenarios for four threatened species separately and in combination. In this way, our results highlight the fire scenarios that are most detrimental to these species and the range of fire management strategies that are most likely to support them and their habitats.

2. Methods

2.1. Overview

We developed our model for Marine Corps Base Camp Pendleton, hereafter Pendleton, a military base in northwestern San Diego County, California, USA. A little over 500 km^2, the base has a high frequency of wildfire that is primarily human-caused, either intentionally or unintentionally. Land managers at Pendleton are required to maintain populations of threatened and endangered species while also meeting the base's mission to support military training exercises. These potentially conflicting conservation and land management objectives provided context for developing a model addressing multiple species and fire regimes.

Pendleton is one of the few remaining locations of critically endangered coastal sage habitat. With the exception of a part of its northern border, Pendleton is surrounded on all sides by urban