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Research article

Environmental and managerial factors associated with pack stock distribution in high elevation meadows: Case study from Yosemite National Park

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ABSTRACT

Parks and protected areas are integral strategies for biological diversity conservation, and their management often involves balancing visitor use with resource protection. Effectively balancing these objectives requires data about how use is distributed within areas of interest and how management strategies and environmental conditions interact to minimize negative impacts. This study examined which environmental and managerial factors most influenced the distribution of domestic pack stock animals, a common visitor use-related activity, when released to graze in high elevation meadows. Using a species distribution modelling approach, MaxEnt, managerial factors were found to be among the top contributors to models. Pack stock animals concentrated use near the locations where they were released as well as portable enclosure fencing confining the lead animal even though the remainder were allowed to roam freely. Elevation was the environmental factor contributing most, with animals remaining at similar elevations to the meadow even if moving into nearby understory. Results highlight the importance of release point and fence locations to overall pack stock animal distribution and rotational or strategic placement can be a tactic for mitigating impacts to sensitive habitats.

1. Introduction

Biodiversity underpins healthy ecosystem function, provides ecosystem services, and supports human well-being. Parks and protected areas (PAs) represent a core component of biodiversity conservation strategies (Chape et al., 2005), with global agreements and efforts striving to increase the number and size of PAs to meet biodiversity conservation goals (Watson et al., 2014). In addition to conserving the resources within their boundaries, PA managing agencies may also have mandates to provide for compatible recreational opportunities. Balancing conservation and recreation needs can be challenging in light of recent estimates indicating terrestrial PAs around the world attract eight billion visits each year collectively (Balmford et al., 2015). Proactive management needs timely and accurate data about recreational use and environmental conditions to assess the magnitude, trends, and significance of recreation-associated disturbance. The purpose of this study is to identify environmental and managerial factors influencing the distribution of one type of visitor-related activity, use of pack stock animals (stock), to assess the influence of management tactics designed to minimize negative impacts.

In many PAs around the world, stock use is an established form of recreation, supports tourism operations, and is often part of the cultural heritage (Barros and Pickering, 2015; Byers, 2009; Cole et al., 2004; Geneletti and Dawa, 2009). The managing organization may also use stock to support administrative efforts. Stock use, which can include horses, mules, donkeys, yaks, or llamas, is one example of a visitor-related activity that can affect the ecological integrity of preserved ecosystems (Barros et al., 2015; Byers, 2009; Cole et al., 2004; Geneletti and Dawa, 2009). Impacts attributed to stock presence in alpine and mountainous landscapes include soil

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compaction, altering of hydrologic patterns, increases in erosion, and trampling (Barros et al., 2014; Byers, 2009; Kuhn et al., 2015; Ostoja et al., 2014). Research demonstrates horse trampling occurs at greater intensities than that of hikers (Weaver and Dale, 1978), and, in some cases, other hooved animals (Cole and Spildie, 1998). Additionally, transporting forage for stock may not always be feasible due to load sizes, geographic location, or invasive species concerns. Instead, stock may be released into meadows and adjacent areas to graze, with estimates indicating an individual horse or mule consumes an average 14.8 kg of forage per night (Jacoby and The Society for Range Management, 1989).

Meadows are vital ecosystems supporting disproportionately high levels of biodiversity. In the western U.S., meadows also represent one of the most at-risk landscapes (Viers et al., 2013). Several studies reveal relationships between stock grazing and impacts to meadow ecosystem function. Overgrazing can decrease vegetation cover and meadow productivity, shift plant species composition through selective grazing of palatable species, change local soil chemistry and micro-climate conditions, increase bare ground cover, and facilitate the encroachment of invasive or woody species (Cole et al., 2004; Kuhn et al., 2015; McClaran and Cole, 1993; Moore et al., 2000; Olson-Rutz et al., 1996a, 1996b; Ostoja et al., 2014). Mitigating impacts from stock in PAs, while providing access for stock users, relies on understanding the interaction between stock and the environment (Moore et al., 2000). Research on the resistance and resiliency of grass, forb, and shrub-dominated habitats indicates proactive management is essential in limiting the propagation and proliferation of negative impacts (Cole et al., 2004; McClaran and Cole, 1993; Olson-Rutz et al., 1996b). Studies of grazing impacts in PAs are often based on inventories made before and after an animal has left the area, employing plots with varying levels of grazing treatments to measure ecosystem response, or observational studies of impacts to a variety of ecosystem components (Alzerreca et al., 2006; Cole et al., 2004; Holmquist et al., 2014; Kuhn et al., 2015; Ostoja et al., 2014).

How grazing intensity and environmental variables vary, however, has been identified as a research need within recreation ecology (Monz et al., 2010). Specifically, researchers and managers highlight a need to understand patterns of stock distribution and use during potential disturbance and how it is associated with environmental (e.g., vegetation composition, access to water) and managerial (e.g., fencing, stock release locations) factors, including overnight releases when direct supervision is less feasible (McClaran, 1989; Ostoja et al., 2014). Studies of stock resource use at the site level offer an opportunity to combine advances in data collection instruments, computing capacity, and statistical modelling methods from several disciplines interested in use-environment interactions to address this research need (Brown et al., 2013; Gaylord and Sanchez, 2014; Jeltsch et al., 2013; Kays et al., 2015; Meijles et al., 2014; Rutter, 2007). The convergence of these advances have facilitated greater integration of animal distribution and movement data with environmental covariates (Kays et al., 2015).

1.1. Research objectives

The purpose of this study is to integrate data collection and analytical techniques from sub-disciplines of ecology to assess environmental and managerial variables influencing fine scale stock distribution and resource use. Specifically, this study:

(1) Identifies which environmental and managerial factors contributed most to models of free-roaming stock distribution in meadows and adjacent areas during overnight release periods; and
(2) Evaluates the accuracy of the models used to characterize stock distribution in relation to environmental and managerial factors.

2. Background literature

To address the research objectives, three components were required: accurate spatio-temporal stock movement data, high-resolution environmental and managerial data, and a modelling method capable of addressing sampling limitations and quantifying model accuracy. This section reviews related work surrounding spatial use data and modelling use-environment interactions to identify which best address the research objectives.

2.1. Spatial use data

In the fields of recreation ecology, animal ecology, and movement ecology, global positioning system (GPS) data tracking visitor and animal movement are increasing in spatial and temporal accuracy, enhanced by expanding data collection capacity and environmental data captured by mobile and remote sensors (Handcock et al., 2009; Kays et al., 2015). Accuracy and capacity improvements are driven by reductions in GPS unit size, increases in battery longevity, and improved data retrieval options, rapidly increasing the amount and quality of tracking data available for analysis (Michelot et al., 2016). The development and application of statistical methods capable of garnering information from complex GPS datasets represents a growing research focus, as data collection capacity has challenged computational capacity and traditional statistical assumptions about independence, and highlighted the need for user-friendly software (Long and Nelson, 2013; Michelot et al., 2016).

2.2. Modelling use-environment relationships

Distribution and movement models have also been employed to draw inference from species occurrence records (Edren et al., 2010). Species distribution models (SDMs) examine occurrence (or presence) records with surrounding environmental variables to determine habitat suitability. The underlying concept of SDMs is that species are more likely to be present in locations with conditions that suit their needs. Distribution models have used environmental envelopes, generalized linear models (GLM), generalized additive models (GAM), support vector machines, and boosted regression trees (BRT), to name a few, and have been applied to a diverse range of terrestrial and marine species to help inform conservation and management (Smith, 2013).

Key assumptions of SDMs, however, are that the presence records are independent from one another or representative of the species' distribution. When leveraging species data derived from GPS or telemetry methods, these assumptions are challenged and no systematic assessment of absences (i.e., where a species is not found) is inherent. Incorporating absence data is ideal for SDMs and allows the prediction of presence probability using methods like logistic regression, without which model outputs should be interpreted as relative rates of occurrence (Merow et al., 2013). Lack of absence data is shared in SDMs derived from museum collections or opportunistic sampling of species locations common in plant and animal ecology and has received considerable attention in the last decade, especially following the development of the modelling tool, MaxEnt (Edren et al., 2010; Elith et al., 2006; Guillera-Arroita et al., 2015; Phillips et al., 2006).

MaxEnt is a machine-learning algorithm built on the principle of maximum entropy (Jaynes, 1957, 1982). The model compares covariate conditions at presence locations to the conditions at