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Monitoring changes of NDVI in protected areas of southern California

Thomas W. Gillespie[a,*], Stacey Ostermann-Kelm[b], Chunyu Dong[a], Katherine S. Willis[a], Gregory S. Okin[a], Glen M. MacDonald[a]

[a] Department of Geography, University of California Los Angeles, Los Angeles, CA 90095-1524, USA
[b] Mediterranean Coast Network, NPS Inventory & Monitoring Program, 401 West Hillcrest Dr., Thousand Oaks, CA 91360, USA

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ABSTRACT

California's Mediterranean ecosystem has been identified as one of the Earth's biodiversity hotspots. The high degree of rapid urbanization along the southern California coastline has resulted in the loss of significant natural areas over the last century and protected areas that do exist may be further threatened by climate change, drought, and fire. We use Moderate Resolution Imaging Spectroradiometer (MODIS) sensor at a 250 m pixel resolution and the Normalized Difference Vegetation Index (NDVI) to monitor temporal/spatial patterns from 2000 to 2016 within Santa Monica Mountains National Recreation Area and Channel Islands National Park. We test the hypothesis that there should be no significant long-term change in protected areas since 2000 and compare impacts of seasonality, drought, and fire. The Santa Monica Mountains National Recreation Area has experienced a long-term decline in vegetation greenness, vegetation types, and is the most significantly impacted with short-term declines during the summer with or without the impacts of fire. Change detection maps show areas of significant decline in NDVI in the Santa Monica Mountains National Recreation Area especially during the summer. The Channel Islands have relatively stable NDVI possibly due to the removal of non-native herbivores and the maritime climate around the Channel Islands may buffer some of the impacts of the regional drought. The MODIS sensors appears appropriate for identifying landscape patterns, time series, change detection maps, and the potential impacts from climate change for each park. Results suggest that all National Park landscapes and vegetation types can be inventoried at a 250 m resolution and monitored at a high temporal resolution.

1. Introduction

California's Mediterranean ecosystem has been identified as one of the earth's "biodiversity hotspots" (Myers et al., 2000). Though this ecosystem is home to a number of endemic flora and fauna species, it is also one of the most highly altered ecosystems on the planet (Newbold et al., 2016). The high degree of rapid urbanization along the southern California coastline has resulted in the loss of significant natural areas and increasing human impacts to the remaining natural systems (Underwood et al., 2009). Landscape-level threats include urbanization, land cover change, changes to vegetation communities, and climate change (Grimm et al., 2008; Fancy et al., 2009). Global climate change is a concern for protected areas in terms of maintaining ecosystem health, and the impacts must be monitored in order to allow natural resource managers to properly respond and prioritize conservation efforts.

Santa Monica Mountains National Recreation Area and Channel Islands National Park are two of the largest protected areas within California's Mediterranean-type ecosystem. These parks contain high species richness, high endemism, and a high number of species on the International Union for Conservation of Nature Red List (Underwood et al., 2009). Both of these southern Californian protected areas will experience substantial climate change according to global and regional climate models (Cayan et al., 2010; Hall et al., 2012). The higher elevations of Santa Monica Mountains are predicted to warm approximately 1.5 °C by 2060 while temperatures closer to the coast and Channel Islands will be mediated by the local cooling effect of the Pacific Ocean and the maritime effect (Cayan et al., 2010). Predicted climate changes may exacerbate the negative effects of past land use and continued human population growth and many have direct impacts on vegetation condition and community types (Underwood et al., 2009; Anderson et al., 2010; Thoma et al., 2016).

One of the known ecological responses to climate change is a shift in the local phenology of plants such as changes in the start and end of the

* Corresponding author.
E-mail addresses: tg@geog.ucla.edu (T.W. Gillespie), Stacey_Ostermann@nps.gov (S. Ostermann-Kelm), chunyudong@ucla.edu (C. Dong), kshwillis@gmail.com (K.S. Willis), okin@ucla.edu (G.S. Okin), macdonal@geog.ucla.edu (G.M. MacDonald).

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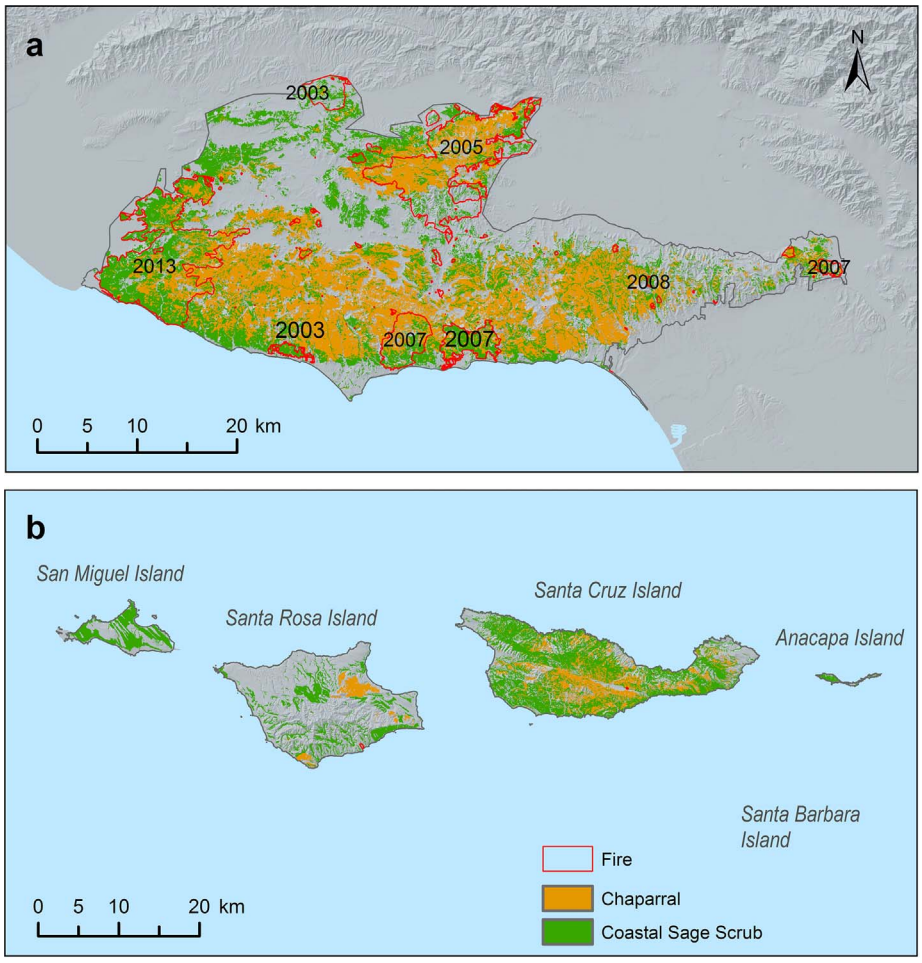

Fig. 1. Maps of the Santa Monica Mountains National Recreation Area (a) and Channel Islands National Park (b). The distributions of chaparral and coastal sage scrub as well as the burned regions during 2000–2016 are also plotted.

growing season, duration of growing season, and maximum productivity (Parmesan and Yohe, 2003). Monitoring phenological changes can help identify the effects of climate change in southern California. Another important impact from climate change is that anthropogenic fires are hypothesized to be becoming more frequent in southern California as the climate warms (Keeley et al., 1999, 2005). These fires are important episodic events, which are unpredictable in time and extent, and can result in rapid and dramatic vegetation change. Fires can fully consume existing stands of shrubland vegetation and create the possibility for dramatic shifts in vegetation composition and species abundances (Keeley et al., 2005).

Remote sensing methods, especially in combination with Geographic Information Systems (GIS) are cost-effective techniques for measuring landscape-level temporal changes over a continuous area (Franklin et al., 2000; Rogan and Chen, 2003). Remote sensing can be used to map changes in land cover type as well as within landscape types and vegetation classes, and is often the primary tool for monitoring landscape changes in protected areas using well established techniques in the remote sensing field (Fraser et al., 2009; Pereira et al., 2013; Willis 2015). In Mediterranean regions, changes in vegetation indices from moderate spectral resolution spaceborne sensors have been significantly associated with plant species richness (Gillespie et al., 2014), live fuel moisture (Roberts et al., 2006; Yebra et al., 2013), post-fire regeneration (McMichael et al., 2004), and plant productivity/stress (Shoshany, 2000). Indeed, moderate resolution imagery from sensors such as NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) may provide a high temporal resolution analysis of protected areas over different spatial and temporal scales. The MODIS sensors on the TERRA and AQUA satellites have 36 spectral bands at 250 m, 500 m, and 1000 m pixel resolution with a nominal revisit time of 1–2 days year-round, making it extremely useful to measure fine-scaled changes in vegetation characteristics and changes in seasonality over time. Protected areas may be monitored from satellite sensors using a vegetation index called NDVI (Normalized Difference Vegetation Index) that is calculated as a function of the visible and near-infrared wavelengths. NDVI ranges from 1.0 to −1.0 with positive values (e.g. 0.5) representing high greenness and negative values (i.e. −0.1) representing little or no vegetation. NDVI represents photosynthetic activity and is associated with biomass, carbon sequestration, plant water stress, and biodiversity (Nagendra et al., 2013; Pereira et al., 2013). Pettorelli et al. (2012) suggested that the NDVI of protected areas, which are less impacted by human activities, can be used to track the effect of climate change on natural ecosystem functioning. There have been an increasing number of studies that have used NDVI to study ecosystem dynamics and disturbance within protected areas (Alcaraz-Segura et al., 2008; Nemani et al., 2009).

There is a need to develop and provide scientifically credible information on the current status and long-term trends in the composition, structure, and function of protected area ecosystems, and to determine how well current management practices are sustaining those ecosystems. This research addressed three primary questions related to monitoring protected areas in Mediterranean ecosystems. First, has there been significant long-term (decadal) declines in NDVI in the Santa Monica Mountain Recreation Area and Chanel Islands National Park and vegetation types? Second, has there been short-term declines in NDVI in protected areas associated with the recent drought and fire? Third, where are the long-term and short-term changes in NDVI within protected areas, and which vegetation types have undergone significant changes?