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Using MODIS NDVI phenoclasses and phenoclusters to characterize wildlife habitat: Mexican spotted owl as a case study

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A B S T R A C T

Most uses of remotely sensed satellite data to characterize wildlife habitat have used metrics such as mean NDVI (Normalized Difference Vegetation Index) in a year or season. These simple metrics do not take advantage of the temporal patterns in NDVI within and across years and the spatial arrangement of cells with various temporal NDVI signatures. Here we use 13 years of data from MODIS (Moderate Resolution Imaging Spectroradiometer) to bin individual MODIS pixels (5.3 ha) into phenoclasses, where each phenoclass consists of pixels with a particular temporal profile of NDVI, regardless of spatial location. We present novel procedures that assign sites to phenoclusters, defined as particular composition of phenoclasses within a 1 km radius. We apply these procedures to Mexican spotted owl (*Strix occidentalis lucida*) nesting locations in the Sacramento Mountain range in south-central New Mexico. Phenoclasses at owl nest sites and phenoclusters around owl nest sites differed from those at and around points randomly placed in forest types that are known to support nesting owls. Stand exam data showed that the phenoclasses associated with owl nest sites are dominated by Douglas-fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*). The availability of phenoclusters and phenoclasses on Mescalero Apache tribal lands differed from those on adjacent National Forest lands within the Sacramento Mountain, consistent with different elevations and forest management practices. Nonetheless owls predominately used the same phenoclasses and phenoclusters in both land ownerships. MODIS phenoclasses and phenoclusters offer a useful means of remotely identifying forest conditions suitable for wildlife. Because the remote sensing data are freely available and regularly updated, they can be part of a cost effective approach to monitor and assess forested wildlife habitat over large temporal and spatial scales.

1. Introduction

Characterizing, managing, and monitoring habitat of wildlife in dynamic landscapes is one of the biggest challenges facing natural resource managers, especially for broadly distributed rare species (Morrison et al., 2012; Sharik et al., 2010; Bartel and Sexton, 2009). Data obtained by satellites are often used to help characterize habitat at large spatial scales including remote regions (Jones and Vaughan, 2010; Gottschalk et al., 2005). In the U.S., for example, national and regional GAP Land Cover is derived from models in which the predictor variables are provided by Landsat Thematic Mapper imagery (USGS, 2011). Another example is Normalized Difference Vegetation Index (NDVI), which estimates photosynthetic activity by measurements (typically from a satellite) of the relative amounts of electromagnetic radiation at 0.66 μm and 0.86 μm (NASA, 2016; Sellers, 1985; Sellers, 1987; Tucker and Sellers, 1986). Many studies have used NDVI estimated at a single point in time, or the average NDVI across a year or season, to help model or map potential habitat (e.g., Shirley et al., 2013; Gillespie et al., 2008; Goetz et al., 2007; McDermid et al., 2005; Venier et al., 2004; Franklin et al., 2002; Osborne et al., 2001; Thibault et al., 1998). A few studies used the intra-annual NDVI profile (a plot of NDVI across dates within a year) to map or predict species occurrence or habitat conditions (Osborne et al., 2001; Kremer and Running, 1993; Wallin et al., 1992). In each case, the temporal NDVI profiles differed between groups (e.g., sites where a species did or did not occur).

In this paper we introduce a new way to use temporal NDVI profiles in studies of wildlife habitat. Specifically, we use a set of temporal NDVI profiles developed for the conterminous U.S. as phenoclasses. Hoffman et al. (2013) produced these phenoclasses from unsupervised classifications of 5.3 ha MODIS pixels (MODIS NDVI Data) based on their annual NDVI profiles over 13 years (2000–2012) (Fig. 1), using methods adopted from White et al. (2005). Each phenological signature

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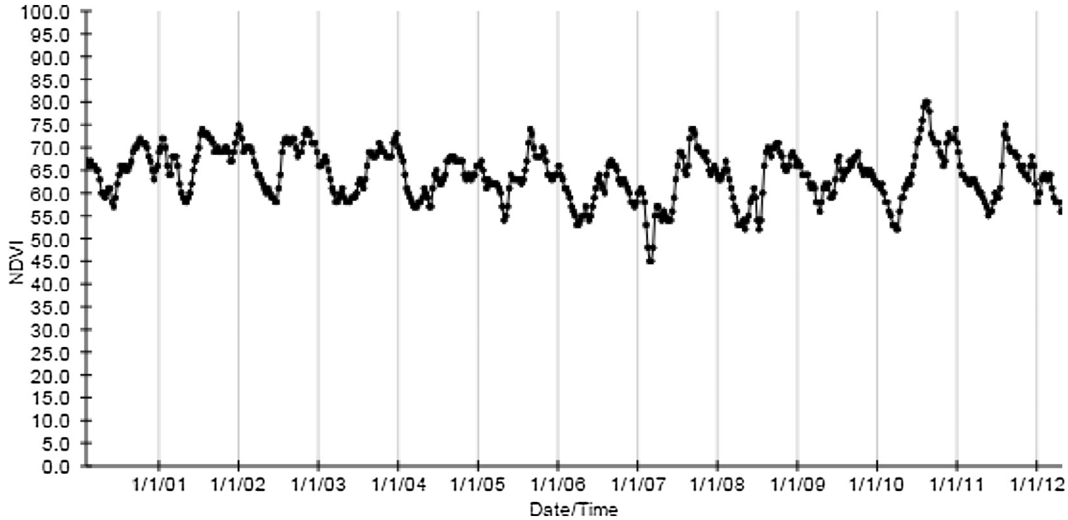

Fig. 1. Normalized Difference Vegetation Index (NDVI) values for an individual MODIS pixel within our study region (Lat: 33.2690 Lon: −105.6095) over the 13 year period (2000–2012). Note the cyclical/reoccurring patterns of higher NDVI values during the growing seasons and lower NDVI values during the winter. Click on the following link to see the map with approximate location of selected pixel: http://forwarn.forestthreats.org/fcav2?theme=CONUS_Vegetation_Monitoring_Tools&layers=PR100MM,AAB&mask=Forest&alphas=1,1&accgp=G04&basemap=Streets&extent=-11791140.499198,3909184.8810125,-11729990.87657,3947823.7988107.

proportionally reflects the seasonal photosynthetic activity of all vegetation types present within a pixel. Thus, each phenoclass can be conceptualized as a vegetation assemblage, or the structure and composition of a site relative to a continuum of vegetation conditions. Expanding beyond a single pixel, we further group neighborhoods (e.g., all pixels within 1 km of a site) into phenoclusters, such that the composition of phenoclasses of neighborhoods in each phenocluster are more similar to each other than to the composition of phenoclasses of neighborhoods assigned to other phenoclusters. Together, phenoclasses and phenoclusters characterize habitat at spatial scales from the individual 5.3 ha pixel up to the neighborhood size (302 ha). We believe this paper is the first application of phenoclass as an indicator of wildlife habitat, and the first use of phenocluster in any context.

In this paper, we describe the process for using NDVI phenoclasses and phenoclusters, as applied to forests used by the Mexican spotted owl in the Sacramento Mountains of New Mexico (Fig. 2). If phenoclasses and phenoclusters can distinguish owl sites from random sites on the landscape, then they can be used to create habitat suitability maps, and can become an innovative, rapid way to assess and monitor habitat of owls over large spatial and temporal scales. To further explore the utility of these descriptors, we used stand exams to characterize phenoclasses and to explain owl associations with certain phenoclasses and phenoclusters in light of previous work on habitat selection by the owl. We further explored whether availability of phenoclasses and owl use differed between the two major land ownerships in the Sacramento Mountains.

2. Methods

2.1. MODIS data

MODIS (Moderate Resolution Imaging Spectroradiometer) satellite images are obtained from the passive sensor systems aboard the Terra and Aqua sun-synchronous satellites. These satellites are designed to monitor the surface of the earth for 15 years and fly in polar orbits, which provide global coverage and repeat sampling under constant illumination. MODIS provides a favorable trade-off between image resolution (231 × 231 m or 5.3 ha) and temporal frequency of imaging. For example, MODIS images are obtained for most locations daily whereas the return time for Landsat is 16 days (Jones and Vaughan, 2010). The shorter return time provides more cloud-free compositing to generate 46 NDVI values per year and a high temporal-resolution NDVI annual profile. Gottschalk et al. (2005) found that multi-temporal images had better discriminatory power than single-date images for detecting wildlife-habitat relationships. MODIS also provides spectral reflectance values for 36 spectral bands whereas comparable models such as Landsat only provide information at 7–8 spectral bands. Lastly, the MODIS data are free and available to the public.

2.2. Phenoclasses

The US Forest Service Eastern Forest Threat Assessment Center (EFETAC) in collaboration with Oak Ridge National Laboratory and NASA Stennis Space Center (hereafter “EFETAC team”) created phenoclass types using k-means clustering techniques described in Hargrove et al. (2014), Hoffman et al. (2013), Hoffman et al. (2010), and White et al. (2005). The phenoclasses were developed for the entire United States at 5 thematic resolutions (100, 200, 500, 1000 and 5000 classes; Table 1). The classes were developed to detect and monitor forest change in areas without ground or aerial surveys (Norman et al., 2013; Mills et al., 2011; Hargrove et al., 2009). The classes were originally termed phenoregions in these publications, but, although it was made clear that they were not spatially contiguous, we rename them phenoclasses here to more explicitly emphasize that they are simply labels applied to given pixel-year combinations. We obtained the phenoclass datasets (Table 1) from the ForWarn (2016) database and Oak Ridge National Laboratory Distributed Active Archive Center (MODIS NDVI, no date).

Using MODIS imagery from 2000 to 2012, the EFETAC team first assigned pixel-year combination a phenoclass according to its annual NDVI profile. Then they assigned each 5.3 ha pixel to the phenoclass that occurred most frequently across the 13 year time period (Fig. 1). When 2 or more phenoclasses were tied for highest frequency, the pixel was assigned to the phenoclass with the highest sum of all 46 annual NDVI values (one every eight days); this sum is approximately proportional to gross primary production, and thus most likely to represent the least disturbed condition of that MODIS cell.

2.3. Phenoclusters

We used a k-means FASTCLUS procedure in SAS 9.4 to cluster sites based on the composition of the ten most common phenoclasses found within a fixed radius neighborhood of a site. The FASTCLUS iterative algorithm seeks to minimize the sum of squared distances from cluster