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Tree senescence as a direct measure of habitat quality: Linking red-edge Vegetation Indices to space use by Magellanic woodpeckers

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ABSTRACT

Accurate estimates of the quality and quantity of remnant habitats is critical for planning management activities for the conservation of threatened species. Although habitat quality usually is understood from a multidimensional niche space approach, the availability of foraging substrates can be a suitable and more proximate index of habitat quality for species with specialized habitat requirements, like woodpeckers that feed almost exclusively on larvae of wood-boring beetles in the trunks and branches of infested trees. Recent approaches use simple mathematical algorithms on spectral bands called Vegetation Indices (VI) to identify infestations, providing a new opportunity to assess habitat quality for woodpeckers. In this paper, we tested the ability of 102 VI to estimate tree attributes explaining habitat quality for Magellanic woodpeckers for its usage as a reliable foraging habitat quality estimator. We hypothesized that space use of Magellanic woodpeckers is positively associated with the spatial distribution of decayed trees in the landscape. We developed a methodological framework based on high-resolution, multispectral imagery with three basic steps. First, we mapped individual *Nothofagus* trees based on estimates of species composition from a supervised classification procedure, VI estimates and image segmentation. Second, we selected the best VI predicting the tree quality for Magellanic woodpeckers. Third, we tested these habitat quality predictors, the species composition and tree age, by using two Synoptic Models of Space Use (SMSU) of Magellanic woodpeckers based on very high-frequency (VHF) radio-telemetry and global positioning system (GPS) telemetry data.

Generalized Linear Mixed Models (GLMM) showed that the VI that best predicted habitat quality at the tree-scale was the Plant Senescence Reflectance Index (PSRI, computed as [Red-Blue]/Red-edge), included in almost all the most parsimonious models. The most parsimonious SMSU included only PSRI as an independent covariate, with a strong positive relation. Although coefficient differences were found between telemetry data (VHF vs. GPS data) both showed a positive overall response. Consequently, Red-edge based PSRI can be considered a reliable estimator of tree-scale foraging habitat quality at landscape extents for future research and management activities including Magellanic woodpeckers living on heterogeneous *Nothofagus* forests.

1. Introduction

Habitat loss and degradation caused by human development represents one of the greatest threats to biodiversity worldwide (IUCN, 2015). Conservation in many human-dominated landscapes is challenged by the lack of accurate estimates of the quality and quantity of remnant habitats needed to support populations of threatened species (Joppa and Pfaff, 2009; Pimm et al., 2014). Yet for certain species assessing habitat at the landscape scale is often a complex task involving high-resolution land cover data measured at the spatial scales over which ecological processes occur (Boyce, 2006; Hölker, 2002; Huston and Huston, 1994). Although habitat quality usually is evaluated from a multidimensional niche space approach that includes multiple abiotic and biotic factors thought to affect species performance (Wen et al., 2015), the availability of foraging substrates can be a suitable and more proximate index of habitat quality for species with specialized habitat requirements (Bull, 1978; Walters et al., 2002). Recent developments of remote sensing systems that can provide fine-grained data (e.g., foraging substrate characteristics such as individual tree's species, height, area, etc.) have made it possible to monitor specific resources in a spatially-explicit manner (Mason et al., 2003). Spatio-temporal changes in vegetation in the landscape, such as leaf pigments, can be assessed by using Vegetation Indices (hereafter VI), which use simple mathematical algorithms to process the spectral reflectance of sunlight (Oumar and Mutanga, 2013; Roberts et al., 2011; Waser et al., 2014). Indeed,

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VI have many advantages on other more complex approaches, such as providing information on particular properties of vegetation, including vegetation structure, plant pigments, canopy moisture, Lignin and Cellulose/Plant residues, plant physiology, and photosynthetic metabolism (Bannari et al., 1995; Chuvieco, 2002; Sims and Gamon, 2002; Thenkabail et al., 2011; Serbin et al., 2012). However, since canopy structure can influence and bias these estimates, inference made by the use of these methods should carefully discuss the source of such variations (Knyazikhin et al., 2013). Nonetheless, the Normalized Difference Vegetation Index (NDVI) is one example that is widely heralded as a reliable monitoring vegetation tool (Rouse et al., 1974; Pettorelli et al., 2005; Fensholt and Proud, 2012; Wen et al., 2015), and prevail over other VI, being the more used and studied VI (Kerr and Ostrovsky, 2003). For instance, VI have improved the knowledge about the distribution of threatened species in heterogeneous landscapes through successfully describing the characteristics of suitable habitat at different spatial scales (Kerr and Ostrovsky, 2003; Turner et al., 2003). Therefore, VI are often included in most parsimonious models as predictor covariates for nearly all ecological space use studies modeling species' occupancy, richness and abundance, among others (e.g., La Sorte et al., 2014; Luo et al., 2012; Jathanna et al., 2015).

In this paper, we developed a remote sensing-based approach to estimate habitat quality based on the availability of foraging substrates for a woodpecker species. Specialist woodpeckers are a particularly appropriate focal group given that they feed almost exclusively on trunks and branches of the trees infested with larvae of wood-boring beetles (Short and Sandström, 1982). Although most remote sensing systems fail to provide information on fine–scale tree features (e.g., individual branches or small trees), satellite-derived images have proved to be useful to quantify the canopy of trees infested by wood-boring saproxylic beetles in hardwood and conifer forests of the north hemisphere (Bright et al., 2012; Coops et al., 2006; Franklin et al., 2003; Hart and Veblen, 2015; Meddens et al., 2013; White et al., 2005; Wulder et al., 2006). For instance, the accelerated tree decay driven by the wood-boring beetles *Dendroctonus* spp., and its coarse-scale impact on timber production and carbon flux dynamics has been studied using remote sensing imagery (Stokland et al., 2012; e.g., Kurz et al., 2008; Wulder et al., 2006).

The introduction of the red-edge band with the launch of RapidEye and WorldView-2 (WV-2) satellite sensors has significantly improved landscape scale assessment of tree senescence and vegetation stress caused by natural factors and environmental disturbances (Adamczyk and Osberger, 2015). VI based on the red-edge band (positioned between the 680–750 nm wavelengths) are accurate proxies for the tree senescence resulting from shifts in foliar chlorophyll *a* and b degradation (Vogelmann et al., 1993; Hörtensteiner, 2006; Eitel et al., 2011). However, estimation of tree senescence based on VI necessitates careful distinction between pixel- (i.e., restricted to some unit area) and tree-based (i.e., restricted to an individual tree) approaches (e.g., Waser et al., 2014). Identification of individual trees in forested landscapes, as required by a proper woodpecker-centered (i.e., tree-based) approach, can be achieved by combining high-resolution multispectral imagery with the image segmentation approach, which uses similarity criteria to group neighboring pixels into regions or segments (Meinel and Neubert, 2004).

Here, we used VI with image segmentation to assess tree habitat quality at the landscape scale for the Magellanic woodpecker (*Campephilus magellanicus*, King 1828), a forest specialist endemic to the temperate forests of southern Chile and Argentina (Short, 1970). While IUCN list this species as Least Concern, the local governmental Cattle and Agriculture Service (SAG) list the Magellanic woodpecker as vulnerable across most of its distribution and endangered in the northern limit of the Valdivian Temperate Rainforest, which has been extracted and degraded over the last two centuries, driving to a woodpeckers' decreasing population trend (Chazarreta and Ojeda, 2011; Lara et al., 2012; IUCN, 2015; SAG, 2015). Magellanic woodpeckers prefer old-growth Southern beech *Nothofagus* forests with large-diameter and advanced heartwood decayed trees, mostly *N. pumilio* (Ojeda and Chazarreta, 2014; Vergara and Schlatter, 2004), which is consistent with large woodpeckers in northern hemispheres that also specialize on decaying trees (e.g. Nappi et al., 2015). Because the Magellanic woodpeckers almost exclusively consume wood-boring larvae of Cerambycidae beetles (Short, 1970), the availability of trees infested with these larvae is perhaps the best proxy of habitat quality for Magellanic woodpeckers. Saproxylic wood-boring insects play a key role in the dynamics of Chilean temperate forests by progressively driving *Nothofagus* tree species to death (see Barriga et al., 1993; Guzmán, 1996; Zuñiga-Reinoso, 2013). Therefore, landscape planning designed to promote the conservation of Magellanic woodpeckers requires identifying suitable forest stands based on unbiased estimates of tree quality.

We hypothesized that space use of Magellanic woodpeckers is positively associated with the spatial distribution of decayed trees in the landscape. To test this hypothesis, we developed a methodological framework with the following steps: First, we mapped individual *Nothofagus* trees using high spatial resolution, multispectral imagery-derived estimates of species composition, VI and image segmentation. Second, we selected the best VI predicting tree quality for Magellanic woodpeckers. Third, we tested these habitat quality predictors by modeling the space use of Magellanic woodpeckers based on two sources of telemetry data.

2. Methods

2.1. Study area

The study area was located on Navarino Island, encompassing approx. 58 km^2 including the coastal town of Puerto Williams, Chile (Fig. 1). This area is part of the Cape Horn Biosphere Reserve (55°S), which is dominated by oceanic climate with a mean annual temperature of 6 °C, precipitation of nearly 500 mm, and climatic conditions typical of isothermal tundra (Rozzi et al., 2006). The habitat largely consisted of a forest mosaic of three *Nothofagus* species (*N. antarctica*, *N. betuloides*, *N. pumilio*), which are mostly infested by the wood-boring Cerambycid *Microplophorus magellanicus*, as reported in the Navarino Island (Cerda and Angulo, 2002; Huerta, 2013, Zuñiga-Reinoso, 2013). Other land cover classes include mixed forests of *Nothofagus* and *Drimys winteri* stands, scrub, grasslands, tundra formations and other land uses (Table 1). The spatial extent, composition and quality of the forest mosaic vary according to past and current human activities, including fires, clearing forest for livestock, firewood extraction, and introduced beavers (*Castor canadensis*) (Rozzi et al., 2006). Despite increasing pressure from urban growth, introduced species and tourism (Arango et al., 2007; Soto et al., 2012), these forest stands represent the southernmost remnant of pristine forests in the world.

2.2. Remote sensing

2.2.1. WorldView-2 image and pre-processing

We used a radiometrically corrected, georeferenced and orthorectified high-resolution WorldView-2 satellite image in bundle modality (panchromatic + 8-band multispectral; see Table S1 in Supplementary material). The image covered the entire study area (lower panel in Fig. 1), and was taken during the Austral Spring, approx. 20 days after *Nothofagus* spp. had fully flushed their leafs, thereby permitting the identification of the main tree species (Wang et al., 2005). The preprocessing of the imagery consisted of three steps: 1) processing raw image digital count values (DCs) to physical values of radiance and reflectance, 2) contrast enhancement by decorrelation (only used for the digital supervised classification scheme, see Section 2.2.2), and 3) pan-sharpening to obtain high-resolution image.