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Land surface phenology as an indicator of biodiversity patterns

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ABSTRACT

With the rapid decline in biodiversity worldwide it is imperative to develop procedures for assessing changes in biodiversity across space. The synoptic view provided by imaging remote sensors constitutes a suitable approach for analyzing biodiversity from local to regional scales. A procedure based on the close relationship between floristic similarity and the similarity in land surface phenology was recently developed and successfully applied to assess diversity patterns using time series imagery acquired by the Moderate Resolution Imaging Spectro-radiometer (MODIS). However, as it depends on high temporal resolution remotely sensed data (e.g., MODIS), the procedure is constrained by the coarse spatial resolution characterizing these high temporal resolution data. Using an optimized technique for image fusion, we combined high temporal resolution data acquired by the MODIS sensor system with moderate spatial resolution data acquired by the Landsat TM/ETM+ sensor systems. Our results show that the MODIS/Landsat data fusion allows the characterization of land surface phenology at higher spatial resolutions, which better corresponded with information acquired within vegetation survey plots established in temperate montane forests located in Wolong Nature Reserve, Sichuan Province, China. As such, the procedure is useful for capturing changes in biodiversity induced by disturbances operating at large spatial scales and constitutes a suitable tool for monitoring and managing biodiversity.

1. Introduction

Human activities continue to put pressure on biodiversity around the globe. To develop effective conservation actions it is imperative to analyze and monitor the spatio-temporal dynamics of biodiversity (such as the number and composition of species), particularly in response to human-induced disturbances. Such analyses require indicators that allow fast, synoptic and accurate assessments of biodiversity patterns at multiple scales (Turner, 2014). The synoptic view provided by imaging remote sensors constitutes a suitable approach for analyzing biodiversity from local to regional scales (Rose et al., 2015; Turner, 2014; Turner et al., 2003). Some studies have evaluated direct pixel-based relationships between the spatial patterns of biodiversity and multispectral imagery (Rocchini, 2007; Rocchini et al., 2010; Thessler et al., 2005; Tuomisto et al., 2003), while others utilize extensive spectral libraries of individual plant species that are then used to map biodiversity patterns using hyper-spectral imagery (Asner and Martin, 2008, 2009; Carlson et al., 2007; Féret and Asner, 2014). Yet, these methods have not seen a widespread adoption due to the low availability and high economic cost of pertinent remotely sensed data (e.g., hyper-spectral imagery). In addition, these methods tend to be constrained to particular geographic locations, individual species and/or species assemblages, and do not necessarily account for the seasonal variability of canopy spectral characteristics in response to the phenologic dynamics of vegetation.

Alternatively, novel procedures for remotely assessing the spatial and temporal changes in the distribution of individual species and of regional biodiversity pools have been devised based on the use of data acquired with a high temporal resolution (Tuanmu et al., 2010; Viña et al., 2008, 2012). Specifically, these procedures have been used for evaluating the spatial distribution of understory species (Tuanmu et al., 2010), for analyzing wildlife habitat suitability (Liu and Viña, 2014; Tuanmu et al., 2011; Viña et al., 2008, 2010), and for evaluating floristic similarity patterns across space (Viña et al., 2012). Based on the close relationship between floristic similarity and the similarity in land surface phenology, these procedures are suitable for assessing the effectiveness of conservation activities (Viña et al., 2012). Their drawback is that the high temporal resolution remotely sensed data required for them are

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also acquired at coarse spatial resolutions (ca. 250 × 250 m/pixel or larger), which in most cases do not completely relate with the spatial resolution of the field data used to calibrate them. The main goal of this study was to explore the suitability of using land surface phenology obtained through the fusion of high temporal resolution but coarse spatial resolution data (i.e., MODIS) with moderate spatial resolution data (i.e., Landsat TM/ETM+) as an indicator of floristic similarity patterns across space.

2. Methods

2.1. Study region

The Wolong Nature Reserve was established in 1975 and currently encompasses ca. 200,000 ha (Liu et al., 1999) (Fig. 1). It is one of the largest nature reserves designated for the conservation of the endangered giant panda (*Ailuropoda melanoleuca*) and contains ca. 10% of the entire wild panda population (State Forestry Administration, 2006). Situated between the Sichuan Basin and the Qinghai-Tibet Plateau in China's southwest Sichuan province, it is characterized by a strong elevational range, from ca. 1200 m to more than 6200 m. Mean annual rainfall is ca. 880 mm, with the monsoon between June and September typically bringing a high frequency of heavy rainfall events (Schaller et al., 1985). Due to its large elevational range, rugged terrain and complex geology and soils, the Reserve exhibits high biological diversity, containing more than 6000 species of plants and animals. In fact, it is located within one of the top global biodiversity hotspots, the Southwest China biodiversity hotspot (Liu et al., 2003; Myers et al., 2000). Vegetation is dominated by temperate montane forests which by 2007 comprised about 38% of the Reserve (Viña et al., 2011), with evergreen and deciduous broadleaf stands located at lower elevations and subalpine coniferous stands located at higher elevations. The dense understory of these forests is dominated by bamboo species such as *Bashania fabri* and *Fargesia robusta*, the staple food of the giant panda (Reid and Hu, 1991; Schaller et al., 1985; Taylor and Qin, 1993).

The Reserve is also home to more than 5000 local residents in over 1200 households distributed in six villages (Fig. 1). These local residents are mainly dependent on farming. In recent years the Reserve has experienced a boom in tourism, with a 10-fold increase in the number of visitors, from ca. 20,000 in the 1990s (Lindberg et al., 2003) to more than 200,000 in 2006 (He et al., 2008). This increase has been accompanied by rapid development of tourism infrastructure (e.g., hotels, restaurants), together with road construction. Previous studies have shown that many forest areas have been replaced by other land cover types resulting in rapid degradation of forests and panda habitat, so that from 1974 to 1997 the degradation continued unabated, and the fragmentation of high-quality panda habitat became more severe (Liu et al., 2001; Viña et al., 2007). More recently, however, the deforestation trend inside the Reserve has been slowing due in part to the implementation of national conservation policies (Viña et al., 2007, 2011).

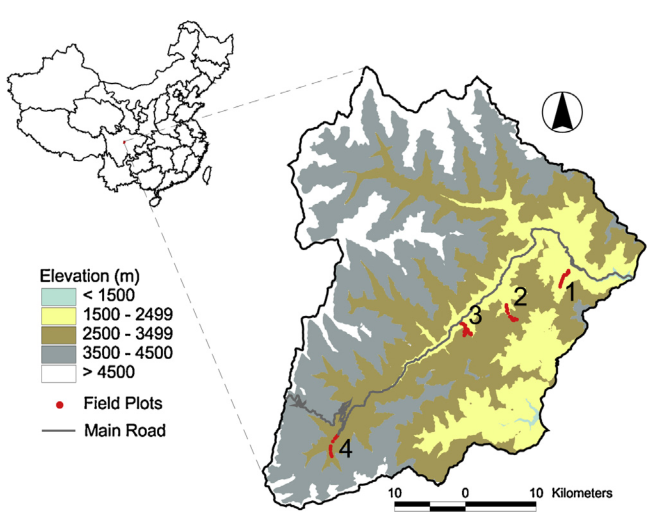

Fig. 1. Topographic map of the study region (i.e., Wolong Nature Reserve) showing the locations of the main road and of the 62 field plots (red dots; not scaled) established along four trails (numbered).

Due to its highly dynamic natural and human components and their interrelations, this Reserve is an ideal coupled human and natural system for examining the dynamics of biodiversity. Our research group has been performing long-term studies in this region since 1996 (Linderman et al., 2006; Liu et al., 1999; Viña et al., 2007; Yang et al., 2015) and many findings and methods developed in this study region have been applied to local, regional, national, and international settings (Carter et al., 2014; Li et al., 2013; Liu et al., 2003; Liu and Viña, 2014, Liu et al., 2016).

2.2. Field data

Vegetation surveys were conducted in the summer of 2007 along four trails across the Reserve (numbered 1–4 in Fig. 1). These trails were chosen because they comprise different types of forests and thus provide a good representation of the forest vegetation in the Reserve. The locations of the survey sites were based on a systematic sampling along each trail. To this effect, a starting location was established ca. 100 m from the beginning of each trail (ca. 100 m from the nearest household location in trails 1–3; Fig. 1). Subsequent survey sites were located at regular intervals of 300 steps (i.e., between 200 and 300 m, depending on topography). A total of 62 sites were sampled along the four trails. A 10 m by 20 m rectangular plot was established in each survey site, with its longer axis perpendicular to the trail. The center of each plot was geo-referenced using Global Positioning System (GPS) receivers, which were also used to collect elevation data. The overall slope at each plot was determined using a clinometer. Tree stem density was established within each plot by counting all stems with a diameter at breast height larger than 5 cm. The species of each tree counted was recorded, together with the presence of understory bamboo species, when present.

2.3. Remotely sensed data

2.3.1. MODIS data

A time-series of 184 images acquired between January 2005 and December 2008 by the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Terra satellite (MOD09A1 – Collection 5; ca. 500 m/pixel) was used to analyze land surface phenology. This image dataset is composed of eight-day composite surface reflectance values collected in seven spectral bands, and corrected for the effects of atmospheric gases, aerosols and thin cirrus clouds (Vermote et al., 1997). This time series of surface reflectance data was used to obtain land surface phenology. Land surface phenology is defined as the seasonal pattern of variation in the vegetated land surface observed using remotely derived vegetation indices. Vegetation indices are mathematical combinations of different spectral bands that constitute semi-analytical measures of vegetation activity. Their main purpose is to enhance the information contained in spectral reflectance data, by extracting the variability due to vegetation characteristics (e.g., leaf area index, vegetation canopy cover) while minimizing soil, atmospheric, and sun-target-sensor geometry effects (Moulin, 1999). Vegetation indices constitute a simple and convenient approach to extract information from remotely sensed data, due to their