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From local spectral measurements to maps of vegetation cover and biomass on the Qinghai-Tibet-Plateau: Do we need hyperspectral information?

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A B S T R A C T

Though the relevance of pasture degradation on the Qinghai-Tibet Plateau (QTP) is widely postulated, its extent is still unknown. Due to the enormous spatial extent, remote sensing provides the only possibility to investigate pasture degradation via frequently used proxies such as vegetation cover and aboveground biomass (AGB). However, unified remote sensing approaches are still lacking. This study tests the applicability of hyper- and multispectral *in situ* measurements to map vegetation cover and AGB on regional scales. Using machine learning techniques, it is tested whether the full hyperspectral information is needed or if multispectral information is sufficient to accurately estimate pasture degradation proxies. To regionalize pasture degradation proxies, the transferability of the locally derived ML-models to high resolution multispectral satellite data is assessed. 1183 hyperspectral measurements and vegetation records were performed at 18 locations on the QTP. Random Forests models with recursive feature selection were trained to estimate vegetation cover and AGB using narrow-band indices (NBI) as predictors. Separate models were calculated using NBI from hyperspectral data as well as from the same data resampled to WorldView-2, QuickBird and RapidEye channels. The hyperspectral results were compared to the multispectral results. Finally, the models were applied to satellite data to map vegetation cover and AGB on a regional scale. Vegetation cover was accurately predicted by Random Forest if hyperspectral measurements were used (cross validated $R^2 = 0.89$). In contrast, errors in AGB estimations were considerably higher (cross validated $R^2 = 0.32$). Only small differences in accuracy were observed between the models based on hyperspectral compared to multispectral data. The application of the models to satellite images generally resulted in an increase of the estimation error. Though this reflects the challenge of applying *in situ* measurements to satellite data, the results still show a high potential to map pasture degradation proxies on the QTP. Thus, this study presents robust methodology to remotely detect and monitor pasture degradation at high spatial resolutions.

1. Introduction

Livestock grazing is the dominant land-use of the grasslands on the Qinghai-Tibet Plateau (QTP). The pastures are the economical basis for the Tibetan people, providing forage for approximately 13 million yaks and 41.5 million sheep (Long et al., 1999) and have been formed by thousands of years of pastoralism (Miehe et al., 2009). However, in the last decades the Tibetans are faced with increasing grazing pressure caused by increasing population numbers (Harris, 2010). Pasture degradation due to over-grazing is presumably the consequence which is strengthened by climate change (Lehnert et al., 2016) and improper grazing management (Cao et al., 2013). The degradation of the pastures is of significant economic importance for the population. In addition, it affects even larger scale patterns such as the discharge flow rates and sediment redistribution in major river catchments (Asner et al., 2004) or an alteration of radiation feedback (Gong Li et al., 2000).

Values for the extent of pasture degradation on the QTP vary heavily, because studies are conducted in a subjective way, are poorly documented, or cover only small spatial extents (Harris, 2010). To overcome these spatial deficits, remote sensing based approaches are needed. Therefore, satellite images with a high

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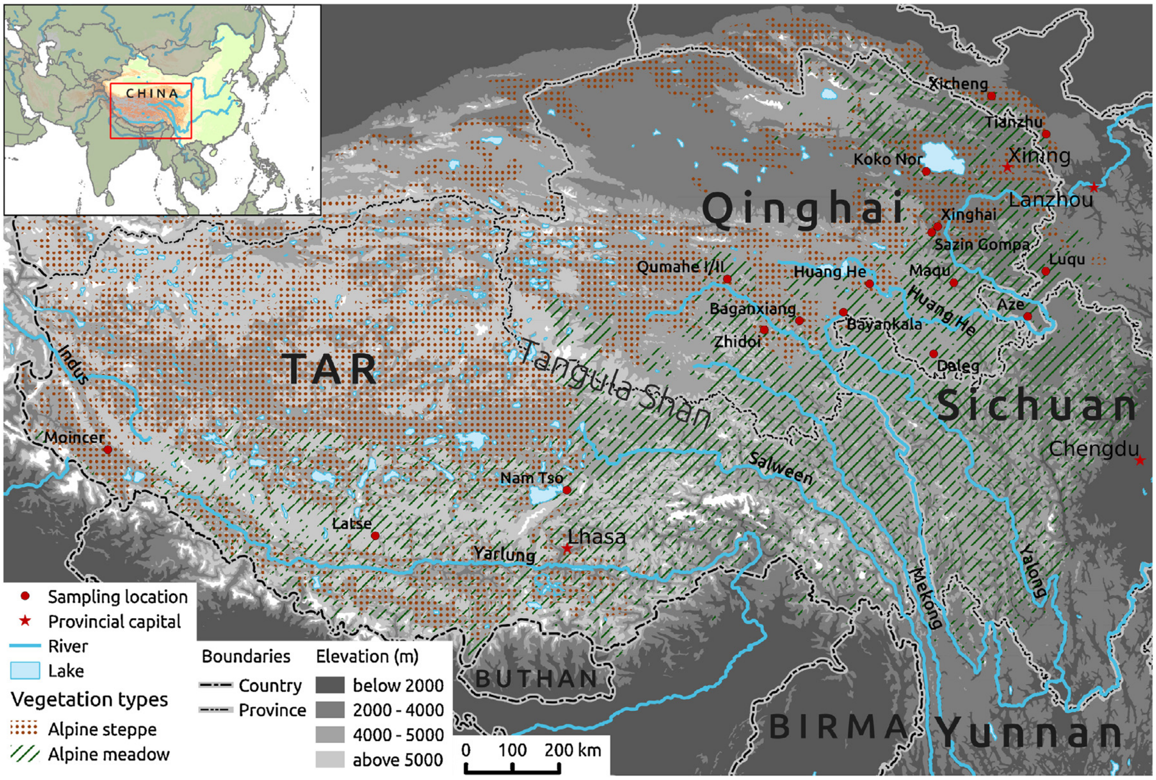

Fig. 1. Map of the study area including vegetation types considered in this study and the position of the 18 sampling locations. The distributions of vegetation types are from Hou (2001) and Miehe et al. (2008b).

spatial resolution taken with sensors like WorldView-2 (WV), RapidEye (RE) or Quickbird (QB) must be analyzed. Due to the large spatial extent and the difficult access to the area, semi-automatic approaches requiring very little field data would be advantageous.

Proxies for pasture degradation on larger scales were successfully derived from multi- (Wessels et al., 2008; Zha et al., 2003) as well as hyperspectral (Beeri et al., 2007; Huang et al., 2004; Lehnert et al., 2014) remote sensing data. While vegetation cover is the most frequently used proxy for pasture degradation in multispectral approaches (Gao et al., 2010; Liu et al., 2004; Lehnert et al., 2015b), hyperspectral data were used to quantify further proxies for pasture degradation including biomass (Itano and Tomimatsu, 2011), species diversity (Fava et al., 2010) and chemical foliage composition (Kokaly and Clark, 1999; Lehnert et al., 2013, 2014). The most commonly considered hyperspectral indices to estimate these proxies encompassed shape and size of absorption features (Mutanga and Skidmore, 2004), red edge parameters (Mutanga and Skidmore, 2007), vegetation indices as well as narrow band indices (Thenkabail et al., 2002). Though some studies compared indicators derived by spectrometer measurements with satellite-derived indices (Numata et al., 2008) there has been little research on applying revealed relationships between the spectrometer-derived hyperspectral indices and proxies for pasture degradation on larger scale multispectral satellite images (Liu et al., 2004; Psomas, 2008).

This study is aimed at assessing the suitability of hyper- and multispectral remote sensing data to regionalize proxies for pasture degradation on the QTP. Therefore,

1 it should be tested if a high spectral resolution of hyperspectral data compared to multispectral approaches considerably improves the estimation accuracy of machine learning models to derive vegetation cover and aboveground biomass (AGB) as proxies for pasture degradation, and
2 the usability of spectrometer measurements should be assessed to derive models applicable to regionalize pasture degradation proxies based on high spatial resolution multispectral satellite images.

2. Data and methods

A valid and comprehensive dataset of field observations to ensure a thorough training and validation of the derived parameter estimations is a prerequisite to perform a regionalization of pasture degradation proxies on the QTP. Therefore, this section is divided into a short description of the study area followed by the acquisition of field data and the description of the satellite data. The main part describes the derivation and regionalization of pasture degradation parameters using hyper- and multispectral data.

2.1. Study area

Alpine meadows and alpine steppes are the dominating vegetation types on the QTP (Hou, 2001) (Fig. 1). Alpine meadows can be found at altitudes between 3500 m and 4500 m a.s.l. where annual precipitation exceeds 400 mm (Sheehy et al., 2006). They usually feature a closed vegetation cover which is unique among the vegetation of the QTP (Miehe, 2004). Alpine meadows are composed of plants of the genus *Carex* (Miehe et al., 2008b) (partly former *Kobresia*, Global Carex Group, 2015), where the dominant species *Carex parvula* typically forms a thick turf-layer protecting the soil surface against erosion (Miehe et al., 2008b). In degraded areas, the turf is less intact (Miehe et al., 2011b). Alpine steppes are dominated by species of the genus *Stipa*. The vegetation cover is typically less than that of alpine meadows and does not have a sod layer. In addition to grasses, cushion plants characterise this vegetation type (Miehe, 2004; Sheehy et al., 2006). For a detailed description of the