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Desert vegetation-habitat complexes mapping using Gaofen-1 WFV (wide field of view) time series images in Minqin County, China

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ABSTRACT

Feedbacks between vegetation and associated habitats play a crucial role in the arid and semi-arid dryland ecosystem for maintaining the stability and sustainability. Due to the high spatial and temporal heterogeneous sparse vegetation with the associated habitats in dryland system, it is a challenge to map their interactions and feedbacks for environment management and policy decision. This paper attempted to develop an algorithm using endmembers (EMs) fraction series unmixed from Gaofen-1 (GF-1) WFV (wide field of view) finer time series images for mapping desert vegetation-habitat complexes as vegetation function groups with associated habitat. The time series of EMs, including green vegetation (GV), sand land (SL), saline land (SA), dark surface (DA) at 16 m subpixel level, derived from Multiple Endmember Spectral Mixture Analysis (MESMA), were combined to obtain classification knowledge describing the interactions and feedbacks between vegetation and habitat, and organized with decision tree (DT). According to the similarity of the interactions and feedbacks in the desert vegetation-habitat complexes, this paper further identified their potential of assessing the status of ecosystems (i.e., land degradation). The results show that the finer time series of EMs with satisfied spatial resolution can discern the sparse vegetation and the associated habitats with an overall accuracy of 83.91%, and help understanding degradation processes (i.e., sandification and local salinization) in the study area.

1. Introduction

Land degradation in drylands, as one of the major threats on the global environment, directly impacts human well-being and social welfare (Millennium Ecosystem Assessment (MEA, 2005). The desert vegetation of dryland ecosystems, dominated by sparse vegetation including shrub, subshrub and desert meadow, is representatively distributed in patches interspersed within a matrix of bare ground and sparse vegetation at multiple scales (Aguiar and Sala, 1999; Deblauwe and Murray, 2008; Schmitz, 2010), and thus forming integrated and complicated groups (complexes) of desert vegetation types and habitats that are connected evolutionarily. Given their multi-scale patchy structure, the functions of desert ecosystem are based on complicated relationships and feedbacks between vegetation and associated habitats in dryland cover complexes (Okin et al., 2016; Peters et al., 2006; Rietkerk and Van, 2008). Thus, to get a world with zero net land degradation (ZNLD) target in dryland system, it is of prime importance to map desert vegetation-habitat complexes revealing complex relationships and feedbacks for management or/and restoration practices and policies.

The conventional inventory for desert vegetation, usually through on-site field survey and mapping, provides detailed location-specific information on vegetation types in patch scale (Mucina et al., 2010), but poses serious limitations to the frequency and/or the large-scale dryland states mapping because of expensive, labor intensive and time-consuming field survey (Sivanpillai et al., 2006; Steele et al., 2012). Consequently, for most drylands, maps of surface cover do not exist (Bestelmeyer, 2015).

Remote sensing is the only accessible tool with in-situ observations to map dryland vegetation states across large areas in a repeatable manner (Hill et al., 2008). Historically, using vegetation phenology, the vegetation was mapped and described with time series coarse-resolution sensors such as Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR) at regional and global level (e.g. Fensholt et al., 2013; Maignan et al., 2008). For more detailed phenological information at fine-scale, conventional broad band remote sensing such as Systeme Probatoire d'Observation de la Terre (SPOT) and Landsat TM/ETM+/OLI

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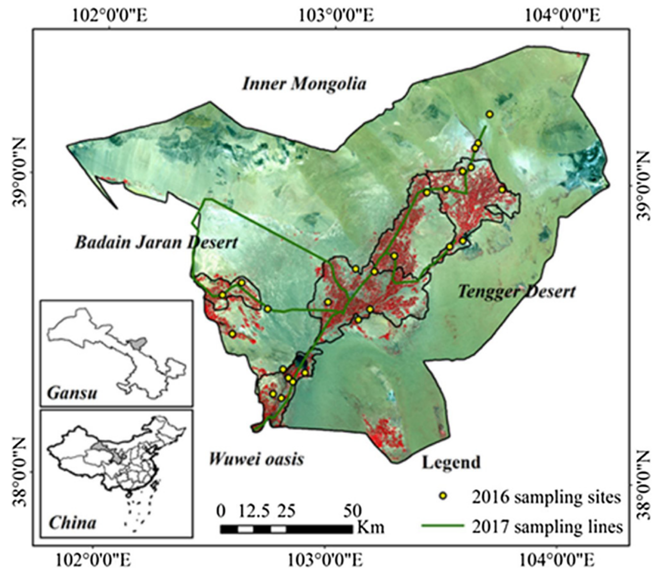

Fig. 1. The false color composites of bands 4, 3 and 2 (R, G & B) without any stretch on 30 August 2015 in Minqin study area, 2016 sampling sites of desert vegetation (yellow points) and 2017 sampling lines (green line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

(Thematic Mapper/Enhanced Thematic Mapper Plus/Operational Land Imager) satellites were widely used (e.g. Röder et al., 2008; Stellmes et al., 2010). Due to the high spatio-temporal heterogeneity of two-phase (i.e., vegetation-bare ground) mosaics in dryland systems, distinguishing the crucial cover types remain a challenge (Sun and Liu, 2015). In addition, the phenology-based vegetation mapping usually ignores the relationships and feedbacks between vegetation and habitat (Douma et al., 2012; Roelofsen et al., 2014).

Given the three and/or four generic endmembers (EMs) (such as soils and substrates, vegetation, and dark materials, SVD) in TM/ETM + broad band imagery (Small, 2004; Small and Milesi, 2013), linear Spectral mixture analysis (LSMA), providing EMs fractional abundance in the subpixel level (Adams et al., 1986;Roberts et al., 1993; Smith et al., 1990; Van der Meer, 1995), can be effectively accessible on vegetation and habitats information using standardized EMs (Small and Milesi, 2013). In temperate dryland system, the fixed four broad EMs (i.e., green vegetation, sand land, saline land and dark surface) were validated from multi-seasonal TM images (Sun and Liu, 2015). Aiming at the spectral and spatial variations of pixel endmembers, Multiple Endmember Spectral Mixture Analysis (MESMA), based on LSMA with adjustment the amount and type of endmembers (Roberts et al., 1998), can provide more reasonable and accurate unmixing results (Eckmann et al., 2008; Quintano et al., 2013). The knowledge of physically-based EMs was furtherly adopted for land cover mapping with the segmentation of EMs (Adams et al., 1995; Lu et al., 2003), and/or the decision tree (DT) approach (Roberts et al., 2002; Sun and Liu, 2015). The temporal dimension – critical to understanding intraannual processes – has generally been sparse at the spatial scales needed. Thus, using conventional broad band remotely sensed data often draw inference from incomplete temporal characterizations of EMs' dynamics, and limit their application in dryland system.

Recently new launched broad band remote sensing, such as Sentinel satellites (Sentinel-1/2) and Gao Fen 1 (GF-1), improves the temporal and spatial resolution significantly for vegetation mapping at landscape level. As an optical satellite, although with only four bands in visible-infrared range (i.e. 450–890 nm), GF-1 provides free images with 16-m spatial resolution and 4-day revisit cycle (China Centre for Ressources Satellite Data and Application (CRESDA, 2015), to reduce longer revisit period and frequent cloud contamination in conventional broad band imagery.

Therefore, in this paper, defined desert vegetation-habitat complex as a complicated group with intense of interaction and feedback between its elements, i.e., desert vegetation and associated habitats, we attempted with GF-1 WFV imagery to develop a procedure with the finer intraannual EMs' series for mapping desert vegetation-habitat complexes with inferred local ecological processes. The specific objectives were (1) to investigate and unmixing four-EM space in GF-1 WFV imagery with MESMA strategy for a consistent intraannual temporal series of both vegetation-related and soil-related EMs, (2) to organize landscape seasonality and ecological processes explicitly for desert vegetation complex mapping, (3) finally, to discuss the potential of the mapping complexes for land degradation/restoration assessment.

2. Study area

As a semi-enclosed inland desert area, Minqin County is located in the Hexi Corridor on the lower reaches of the Shiyang River, Gansu Province, northeast China (ranging from 101° 49′ to 104° 12′ E and from 38° 03′ to 39° 28′ N) and surrounded by Tengger desert and Badain Jaran desert (Fig. 1). From the Neolithic Age to the Han Dynasty (AD 111), Minqin County was a swamp covered almost by Lake, but the subsequent large-scale development of oasis agriculture and irrigation activities caused severe desertification with the considerably reducing upstream surface runoff and the sharply falling groundwater table (Sun et al., 2005). Historically, natural vegetation suffered a large-scale degradation from the swamp vegetation to the halophyte meadow, and to the nowadays climax community desert plants (Chang et al., 2007, 2008). Nowadays, the desert vegetation is a pivotal ecozone between desert and oasis for wind prevention and sand fixation, however, it is unknown whether the natural desert vegetation function groups recover to self-sustain at landscape level for ZNLD after nearly two decades rehabilitation and conservation.

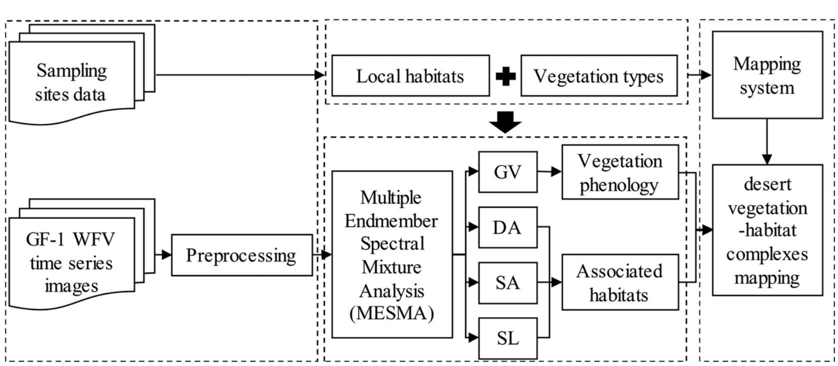

Fig. 2. The technical route for desert vegetation-habitat complexes mapping.