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Segmentation of Landsat Thematic Mapper imagery improves buffelgrass (*Pennisetum ciliare*) pasture mapping in the Sonoran Desert of Mexico

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A B S T R A C T

The invasive exotic buffelgrass (*Pennisetum ciliare*) is a principal threat to the Sonoran Desert of southwestern North America. Buffelgrass is cultivated in cattle pastures throughout Mexico's northwestern state of Sonora, where it poses an invasion threat to surrounding desert lands. Automated remote sensing methods to detect buffelgrass pasture conversion at a regional scale have shown limited success, due in part to variable land-cover conditions, and in part to intrinsic heterogeneity in desertscrub land-cover. This paper discusses a novel technique for delineating and mapping buffelgrass pastures based on vector-based satellite image segmentation followed by pixel-based classification using ancillary spatial environmental data. Based on quantitative accuracy metrics and visual inspection of known pasture sites, we report that segmentation considerably improved the mapping process, in particular the detection and delineation of pastures. Comparisons of paired classifications with segmented and nonsegmented imagery revealed higher overall map accuracies and higher buffelgrass class accuracies, as well as lower errors of commission and omission for buffelgrass in segmented maps. This new application of object-based image analysis has promising implications for ongoing efforts to map and monitor buffelgrass expansion region-wide and other similar changes in land-cover type and condition across human-modified landscapes.

Introduction

The desert of Mexico's northwestern state of Sonora is historically a site of extensive cattle grazing (Jordan, 1993), with approximately 15 million ha, ~85% of the state, designated as rangeland (INEGI, 1996). In response to the widespread degradation of Sonoran ranges by overstocking (Bahre, 1991) and an imperative to boost local ranchers' incomes (Ibarra Flores, Moreno Medina, Martín Rivera, Denogean Ballesteros, & Gerlach Barrera, 2005), land-use policy in the region since the 1950s has promoted the cultivation and intensive management of exotic pasture (Brenner, 2010, 2011). The favored species for the conversion of native range to pasture is buffelgrass (*Pennisetum ciliare*), an Indo-African perennial bunchgrass well suited to arid environments such as the Sonoran Desert (Ibarra-Flores, Martín-Rivera, Denogean Ballesteros, & Aguirre-Murrieta, 2009). Pasture conversion leaves a clear expression on the landscape, as the first steps of the process, known locally as "*desmonte*," involve removing the native vegetation with a bulldozer and tilling the soil (Fig. 1). Because buffelgrass is an aggressive invader of undisturbed as well as disturbed landscapes, pasture conversion poses a host of serious ecological threats throughout the Sonoran Desert ecoregion (Búrquez-Montijo, Miller, & Martínez-Yrizar, 2002; Van Devender & Dimmitt, 2006). An efficient, reliable method for the detection of buffelgrass pasture is thus necessary for monitoring the extent of this landscape change and informing Sonoran Desert conservation policy (Marshall et al., 2000; Nabhan & Holdsworth, 1998; Pima County Government, 2006).

Land-cover classification methods using remotely sensed imagery offer an important opportunity to map and monitor Sonoran Desert pasture conversion (Nagler, Glenn, Franklin, Lampkin, & Huete, 2009). The *desmonte* process changes vegetation and soil characteristics such that cleared pasture sites are visible to the trained eye in aerial photographs, as well as most high- and some medium-resolution satellite imagery (Franklin et al., 2006) (Fig. 2). Still, detection of even the complete conversion of landscape patches from desertscrub to buffelgrass presents

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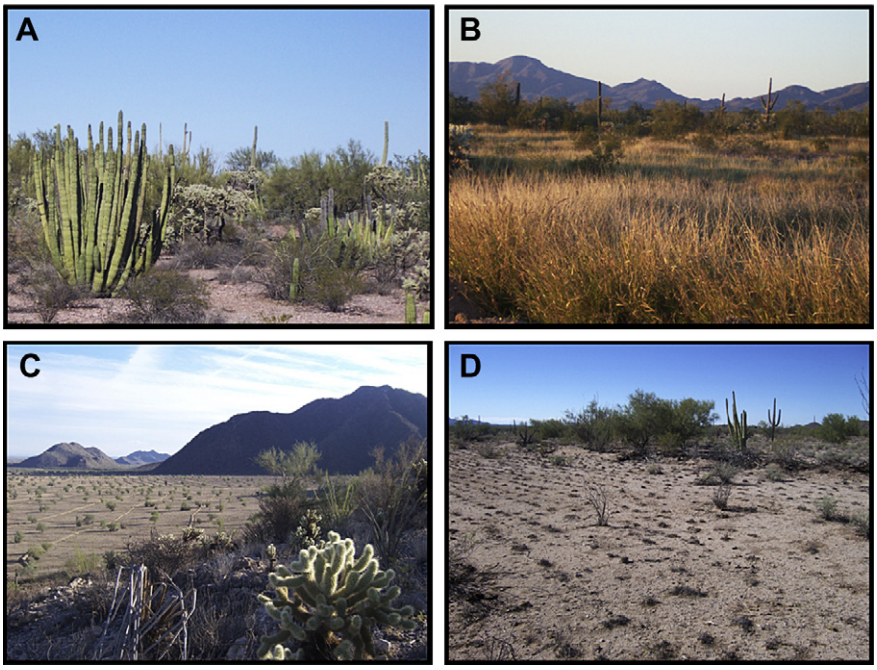

Fig. 1. Diverse native Sonoran desertscrub (A) is cleared with a bulldozer and the underlying land is tilled then converted to buffelgrass pasture (B). The resulting savanna-like landscape (C, midground) may contain dense stands of buffelgrass (as in B), but may also be degraded to bare soil by overgrazing (D).

several challenges, owing to the open canopy and low productivity of native vegetation (Okin & Roberts, 2004), fine-grained spatial and temporal heterogeneity in precipitation (Adams & Comrie, 1997), and widespread overgrazing (Bahre, 1991; Balling, Klopatek, Hildebrandt, Moritz, & Watts, 1998). Pastures show considerable variability in spectral reflectance within their boundaries, a result of buffelgrass cover ranging from nearly 100% in ungrazed parcels during the rainy season to bare soil in conditions of drought or heavy grazing (Nagler et al., 2009; Van Devender & Dimmitt, 2006).

Theory

Mapping land-cover patterns and monitoring land-use processes in heterogeneous and dynamic landscapes are challenges facing research across various disciplines (Bhaskaran, Paramananda, and Ramnarayan 2010; Christman, 2010; Miller & Rogan, 2008; Richards & Jia, 2006; Shao & Wu, 2008). In this case, spectral similarities among natural and exotic land covers make pasture detection with spectral data alone extraordinarily difficult (Franklin et al., 2006, 2009). In the absence of an unequivocal spectral reflectance signal,

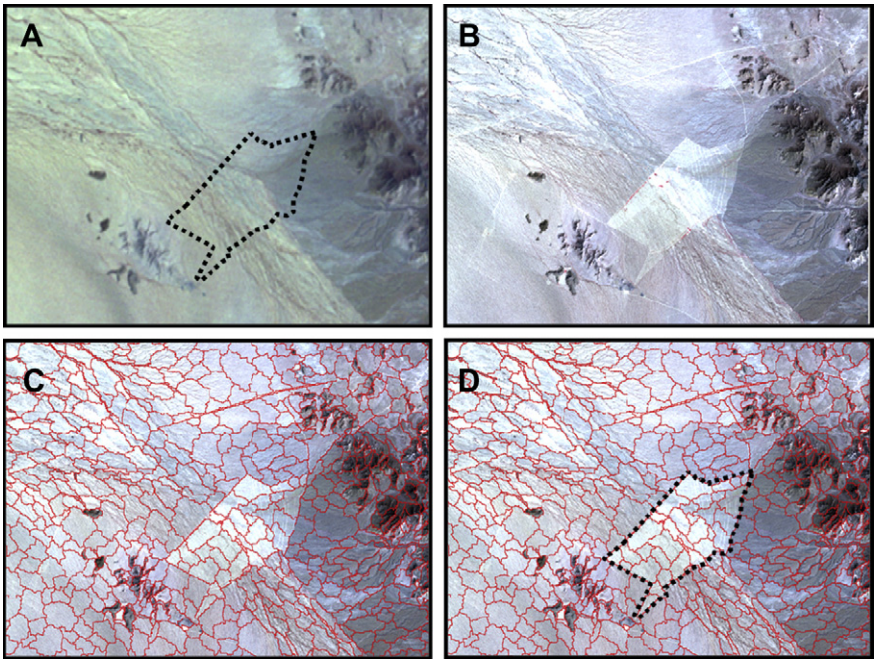

Fig. 2. False-infrared color composite images showing intact native desert in 1990 (A) having been converted to a large buffelgrass pasture by 2007 (B). A sample vector segmentation of the near infrared band in shown in solid lines (C) corresponds with the visible buffelgrass pasture boundaries, shown in the dotted line (D). See Fig. 3(a) for the approximate location of this site within the study area.