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Landcover classification of the Lower Nhecolândia subregion of the Brazilian Pantanal Wetlands using ALOS/PALSAR, RADARSAT-2 and ENVISAT/ASAR imagery

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ABSTRACT

The Lower Nhecolândia subregion of the Brazilian Pantanal is part of a large continuous tropical wetland that exhibits a high biodiversity of flora and fauna species, and many threatened habitats. The spatial distribution of these habitats influence the abundance and interactions of animal species, and the change or destruction of habitat can cause the disturbance of key biological processes. This study uses multi-temporal L-band ALOS/PALSAR, C-band RADARSAT-2, and ENVISAT/ASAR data to map ecosystems and create a lake distribution map of the Lower Nhecolândia subregion in the Brazilian Pantanal. First, backscattering analysis was conducted on individual training objects to gain a better understanding of the backscattering characteristics of each class. Then, a Level 1 object-based image analysis (OBIA) classification based on hierarchical principles first classified the region into "Lakes" and "Not Lakes". This was followed by a Level 2 classification defining six vegetation habitats (Forest Woodland, Open Wood Savanna, Open Grass Savanna, Agriculture, Swampy Grassland and *Vazantes*) which was achieved at an overall accuracy of 83%. A Level 3 classification defined the "Lakes" class into a) Fresh (*baías*) and Brackish (*salinas*) lakes (accuracy results of 98%); and a further classification level dividing the fresh lakes, b) Fresh Lakes with floating and emergent vegetation (*baías*), and Fresh Lakes with the presence of *Typha (salobras)*, and including the Brackish lakes (*salinas*) (overall accuracy results of 81%). The results of this study provide the first fine spatial resolution classification showing the spatial distribution of terrestrial and aquatic habitats for the entire subregion of Lower Nhecolândia using dual season, dual polarization C and L-band SAR imagery. The produced maps will provide valuable habitat information to help define conservation strategies and aid further research in the area.

1. Introduction

Anthropogenic activities currently influence most of the terrestrial biosphere and are growing in intensity and scope. The consequent habitat loss and degradation weaken ecosystem functions at local, regional and global scales (Kerr & Ostrovsky, 2003). Thus, spatial distribution of land use/land cover data is essential for the analysis of ecosystem processes, both in terms of forming baseline data, and for subsequent monitoring over time (Anderson et al., 1976; Wang et al., 2009). Specifically, land cover data are required to assess environmental impacts, manage wildlife resources, monitor land cover change, and to consider future impacts (Anderson et al., 1976). Yet, given the size and inaccessibility of many global ecosystems, conventional methods of data acquisition can be complex. In many cases, remote sensing technology offers the only reliable process for determining ecologically valuable information regarding the characteristics of habitats, and monitoring land cover changes resulting from anthropogenic or natural processes across large scales (Kerr & Ostrovsky, 2003; Laba et al., 2002; Lowry et al., 2007).

Wetland regions are regarded as one of these difficult areas to monitor through conventional methods due to their relative inaccessibility and seasonally dynamic nature. Prior to the advent of remote sensing technology, wetland mapping was largely based on ground surveys of soil and vegetation inventories gathered through extensive and time consuming field work requiring ancillary data analysis and visual estimations of ground cover, and consequently, were only practical on small scales (Hewes, 1951; Lee & Lunetta, 1996; Mitsch & Gosselink, 2007). Aerial photographs have proved useful for providing a broader understanding of hydrology and vegetation patterns; however aerial photography is expensive to obtain, and so is also only practical for smaller scale mapping efforts. Furthermore, mapping via aerial photos relies on the subjectivity of the interpreter, and so can be problematic in terms of repeatability (Ramsey & Laine, 1997). The size and relative inaccessibility of wetland ecosystems renders these traditional methods difficult and expensive. As such, satellite remote sensing presents a cost effective, efficient and practical approach that can be used to map wetland landscape distribution over a large area with advantages that include multi-spectral and multi-temporal data collection (Ozesmi & Bauer, 2002; Rundquist et al., 2001).

Optical satellite imagery has shown promising results for many wetland monitoring purposes. One of the first uses of satellite imagery for wetlands mapping involved the use of Landsat MSS to classify the wetlands of Nebraska Sand Hills (Seevers et al., 1976). More recently, for example, optical imagery have been used to classify general vegetation

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land cover and broad vegetation assemblages, including tropical freshwater swamp in Australia (Harvey & Hill, 2001), coastal salt marsh mapping in California (Li et al., 2005), and classification of marsh and swamp cover in the Harike wetlands ecosystem in Punjab, India (Chopra et al., 2001). However, optical systems are limited in that they cannot penetrate cloud cover or dense vegetation canopies (Costa, 2004; Hess et al., 1995; Silva et al., 2008; Siqueira, 2003). The cloud cover issue can be especially problematic in humid tropical and subtropical regions. For example, the Global Environment Facility (GEF) used a selection of Landsat imagery compiled over approximately five years to complete a single, cloud-free mosaic of the entire Brazilian Pantanal wetlands (GEF, 2004). As an alternative, synthetic aperture radar (SAR) satellites operate in the microwave region of the electromagnetic spectrum (approximately 1–100 cm in wavelength), typically allowing penetration of both forest canopy and cloud cover, thus overcoming the limitations of optical imagery for land cover and inundation mapping (Dobson et al., 1996; Silva et al., 2008). SAR systems are therefore recommended for tropical/semi-tropical wetlands, where cloud cover is an issue, and L-band SAR particularly for wetland regions with significant dense canopy cover (Henderson & Lewis, 2008; Kasischke et al., 1997).

The availability of SAR imagery from the Advanced Land Observing Satellite (ALOS) Phased Array L-band Synthetic Aperture Radar (PALSAR), the RADARSAT-2, and ENVISAT/ASAR, and other SAR systems offers a unique opportunity for mapping and monitoring the spatial and temporal dynamics of large tropical wetland ecosystems. For instance, Lucas et al. (2007) evaluated the potential of L-band SAR for quantifying and monitoring mangrove populations in the tropics. In Gabon, Africa, Simard et al. (2002) combined ERS-1 and JERS-1 imagery to map tropical coastal vegetation. Also in Africa, Rebelo (2010) employed a combination of multitemporal L-band ALOS/PALSAR imagery with Landsat TM and ASTER imagery to successfully map two wetland sites: Lake Chilwa, Malawi, and Lake Urema, Mozambique. In the Amazon region of Brazil, Hess et al. (2003) used dual-season L-band SAR imagery from JERS-1 to map seasonal inundation and vegetation for the central Amazon basin, and determined that the use of images acquired at high and low inundation stages allowed the delineation of vegetation types that could not be distinguished on a single date. Also in the Amazon floodplain, Costa (2004) used a combination of multi-temporal C-band (RADARSAT) and L-band (JERS-1) imagery to classify vegetation communities. More recently, Silva et al. (2010) successfully applied a more complex object-oriented and hierarchical classification method combining temporal imagery from SAR (RADARSAT-1) and optical (MODIS) to map the seasonal variation in aquatic vegetation cover on the Amazon floodplain. In the Pantanal wetlands of Brazil, Costa and Telmer (2006) utilized a combination of C-band (RADARSAT-1) and L-band (JERS-1) imagery to classify the geochemically varied lakes in the Nhecolândia region of the Pantanal, based on the specific types of aquatic vegetation associated with each geochemical condition. Evans et al. (2010) utilized an object based image analysis (OBIA) approach combining temporal SAR (ALOS/PALSAR ScanSAR) and RADARSAT-2 imagery to map the land cover and inundation patterns for the entire Pantanal. The SAR derived classification maps of the Pantanal are either restricted to a single habitat, such as lakes (Costa & Telmer, 2006), or are limited by a coarse spatial resolution imagery (Evans et al., 2010). Therefore, the primary goal of this research is to define on a regional scale the distribution of the variety of habitats in the Lower Nhecolândia sub-region of the Pantanal, using a dual-season set of fine spatial resolution C-band and L-band SAR imagery, employing a hierarchical object-based image analysis approach.

2. Study area

The Pantanal wetlands of South America are one of the largest and most important tropical wetland ecosystems globally, covering an area of approximately 160,000 km^2 during maximum inundation (Junk et al., 2006). The Pantanal is primarily located in west central Brazil, with roughly 10% reaching into Paraguay and Bolivia. The Paraguay River, its tributaries, and the rainfall patterns of the region, support an annual flood regime that varies both temporally and spatially, and helps to characterize the geomorphology and the abundance of biodiversity in the Pantanal ecosystem (Hamilton et al., 1996; Junk et al., 2006). The Pantanal wetland is comprised of a number of floodplain subregions with particular characteristics in terms of ecology, hydrology and geomorphology. Flooding in these subregions is distinctly seasonal, but the timing varies between subregions due to the slow passage and delayed release of floodwaters (Hamilton, 2002; Hamilton et al., 1996).

The Lower Nhecolândia subregion of the Pantanal, the focused area of study for this paper, is located in the south-central Pantanal — northwest latitude, longitude and southeast latitude, longitude: 18°40′S, 57°02′W and 19°35′S, 55°32′W, respectively. This subregion, as defined in Hamilton et al. (1996), is bordered by the Negro River to the south and the Taquari River to the north and occupies an area of approximately 8220 km^2 (Fig. 1). This subregion exhibits a high diversity of flora and fauna species, and is greater in terms of wildlife species richness and abundance than the rest of the Pantanal due to its high environmental heterogeneity. Because of this high diversity of wildlife, the Lower Nhecolândia subregion is the focus of several threatened species home range studies, including: the marsh deer (*Blastocerus dichotomus*) (Tomas et al., 2000), jaguar (*Panthera onca*) (Cavalcanti & Gese, 2009), and the giant anteater (*Myrmecophaga tridactyla*) (Medri & Mourão, 2005), as well as studies focused on abundance of fish communities in the aquatic habitats (Suarez et al., 2004), deforestation as a result of cattle ranching (Seidl, 2000), and wildlife habitat selection studies (Desbiez et al., 2009). Specifically, Desbiez et al. (2009) identifies several key landscapes at a local scale selected by native mammalian species, including: floodplain landscape (Pampas deer, capybara); *cerrado* (savanna) (crab-eating fox); forest (peccaries, howler monkeys, coati, southern anteater, ocelot, and jaguar); scrub grassland (giant anteater); and forest-edge (grey brocket deer, and southern anteater). Some of these landscape categories, such as forest, are of key importance as night time shelter for species that prefer open grasslands during the day, and also as vital refuges for all terrestrial species during times of extreme flooding, as they occur at slightly higher elevations (Desbiez et al., 2009). Furthermore, aquatic habitats play an important role for many bird species during drought periods (Donatelli, 2001), and temporary waterways formed during flood periods provide vital migration corridors for many fish species (Fernandes et al., 2010). The aquatic macrophytes found in these waterways, as well as within the numerous fresh-water lakes, are an important food source for the white-lipped peccaries during periods when fruits are scarce, and saline lakes are key habitats for large concentrations of wading birds (Donatelli, 2001).

An important component of habitat diversity in Lower Nhecolândia is its monomodal flooding cycle, with high waters occurring from February to April, and low waters from August to November (Hamilton et al., 1996). Lower Nhecolândia has a relatively closed drainage system with little connection to major fluvial systems, and an abundance of small lakes/ponds (Pott & Pott, 2011a). The region has a highly heterogeneous and dynamic landscape, with forest, savanna, wild grasslands, introduced pastures, seasonal waterways, herbaceous vegetation, aquatic macrophytes and numerous lakes locally called *baías, salobras,* and *salinas*, all occurring in close proximity to each other (Fig. 1). However, the internal phytogeography of this entire region is still inadequately documented (Pott et al., 2011). At a broad scale, the landscape units in the Lower Nhecolândia region are characterized by 1) woody vegetation (*cerrado/cerradão*); 2) herbaceous vegetation (*campos*); and, 3) frequently and/or permanently aquatic or swampy terrain, although there is not always a definitive boundary between these three landscapes. Characterization of the smaller scale landscape units as described by several authors are outlined in Table 1 (Campos Filho, 2002; Nunes da Cunha & Junk, 2011; Nunes da Cunha et al., 2007; Por, 1995; Pott & Pott, 2000, 2011a, 2011b; Pott et al., 2011), with field photos of the corresponding classes in Fig. 2.

The Lower Nhecolândia region is a globally unique environment consisting of tens of thousands of geochemically diverse lakes,