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Original Paper
Mapping floristic communities in Southern Africa savannas, Mozambique

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Abstract
The present study was carried out in Limpopo National Park (LNP) with the objective to map floristic communities that occur inside the park. Three (3) Landsat 8 satellite images were obtained by Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) tools and were pre-processed and classified, culminating in six (6) types of land use and cover. The floristic survey consisted of stratified sampling in three (3) main LNP landscapes types, namely landscape of limestone soils, landscape of rhyolite shallow soils and landscape of deep sandy soils. The final map presents 13 floristic communities identified by the names of greatest value of ecological importance (IVI) species. The community of *Terminalia sericea* / *Combretum apiculatum* / *Guibourtia conjugata* / *Colophospermum mopane* presented a larger occurrence area. *Colophospermum mopane* was the most representative species among the mapped communities, mostly occurring in association with other species. The overall accuracy was 74% and the Kappa index was 68%, thus giving a good rating. The mapping also showed that human occupied areas are larger than some floristic communities areas, so we suggest that these smaller communities, should be given priority actions for their conservation, especially those without human occupation.
Key words: floristic community, land cover, Limpopo National Park, mapping.

Resumo
O presente estudo foi realizado no Parque Nacional do Limpopo (PNL), com o objetivo de mapear comunidades florísticas que ocorrem no parque. Foram obtidas três (3) imagens do satélite Landsat 8 com os sensores Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), para as quais foi feito o pré-processamento e a classificação, culminando em seis (6) tipos de uso e cobertura de terra. O levantamento florístico consistiu numa amostragem estratificada por paisagem, nomeadamende paisagem de solos calcários, paisagem de solos rasos de riolito e paisagem de solos arenosos profundos. O mapa final apresenta 13 comunidades florísticas identificadas pelos nomes das espécies de maior valor de importância ecológica (VI). A comunidade de *Terminalia sericea* / *Combretum apiculatum* / *Guibourtia conjugata* / *Colophospermum mopane* apresentou maior área de ocorrência. *Colophospermum mopane* foi a espécie mais representativa entre as comunidades mapeadas, ocorrendo em maior parte associada com outras espécies. A exatidão global foi de 74% e o índice Kappa foi 68%, atribuindo assim um nível de boa classificação. O mapeamento também demonstrou que áreas de ocupação humana são maiores que as áreas de cobertura de algumas comunidades florísticas, deste modo sugerimos que estas comunidades menores sejam priorizadas na conservação, especialmente aquelas que não apresentam ocupação humana.
Palavras-chave: comunidade florística, cobertura de terra, Parque Nacional de Limpopo, mapeamento.

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Introduction

Over the last century, a significant loss of forest cover has occurred at the global level due to anthropogenic activities such as agriculture, urbanization, mining and logging, jeopardizing biodiversity conservation (Geist & Lambin 2002; Díaz *et al.* 2006; Bunting *et al*. 2010). Forest vegetation provides habitat for several living beings and plays a key role in affecting global climate (Xiao *et al.* 2004; Huang *et al.* 2008; Lucas *et al.* 2008). Furthermore, biodiversity ecosystem services which are closely linked to well-being and human society subsistence are also threatened (Rikimaru *et al*. 2002; Ploton *et al.* 2012). For instance, forest resources are well known for being an integral component of a society' economy and the environment (Chazdon 2008; Bullock *et al*. 2011). These provide several products and ecosystem services such as food, fiber, wood and nutrient cycling (Isbell *et al*. 2011; Ploton *et al*. 2012), and thus play a vital role in maintaining ecological balance (Roy & Joshi 2002; Rai 2012). Growing awareness that forests provide multiple benefits to humankind has created a global concern for their protection and conservation (Roy & Joshi 2002; Balvanera *et al.* 2006; Bullock *et al*. 2011; Isbell *et al*. 2011).

Vegetation mapping and classification are important tools to protect, conserve, and manage natural resources. Thus, mapping and delimiting conservation areas are fundamental for conserving and restoring natural ecosystems (Myers *et al.* 2000; Redford *et al*. 2003; Huang *et al.* 2008; Lucas *et al*. 2008). Mapping in conservation units currently presents several steps, such as the use of remote sensing and floristic surveying (Adam *et al*. 2010). This information is mainly applied to landscape planning and biodiversity conservation (Rapinel *et al.* 2018; Adam *et al.* 2010; Hasmadi *et al.* 2010). It has also generally been used to find spatial plant distribution, disturbances, identify animal species habitat, among other factors (Wagner *et al*. 2000; Moreno & Halffter 2001).

Remote sensing is a technique which captures data from an object without any physical contact through its spectral response and electromagnetic radiation, and thus is a good alternative to map areas (Beeri *et al.* 2007; Xie *et al.* 2008). Vegetation physiognomy maps can be generated from satellite sensor data (*i.e.* acquired by SPOT or LandSat sensors) by applying supervised or unsupervised pixel classification techniques (Wang & Boesch 2007; Reddy *et al.* 2016; Hansen *et al.* 2013). In addition, more detail can be added to physiognomy maps by adding floristic composition information, such as the importance value index of species (Rapinel *et al.* 2018). These data can be obtained from phytosociological surveys and analysis (Hasmadi *et al.* 2010; Kurtz *et al.* 2018). Vegetation classification by using remote sensing systems has been an indispensable tool in the process of creating an updated vegetation map, as well as a basic requirement for monitoring landscapes (Foody & Cutler 2003; Giri *et al*. 2011).

In this work remote sensing mapping methods combined with floristic surveys were conducted regarding *Mopane* formations in a Protected Area in Limpopo National Park (LNP). Uncontrolled fires in LNP related to shifting cultivation practices, hunting small animals, and firewood (among others) are the main threats to biodiversity and habitats, as well as changing floristic landscape patterns of the region (Grossman & Holden 2002; Milgroom & Spierenburg 2008; Witter 2013; Everatt *et al*. 2014). Despite this, mapping vegetation and human occupation is very important because maps can be used to plan and manage landscapes.

Thus, the present study aims to map floristic communities in LNP for the year 2014, with the following hypotheses: (i) all floristic communities are larger than the human occupation areas in the park; and (ii) *Colophospermum mopane* is distributed in all floristic communities, showing evidence of wide niche amplitude of this species in the ecosystem.

Material and Methods

Study area

The *Mopane* ecoregion extends for about 555,000 km^2, thus forming a generalized type of vegetation covering areas in Angola, Botswana, Namibia, Zimbabwe, Zambia, Mozambique, Malawi and South Africa (Timberlake *et al*. 2010; Makhado *et al.* 2012). Limpopo National Park (LNP) is one of the largest natural parks in Mozambique, extending around 10,000 km^2, and is also considered the largest national conservation area of the *Mopane* ecosystem (Stalmans *et al*. 2004; Marzoli 2007). Few floristic surveys have been carried out in the park partly due to difficulties of access (Lunstrum 2008; MITUR 2003; Stalmans *et al.* 2004; Everatt *et al.* 2014).

LNP is part of the Greater Limpopo Transfrontier Park (PTGL), which joins Kruger National Park (PNK) in South Africa, and Gonarezhou National Park (PNG) in Zimbabwe. The Mozambican part of the cross-border Park is located in north of the Gaza Province, southern region of Mozambique (MITUR 2003; Stalmans *et al*. 2004). The park is located in a semi-arid climate, BSh and BWh according to the Koppen classification. The maximum average diurnal temperature increases from South to the North, with an absolute maximum above 40 °C in November to February. The average annual precipitation varies from 360 mm in the northern part to more than 500 mm west of the park (Rubel & Kottek 2010).

Three main landscapes cover the park, namely: (i) Landscape of deep sandy soils: also conventionally designated by Nwambia sandveld, covers approximately 458,641 ha (41.1%) of the LNP area, extending from the northwest border with the Kruger National Park (KNP) in a downward direction towards the confluence of the Limpopo and Olifants rivers. It is characterized by sandy substrates, including deep reddish soils and interior dunes with a pH ranging from 4.3 to 5.5 (Van Rooyen *et al*. 1981). There is also vegetation with few trees and shrubs mostly ranging between 2 and 4 m high (Gertenbach 1983; Stalmans *et al.* 2004). (ii) Landscape of limestone soils: also conventionally designated by *Mopane* on calcrete, covers 415,890 ha (38.8%) of the LNP area and is distributed on both sides of the Shingwedzi River Valley, particularly in steep slopes and limestone ravines (Stalmans *et al.* 2004). Soils are shallow, mainly consisting of limestone, with about 10% of the soil surface covered by rocks and pH ranging from 7.9 to 8.4 (Van Rooyen *et al*. 1981). (iii) Landscape of rhyolite shallow soils: also conventionally designated by Lebombo north, occurs in the West of LNP along the Shingwedzi River covering about 39,878 ha (3.5%) of the park (Stalmans *et al*. 2004). The surface layer is extremely stony with shallow soils derived from rhyolite, with about 80% being covered by stones and rocks, and in many cases it is not considered as a soil type (Van Rooyen *et al*. 1981; Stalmans *et al.* 2004).

One motivation to study the chosen area was the dependence on natural resources as a subsistence means for the population living within the LNP being extremely high, which translates into increasing pressure on the ecosystem and its long-term sustainability (MITUR 2003; Stalmans *et al.* 2004).

Acquiring satellite imagery and pre-processing

The satellite images were provided from Landsat 8 satellite (OLI and TIRS sensors) free of charge from the United States Geological Survey (USGS) website (USGS 2013). Considering that LNP is spatially located in several images of the satellite platform, three (3) images were acquired to compose the mosaic (Tab. 1). Image pre-processing consisted of: (i) radiometric corrections using satellite band metadata such as sun elevation (degree) and image data acquisition; and (ii) band combinations (Bands 4, 3 and 2; red, green and blue, respectively), both using Envi 5.0 and ArcMap 10.3 software (Lillesand & Kiefer 2000; Du *et al.* 2002; Cohen *et al.* 2003; Song & Woodcock 2003; Coppin *et al.* 2004). The last software was only used to cut the satellite images mosaic to obtain the park's feature using the clip raster function in the Arcmap 10.3 (ESRI 2011). The Marzoli (2007) shapefile was used for this park edge cutting.

A visual analysis of regions of interest (ROIs) was also performed, in which the units of provisional land use and land cover were obtained. Determining the potential LNP land uses was based on the FAO (2010) classification. Thus, six (6)

Table 1 – Satellite images metadata details used to compose a mosaic in Limpopo National Park, Mozambique, Southern Africa.

	Image I	**Image II**	**Image III**
Path	168	168	169
Row	77	76	76
Acquisition data	5/05/2014	5/05/2014	15/04/2014
Cloud cover	0.04	0.02	0.01

types of land use and land cover were identified, namely: Shrubland (Sh), Grassland (Gr), Open forest (OF), Deciduous forest (DF), Evergreen forest (EF) and Human settlement (HS). The latter combines dwellings, infrastructure and cultivation fields.

Sampling and classification of satellite images

After elaborating the preliminary map, 69 confirmation points were allocated ranging from 11 to 12 sample points per elaborated preliminary class in order to compare with the ground reality, and thus enable greater precision for the final map. The supervised classification was used through the Maximum Likelihood classifier in the Envi 5.0 software, assuming a description of the types of forest cover and current land use found on the confirmation points (Langley *et al.* 2001; Tso & Olsen 2005; Jensen 2005; Saba *et al.* 2010). Thus, combinations were made between FAO (2010) vegetation physiognomy classification and reality found in the field to compile the final map.

Validation and accuracy assessment

An error matrix was constructed for map validation, which represents the distribution of correctly and erroneously classified pixels. This matrix is used to evaluate the result of a classification in order to verify the quality of data contained in a classification (Stuart *et al*. 2006; Lu & Weng 2007; Lillesand *et al.* 2008). In this matrix, columns are usually taken as correct (reference data) and lines are used to show what has been classified on the map or in generated classification of remote sensing data (Congalton *et al*. 1998; Lillesand *et al.* 2008). In order to evaluate the thematic accuracy, Landis & Koch (1977) proposed: (i) Kappa index (K), (ii) Overall accuracy index (OA), (iii) omission error (OE), and (iv) Commission error (CE). The relationship between these data sets is usually summarized in an error matrix or a contingency table (Lillesand & Kieffer 1994; Saba *et al.* 2010).

Floristic characterization

The floristic survey consisted in stratified sampling by landscape type. Twelve sample points representing the three (3) main landscapes types present in LNP were allocated, making up four (4) points for each landscape. Data collection was based on the Point-Quadrant Method, in which the following parameters were measured within each plot for the nearest tree/shrub in each of the four quarters surrounding the central recording: (i) base diameter at ground level for individuals ≤ 2 m high; (ii) diameter at breast height for individuals > 2 m high; and iii) the tallest tree/shrub. All were identified according to APG IV (APG 2016). Each sampling point had six (6) transepts of 160 m each consisting of pairs, thus forming three (3) pairs and equidistantly spaced apart by 200 m (Trollope & Potgieter 1986; Durigan 2003; Freitas & Magalhães 2012). Each transect presented four (4) plots, thus making eight (8) plots per pair and 24 plots at the sampling point (Fig. 1), totaling 96 plots sampled for the three (3) landscape types.

Vegetation data were quantitatively analyzed in terms of relative density, relative frequency, and relative dominance, from which the importance value index (IVI) was calculated. The species names which compose the mapped communities correspond to those that presented the highest ecological importance value (IVI). Thus, the community consists of high IVI species which differed significantly (Tukey 5%) from other species. In the case where two or more species is representing the community, there did not differ significantly in the IVI.

The sampling was simultaneously performed to the mapped land cover classes (Phytophysiognomies) as a way of giving details about the floristic composition, so the final community map had both data sets incorporated (Phytophysiognomies and their corresponding composition). This was performed in Arcmap 10.3 through overlapping geographical coordinate plots (where the floristic characterization was done) with mapped physiognomy polygon class area.

Results and Discussion

The elaborated final map in World Geodetic System (WGS) 84 *datum* presents 13 floristic community classes (grouped by preliminary land use and land cover classes and species composition) (Fig. 2).

Among the resulting classes, Open Forest physiognomy community of *Terminalia sericea* Burch. *ex* DC./*Combretum apiculatum* Sond./ *Guibourtia conjugata* (Bolle) J.Léonard/ *Colophospermum mopane* (J.Kirk *ex* Benth.) J. Léonard presented the largest coverage area with about 2,458 km^2, making up 24.37% of LNP area. Species coverage results corroborate studies done by Martini *et al.* (2016) in Gonarezou Park, Zimbabwe (adjacent area to LNP), where they found greater representativeness of *Colophospermum mopane* in the mapped classes. Bila & Mabjaia (2012) found the same result around the study area with 86.68 % of importance value index (IVI). Although *C. mopane* presents wide distribution in the park, this does not occur in a restricted way; it occurs associated with other species such as *Combretum apiculatum*, *Terminalia sericea*, and *Guiboutia conjugata*, among others (O'connor 1998; Sebego *et al*. 2008; Gandiwa & Kativu 2009; Ribeiro *et al.* 2010). On the other hand, *Acacia xantophloea*/*Faderbia alba* and *Androstrachys jonsonii* did not occur in association with *C. mopane*, which may be due to the soil type that these species occur in (O'connor 1998; Gandiwa & Kativu 2009; Gandiwa *et al.* 2011).

The greater representativeness of *C. mopane* in the mapped communities is due to this species possessing physical characteristics and physiological mechanisms to tolerate water stress and high temperature conditions, demonstrating wide niche amplitude of this species in the ecosystem (Hempson *et al.* 2007; Makhado *et al.* 2014). Despite disturbances caused by fire and herbivory activities by megafauna, this species can survive due to its high capacity for regrowth and production of inhibitory chemical substances against herbivores. On the other hand, its wood calcium oxalate crystals contribute to higher density as well as fire resistance (Mlambo & Mapaure 2006; WhiteCross *et al*. 2012; Stevens *et al*. 2014).

Human occupation accounts for 4.2% of the park, surpassing some existing floristic community areas (Tab. 2). The Open Forest physiognomy community of *Acacia tortilis* Hayne/ *Colophospermum mopane* (J.Kirk *ex* Benth.) J. Léonard/*Terminalia sericea* Burch. *ex* DC./ *Guibourtia conjugata* (Bolle) J. Léonard presented the most human settlements in its surroundings. Anthropogenic disturbances can cause a change in the forest structure, species composition and changes in landscape patterns, causing lower resilience to extreme natural phenomena events such as cyclones and fire (Thompson *et al.* 2002;

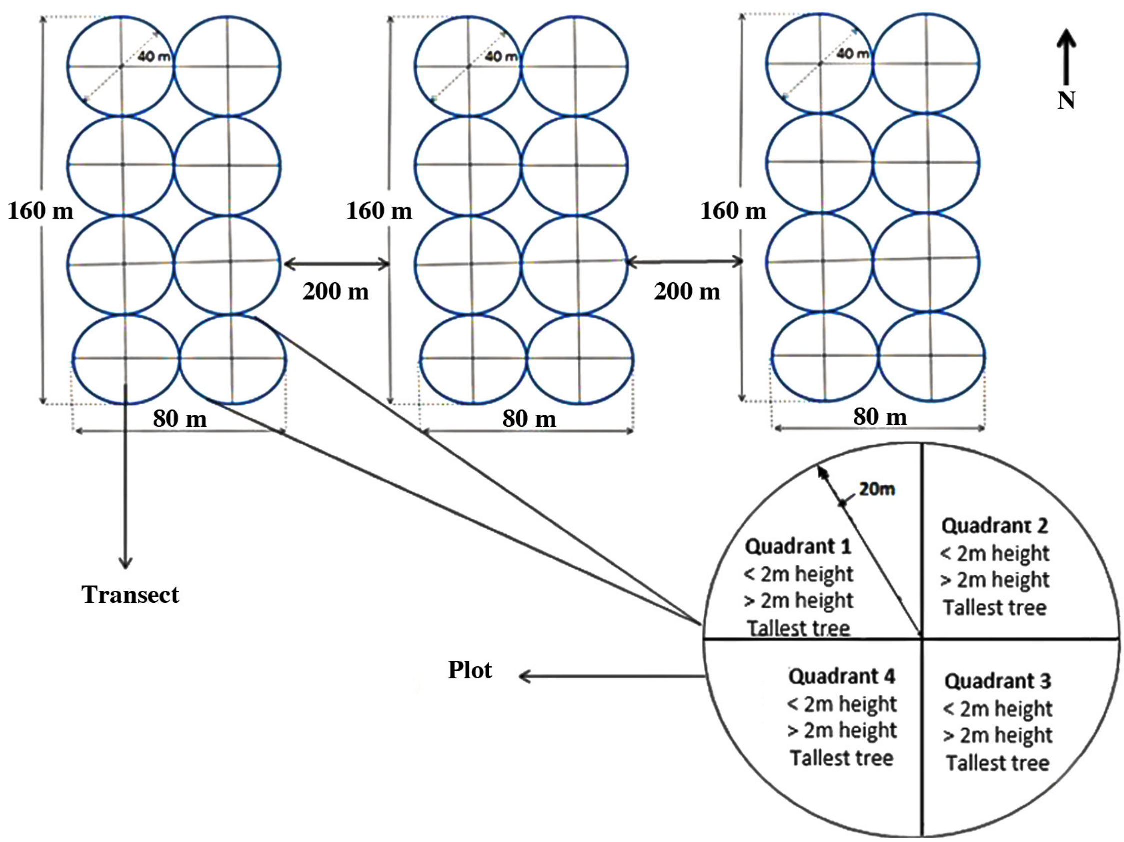

Figure 1 – Distribution of plots for floristic survey in Limpopo National Park, Mozambique, Southern Africa.

Chazdon 2003; Echeverría *et al.* 2007). Some studies have demonstrated a negative effect among traditional LNP communities and the local biodiversity coexistence. Everatt *et al.* (2014) found declining lion populations due to interaction with domestic animals from disease transmission and dynamics in predator-prey relationship, while other authors have reported an intense conflict between local communities and elephants (Wolmer 2003; Milgroom & Spierenburg 2008; Dunham *et al.* 2010; Witter 2013; Cook *et al.* 2015).

In contrast, coexistence between traditional communities and the local flora comes from longer periods, even before LNP became a conservation area (MITUR 2003; Massé 2016; Givá & Raitio 2017; Conceição *et al.* 2017). This anthropogenic occupation is accompanied through their habits, customs and cultural values, and it could explain the current landscape dynamics shaped by fire used by the local communities for subsistence purposes (MITUR 2003; Archibald *et al.* 2012; Archibald 2016; Massé 2016). In spite of being an anthropogenic disturbance, fire is a very important and essential event for African savanna dynamics, acting on pyrophytic seed germination, as well as facilitating tree and grass coexistence (Bond & Keeley 2005; Foster *et al.* 2017). However, its frequency and intensity should be controlled so as not to damage biodiversity (Bond & Keeley 2005; Lloret *et al.* 2005; Just *et al.* 2016; Foster *et al.* 2017). Thus, mapping floristic communities demonstrates the spatial dimension of human occupation and resource use. Not only, but also identification of floristic communities, associated with anthropogenic activities, such as fire, allowing park's managers to prioritize conservation actions (Ribeiro *et al.* 2019).

The digital classification accuracy was explained using Overall accuracy and Kappa index (Tab. 3). Overall accuracy was 74%, which

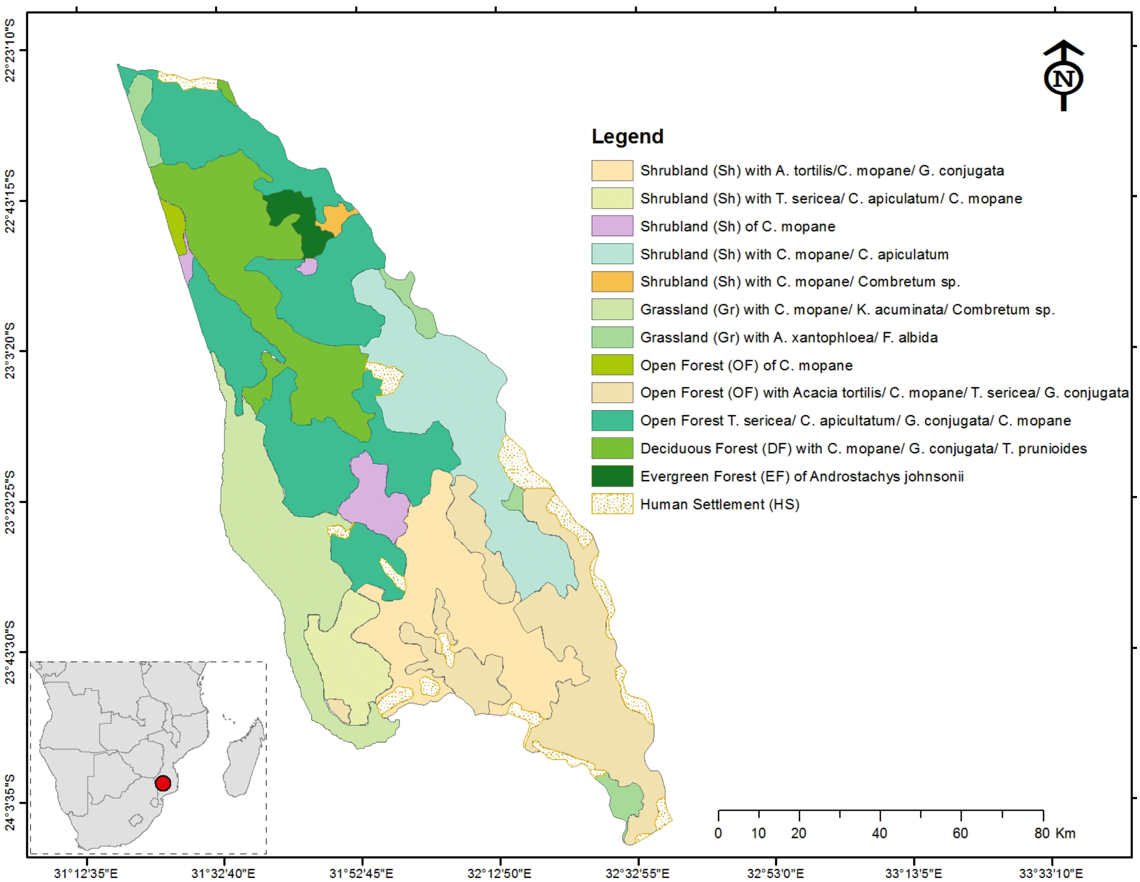

Figure 2 – Floristic communities classes mapped by World Geodetic System (WGS) 84 datum in Limpopo National Park, Mozambique, Southern Africa.

Table 2 – Floristic communities classes by occupied area in Limpopo National Park, Mozambique, Southern Africa.

Classes	**Area (km²)**	**Coverage (%)**
Open Forest (OF) with *Terminalia sericea* Burch. *ex* DC. / *Combretum apiculatum* Sond. / *Guibourtia conjugata* (Bolle) J.Léonard / *Colophospermum mopane* (J.Kirk *ex* Benth.) J.Léonard	2458	24.37
Open Forest (OF) with *Acacia tortilis* Hayne / *Colophospermum mopane* (J.Kirk *ex* Benth.) J.Léonard / *Terminalia sericea* Burch. *ex* DC. / *Guibourtia conjugata* (Bolle) J.Léonard	1533	15.20
Deciduous Forest (DF) with *Guibortia conjugata* (Bolle) J.Léonard / *Terminalia prunioides* M.A.Lawson	1204	11.94
Shrubland (Sh) with *Colophospermum mopane* (J.Kirk *ex* Benth.) J.Léonard / *Combretum apiculatum* Sond.	1184	11.74
Shrubland (Sh) with *Acacia tortilis* Hayne / *Colophospermum mopane* (J.Kirk *ex* Benth.) J.Léonard / *Guibourtia conjugata* (Bolle) J.Léonard	1161	11.51
Grassland (Gr) with *Colophospermum mopane* (J.Kirk *ex* Benth.) J.Léonard / *Kirkia acuminata* Oliv. / *Combretum apiculatum* Sond.	1050	10.41
Human Settlements (HS)	425	4.21
Shrubland (Sh) with *Terminalia sericea* Burch. *ex* DC. / *Combretum apiculatum* Sond. / *Colophospermum mopane* (J.Kirk *ex* Benth.) J.Léonard	360	3.57
Shrubland (Sh) of *Colophospermum mopane* (J.Kirk *ex* Benth.) J.Léonard	250	2.48
Grassland (Gr) with *Acacia xanthophloea* Benth. / *Faidherbia albida* (Delile) A.Chev.	243	2.41
Evergreen Forest (EF) of *Androstachys johnsonii* Prain	133	1.32
Open Forest (OF) with *Colophospermum mopane* (J.Kirk *ex* Benth.) J.Léonard	45	0.45
Shrubland (Sh) with *Colophospermum mopane* (J.Kirk *ex* Benth.) J.Léonard / *Combretum sp.*	41	0.41
Total	**10087**	**100**

means that the probability of obtained classes from satellite images reflects 74% of the ground reality. However, according to Congalton & Green (2019), overall accuracy is an index which overestimates the classification accuracy, and the Kappa index would be a more appropriate assessment since it incorporates information from poorly ranked pixels, not just overall accuracy (Lillesand & Kiefer 1994; Breiman 2001; Rapp *et al*. 2005). Commission error was higher in the EF class, about 33%, which means that two (2) of the three (3) pixels of this class on the thematic map were correctly classified, and one (1) was wrongly classified; which means they have been included in this class until they belong to them. On the other hand, this error was lower in the OF class because only one (1) of the eight (8) existing pixels is wrongly included in this class. The largest omission error was 36%, and this was in the OF class. This means that seven (7) of the eleven pixels in this class were correctly classified, and the remaining four (4) were wrongly classified (excluded from this class). However, this error was lower on Gr class, where only two (2) of the 14 existing pixels were excluded from this class.

The Kappa index was 68%, ranging between 60 to 80% of this index, and indicating that the classification is good (Breiman 2001; Lillesand *et al*. 2008; Congalton & Green 2019). Although this index could be higher, the accuracy depends on several factors such as terrain complexity, spatial and spectral resolutions of the sensor system, classification algorithm itself and the number of sampling points (Landis & Koch 1977; Crósta 1992; Moreira 2003; Schowengerdt 2007).

Table 3 – Error Matrix representing the distribution of classified pixels (vegetation physiognomy) for validation in Limpopo National Park, Mozambique, Southern Africa.

	Ground truthfulness							
Classes	**HS**	**Gr**	**Sh**	**OF**	**DF**	**EF**	**Total**	**OE (%)**
HS	14	2	1	0	1	1	19	26
Gr	0	12	0	0	2	0	14	14
Sh	0	1	5	0	1	0	7	29
OF	3	0	0	7	1	0	11	36
DF	0	1	1	1	11	0	14	21
EF	1	0	0	0	0	2	3	25
Total	18	16	7	8	16	3	**69**	
CE (%)	22	25	29	13	31	33		
Overall accuracy: 74%								Kappa (K): 68%

Conclusion

Colophospermum mopane presents wide distribution in the park which does not occur in a restricted way, but is associated with other species, demonstrating a wide niche amplitude of this species in the ecosystem. The elaborated map presents much information regarding different physiognomies and floristic compositions of the park. Therefore, it is recommended that LNP managers use this information for fire management since the park is frequently devastated by fires, as well as deepening studies on the effect of burning in these floristic communities. On the other hand, the map information shows that areas of human occupation are larger than some floristic communities; these anthropogenic activities must be evaluated so that they do not harm the park's biodiversity conservation. Thus, it is reasonable to suggest that communities without human presence, especially the smaller communities, should be given priority actions for their conservation.

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