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USE OF LANDSAT IMAGERY TO MAP SPREAD OF THE INVASIVE ALIEN SPECIES *Acacia nilotica* IN BALURAN NATIONAL PARK, INDONESIA

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ABSTRACT

In the late 1960s, *Acacia nilotica* was introduced to Baluran National Park to establish fire breaks which would prevent the spread of fire from Baluran Savanna to the adjacent teak forest. However, *A. nilotica* has spread rapidly and has threatened the existence of Baluran Savanna as it has caused an ecosystem transition from an open savanna to a closed canopy of *A. nilotica* in some areas. This study is one of the few that examines *A. nilotica* invasion in Baluran National Park through remote sensing. Land cover dynamics were quantified using a supervised classification approach on Landsat 7 and 8 multi-spectral images. Results showed that savanna and *A. nilotica* can be recognized using a composite of bands 6, 5 and 3 of the Landsat 8 image. Across a 14-year period (2000-14), *A. nilotica* has spread far north and south from its originally introduced location, invading not only savannas, but also dry forests in the Baluran National Park. The savanna size has decreased by 1,361 ha, meanwhile the *A. nilotica* stand has increased by 1,886 ha over this period. Spatial distribution of *A. nilotica* in Baluran National Park showed a clumped pattern. *Acacia nilotica* which develops into a homogeneous stand in the north-west and eastern parts of the national park occupied an area of 3,628 ha or about 14.5% of the total area. This study has demonstrated that remote sensing technology can be effectively used to estimate the patterns of distribution and amount of *A. nilotica* cover change over the whole Baluran National Park. This is one advantage of remote sensing and GIS, as it is difficult and expensive to make such direct assessments using the conventional approach of field survey and vegetation analysis.

Keywords: *Acacia nilotica*, Baluran National Park, remote sensing, supervised classification

INTRODUCTION

The role of remote sensing (RS) and geographical information systems (GIS) in fire and vegetation management has now been recognized as commonplace with studies involving mapping and analyzing fire history (Adab *et al.* 2013; Kanga *et al.* 2014; Sivrikaya *et al.* 2014). For instance, in order to create the forest fire models using multitemporal satellite image Aster data of 2001, IRS LISS-III data of 2009 and physics parameters (metrological, topographical and forest type-density) in Shimla district-India (Kanga *et al.* 2014). Sutomo and van Etten (2017) used a GIS for predictive vegetation mapping using models that linked vegetation units to map environmental variables across the extensive areas. Furthermore, to test whether remote sensing was capable of capturing the spatial pattern of plant strategy types, a connection between the three main ecological strategies of plants and their canopy reflectance were set up by Schmidtlein *et al.* (2012). Apparently, all three primary strategy types could be mapped using remote sensing. A considerable volume of information has been disseminated on the use of RS/GIS in savanna ecosystems (Sano *et al.* 2010; Levin *et al.* 2012; Mishra & Crews 2014; Reza 2014; Salako *et al.* 2017; Sutomo & van Etten 2018), yet, less studies have addressed the use of RS/GIS in mapping invasive alien plant species, especially in savanna-dominated landscapes.

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Figure 1 Stand of *Acacia nilotica* in Bekol Savanna Baluran National Park, Indonesia

Acacia Mill. is the main genus in the Leguminosae-Mimosoideae with roughly 1,200 species distributed mostly in tropical and subtropical regions (Abari *et al.* 2012). *Acacia nilotica* is a dominant colonizer in many parts of the world including protected areas such as Baluran National Park in East Java Province, and Wasur National Park in Papua (Padmanaba *et al.* 2017). Baluran National Park covers a vast area of 25,000 ha and mostly consists of savanna and dry forest. The exotic *A. nilotica* was introduced into Baluran National Park in the late 1960s to create fire breaks to prevent fires spreading from Baluran Savanna into the adjacent teak forest. However, *A. nilotica* has recently spread rapidly and been threatening the existence of Baluran Savanna and changing some areas of these open savannas into closed canopies of *A. nilotica* (Fig. 1) (Padmanaba *et al.* 2017; Sutomo *et al.* 2016b). Based on modelling, global climate change is likely to increase the potential distribution of *A. nilotica* in Indonesia, increasing the area at risk of invasion (Sutomo & van Etten 2017; Sutomo *et al.* 2016b). Due to the loss of browsing and grazing fields this change in condition has also threatened the large mammals of Baluran Savanna such as the barking deer (*Muntiacus muntjak*), sambar deer (*Cervus unicolor*) and banteng or wild ox of Java (*Bos javanicus*) (Sutomo 2016).

This study is one of the few studies of its kind that examines *A. nilotica* invasion in Baluran National Park through remote sensing. Although a spatial analysis of *A. nilotica* invasion covering areas in Baluran National Park was conducted, the study was not based on Landsat images and did not provide information of *A. nilotica* coverage change. Other field studies on *A. nilotica* which partly took place in Bekol savanna, Baluran National Park, were also conducted yet, ignored the capabilities of remote sensing analysis (Caesariantika *et al.* 2011; Djufri 2012). Another study (Siswoyo 2014) in the national park used Landsat images, but the assessment was only on one particular year with no information on *A. nilotica* cover changes. A combined field and GIS study (Sutomo *et al.* 2016b) provided information about the changes in *A. nilotica* stands, but only covered the Bekol savanna area. Therefore, the objectives of this paper were to provide information on the distribution of the invasive alien species (IAS) *A. nilotica* over the whole Baluran National Park using Landsat images analysis and to calculate the changes in the savanna and *A. nilotica* covers following 14 years of invasion (2000-2014).

MATERIALS AND METHODS

Baluran is a low plateau in the rain shadow of mountain ranges located at the north-east tip of East Java. The area has been used for hunting since the 1900s. In 1937, the Dutch Government proclaimed this area as a wildlife reserve (decree GB. No. 9 dated 25 September

1937 Stbl. 1937 No. 544) to conserve large mammals, mainly wild ox of Java, also known as banteng (*Bos sundaicus*), that had already inhabited the surrounding areas. This decree was then reinstated by the Indonesian Agriculture Minister in 1962 (decree No. SK/II/1962 dated 11 May 1962) and then it was proclaimed as a national park in 1980. Baluran National Park covers a vast area of 25,000 ha and it is located in Situbondo District, East Java Province. Its northern border is the Madura Strait and its eastern border is the Bali Strait.

Satellite images of Baluran National Park for the year 2000 and year 2014 were downloaded from Landsat 8 and Landsat 7 (http://earthexplorer.usgs.gov/) path 117, row 065 (Table 1). The images downloaded were selected because these were either not covered by clouds or had minimal amounts of the cloud cover and had level 9 image quality (no errors detected, perfect scene). Images were both selected in the middle of the dry season when differences between forest and savanna would likely be more acute.

Table 1 Details of images downloaded for remote sensing analysis

Images	Landsat satellite	Date acquired	Spatial resolution (meters)	Image quality	Path/Row	Cloud cover (%)	Total band	Image band stacked	Sensitivity
1	7	07/09/2000	30	9	117/065	25.83	8	2(G) 4 (NIR-1) 5 (NIR-2)	8 bit/pixel
2	8	12/10/2014	30	9	117/065	19.43	11	3 (G) 5 (NIR) 6 (SWIR-1)	12 bit/pixel

Notes: G = Green; NIR = Near-Infrared; SWIR = Shortwave Infrared

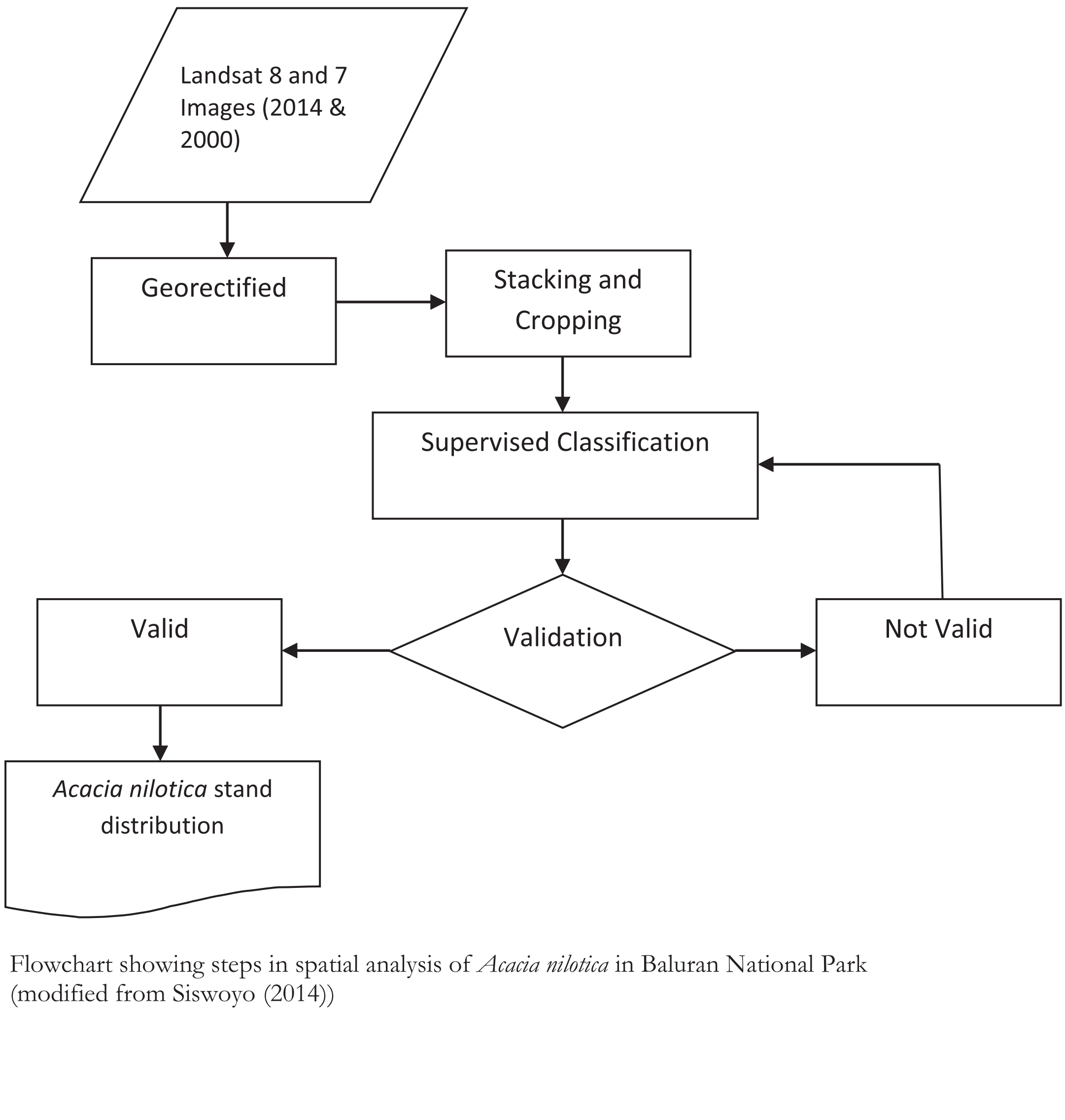


Figure 2 Flowchart showing steps in spatial analysis of *Acacia nilotica* in Baluran National Park (modified from Siswoyo (2014))

The ground survey was done in October 2014 with a total of 60 sites placed randomly in three different vegetation types, namely savanna, dry forest and *A. nilotica* stand. The presence-absence of *A. nilotica* was recorded and the geographical position was marked at the centre of each plot with a GARMIN handheld GPS. Landsat images used were georectified to reduce geometric distortion (Fig. 2). For Landsat 8, the bands 6 (1.57-1.65 μm), 5 (0.85-0.88 μm) and 3 (0.53-0.59 μm) were then used and for Landsat 7, the bands 5 (1.55-1.75 μm), 4 (0.77-0.90 μm) and 2 (0.52-0.60 μm) were chosen and each of these bands were composited into the RGB (Red-Green-Blue) image system. These bands were chosen as they are widely used and recommended to map contrasting vegetation types (such as savanna and forest; Barsi *et al.* 2014). These results were then loaded as RGB images and used as the basis for classification (Fig. 2). After layer stacking, the image was cropped so as to include the whole Baluran National Park area. Pan-sharpening was then processed using band 8 panchromatic to enhance and sharpen the composite images facilitating determination of the region of interest on classification since it has a more detailed spatial resolution.

Classification of savanna, forest and *A. nilotica* stand were conducted using supervised classification via a maximum likelihood approach within ENVI 4.5 with the field plot data used as training sites. The classification results (map) were validated by comparing them with ground survey points and were also checked using Google Earth and field observations, and were found to be of acceptable accuracy. Once the classification was finished, each class was then converted to individual layer and saved as a shape file to be analyzed in ArcGIS 10.1. The data layers were projected into datum WGS 1984, with the map projection being Universal Transverse Mercator, Zone 49 South. The size of each area/class was then calculated in ArcGIS for each image (year 2000 and 2014) to obtain quantitative information on the coverage of various land cover types and on the change in *A. nilotica* cover in Baluran National Park over the 14 years study period.

RESULTS AND DISCUSSION

Savanna was clearly shown in the image as a mix of bright glossy white and light to semi-dark purple-ish colors, while *Acacia nilotica* stands were represented as a mix of semi-dark green and light to dark brown (Fig. 3). The spatial pattern of *A. nilotica* vegetation cover consisted of a low density of green spots on a light brown background because it was influenced by the open leaf architecture of the *A. nilotica* trees occurring over dry grass or exposed soil of the underlying savanna (images were taken during the dry season when grasses were cured or dead). Overall (total) accuracy of the classification was 83% (Table 2). In terms of user accuracy (proportion of map predictions which were correct), the highest was *A. nilotica* stand (88%). In terms of producer accuracy (the proportion of reference sites accurately predicted by the map), the highest was savanna (100%) followed by *A. nilotica* stand (83%) and dry forest (75%).

Table 2 Accuracy test of the produced map

Field \ Satellite Image	*Acacia nilotica* stand	Savanna areas	Dry forest	Total	UA (%)	PA (%)	OE (%)	KE (%)	Mapping accuracy (%)
Acacia nilotica stand	15	0	2	17	0.88	0.83	0.12	0.17	0.87
Savanna areas	1	7	2	10	0.10	1.00	0.30	0.00	0.68
Dry forest	2	0	12	14	0.14	0.75	0.14	0.25	0.83
Total	18	7	16	41					0.83

Notes: UA = user's accuracy, PA = producer's accuracy, OE = omission's error, KE = commission's error.

In the year 2000, *A. nilotica* mainly occurred around the Bekol Savanna area and its surrounds (Fig. 4). Fourteen years later, *A. nilotica* has spread far north and also south of the national park areas, invading not only savannas, but also dry forests (Fig. 4). Over the same period, the savanna size decreased from approximately 6,510 ha in 2000 to 5,149 ha in 2014 (a decline of 1,361 ha) (Fig. 5). In contrast, the *A. nilotica* stand area has increased by around 1,886 ha (from 1,742 ha in 2000 to 3,628 ha in 2014, some 108% increase) (Fig. 5). The spatial distribution of *A. nilotica* over the whole Baluran National Park shows a highly clumped pattern (Fig. 4), occurring as patches of dense stands in distinct parts of the park. Landsat 8 image analysis for October 2014 indicated that *A. nilotica* grows as homogeneous stand in north-west and eastern parts of the national park (Fig. 6). In 2014, *A. nilotica* occupied an area of 3,628 ha, equal to 14.5% of Baluran National Park total area.

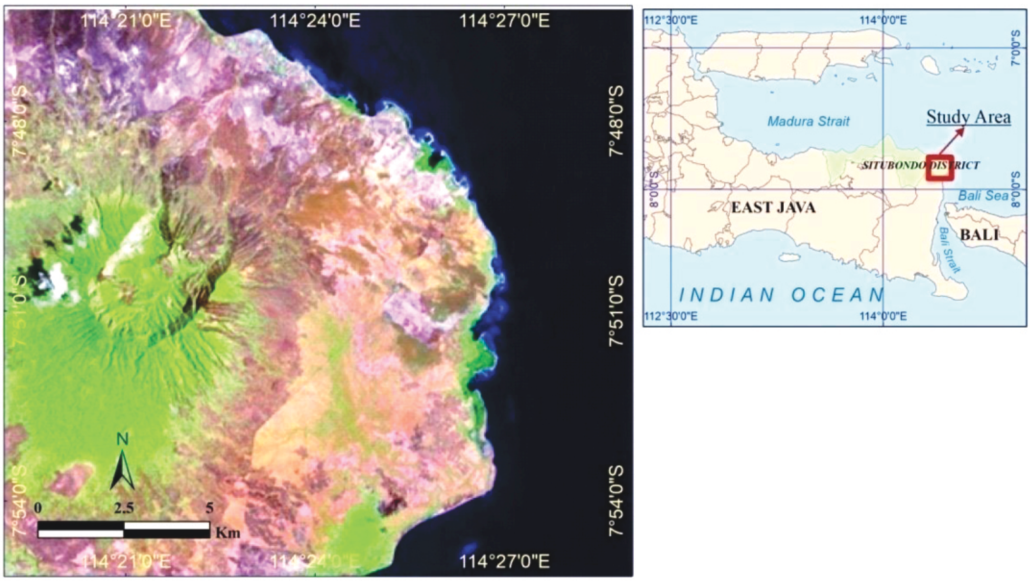
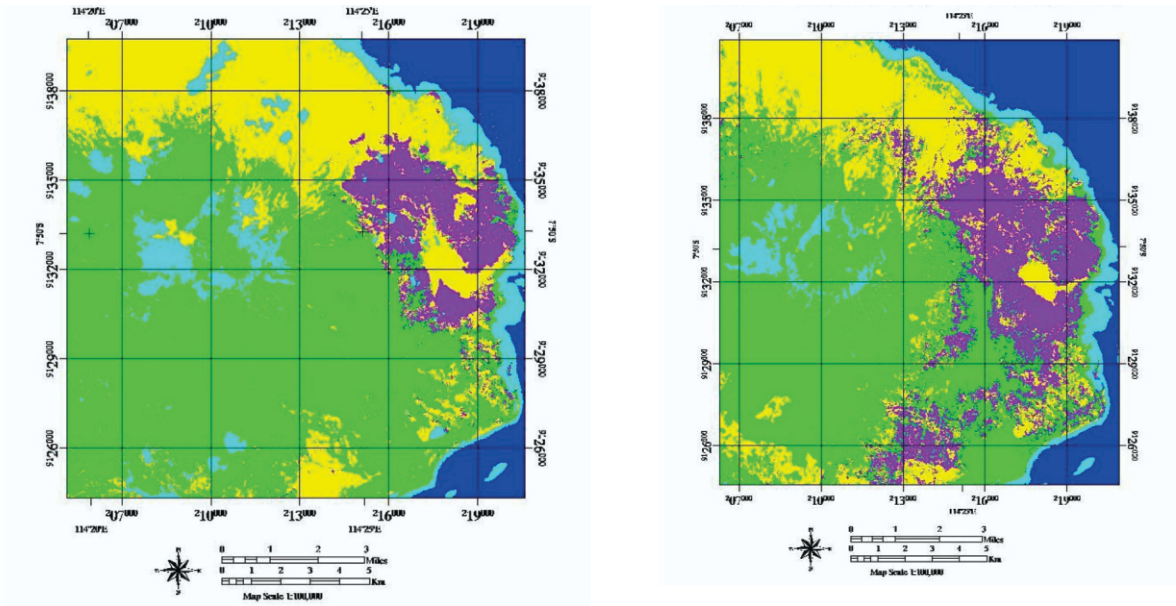


Figure 3 Different colors and patterns of savanna and distinct *Acacia nilotica* stand was shown in this combination of band 6, 5 and 3 of Landsat 8 image of Baluran National Park in 2014



A B

Figure 4 Expansion of *Acacia nilotica* stands in Baluran National Park over 14 years. Left (a) – *A. nilotica* distribution in 2000, right (b) - *A. nilotica* distribution in 2014. Yellow area in the middle is Bekol savanna area, purple area is *A. nilotica* area and green color is forest

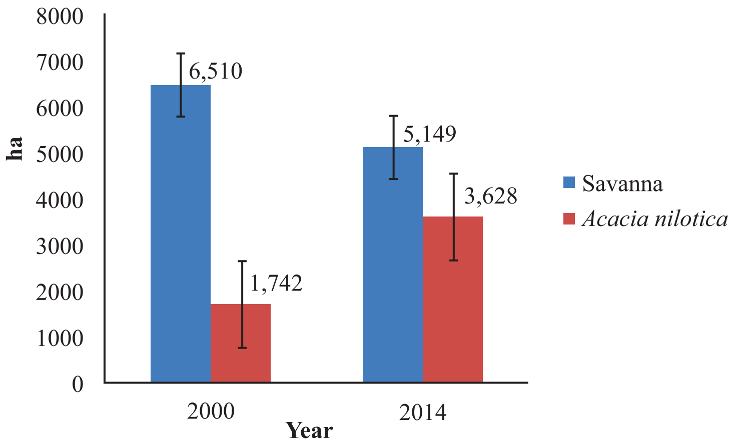


Figure 5 Changes in area size (data extracted from the created map) for savanna and *Acacia nilotica* stand between year 2000 and 2014 in Baluran National Park

The estimated area of the *A. nilotica* stand in this study is likely to be smaller than actual occurrence in the field and this is reflected in the accuracy assessment data shown above. This is because Landsat images cannot identify *A. nilotica* that grows individually or in small clumps that may be smaller than the Landsat image pixel size. The pixel size of the Landsat images is 30 x 30 m, which means that only vegetation type or *A. nilotica* stand that has the size at least 500 m^2 can be detected as one pixel (Siswoyo 2014). If it is 500 m^2 out of 900 m^2 (the pixel size), it will be the dominant type and therefore, will be classified as *A. nilotica*. In other words, *A. nilotica* needs to be the dominant cover type in a pixel for it to be recognized as *A. nilotica* cover.

Using remote sensing analysis, a supervised classification of Landsat image from the year 2000 and 2014 shows a decrease in savanna areas and corresponding increase of *A. nilotica* stand in Baluran National Park. *A. nilotica* has clearly spread rapidly over the 14 years and has mainly invaded areas of savanna. The thickening of *A. nilotica* over this period has also converted much of this savanna vegetation into dense stands of *A. nilotica* which are now growing in a structurally homogeneous and mostly single-species stand in the northwest and eastern parts of the national park. In the year 2000, *A. nilotica* mainly occurred in a lowland area around the Bekol Savanna area and its surrounds. Fourteen years later *A. nilotica* spread far north and also south of the national park areas, invading not only savannas but also dry forests.

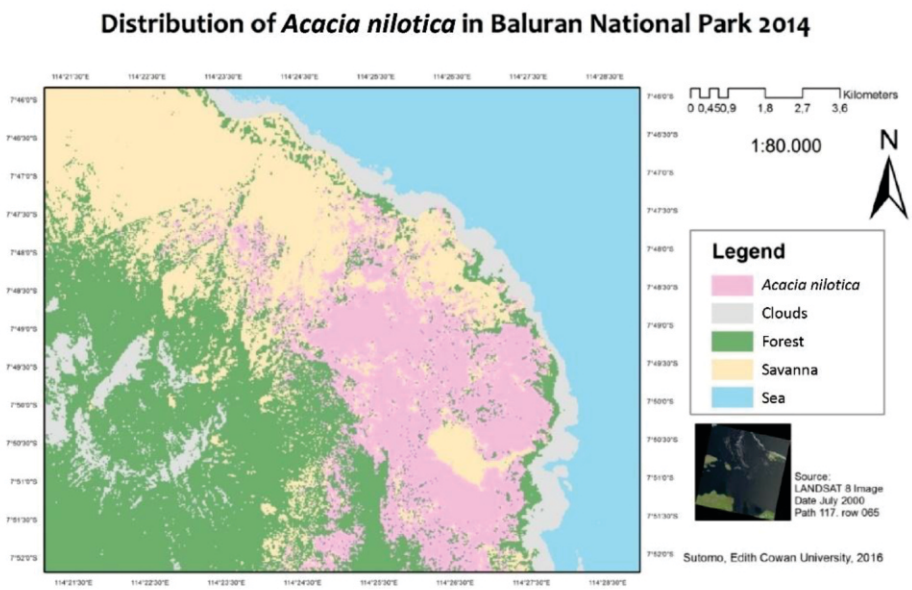


Figure 6 Distribution of *Acacia nilotica* stands in 2014 in Baluran National Park

Acacia nilotica was first planted in Bekol Savanna area in the 1960s (Siswoyo 2014). A study using field mapping and spatial analysis in GIS, reported that in one-year period the savanna area in Bekol Savanna has decreased due to the invasion of some 85 ha new *A. nilotica* stands (Sutomo *et al.* 2016b). These newly expanded areas mainly consisted of *A. nilotica* saplings and seedlings. This area also contained other less dominant woody species such as *Azadirachta indica, Ziziphus rotundifolia, Thespesia lampas, Polytrias amaura* and *Dichanthium coricosum*. Few other studies documented other locations where *A. nilotica* had been expanding, such as in *Balanan, Kramat* and *Curah Udang* (Sutomo 2016; Sutomo *et al.* 2016b; Siswoyo 2014).

Besides the dry forest, the lowland savanna area is an important habitat for large mammal grazers, such as wild buffalo, deer and wild ox of Java (also known as banteng). Invasion of *A. nilotica* in these areas is likely to lead to changes in the feeding behavior of these grazers and may also cause the spread of this invasive species further into the national park. *Acacia nilotica* is mostly unpalatable to these herbivores as this plant possesses thorny spikes on its branches making it difficult for the herbivores to consume the leaves. However, the pods that dropped to the ground are usually consumed by herbivores during the prolonged dry period when fresh shoots of grasses and other herbs are scarce. At the end of the wet season toward the dry season, mature *A. nilotica* pods drop from the trees and are consumed by herbivores, such as, water buffalo, thereby spreading *A. nilotica* further into the national park. A vast amount of seeds was found in buffalo stools, at approximately 166 seeds of *A. nilotica* per 100 g of buffalo stools/faecal dropping (Sutomo *et al.* 2016a).

This study actually demonstrated that remote sensing technology can effectively and accurately quantify patterns of vegetation distribution and changes in *A. nilotica* cover in Baluran National Park. The technique is likely to be suitable also for mapping and quantifying other woody plant invasion into savanna ecosystems. Remote sensing and GIS are more advantageous as they require fewer resources and are less demanding method for invasive species studies compared to the conventional approach of field vegetation survey and analysis (Sutomo & van Etten 2018). This technique has been also used in Indonesia and a range of literature has demonstrated the use of remote sensing and the available tools in GIS for various ecological studies such as for habitat suitability (Varatharajan *et al.* 2018), land use and cover (Sano *et al.* 2010; Sutomo & van Etten 2018), species conservation (Iskandar *et al.* 2012), and many others. In terms of savanna ecosystem studies, remote sensing could provide further insights into the patterns of habitat fragmentation due to invasive alien species, as well as fire events.

CONCLUSION

Remote sensing techniques were successfully applied to determine the expansion of the invasive plant *Acacia nilotica* and the decrease in savanna area within Baluran National Park. Analysis using Landsat images showed that the savanna size has decreased by 1,361 ha, while *A. nilotica* stand increased by 1,886 ha. Spatial distribution of *A. nilotica* in Baluran National Park showed a clumped pattern. *A. nilotica* which grew into a homogeneous stand in the northwest and eastern parts of the national park has occupied an area of 3,628 ha or about 14.5% of the total area of Baluran National Park.

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