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Digital Mapping Of Invasive *Acacia Mangium* Willd. Trees Along Telisai-Lumut Highway Along The Andulau Forest Reserve

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Abstract: *Invasive alien Acacia trees have become a serious environmental problem in Brunei Darussalam, spreading into the vulnerable heath and mixed dipterocarp forest ecosystem where it has started replacing the native flora and contributing to forest fire. In this work, we study the spread of Acacia trees by analyzing images taken by drones along a newly developed highway within the vicinity of Andulau Forest Reserve in Brunei Darussalam. Based on the analysis, we aim to understand the Acacia spread and its habitat preference, which will be a critical factor in planning the future roadmap to maintain a sustainable and healthy forest ecosystem, and safety from potential forest fires. The Unmanned Aerial Vehicles (UAVs) were utilized to capture high-resolution images along the Telisai-Lumut highway and were subsequently analyzed images using ArcGIS software, to map and study the Acacia's distribution and habitat preferences, which will aid in understanding of Acacia's rapid dispersion. Our preliminary results show highest Acacia density and numbers closer to the highway. The barren loose sandy soil combined with the open terrain limits local forest tree growth but seems to provide good habitat for Acacia trees. Our results suggest that the highway provides an important dispersal opportunity for Acacia trees, bringing them in direct proximity of an undisturbed forest reserve. This may increase the risk of spread of this species into the forest, and importantly, given the fire proneness of Acacia, may lead to wildfires that threaten the neighbouring forest reserve. Keeping vegetation short and removing Acacia's close to the highway may mitigate these risks. Efforts such as spreading awareness on Acacia's invasiveness, identification and removal of Acacia trees, habitat restoration projects and meticulous evaluation for any introduced species should be done.*

Keywords: Alien *Acacia*; Brunei; highway; distribution; unmanned aerial vehicle.

Introduction

Brunei's forest reserves cover ~41% of its total land area and the biodiversity of its forests is among the highest in the world [1], [2]. A main threat to this biodiversity is the introduction of invasive species, such as *Acacia*, a native of Australia. *Acacia* trees were farmed in Brunei in the early 1990's as plantation trees to help reduce erosion damage along roads following heavy rainfall [3]. *Acacia*s are known to be frequently used for soil erosion control, woodwork and other products. According to [4], *Acacia* trees in Brunei are largely spread within the coastal areas characterized by sandy soils and near settlement areas.

Brunei has an active infrastructure development program under the government vision "Wawasan 2035", which is aimed at increasing the standard of living [5]. As part of this development, the Telisai-Lumut highway was completed in June 2016 to help increase the connectivity between the east and west side of the country [6], [7], [8]. The highway was built directly adjacent to the Andulau Forest Reserve, without any buffer zone, meaning that there is now a very sharp boundary between forest and open land. Both Mixed Dipterocarp Forest and Heath Forest are found along the highway. The construction of the highway has introduced several threats for the environment such as increased roadkill, change of drainage systems, air and noise pollution, edge effects and animal and plant movement restrictions [9]. Linear clearings along tropical forests edges can also heighten the growth and spread of alien species such as Acacia trees.

Exotic Acacia trees: (i) Acacia auriculiformis A. Cunn. ex Benth.; (ii) Acacia mangium Willd.; (iii) Acacia ciccinata F.Muell., were deliberately planted after the construction of the Tutong-Muara highway in the 1990's, in an effort to rehabilitate the cleared land [3]. These Acacia trees are evergreen fast-growing trees that can grow up to 30 m tall, are found in low-elevations and are adapted to acidic and poor nutrient soils [10], [11], [12]. Due to its rapid growth and agility, the species has managed to spread widely along the coastal areas and settlements in Brunei, replacing much of the native flora. As part of a larger project that aims to map the spread of invasive Acacia trees across Brunei using remote sensing and computer recognition technologies, this paper presents the initial results of a remote sensing campaign to visually map Acacia trees in a single site along the Telisai-Lumut highway. The objectives of this paper are: a) geo-mapping Acacia trees along the Telisai-Lumut highway using RGB images taken from drones, and b) determine patterns in the spread of Acacia trees in relation to distance to the highway.

Methods

Study Site

This study was conducted in a single location along the Telisai-Lumut Highway, Brunei Darussalam (Figure. 1). The presence of A. mangium and A. auriculiformis were observed along the highway roadside. The study site was partly cleared for highway construction, with the cleared areas consisting of sandy soils with several water drainages as a consequence of erosion. Most of the open area was covered by grasses and bare soil.

Data collection

High-resolution aerial images, taken at an altitude of 80 m above ground level, with geographical positioning system (GPS) locations were captured by drone (DJI Mavic 2 Pro) using a drone configuration application called "DroneDeploy". This application allows the planning of drone flight and configuration of flight settings, so that the whole area of interest (a stretch of highway and the surrounding cleared area and forest edge) could be captured in overlapping images. These images were changed into orthophoto's (aerial image that has been geometrically corrected to a uniform scale and map projection) and combined as a single map of the study area with the use of Agisoft Metashape software.

Acacia identification and annotation in the images was done visually, using a set of ground-truthed *Acacia* trees. *Acacia* trees are relatively easy to recognize due to their specific canopy colour, which tends to be light greyish-green and differs from the dark green native vegetation. Based on this specific colour, all *Acacia* trees, and their canopy sizes were identified in the mapped area using ArcGIS pro software 3.0 to manually annotate *Acacia* trees. Each tree was captured using polygons encompassing their crown area.

Statistical Analysis

To determine the spread of *Acacia* trees, ArcGIS pro software 3.0 was used: 1) to calculate the total area of *Acacia* polygons, total number of *Acacia* polygons and density of *Acacia* polygons in 20 m distance intervals away from the highway. Linear regression analysis was used to detect significant patterns in *Acacia* polygon area, *Acacia* polygon number and *Acacia* polygon density in relation to distance from the highway.

Results

The captured study area consisted of 70% cleared area, which is also where all the Acacia trees were located as shown on Figure 1. Figure 1A shows the study area with reference to the Telisai-Lumut Highway. Figure 1B shows the location of *Acacia* trees with references to 20 m distance intervals as well as forest area boundary. No Acacia trees were detected inside the forest area.

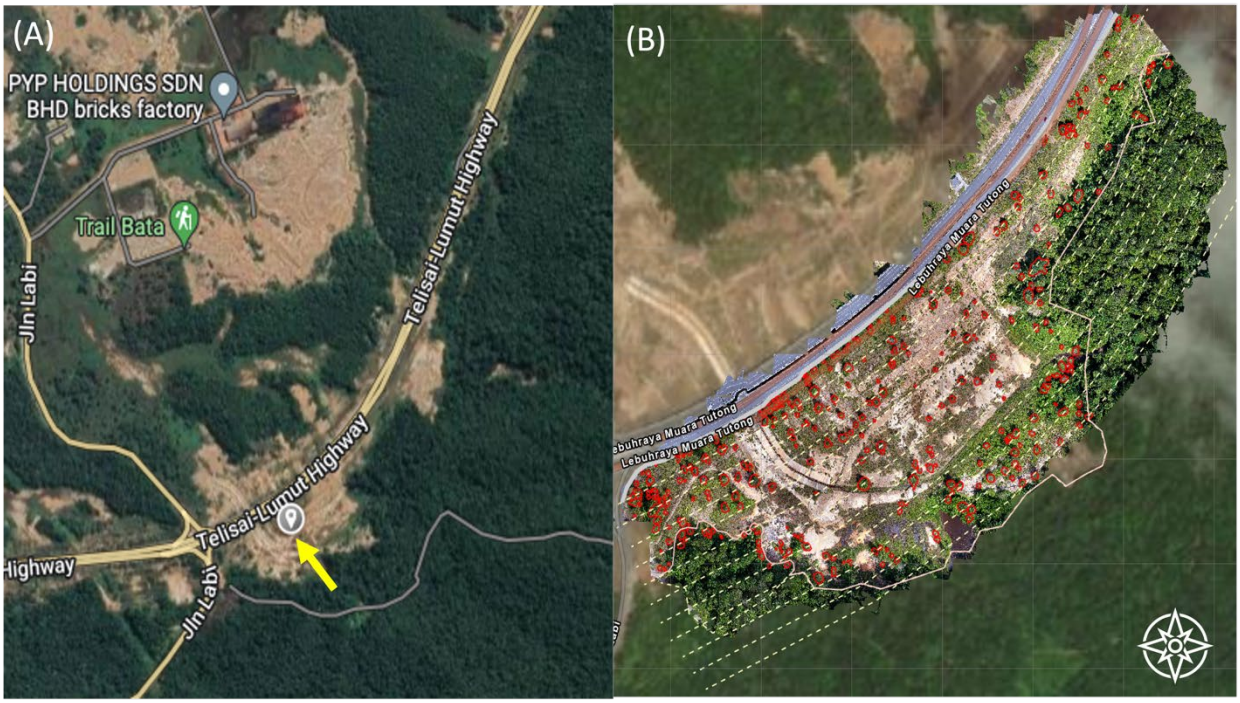

Figure 1: (A) Map of the Telisai-Lumut highway study area (yellow arrow), with (B) showing the Acacia trees as polygons (red) and the 20 m distance intervals (yellow dotted lines) used to calculate Acacia density and size in relation to distance from the highway. The solid yellow line demarks the cleared area forest boundary.

There were significant differences in the number of *Acacia* trees and the distance from the highway as shown in Figure 2A ($df= 1$, $P<0.05$). This pattern remains significant when corrected for survey area, i.e., *Acacia* tree density decreases away from the highway ($df= 1$, $P<0.05$) (Figure 2B). Interestingly, while *Acacia* tree density decreases away from the highway, *Acacia* tree size (based on average canopy sizes) increases away from the highway ($df= 1$, $P<0.05$) (Figure 2C) indicating that most young trees (recruitment) is found near the highway.

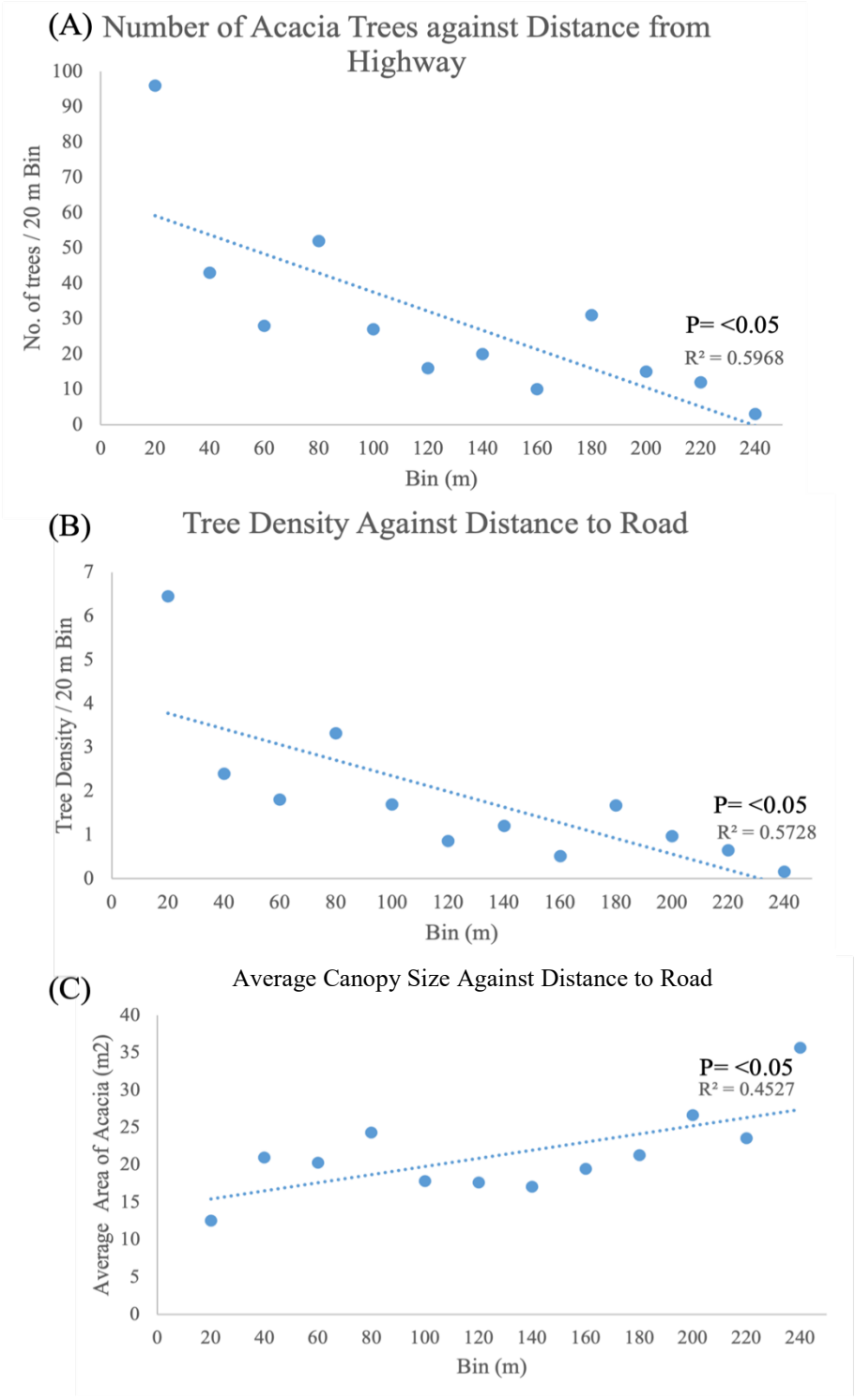

Figure 2: Scatter plots and corresponding regression lines of (A) Number of Acacia trees per 20 m Bin (B) Tree density per 20 m Bin (C) Average canopy size of Acacia per 20 m Bin

Discussions

The observed Acacia trees located closer to the roadside were smaller (based on average canopy size) than those further away from the highway as shown in Figure 2C. This shows that most Acacia recruitment is taking place near the highway, indicating that the highway serves as an important dispersal pathway for Acacia trees. Although most Acacia trees are found near the highway (Please see Figures 2A and 2B), several have managed to spread further away and have even reached the forest edge. These trees are on average larger than the ones near the highway, indicating that they are not yet recruiting in large numbers. However, over time these trees may become dispersal kernels for spread into the forest itself, although this may also depend on canopy openness of the forest as Acacia trees are light demanding and cannot establish in a shaded forest understory [13].

The biggest risk, however, is not that *Acacia* will start spreading into the forest itself, but that it will create an environment along the forest edge that is conductive of forest fires. Such forest fires may enter the forest edges and thus lead to a retreat of the forest, given the *Acacia* seeds were capable of germinating faster in burnt area by double to quadruple times [14], the open area will then be quickly regrown by *Acacia* trees. Nevertheless, *Acacia*'s are more susceptible to fire if the stem diameter is less than 10 cm [11] hence, with more new growths along the highway the higher chances of wildfires occurring. There has been attempts and plans by the Brunei Fire and Rescue Department official to create firebreaks especially along Seria-bypass where fire occur often [15], however there is no evidence that these plans are being attempted along Telisai-Lumut highway. Since forest fires usually takes place during dry season (February to April), this early detection of *Acacia* may help on alternative solutions through regeneration of the forest area [15], [16]. It is estimated that forest re-establishment may take at least four to five years for first large shoots of saplings [17] but up to a decade to restore from fire. Hence, act of reforestation will increase its probability of success.

Conclusions

Our study reveals that the Telisai-Lumut highway acts as a dispersal opportunity for Acacia trees, with very high Acacia recruitment rates near the highway and some Acacia's already reaching the forest edge. This presents an acute risk to the forest as Acacia forests tend to have high fire proneness, fires that may spread into the bordering forest reserve. It is of the utmost importance that the Acacia density be controlled along the highway, or that fire mitigation measures are taken that prevent forest fires from taking place in the first place. This may entail keeping the road edges shortly trimmed so that they do not provide fuel for fires.

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