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SHORT COMMUNICATION

FARMERS' PERSPECTIVE AND A GEOSPATIAL APPROACH ON THE DISTRIBUTION OF *Mimosa pigra*: A STUDY IN MATARA DISTRICT, SRI LANKA

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ABSTRACT

***Mimosa pigra* L. is an invasive prickly plant that has been scattered in agricultural lands in the Southern Province of Sri Lanka. This study was aimed to understand the farmers' perspectives on the spread of *M. pigra* in Matara district, Sri Lanka while uplifting awareness and estimating the distribution of the weed to support control activities. Semi-structured interviews with a pretested sample questionnaire survey were carried out among 400 randomly selected farmers among 16 Divisional Secretariats Divisions (DSDs) in the district. The spread areas of *M. pigra* were estimated using modern geospatial techniques, where images of unmanned aerial vehicle (UAV) (DJI Macvi Pro) were taken for mapping the affected area. UAV was captured 26.8 ha (5.84% of the total land area) of *M. pigra* invaded land extent in Akuressa and Malimbada DSDs. Based on the survey, 91.5 % of the farmers had no previous knowledge of controlling the particular weed. Approximately, 22.8% of the farmers expressed interest to establish *Cinnamomum* sp. as a perennial crop, and 11.8% suggested cultivating vegetables as the annuals in the areas invaded by *M. pigra*. The geospatial techniques used in this study was correctly identified the spread of *M. pigra*, which is very useful information for controlling weeds. Further research activities are suggested within the adaptive management framework and suitability of *Cinnamomum* sp. cultivation in *M. pigra* affected areas.**

Keywords: *Cinnamomum* sp., geospatial techniques, invasive plants, *Mimosa pigra*, Unmanned aerial vehicle

INTRODUCTION

Mimosa pigra (Giant Mimosa) is a native plant of Central America and becomes a serious environmental, agricultural, and economical issue in many countries since it has been introduced accidentally or deliberately (Groves 2002). It was first recorded in Sri Lanka in 1997, and the species is mainly confined to the Central and North Western Provinces of Sri Lanka (Marambe *et al*. 2014). According to Marambe *et al*. (2014), *M. pigra* has spread approximately 200 ha along the Mahaweli River and its tributaries. However, in 2012, it was found that fallow paddy fields were invaded by *M. pigra* in Akuressa and Malimbada Divisional Secretariats Divisions (DSDs) in Matara district. The spread is mainly observed near the riverbank of the Nilwala River. Therefore, it is hypothesized to spread during floods. However, there are no precautions to prevent and control the dissemination of the seeds of the plant.

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The spread of *M. pigra* is well concerned in countries such as Australia, America, Africa, Malaysia, Taiwan, India, Thailand, and countries in Pacific islands, (Groves 2002; Heard and Pettit 2005; Rijal and Cochard 2016; Shanungu 2009; Wongsiriamnuay and

Tippayawong 2012). Currently, *M. pigra* invasion became a serious threat to the natural ecosystem of Sri Lanka (Marambe *et al*. 2014). In tropical climates, *M. pigra* germinates around the year and grows very fast up to 6 m tall (Karim and Mansor 2013; Ostermeyer and Grace 2007). It prefers wetland places in the humid (flood plain, swamps, shallow dams, and riparian zones) and subhumid tropics with a wide variety of soils from clay to sandy clay (Karim and Mansor 2013; Okonkwo *et al*. 2016; Wongsiriamnuay and Tippayawong 2012). Concerns to the unified framework of biological invasion, *M. pigra* in Sri Lanka can be categorized under group 'E' (Blackburn *et al*. 2011) which constitutes only invasive species, with characteristics such as dispersal, survival, and reproduction in multiple sites across a greater or lesser spectrum of habitats (Blackburn *et al*. 2011; Richardson *et al*. 2000; Richardson *et al*. 2011). Thus, it needs to give more attention to the spread of *M. pigra* as an invasive plant because it is a serious threat to biodiversity with increasing magnitude in Sri Lanka.

M. pigra has potential impacts on biodiversity, the sustainability of agriculture, tourism, restrict stock movement and access to waterways, irrigation projects, competing with pastures, and the traditional lifestyle of farmers (Karim and Mansor 2013; Ostermeyer and Grace 2007; Thi *et al*. 2011; Walden *et al*. 2004; Wongsiriamnuay and Tippayawong 2012). *M. pigra* incurs economic losses to paddy farmers, anglers, ranchers and greatly impacts wetland ecosystems following Australia, South East Asia, and Africa (Rijal and Cochard 2016) which can similarly be observed in Sri Lanka.

In the control of *M. pigra*, the living mimosa plants were difficult to burn and cut, because the stems re-sprouted quickly after treatment (Thi *et al*. 2004). Mimosa seeds can survive in fire (Paynter 2004b) and fire-triggered mimosa seed germination (Thi *et al*. 2004). Therefore, it is clear that the burning land is prone to rapid recolonization (Paynter 2004b). Moreover, it is also tolerant to flood (Wongsiriamnuay and Tippayawong 2012).

Control of *M. pigra* is possible using herbicides at a low cost (Beilfuss 2007; Rijal and Cochard 2016; Thi *et al*. 2004). Nevertheless, it is not an environmentally friendly approach according to the current global trend towards greener solutions. Although biological control is now having a greater impact on mimosa performance (Paynter 2004a), the time and cost for the biological control program do not fit with Sri Lanka's context, as it needs prior research before introducing the new species to high biodiversity country.

Introduction and invasion of *M. pigra* in the Southern Province of Sri Lanka were poorly documented and very few research activities were conducted. The farmers' perspective on the spread of *M. pigra* and its real distribution has not been studied yet. Marambe *et al*. (2014) mentioned that GPS technology was currently being used to study the extent of the spread of this species in the Central and Northern Provinces of Sri Lanka. However, there is no considerable awareness and a particular idea of control measures about *M. pigra* among agriculture officers and farmers. Considering the timely necessity, this study was aimed to understand the farmers' perspective on the spread of *M. pigra* in Matara District to estimate the distribution of the plant and to support control activities. We also predicted that the questionnaire could be boosted up the farmers' awareness of *M. pigra* and support the new findings of the control of *M. pigra*.

MATERIALS AND METHODS

Farmers' perspective on the spread of *M. pigra*

Semi-structured interviews using a pretested questionnaire survey were carried out among 400 randomly selected farmers among 16 DSDs in the Matara district. The 16 DSDs are Akuressa, Athuraliya, Devinuwara, Dickwella, Hakmana, Kamburupitiya, Kirinda Puhuwella, Kotapola, Malimbada, Matara, Mulatiyana, Pasgoda, Pitabeddara, Thihagoda, Weligama, and Welipitiya. The data collection was carried from July to October 2018. The data collected via questionnaire was focused on (1) demographic factors of the respondents, (2) awareness of *M. pigra* and its identification and invisibility, (3) contribution from the media to increase the farmers' awareness of the spread of *M. pigra*, (4) awareness about the methods of *M. pigra* propagation and distribution, (5) understanding about the lands affected by *M. pigra* (6) awareness of other plant types associate with *M. pigra* and its impact on other plants growth (7) awareness of the importance or usages of *M. pigra* (8) perspective of the effect of *M. pigra* spread on animal husbandry and other animals, (9) awareness of different available control methods of *M. pigra* (10) willingness on the cultivation of perennials and annuals after removing of *M. pigra* (11) awareness of the extent of the distribution of *M. pigra* in the area, its arrival, and type of the land. A Pearson correlation was used when assessing the relationship between two continuous variables with Bonferroni correction using Past4.01 software.

Distribution of *M. pigra*

Study area and collection of UAV data

According to the questionnaire survey findings, it was understood that studying the distribution of *M. pigra* was important in the study area. Therefore, three Grama Niladhari Divisions (GND) (Paraduwa South, Paraduwa East, and Pahala Kiyaduwa) in Akuressa and Malimbada DSDs that showed high infestation was selected. The geographical setting of the study area according to the projection system WGS_1984_UTM_Zone_44N as shown in Fig. 1. The total land extent of the study area is around 1,134 ac.

DJI Mavic Pro was used as the UAV platform to collect remote sensing data of the study area. The UAV has a stabilized camera mounted on it. The focal length of the camera is 2.2 mm and it can produce imageries in visible spectral (RGB) bands. The UAV platform is specifically suitable for studying

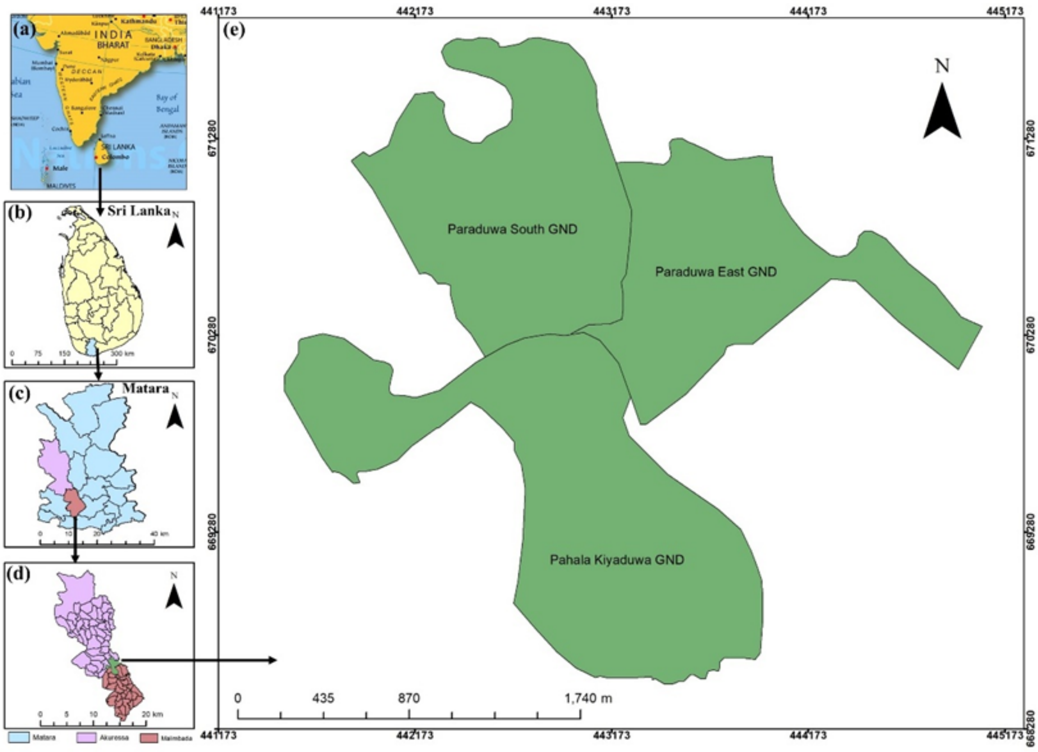

Figure 1: The location map of the study area in Matara district, Sri Lanka; (a) map of South Asia showing Sri Lanka (Nations Online 2019); (b) district map of Sri Lanka showing Matara district; (c) map of Matara district showing Akuressa and Malimbada DSDs; (d) map of Akuressa and Malimbada DSD showing the study area; and (e) the study area (Survey Department 2019)

vegetation. The resolution of the imageries at the typical flying height of 50 m is around 2 cm (DJI 2019).

The first step of UAV data acquisition was the preparation of the flight plan to cover the whole study area. For this purpose, a mobile application of Pix4D Capture was used. A predefined flight plan with a constant shutter speed of the UAV camera was used to ensure the best coverage of the study area and without affecting the motion of the UAV for the quality of the images (Drone Deploy 2019). The GPS receiver of Mavic Pro UAV supports the Global Navigation Satellite System (GNSS), which can access the best combination of satellites and provide positional accuracy of around 3 m (Suzuki *et al*. 2016). UAV data was acquired to cover key growing areas of *M. pigra*. The UAV data were acquired between 9–11 a.m. with the flight parameters, 50 m flight altitude, 90o camera angle (orthogonal view or nadir position), 80% front overlap, and 60% side overlap. The attitude helps maintain the spatial resolution of the UAV images around 2 cm. The overlapping (front and side) allows for correcting mosaicking by matching key points of the images and compensating wind disturbance and GPS errors to generate a complete mosaicked orthophoto (Drone Deploy 2019).

Data description and data processing

The list of data sources used to estimate the spread of *M. pigra* in the study area is shown in Table 1.

Agisoft PhotoScan was used to process the collected UAV images. The software allows generating mosaicked orthophoto of the study area by using multiple images captured by UAV. The collected UAV images were required to import into the software for preprocessing. The software allows converting the images acquired by UAV into geotagged two-dimensional mosaicked orthophoto with a 2 cm spatial resolution (Agisoft 2014).

Extraction of land cover

Four types of machine learning (ML) techniques, namely, support vector machine (SVM), k-nearest neighbour (KNN), random forest (RF), and neural networks (NN), were used for the extraction of the land cover of the study area with the use of R software (Priyankara *et al*. 2019). Both overall accuracy and the kappa statistic were higher (over 90%) with the SVM, and the method was selected to extract the land cover of the study area. Mosaicked-orthophoto of the study area was classified into two land cover types, namely, *M. pigra* (MP) and other lands (OL) for this study. The accuracy of the classified land cover map was evaluated using 100 reference points. Stratified random sampling techniques were used to generate the reference points (Stehman 2009). Mosaicked-orthophoto and Google Earth were used as a source of reference information for the land cover map.

RESULTS AND DISCUSSION

Farmers' perspective on the spread of *M. pigra*

The majority of the farmers (48%) were between the ages of 41 and 60, while 43.3% were between the ages of 21 and 40. The remaining farmers were less than 20. Moreover, 55.2% of the farmers were recorded as male. There was no correlation between gender and age in the awareness and identification of *M. pigra* ($p > 0.05$; $r = 0.21029$).

According to the results of the questionnaire survey, the level of awareness of *M. pigra* among the participants was 53.2%, while more than 70% had no idea about this plant's

Table 1: List of data sources used for the estimation of the spread

Type	Data	Source	Year
Primary	UAV images (2 cm resolution)	UAV data acquired during fieldwork	2018
Secondary	GND map of Sri Lanka (1:50,000)	Department of Survey, Sri Lanka	2012

invasiveness (Table 2). It was noted that more than half of the respondents could identify *M. pigra*. The majority of the participants (47.6%) stated that the place of distribution of *M. pigra* was not known while 32.2% stated that they had seen the growth of the plant in Athuaraliya (4.7%) and Akuressa (32.2%) areas and it was very lower level (< 1%) in other areas (Table 2). The findings of the study proved that the flood plains are the most favourable habitat for *M. pigra* in this area as reported by many researchers (Beilfuss 2007; Walden *et al*. 2000; Okonkwo *et al*. 2016).

The participants of 55.2% said that they do not know the exact date of the first observation of the plant in the area. However, 29% of the participants stated that they have encountered *M. pigra* during the period 2009 - 2014, which seems like an outbreak. 7.2% and 6% of participants said they observed the plant in the area during the periods 2003 - 2008 and 2015-2018, respectively (Table 2). According to the responses from the participants, the number of encounters was recorded in the period 1997-2002, which was about 2.5%. Results were given the idea about the spreading magnitude of *M. pigra* in the surveyed areas.

In response to the farmers' awareness of the extent of the distribution of the plant in the area, about 74.6% of them do not have any idea about the extent of the distribution (Table 2). The participants of 13.7% stated that the land extent of the spread is around 26 -50 acres (Table 2). Furthermore, 48% of them stated that the status of the land in which the highest occurrence of *M. pigra* plants is not known to them (Table 2). However, 21% stated that the occurrence is highly seen on low land while 7.7% stated that it is seen on uplands (Table 2). Additionally, 8% of the participants stated that the occurrence is similar in both uplands and lowlands.

The contribution from the media to increase the farmers' awareness of the spread of the plant was minimal. Many farmers (46.8%) said that they did not hear anything from the media related to the spread of the plant, but some farmers acquire information from various sources including newspapers/ magazines (14.4%), television/radio (13.4%) (Table 2). In addition, mostly, they got to know about the spread of the plant from their day-to-day working experiences in the fields and other experienced farmers in the area. Despite the fact that the internet makes people aware of a wide range of issues, the information gained through the internet was minimal (0.5%) in this case. It might be because of the barriers related to accessibility to the internet, such as lack of devices, connectivity, and knowledge. However, the farmer's community has a very low interest to observe alien species (Nghiem *et al*. 2013). Thus, this reason will be caused to spread of several invasive species like *M. pigra* belonging to other countries.

M. pigra reproduces primarily by prolific seed production and vegetatively through cut stems (Okonkwo *et al*. 2016). However, many farmers did not know about the exact propagation method (47%), while 44.8%, 2% and 6.2% of farmers respectively stated seeds, vegetative parts and both as main propagation methods of *M. pigra* (Table 2). The results also revealed that the awareness of propagation of *M. pigra* is important since farmers are using *M. pigra* sticks to support the vine crops in their fields.

In response to the mode of distribution, farmers reported various methods such as flood (31.3%), wind (21.3%), animals (3.8%), animal faeces (5.6%), and human activities (7.5%). Whereas the rest (29%) did not have an idea about the method of propagation (Table 2). *M. pigra* produces copious light seeds which can float on the water and are mostly carried from one place to another by floating on water (Lonsdale 1993; Rijal and Cochard 2016; Karim and Mansor 2013). The shreds of evidence that plants have been colonized along the riverbanks were reported in floating plains in Adelaide River in Northern Australia, Mekong River in Cambodia, and Mahaweli River in Sri Lanka and (Marambe *et al*. 2014; Rijal and Cochard 2016). Because of the annual flood of the

Nilwala River, farmers are not willing to collide with *M. pigra* that is similarly observed by Rijal and Cochard (2016) in Cambodia and Thi *et al*. (2011) in Vietnam. The segments of *M. pigra* pod are enclosed with bristles that facilitate them to adhere to animals and clothing. The seeds are also dispersed adhering to vehicles and other machinery (Walden *et al*. 2000).

As mentioned in Table 2, among the croplands, 33.3% were paddy, and paddy lands were highly affected than tea (0.7%), rubber (0.7%), and cinnamon (0.3%) lands. The farmers said that the most prominent types of plants are vines (20%) followed by bushes (14.4%). Other than that, the calculated percentages show that the occurrence of trees, grasses, and bushes accounts for 7.7%, 6.5%, and 3.7%, respectively (Table 2). Therefore, it is clear that any type of plant can be seen along with *M. pigra*, especially vines and bushes. Nearly half of the participants (49.3%) said that there is an impact to grow other plant species with *M. pigra* and the rest did not have any clear idea about that.

Few questions were raised on the importance or usages of the plant, where, 91% of the participants said that there is no importance while the rest highlighted the following importance such as compost making (6.5%), mulching (1%), firewood (1%), animal feed, and fencing (0.4%) (Table 2). The literature says that *M. pigra* is used in folk medicine, green manure, poles, hedges, as ornamental plant, erosion control, animal feed, timber, temporary fences, and fuel wood (Shorinwa *et al*. 2015; Wongsiriamnuay and Tippayawong 2012; Okonkwo *et al*. 2016). Here it is convinced that *M. pigra* utilization as an energy source may be a useful option.

Animal husbandry is also an important livelihood in the Southern Province of the country, hence, the impact of this invasive weed on animal husbandry was evaluated. According to the participants, the majority (55.5%) did not have a clear idea about the effect of the plant on animal husbandry. However, 39.1% stated that there was an impact on animal husbandry. Accordingly, the main impact on animal husbandry was the reduction of grassland (34.4%), ultimately causing feed stress on grazing animals (Table 2). Further, the distribution of this plant is causing injury to the animals (Table 2). The impact is not only limited to farm animals. 15.2% of the participants mentioned that other animals are also affected by this plant species and 26.1% said there is no impact on other animals. Wongsiriamnuay and Tippayawong (2012) observed that the thorny *M. pigra* replaces grasslands and reduces available habitat for animals. The effect of *M. pigra* on the reduction of waterbird population was also observed by Shanungu (2009) and Walden *et al*. (2004), and an unsatisfactory microhabitat for lizards and amphibians were also reported by Walden *et al*. 2004. The main impacts on other animal species are loss of habitat (6.2%), feed shortage (3.7%), injuries (3.7%), and reduction of fish (1.7%) (Table 2).

The awareness of different available control methods is vital to control this invasive plant species in the region. The participants of 70% were not aware of the available control methods. The most known controlling methods were burning (5.1%), uprooting (7.3%), and both uprooting and burning (8.1%) (Table 2). The effectiveness and success of the controlling methods were least known by most of the participants (91.5%). The participants of 7.2% stated that the controlling methods they were applied are moderately successful. The results revealed that there is a low concern about control methods of *M. pigra*.

Cutting and/or digging out of mimosa plants was commonly practised in fields (Rijal and Cochard 2016), including in Sri Lanka (Personal observation, Perera PCD). However, cutting and burning is not effective (Thi *et al*. 2004). *M. pigra* controls using herbicides (e.g. paraquat, metsulfuron methyl, triclopyr butoxy ethyl ester, and glyphosate) (Son *et al*. 2004), however, it is not an environmentally friendly method and it will also affect the native plants. The invasion of mimosa in rice fields has increased expenses for soil preparation and for labour to remove

mimosa before cultivation (Thi *et al*. 2011; Rijal and Cochard 2016) which is similar to the context in Sri Lanka.
Most of the participants (76.9%) did not have any awareness and idea about the control measures taken by the government. The participants of 23.1% knew about there are some government projects to control this plant but with less success. Awareness programs were suggested to conduct among the communities in the affected areas. Marambe *et al*. (2014) mentioned that they have resulted in several community participatory activities to eradicate small patches of *M. pigra* from the Central Province. Nearly 22.8% suggested establishing cinnamon on lands that were occupied *M. pigra*, as the perennial crop while 28.5% have no idea. Consequently, cultivate vegetables such as the annuals (11.8%), Rubber (11.3%), Coconut (6.5%), Tea (1.2%), Fruit (6.6%) and Others (11.2%) were suggested (Table 2).

Considering the management practices of *M. pigra*, ecological research in Australia showed that fire may burn the vegetation, but the plant easily reestablishes from soil seed banks (Rijal and Cochard 2016). Only a small number of potential biocontrol agents showed any measurable impacts on plant vigour and seed banks (Heard 2012). Therefore, biocontrol and fire, the use of herbicides, mechanical control, restoration, and management of native vegetation have been focused understudying integrated approaches (Paynter 2004; Paynter and Flanagan 2004; Thi *et al*. 2004). Thus, the respondents' suggestion of the establishment of cinnamon on *M. pigra* invaded land will be a new aspect and can be implemented after further research studies as the control of *M. pigra*.

According to the above results were revealed that there is no exact idea about the distribution of *M. pigra* in the affected area. It is essential to identify the exact distribution of *M. pigra* before going to plan the control, strategy, and control of the further spread of *M. pigra* for future administrative works.

Spatial Distribution of *M. pigra*
Table 3 shows the results of the accuracy assessment of the technique used to extract the land cover of the study area. The overall accuracy and the kappa statistic are 96.2% and 0.94, respectively, which shows how accurate the method is for identifying the land cover in the study area.

Fig. 2 shows the results of the extraction of land cover and Table 4 shows the relevant descriptive statistics of the extraction of land cover, in the study area. The total land extent of the study area is 458.83 ha, and 5.84% of the land extent of the total extent already was invaded by *M. pigra*. The spread of *M. pigra* is more serious in the GNDs Paraduwa South and Paraduwa East than Pahala Kiyaduwa.

The study was tried to apply some of the novel technologies to identify the spread of the plant as a case study, which is limited to a small area but can be applied to a large extent in a practical context with some limitations. The method was able to detect the spread of the plant spatially and also its extent preciously. The findings will ultimately help to be aware of the farmers in the study area about the spread of the plant in spatial means and the findings will help to take the necessary control measures to eradicate the plant from the study area for the continuation of the agriculture activities. The UAV-based remote sensing method applied to estimate the distribution of the spread of the plant is very accurate in comparison with other methods applied previously to identify the spread of this kind of invasive plant. In the case study, it was considered only two types of land cover, namely, land affected by the plant and other lands. It can be further improved by identifying other land use/land cover types to evaluate the impact of the plant on other activities and can be considered in future studies. The method is flexible to carry out in any field where accessibility is limited and possible to monitor the progress of the controlling activities of the plant frequently. The cost for the identification, monitoring and controlling activities of the plant with the application of the method is considerably lower than other methods. The method is

Table 2: Results of the questionnaire survey on the farmers' perspective on the spread of *M. pigra*

Variables	*Categories*	*Percentage (%)*
Farmers responses as awareness, identification, and invasibility of M. pigra;		
(a) Awareness	Yes	53.2
	No	46.8
(b) Identification	Yes	53.2
	No	46.8
(c) Known as an invasive	Yes	30.1
	No	69.9
Knowledge of farmers on M. pigra through informational sources	No source	46.8
	Conferences	5.2
	News papers/ Magazines	14.4
	TV	7.5
	Internet	0.5
	Others	3.2
	TV and News papers	13.4
	All above media	9.0
Known information among farmers on M pigra;		
(a) Awareness on reproduction	Not known	47.0
	Vegetative parts	2.0
	Seeds	44.8
	Both sexual and asexual	6.2
(b) Types of distribution	Not known	29.7
	Flood	31.3
	Wind	21.3
	Animal	4.8
	Animal faeces	5.6
	Human activities	7.5
Understanding of farmers about M. pigra effect among different land types	Not known	64.9
	Paddy	33.3
	Tea	0.7
	Rubber	0.7
	Cinnamon	0.3
Farmers' awareness about different plant types associated with M. pigra;		
(a) Farmers' observation of different plant types	Not known	47.0
	Trees	7.7
	Bushes	14.4
	Shrubs	3.7
	Vines	20.6
	Grasses	6.5
(b) Percentage of farmers' positive and negative response about impacts among other plants growth	Not known	50.7
	Yes	49.3

Continued Table 2

Variables	***Categories***	***Percentage (%)***
Farmers' interest to utilize M pigra in their livelihood	No use	91.0
	Firewood	1.0
	Compost making	6.5
	Fencing	0.2
	Animal feed	0.2
	Mulch	1.0
(a) Animals belong to husbandry	Not known	59.5
	Reduction of grass-land	34.4
	Injuries to animal	6.1
(b) Animals in the surrounding environment	Not known	84.7
	Loss of habitat	6.2
	Feed shortage	3.7
	Injuries	3.7
	Reduction of fish	1.7
Awareness of different available control methods of M. pigra	Not known	79.5
	Burning	5.1
	Uprooting	7.3
	Uprooting and burning	8.1
Willingness of farmers on future cultivation of perennials and annuals after removing of M. pigra	No idea	28.5
	Cinnamon	22.8
	Rubber	11.3
	Coconut	6.5
	Tea	1.2
	Vegetables	11.8
	Fruit	6.6
	Ornamentals	0.1
	Other	11.2
Farmers' assumption for M. pigra arrival by year	Not known	55.2
	1997-2002	2.5
	2003-2008	7.2
	2009-2014	29.1
	2015-2018	6.0
Farmers' awareness of the extent of the distribution of M. pigra		
(a) Area	Not known	74.6
	1-25 acres	5.7
	26-50	13.7
	>50	6.0
(b) Land types	Not known	48.0
	Upland	15.2
	Lowland	21.1
	Both	15.7

Source: Field survey, 2018

Table 3. Accuracies and kappa coefficient of land cover classification in the study area

Accuracy	Land cover category	2018
User accuracy (%)	*Mimosa pigra* (MP)	95.75
	Other lands (OL)	96.21
Producer accuracy (%)	*Mimosa pigra* (MP)	97.81
	Other lands (OL)	95.82
Overall accuracy (%)		96.20
Kappa coefficient		0.94

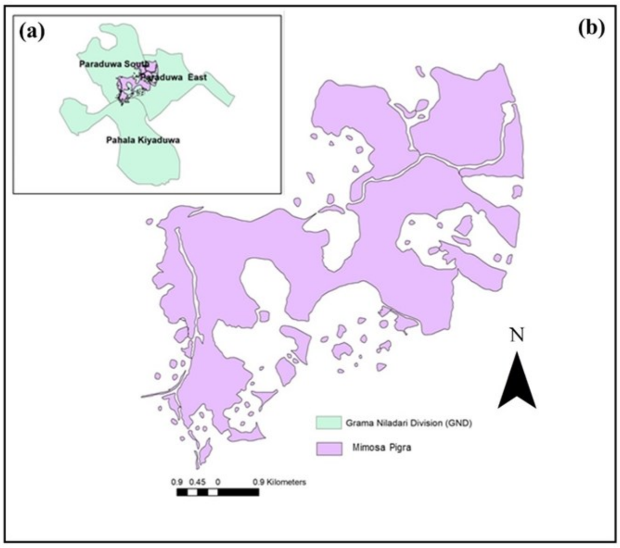

Figure 2: Distribution of *M. pigra* in the study area. (a) land cover map of the study area; and (b) map of *M. pigra*

Table 4: Descriptive statistics for *M pigra* distribution in the study area

Land cover	Paraduwa South		Paraduwa East		PahalaKiyaduwa		Total Area	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Mimosa pigra (MP)	13.09	9.18	12.44	10.41	1.27	0.65	26.80	5.84
Other lands (OL)	129.64	90.82	107.02	89.59	195.37	99.35	432.03	94.16
Total	142.73	100.00	119.46	100.00	196.64	100.00	458.83	100.00

having light limitations such as shorter flight duration, difficulties in maintaining flight altitude, the stability of UAV, and manoeuvrability due to wind and turbulence (Sylvester, 2016).

CONCLUSION

Farmers' awareness of the spread of the plant, its distribution, and extent were very minimum in the area. Cultivation of cinnamon and vegetable in the affected areas is a viable option to control the spread of the plants. UAV was captured 26.8 ha (5.8 % of the total land area) of *M. pigra* invaded land extent in Akuressa and Malimbada DSDs among the total land extent of 458.83 ha. The novel UAV-based remote sensing methods can play a vital role in the estimation of the distribution of the invasive plant preciously. Further research studies are suggested within adaptive management frameworks and suitability of *Cinnamomum* sp. cultivation in *M. pigra* affected areas.

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AUTHOR CONTRIBUTION

PCDP conceptualized and designed the study. PCDP, PP, and APSM conducted the survey and collected the UAV data. PCDP and PP analyzed the data. PCDP and PP wrote the paper with input from all authors. All authors discussed the results and commented on the manuscript.

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