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INFLUENCE OF *ALSTONIA MACROPHYLLA* SPREAD ON THE RESTORATION SUCCESS OF PINE CONVERSION PROGRAMS IN SRI LANKA

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Establishment of exotic invasive species causes many negative implications in restoration programmes such as out competing native species, thereby altering the structure, composition and function of the target ecosystem. Although *Alstonia macrophylla* is an exotic invasive tree species in Sri Lanka, its impact on native flora is undermined due to its timber value. The influence of *A. macrophylla* on the composition and dynamics of new recruits in an eleven-year-old restoring pine plantation (RP) was investigated and compared to a 25–30-year-old unrestored Pine plantation (UP) in Hantana, Sri Lanka. In both stands, the dominant species and the highest densities in all life stages (seedlings, saplings and trees) of the woody plants were represented by *A. macrophylla*. This species survived better than the non-*Alstonia* species in RP, than in UP, and was well represented in all diameter at breast height (dbh) classes in RP. The negative correlation between rainfall and mortality of *Alstonia* and non-*Alstonia* was stronger in UP than that in RP. The study concludes that considering life history strategies and invasive behavior of *A. macrophylla* in pine conversion programmes, they must be managed at different time scales (short, mid and long term) using silvicultural techniques to achieve restoration goals in the mountainous regions of Sri Lanka.

Keywords: *Alstonia macrophylla*, pine conversion, invasive species, rainfall, restoration

INTRODUCTION

Alien invasive species (AIS) continue to impact structure and function of natural ecosystems by interfering with the establishment of native species, community structure, assembly and successional dynamics (Powell et al. 2011, Weidlich et al. 2020). They can threat biodiversity and alter soil properties, nutrient cycling, fire regimes, hydrology and ultimately lead to cascading negative effects on human well-being (D'Antonio & Meyerson 2002, Powell et al. 2011, Weidlich et al. 2020). The AIS are the most critical barriers for restoring native ecosystems as they interfere with ecological restoration processes by decreasing native biodiversity and reducing ecological services, as a result failing restoration efforts (D'Antonio & Meyerson 2002, Powell et al. 2011, Weidlich et al. 2020). Thus an assessment of the magnitude of their impacts on natural ecosystems with supporting experimental data on species-level impacts of exotic plant species on native plant species is required to effectively control their invasions (Levine et al. 2003, Stinson et al. 2007). However, only a limited number of forest management and silvicultural approaches have been explored to avoid, mitigate or repair the potential damage from invasive species (Muzika 2017).

Alstonia macrophylla (Apocynaceae) or devil tree is a medium-sized tree (20 m) with blackish green stem, leaves arranged in whorls in 4-angled branches, smooth bark with milky latex, yellowish-white terminal cymes in umbels with a pleasant smell (pollinated by insects) and pendulant double follicles with flat wind-dispersed seeds (Figure 1). This species is native to Indonesia, Malaysia, the Philippines, Thailand and Vietnam and it was intentionally introduced to Sri Lanka from Malaysia for its good quality timber, which is widely used for construction purposes, furniture and flooring (Wijesundara 2010). The bark has medicinal values and is used in decoction, infusion, tincture and for wine preparation (Wijesundara 2010). However, *A. macrophylla* is considered as an invasive species in Hawaiian Islands, Singapore and in Sri Lanka (Fleischmann 1997, Wijesundara 2010, PIER 2013). It is listed as a high-risk invader in Singapore and Hawaii, according to the Australian/New Zealand Weed

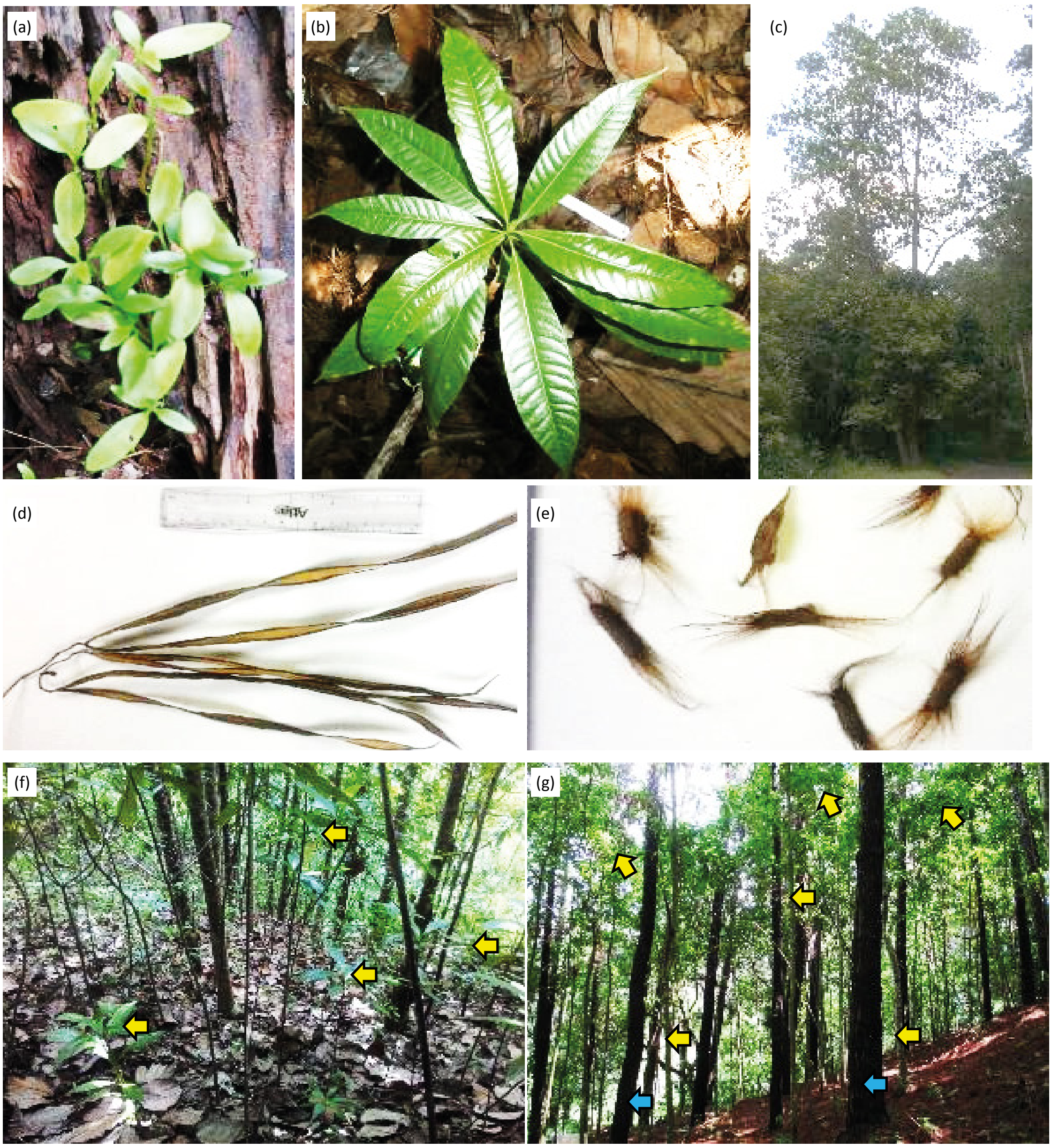

Figure 1 a) Seedlings, b) saplings, c) trees, d) schizocarp fruit, e) glabrous or ciliate, oblong seeds of *Alstonia macrophylla*, f) *Alstonia macrophylla* seedlings dominating the understory of RP, g) overstorey of UP dominated by light colour stems of *Alstonia macrophylla* (shown with yellow arrows) and dark colour stems of *Pinus caribaea* (shown with blue arrows)

Risk Assessment (PIER 2013). In Sri Lanka, it rapidly colonises open areas including secondary forests in the lowland wet zone (Tomimura et al. 2012). Moreover, it has spread to Caribbean pine plantations in the buffer zone of Sinharaja Forest Reserve in southwest Sri Lanka (Tomimura 2008).

The United Nations General Assembly announced 2021–2030 as the decade on ecosystem restoration (Weidlich et al. 2020). In many instances, opening up areas as restoration prescriptions leads to biotic invasions (Weidlich et al. 2020). Despite many studies on plant invasion, little is known about the status and the management of invasive plant species in restoration sites worldwide (Weidlich et al. 2020). There are several studies on the conversion of monoculture pine plantations to mixed-species stands in Sri Lanka, in terms of the growth performances of re-planted species and natural regeneration after restoration efforts (Tomimura 2008, Ambagahaduwa et al. 2009, Jayawardhane & Gunaratne 2020). Nevertheless, there are no published records on the effects of invasive species on the restoration success of silviculturally-managed (thinned and enriched) pine plantations in the mountainous regions. In 2015, restoration success was recorded following thinning and enrichment planting with four broad-leaved species in a pine plantation (*Pinus caribaea*), in terms of improved vegetation structure and higher diversity of naturally regenerating native plant species, compared to an unrestored pine plantation in Sri Lanka (Jayawardhane & Gunaratne 2020). Although there was only a few seedlings, saplings and mature trees of *A. macrophylla* when thinning and enrichment planting was initiated in the restoration site in 2003, by 2015 the site was highly invaded by all life stages of *A. macrophylla*, after 12 years of initiation of the restoration trial. Moreover, even in the UP site all life stages of this invasive species were recorded by 2015.

Thus, we hypothesised that all life stages (seedlings, saplings and mature trees) of *A. macrophylla*, found over-dominating in both restored and unrestored stands, exert a negative impact on the newly establishing seedlings of 'non-*Alstonia* species'. The effect of *A. macrophylla* on the restoration of silviculturally-managed pine plantations in Hantana, Sri Lanka was quantified by comparing the species abundance, densities of newly recruited and established plant categories (i.e. *Alstonia vs* non-*Alstonia* species), vegetation structure of the stands in terms of diameter at breast height (dbh) classes and the survival of *Alstonia* and non-*Alstonia* species. The relationship between seedling emergence and seedling establishment as well as the relationship between seedling emergence and seedling mortality with rainfall was tested between the two plant categories.

MATERIALS AND METHODS

Study site

This study was conducted from March to August 2015 in the Hantana Mountain Range (HMR) (7° 17' N and 80° 36' E) in central Sri Lanka (Figure 2a, b). The HMR was declared as an environmental protected area in 2010 by the Central Environmental Authority due to its significance on biodiversity and hydrology (Gunasekara et al. 2011). The mean annual temperature of the area is 29.3 °C and the mean annual precipitation is 2539.8 mm (Figure 2c). The terrain is hilly and steeply dissected with narrow sloping valleys at an elevation range of 518–1110 m. In the 1980s, the Forest Department of Sri Lanka reforested degraded grasslands in HMR with *P. caribaea* to protect water catchments of Mahaweli river (Ambagahaduwa 2008). However, most of these plantations have not been silviculturally-managed since their establishment to improve ecosystem services provided by them. Moreover, *P. caribaea* has been reported to invade degraded areas and cause environmental problems in the mountainous region in Sri Lanka (Medawatte et al. 2014).

Considering the unacceptance of pines by the society and ecological issues associated with pine plantations, a restoration trial was initiated by the Department of Botany, University of Peradeniya to convert a monoculture pine stand into a mixed species stand, to enhance ecosystem services provided by them (Ambagahaduwa et al. 2009). In 2003, a pine stand which was in lower HMR, located 4 km southwest of Kandy city and at the northwestern end of the hill range, was thinned to create strip cuts of different width to open the pine canopy, enabling light to reach the ground layer. In 2004, the strips were planted with four ecologically and economically valuable broad-leaved tree species. In 2009, removal of the remaining pine trees was initiated and then onwards the site has been left to regenerate naturally (Jayawardhane & Gunaratne 2020). This site was referred to as the restoring pine plantation (RP). A 25–30 years old unrestored pine stand (UP) at the same elevation range was selected as the control site (Figure 2b).

Experimental design and vegetation sampling

Sampling was conducted from March to July 2015 within the same sampling plots established in RP and UP to determine the restoration success of silviculutral practices in a pine conversion program (Jayawardhane & Gunaratne 2020). Fifteen plots of 5 × 5 m^2 were established randomly in both RP and UP, using Arc Geographical Information System (GIS) and Global Positioning System (GPS). Inside each plot, three 1 × 1 m^2 sub plots were established randomly (a total of 45 subplots in each plantation). All newly emerged and established seedlings (< 50 cm in height) of both *Alstonia* and non-*Alstonia* in 1 × 1 m^2 plots, and saplings (50–300 cm in height) and trees (> 300 cm in height) in 5 × 5 m^2 plots were tagged

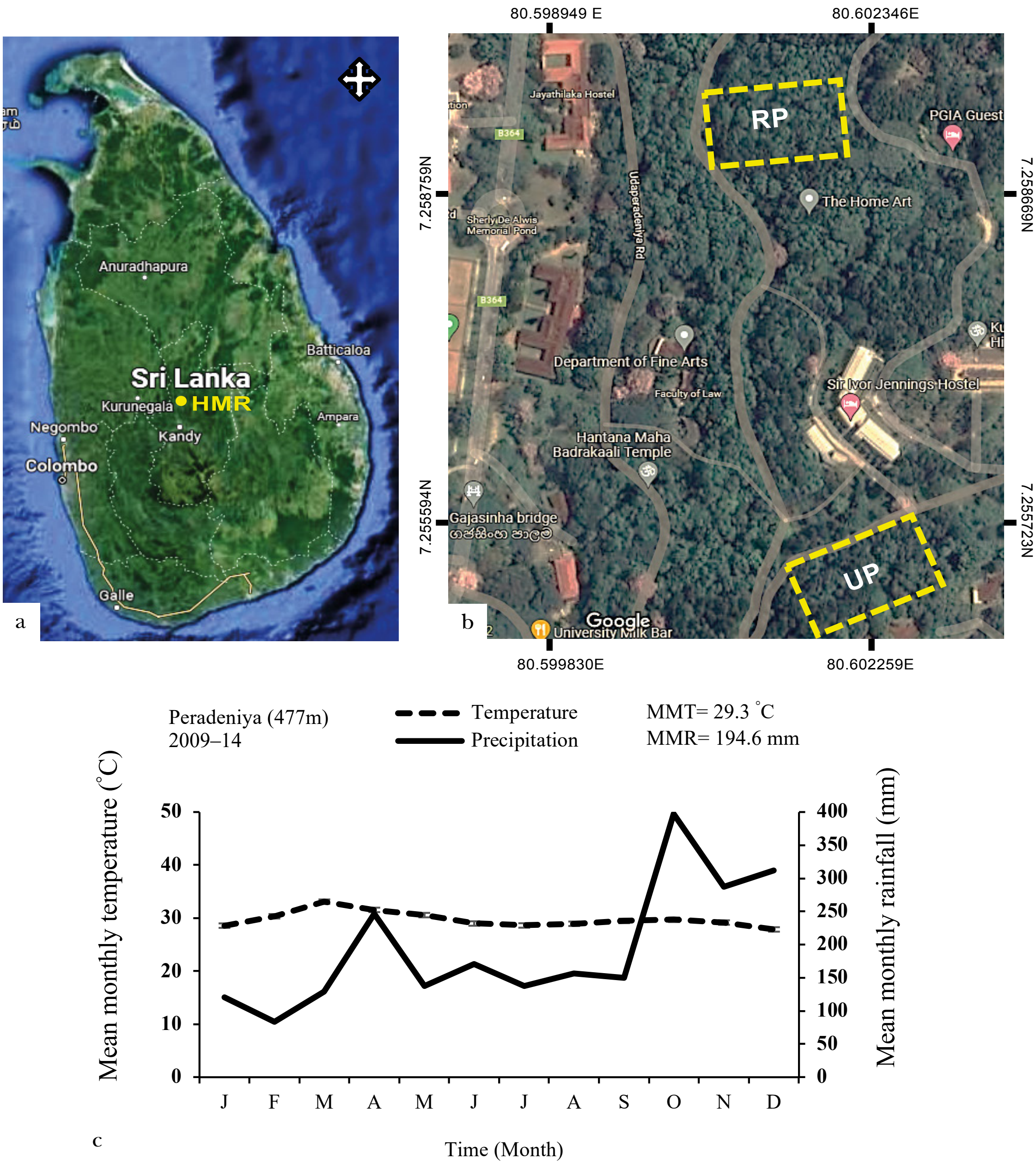

Figure 2 a) Location map of HMR, Sri Lanka (shown with a yellow circle), b) restoring pine plantation (RP) and unrestored pine plantation (UP) (source: google maps) and c) Climatic diagram for Peradeniya, Sri Lanka, prepared from the data collected at Natural Resource Management Centre, Peradeniya (2009–14)

and recorded every two weeks for six months. The height of all the life stages of both plant categories were recorded using a ruler, a pole and a clinometer. The dbh of stems (saplings and trees of both plant categories) at 1.3 m above ground level was measured using a dbh tape.

Seedling reference collections at the Department of Botany, University of Peradeniya and field manuals were used to identify life stages of plant species, and to obtain their ecological information (families, genera, species, ecological origin) (Dassanayake & Fosberg 1977–1998, Ashton et al. 1997, Vlas & Vlas 2000). Monthly rainfall and temperature records from 2009 to 2014 were obtained from the Natural Resource Management Centre, Peradeniya, Sri Lanka (at 477 m elevation).

Data analysis

Rank abundance curves were constructed for all species in both sites by considering the proportion of each species to the total number of individuals recorded for each site. Mean densities of newly recruited species of both *Alstonia* and non-*Alstonia* were calculated as the total number of individuals per hectare. Densities of dbh groups were calculated from the number of individuals in different dbh classes in both sites. Survival percentages of all life stages representing plant categories in both sites were also calculated. One-way ANOVA was conducted in Minitab version 17 software (Minitab, LLC 17.2.0) with Tukey pair-wise comparisons to compare the parameters between different life stages of the two sites (RP and UP). Pearson correlation (PC) was used to analyse the correlation between seedling emergence of *Alstonia vs* mortality of *Alstonia*, or mortality of non-*Alstonia* species. The linear correlation between rainfall and seedling emergence, and the mortality of *Alstonia* and non-*Alstonia* species was also analysed. The mean monthly rainfall values relevant to the six month period of the study was derived from 2009–2014 rainfall data set.

RESULTS

Dominance of *Alstonia macrophylla* representing life stages of woody species (RP > UP)

Species belonging to 23 plant families, 34 genera and 36 species were recorded from both sites. The *A. macrophylla* was the only woody invasive species recorded in both RP and UP. It was the most dominant species representing all three life stages (seedlings, saplings and trees) in both sites (Figure 3). Its highest abundance was recorded by trees in UP and then by seedlings and saplings in RP. Early successional species dominated all life stages in RP, where the five most abundant species representing all three life stages were pioneers. In UP, the five most abundant species of seedlings and trees were pioneer species. When considering saplings in UP, except *Pagiantha dichotoma*, all other species were pioneers.

Influence of *Alstonia macrophylla* on the stand structure

A higher density of each life stage (seedlings, saplings, trees) of *A. macrophylla* was recorded in RP than in UP (Figure 4a). *A. macrophylla* was well-represented in all dbh classes in both sites and it was highly abundant in all dbh classes except 0–0.70 cm class in UP (Figure 4b). In UP, seedling density of *Alstonia* species in 0–0.70 cm dbh class was significantly lower than that of RP. Seedling density of non-*Alstonia* species in 0.71–2.81 cm dbh class was significantly higher (8.5 times) in RP than that of UP.

Survival of *Alstonia* and Non-*Alstonia* species in RP and UP

The highest survival percentage among all life forms was recorded by the seedlings of non-*Alstonia* species in UP (100%) followed by *A. macrophylla* trees in RP (87%) (Figure 5). However, more than 50% of all life stages of *A. macrophylla* survived from all three life stages in RP. Seedlings and saplings of *A. macrophylla* survived better in RP while none of their seedlings survived by the end of the study period in UP.

Influence of *Alstonia macrophylla* on seedling mortality

Emergence of *A. macrophylla* influenced its own seedling mortality, more than the mortality of non-*Alstonia* species. There was a very strong positive correlation between the densities of newly emerged *Alstonia* seedlings and mortality of earlier emerged *A. macrophylla* seedlings in both stands (RP: emerged seedlings and dead seedlings = +0.955; UP: emerged seedlings and dead seedlings = +1.0) (Table 1). Further, there was a strong positive correlation between the newly emerged *A. macrophylla* seedlings and the mortality of non-*Alstonia* seedlings in UP (+0.505). However, there was no or negligible correlation between the newly emerged *A. macrophylla* seedlings and the dead non-*Alstonia* seedlings in RP.

Influence of rainfall on seedling emergence and mortality

The area received comparatively high amount of rainfall in October, while March, May and July received comparatively lower rainfall than in other months during the study period (Figure 2c). The rainfall influenced the seedling emergence of *A. macrophylla* (Figure 6a, b). In RP, the highest emergence of *Alstonia* seedlings was recorded in May while that of UP was recorded in April. However, the highest seedling emergence of non-*Alstonia* species in both sites was recorded in March. Following the highest rainfall in April, by May nearly six times higher

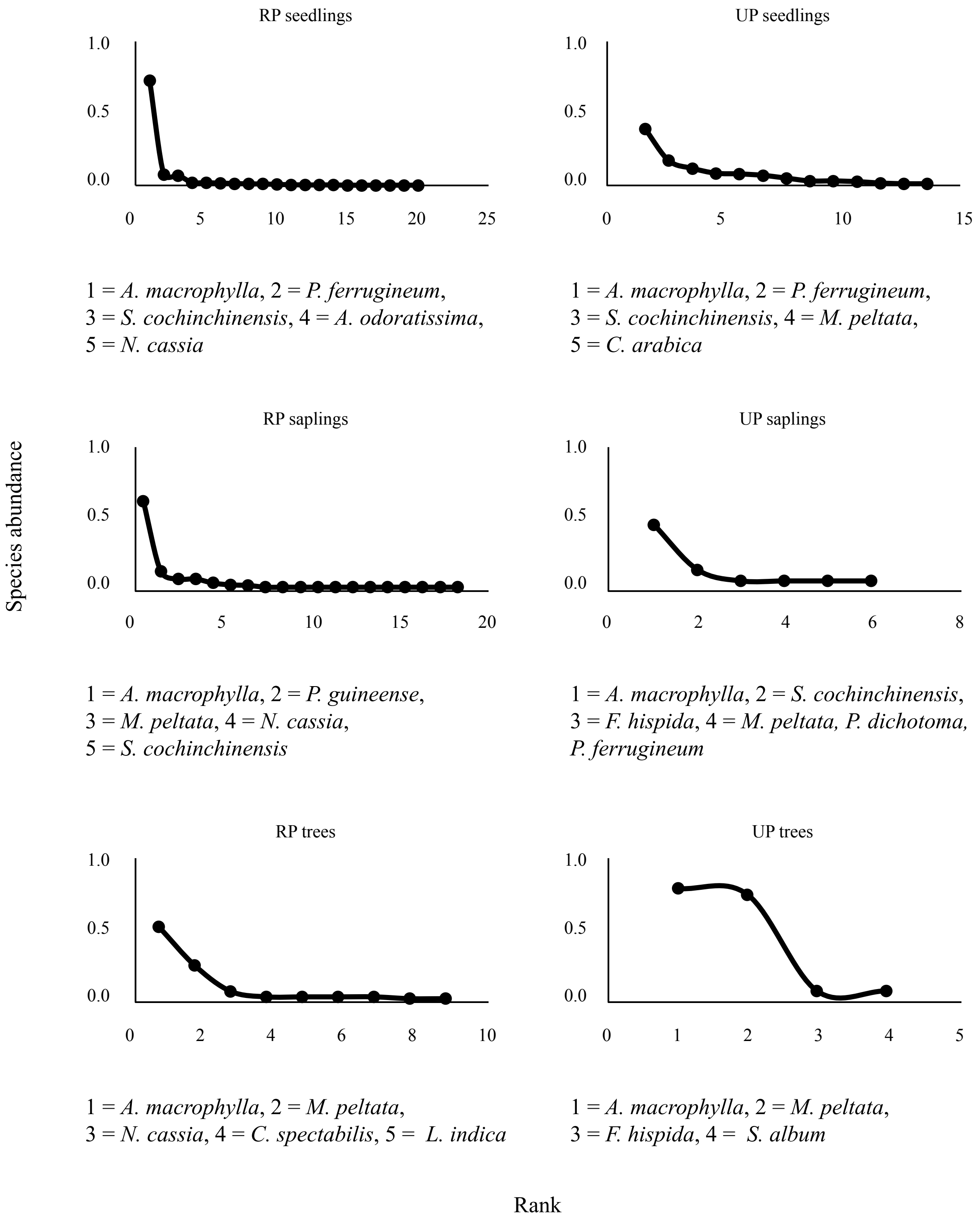

Figure 3 Rank abundance curves of the five most abundant seedlings, saplings and trees of woody species in the two plantations in the presence of *Alstonia macrophylla*; RP = restoring pine plantation, UP = unrestored pine plantation at lower Hantana, Sri Lanka; species listed above: *Alstonia macrophylla, Albizia odoratissima, Cassia spectabilis, Coffea arabica, Ficus hispida, Leea indica, Macaranga peltata, Neolitsia cassia, Pittosporum ferrugineum, Pagiantha dichotoma, Symplocos cochinchinensis* and *Santalum album*

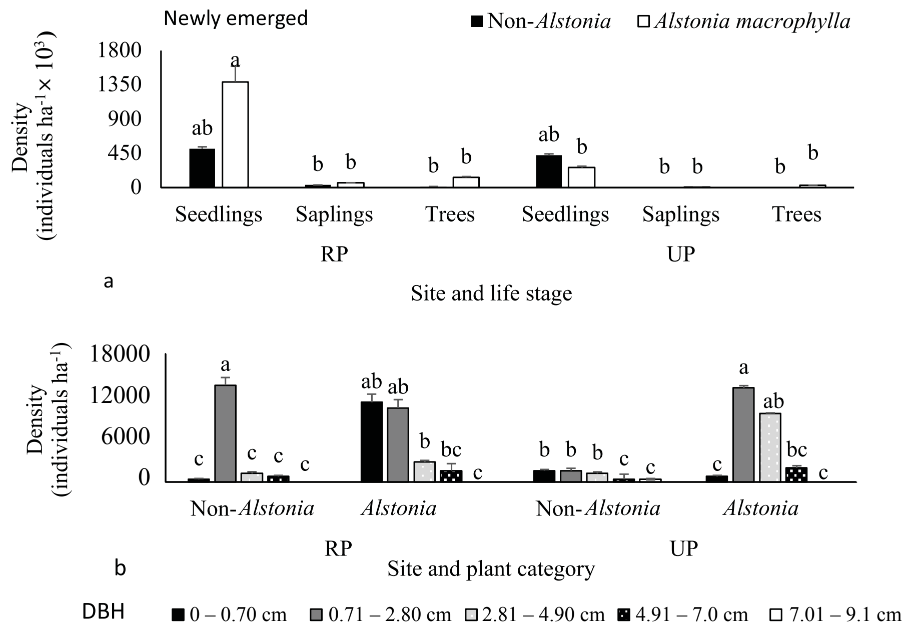

Figure 4 a) Densities of *Alstonia* and non-*Alstonia* species recorded during six months of the study period in both restored pine plantation (RP), unrestored pine plantation (UP), b) densities of *Alstonia* and non-*Alstonia* species according to the dbh classes; different letters indicate significant differences at $p < 0.05$, $n = 15$

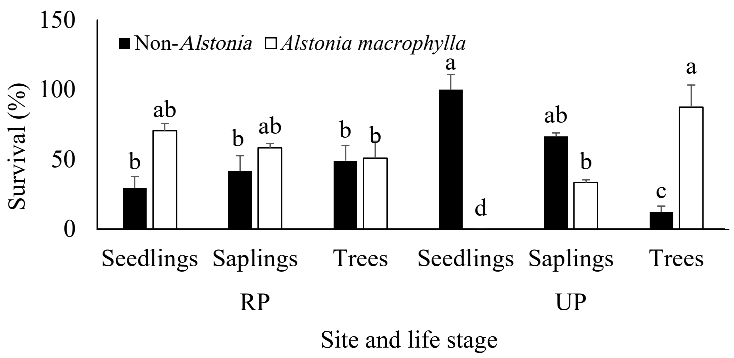

Figure 5 Percentage survival of *Alstonia* and non-*Alstonia* species from March to August 2015 in restored pine plantation (RP) and unrestored pine plantation (UP); different letters indicate significant differences at $p < 0.05$, $n = 15$

Table 1 Pearson's correlation between seedlings of *Alstonia* and non-*Alstonia* species in both stands

Site	Factors	PCC	p-value	Relationship
RP	Emerged *Alstonia* seedlings & dead *Alstonia* seedlings	0.955	0	Very strong positive
	Emerged *Alstonia* seedlings & dead non-*Alstonia* seedlings	-0.005	0.985	No or negligible
UP	Emerged *Alstonia* seedlings & dead *Alstonia* seedlings	1.000	0	Very strong positive
	Emerged *Alstonia* seedlings & dead non-*Alstonia* seedlings	0.505	0.055	Strong positive

PCC = Pearson correlation coefficient using Minitab software, relationships were interpreted according to https://www.leadquizzes.com/blog/pearson-correlation-coefficient-formula/

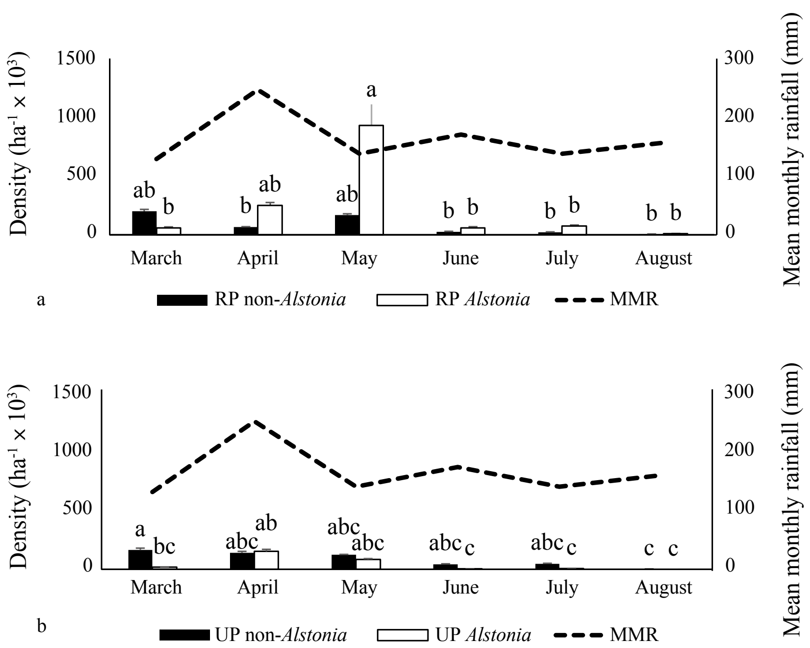

Figure 6 Densities of newly emerged *Alstonia* and non-*Alstonia* species during six months of the study period in both Pine plantations and the mean monthly rainfall in the study area — a) restoring pine plantation (RP), b) unrestored pine plantation (UP); different letters indicate significant differences at $p < 0.05$, $n = 15$

recruitment of *Alstonia* seedlings was recorded from RP when compared to Non-*Alstonia* species. It was eleven times higher than Non-*Alstonia* seedling recruitment in UP. More seedlings of both *A. macroplylla* and non-*Alstonia* species established from March to May, while in the following months (May–August), more species (*Alstonia* > non-*Alstonia*) died in both sites. There was a very strong positive correlation between rainfall and the emergence of *A. macrophylla* seedlings in UP (+0.732) whereas in RP there was no or negligible relationship (-0.729) (Table 2). There was a moderately negative relationship between rainfall and seedling emergence non-*Alstonia* in RP and no relationship between rainfall and seedling emergence of non-*Alstonia* in the UP (RP = -0.329, UP = +0.142). Moreover, there was a strong negative correlation between rainfall and the seedling mortality of both *Alstonia* (-0.410) and non-*Alstonia* (-0.449) in UP, while there was a negligible and a weak negative relationship for non-*Alstonia* (-0.065) and *Alstonia* (-0.222) in RP, respectively (Table 2).

Table 2 Pearson's correlation between the mean monthly rainfall and the seedling emergence and mortality of *Alstonia* and non-*Alstonia* species in restored (RP) and unrestored pine stands (UP)

Site	Factors	PCC	p-value	Relationship
RP	MMR and emerged non-*Alstonia*	-0.329	0.524	Moderate negative
	MMR and emerged *Alstonia*	-0.079	0.881	No or negligible
	MMR and dead non-*Alstonia*	-0.065	-0.903	No or negligible
	MMR and dead *Alstonia*	-0.222	0.673	Weak negative
UP	MMR and emerged non-*Alstonia*	0.142	0.789	No or negligible
	MMR and emerged *Alstonia*	0.732	0.098	Very strong positive
	MMR and dead non-*Alstonia*	-0.410	0.420	Strong negative
	MMR and dead *Alstonia*	-0.449	0.372	Strong negative

MMR = mean monthly rainfall, PCC = Pearson correlation coefficient using Minitab software, relationships were interpreted according to https://www.leadquizzes.com/blog/pearson-correlation-coefficient-formula/

DISCUSSION

There are many records of exotic plants becoming aggressive invaders outside their home range where they show higher relative performance in the new site by exerting stronger negative impacts on co-occurring plants through understory competition or overstorey canopy effects (Callaway & Ridenour 2004). *Alstonia macrophylla* is an exotic species introduced to Sri Lanka (Wijesundara 2010). It reaches a canopy height of 20 m and it is mostly found growing in open areas in Caribbean pine plantations, rainforest gaps and secondary forests southwest Sri Lanka (Tomimura 2008). By comparing the different ecological parameters between *Alstonia* and non-*Alstonia* species, it can be predicted whether the prevalence of this alien invader plays a decisive role in altering the composition and structure of silviculturally-managed restored pine plantations in central Sri Lanka.

Shade intolerant pioneer species tend to favor the light-rich microhabitats that are created by gaps (Kneeshaw & Prévos 2007). Similar to the use of silviculture techniques that are analogous to natural disturbance in North America, this restoration trial in Sri Lanka used thinning of pines to create canopy gaps with light-rich environment, promoting the establishment of early successional species (Muzika 2017). This enabled the colonisation of early successional species in RP, and the five most dominant new recruits representing all life stages were pioneer species in RP. Moreover *A. macrophylla* dominated new recruits (seedlings and saplings) than the non-*Alstonia* species in RP than UP. Further, higher seedling and sapling densities of *Alstonia* was recorded in RP than UP, and > 50% of survival was recorded in all life stages of *Alstonia* in RP. Since *A. macrophylla* had high dominance in RP, if not monitored and managed using silvicultural prescriptions, overdominance of this species may strongly influence the future stand structure and composition of RP, which would result in deviation from restoration targets. However, none of the seedlings of *A. macrophylla* survived in UP at the end of the study period, probably due to canopy shade created by pine trees, or/and allelopathic compounds released by the pine needles, or/and the thick mat of pine needles hindering the emergence and establishment of seedlings (Nissanka et al. 2005). Bandumala (2018) noted that *A. macrophylla* forms dense stands, shade out native species in the forest floor, competes with native species for nutrients and reduces the survivability of native plant species, thereby reducing the diversity of rainforests.

Dyderski and Jagodzinski (2021) assessed the impacts of the three most frequent invasive tree species in European forests (*Prunus serotina*, *Quercus rubra* and *Robinia pseudoacacia*) and confirmed that invasive tree species affect the natural regeneration of these forests by decreasing the regeneration density of native tree species, homogenising species composition, and supporting natural regeneration of sub-canopy and shrub species. In contrast, emerging *A. macrophylla* seedlings had a strong positive relationship between dead *Alstonia* than non-*Alstonia* species in both sites, indicating high intra-species competition than inter-species competition for resources. However, in the restoring site, the emergence of *Alstonia* did not have a negative effect on the establishment of the seedlings of non-*Alstonia* species, asserting more research on the facilitative role of *Alstonia* seedlings in promoting natural regeneration. Moreover *A. macrophylla* was among the most frequently used species by avifauna in lower Hantana region in Sri Lanka due to its height which provides many microhabitats (Gunartane & Gunatilleke 2003). Thus, this species can act as recruitment loci to attract seed dispersers to restoration sites, enhancing natural regeneration. According to Rodriguez (2006), the facilitative impacts of invasive species on native species can have cascading effects across trophic levels, re-structure communities and lead to evolutionary changes. The results, suggest that emergence of *Alstonia* seedlings negatively affected the survival of its own seedlings in both sites, and negatively affected the survival of non-*Alstonia* species in UP. Further, rainfall also governed the seedling survival in both stands. More *Alstonia* and non-*Alstonia* seedlings emerged following the rainy period (May) in RP than in UP, and the seedling densities decreased when the area received less rainfall (June–August). Mortality of Alstonia and non-Alstonia in UP had a stronger negative correlation with rainfall than that in RP.

Management of alien plants has become a high priority challenge for the conservation of native species in natural ecosystems due to their ecological and socioeconomic impacts (Swab et al. 2008). Approaches to manage invasive species should be tailored to specific circumstances, considering invasion intensity, long-term management goals and role of the invasive species (defoliator, direct mortality agent, host stressor facilitator) (Muzika 2017). Due to the value of timber, the invasive behavior of *A. macrophylla* seems to be undermined in the forestry sector of Sri Lanka. This leads *A. macrophylla* to outcompete the native and endemic flora, providing opportunity for its faster spread in open disturbed sites in the wet zone of Sri Lanka (Tomimura 2008, Bandumala 2018). The successful removal of an alien species requires both the effective elimination of alien plants and the restoration of native plant communities, back to climate ready vegetation, most likely to survive in the new climate (Hulme 2006). Bandumala (2018) suggested hand pulling, digging, de-barking and basal cutting to control the spread, growth and density of *A. macrophylla*. However, during the research it was observed that basal cuttings did not effectively eliminate the species because the plants that had been damaged by animals or humans were re-generating faster from their basal stems. Therefore, the study proposes manual removal of *A. macrophylla* during the younger stages (seedlings and saplings) and harvesting at adult stage, considering their timber quality. This will enable the management of *A. macrophylla* in restoration sites in order to achieve desirable restoration goals, assisting biodiversity enhancement and improving of livelihoods of local communities.

CONCLUSIONS

Although *A. macrophylla* was dominant in all life stages in RP, it can be managed to assist natural regeneration since it does not exert a negative impact on seedling establishment of non-*Alstonia* species. However, appropriate interventions (short, mid and long term) are needed not only to monitor and promote natural regeneration but also to manage invasive species in restored pine stands to achieve restoration goals.

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