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ASSESSMENT OF SEEDLING ABUNDANCE, SURVIVAL AND GROWTH OF TWO DIPTEROCARP SPECIES IN PEAT SWAMP FORESTS OF BRUNEI DARUSSALAM

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ABSTRACT

Dryobalanops rappa Becc. and *Shorea albida* Sym. are Bornean endemics of high conservation value and increasingly threatened by anthropogenic disturbances. *In-situ* study of seedling abundance and growth performance of these Dipterocarp species was conducted in two selected peat swamp forests of Brunei Darussalam, following a mast fruiting event in March–May 2014. Within six 6 x 6 m plots at each forest site, *D. rappa* seedlings at the Anduki peat swamp forest and *S. albida* seedlings at the Badas peat swamp forest were measured for abundance at the initial census in September 2014, as well as survival and relative growth rates (RGR) after a period of 5 months, with the final census in February 2015. We found significantly higher seedling abundance for *D. rappa* (1885 ± 208) than *S. albida* (160 ± 71). Significantly higher percentage survival was recorded for *D. rappa* seedlings (90.8 ± 2.2%) in comparison to *S. albida* seedlings (81.7 ± 2.2%). *S. albida* seedlings (0.24 ± 0.02 mm mm^{-1} $month^{-1}$) showed significantly greater RGR in stem diameter than *D. rappa* seedlings (0.18 ± 0.02 mm mm^{-1} $month^{-1}$), however, there were no significant differences in the RGRs based on seedling height, leaf number and biomass between *D. rappa* and *S. albida* seedlings. In terms of seedling abundance and percentage survival, *D. rappa* seedlings appeared to be more successful in regeneration and may potentially be used for rehabilitation of degraded tropical peat swamps and other forest types. Our results suggested that greater conservation efforts of peat swamps must be made to protect the Bornean endemic plant species, in particular *S. albida*.

Keywords: Borneo, Dipterocarpaceae, *Dryobalanops rappa,* relative growth rates, *Shorea albida*

INTRODUCTION

Peat swamp forest is a unique ecosystem that represents the second major forest type in Brunei Darussalam, accounting for 15.6% (or 90,884 ha) of Brunei's forest (Wong *et al.* 2015; Forestry Department 2016). It is mainly located in the Belait district, interconnecting with the peat swamps of the Baram basin in Sarawak. Bornean peat swamp forests are ombrogenous and have six 'phasic communities', each consisting of distinct plant communities (Anderson 1963). Over the years, there has been a significant reduction in peat swamps in Brunei Darussalam mainly due to infrastructure development and forest fires (Pg Harun 2015; Wong 2016). Peat swamps house unique flora, some of which are endemic and increasingly threatened in their natural ranges due to anthropogenic disturbances such as legal or illegal logging, forest fires and land-use changes (Yule 2010; Posa *et al.* 2011). Most tree families in lowland dipterocarps are found in peat swamps, but many peat swamp species are restricted and physiologically adapted to this extreme forest environment (Ng & Ibrahim 2001).

In Brunei Darussalam, extensive stands of *Dryobalanops rappa* Becc. or 'Kapur paya' exist on shallow peat overlying sand in Lumut and Anduki, while pure stands of *Shorea albida* Sym. occur in the 'padang alan' and 'alan bunga' peat swamp forests of Badas, both in the Belait District (Anderson 1964; Ashton *et al.* 2003; Wong *et al.* 2015). The Anduki peat swamp forests experienced massive forest fires during the

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1997–1998 El Niño drought (Wooster *et al.* 2012), resulting in fragmented stands of intact *D. rappa* existing within an otherwise developed area. Low regeneration rates have been observed in natural *D. rappa* populations (Wong & Kamariah 1999), and this species is increasingly threatened from illegal logging (Phillips 1998). The Badas peat swamps consist of gregarious stands of *S. albida* that are decreasing in population density and have been showing few signs of natural regeneration for the past 30 years (Kobayashi 1998). The IUCN Red List classifies *S. albida* as endangered due to rapid population loss within its natural forest ranges, coupled with a regeneration status that is reported to be virtually non-existent (Ashton 1998). Furthermore, *S. albida* is endemic to north and west Borneo (Ashton 1998) and so the remaining stands in the Badas peat swamps in Brunei are likely to be one of the few remaining intact stands of *S. albida* in Borneo and globally (Forestry Department 2014).

Both *D. rappa* and *S. albida* are important timber tree species that rely on irregular mass flowering and mast fruiting episodes as a means of their natural regeneration (Appanah & Turnbull 1998). Although several studies have been conducted on the survival and growth of Dipterocarpaceae seedlings in Bornean forests (Turner 1990; Delissio *et al.* 2002; Nakagawa *et al.* 2005; Shimamura *et al.* 2006; Takeuchi & Nakashizuka 2007; Daisuke *et al.* 2013), only a few have focussed specifically on peat swamp species (Ibrahim 1996; Gavin & Peart 1997; Saito *et al.* 2005; Jans *et al.* 2012), and no study has been conducted on *S. albida* seedlings to date.

Following a small mass flowering and a mast fruiting event in the Badas and Anduki peat swamps in March–May 2014, the abundance, survival and growth of *D. rappa* and *S. albida* seedlings at the understorey of these two peat swamp forests were assessed in Brunei Darussalam. Our study provides preliminary findings on two native Dipterocarp species that can potentially be utilised in efforts to naturally regenerate and rehabilitate disturbed peat swamp forests.

MATERIALS AND METHODS

The study was conducted in the Anduki and Badas peat swamps located in the Belait district, Brunei Darussalam, north-west Borneo, at distances of *ca.* 14 km from each other by road. A dominant dipterocarp species (Dipterocarpaceae) in each peat swamp site was selected. The Anduki peat swamp (4°37'39.00"N, 114°22'1.14"E) is located in the coastal areas of Belait district within the Anduki Forest Reserve and is dominated by *Dryobalanops rappa* Becc. The Badas peat swamp (4°34'9.12"N, 114°24'40.08"E) is located further inland, south of Seria and is mainly populated by *Shorea albida* Sym. A total of six plots (6 m x 6 m or 36 m^2 each) plots were set up: three plots of *Shorea albida* at Badas and three plots of *Dryobalanops rappa* at Anduki. Plots were located *ca.* 50 m away from each other and each plot was set up with a mother tree of the respective species located at the centre of the plot. Abundance of *D. rappa* seedlings in Anduki and *S. albida* seedlings in Badas were quantified per plot at the initial census in September 2014, *ca.* 3–5 months after the mass flowering and mast fruiting events. Within each plot, 40 seedlings of either *D. rappa* (at Anduki) or *S. albida* (at Badas) were randomly chosen and tagged in September 2014. The seedling censuses were conducted twice, in September 2014 and after 5 months, in February 2015. The tagged seedlings were measured for percentage survival, stem height (measured from the point of measurement painted white on soil surface to the top leaf bud), stem diameter and number of leaves (counted fully expanded leaves, excluding heavily eaten leaves i.e. approximately 70% of lamina eaten and dead leaves) at both censuses.

A total of 10 seedlings of each species were randomly chosen from outside each of the three study plots per census and harvested to provide estimates of initial and final dry biomass. At both harvests, seedlings were washed with distilled water, oven-dried at 60°C for 48 h and weighed. The relative growth rate (RGR) based on stem height (RGRH), stem diameter (RGRD), number of leaves (RGRL) and biomass (RGRB) per seedling over the five-month census period were calculated following Hunt (1982): RGR = ($\log_e W_2 - \log_e W_1$) / ($t_2 - t_1$), where W_2 and W_1 are stem height, stem diameter, total number of leaves or biomass and $t_2 - t_1$ is 5 months. To compute RGRB, seedlings were paired by ranked values of seedling biomass at the initial and final harvests.

Between-species differences seedling abundance, percentage seedling survival and RGR values were determined using t-tests in R 2.15.2 (R Core Team 2014). All data were first explored to confirm the normality of residuals and homogeneity of variances, and where necessary, data was $\log_{10}$-transformed, with the exception of percentage survival, which was arcsine-transformed.

RESULTS AND DISCUSSION

Using the initial census survey, *D. rappa* seedlings at the Anduki peat swamp forest showed significantly higher mean abundance per 36 m^2 plots compared to *S. albida* seedlings at the Badas peat swamp (*D. rappa*: 1885 ± 208 vs. *S. albida*: 160 ± 71, $p < 0.01$). This is a probable reflection of the higher density of adult *D. rappa* trees in Anduki, compared to the more sparsely populated adult *S. albida* trees in Badas (pers. obs.). Additionally, the higher *D. rappa* seedling abundance may be due to higher abundance of flowering mother trees, as almost all mature *D. rappa* trees flowered at Anduki whilst not all mature *S. albida* trees flowered at Badas during the same mass flowering event in 2014 (pers. obs.). Other studies have similarly documented a positive relationship between the number of mother trees and seedling density, with the highest seedling densities found in areas with high adult abundance (Itoh *et al.* 1997; Webb & Peart 1999; Backlund 2013).

Mean percentage survival of tagged *D. rappa* seedlings over the period of 5 months was significantly greater than *S. albida* seedlings (90.8 ± 2.2% vs. 81.7 ± 2.2%, $p < 0.05$). All relative growth rates (RGRs) data of both species showed similar growth rates (Fig. 1) that there were no significant differences in all relative growth rates (RGR) except for RGR in stem diameter (RGRD), in which *D. rappa* seedlings had significantly lower RGRD than those of *S. albida* seedlings (0.18 ± 0.02 vs. 0.24 ± 0.02 mm mm^{-1} $month^{-1}$; $p < 0.01$; Fig. 1B). Other studies in Brunei Darussalam have recorded higher survival and RGR for *D. rappa* seedlings planted in lowland mixed dipterocarp forest (Sukri 2010) and degraded heath forest (W. H. Tuah, unpubl. data). Natural disturbance within the understorey may influence the survival of tree seedlings (Appanah & Turnbull 1998) and can be an explanation for the low percentage survival of *S. albida*. Yamada (1997) reported that Badas peat swamp has higher incidences of fallen trees and presence of buttress roots on its forest floor compared to Anduki peat swamp. During the rainy season between December 2014 – January 2015 in Badas, *S. albida* seedlings may not survive when hit by fallen trees and branches, thus decreasing its survival percentage. Through the mast fruiting period, the *S. albida* seeds may fall on the false forest floor in Badas, which is formed from litter accumulation on buttress roots. This may lead to *S. albida* seedlings mortality as the false floor may fall to the peat when disturbed.

Seedling predation and microenvironment also influence seedling survival, and it has been recorded elsewhere in Borneo that late fruiting of *Shorea* species increased the possibility of seed losses to predation (Curran & Webb 2000). Anduki peat swamp has different physiological environment compared to Badas peat swamp forest in terms of its natural disturbance. Fragmentation of the Anduki forest due to rapid forest fires may cause its forest floor to develop shallow litter and peat overlying sandy soil (Yamada 1997). The Anduki Forest Reserve is dependent on waterlogged conditions to maintain the peat bog (Yussof 2015) and *D. rappa* seedlings are well-adapted to waterlogged peat (Yamada & Suzuki 2004). Survival and growth of *S. albida* seedlings have been found to be negatively affected by low light intensity (Kobayashi 1998), water shortage during dry spells (Kobayashi 1998) and excessive water during rainy period (Dixon *et al.* 2013), which may be factors that explain their low survival rates in Badas.

D. rappa is a light-demanding species (Ashton *et al.* 2003), while *S. albida* seedlings have been recorded as shade-intolerant (Kobayashi 1998; pers. obs.). Regardless of the light environment, light-demanders tend to possess larger specific leaf area and higher photosynthetic capacity, which result in greater carbon gain, and potentially higher survival, compared to shade-tolerant species (Ghazoul & Sheil 2010). Light has

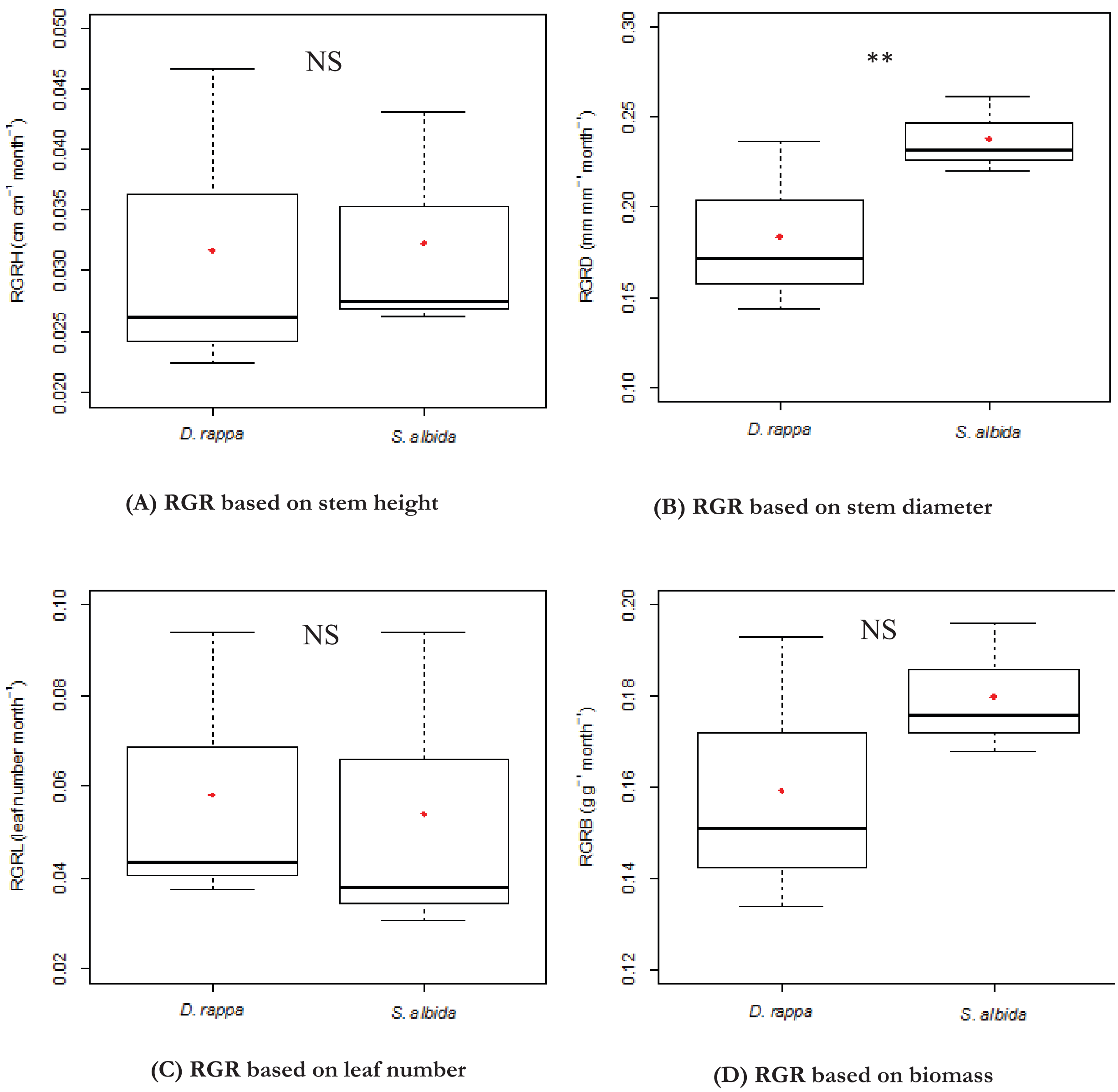

Figure 1 Differences in relative growth rates (RGR) for *Dryobalanops rappa* seedlings in Anduki and *Shorea albida* seedlings in Badas: (A) RGRH (stem height; cm cm^{-1} $month^{-1}$), (B) RGRD (stem diameter; mm mm^{-1} $month^{-1}$), (C) RGRL (number of leaves; leaf number $month^{-1}$) and (D) RGRB (biomass; g g^{-1} $month^{-1}$). RGR data were determined for the 40 tagged *D. rappa* and *S. albida* seedlings, except for RGRB which was determined for the 10 seedlings harvested outside each plot at each census. The asterisk sign within each RGR denotes significant differences of means between species (marked with red dots) using t-tests (*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$). NS=Non-significant.

been recognised to significantly influence survival and growth of Dipterocarp seedlings (Scholes *et al.* 1996; Whitmore & Brown 1996). For example, *D. rappa* and *S. albida* saplings were planted in the open in ongoing reforestation trial plots of degraded waterlogged heath forests (*Kerapah* forests) in Brunei Darussalam, and have performed successfully in terms of its survival and growth rates over a period of more than a year (W. H. Tuah, unpubl. data).

It was found that *S. albida* seedlings had significantly higher RGRD compared to *D. rappa* seedlings. This suggests that in the shaded understorey of peat swamp forests, *S. albida* seedlings allocated more resources to stem diameter growth than height growth. Tropical tree species that preferentially invest resources into stem diameter growth and wood density typically exhibit traits that defend against herbivory and pathogens, as well as for the development of their root system (Kitajima 1994), all of which decrease investment into height growth. The Badas peat swamp forest has a flat, densely crowded canopy (Yamada 1997), which restricts light entry to the understorey and may further inhibit height growth of *S. albida* seedlings. These shade-intolerant *S. albida* seedlings (Kobayashi 1998) require ample light to grow in height. Higher growth rates of *S. albida* in the open areas than in the closed canopy forest was recorded in the ongoing rehabilitation trial plots in the *Kerapah* forests of Brunei Darussalam (W. H. Tuah, unpubl. data).

Both the *Dryobalanops rappa* peat swamp forest in Anduki as well as the *Shorea albida* peat swamp forest in Badas have been identified as critical habitats that are of high conservation value (Forestry Department 2014). Peat swamps are highly vulnerable to fires, particularly during the dry season and when the water table have been lowered (Yule 2010). Changes in drainage and hydrological conditions significantly increase repeated fire events (Posa *et al.* 2011). Repeated fires in Anduki and Badas, especially during drier periods and drought events, coupled with slow seedling growth rates, will undoubtedly result in further losses of both *D. rappa* and *S. albida* populations. In the case of *S. albida*, this loss will be further exacerbated by the low number of survived seedlings and mother trees flowering at the same time (pers. obs.).

CONCLUSION

This study recorded significant findings on *Dryobalanops rappa* seedlings in Anduki and *Shorea albida* seedlings in Badas. *D. rappa* seedlings were more abundant than *S. albida* seedlings, and also showed higher percentage seedling survival. *S. albida* seedlings, however, appeared to invest more in stem diameter growth, as their relative growth rate in terms of stem diameter was significantly higher compared to *D. rappa* seedlings. We suggest that *D. rappa* seedlings may be suitable as a species that can be used to rehabilitate degraded peat swamp forests, but detailed, longer term studies are needed to further support this conclusion. Finally, given that peat swamps forests are fast disappearing due to natural and anthropogenic disturbances, their protection and conservation efforts should be prioritised to protect the Bornean endemic plant species, in particular *S. albida*.

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