



Natural regeneration potential of Andaman Padauk (*Pterocarpus dalbergioides*) in sustaining the tropical forests of Andaman & Nicobar Islands, India

Iyyappan Jaisankar¹ · R. Jayakumara Varadan¹ · Bosco Augustine Jerard¹ · Ganguly Nabanita² · Muthu Rajkumar² · Ayyam Velmurugan¹ · S. K. Zamir Ahmed¹ · Ezekiel Manasseh Moses¹

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Abstract

Natural regeneration potential is an important indicator for any forest ecosystem and Andaman Padauk (*Pterocarpus dalbergioides*) is the principal timber tree endemic to Andaman & Nicobar Islands. This study analyzed the natural regeneration potential of Andaman Padauk under different disturbance regimes across its distribution range with regard to population dynamics, growth pattern, population structure, population status and allometry. Contrary to the perception that it is a poor regenerator, the species showed a luxuriant growth. While ephemerals, seedlings, saplings, poles and total regenerates are significantly high at the leading edge of its habitat, trees are significantly high at the trailing edge. Their heights are mostly positively skewed and normally distributed. With a reverse-J shaped demography, the species is in its most dominant form in the stand. Though its population status is declining, the prospects of population stabilization are high. There exists a strong proportionality between DBH and height of regenerates. Hence, the species should be assisted through considered disturbance to realize its natural regeneration potential. As all the species under the pantropical *Pterocarpus* genus share a number of growth and reproductive traits, the path breaking findings of this study emanated from refined methodologies will help assess the natural regeneration potential of other species whose existence is threatened by either unstable or declining population in their habitat.

Keywords Andaman Padauk · Natural regeneration · Allometry · Population dynamics · Population structure

Introduction

World has 3999 million ha of forests wherein 93% are natural forests and the rest are planted forests (FAO 2015). While natural forests conserve the genotypic diversity and maintain the natural tree species composition, structure and ecological dynamics; planted forests are established for the purpose of industrial timber production. But, together they provide a bulk of timber and non-timber products like sawn wood,

round wood, fire wood, charcoal, paper, fodder, medicinal & aromatic plants, gums & resins, wild fruits & vegetables, nuts and seeds (FAO 2018). For the same reason, forests are being exploited indiscriminately oblivious of their ecological and environmental services like water purification, erosion control and carbon sequestration.

Recognizing the crucial role of forests in eradicating poverty, ending hunger, achieving inclusive growth, narrowing inequalities, mitigating climate change and managing natural resources, Sustainable Development Goal (SDG) 15.2 of United Nations has explicitly called for sustainable management of all types of forests, to halt deforestation, to restore degraded forests and to substantially increase afforestation and reforestation globally (FAO 2018). Going by a conservative estimate of 2000 USD per ha for artificial regeneration, the cost of achieving restoration is quite high (Löf et al. 2019) which risks Official Development Assistance (ODA) and public expenditure on conservation and sustainable use of forests as envisaged by SDG 15.B (FAO 2018).

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✉ R. Jayakumara Varadan
varadan.iari@gmail.com

¹ ICAR-Central Inland Agricultural Research Institute, Port Blair, Andaman and Nicobar Islands, India

² Department of Environment & Forests, Andaman & Nicobar Administration, Port Blair, Andaman and Nicobar Islands, India

Natural regeneration, the spontaneous recovery of native tree species that colonize and establish in abandoned fields or natural disturbances (Crouzeilles et al. 2017) offers a cost-effective option for large-scale forest restoration (Chazdon and Guariguata 2016). A Naturally regenerating forest will emerge as a complex adaptive system that possesses eight key properties, viz. heterogeneity, hierarchy, self-organization, openness, adaptation, memory, nonlinearity and uncertainty (Filotas et al. 2014) which confer resilience on the system following disturbances or major shocks (Cumming 2011). In addition to enhancing resilience and supplying multiple ecosystem goods and services, natural regeneration can be highly effective for recovering local biodiversity, species interactions and movement within landscapes (Rahman et al. 2011). However, it relies on the inherent regeneration potential of the native tree species in terms of seed production, dispersal, germination, seedling establishment and growth of the seedlings under varied environmental conditions like climate, soil characteristics, disturbance regimes and seed bank composition (Bawa and Seidler 1998; Luo et al. 2017; Sharma et al. 2018).

Pterocarpus is a pantropical genus of dalbergioid legumes (Lavin et al. 2001) having an estimated 32 species distributed across tropical Africa, Neotropics and Indomalaya (Saslis-Lagoudakis et al. 2011). While India shares the habitat of *P. marsupium* with other Asian countries like Sri Lanka, Nepal, Bangladesh and Taiwan, *P. santalinus* and *P. dalbergioides* are endemic to Eastern Ghats of Peninsular India and Andaman Islands, respectively (IUCN 2020). Apart from a few sporadic studies on *P. dalbergioides* (Prasad et al. 2008), *P. santalinus* (Ankalaiah et al. 2017), *P. angolensis* (Gonçalves et al. 2018) and *P. soyauxii* (Mokake et al. 2018), the natural regeneration potential of these pantropical but yet endemic species is still unexplored. Therefore, scrutinizing the natural regeneration potential of these heavily traded timber species gains significance in the light of unsustainably declining population (Winfield et al. 2016) leaving them near threatened to endangered in their natural habitat (Barstow 2018).

Andaman & Nicobar Islands is one of the nine Union Territories of India, strategically located in the south-eastern Bay of Bengal 1200 km away from the mainland as a gateway to ASEAN countries. Aligned in north–south direction between 92.12° and 93.57° E longitude; and between 6.45° and 13.41° N latitude with 10°N channel separating Andaman group from Nicobar group of Islands, the archipelago comprises of 836 islands, islets and rocks (DoEF 2017) covering a geographical area of 8249 sq.km, accommodating 0.38 million population including 28,530 notified tribes (MoHA 2011). Apart from the rapidly urbanizing South Andaman district where the capital town of Port Blair is located, the Islands is predominantly rural with dispersed settlements.

Staying true to its biodiversity hotspot tag, the ecosystem of this tropical Islands is highly diversified with innumerable endemic species. The land use pattern is highly conservative as 86% of area is legally preserved under 12 forest types (Champion and Seth 1968). Andaman Padauk (*Pterocarpus dalbergioides* Roxb.) is the principal timber tree endemic to Andaman group of Islands forming an important component of moist deciduous and semi-evergreen forests (Rao 2000).

In moist deciduous forest, the species occurs in the top canopy along with *Terminalia bialata*, *T. citrina*, *T. procera*, *Canarium euphyllum*, *Pterocymbium tinctorium*, *Tetrameles nudiflora*, *Albizia lebbek*, and *Lagerstroemia hypoleuca*; the middle story is occupied by *Lannea coromandelica*, *Adenanthera microsperma*, *Dillenia andamanica*, *Diospyros marmorata*, *Cratoxylum formosum*, *Semecarpus kurzii*, *Pterospermum aceroides*, *Murraya paniculata*, and *Atalantia monophylla*; and the lower story species are *Canthium gracilipes*, *Rinorea bengalensis*, *Glycosmis pentaphylla*, and *Tabernaemontana alternifolia*. In semi-evergreen forest, it occurs in the top canopy along with *Dipterocarpus grandiflorus*, *D. gracilis*, *Pterygota alata*, *Pterocymbium tinctorium*, *terminalia bialata*, *T. procera*, *Albizia chinensis*, *A. lebbek*, *Artocarpus lacucha*, and *A. chama*; the middle canopy is dominated by *Lagerstroemia hypoleuca*, *Dillenia andamanica*, *Pometia pinnata*, *Horsfieldia irya*, *Xanthophyllum andamanicum*, *Fagraea racemosa*, *Sageraea elliptica*, *Aporosa villosa* and *Maesa andamanica*; and the under story consists of *Licuala peltata*, *Caryota mitis*, *Areca triandra*, *Leea indica*, and *Clerodendrum infortunatum* (Alappatt 2017).

The slow growing tree takes about 35–40 years for the extraction of good quality timber (Rao 2000) and reaches a height of above 30 m attaining a girth of over 3 m, often with very large buttresses (Ganapathy and Rangarajan 1964). Owing to good polishing and termite resistance, the moderately hard crimson wood is used in high-class joinery, furniture, cabinetry, fancy turnery, carving and sculpting, inlay, flooring, knife handles, veneer and tool handles, boat building, paddles, oars, agricultural implements, billiard tables, decorative woods and in dye making (Prasad et al. 2008).

Like any other tropical forests of the world, Andaman forests are also subjected to deforestation leading to fragmentation of the forest system, resulting in extinction of valuable species from their native habitats. This problem is a significant issue for Andaman Padauk whose population is affected by legal and illegal logging on the one hand and scanty natural reproduction on the other hand (Prasad et al. 2008; Ganapathy and Rangarajan 1964). Therefore, the present study was undertaken during April 2019 to examine the natural regeneration potential of Andaman Padauk under various physiographic conditions of Andaman Islands in terms of population dynamics, growth pattern, population structure, population status and allometry.

Materials and methods

Study area

In accordance with the objective of the study, four locations, viz. Mohanpur and Lamiya Bay in North Andaman, Prolobjig in Middle Andaman and Hut Bay in South Andaman were purposively selected to cover the whole range of species distribution from 10°39'N to 13°15'N covering an area of 6408 sq km. (Fig. 1).

All these sites falling under protected forests are slopy lands that have undergone disturbance in one way or other. While a dead bamboo grove has disrupted the canopy cover at Mohanpur, a road cutting across has broken the canopy contiguity at Lamiya Bay. Even as Prolobjig is an erstwhile selective logging plot, Hut Bay is an abandoned quarry (Fig. 2).

Sampling design

At the outset, the study area was transected to have a general idea about the species composition wherein Padauk regenerates had a dominant presence over *Terminalia*

bialata, *Canarium euphyllum*, *Albizia lebbek*, *Lagerstroemia hypoleuca*, *Dillenia andamanica*, *Diospyros marmorata*, *Semecarpus kurzii*, *Lansea coromandelica*, *Calamus viminalis*, *Gigantochloa nigrociliata*, and *Sageraea elliptica*. Following a stratified random quadrat method with a sampling design similar to Tesfaye et al. (2002), Malik et al. (2012), Gao et al. (2017), Gonçalves et al. (2018), Rahman et al. (2020), and Maua et al. (2020) two quadrats of size 20 m × 20 m (400 m²) were laid each at a distance of 10 m uphill and downhill from a padauk tree. Within each of these quadrats, 10 random sub-plots of size 2 m × 2 m (4 m²) were laid from which relevant data were collected. Thus, the total sample size amounted to 80 plots of 4 m² with 20 at each of the four locations.

Data

The information on number of padauk regenerates, their height and Diameter at Breast Height (DBH) were collected from each of the sub-plots of the sampling quadrats. While the number of regenerates was enumerated manually, their height and DBH were calculated using measuring tape and Digital Vernier Caliper, respectively.

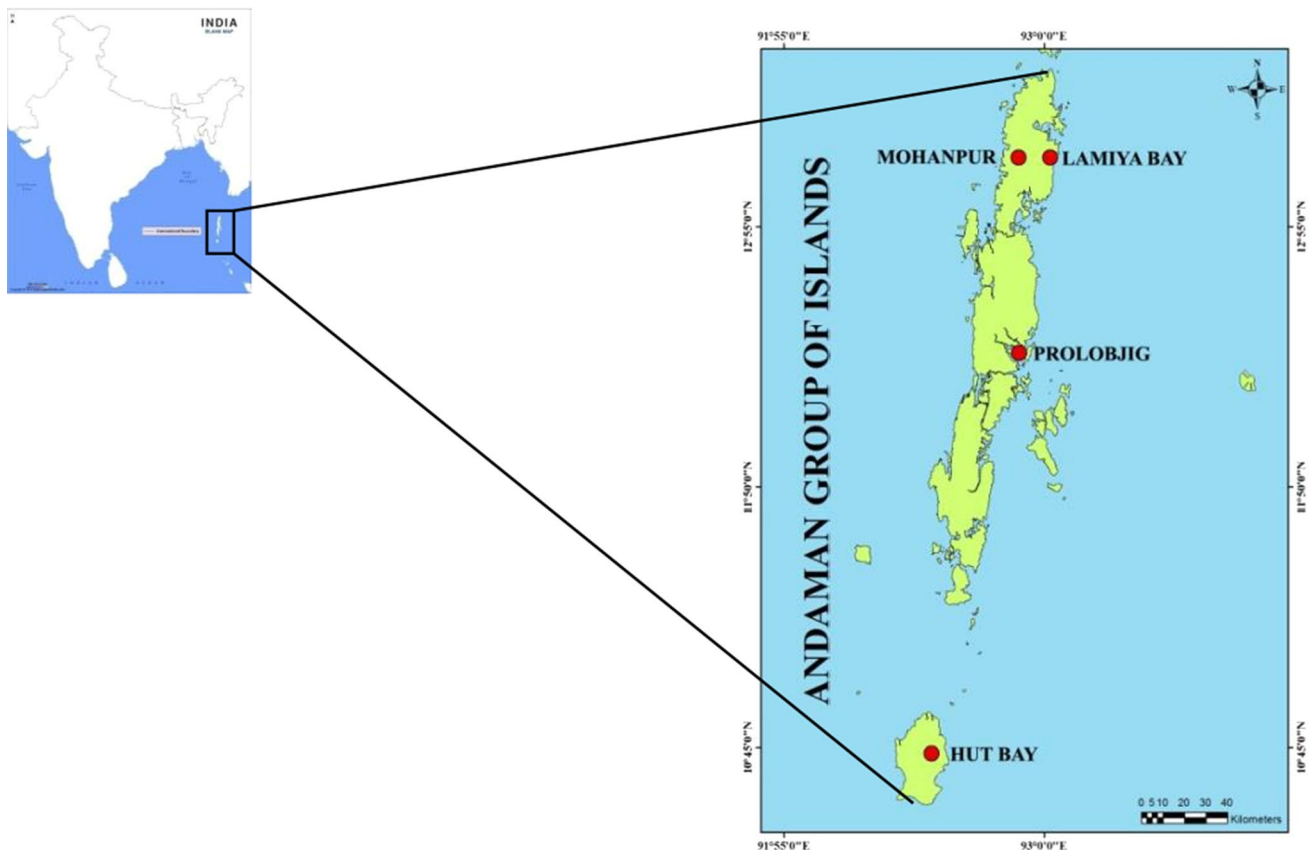


Fig. 1 Location of experimental sites across Andaman group of Islands

Fig. 2 Growth pattern of padauk regenerates at a) Mohanpur, b) Lamiya Bay, c) Prolobjig and d) Hut Bay



Methodology

Population dynamics, growth pattern, population structure, regeneration status and allometry were analyzed to compare and contrast the natural regeneration potential of Andaman Padauk among different locations across Andaman Islands and between uphill and downhill of a padauk tree in slopy lands.

Population dynamics

The presence of sufficient number of seedlings, saplings and young trees in a given population provides valuable information about the population dynamics and indicates a successful regeneration of forest species (Saxena and Singh 1984; Dang et al. 2010; Dolanc et al. 2013). Different studies have applied different yardsticks to classify the regenerates either on the basis of height or diameter of the stem; or both in tandem. To mention a few, Malik et al. (2012) classified the regenerates as recruits that are current year's seedlings, unestablished with height < 2 m and established > 2 m; Juřička et al. (2019) categorized as seedlings of height < 137 cm and saplings of 137–200 cm with further division of seedlings into four sub-categories; Nerlekar et al. (2019) considered plants having a DBH \geq 10 cm as trees, 1–10 cm as saplings and < 1 cm as seedlings; and de Carvalho et al. (2017) divided the plants into seedlings 0.5–1 m tall, small saplings 1–3 m tall, large saplings > 3 m tall and \leq 5 m DBH; and poles 5–10 cm DBH.

Considering the morphology of padauk regenerates in the sampling plots, the plants were categorized as ephemerals of height < 30 cm, seedlings 30–100 cm, saplings 100–200 cm, poles 200–300 cm and trees > 300 cm for the study. The number of individuals under each of these categories in 10 sub-plots of a quadrat was enumerated separately, averaged and represented as:

$$\text{Plant density} = \frac{\text{No. of plants}}{\text{area of the sub - plot}} (\text{No./4m}^2)$$

Subsequently, the plant density of regenerates was examined for its significant difference among the four study locations using One-way ANOVA and Tukey's Post Hoc Test (Do et al. 2016; Hallsby et al. 2015).

Growth pattern

The height of enumerated regenerates was analyzed for its mean, median, mode, range and inter-quartile range through Box Plot technique to compare and contrast the growth pattern of padauk regenerates among the study locations.

Population structure

Population structure is defined as the proportion of plants under different life stages of a species per unit area (Endels et al. 2004). It indicates the regeneration process at a certain moment in time (Poorter et al. 1996). Height/

DBH-class (Gao et al. 2017; Khan et al. 1987) and height-class (Tesfaye et al. 2002) distribution that work well in treelets (Condit et al. 1998) are often used to represent the population structure of forests.

A reverse-J shaped distribution with plenty of individuals in the small size classes indicates good regeneration (Khamyong et al. 2003), while a J-shaped distribution with relatively few individuals in the small size classes indicates poor regeneration and probably declining population (Kumar et al. 2016). Similarly, a bell-shaped distribution with many saplings between few seedlings and adults is attributed to disturbed forest in which regeneration is hampered (Saxena et al. 1984), while an inverted-bell shaped distribution illustrates a recovering population that experienced a period of very poor recruitment (Hall and Bawa 1993). The size-class distribution diagrams are further tested for Pearson Correlation, wherein a negative correlation indicates the reverse-J shaped curve, a positive correlation indicates the J-shaped curve and no correlation indicates haphazard population distribution (Poorter et al. 1996).

Accordingly, the calculated plant density was proportionalized among different categories of regenerates and plotted as height-class distribution in a Line Graph to elucidate the population structure of padauk regenerates in uphill, downhill and whole of the four locations, followed by correlation analysis.

Population status

Successful regeneration of a species depends on its ability to produce new seedlings and the ability of seedlings and saplings to survive and grow (Good and Good 1972). Thus, the population status of a species is determined either by the proportion of seedlings and saplings in total regenerates (Bhuyan et al. 2003), the relative proportion of all life stages of regenerates (Shankar 2001) or by the presence of certain minimum quantity of plants under each life stage of regenerates (Juřička et al. 2019).

In the current study, the population status of padauk was determined based on the proportion of seedlings in total regenerates excluding ephemerals (Baboo et al. 2017; Sagar and Singh 2004): (i) 0% was considered as conservation focused species, (ii) 1–24% was considered as severely declining species, (iii) 25–49% was considered as declining species, (iv) 50–66% was considered as relatively stable species, (v) 67–99% was considered as potentially expanding species, and (vi) 100% was considered as newly recruited species from neighboring areas. The results have been illustrated as Percentage Bar Graph (Paul et al. 2019).

Allometry

Forests play a significant role in mitigating climate change by sequestering atmospheric carbon (Nogueira Junior et al. 2014; Istrefi et al. 2019). Hence, accurate estimates of forest biomass are crucial for quantifying the restoration level of degraded forests in view of emerging carbon credit market opportunities under Reducing Emission from Deforestation and Forest Degradation (REDD+) (Djomo et al. 2016; Mugasha et al. 2016). While it is practically easy to measure DBH of all trees within the sample plot, height, wood density, crown length, crown width, crown area, crown diameter, height-to-diameter ratio, age, etc. are measured only for a few trees during forest inventories (Ahmadi et al. 2013; Li et al. 2015; En et al. 2019). As these tree attributes are functionally related, allometric equations are worked out among them to indirectly estimate the forest biomass (Chave et al. 2015).

Here, the height and DBH of poles and trees above 2 m height in the study areas were examined for their allometric relationship through Scatter Plots and Pearson Correlation (Daba and Soromessa 2019; Jia and Zhou 2018) to enable estimation of biomass of padauk forests.

All analyses were carried out in SPSS software.

Results

Population dynamics of padauk regenerates

Among the four study areas, the density of ephemerals was significantly high at Lamiya Bay on the downhill on a par with Mohanpur, uphill on a par with Hut Bay and combined on a par with Mohanpur (Table 1). On the other hand, there was no significant difference in the density of seedlings among the downhill of study areas, but it was significantly high at Mohanpur on the uphill and combined on a par with Lamiya Bay. While there was no significant difference in the density of saplings among the uphill of study areas, it was significantly high at Mohanpur on the downhill and combined on a par with Prolobjig. Similarly, the density of poles was not significantly different among the uphill of study areas, but it was significantly high at Lamiya Bay on the downhill and combined, both on a par with Mohanpur and Prolobjig. Incidentally, the density of trees was significantly high at Hut Bay on both gradients and combined. Overall, the density of total regenerates was significantly high at Mohanpur on the downhill and combined, both on a par with Lamiya Bay and Hut bay.

Table 1 Population dynamics of padauk regenerates across gradients and locations

Regenerate	Gradient	Plant density (Mean no. of plants/4 m ²)			
		Mohanpur	Lamiya Bay	Prolobjig	Hut Bay
Ephemerals	Downhill	15 ^a	15.7 ^{a**}	9.6 ^b	11.5 ^b
	Uphill	11.6 ^b	15.1 ^{a*}	10.1 ^b	12.7 ^{ab}
	Combined	13.3 ^{ab}	15.4 ^{a*}	10.0 ^c	12.1 ^{bc}
Seedlings	Downhill	5.5	5.9	4.3	5.2
	Uphill	8.4 ^{a*}	5.4 ^b	5.3 ^b	5.1 ^b
	Combined	7.0 ^{a*}	5.7 ^{ab}	4.8 ^b	5.2 ^b
Saplings	Downhill	4.6 ^{a*}	2.6 ^b	3.1 ^b	2.4 ^b
	Uphill	3.2	2.8	2.9	3.0
	Combined	3.9 ^{a*}	2.7 ^b	3.0 ^{ab}	2.7 ^b
Poles	Downhill	1.6 ^a	1.7 ^{a**}	1.1 ^a	0.1 ^b
	Uphill	1.4	1.6	1.5	0.5
	Combined	1.5 ^a	1.7 ^{a**}	1.3 ^a	0.3 ^b
Trees	Downhill	2.7 ^b	2.5 ^b	2.1 ^b	7.0 ^{a**}
	Uphill	2.1 ^b	2.4 ^b	1.7 ^b	4.5 ^{a*}
	Combined	2.4 ^b	2.5 ^b	1.9 ^b	5.8 ^{a*}
Total	Downhill	29.4 ^{a**}	28.4 ^a	20.2 ^b	26.2 ^a
	Uphill	26.7	27.3	21.5	25.8
	Combined	28.1 ^{a*}	27.9 ^a	20.9 ^b	26.0 ^a

Comparative plant densities superscripted by same letter are on a par with one another

Symbols ** and * indicate 1% and 5% levels of significance respectively

Growth pattern of regenerates

Further scrutiny on the growth pattern of enumerated regenerates revealed that the height of ephemerals was normally distributed around 18 to 20 cm with half of them concentrated on the higher end between 15 and 23 cm (Fig. 3). While the height of seedlings at Lamiya Bay and Hut Bay was normally distributed around 61 to 62 cm with half of them concentrated evenly between 41 and 80 cm, the same

at Mohanpur and Prolobjig was positively skewed around 43 to 44 cm with half of them concentrated on the lower end between 36 and 62 cm. Similarly, the height of saplings across all the study locations was normally distributed around 143 to 157 cm with half of them spread between 122 and 178 cm.

On the other hand, the height of poles at Mohanpur, Lamiya Bay and Prolobjig was negatively skewed around 264 to 275 cm with half of them spread between 224 and 283 cm, while the same at Hut bay was positively skewed around 275 cm with half of them concentrated on the higher end between 265 and 291 cm. Similarly, the height of trees at Mohanpur and Prolobjit was negatively skewed around 411 cm with half of them spread between 356 and 458 cm while the same at Lamiya Bay and Hut Bay was positively skewed around 375 to 415 cm with half of them spread between 336 and 475 cm. Overall, the height of all regenerates at Mohanpur ranged from 8 to 487 cm, positively skewed around 32 cm with half of them spread between 21 and 128 cm, while the same at Lamiya Bay ranged from 5 to 476 cm, positively skewed around 24 cm with half of them spread between 18 and 96 cm. Even as the height of all regenerates at Prolobjig ranged from 8 to 496 cm, positively skewed around 33 cm with half of them spread between 21 and 144 cm, the same at Hut Bay ranged from 6 to 562 cm, positively skewed around 38 cm with half of them spread between 19 and 178 cm.

Population structure of padauk regenerates

The height-class distribution of padauk regenerates on the downhill, uphill and mean at Mohanpur has revealed a closely plotted and relatively flatter reverse-J shaped curves with significant correlation coefficients of - 0.56, - 0.63 and - 0.60, respectively, while the same at Lamiya Bay has shown overlapping and relatively steeper reverse-J shaped curves with significant correlation coefficients of - 0.55, - 0.54 and - 0.54, respectively (Fig. 4).

Fig. 3 Location-wise height pattern of padauk regenerates

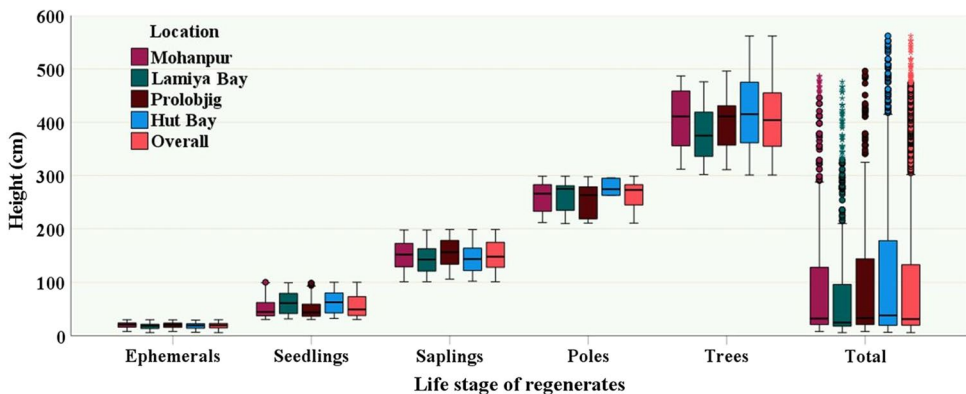
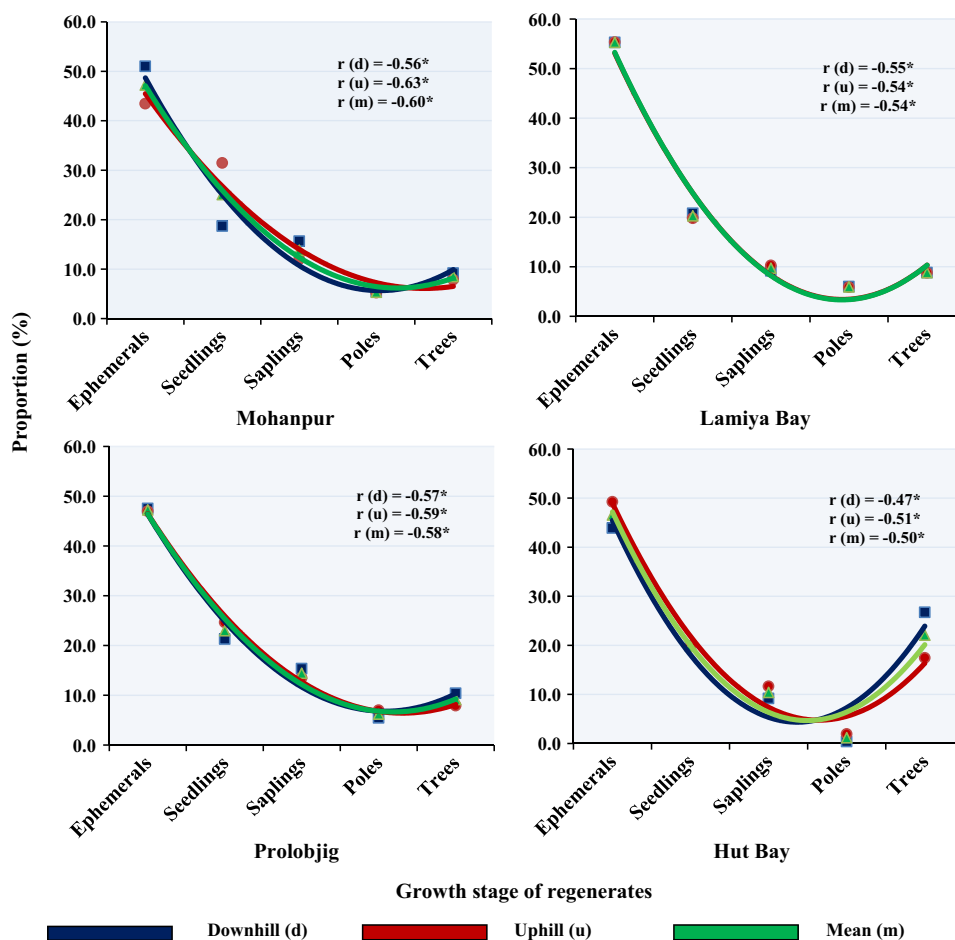


Fig. 4 Height-class distribution of padauk regenerates



Similarly, the distribution at Prolobjig has shown overlapping and relatively flatter reverse-J shaped curves with significant correlation coefficients of -0.57 , -0.59 and -0.58 , respectively. Strikingly, the distribution at Hut Bay has exhibited closely plotted and relatively steeper reverse-J shaped curves that elongates further to form inverse-bell shaped curves with significant correlation coefficients of -0.47 , -0.51 and -0.50 , respectively.

Population status of Andaman Padauk

With 38% seedlings, the population on the downhill of Mohanpur is declining, while the same is relatively stable on the uphill with 56% seedlings (Fig. 5). Overall, the population of Andaman Padauk at Mohanpur is declining with 47% seedlings. On the other hand, the population on the downhill, uphill and overall at Lamiya Bay is declining with around 45% seedlings. With 41 to 46% of seedlings, the population on the downhill, uphill and overall at Prolobjig is also declining. In consonance with the population structure, the trees have almost replaced the poles at Hut Bay and their proportion on the downhill has far exceeded that of seedlings

and almost equaled on the uphill. With 35 to 39% seedlings, the population at Hut Bay is also declining.

Allometry

The allometric relationship between DBH and height of poles and trees across the study areas shows that the DBH and height are strongly correlated at Mohanpur and Prolobjig with significant correlation coefficients of 0.91 and 0.88, respectively (Fig. 6). Though significantly correlated, the relationship between DBH and height at Lamiya Bay and Hut Bay is weak with correlation coefficients of 0.31 and 0.50, respectively.

Discussion

Natural regeneration potential is an important indicator for any forest ecosystems (Rahman et al. 2011) and Andaman Padauk, the State Tree is a historical legacy to the economy of the Islands. This study for the first time has comprehensively analyzed the natural regeneration potential of Andaman Padauk across its whole habitat from five different

Fig. 5 Proportion of different categories of regenerates across gradient and location

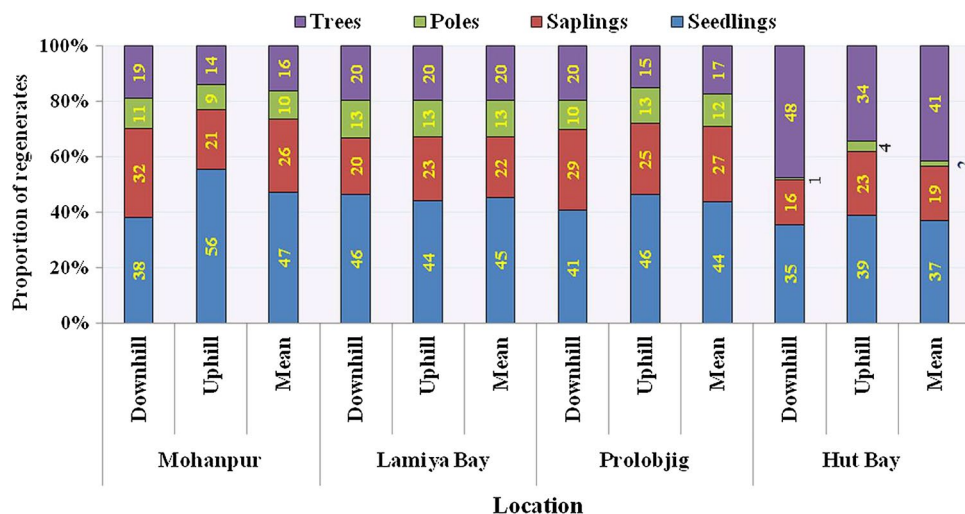
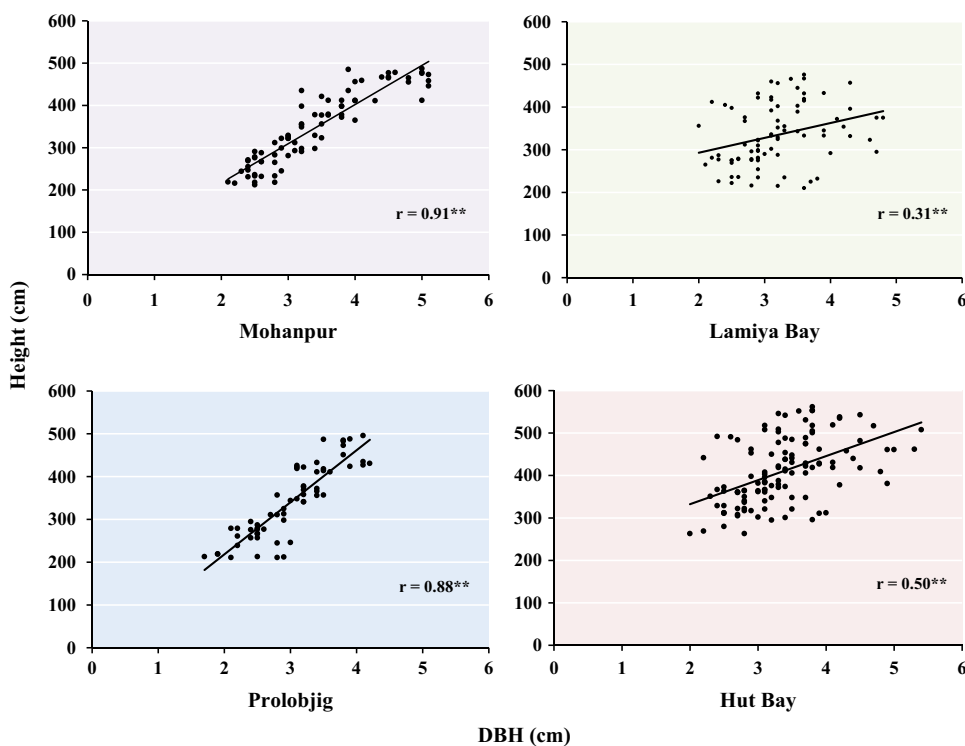


Fig. 6 Scatter plot of DBH-Height relationship. Note: r indicates Pearson Correlation Coefficient and symbol ** indicates 1% level of significance



perspectives. At the outset, all the study locations were found endowed with all stages of regenerates from recruits to trees in their population signifying a successful regeneration (Saxena and Singh 1984). Contrary to the observation of Prasad et al. 2008 that Andaman Padauk is a poor regenerator owing to absence of regenerates in the padauk bearing semi-evergreen and moist deciduous forests of North Andaman, the extrapolated average population density of 64,219 regenerates/ha across all the study locations comprising 31,656 recruits, 14,094 seedlings, 7688 saplings, 2969 poles and 7813 trees has far exceeded the stipulations laid out under various studies (Juřička et al. 2019; Chacko

1965; Luo et al. 2017), thanks to the disturbance caused by dead bamboo grove, secondary road, selective logging and quarrying. Canopy gap created by such disturbance regimes has increased the light level and soil temperature providing favorable germinating conditions and thus triggering regeneration (Peters 1994).

Moreover, difference in forest structure and physiographic conditions among the study locations that stretch across 3° latitude has led to irregular spatial distribution of the species (Ward et al. 2006). While ephemerals and poles were significantly high at Lamiya Bay; and seedlings and saplings were significantly high at Mohanpur—both at the

leading edge of the habitat, trees were significantly high at Hut Bay, the trailing edge (Wei et al. 2015). Overall, the total regenerates were significantly high at Mohanpur, again at the leading edge of Andaman Padauk's distribution range. The height analysis has confirmed a healthy growth pattern of padauk regenerates.

Though the germination capacity of Andaman Padauk is quite high at 45%, ultimate survival is reduced by half due to mortality in early seedling stage (Ganapathy and Rangarajan 1964). Accordingly, its population structure in all the study locations exhibited a reverse-J shaped distribution indicating that a small fraction of ephemerals survive to become large trees. Nevertheless, the reverse-J shaped distribution with highest number of individuals in ephemeral stage and the number gradually decreasing in seedling, sapling, pole and tree stages shows that Andaman Padauk is in its most dominant form in the stand at present (Malik and Bhatt 2016). Exceptionally, the elongated reverse-J shaped curve to form an inverted-bell shape is a case of past intense harvesting of adults at Hut Bay, wherein the remnant trees grew and began regenerating (Hall and Bawa 1993). Although, the fate of a species cannot be predicted from the shape of size-class distribution curve alone, a constant lack of regeneration gives a good indication that the forest ecosystem is disturbed (Lykke 1998).

The forest wealth depends on the potential regenerative status of species composing the forest stand in space and time (Jones et al. 1994). Except for the uphill of Mohanpur where the population status was relatively stable, all the other study locations and gradients have exhibited a declining population status. However, considering the luxuriant growth of regenerates in all the study locations wherein ephemerals share around 50% of total population with the prospects of at least 25% of them graduating to seedlings, the population status of Andaman Padauk across its distribution range can be conveniently considered as relatively stable.

Tree height together with DBH defines the main structural pattern of forest systems (Nogueira Junior et al. 2014). Among DBH, wood specific gravity, height and forest type that are primarily applied in different combinations to develop biomass regression models (Chave et al. 2005), power equation incorporating the compound variable of DBH and height proved to be the most appropriate model for predicting the biomass of Andaman Padauk (Jaisankar et al. 2020a) as it takes care of heteroscedasticity exhibited by biomass data (Istrefi et al. 2019). By showing a strong proportionality between DBH and height, the growth pattern of regenerates at Mohanpur and Prolobjig has asserted the reliability of these variables for biomass estimation. But a weak proportionality shown by the regenerates at Lamiya Bay and Hut Bay necessitates relating DBH and height to other structural and functional

characteristics for accurate biomass estimation of padauk forests in such localities.

Conclusions

An understanding of seed morphology and the processes that affect regeneration of a species is of crucial importance to forest managers to utilize a given forest ecosystem wisely and sustainably (Slik et al. 2003; Pala et al. 2012; Jaisankar et al. 2020b). Luxuriant growth, healthy growth pattern, ideal population structure, prospects of population stabilization and DBH-height proportionality of regenerates under different disturbance regimes across the distribution range assert the importance of considered disturbance in stimulating natural regeneration of Andaman Padauk (Hobbs and Huenneke 1992). But the underlying challenge is not to exceed the little understood or unknown thresholds of ecosystem resilience (Karsten et al. 2014). In this regard, Assisted Natural Regeneration (ANR) which is an inexpensive but effective technique that employs simple methods like weed suppression, fire management, protection against grazing, assisting seed dispersal and tending of seedlings comes handy in restoring the degraded forests (Durst et al. 2011). Moreover, special priority to conserve this gifted timber species while executing the ambitious tourism projects that are underway would further strengthen the value of ecotourism in the Islands. As all the species under *Pterocarpus* genus share a number of growth and reproductive traits (Winfield et al. 2016), the path breaking findings of this study emanated from categorization of *P. dalbergioides* regenerates, analysis of their growth pattern, determination of their regeneration status and their delineation for allometry will help assess the natural regeneration potential of other species across the tropics whose existence is threatened by either unstable or declining population in their habitat.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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