Journal of the Marine Biological Association of the United Kingdom

cambridge.org/mbi

Marine Record

Cite this article: Singh AR, Thirumurugan V, Prabakaran N (2024). Distribution of *Avicennia spp.* in the Andaman and Nicobar Islands with special reference to new distributional reports and post-tsunami colonization patterns. *Journal of the Marine Biological Association of the United Kingdom* **104**, e43, 1–7. https://doi.org/10.1017/S0025315424000262

Received: 22 November 2023
Revised: 4 February 2024
Accepted: 14 February 2024

Keywords:
landmass subsidence; landmass uplift; mangrove succession; new intertidal; pioneer mangrove; vegetation colonization

Corresponding author:
Nehru Prabakaran;
Email: nehrumcc@gmail.com

Distribution of *Avicennia spp.* in the Andaman and Nicobar Islands with special reference to new distributional reports and post-tsunami colonization patterns

Anoop Raj Singh[1,2], Vedagiri Thirumurugan[1,3] and Nehru Prabakaran[1]

[1]Wildlife Institute of India, Chandrabani, Dehradun 248 001, India; [2]Gurukula Kangri (deemed to be) University, Haridwar 249 404, India and [3]Department of Botany, Madras Christian College (Autonomous), Tambaram East, Chennai 600 059, India

Abstract

Post 2004 tsunami and earthquake, the landmass of Andaman and Nicobar Islands (ANI's) experienced uplift (North Andaman and Mayabunder) and subsidence (South Andaman & Nicobar Islands). The altered geomorphology modified the tidal regime, which resulted in mangrove degradation in their current locations and the formation of new intertidal zones potential for mangrove colonization. *Avicennia* species; a pioneer in mangrove succession was expected to colonize such new intertidal zones. Therefore, to understand the colonization pattern of *Avicennia* species in these new intertidal zones and their distribution in the old forests, we surveyed 79 sites across ANI's (55 Andaman and 24 Nicobar Islands). Our survey confirms the presence of three *Avicennia* species namely *A. marina*, *A. officinalis,* and *A. alba* – a new distribution record to the ANI's. Further, *A. marina* was found to be the most widely distributed, and abundant among three *Avicennia* species (Relative Abundance (RA) – 97.92%; Relative Frequency (RF) – 68.75%). In contrast, *A. officinalis* (RA – 1.93%; RF – 26.25%) and *A. alba* (RA – 0.16%; RF – 5%) were found limited in their distribution and abundance. As per the IUCN Red List, the *Avicennia* population is decreasing globally, whereas, its population may increase significantly across ANI's due to the availability of vast new intertidal zones. Hence, *Avicennia* spp. can be utilized in the plantation programs to facilitate rapid colonization in the unvegetated potential mangrove habitats across ANI's. Such an effort will improve the mangrove ecosystem services that were hampered due to mangrove degradation by the 2004 tsunami.

Introduction

Avicennia genus with eight species is the most diverse genera among all the mangroves (Tomlinson, 1986; Duke, 1991; POWO, 2023). They are also the most cosmopolitan in their distribution; reported from 30°N to 30°S latitude, native to ~120 countries of tropics to temperate, while introduced to the coast of California, United States (POWO, 2023). Alongside broad distribution, the *Avicennia* genus in general tends to form mixed to mono-dominant stands virtually located throughout tidal ranges i.e., from seawards to landward zones of mudflats, estuarine, and deltaic coasts (Tomlinson, 1986; Duke, 1991; Thatoi *et al.*, 2016). Their adaptability and widespread existence along the equator pose an intriguing question on their propagule dispersal across the continent (Clarke, 1993; Wong *et al.*, 2020). *Avicennia* is also among the genera whose species (e.g., *Avicennia marina*) have a high threshold for the environmental factors which enables them to be a better successional species in the degraded mangroves and new intertidal zones created by soil accretion or erosion (Huxham *et al.*, 2018; ShivaShankar *et al.*, 2022; Zimmer *et al.*, 2022).

The Andaman and Nicobar Islands (hereafter ANI's) are among the global hotspots for mangrove species richness and are endowed with about 80% ($n = 38$) of total mangrove species found in India ($n = 46$) (Ragavan *et al.*, 2015). Three out of eight *Avicennia* species namely *A. marina* (Forssk.) Vierh., *Avicennia officinalis* L., and *Avicennia alba* Blume are distributed in India (Kathiresan, 2010; Ragavan *et al.*, 2016a, 2016b). However, their spread within various mangrove patches of India is inconsistent. For instance, *A. officinalis* is not distributed in the mangroves of Lakshadweep, and Daman & Diu on the West coast, while, the presence of *A. marina* in the mangroves of Lakshadweep Islands is doubtful (Ragavan *et al.*, 2015). Similarly, *A. alba* is distributed in most parts of the east coast of India, however, their distribution is either absent (Tamil Nadu, Daman & Diu) or doubtful (Kerala, Lakshadweep, ANI's) in Southern India and the Islands (Ragavan *et al.*, 2014). A few studies published before the 2004 tsunami have included *A. alba* in their mangrove flora checklist from the ANI's (Das and Dev Roy, 1989; Dagar *et al.*, 1993; Jagtap, 1994; Dagar and Singh, 1999; Debnath, 2004). However, recent studies (post 2004 tsunami) have ruled out the occurrence of *A. alba* in the ANI's and suggested the doubtful records by the previous studies as misidentification of the morphological variants of *A. marina* (Goutham-Bharathi *et al.*, 2014; Thatoi *et al.*, 2016; Ragavan *et al.*, 2016b). Also, upon cross-verification with other recently published literature, and the herbarium repository at the Botanical Survey of India, Port Blair, ANI's the authors could not find any relevant specimens, locations, or photographs of *A. alba* from the ANI's.

Following the 2004 Sumatra-Andaman earthquake and Indian Ocean tsunami, the mangrove forest of ANI's has experienced a loss of ~190 sq. km. of mangrove cover and a constant deterioration owing to alteration in the tidal water regime caused by the coastal uplift and subsidence across the ANI's (Nehru and Balasubramanian, 2018; Majumdar *et al.*, 2019; Ramakrishnan *et al.*, 2020; ShivaShankar *et al.*, 2020). The coastal uplift was recorded highest in the West coast of North Andaman (1.35 m); while the highest subsidence was reported from the Southern tip of Great Nicobar Island (2.85 m) (Malik *et al.*, 2006; Meltzner *et al.*, 2006). The land uplift and subsidence have created vast new intertidal zones suitable for mangrove colonization on the uplift seafloor and subsided terrestrial zones (Nehru and Balasubramanian, 2018; Ramakrishnan *et al.*, 2020; ShivaShankar *et al.*, 2020). To understand the pattern of mangrove colonization at respective new intertidal habitats, we conducted an extensive mangrove vegetation survey across the ANI's. Further, *Avicennia* species being one among the pioneer species and aggressive colonizers on the bare intertidal zones, we expect that these species will colonize better than other mangroves due to their competitive advantage of having high environmental thresholds (e.g., salinity), efficient propagule dispersal and establishment strategies (Clarke and Myerscough, 1993; Friess *et al.*, 2012). Therefore, our study aims to explore the spatial distribution, abundance, and colonization patterns among the *Avicennia* species across the new intertidal zones formed after the coastal uplift and subsidence in ANI's.

Methodology

The vegetation survey was conducted from 2019 to 2023 during the non-monsoon season of each year (January to May) across the Andaman and Nicobar Islands focusing on the new intertidal zones formed due to coastal uplift (i.e., uplift reef bed and seafloor) and subsidence (i.e., drowned terrestrial zones) (Figure 1). Field sites were selected with the help of previous field experiences of the authors (Nehru and Balasubramanian, 2012, 2018), Google Earth images, and published literature (Majumdar *et al.*, 2019; Ramakrishnan *et al.*, 2020; ShivaShankar *et al.*, 2020). At each selected site, three belt transects perpendicular to the coastline were laid randomly at a minimum distance of 50 m to cover the site heterogeneity. Further, each belt constitutes at least three vegetation plots of 10 × 10 sq. m at every 50 m for tree enumeration (⩾10 cm Girth at Breast Height (GBH)) with nested subplot of 3 × 3 sq. m for sapling (<10 cm – ⩾1 cm GBH) and 1 × 1 sq. m (<1 cm GBH) for seedling enumeration. The geo-coordinate of the plot and characteristics of soil substratum in the site were noted. Additionally, species exploration was conducted at each site to ensure the documenting of species that were present in the site but not represented in the plot.

Results

We found three species of the genus *Avicennia (A. alba, A. officinalis,* and *A. marina*) colonizing the islands at the new and old intertidal habitat (Figure 1). Out of 79 surveyed sites, the genus *Avicennia* was present at a total of 55 sites (Relative Frequency (RF) = 70%) including 46 sites (84%) from Andaman Islands and nine sites (16%) from Nicobar Islands (Figure 1). However, only one site in North Andaman was found colonized by all three species of *Avicennia*, while, overall 19 sites in the Andaman Islands were colonized by two species of *Avicennia* (*A. marina* and *A. officinalis*). Further, we did not encounter *A. officinalis* from the Nicobar Islands, while only three sites in Great Nicobar were colonized by two *Avicennia* species (*A. alba* and *A. marina*).

Among all the three *Avicennia* species, considering all the cohorts (trees, saplings, and seedlings) *A. marina* was the most abundant (Relative Abundance (RA) – 97.92%), and widely distributed species (RF – 68.75%) across the islands, followed by *A. officinalis* (RA – 1.93%) which was present at 25 sites (RF – 26.25%) (Figure 1). *A. alba* was the rarest (RA – 0.16%) among all the three species, which was recorded only from four sites (RF – 5%) in ANI's (Figure 1). Similarly, the relative abundance of *A. marina* tree was highest (RF – 99.66%), followed by *A. officinalis* (RF – 0.17%), and *A. alba* (RF – 0.17%). The relative abundance of the recruitment (sapling and seedling) cohort was dominated by *A. marina* (RF – 96.5%), followed by *A. officinalis* (RF – 3.4%), and *A. alba* (RF – 0.16%) (Figure 2A & B). Further, the key features documented to identify and differentiate among the three *Avicennia* species found in Andaman and Nicobar Islands were their leaf tip, flower size with the arrangement, propagule shape, and bark colour (Figure 3) (Table 1).

During the March 2022 vegetation survey, *A. alba* was found colonizing the uplift site, on the west coast of North Andaman Islands (13° 26′ 38.04″ N — 92° 52′ 41.88″ E) (Figure 4A). This particular site has experienced land uplift up to ~1.3 m, and the new intertidal habitat was formed at seaward that receives tidal water inundation during most of the high tides. Due to acute uplift, the substratum was predominantly consisting of calcareous dead coral boulders, reef beds, and coarse sand. There was no remnant mangrove patch close to the site except for some fringing mangroves and isolated trees along the creeks. The two *A. alba* trees colonized at this site were located beside a small water channel. The trees were in the flowering stage (March) with multiple branches of ~30 cm GBH and ~8 m in height. *Avicennia alba* was also accompanied by other two *Avicennia* species (*A. marina* and *A. officinalis*) with copious saplings, and seedlings of all three species (Figure 4A). A voucher specimen of the *A. alba* materials collected from North Andaman is submitted to the herbarium at Wildlife Institute India, Dehradun (Voucher specimen no. 12905, Anoop Raj Singh & Nehru Prabakaran).

We encountered five individuals of *A. alba* from three sites of Great Nicobar Island (Swaroop Nallah: 6° 49′ 17.00″ N – 93° 53′ 53.16″ E, Jogindar Nagar (13 km): 6° 56′ 56.31″ N – 93° 54′ 32.41″ E, and Galathea Bay: 6° 50′ 21.19″ N – 93° 51′ 22.03″ E) (Figure 4B & C). *Avicennia alba* at Swaroop Nallah was found alongside *A. marina* with abundant seedlings. Whereas, in 13 km, the *A. alba* was growing along with the *A. marina* in the landward zone adjacent to the *Nypa fruticans* and planted *Cocos nucifera*. In Galathia Bay, it is growing in the seaward fringes where the mangrove colonization was sparse; the single tree encountered here with a girth size of 45 cm and 10 m in height was in flowering and fruiting stage (July) (Figure 4B & C). The *A. alba* trees were thickly dense, with multiple branches and broad crowns. All three sites in Great Nicobar having vast intertidal zones may facilitate aggressive colonization of *Avicennia* species in the future.

Discussion and conclusions

Avicennia species are one among the aggressive colonizers during mangrove succession in the degraded/disturbed mangrove forests and new intertidal zones formed due to soil accretion (Friess *et al.*, 2012; Huxham *et al.*, 2018; Zimmer *et al.*, 2022). Their ability to tolerate a euryhaline range of soil and water, prolonged tidal water inundation, and cryptovivipary (embryo fatten to break the seed coat while remaining attached to the mother tree) allows them to quickly establish and outcompete their competitors

https://doi.org/10.1017/S0025315424000262 Published online by Cambridge University Press

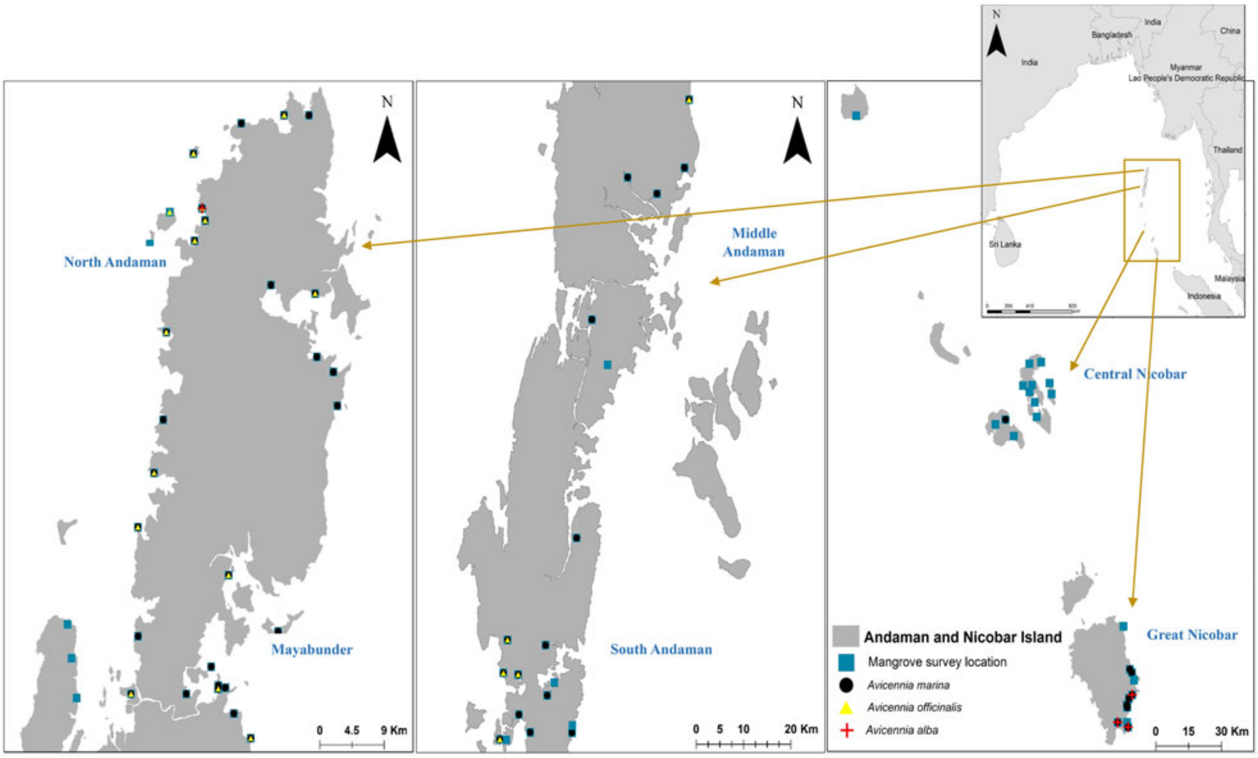

Figure 1. Spatial representation of Andaman and Nicobar Islands with representation of total number of sites visited across islands (blue square), and occurrences of *Avicennia marina* (black circle), *A. officinalis* (yellow triangle), and *A. alba* (red plus).

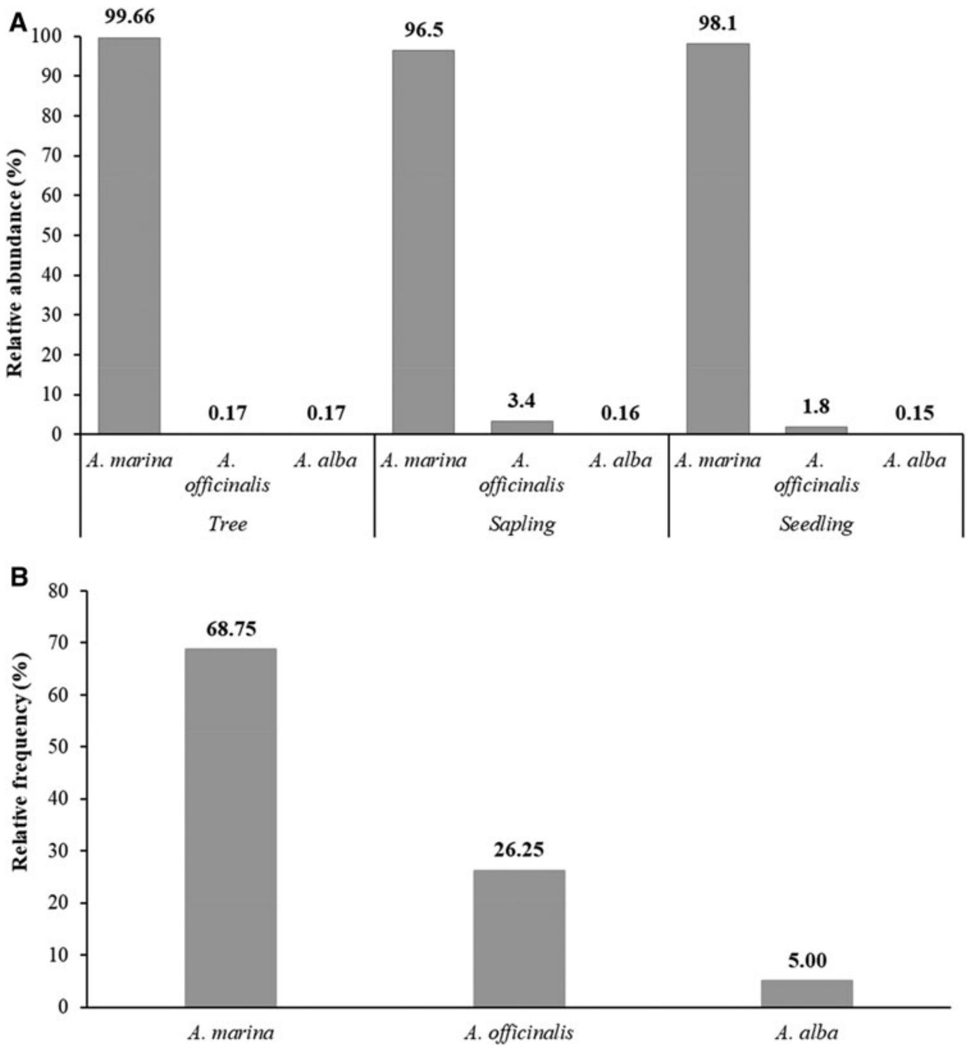

Figure 2. A: Relative abundance of all the three *Avicennia* species found each tree, sapling, and seedling cohort, B: Relative frequency of all the three *Avicennia* species found in the islands.

https://doi.org/10.1017/S0025315424000262 Published online by Cambridge University Press

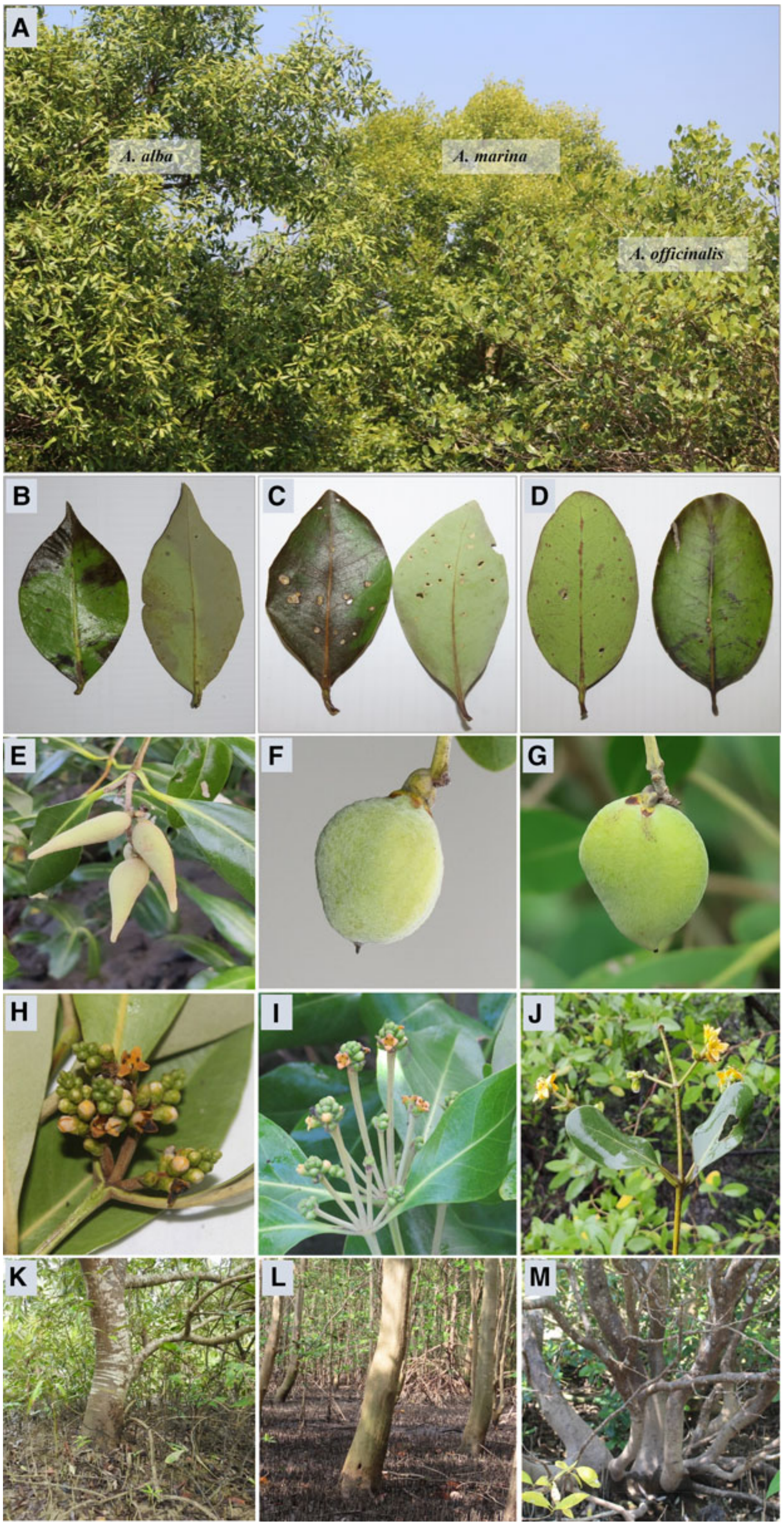

Figure 3. Key features to identify three *Avicennia* species (left – *A. alba*, middle – *A. marina*, and right – *A. officinalis*) occur in the Andaman and Nicobar Islands. A: tree crown; B, C, & D: leaf shape and tip; E, F, & G: propagules shape and beak; H, I & J: flower; K, L, & M: bark.

Table 1. Key identification features to be observed in the field to identify and differentiate among the three *Avicennia* species found in the mangroves of ANI's

S. No.	Key identification features	*Avicennia alba*	*A. marina*	*A. officinalis*
1	Leaf apex	Acuminate (Figure 3B)	Acute (Figure 3C)	Obtuse (Figure 3D)
2	Propagules shape	Elongated and inverted cone with straight beak (Figure 3E)	Nearly triangular with straight beak (Figure 3F)	Nearly triangular with a curved beak (Figure 3G)
3	Flower inflorescence	Spicate (Figure 3H)	Capitate (Figure 3I)	Capitate (Figure 3J)
4	Bark colour	Brown with numerous stomatal openings (white) (Figure 3K)	Beige (light yellowish) with multiple flakes on the bark (Figure 3L)	Brown with numerous stomatal openings (white) (Figure 3M)

https://doi.org/10.1017/S0025315424000262 Published online by Cambridge University Press

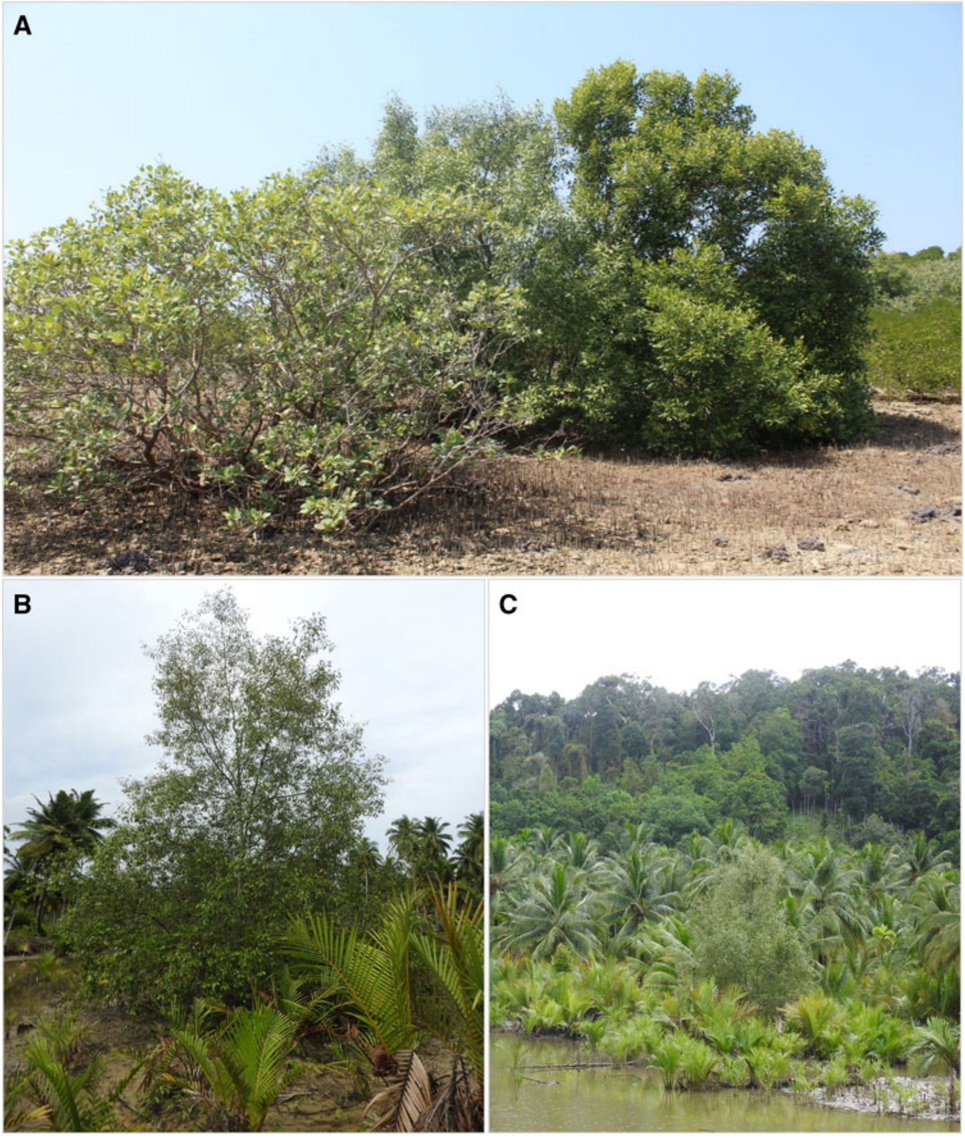

Figure 4. *A. alba* colonizing in the new intertidal habitat created post tsunami due to land uplift and subsidence. A: All the three *Avicennia* species colonizing at seaward zone on the uplift sites of North Andaman Islands, B & C: *A. alba* colonization at the landward zone in the subsided sites of Nicobar Islands along with *Nypa fruticans* and planted *Cocos nucifera*.

(Burchett *et al*., 1984; Duke, 1991; Clarke and Myerscough, 1993). These characteristics together are also responsible for their widespread distribution across the globe (Smith, 1987; Duke, 1991; Clarke, 1993). However, *Avicennia* distribution in the mangrove forest is noticeably restricted mostly to seaward and landward zones and does not form stand in mid-zone (Smith, 1987). We also observed a similar pattern in the mangrove forest of ANI's where *Avicennia* was either present towards the seaward zone or landward zone. *Avicennia's* are characteristically photophilic species that require a high amount of sunlight (shade intolerant) for their growth and development, which is usually abundant at landward and seaward zones compared to mid-zone where the canopy is saturated (Smith, 1987). Also, the mid-zone habitat is aggressively used by Grapsid crabs that profusely predate on the propagules of *Avicennia* species limiting the regeneration of *Avicennia* stand in the mid-zone (Smith, 1987). Hence, the formation of new intertidal habitat at the landward zone in subsided sites and seaward zone in the uplift site due to coastal subsidence and uplift across the ANI's becomes the perfect habitat for *Avicennia* to colonize (Thirumurugan *et al*., 2022).

A. marina was found colonizing aggressively on the new intertidal zones across the ANI's and created monodominant stands in the new intertidal zones. Also, this species is particularly the most abundant in the seaward new intertidal zones in North Andaman (sites characteristics of loose and fine sediments of sea floor exposed due to uplift) and on the extreme south of Great Nicobar Island (sites characteristic of subsided terrestrial zones with fine to coarse sandy substratum). *A. marina* has peculiar root-shoot growth specification where the root grows at a much faster rate compared to the shoot, allowing *Avicennia* propagules to quickly hold on to the substratum and colonize despite the short window of opportunity offered by the new intertidal habitat formed especially at seaward zone, where the propagule establishment is restricted by frequent and long-duration of tidal water inundation (Balke *et al*., 2011). Hence, due to their root-shoot specification, they could successfully colonize across the ANI's and are likely to spread at a much faster rate in the near future. Further, amongst three *Avicennia* species, *A. marina* possesses the highest degree of salinity tolerance causing their high abundance, and wide distribution from hypersaline habitat (seaward/mid-zone – range 15 to 25 ppt) to hyposaline habitat (landward – range 5 to 15 ppt), across the islands (Downton, 1982). Contrarily, *A. officinalis* exclusively prefers high salinity areas and barely colonizes at landward zone (no salt habitat)

https://doi.org/10.1017/S0025315424000262 Published online by Cambridge University Press

(Downton, 1982). Their occurrence in the Andaman Islands before the 2004 tsunami might have facilitated them to colonize the new intertidal habitat created in the Andaman Islands. While, the occurrence of *A. officinalis* in the mangroves of the Nicobar Islands has not been reported despite the vast intertidal area available for colonization post land-subsidence (Prabakaran *et al*., 2021). Naturally *A. officinalis* is not very successful in colonization in the islands, and rare to form monodominant stand which indicates they may have a relatively lesser threshold to disturbances. So, even if the propagules of *A. officinalis* might have managed to reach the Nicobar Islands, they may have found it difficult to colonize and proliferate compared to the other two *Avicennia* species.

The disjunct presence of *A. alba* on the northern extreme (North Andaman west coast) and southern extreme (Great Nicobar east coast) followed by their complete absence across the stretches of the ANI's is scientifically intriguing. Though there were unconfirmed reports of *A. alba* in the ANI's (Das and Dev Roy, 1989; Dagar *et al*., 1993; Jagtap, 1994; Dagar and Singh, 1999; Debnath, 2004), the recent more comprehensive exploration across the ANI's during 2009–2015 by Nehru and Balasubramanian (2011), Goutham-Bharathi *et al.* (2014), and Ragavan *et al.* (2015) could not locate this species in the islands. Moreover, Ragavan *et al.* (2015) ascertained that the earlier unconfirmed reports of *A. alba* were misidentification of the morphological variants of *A. marina* by the earlier studies. Also, the current study documented a maximum GBH of 45 cm *A. alba* trees and did not find any old trees that would have had before the 2004 tsunami origin. The extensive survey between 2009–2011 by Nehru and Balasubramanian (2018) and subsequent surveys by Ragavan *et al.* (2015) and Goutham-Bharathi *et al.* (2014) during 2012–2014 in Great Nicobar Islands did not report *A. alba.* Therefore, we assume that *A. alba* either occurred rarely or was absent in ANI's before the tsunami. Also, extreme events like cyclones and tsunamis in the Indian Ocean and Bay of Bengal may have facilitated propagule dispersal into ANI's from the neighbouring coastal lines. For example, the monsoonal current pattern of Indian Ocean Rim Countries (IORC) like Indonesia, Singapore, Thailand, Myanmar, and Bangladesh – where *A. alba* is abundantly found – are closely allied with ANI's (Turner and Yong, 1999; Imai *et al*., 2009; Chandran *et al*., 2018; Setyadi *et al*., 2021; Aye *et al*., 2022). Thus, these events may have led to the establishment of a new population in the new intertidal zones of Great Nicobar and North Andaman Islands. Also, it is noteworthy that we have found numerous seedlings of *A. alba* colonizing the seaward zones of its present locations in Great Nicobar and North Andaman. This species is also observed by the authors to form monodominant stands in the mangroves along the seaward zones across the eastern coast of India (e.g., Sundarbans, Bhitarkanika, Coringa). Therefore, the presence of *A. alba* is arguably recent in the ANI's, like *Sonneratia ovata* (Nehru and Balasubramanian, 2012), *A. marina* (Thirumurugan *et al*., 2022) and *Aegiceras corniculatum* (Thirumurugan *et al*., 2023) in the Nicobar Islands. However, *A. alba* is expected to spread faster in the seaward zones of the new intertidal habitat and soon establish monodominant stands over the course of mangrove succession. A long-term monitoring of this succession would be required to understand the future patterns.

As per the IUCN Red List, the three *Avicennia* species found in ANI's are under the 'Least Concern' category, but their population status is declining consistently throughout the globe (IUCN, 2023). Concerning the global trend, it is very likely that the population status of *Avicennia* species would increase several folds due to the formation, and availability of vast new intertidal areas post coastal uplift and subsidence throughout the ANI's. Hence, it is recommended that the *Avicennia* species being one of the suitable species for the colonization of the new intertidal area should be strongly endorsed by the forest manager for a better success rate of mangrove plantation drive in the islands. Further, *A. alba* being the least abundant and rare species among all the three *Avicennia* needs an extensive exploration in the remaining mangrove patch of the islands to better understand the *A. alba* population status. Also, further studies focusing on the long-term monitoring of mangrove succession in the new intertidal zones, population genetics to ascertain the potential source of newly established populations of *A. alba*, and creating habitat suitability model to predict the futuristic spread of *Avicennia* spp. across the ANI's would be important to scientifically manage the plantation drives by the forest managers and local administration in the ANI's.

Acknowledgements. We are highly thankful to the DST-Inspire Faculty Programme (DST/INSPIRE/04/2018/001071/FA18-LSPA111) by the Department of Science and Technology, Government of India, and the Rufford Small Grant (grant ID – 32387-1) by The Rufford Foundation for financial support of the research work. We acknowledge encouragement by the Director, Dean, and Faculties at the Wildlife Institute of India. We extend our heartfelt thanks to the Department of Environment and Forest, Andaman and Nicobar Islands for field permission, manpower, and logistics support for the smooth conduct of fieldwork.

Authors' contributions. CRediT authorship contribution statement

ARS: Funding acquisition, Conceptualization, Methodology, Data collection & curation, Validation, Visualization, Writing – original draft, Writing – review & editing. **TMV:** Methodology, Data collection & curation, Validation, Writing – review & editing. **NP:** Project administration, Supervision, Funding acquisition, Conceptualization, Methodology, Data collection & curation, Validation, Visualization, Writing – review & editing.

Financial support

1. DST-Inspire Faculty programme (Grant ID: FA18-LSPA111)
2. 1st Small grant by The Rufford Foundation (Grant ID: 32387-1)

Competing interests. None.

Data availability. Data will be provided on request.

References

Aye WN, Tong X and Tun AW (2022) Species diversity, biomass and carbon stock assessment of Kanhlyashay Natural Mangrove Forest. *Forests* **13**, 1013.

Balke T, Bouma TJ, Horstman EM, Webb EL, Erftemeijer PL and Herman PM (2011) Windows of opportunity: thresholds to mangrove seedling establishment on tidal flats. *Marine Ecology Progress Series* **440**, 1–9.

Burchett MD, Field CD and Pulkownik A (1984) Salinity, growth and root respiration in the grey mangrove, *Avicennia marina*. *Physiologia Plantarum* **60**, 113–118.

Chandran ST, Raj SB, Ravindran S and Narayana SV (2018) Upper layer circulation, hydrography, and biological response of the Andaman waters during winter monsoon based on in situ and satellite observations. *Ocean Dynamics* **68**, 801–815.

Clarke PJ (1993) Dispersal of grey mangrove (*Avicennia marina*) propagules in southeastern Australia. *Aquatic Botany* **45**, 195–204.

Clarke PJ and Myerscough PJ (1993) The intertidal distribution of the grey mangrove (*Avicennia marina*) in southeastern Australia: the effects of physical conditions, interspecific competition, and predation on propagule establishment and survival. *Australian Journal of Ecology* **18**, 307–315.

Dagar JC and Singh NT (1999) Plant resources of the Andaman and Nicobar Islands. Dehradun: Bishen Singh Mahendra Pal Singh, p. 985.

Dagar JC, Singh NT and Mongia AD (1993) Characteristics of mangrove soils and vegetation of Bay Islands in India. In Lieth H and Al Masoom AA (eds), *Towards the Rational Use of High Salinity Tolerant Plants*. Task for vegetation science, vol **27**. Dordrecht: Springer, pp. 59–80. https://doi.org/10.1007/978-94-011-1858-3_6

Das AK and Dev Roy MK (1989) A general account of the mangrove fauna of Andaman and Nicobar Islands. Fauna and conservation areas: 4. Published by the Director, Zoological Survey of India, Kolkata, India, 173 pp.

Debnath HS (2004) *Mangroves of Andaman and Nicobar Islands; Taxonomy and Ecology (A community profile)*. Dehradun: Bishen Singh Mahendra Pal Singh, 987 pp.

Downton WJS (1982) Growth and osmotic relations of the mangrove *Avicennia marina*, as influenced by salinity. *Functional Plant Biology* **9**, 519–528.

Duke NC (1991) A systematic revision of the mangrove genus Avicennia (Avicenniaceae) in Australasia. *Australian Systematic Botany* **4**, 299–324.

Friess DA, Krauss KW, Horstman EM, Balke T, Bouma TJ, Galli D and Webb EL (2012) Are all intertidal wetlands naturally created equal? Bottlenecks, thresholds and knowledge gaps to mangrove and saltmarsh ecosystems. *Biological Reviews* **87**, 346–366.

Goutham-Bharathi MP, Roy SD, Krishnan P, Kaliyamoorthy M and Immanuel T (2014) Species diversity and distribution of mangroves in Andaman and Nicobar Islands, India. *Botanica Marina* **57**, 421–432.

Huxham M, Berger U, Skov MW and Sousa WP (2018) Kropotkin's garden: facilitation in mangrove ecosystems. In Bohn K, Hawkins S, Firth LB and Williams GA (eds), *Interactions in the Marine Benthos – A Regional and Habitat Perspective*. Cambridge, MA: Cambridge University Press, 431 pp.

Imai N, Takyu M and Nakamura Y (2009) Growth, crown architecture and leaf dynamics of saplings of five mangrove tree species in Ranong, Thailand. *Marine Ecology Progress Series* **377**, 139–148.

IUCN (2023) The IUCN Red List of Threatened Species. Version 2022–2. Available at https://www.iucnredlist.org/species/178828/7619457 (Accessed 10 November 2023).

Jagtap TG (1994) Marine flora of Andaman and Nicobar group of Islands, Andaman Seas, India. In Suryanarayan V and Sudarsen V (eds), *Andaman and Nicobar Islands: Challenges of Development*. Delhi: Konark Publishers, pp. 133–143.

Kathiresan K (2010) Importance of mangrove forests of India. *Journal of Coastal Environment* **1**, 11–26.

Majumdar D, Chakraborty S, Saha S and Datta D (2019) Geospatial analysis of the effects of tsunami on coral and mangrove ecosystems of Mayabunder in Andaman Islands, India. *Brazilian Journal of Oceanography* **67**, e19258.

Malik JN, Murty CVR and Rai DC (2006) Landscape changes in the Andaman and Nicobar Islands (India) after the December 2004 great Sumatra earthquake and Indian Ocean tsunami. *Earthquake Spectra* **22**(3_suppl), 43–66.

Meltzner AJ, Sieh K, Abrams M, Agnew DC, Hudnut KW, Avouac JP and Natawidjaja DH (2006) Uplift and subsidence associated with the great Aceh-Andaman earthquake of 2004. *Journal of Geophysical Research: Solid Earth* **111**, B02407.

Nehru P and Balasubramanian P (2011) Re-colonizing mangrove species in tsunami devastated habitats at Nicobar Islands, India. *Check List (Luis Felipe Toledo)* **7**, 253–256.

Nehru P and Balasubramanian P (2012) Sonneratia ovate Backer (Lythraceae): status and distribution of a near threatened mangrove species in tsunami impacted mangrove habitats of Nicobar Islands, India. *Journal of Threatened Taxa* **4**, 3395–3400.

Nehru P and Balasubramanian P (2018) Mangrove species diversity and composition in the successional habitats of Nicobar Islands, India: a post-tsunami and subsidence scenario. *Forest Ecology and Management* **427**, 70–77.

POWO (2023) Avicennia L. The Royal Botanic Gardens. Available at https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:41194-1#children (Accessed 15 October 2023).

Prabakaran N, Bayyana S, Vetter K and Reuter H (2021) Mangrove recovery in the Nicobar archipelago after the 2004 tsunami and coastal subsidence. *Regional Environmental Change* **21**, 87.

Ragavan P, Saxena M, Saxena A, Mohan PM, Sachithanantham V and Coomar T (2014) Floral composition and taxonomy of mangroves of Andaman and Nicobar Islands. *Indian Journal of Geo-marine Science* **43**, 1031–1044.

Ragavan P, Saxena A, Mohan PM, Ravichandran K, Jayaraj RSC and Saravanan S (2015) Diversity, distribution and vegetative structure of mangroves of the Andaman and Nicobar Islands, India. *Journal of Coastal Conservation* **19**, 417–443.

Ragavan P, Saxena A, Jayaraj RSC, Mohan PM, Ravichandran K, Saravanan S and Vijayaraghavan A (2016a) A review of the mangrove floristics of India. *Taiwania* **61**, 224–242.

Ragavan P, Mohan PM, Saxena A, Jayaraj RSC, Ravichandran K and Saxena M (2016b) Mangrove floristics of the Andaman and Nicobar Islands: critical review and current scenario. *Marine Biodiversity* **48**, 1291–1311.

Ramakrishnan R, Gladston Y, Kumar NL, Rajput P, Murali RM and Rajawat AS (2020) Impact of 2004 co-seismic coastal uplift on the mangrove cover along the North Andaman Islands. *Regional Environmental Change* **20**, 1–12.

Setyadi G, Pribadi R, Wijayanti DP and Sugianto DN (2021) Mangrove diversity and community structure of Mimika District, Papua, Indonesia. *Biodiversitas Journal of Biological Diversity* **22**, 3562–3570.

ShivaShankar V, Narshimulu G, Kaviarasan T, Narayani S, Dharanirajan K, James RA and Singh RP (2020) 2004 Post tsunami resilience and recolonization of mangroves in South Andaman, India. *Wetlands* **40**, 619–635.

ShivaShankar V, Purti N, Ganta N, Mandal KK, Singh RP, Kaviarasan T, Satyakeerthy TR and Jacob S (2022) Assessment of the hydrological and erosive status of South Andaman's watersheds using drainage morphometric studies and climatic water balance model. *Geocarto International* **37**, 13391–13418.

Smith III TJ (1987) Seed predation in relation to tree dominance and distribution in mangrove forests. *Ecology* **68**, 266–273.

Thatoi H, Samantaray D and Das SK (2016) The genus Avicennia, a pioneer group of dominant mangrove plant species with potential medicinal values: a review. *Frontiers in Life Science* **9**, 267–291.

Thirumurugan V, Singh AR and Prabakaran N (2022) First report on the occurrence of *Avicennia marina* (Forssk.) Vierh.(Acanthaceae) in the Nicobar archipelago. *Ocean and Coastal Research* **70**, e22013.

Thirumurugan V, Singh AR, Gnanasekaran G and Prabakaran N (2023) First report on the distribution of Aegiceras corniculatum (L.) Blanco (Primulaceae) from the Nicobar archipelago, India. *Ocean and Coastal Research* **71**, e23034.

Tomlinson PB (1986) *The Botany of Mangroves*. Cambridge, UK: Cambridge University Press, 413 pp.

Turner IM and Yong JWH (1999) The coastal vegetation of Singapore. In Clive Briffett and Ho Hua Chew (eds), *State of the Natural Environment in Singapore*. Singapore: Nature Society, pp. 5–23.

Wong YY, Foong SY, Lai TL, Dai L, Mao LM and Wang YS (2020) Dispersal property and early growth of mangrove propagules of *Rhizophora apiculata* and *Avicennia marina*. *Malayan Nature Journal* **72**, 485–501.

Zimmer M, Ajonina GN, Amir AA, Cragg SM, Crooks S, Dahdouh-Guebas F and Wodehouse D (2022) When nature needs a helping hand: different levels of human intervention for mangrove (re-) establishment. *Frontiers in Forests and Global Change* **5**, 784322.