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First report on the occurrence of *Avicennia marina* (Forssk.) Vierh. (Acanthaceae) in the Nicobar archipelago

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ABSTRACT

The 2004 Sumatra-Andaman earthquake (9.2 *Mw*) and tsunami that followed it resulted in uplift and subsidence across the Andaman and Nicobar archipelago. This unusual natural event severely affected the mangrove and coastal ecosystems across the Andaman and Nicobar Islands. The tsunami and land drowning of 1.1-2.85 m resulted in considerable loss of mangrove habitats in the Nicobar archipelago. Meanwhile, the land drowning also created new intertidal habitats in the earlier terrestrial zones that are now providing suitable conditions for the colonization of mangroves. During the long-term monitoring of mangrove colonization in these new inter-tidal zones, we identified the first occurrence of the *Avicennia marina* (Forssk.) Vierh. in the Nicobar archipelago. The distribution of *A. marina* and the characteristics of its colonizing sites are discussed herein.

Keywords: New intertidal habitats, Seed dispersal, Subsidence, Successional mangrove forest, 2004 tsunami.

Mangroves play a crucial role in the maintenance of coastal biodiversity and provide innumerable ecosystem services (Primavera et al., 2019). Despite their importance, mangroves are being lost at an alarming rate of 0.16-0.39 % globally per year (Hamilton and Casey, 2016), and 20-35% of global mangrove cover has been lost over the past 50 years (Polidoro et al., 2010). The primary reason behind this is land use changes by human activities (Richards and Friess, 2016; Goldberg et al., 2020). Natural disturbances such as tropical cyclones, storms, and extreme events like tsunami can also cause minimal to extreme damage to the mangrove forest in proportion to their intensity (Dahdouh-Guebas et al., 2005; Simard et al., 2019). Recently, the 2004 Indian Ocean tsunami and resulting geomorphological changes (coastal uplift & subsidence) adversely affected mangroves across Southeast Asia, and site-specific studies have indicated that the impacts depended on the intensity of the tsunami and the geomorphological changes (Alongi, 2008; Nehru and Balasubramanian, 2018; Ramakrishnan et al., 2020).

The 26 December 2004 Sumatra-Andaman earthquake (9.2 *Mw*) caused by the tectonic plate slip on the subduction interface between the Indo-Australian plate, Burma plate (Andaman and Nicobar Islands), and Aceh province, Sumatra, caused a devastating tsunami in the Indian Ocean (Meltzner et al., 2006). In addition to being subject to high-intensity tsunami waves, the mangroves of the Nicobar archipelago were also heavily impacted by land drowning/subsidence of 1.1-2.85 m (Porwal et al., 2012). The impact of tsunami and subsidence resulted in the loss of 97% mangroves in the archipelago (Nehru and Balasubramanian, 2018). While the subsidence resulted in permanent inundation in mangrove habitats, inflicting mass tree mortality, it also formed new intertidal habitats suitable for mangrove colonization on the former

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terrestrial zones (e.g., agriculture fields, coconut groves, forests) (Nehru and Balasubramanian, 2018). These terrestrial zones were dominated by tree species like *Terminalia bialata* (Roxb.) Steud., *Terminalia catappa* L., *Syzygium samarangense* (Blume) Merr. & L.M.Perry, and *Sterculia* spp. A few post-tsunami studies have documented mangrove species diversity in the new intertidal habitats across the Nicobar archipelago (Goutham-Bharathi et al., 2014; Ragavan et al., 2015; Nehru and Balasubramanian, 2011, 2018). In addition, extensive mangrove floristics studies are also available for the pre-tsunami period (Dagar et al., 1991; Jagtap, 1992). The previous mangrove flora of the Nicobar archipelago was dominated by *Rhizophora stylosa* Griff. and *Bruguiera gymnorhiza* (L.) Lam. The common species are *Acrostichum aureum* L., *Excoecaria agallocha* L., *Heritiera littoralis* Aiton, *Lumnitzera littorea* (Jack) Voigt, *Rhizophora mucronata* Lam., and *Sonneratia alba* Sm. (Dagar et al., 1991; Jagtap, 1992). Interestingly, *Avicennia marina* (Forssk.) Vierh., a common species present across the nearby archipelagos, was not reported in the above studies. Based on our long-term monitoring of mangrove colonization in the new intertidal habitats, we report the occurrence of *A. marina* from the Nicobar archipelago and provide details on its distribution and site characteristics where it is colonizing.

The Nicobar archipelago is a submerged mountain range of Arakan-Yoma situated southeast of the Bay of Bengal (Nehru and Balasubramanian, 2018), and is comprised of 21 islands with an area of 1841 km². Intensive field surveys were carried out to document the post-tsunami colonization of mangrove species across the Nicobar archipelago during 2009-2011, 2019, and 2021 (Figure 1). During recent surveys in 2019 and 2021, *A. marina* was documented in few survey sites. Along with the GPS location, herbarium specimens, species abundance, and detailed site information were also collected from all the sites where *A. marina* was identified. The herbarium (Vedagiri Thirumurugan 12901, 12902, and 12903) were prepared and deposited in the herbarium at the Wildlife Institute of India, Dehradun.

A total of 35 sites during 2009-2011 and 19 sites during 2019-2021 were surveyed across the Nicobar archipelago to document mangrove colonization in the new intertidal zones. *A. marina* was recorded in nine sites surveyed during 2019–2021 (Figure 1) but had not been recorded during the

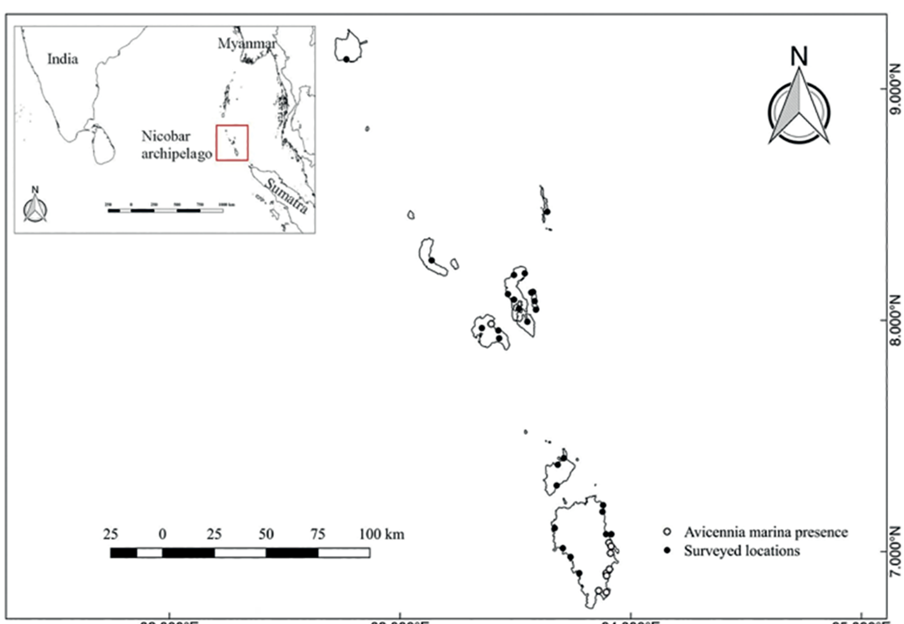

Figure 1. Survey locations (n=35) and locations where *Avicennia marina* present (n=9) within the Nicobar archipelago.

initial surveys in 2009–2011. The species was reported from only two islands, namely Great Nicobar (8 sites) and Katchall (1 site) (Table 1). *A. marina* is mostly colonizing on the firm and sandy substratum adjacent to the water channels, where tidal inundation is frequent (Figure 2 & 3). Only in Marine Katchall was the species present adjacent to the terrestrial forest, where the soil is firm and elevated (Figure 2). In most of the sites in Great Nicobar Island, *A. marina* was growing together with *Sonneratia* spp*., Rhizophora* spp., and *Bruguiera gymnorhiza.* In Dunginallah, Joginder Nagar, Lakshmi Nagar, and Vijay Nagar, *A. marina* was mostly found as isolated patches colonizing in barren areas. The species was in flowering and fruiting during the recent survey between March-April 2021.

All sites with *A. marina* were characterised by a few mature trees, saplings, and copious seedlings (Table 1). The largest tree was recorded from Lakshmi Nagar, with 70 cm GBH (9 m height), located inside the closed canopy of *Sonneratia alba* stand. In Marine Katchall, a 61 cm GBH tree (8 m height) was measured from inside the *Rhizophora apiculata* patch. In both sites, plenty of *A. marina* seedlings were found in open areas. In most sites (Marine Katchall, Dunginallah, Lakshmi Nagar, Vijay Nagar), we observed a mature tree (between 50–70 cm GBH) with 100–300 seedlings and saplings within a radius of approximately 100 m of the mature tree. In Lakshman beach and Magar Nallah, there are no mature trees, but a decent population of saplings and seedlings (up to 100 individuals) was recorded. In Galathea bay, we found a single tree with multiple branches (n=17), ranging from 30-50 cm GBH. Most sites experience grazing pressure of free range cattle from human settlements. Hence, the *A. marina* colonizing these barren areas are mostly browsed and spreading horizontally.

A. marina is a globally widespread mangrove species with a native range extending from East Africa to New Zealand (Duke at al. 2010). It is commonly found across Asia and the archipelagos adjacent to Nicobar (eg: Andaman archipelago and Indonesia, Duke et al., 2010). Interestingly, it had never been reported in the Nicobar archipelago, neither from pre-tsunami explorations (Sahni, 1953; Dagar et al., 1991; Dagar and Singh, 1999; Sinha, 1999; Debnath, 2004; Jayanthi, 2017) nor from previous post-tsunami studies (Nehru and Balasubramanian, 2011; Goutham-Bharathi et al., 2014; Ragavan et al., 2015; Nehru and Balasubramanian, 2018). Though Gopinathan and Rajagopalan (1983) reported this species in Nancowry Island, it was not substantiated with herbarium specimens or other information (eg. distribution, density, etc.) critical to ascertain the presence of the species. We assume that either the species was rare in the archipelago prior to tsunami but not reported by earlier explorers, or the propagules of *A. marina* dispersed by water currents from adjacent archipelagos (eg. Indoneasia and Malaysia) could be establishing a new population in the Nicobar archipelago on the new inter-tidal areas where the environmental parameters (eg. soil, tidal flooding, salinity etc.) may be providing a

Table 1. Details of sites and the abundance of *Avicennia marina* recorded from Nicobar archipelago. Sites with s. no. 2-9 are from Great Nicobar Island; the site with s. no. 1 is from Katchall Island.

S.no	Location	Seedlings (< 1 cm GBH)	Saplings (1 - 10 cm GBH)	Trees (>10 cm GBH)	Largest GBH (cm)	Cattle pressure	Pre-tsunami habitat history
1	Marine Katchall*	50-70	15-20	2-4	61 cm	No	Human habitation
2	Dunginallah	300-500	20-40	2	55 cm	No	Terrestrial forest
3	Lakshman beach	70-80	20-25	-	-	High	Terrestrial forest
4	Magar nallah	20-30	5-10	-	-	High	Terrestrial forest
5	Jogindernagar	600-800	15-30	-	-	Minimal	Agriculture field
6	Vijay nagar	300-400	20-40	2-5	-	Minimal	Agriculture field
7	Laxminagar	300-400	10-25	2	70 cm	High	Agriculture field
8	Swaroop bridge	2-5	-	2	55 cm	High	Agriculture field
9	Galatia bay	3-7	1-3	1	51	High	Agriculture field

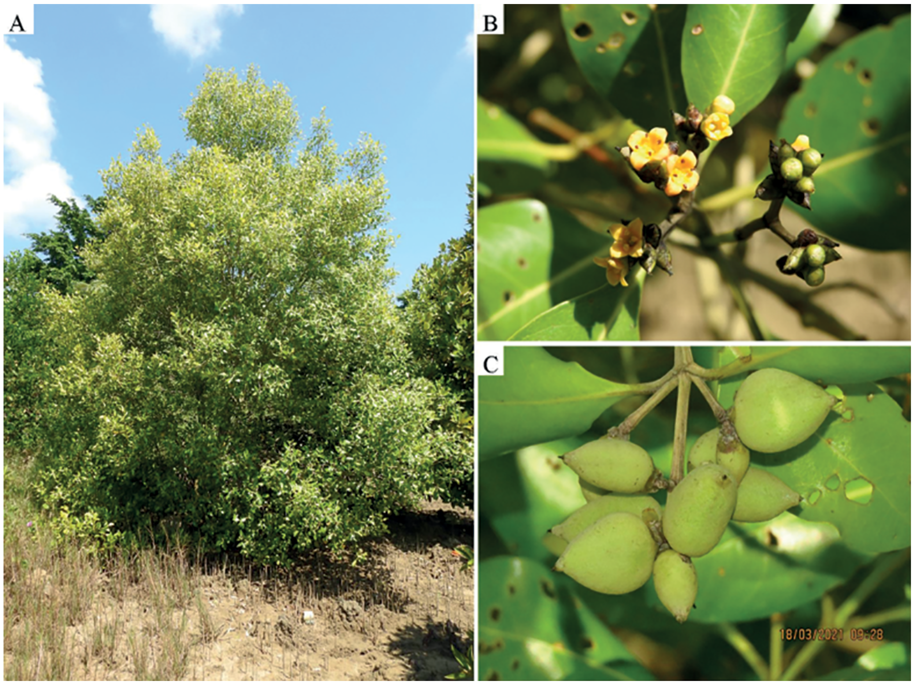

Figure 2. A) A tree of *Avicennia marina* adjacent to terrestrial zone at Marine katchall, Katchall Islands. Flowers (B) and fruits (C) are commonly seen during February to April. (Photo credits: A&B - Thirumurugan Vedagiri; C - Anoop Raj Singh).

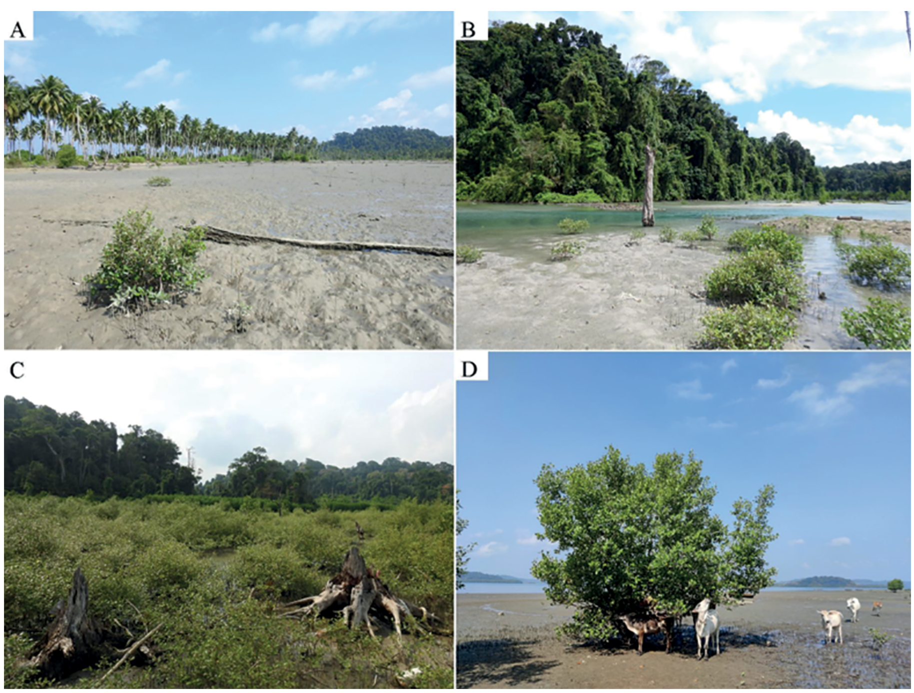

Figure 3. *Avicennia marina* established on sandy barren area (A) and near water channel (B) in Dunginallah. C) mono-dominant presence of *Avicennia marina* in Joginder Nagar. D) Livestock browsing on *Avicennia marina* tree and seedlings. (Photo credits: A,B,C - Thirumurugan Vedagiri; D - Nehru Prabakaran).

conducive environment for the rapid spread of this species compared to other mangroves. Similar conclusions were derived for another mangrove species, *Sonneratia ovata*, first observed in the Nicobar archipelago after the 2004 tsunami (Nehru and Balasubramanian, 2012). It is noteworthy that both islands where *A. marina* is now reported had lost all mangroves after the 2004 tsunami (Nehru and Balasubramanian, 2018).

Ocean currents play a significant role in the dispersal of *A. marina* propagules better adapted to water dispersal in high wave and tidal influenced coastal areas (Yun, 2012). The propagules of *A. marina* are small, light, float for several days (15 days), and are viable in seawater for more than 240 days (Steele, 2006). These characteristics are an advantage for long-distance dispersal of mangrove propagules. Studies have suggested that *A. marina* propagules can travel for long distance (>50 km, Clarke, 1993), though the majority disperses only short distances and strand proximate to the parent tree (Clarke and Myerscough, 1991). An experiment using drift cards mimicking *A. marina* propagules showed dispersal of 700 km in 42 days (Steinke and Ward, 2003). It is noteworthy that an enormous pile of debris from the nearby Southeast Asian countries was deposited on the coasts of the Nicobar archipelago immediately after the 2004 tsunami (Sankaran, 2005). In addition, these areas also receive a heavy pile of marine debris from many Asian countries during each monsoon (May-December) and cyclone. Therefore, one cannot discount the role of tsunamis, cyclones, and other extreme weather events in aiding the long-distance dispersal of *A. marina* propagules from the adjacent archipelagos and establishing a new population in the Nicobar archipelago. As such, it is likely that the surviving propagules, be they from the rare trees within the Nicobar archipelago or having drifted from nearby archipelagos, have established a few trees in the new inter-tidal zones of the Nicobar archipelago, which now lead to the widespread colonization of this species in the new mud flats that are not colonized by other mangrove species.

A. marina is one among pioneer mangrove species that quickly colonize newly formed mudflats with high proportion of sand (Lin and Wei, 1983; Terrados et al., 1997). Tolerance to hypersaline conditions and its fast spreading nature aid in the successful colonization of stressful environments typical of new mudflats, where other mangrove species may have difficulty e stablishing themselves (Clarke and Myerscough, 1993; González et al., 2010). During our April 2019 survey at Dunginallah, we observed a patch of *A. marina* consisting of one mature tree and approximately 80 seedlings on the mouth of a creek where the substratum is sandy and was frequently inundated with tidal water. During the 2021 survey, we observed that the species had spread across most part of the creek, and that abundance had increased by four to five times within two years. The high abundance of *A. marina* seedlings in Dunginallah and other sites suggests the species will continue to spread across new inter-tidal areas and will soon become a dominant species in the archipelago, as many of the mangrove colonizing sites still have considerable vacant area to be colonized, even 16 years after the tsunami (Prabakaran et al., 2021); we predict that *A. marina* may take advantage of this vacancy in new intertidal zones to colonize them in the near future. We observed that sites with minimal to no cattle grazing had a higher abundance of *A. marina* compared to those with high cattle grazing. As such, high anthropogenic pressure and heavy cattle grazing could be a major impediment for the spread of *A. marina* in the Great Nicobar Island.

The new intertidal habitat formed after the tsunami and subsidence in the Nicobar archipelago provides a unique opportunity to study the colonization and spread of many mangrove species. *A. marina*, hitherto not reported from this archipelago, appears to take advantage of these new habitats, spreading faster than other species. Understanding the genetic composition of *A. marina* in the Nicobar archipelago is vital to realize the potential post-tsunami spread of propagules from adjacent archipelagos. Moreover, long-term monitoring of new intertidal habitats in the Nicobar archipelago would be essential to understand successional dynamics, species competitions, and evolution of interspecific spatial distribution patterns of the mangrove forests.

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AUTHOR CONTRIBUTIONS

V.T.A.: Data collection; Writing- Original manuscript; Writing- Original manuscript, review & editing.

A.R.S.B.: Data collection; Writing- review & editing.

N.P.C.: Conceptualization; Supervision; Funding; Fieldwork; Writing- Original manuscript; review & editing.

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