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Diversity and conservation of mangrove ecosystems of the Andaman and Nicobar Islands: A review

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Abstract
The Andaman and Nicobar Islands (ANI) harbour one of the most diverse mangrove ecosystems in the Indian Ocean. They represent a critical biogeographic link between the Indian subcontinent and Southeast Asia. This review synthesises current knowledge on species diversity, distribution, ecological functions, and conservation challenges, with particular emphasis on the impact of the 2004 Indian Ocean earthquake and tsunami. Documented species richness stands at 38 true mangrove species. This is approximately 50% of the global total. This underscores the archipelago's exceptional conservation significance. Although there is extensive legal protection, these ecosystems face threats from coastal development, hydrological modification, sea-level rise, and anthropogenic marine debris (AMD). Recent monitoring studies (2021–2024) confirm ongoing natural colonisation after the devastating tsunami. This reinforces the importance of natural regeneration over artificial planting. The review advocates an ecosystem-based management framework and long-term ecological monitoring to conserve this globally significant and dynamic island mangrove system.

Keywords: Mangroves, Andaman and Nicobar Islands, species diversity, 2004 tsunami, anthropogenic marine debris, coastal conservation

Introduction

Mangroves are intertidal forest ecosystems. They thrive at the land-sea interface and are found in tropical and subtropical regions. They are considered the world's most productive coastal ecosystems (Bhowmik, 2022; Kathiresan & Bingham, 2001; Alongi, 2008) [2, 5, 16]. They have many specialised adaptations such as aerial roots, pneumatophores, and salt-exclusion mechanisms. These adaptations help mangroves to survive in anoxic, saline substrates, although they are subjected to periodic inundation. Globally, mangroves deliver vital ecosystem services including shoreline stabilisation, carbon sequestration, and nursery support for commercially important fisheries (Donato *et al*., 2011; FAO, 2020; Friess *et al*., 2022) [9, 11].

Southeast Asia is one of the important places of global mangrove diversity. However, these ecosystems now face increasing pressure from coastal development and climate change (Giri *et al*., 2014) [12]. Within India, the Andaman and Nicobar Islands (ANI) are of exceptional ecological significance. The archipelago serves as a biogeographic bridge between the Indian subcontinent and Southeast Asia. This has resulted in very high mangrove species richness in ANI. The region hosts nearly half of the world's true mangrove species (Ragavan *et al*., 2016) [22]. According to the India State of Forest Report (ISFR) 2023[1], the ANI accounts for approximately 12.39% of India's total mangrove cover of 4,991.68 sq. km. This represents the third largest mangrove area in the country, after West Bengal and Gujarat, and the highest in terms of species diversity.

An important event in the recent history of ANI was the 26 December 2004 Indian Ocean earthquake and tsunami. The ecological impact of this event on the mangrove was enormous. In addition to direct wave damage, co-seismic tectonic uplift and subsidence permanently altered tidal regimes and coastal geomorphology. This led to widespread mangrove mortality and habitat transformation (Das *et al*., 2014) [8]. More than two decades later, ongoing monitoring studies document continued natural succession in post-tectonic intertidal habitats (Singh *et al*., 2024) [24]. This offers a unique natural condition for studying mangrove resilience.

Although mangroves are legally protected under the Coastal Regulation Zone (CRZ) notifications and the Wildlife Protection Act, ANI mangroves face growing anthropogenic pressures. Some important anthropogenic pressures are infrastructure expansion, hydrological modification, pollution, and the poorly quantified but globally recognised threat of anthropogenic marine debris (AMD) (Giri *et al*., 2014; Kiruba-Sankar *et al*., 2025) [12, 17]. A number of studies have documented floristic and post-tsunami recovery; however, a synthesised and up-to-date review that incorporates recent research advances is lacking. This paper aims to consolidate existing knowledge on the diversity, distribution, ecosystem services, and conservation challenges of ANI mangroves. It further aims to provide a foundation for future research and outline an adaptive management framework appropriate for this dynamic island system.

Study Area

The Andaman and Nicobar Islands form a remote oceanic archipelago in the Bay of Bengal, spanning approximately 6°–14° N and 92°–94° E. Administratively a Union Territory of India, the chain comprises over 836 islands, islets, and rocky outcrops, with only a fraction permanently inhabited. Biogeographically, ANI lies at the junction of the Indian and Southeast Asian regions. Because of this, there is an exceptionally high coastal and marine biodiversity (Ragavan *et al*., 2016) [22].

The islands are of tectonic origin. They form part of the Sunda subduction zone (Curray, 2005) [7]. This results in a highly indented coastline with numerous sheltered bays, tidal creeks, and estuaries. These geomorphic features provide ideal low-energy environments for mangrove establishment. Unlike the extensive deltaic mangroves of mainland India, ANI mangroves are primarily fringing forests. They are associated with short, rain-fed streams and protected embayments. This makes them closely coupled to local hydrology rather than large river systems (Ragavan *et al*., 2016) [22].

The climate is tropical maritime. There is a uniform annual temperature range of 23–34°C and high annual rainfall exceeding 3,000 mm. Mangrove hydrology is governed by semi-diurnal tides and rainfall runoff. This creates pronounced salinity gradients that strongly influence species distribution and zonation (Das *et al*., 2014) [8]. The islands lie in India's seismic zone V. The seismically active tectonic setting means that geomorphic processes operate on timescales relevant to ecological dynamics. This is a feature rare among global mangrove systems (Ramakrishnan *et al*., 2020) [10].

Mangrove Diversity, Floristics, and Species Composition

The mangrove ecosystems of the ANI are among the most species-rich in the Indian Ocean region. This high diversity is due to the archipelago's biogeographic position, island geomorphology, and historically low levels of large-scale anthropogenic disturbance (Ragavan et al., 2016) [22].

1. Species Richness and Global Significance

Comprehensive floristic surveys have documented 38 species of true mangroves in ANI **(Table 1),** belonging to 19 genera and 13 families (Ragavan *et al*., 2016) [22]. This represents approximately 50% of the global true mangrove species pool. This diversity far exceeds mainland Indian systems and underscores the archipelago's global conservation significance. Species diversity is higher in the Andaman group (35 species) than in the Nicobar Islands (21 species). Nehru & Balasubramanian (2018) [20] have linked this pattern to differences in geomorphology, disturbance history, and the severe impacts of tectonic subsidence in the Nicobars following the 2004[23] earthquake.

Recent floristic surveys have further enriched the known inventory with new records for India, including *Sonneratia lanceolata*, *S. ovata*, *S.* × *urama*, and *S.* × *gulngai*, together with new distributional records for the islands such as *Excoecaria indica* and *Rhizophora* × *annamalayana*, and the rediscovery of three species—*Sonneratia griffithii*, *Brownlowia tersa*, and *Acanthus volubilis*—after a gap of approximately 90 years (Ragavan *et al*., 2016) [22]. Five species carry significant IUCN conservation importance: *S. griffithii* (Critically Endangered), *Excoecaria indica* (Data Deficient), and *Brownlowia tersa*, *Phoenix paludosa*, and *S. ovata* (Near Threatened).

New distribution records continue to accumulate. Thirumurugan *et al*. (2022) [29] reported the first occurrence of *Avicennia marina* in the Nicobar archipelago, while subsequent work documented *Aegiceras corniculatum* from the Nicobars for the first time (Thirumurugan *et al*., 2023). Singh *et al*. (2024b) [25, 30] documented new distributional records for *Avicennia* species across ANI with reference to post-tsunami colonisation patterns. These findings highlight that species inventories remain dynamic decades after the 2004 disturbance.

Table 1: List of 38 true mangrove species recorded from the Andaman and Nicobar Islands, India (Source: Ragavan *et al*., 2016) [22].

S. No.	Scientific Name	Family
1	*Acanthus ebracteatus Vahl*	Acanthaceae
2	*Acanthus ilicifolius L.*	Acanthaceae
3	*Acanthus volubilis Wall.*	Acanthaceae
4	*Avicennia alba Blume*	Acanthaceae
5	*Avicennia marina (Forssk.) Vierh.*	Acanthaceae
6	*Avicennia officinalis L.*	Acanthaceae
7	*Nypa fruticans (Thunb.) Wurmb*	Arecaceae
8	*Phoenix paludosa Roxb.*	Arecaceae
9	*Dolichandrone spathacea (L.f.) Baill. ex Schumann*	Bignoniaceae
10	*Lumnitzera littorea (Jack.) Voigt*	Combretaceae
11	*Lumnitzera racemosa Willd.*	Combretaceae
12	*Excoecaria agallocha L.*	Euphorbiaceae
13	*Cynometra iripa Kostel.*	Fabaceae
14	*Pemphis acidula J.R. Forst.*	Lythraceae
15	*Sonneratia alba Sm.*	Lythraceae
16	*Sonneratia apetala Buch.-Ham.*	Lythraceae
17	*Sonneratia caseolaris (L.) Engl.*	Lythraceae
18	*Sonneratia griffithii Kurz.*	Lythraceae
19	*Sonneratia lanceolata Blume*	Lythraceae
20	*Sonneratia ovata Backer*	Lythraceae
21	*Sonneratia × urama N.C. Duke*	Lythraceae
22	*Sonneratia × gulngai N.C. Duke*	Lythraceae
23	*Brownlowia tersa (L.) Kosterm.*	Malvaceae
24	*Heritiera littoralis Dryand.*	Malvaceae
25	*Aglaia cucullata (Roxb.) Pellegr.*	Meliaceae
26	*Xylocarpus granatum J. Koenig*	Meliaceae
27	*Xylocarpus moluccensis (Lam.) M. Roem.*	Meliaceae
28	*Aegiceras corniculatum (L.) Blanco*	Primulaceae
29	*Aegialitis rotundifolia Roxb.*	Plumbaginaceae
30	*Acrostichum aureum L.*	Pteridaceae
31	*Acrostichum speciosum Willd.*	Pteridaceae
32	*Bruguiera cylindrica (L.) Blume*	Rhizophoraceae
33	*Bruguiera gymnorrhiza (L.) Lam.*	Rhizophoraceae
34	*Ceriops decandra (Griff.) Ding Hou*	Rhizophoraceae
35	*Ceriops tagal (Perr.) C.B. Rob.*	Rhizophoraceae
36	*Rhizophora apiculata Blume*	Rhizophoraceae
37	*Rhizophora mucronata Lam.*	Rhizophoraceae
38	*Scyphiphora hydrophyllacea C.F. Gaertn.*	Rubiaceae

2. Dominant Taxa and Structural Backbone

The mangrove flora is dominated by the families Rhizophoraceae, Acanthaceae (including Avicenniaceae), Sonneratiaceae (Lythraceae *sensu lato*), Euphorbiaceae, and Meliaceae. Genera such as *Rhizophora*, *Bruguiera*, *Avicennia*, *Sonneratia*, *Ceriops*, and *Xylocarpus* form the structural backbone of most forests. *Rhizophora* and *Bruguiera* species, with their complex prop-roots and knee-roots, dominate middle intertidal zones, enhancing sediment trapping and stabilisation. Pioneer seaward zones are typically occupied by *Avicennia* and *Sonneratia* species, capable of tolerating frequent inundation and high salinity (Tomlinson, 1986; Kathiresan & Bingham, 2001) [16, 31]. Landward transition zones support species of lower flooding tolerance, including *Xylocarpus granatum*, *Heritiera littoralis*, and *Excoecaria agallocha*.

3. Biogeographic Affinities and Rare Species

The floristic composition shows strong affinities with Southeast Asian mangrove assemblages, particularly those of Myanmar, Thailand, Malaysia, and Indonesia. The presence of regionally rare and mainland-absent species, including the critically endangered *Sonneratia griffithii* and the near-threatened *Brownlowia tersa*, highlights ANI's role as an important biogeographic bridge and genetic reservoir within the Indo-West Pacific bioregion (Ragavan *et al*., 2016; f *et al*., 2014) [22, 26]. This position makes ANI critical not only as a centre of diversity but also as a potential source of propagule dispersal that maintains genetic connectivity across the eastern Indian Ocean.

This high species diversity and structural complexity contribute to ecosystem resilience. This enables ANI mangroves to better withstand environmental stressors, which is a key attribute for long-term conservation (Alongi, 2008) [2]. The concurrent presence of multiple functional groups, including pioneer colonisers, canopy dominants, and transitional species, provides the successional diversity needed for recovery following disturbance.

Ecosystem Functions and Services

The mangroves of the Andaman and Nicobar Islands deliver a broad spectrum of ecosystem services. These services are essential for coastal resilience, biodiversity, and human well-being (Alongi, 2008; Ragavan *et al*., 2016) [2, 22].

1. Coastal Protection and Fisheries Support

Dense mangrove forests are dominated by *Rhizophora* and *Bruguiera* with complex root systems. They attenuate wave energy, stabilise sediments, and reduce shoreline erosion. Their role as natural buffers was evident during the 2004 tsunami. It was observed that intact mangrove belts reduced inland erosion and damage in sheltered settings (Alongi, 2008) [2]. In island environments, where hard engineering infrastructure is a limited option, mangroves function as an important natural coastal defence. Menéndez *et al*. (2020) [19] estimated that mangroves globally provide flood protection benefits worth over USD 65 billion annually. This underscores the economic rationale for their conservation.

The structurally complex root environment also provides nursery and refuge habitats for numerous fish, crustaceans, and molluscs. Thus, mangroves also support high secondary productivity. Strong ecological connectivity between mangroves, seagrass meadows, and coral reefs enhances broader coastal biodiversity and fisheries productivity (Kathiresan & Bingham, 2001) [16].

2. Blue Carbon Sequestration and Climate Regulation

Mangroves are recognised as major blue carbon ecosystems globally. They store substantial organic carbon stocks that often exceed those of terrestrial tropical forests per unit area. This is primarily due to significant below-ground storage in waterlogged, anaerobic sediments (Donato *et al*., 2011; Alongi, 2014) [9, 12]. Global estimates of mangrove organic carbon stocks range from 5.23 to 8.63 Pg C, with mean soil carbon burial rates of approximately 184 g C m^{-2} yr^{-1} (Alongi, 2022) [4]. A meta-analysis of Indian blue carbon ecosystems estimated a total mangrove carbon stock of approximately 67 Tg C for Indian mangroves, with green payment values potentially reaching USD 9.6 billion (Akhand *et al*., 2023) [1].

3. Integrated Benefits for Climate Adaptation

ANI mangroves contribute to climate change mitigation and adaptation through carbon sequestration, shoreline stabilisation, and flood regulation. They maintain surface elevation through sediment accretion. This allows them to respond dynamically to gradual sea-level rise (Alongi, 2014; IPCC, 2019). Friess *et al*. (2022) [11, 12] reviewed the projected responses of mangroves under 2°C warming scenarios. They found complex and site-specific outcomes depending on the interaction of temperature, rainfall, salinity, and sea-level change. This further emphasises the need for localised, adaptive management in island contexts such as ANI.

The multifunctionality of ANI mangroves as biodiversity reservoirs, carbon sinks, coastal buffers, and fisheries nurseries is thus very significant. This also strengthens the rationale for their conservation and integration into coastal and climate policy.

Threats, Pressures, and Conservation Challenges

Despite high ecological value and legal protection, mangroves of the ANI face intensifying threats. These threats arise from anthropogenic activities, natural disturbances, and climate change. These pressures are amplified in island ecosystems characterised by limited land availability and strong dependence on coastal resources (Giri *et al*., 2014; Ragavan *et al*., 2016) [12, 22].

1. Anthropogenic Pressures

1.1 Coastal Development and Hydrological Modification

Several coastal development initiatives, such as the expansion of ports, roads, tourism facilities, and urban settlements, particularly in South Andaman, drive direct mangrove loss and fragmentation. Also, the construction of embankments and culverts across tidal creeks impedes natural hydrology. This leads to hypersalinity, waterlogging, or desiccation stress (Kathiresan & Bingham, 2001; Giri *et al*., 2014). Prabakaran *et al*. (2025) [12, 16, 21] highlight that governance fragmentation across multiple agencies with overlapping mandates exacerbates the difficulty of regulating cumulative development impacts.

1.2 Anthropogenic Marine Debris (AMD) Pollution

A critical and emerging threat is the accumulation of anthropogenic marine debris (AMD). A recent baseline assessment in South Andaman mangroves recorded high debris densities, with plastics constituting 69% of all items, dominated by PET bottles and packaging materials (Kiruba-Sankar *et al*., 2025) [17]. Land-based sources, which are directly linked to inadequate waste management and tourism, accounted for over 80% of this debris. This finding is broadly consistent with studies elsewhere in India: Luo *et al*. (2021) [18] and a systematic review by Sridhar *et al*. (2024) [27] confirm that mangroves globally function as efficient debris traps due to their complex root architecture. Another study in Goa found that plastics contribute 66% of total litter, with 89% attributable to land-based sources (Jayakumar *et al*., 2025) [15].

Plastic pollution poses direct risks to mangrove health. Plastics cause suffocation of roots, sediment toxicity, and ingestion by associated fauna. Laboratory experiments have demonstrated significant leaf loss and increased mangrove mortality as pneumatophore coverage by plastic increases (van Bijsterveldt *et al*., cited in Gutow *et al*., 2022). Microplastic contamination in mangrove sediments is increasingly documented across Indian coastal systems. However, data for ANI specifically is absent. This is a critical gap requiring urgent investigation (Talukdar *et al*., 2023) [28].

1.3 Localised Resource Extraction and Tourism Pressure

In ANI, large-scale commercial exploitation is limited. However, localised mangrove harvesting of fuelwood and poles persists. Such extraction reduces forest structural complexity and increases erosion vulnerability. Tourism-related activities and associated waste disposal further aggravate the problem. As tourism infrastructure in ANI expands, the coupling between visitor numbers and debris loading is expected to intensify. Therefore, an integrated waste management plan at the landscape level is necessary.

2. Natural and Climate Change-Related Stressors

2.1 Tectonic and Storm Events

Located in India's seismic zone V, ANI mangroves are uniquely vulnerable to tectonic disturbances. This was evidenced by the 2004 earthquake. Assessments on coastal vulnerability using high-resolution satellite imagery were carried out after the 2004 earthquake. The data from satellite imagery confirm that sites across the uplift-subsidence gradient created by the 2004 earthquake exhibit distinct and persistently elevated vulnerability profiles. Another disturbance can be from cyclones. Though less frequent than on the eastern Indian mainland, it can cause canopy damage, uprooting, and sediment redistribution. This can temporarily reverse successional trajectories.

2.2 Sea-Level Rise and Climatic Shifts

Sea-level rise poses a paramount long-term threat. The capacity of mangroves to adapt through vertical accretion or landward migration is constrained by steep island topography. This increases the risk of coastal squeeze and habitat loss (Alongi, 2014; IPCC, 2019). Veettil *et al*. (2020) [12, 32] modelled a 1 m sea-level rise scenario for ANI. They projected a significant landward retreat of mangrove habitat with limited migration corridors. Projected changes in rainfall seasonality may also alter critical freshwater inputs. This can exacerbate salinity stress for landward species and undermine the hydrological conditions upon which natural regeneration depends.

CIFOR-ICRAF field campaigns conducted between 2021 and 2024, including the installation of 17 Rod Surface Elevation Tables (rSETs) in 2022 across the post-2004 uplift-subsidence gradient, are now providing long-term data on sedimentation dynamics and mangrove elevation change. This is the first such dataset for ANI. These data will be critical for assessing whether ANI mangroves are maintaining pace with projected sea-level rise and for calibrating adaptive management responses.

3. Systemic Conservation Challenges

3.1 Fragmented Governance and Ineffective Restoration

Mangrove conservation involves multiple agencies with overlapping work and mandates. This can lead to fragmented decision-making. Post-tsunami planting initiatives have sometimes emphasised scale over ecological context. This has resulted in low survival rates. Evidence confirms that natural regeneration supported by hydrological restoration outperforms poorly planned plantations (Das *et al*., 2014). Prabakaran *et al*. (2025) [8, 21] describe a pattern of 'shifted baselines' in governance.

3.2 Lack of Long-Term Ecological Monitoring

ANI is uniquely positioned due to its dynamic tectonics, climate sensitivity, and escalating anthropogenic pressures. Sustained long-term ecological monitoring is absent. This constrains the ability to detect cumulative impacts, successional shifts, and the effectiveness of management interventions. While the ongoing CIFOR-ICRAF rSET programme and the post-tsunami colonisation monitoring studies (Singh *et al*., 2024) [24] are important advances, broader multi-site, multi-parameter monitoring networks are still lacking. This gap is particularly acute and needs urgent attention.

Conclusion

The mangrove ecosystems of the Andaman and Nicobar Islands represent a global conservation priority. The priority stems from the following facts: a) their exceptional diversity of 38 true mangrove species, representing approximately 50% of the global pool; b) their strong Southeast Asian floristic affinities; c) their dynamic island-based ecology distinguishes them sharply from mainland systems; and d) their functions as a critical genetic reservoir and dispersal corridor within the Indo-West Pacific region.

A defining characteristic of the ANI environment is its tectonic activity. The 2004 earthquake induced profound vertical land movements that fundamentally altered the coastal template for mangroves. This caused mortality on a scale that wave energy alone could not explain. More than two decades of subsequent research have documented a remarkable capacity for natural regeneration in newly formed intertidal habitats. Ongoing colonisation is still being recorded across a range of sites in the 2020s[19]. This trajectory underscores the primacy of preserving natural hydrological and geomorphic processes as the foundation of conservation strategy.

The future of ANI mangroves requires the integration of the latest scientific advances. This includes rSET-based sedimentation monitoring, spatiotemporal remote sensing, blue carbon stock quantification, and AMD baseline assessment. This will ensure an adaptive management framework that connects research, policy, and local stewardship. Therefore, protecting these natural assets is not only an ecological necessity but also a foundational investment. This will address the long-term sustainability and resilience of these islands.

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