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Mangrove governance, its challenges, and responses to the 2004 earthquake and tsunami in the Andaman islands, India: A stakeholder perspective

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ABSTRACT

The Andaman Islands in India offer a unique case for studying mangrove social-ecological system (SES) governance due to their expansive mangrove cover of 600 km^2 (~12 % of India's mangrove area), multicultural population, centralised governance from mainland India, and the 2004 earthquake and tsunami's transformative impacts on the islands. This study examines multiple stakeholder perceptions of mangrove SES governance, its challenges, and changes caused by the 2004 seismic event's subsidence and uplift. Further, we discuss strategies for addressing the governance challenges. We conducted and analysed 62 in-depth semi-structured interviews with diverse stakeholders in areas affected by subsidence and uplift, supplemented by a document analysis of scientific literature, regulations and policies. Findings show that while mangrove tree harvesting is prohibited, the mangrove fisheries sector remains under-regulated and poorly monitored. Mangrove planting by the Forest Department increased post-tsunami, driven by the recognition of coastal protection services, but often failed due to non-adaptation to elevation changes. Key governance challenges include top-down exclusionary management by the Forest Department, regulatory ambiguities over mangrove resources, lack of cross-sectoral collaboration, limited community participation due to complex settler histories, and stakeholder conflicts over resource use and ownership. These challenges are exacerbated by the 2004 seismic event. To overcome these barriers, clear resource management guidelines, scientific assessments and input, regular monitoring and improved stakeholder communication and participation are essential for fair decision-making and consistent implementation.

1. Introduction

Mangrove ecosystems constitute a group of plants, associated fauna (*e.g.* fish, crustaceans, molluscs) and other organisms (*e.g.* fungi, bacteria) present in intertidal zones in tropical, sub-tropical, and warm temperate coastal areas (Dahdouh-Guebas et al., 2021). They are vital for sustaining coastal populations and livelihoods, directly or indirectly, by providing diverse ecosystem services, including fishery resources,

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coastal protection, and cultural services (zu Ermgassen et al., 2021; Friess et al., 2024). Viewing mangroves as a 'social-ecological system' (SES) considers the interactions between the natural ecosystem and multiple human stakeholders and their associated governance structures (Santos et al., 2017; Dahdouh-Guebas et al., 2021; Mafaziya Nijamdeen et al., 2024).

The governance and management of mangrove SESs is challenging given the diverse stakeholders with differing perceptions and interests, the overlap of marine and terrestrial resources, and the resulting ambiguities in resource use and tenure (Golebie et al., 2021; Mafaziya Nijamdeen et al., 2023a). Understanding governance requires insight into 'who' makes decisions, 'what' their powers and responsibilities are, and 'how' decisions are made and exercised (or not) (Bennett and Satterfield, 2018). The effectiveness of these decisions depends on how it is perceived by multiple stakeholders and whether resulting policies and processes address local needs (Bennett et al., 2017; Schoon and Cox, 2018). Additionally, with increasing natural and anthropogenic stressors impacting mangrove SESs, governance and management need to adapt to these changing contexts to be effective (Poti et al., 2022).

The Andaman Islands in India offer a distinct case for studying mangrove SES governance. This is because the islands are characterised by an expansive mangrove cover of over 600 km^2, constituting 12 % of India's mangrove area (Forest Survey of India, 2023), presence in a seismically active region, a multicultural population, complex migration histories, livelihood dependence on agriculture, fisheries and tourism, and centralised governance with a distant decision-making centre (Oommen and Ramesh, 2019; Deol, 2021). According to the India State of Forest Report (Forest Survey of India, 2023), there has been a loss of 357 km^2 (37 %) of mangrove cover in the islands between 1989 and 2019. Specifically, the loss attributed to natural drivers associated with the 2004 seismic event was approximately 190 km^2 (Singh et al., 2024a), in addition to anthropogenic stressors such as land use change for agriculture and settlements.

The 2004 Sumatra-Andaman earthquake (9.1–9.3 *Mw*) and tsunami severely affected the archipelago's coastal ecosystems (Sankaran et al., 2005). The Andaman and Nicobar Islands (ANI), situated around 100 km from the epicentre, bore the brunt of the disaster, enduring high-intensity tsunami waves, some as tall as 10 m, along with land subsidence and uplift (Roy and Krishnan, 2005; Porwal et al., 2012). This led to varied impacts across the islands, with some areas subsiding in South Andaman by 0–1 m, remaining unaffected in Middle Andaman, or being uplifted in North Andaman by 0–1.35 m (Malik et al., 2006; Rajendran et al., 2007). These abrupt changes in ground elevation altered sea levels and tidal patterns, significantly disturbing and degrading mangroves (Ramakrishnan et al., 2020; ShivaShankar et al., 2020). Furthermore, it poses challenges for mangrove SES governance and presents a unique case for understanding how people and governance perceive and respond to these drastic changes.

There is increasing ecological research on the impacts of the 2004 event on mangrove dynamics through field and remote sensing-based studies in the islands (Ramachandran et al., 2005; Dharanirajan et al., 2007; Ray and Acharyya, 2011; Majumdar et al., 2019; Ramakrishnan et al., 2020; ShivaShankar et al., 2020; Nehru and Balasubramanian, 2018; Prabakaran et al., 2021; Nath et al., 2022; Singh et al., 2024a, 2024b, 2025; Thirumurugan et al., 2024). However, the stakeholder perceptions and mangrove SES governance remains underexplored, both generally and specifically in the context of the 2004 seismic event. In this paper, we aim to provide an overview of mangrove SES governance and its challenges; to analyse stakeholder perceptions of mangrove SES change and governance responses (or lack thereof) in the aftermath of the 2004 seismic event; and to discuss strategies in addressing mangrove governance challenges. We specifically focus on degraded mangrove areas that have experienced uplift and subsidence in the Andaman group of islands (hereafter referred to as the 'Andamans' or 'Andaman Islands' or 'the islands') within the Andaman and Nicobar Islands (ANI).

2. Materials and methods

2.1. Study site description

The Andaman Islands are situated approximately 1100 km East of mainland India, in a seismically active area where geological forces (volcanic activity, land subsidence and uplift) have influenced the archipelago's topography (Malik et al., 2006). With a total geographical area of 6408 km^2, the Andaman archipelago comprises 325 islands, 24 of which are inhabited, and are divided into two administrative districts: North and Middle Andaman (3736 km^2) and South Andaman (2672 km^2) (Fig. 1).

The Andaman Islands are ecologically diverse and are part of the Indo-Burma global biodiversity hotspot (Mittermeier et al., 2011), with ~11,000 animal taxa (over 1100 endemic species) and ~2649 plant taxa (over 300 endemic species) reported (Ramakrishna et al., 2010; Botanical Survey of India, 2020). Mangrove forests in the Andamans were reported to comprise 35 true mangrove species and 4 hybrids (Ragavan et al., 2018; Singh et al., 2024b).

Following India's independence from British rule in 1947, the Andamans along with the Nicobar Islands, transitioned to a Union Territory, wherein decisions are made top-down and implemented by the Government of India (GoI), which designates various administrative departments within the islands (Aufschnaiter, 2020). In terms of societal composition, the islands' population of 400,000 people primarily comprises migrant settlers and their descendants from mainland India, Bangladesh, Myanmar, and Sri Lanka, with a smaller population of indigenous inhabitants belonging to five indigenous communities: the Great Andamanese, the Jarawa, the Onge, the Sentinelese and the Nicobarese (Census of India, 2011; Advani, 2020). The indigenous communities have experienced a persistent decline over the past 150 years due to the colonial settlement regime on the islands (Vaidik, 2010). The current settler population represents a heterogeneous mix of ethnicities and linguistic communities, predominantly speaking Hindi, Bengali, Tamil, Telugu, Malayalam and Karen, among other languages (Directorate of Economics and Statistics, 2010).

2.2. Data collection

This study employed a qualitative approach, primarily drawing on two key methods: semi-structured interviews and document analysis. Semi-structured interviews were conducted with multiple stakeholders involved in the use and governance of mangrove SESs in the Andaman Islands (see Appendix 1 for the full interview guide). Complementing this, a document analysis of secondary sources including technical reports, government regulations, management plans, and policies was carried out to contextualise and triangulate the findings.

The fieldwork was conducted in three distinct phases across the islands: January to March 2020 and January to May 2022 in South Andaman and January to May 2023 in North Andaman. This research obtained all necessary ethical approvals and fieldwork permissions. Ethical clearance was granted by the Université Libre de Bruxelles (File No. 34805910), in coordination with the local collaborating organisations. The study was designed and conducted in collaboration with local research and conservation organisations, including the Andaman Nicobar Environment Team (ANET), Dakshin Foundation, and the Wildlife Institute of India. These partnerships contributed to the research design, facilitated field access, and ensured alignment with local ecological and socio-cultural contexts.

2.2.1. Selection of villages and participants

A total of seven villages were selected for interviews based on the presence of mangrove forests, identified using Google Earth imagery and previous studies that analysed mangrove distribution across the Andaman Islands (Majumdar et al., 2019; Ramakrishnan et al., 2020; Nath et al., 2022; Singh et al., 2024b, 2025). The selection also considered the

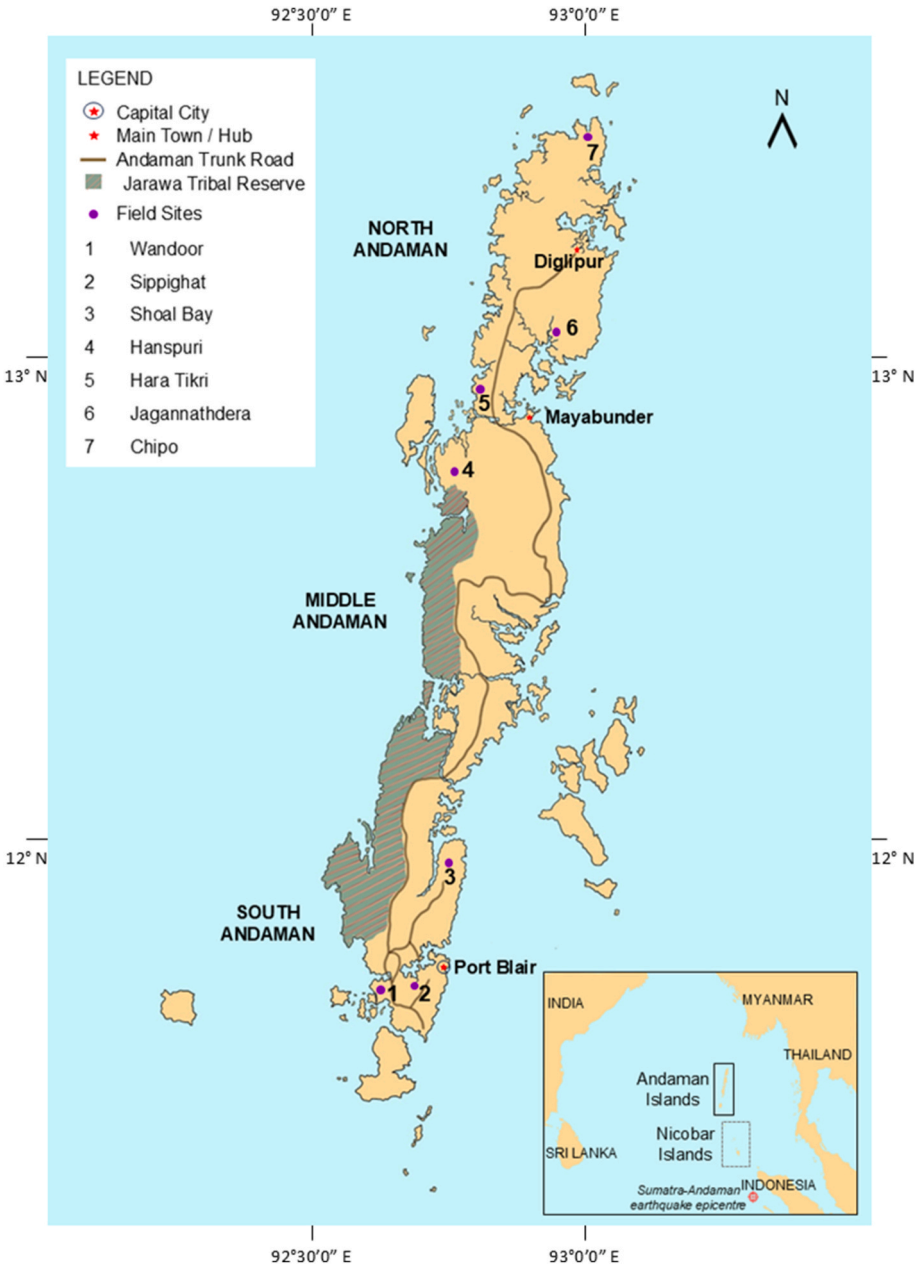

Fig. 1. Map of the Andaman Islands, field sites and an inset showing neighbouring countries.

dependence of villagers on mangrove-based fisheries, verified through local resource persons, the impact of tectonic shifts on mangrove ecosystems, and the spatial distribution of villages across uplifted and subsided sites informed by both satellite imagery and the aforementioned studies. The selected villages included four from uplifted sites in North Andaman (Chipo, Jagannathdera, Hara Tikri and Hanspuri) and three from subsided sites in South Andaman (Shoal Bay, Sippighat and Wandoor) (Fig. 1). Notably, some of these selected villages were situated in remote locations, requiring considerable time and effort to reach, with hours of walking or boat rides being necessary. This intentional inclusion of remote villages ensured a breadth of voices and knowledge beyond the typical research hubs in the Andamans.

The research design included a purposive sampling strategy, a non-probability sampling method involving the strategic selection of participants considered relevant to answer the research questions related to mangrove SESs, while ensuring the inclusion of diverse perspectives by covering the predominant migrant settler communities and stakeholder types (Bryman, 2016). Potential respondents were identified by exploratory conversations in initial stages, followed by snowball sampling to identify key informants, who then recommend relevant individuals for the interviews.

The types of respondents considered for the interviews were as follows.

1. Individuals from villages close to mangroves that were affected by coastal uplift and subsidence, considering their age, gender and profession. These individuals included men and women who were above 25 years of age, as well as elders, fishers, and mangrove mud crab (*Scylla* spp.) collectors.
2. Representatives (retired or serving) from various government departments, including the Forest, Fisheries and Revenue Departments—spanning officers and employees at various hierarchical levels.
3. Academic mangrove researchers in the Andamans.

4. Members of civil society actively engaged in mangrove-related work.

2.2.2. Conducting interviews

We used semi-structured interviews, a method that utilises predetermined interview guide to maintain a consistent focus across participants, while also allowing interviewers the flexibility to probe deeper into emerging topics or new lines of inquiry as the interview unfolds (Young et al., 2018). This approach enables adaptable conversations that yield diverse and context-specific responses, allowing researchers to collect rich stories, narratives, and personal accounts from participants, especially when exploring complex issues (Young et al., 2018; Tracy, 2019).

Each new village was entered with a local resource person from the community, facilitating the establishment of trust. The interviews were conducted in person in households, in tea shops, and government stakeholders were interviewed in their offices. Before each interview, participants were provided with a comprehensive explanation of the study's purpose, their roles (pertaining to mangrove stakeholder relevance) and rights (including voluntary participation and withdrawal at any time), and thereafter seeking their verbal informed consent (Wiles, 2013). We implemented measures to safeguard the confidentiality and anonymity of participants by protecting their personally identifiable information at all steps of the research.

The guiding interview questions were adapted based on context and the stakeholder addressed. Broadly, the questions were related to perceived changes in mangrove SESs and resources, the future of mangroves and resources, perceptions of governance, relationships between stakeholders and priorities for research and management (complete interview guide in Appendix 1). Additional questions supported deeper exploration and explanation of relevant areas as they arose from the interview conversation. These questions were designed based on previous mangrove SES studies (*e.g.* Nfotabong-Atheull et al., 2011; Treviño, 2022; Mafaziya Nijamdeen et al., 2023b) and preliminary exploration of the islands. The interview guide was tested with 6 pilot respondents and then modified based on their feedback. Responses from the pilot respondents were not included in the analysis. The interviews lasted between 19 and 125 min. In total, 62 interviews were conducted (see Table 1 for more information on respondent profiles). We experienced four refusals, with time constraints cited as the reason for each. Translators were approached only when interviews were conducted in languages such as Karen and Bengali, as most participants were comfortable in Hindi, the language used for interviews, observations and communication. Detailed running notes were taken, and most interviews were recorded using a digital voice recorder (with the permission of the respondent) and transcribed and translated at the earliest convenience.

2.2.3. Document analysis

To complement our interviews, we conducted a document analysis to extract content from relevant policy and regulatory materials. All documents were systematically reviewed to understand mangrove management and governance in the islands. The analysis also served to verify, triangulate, and corroborate information obtained through interviews. Additionally, it informed the design of the interview guide and helped identify key stakeholders.

The documents reviewed included Forest Department working plans, national and island-level forest and fisheries policies, coastal development plans, technical reports from governmental and non-governmental organisations, and content from ANI administration websites. Sources were selected based on their relevance to atleast one of these three main policy domains: mangrove forest and fisheries management, post-2004 tsunami response, and coastal development planning. Specifically, we analysed these documents to extract information on institutional roles and responsibilities, regulatory frameworks, policy implementation, post-disaster responses, and policy and coordination gaps. A list of the reviewed documents, along with summaries, is provided in Appendix 2. Several documents were not available online and were accessed through in-person visits to Department head offices in Port Blair, the capital of ANI.

Table 1
Profile of the interviewed respondents.

Respondent profile	Number (N = 62)
Stakeholder type	
Local communities (fishers, crabbers, elders)	38
Forest department officials (retired and serving)	11
Fisheries department officials	3
Revenue department officials	2
Researchers	5
Civil society members	3
Gender	
Women	23
Men	39

2.3. Data analysis

Qualitative data analysis was iterative, taking place at all stages of the research, from fieldwork to writing, to help focus and shape the study as it proceeded. The data were first prepared by translating and transcribing all the interviews. Subsequently, the transcripts were thoroughly examined through repeated readings, and brief visual summaries were made for each interview (Appendix 3). Additionally, the policy documents were analysed to extract relevant information described in section 2.2.3. Qualitative data analysis involves breaking down data into smaller units to uncover their characteristic elements and structure (Creswell and Poth, 2017). This is done by labelling, organising and interpreting data with reference to a set of 'codes,' 'categories,' or 'themes'. During this process, the first author used in vivo coding, wherein segments of data were labelled descriptively or conceptually into themes, using participants' exact words or phrases (Tracy, 2019). This approach facilitated the assignment of themes directly reflecting participants' perspectives ('emic' perspective; see Tracy, 2019). Using axial coding, common themes were then identified, grouped, and reorganised into broader thematic categories. The generated coding maps are presented in Appendix 4. Data analyses were conducted using MaxQDA 2022 software (VERBI Software, 2021).

3. Results

3.1. Mangrove governance framework and administrative roles

The analysis of regulations, policies and stakeholder perceptions suggests that mangrove governance in the Andamans involves three primary administrative actors: the Forest Department, the Fisheries Department, and the Revenue Department. The Forest Department holds central authority in environmental resources, with approximately 88 % (4954 km^2) of the islands' land area (5629 km^2) classified as reserve forests and protected areas under its jurisdiction (Directorate of Economics and Statistics, 2023, Appendix 5). In contrast, only 6 % (338 km^2) of the land area is allocated for private settlement and agriculture, managed by the Revenue Department (Directorate of Economics and Statistics, 2023).

Mangrove forests receive legal protection under key instruments such as the Indian Forest Act 1927 (IFA), the Wildlife (Protection) Act 1972 (WLPA), and the Island Protection Zone Notification 2019 (IPZ) (Department of Environment and Forests, 2016; summaries provided in Table 2). The Forest Department enforces these laws, including a ban on mangrove tree cutting established in 1986.

3.2. Stakeholder perceptions of mangrove governance

Interviews with local stakeholders emphasised the Forest

Table 2
Summary of the management guidelines for mangroves in the Andaman Islands.

Regulatory/Policy Mechanism	Explanation
Mangrove Cutting Ban Order 1986	Mangrove tree extraction and cutting is prohibited.
Indian Forest Act 1927 (IFA)	Legal framework for the conservation and management of forests in India. The Act establishes the concept of 'Reserved Forests', where the government/Forest Department has exclusive control over the land, and regulates activities such as grazing, cultivation, fishing and timber extraction within these areas. Various penalties including fines and imprisonment based on type of prohibited activity.
Wildlife (Protection) Act 1972 (WLPA)	Legal framework to designate certain areas as 'Protected Areas' which may include 'National Parks', 'Wildlife Sanctuaries', 'Conservation Reserves' and 'Community Reserves' where special provisions are made for the protection of flora and fauna. Restricted activities, based on type of protected area, may include hunting, poaching, grazing, and any other form of exploitation that could be detrimental to the flora and fauna, including mangrove ecosystems. Fishing operations are prohibited in designated protected areas.
Island Protection Zone Notification 2019 (IPZ)	Categorises islands by size, ecological significance and population for regulating developmental activities in these zones. Mangroves fall under Zone 1 (ICRZ-IA) as 'ecologically sensitive areas'. Government-owned mangrove areas exceeding 1000 m^2 require a 20 m buffer - for public facilities such as developing parks, laying pipe and transmission lines, road construction on stilts, mangrove research and conservation activities. Construction of roads on stilts in ICRZ-IA areas allowed exceptionally for defence, strategic, or public utility purposes, subject to detailed impact assessments by relevant authorities. If such roads affect mangroves, compensatory plantation of at least three times the affected area is mandatory.
Andaman and Nicobar Islands Marine Fishing Regulations of 2004	Provides guidelines to regulate fishing in territorial waters, regulate mesh sizes and demarcate zones. Every fishing vessel or boat for the purpose of fishing in a specified area needs to be registered and licensed. Fishing Zone A (Territorial waters up to 6 nautical miles) - fishing vessels with 30HP engines including traditional and non-mechanised boats. Fishing gear permitted - Gill net above 25 mm mesh size, hook and line, shore seine/drag net of mesh size above 25 mm, fish traps. Prohibited gear - knotless gill net made of monofilament twine ('plastic jal') and barrier nets made of mosquito net or cloth are not allowed in coastal areas, estuary mouths and creeks. Crab size regulations - *Syclla serrata* below 8.4 cm carapace width; *Scylla tranquebarica* below 12.3 cm and any crab with egg mass in abdomen not permitted.
Port Blair Master Plan 2030	Under the 'Submerged Land' classification - lands submerged during the tsunami 2004 and the lands which are prone to flooding during monsoon and seasonal rains have been zoned under this classification. These lands are vulnerable to inundation and hence they do not qualify for any construction activity in the normal circumstances, to protect the lives and properties from calamities. However, total prevention of development in these lands will lead to reduction of substantial extent of land for development purposes. Therefore, the authority can consider and grant permission for construction activities in these lands on a case-to-case basis, ensuring adequate protection in case of any exigencies.

Department's dominant role in mangrove management, which many community members interpreted as exclusionary. Mangroves were widely referred to as "property" that "belongs" to the Forest Department, and the enforcement of strict rules without community engagement led to feelings of apprehension and alienation. Interviewed officials acknowledge their top-down approach, underscoring the necessity of instilling fear in the public to assert authority.

All community members interviewed were aware of the ban on mangrove cutting. When discussing mangroves on the islands, respondents consistently emphasised that *"cutting mangroves is absolutely prohibited."* They further elaborated on the heavy fines and potential imprisonment associated with this offence (see for example Fig. 2). However, responses from community members regarding the exact amount of the fine varied, ranging from 50 INR to 50,000 INR. According to the document analysis, the IFA 1927 (recently proposed for amendment in 2019) states that illegal tree felling in Reserve Forest

Fig. 2. Photo of an installation in the Forest Department Interpretation Centre at Wright Myo, South Andaman that exemplifies the role of the Forest Department as the main mangrove regulatory actor in the islands and the mangrove cutting ban. Photograph taken by Meenakshi Poti (March 17, 2022).

areas can incur a fine of up to 500 INR[1] and, in some cases, imprisonment for up to 6 months (Table 2). A Range Forest Officer noted that this fine was insufficient and advocated for updating laws to reflect current economic conditions.

While restrictions on the use of mangrove forest resources are widely acknowledged by stakeholders, the governance of fishing activities within mangrove areas is perceived as less stringent and poorly defined. Respondents indicated that rules related to mangrove and creek fishing are unclear and rarely enforced. The Andaman and Nicobar Islands Marine Fishing Regulation 2004 (MFR) categorises fishing zones and prohibits specific fishing gear in designated areas; however, it does not include explicit provisions governing fishing within mangrove ecosystems or creeks (Table 2). Furthermore, despite the economic significance of the mangrove crab fishery sector in the Andamans, multiple respondents noted the absence of targeted policy measures addressing this sector, with only a minimum harvestable size restriction under the MFR 2004.

Moreover, the rules regarding fishing in 'Reserve Forest' remain unclear for all stakeholders. Eight Forest Department officials suggest that fishing in Reserve Forest areas is prohibited based on the IFA 1927. However, they further expressed that these rules are a grey area and enforcement is limited because of the dependence on mangrove fishing as a local livelihood, unless the activity transgresses into Protected Areas designated by the WLPA 1972, which receive a higher protection status. For example, in the surveyed village of Jagannathdera in North Andaman, crabbers reported sudden prohibitions imposed by the Forest Department on crab catching in areas deemed 'Reserve Forests', claiming no prior awareness of these rules. This contributed to uncertainty and concerns about nonuniform enforcement and perceived inequities in access to mangrove resources.

3.3. Post-tsunami shifts in mangrove perceptions and governance

The 2004 earthquake and tsunami are widely recognised as 'turning points' in the island's history, often referred to as the 'pre-tsunami' and 'post-tsunami' periods by interview respondents. The seismic event's effects are evident in topographical changes, including land subsidence and uplift, as well as economic transformations resulting from aid and damage. Memories of the catastrophic event, witnessed by each respondent, remain vivid in the collective consciousness, recounted with a level of detail as if it occurred yesterday. Moreover, the lived experience of the tsunami has instilled an appreciation for mangroves among stakeholders. All 49 local community respondents highlighted the importance of mangroves as protective barriers against tsunamis, cyclones, and storms.

3.3.1. Post-tsunami mangrove restoration initiatives

In the years following the tsunami, the Forest Department initiated large-scale mangrove restoration projects. According to 11 respondents from the Forest Department, mangrove restoration efforts and funding increased in the Andamans after the tsunami, driven by the recognition of their coastal protection role. Secondary data suggests that funding for mangrove and littoral forest conservation increased by 6 times between 2009 and 2020 (data pre-2009 was not accessible) (Department of Environment and Forests, 2019, Appendix 6). According to Forest Department's working plans, each administrative division is tasked with planting at least 2 ha of mangroves annually (Department of Environment and Forests, 2016). However, challenges emerged in the execution of these projects. In pursuit of meeting these targets, the Forest Department embarked on several failed restoration attempts. Ongoing research and field observations by the author team suggest that these restoration failures are largely due to the selection of unsuitable sites and inappropriate mangrove species (field observations by ARS and NP). For example, at a surveyed site in the Radha Nagar creek, Paschimsagar (North Andaman), mangroves had naturally colonised the area prior to the 2004 seismic event. However, following land uplift, the site experienced significant mangrove degradation due to the cessation of regular tidal inundation, except during spring tides via a subterranean channel. These new conditions were more suitable for back mangrove species such as *Heritiera littoralis* Aiton, *Phoenix paludosa* Roxb., *Excoecaria agallocha* L., and mangrove associates like *Cerbera odollam* Gaertn (Singh et al., 2025). Despite this, the area was erroneously planted with *Rhizophora* spp., favoured by forest managers for its ease of seed collection and propagation, which require frequent tidal inundation. As a result, the plantations failed to establish. Forest Department officials acknowledged the challenges of post-tsunami restoration, noting that the event created unprecedented environmental changes to which existing management practices were ill-equipped to respond.

Mangrove researchers who were interviewed highlighted the paucity of information and restricted access to data on mangrove restoration practices, attempts and their results. Additional restoration challenges indicated by Forest Department officials and researchers include the lack of scientific monitoring and research, uncertainty in managing restoration efforts in post-tsunami submerged areas and uplift areas, scarcity of available suitable land for planting mangrove saplings and issues related to herbivory caused by exotic and invasive spotted deer and the impact of cattle grazing on restoration initiatives.

3.3.2. Governance challenges in post-tsunami subsided areas

In South Andaman, the 2004 tsunami and subsequent land subsidence caused the permanent inundation of certain coastal areas, leading to the loss and degradation of approximately 43 km^2 of mangrove habitat (Rajendran et al., 2007; Department of Environment and Forests, 2016; ShivaShankar et al., 2020). These changes also created new intertidal zones with potential for natural mangrove colonisation (Fig. 3; ShivaShankar et al., 2020). However, interviews and document analysis revealed that much of this newly formed intertidal land falls under private ownership, intensifying existing land ownership conflicts (Department of Environment and Forests, 2016; Committee on Land Matters in ANI Report, 2017). Respondents noted that this situation creates uncertainty about the future of the regenerating mangroves and poses new governance challenges for their protection and management.

Coastal villages in South Andaman, traditionally situated on low-lying flat land used for rice cultivation, and hilly land designated for homesteads, were severely affected by the tsunami (Dharanirajan et al., 2007; Velmurugan et al., 2015; Committee on Land Matters in ANI Report, 2017). It is estimated that between 13 and 33 km^2 of 'Revenue Land' (used for private settlement and agriculture) was submerged, making it unsuitable for cultivation due to increased soil salinity and ongoing inundation (Committee on Land Matters in ANI Report, 2017). This loss of cultivable land, combined with limited land on higher ground and a growing urban population, has resulted in a rapid increase in land reclamation on previously unsuitable low coastal flats (Fig. 3).

We found that there is currently no specific regulatory framework to address the changes caused by land subsidence and mangrove colonisation. Land reclamation is allowed with permission from the Deputy Commissioner of the district. Forest Department officials stated that mangrove cutting is prohibited regardless of the land type, whereas Revenue Department officials argued that such restrictions should not apply to 'Revenue Land' areas. The governance of these newly subsided areas is complicated by ongoing conflicts between the Forest and Revenue Departments, which impede efforts to resolve land disputes effectively.

Two Forest Department officials suggested that the submerged areas could be officially classified as 'tidally influenced water bodies' under the IPZ Notification 2019 or as 'Wetlands' under the Wetland (Conservation) Rules 2017. However, hesitation exists due to concerns about private property rights and potential local and political resistance to

[1] 1 INR = 0.011 EUR (18/06/2024) Mangrove charcoal in mainland India costs approximately 15–50 INR per kg as of June 2024 (IndiaMART, 2024).

Fig. 3. Images of subsided sites in South Andaman: (A) presents an aerial view of subsided areas (location: Sippighat, April 15, 2019); (B) illustrates subsidence-induced mangrove degradation due to hypoxic conditions (resulting from higher frequency and duration of tidal inundation) (location: Red Skin Island, June 13, 2023); (C) shows mangrove recolonisation in tsunami-inundated private land (location: Wandoor, February 02, 2023); (D) depicts land reclamation activities (location: Sippighat, March 17, 2022). Photographs taken by (A) Adhith Swaminathan, (B) Anoop Raj Singh, (C) and (D) Meenakshi Poti. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

enforcing environmental regulations. One Forest Department staff member encapsulated these conflicts during an interview, stating: *"The primary land-related conflict in the islands revolves around the tussle between us [the Forest Department] and the Revenue Department. Technically, tsunami-submerged lands should fall under our department's jurisdiction for protection, but the reality on paper is challenging. With only 6 % of available land for development, the Revenue Department faces constraints and is reluctant to let go of this land. Additionally, since submerged areas are situated in close proximity to Port Blair and are prime urban properties, the situation becomes even more complex. Resolving this conflict appears unlikely unless we [Forest Department] are willing to concede some land to the Revenue Department, with the condition of acquiring tsunami-affected lands in exchange. Unfortunately, I believe it is too late, as people have already commenced construction of buildings on the reclaimed land, rendering this issue exceedingly sensitive and complex to address at present."*

Additionally, three local community members and interviewed researchers raised concerns about the potential environmental consequences of unchecked development, cautioning against prioritising development at the cost of ecological health. Conversely, the Committee on Land Matters in ANI Report (2017) called for a shift in land management practices, advocating for the release of more forest land for development and critiquing the preservation of forest cover as a hindrance to economic growth and livelihood opportunities.

This discourse also mirrors broader discussions within fisheries development plans, where some officials from the Fisheries Department have pushed for mangrove aquaculture, particularly in the subsided areas. The ANI Fisheries Policy (2018) highlights that, although there is significant brackish water available (330 km^2), aquaculture is practically absent on the islands due to the presence of mangroves in designated reserved forest areas. One Fisheries Department official voiced concerns about the constraints on development, stating: *"These islands are overburdened with environmental regulations and protection. In the name of the environment, Andamans development is slow. They need to change the environmental laws and de-reserve demarcated mangrove areas for aquaculture so that Andamans can become a role model for other places in India - because it is an island we should be able to easily implement pilot aquaculture projects here."*

Local communities and researchers warn against prioritising economic development at the cost of environmental integrity. Meanwhile, the Committee on Land Matters in ANI Report (2017)has called for more flexible land management approaches to support economic growth. The Fisheries Department has also expressed concern that current regulations hinder opportunities for aquaculture in these newly formed intertidal areas. Despite broad recognition of the challenges, respondents state there is little proactive regulatory response, and officials often default to a "wait-and-see" approach, which may increase long-term risks.

3.3.3. Governance challenges in post-tsunami uplifted areas

In North Andaman, land uplift following the 2004 earthquake and tsunami led to decreased relative sea levels and exposure of previously submerged coral reefs. This uplift caused extensive mangrove degradation, with losses ranging from 40 to 100 % at different sites due to the absence of tidal flooding (as shown in previous studies Ray and Acharyya, 2011; Majumdar et al., 2019; Ramakrishnan et al., 2020, Fig. 4). In the former landward mangrove zones, terrestrial vegetation has since colonised the area as a result of the altered soil and hydrological conditions (Ramakrishnan et al., 2020).

Community respondents in the four uplifted villages consistently reported that mangroves are now significantly farther from their settlements. They noted a severe reduction in tidal water flow through the channels, which they associated with substantial degradation of local fishing grounds and declines in fishery resources. Fishers commonly remarked on the decline in fish and crab populations, often using phrases such as *"we are not getting as much as before"* and *"fish and crabs have declined drastically as they can no longer enter the channels."* Alongside the impacts of mangrove loss, respondents also referred to increasing demand for fishery resources, inadequate monitoring and enforcement, and the use of unsustainable fishing gear as contributing factors.

An elderly fisherwoman from Chipo village, an uplifted site in North Andaman recounted *"Previously, this area was all mangrove, but now it is*

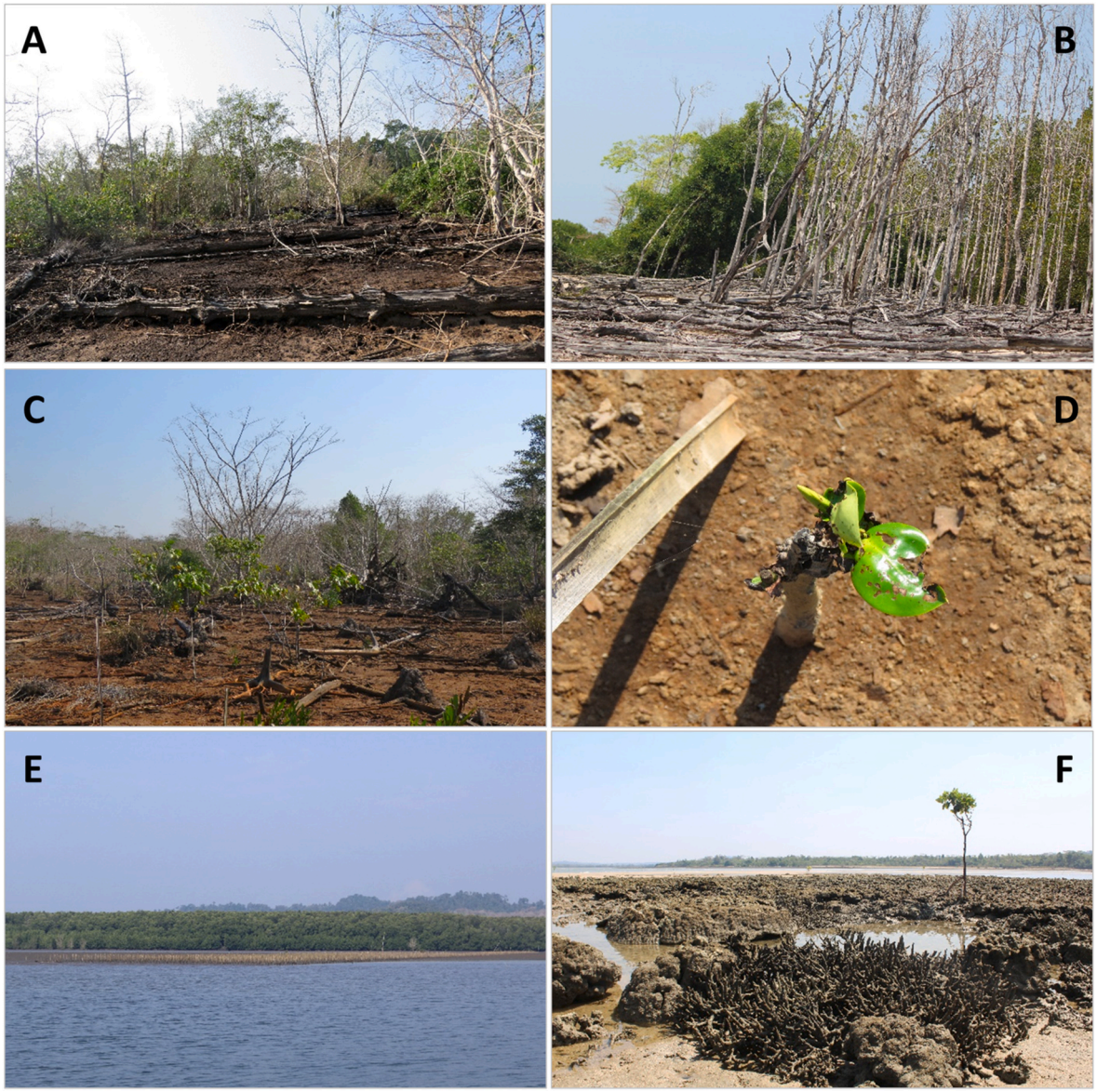

Fig. 4. Images of uplifted sites in North Andaman: (A) and (B) show mangrove degradation due to land uplift and permanent cessation of tidal water inundation (locations: Radha Nagar creek and Thorn Hill Island, 03/03/2022 and February 05, 2020); (C) depicts a failed mangrove restoration attempt in a degraded mangrove forest area (landward zone) that does not receive tidal inundation through subterranean channels (wrong site and wrong species plantation) (location: Kishori Nagar Creek, February 10, 2021); (D) illustrates herbivory pressure on the mangrove plantation (location: Kishori Nagar Creek, February 10, 2021); (E) showcases mangrove plantation at the newly created uplift areas (seaward zone) highly influenced by tidal inundation (location: outside the Kalighat Creek, March 26, 2022); (F) demonstrates mangrove colonisation at the uplifted coral and reef beds boulders (location: Radha Nagar Beach, February 10, 2021). Photographs taken by Anoop Raj Singh.

turning into 'jungle' [terrestrial forest] after the land rose abruptly in one event … I used to fish right in my backyard, but now, because the tidal water no longer reaches here and has dried up due to the tsunami, I have to trek long distances of 1 km to reach the sea." She further explained, "Before the tsunami, I would put my baby to sleep, start cooking rice over a fire, and then head out for fishing in the nearby mangroves, which were just a 5-min walk away. I would catch some fish using my hook and line, return home to cook them, and by then, my baby would be awake and the rice ready. However, now, I have to walk for more than 30 to 40 min to reach the mangrove creek, and even after spending 1 to 2 h, I hardly catch 1 or 2 fish. There are barely any fish left in the mangrove channels, and we have to spend hours. Everything changed here after the tsunami."

In response to these coastal changes and the reduced availability of fishery resources, respondents described a gradual shift in livelihoods. This included the adoption of small-scale agriculture such as the cultivation of supari (*Areca catechu* L.) and reliance on private daily wage labour. Eleven respondents specifically mentioned the conversion of degraded mangrove areas into farmland for bananas, betel nut, and ginger cultivation. These newly cultivated zones are located in areas previously occupied by mangroves that are now dry due to the uplift. According to Forest Department officials, these activities are considered encroachments on 'Reserve Forest' land and are therefore illegal. However, officials cited constraints such as limited staff and funding as key challenges in monitoring and addressing these encroachments.

Two types of vegetation successional zones have emerged in the uplifted areas: (1) mangrove colonisation on previously submerged coral reef zones, and (2) terrestrial plant colonisation in degraded mangrove zones. According to Forest Department officials, efforts to manage these zones have faced considerable difficulties. They described that in the reef zones, high tidal action and calcareous substrates have inhibited the

establishment of mangrove propagules. In the former mangrove zones, plantation efforts of terrestrial plants have also reported to have failed. These areas were found unsuitable for both native mangrove species such as *Rhizophora* spp. and *Bruguiera gymnorhiza* (L.) Lam. ex Savigny, and for terrestrial tree species like *Lagerstroemia hypoleuca* Kurz. Additionally, these open degraded lands are now dominated by invasive plant species such as *Chromolaena odorata* (L.) R.M.King & H.Rob. and ferns like *Acrostichum aureum* L (Singh et al., 2025). Interviewed researchers and Forest Department officials also observed high levels of grazing by invasive spotted deer (*Axis axis*), which hindered the growth of both planted saplings and natural regeneration. Forest Department officials stated that no active management was being undertaken to address this issue because spotted deer are protected under the Wildlife Protection Act (WLPA) 1972. They identified a need for additional scientific expertise, training, and human resources to develop and implement effective restoration strategies in these newly emerged successional zones.

3.4. Underlying governance challenges

Stakeholder perspectives highlighted several underlying challenges in mangrove governance, primarily attributed to centralised control, bureaucratic structures, and limited community engagement. Respondents noted that governance systems in the Andaman Islands are highly centralised due to the islands' Union Territory status, with policies and decisions predominantly shaped at the national level. This centralised approach was perceived to contribute to the exclusion of local voices and a lack of responsiveness to island-specific needs.

Several government officials described the rigidity of existing bureaucratic processes. A Forest Department official noted that even minor management adjustments require approval from central authorities, slowing down the decision-making process. For example, an official expressed that the *"Forest department is handcuffed by stringent rules. Any management procedure that needs change must be approved by the central government after extensive paperwork."*

The Fisheries Department also acknowledged the necessity for mangrove-specific fisheries regulations but cited challenges in policy formulation from New Delhi, where local socio-ecological contexts may not be fully understood. Respondents further highlighted that many officers serving in the Andamans are posted from mainland India on short-term assignments. This transient staffing structure was reported to undermine continuity, accountability, and the long-term implementation of policies and regulations.

Accounts from both government and community respondents pointed to a general reluctance within the bureaucracy to act proactively. The initiation of management actions was often linked to the personal interest or motivation of individual officers, with institutional inertia described as a barrier to change. Some officials characterised the bureaucratic procedures as outdated and resistant to innovation. One government official expressed that *"the governance in Andamans is old-fashioned, like the British colonial times, and it does not adapt to the changing environment, people or economy. That is why Andamans is stuck in time and remains ignored"*.

Community members consistently reported low levels of participation in mangrove governance processes. Respondents described awareness campaigns by the Forest Department as infrequent and unidirectional, lacking meaningful opportunities for dialogue or collaboration. The top-down nature of governance, coupled with the islands' multicultural demographic, was seen as contributing to fragmented community engagement. The absence of inclusive governance mechanisms has complicated the relationship between local communities and state authorities, further limiting the potential for co-management or locally informed conservation strategies.

4. Discussion

This study highlights how mangrove governance in the Andaman Islands is shaped by long-standing institutional hierarchies, conflicting departmental mandates and shifting ecological baselines in the wake of the 2004 earthquake and tsunami, which impacts mangrove restoration policies and practice. The Forest Department's continued dominance reflects an entrenched top-down model and reinforces perceptions of mangroves as state "property." This stems from long-standing bureaucratic practices, such as restrictions on access to forest and fishery resources, the requirement of permissions for use, or the absence of community involvement in decision-making. In this way, the perception of ownership is shaped both by what people are told and how state control is exercised in everyday governance. Previous scholars suggest that the Indian Forest Department inherited a feudal attitude towards land management from the British and Indian landlords, often at the expense of indigenous people and local communities (*e.g.* Guha, 1983; Bandopadhyay, 2010; Springate-Baginski et al., 2013; Simlai, 2022). While this centralised control in natural resource management provides legal protection on paper, it diminishes local decision-making, renders information less accessible, and weakens trust in conservation efforts (Bluwstein et al., 2016).

Accounts from respondents reveal a widespread lack of clarity around what activities are permitted in mangrove areas, particularly in Reserve Forests. Many fishers described their confusion regarding sudden restrictions or unclear fines. This disjuncture between policy and practice mirrors similar gaps documented in coastal governance globally (Blaber, 2013; Saavedra-Díaz et al., 2015; Cormier-Salem, 2017). A particularly neglected dimension is the governance of mangrove-associated livelihoods, particularly mangrove crabbing. This is evidenced in many sites worldwide where mangrove fisheries are poorly regulated, leading to declines in resource catch and size because of high fishing pressure (Carrasquilla-Henao et al., 2019; Reis-Filho et al., 2019).

Stakeholder perceptions suggest that the relevant administrative departments operate independently, with conflicting mandates related to mangrove governance. Particularly, collaboration among the Forest and Fisheries Departments is perceived to be minimal, leading to instances of departments blaming each other and with little willingness to work together. The transitional and intertidal nature of mangrove ecosystems between land and sea makes it difficult to define clear administrative boundaries and resource use, also shown in previous studies (Golebie et al., 2021; Mafaziya Nijamdeen et al., 2023a). This may often lead to conflict between different governmental departments with overlapping areas of jurisdiction (Carter et al., 2015; Rog and Cook, 2017; Mafaziya Nijamdeen et al., 2024). Moreover, Rotich et al. (2016) highlight that mangrove management approaches are rarely tailored to unique conditions of mangrove ecologies and position in the land-sea interface. Instead, practices established for terrestrial forests are applied to mangrove governance.

While the Forest Department focuses on protection, the Fisheries Department promotes aquaculture and economic development. These tensions reflect the broader failure to establish integrated, ecosystem-based governance. Such disjointedness is not unique to the Andamans, it aligns with patterns observed in other mangrove systems (Carter et al., 2015; Rotich et al., 2016) but is intensified here by the archipelago's Union Territory status and associated bureaucratic structures. Many senior officials rotate in and out of the islands after short tenures, resulting in weak institutional memory and inconsistent policy application. A Fisheries Department official expressed concern that: *"these islands are overburdened with environmental regulations and protection. In the name of the environment, Andamans development is slow. They need to change the environmental laws and de-reserve demarcated mangrove areas for aquaculture so that Andamans can become a role model for other places in India - because it is an island we should be able to easily implement pilot aquaculture projects here"*.

While many of the governance challenges outlined above are common across mangrove regions, the situation in the Andaman Islands is uniquely shaped by the dramatic land elevation changes triggered by the 2004 earthquake and tsunami. These changes blurred administrative boundaries and compounded existing institutional limitations. The 2004 seismic event marked a pivotal shift in both the ecological and institutional landscapes of the islands. Communities across the archipelago came to view mangroves as life-saving buffers against future disasters, echoing post-tsunami sentiments in mainland India (Badola and Hussain, 2005; Khan and Ali, 2017). This widespread perception helped elevate mangroves in policy discourse. However, the scientific evidence on their protective role remains mixed and highly context-dependent, with effectiveness influenced by factors such as forest width, topography, and geomorphology (Dahdouh-Guebas and Koedam, 2006; Cochard et al., 2008; Feagin et al., 2010; Temmerman et al., 2023). Despite these nuances, the popular "bioshield" narrative gained traction post-tsunami, driving a sharp increase in mangrove planting in various tsunami affected areas (Kamthonkiat et al., 2011; Brown et al., 2015).

This post-tsunami restoration boom in the Andamans led to rapid plantation campaigns prioritising coverage over ecological suitability, with poorly selected sites, low survival rates, and minimal community involvement. In general, Kodikara et al. (2017), from their study in Sri Lanka, advocate adhering to the precautionary principle, whereby existing mangrove habitats should be protected, and restoration initiatives should prioritise degraded areas, provided that the environmental conditions support mangrove growth. Additionally, before initiating mangrove planting in areas affected by significant topographical changes (i.e. subsidence and uplift), a comprehensive scientific assessment is essential to determine the feasibility of mangrove growth at these sites. For example, Feagin et al. (2010) showed that in Sri Lanka, more than 90 % of the coastline is susceptible to ocean surges such as tsunamis, while mangroves can only thrive along less than one-third of this coastline. Brown et al. (2015) further emphasises that in cases where drastic topographical changes take place, mangrove restoration should be exercised only after a period of long observation, stabilisation of environment and responding to essential humanitarian issues (water, food and shelter). Restoration without monitoring and feedback mechanisms between research and practice could lead to maladaptation and wastage of financial resources (Brown et al., 2015; Ellison et al., 2020).

Similar to practices observed on the east coast of India, where the Forest Department used Casuarina plantations to claim communal lands (Mukherjee et al., 2010; Feagin et al., 2010), mangrove restoration in the Andamans became a means to assert territorial authority. The perception of mangroves as state-owned resources was further entrenched, sidelining both scientific expertise and local knowledge. Government officials often cited the islands' multicultural settler population as a challenge to participatory engagement, yet studies suggest that marginalised communities, particularly among settlers, have historically been excluded from decision-making (Zehmisch, 2012; Advani, 2020; Deol, 2021). This institutional context allowed restoration projects to proceed largely without local participation or scrutiny.

The earthquake-induced geomorphic changes i.e. uplift in the north and subsidence in the south, further exposed institutional inertia and governance path dependencies. In uplifted regions, the sudden loss of mangroves and tidal access led to ecosystem collapse and severe fishery decline. Yet, governance responses continued to rely on pre-tsunami forest classifications and rigid management mandates, resulting in repeated restoration failures. In the south, newly formed wetlands from subsidence led to overlapping jurisdictional claims between the Forest and Revenue Departments. These transformed landscapes fall outside existing administrative and legal categories, leading to contradictory policies or governance inaction. The absence of legal reclassification and updated land-use policies has created a governance deadlock.

Although stakeholders across sectors acknowledge the emerging challenges, few concrete steps have been taken to address policy and jurisdictional gaps. This prevailing "wait-and-see" approach is especially concerning given the collective recognition that inaction could heighten vulnerability in the face of future disasters. The broader literature on global environmental change warns that such institutional inertia, or resistance to change, can exacerbate social and ecological vulnerabilities and result in maladaptive outcomes (Meadowcroft, 2009; Taylor, 2016; Schipper, 2020).

Despite these institutional shortcomings, the study found strong community support for mangrove conservation, especially when framed around coastal protection and food security. Yet, this support remains untapped due to poor outreach, limited trust, and unidirectional communication. Engagement is often symbolic rather than substantive, creating further distance between state actors and local communities. Involving communities as ecological stewards, through training, paid employment, and recognition of traditional knowledge, can improve both ecological success and governance legitimacy.

Ultimately, the Andaman Islands offer a compelling case of how environmental change, institutional legacies, and administrative inertia intersect to shape governance outcomes. Addressing these challenges requires not only ecological restoration but also structural reforms, including revising land classifications, clarifying departmental responsibilities, and developing integrated governance frameworks. For instance, Mafaziya Nijamdeen et al. (2024), in their study of mangrove governance in Sri Lanka, propose the creation of a dedicated entity to manage all mangrove-related policies under a single umbrella. Such an approach could help better address the unique complexities of intertidal mangrove ecosystems (Rotich et al., 2016). However, any such efforts must begin with recognising local and scientific knowledge, ownership, and the lived realities of those directly affected by policy decisions.

5. Study limitations and future research avenues

This study is constrained by its exclusion of villages in Middle Andaman that did not undergo earthquake-induced subsidence or uplift. The scope of this study lies in examining the perceptions and governance dynamics shaped by these extreme geological phenomena. However, the findings may not fully capture the breadth of perspectives and governance responses across all villages in the Andamans that were unaffected by the extreme seismic event. Future research could explore these non-affected villages to provide a more comprehensive understanding of the broader socio-environmental dynamics in the islands. Furthermore, this study does not explore the perceptions of indigenous people, as separate permits and procedures are required for such inquiries. We focus on the perceptions of migrant settlers who often originate from a non-mangrove heritage due to the island's unique history. Considering the Andamans hosts a multicultural population with different migration histories, people may have multiple ways of using and perceiving mangroves. Future studies could explore how the multicultural knowledge and migration histories of the various communities on the islands are related to mangrove use and knowledge. Additionally, obtaining a quantitative understanding of mangrove ecosystem services and their potential correlation with mangrove vegetation change in subsided and uplifted areas could yield valuable insights for decision-making processes. In line with our approach, studies need to focus beyond urbanised or well-connected hubs and include interior villages, where inhabitants are overlooked both in research and practice. Lastly, fostering data sharing between researchers and decision-makers is vital, especially given the bureaucratic barriers that impede research activities on the islands. Overcoming these challenges could facilitate a more collaborative and informed approach to managing mangrove SESs in the Andaman Islands.

6. Conclusion

By combining semi-structured interviews to capture stakeholder perceptions and secondary data analysis to understand regulatory and policy mechanisms, we provide insights on mangrove governance and

its implications, and additionally identify research and policy gaps in the Andamans. Our findings reveal that while mangrove trees receive formal protection in regulations implemented by the Forest Department, the fisheries sector remains under-regulated considering the demand and pressure on mangrove fishery resources. We found that the uncertainty surrounding mangrove fishing in forest areas, coupled with a lack of comprehensive fisheries documentation, contributes to its regulatory oversight. Addressing this issue requires collaborative efforts between administrative bodies (Forest and Fisheries departments) to manage overlapping jurisdictions.

Mangrove governance in the Andamans is characterised by a top-down approach, with the Forest Department being the dominant actor. This centralised authority and power exhibits minimal cross-sectoral collaboration, communication and the absence of community participation. Additionally, our findings highlight that the 2004 seismic event reinforced the authority of the department by focusing attention on mangroves and promoting restoration efforts, explicitly without the consultation of community members. Furthermore, mangrove governance is hindered by bureaucratic inertia driven by distant decision-making centres originating in mainland India and the perceived 'complexity' and 'sensitivity' in addressing resource use and land ownership issues in the subsided and uplifted areas.

To address the mangrove governance challenges, there is a need to incorporate scientific expertise, update and enforce relevant laws, particularly in the fisheries sector, and ensure active involvement of local communities throughout the decision-making process. These findings have broader implications, extending beyond the Andamans to other regions facing similar challenges in mangrove governance with the increase in environmental changes and the inherent complexities of managing transitional ecosystems.

CRediT authorship contribution statement

Meenakshi Poti: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Anoop Raj Singh:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation. **Kartik Shanker:** Writing – review & editing, Supervision, Resources, Project administration. **Nico Koedam:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Nehru Prabakaran:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Farid Dahdouh-Guebas:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Jean Hugé:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2025.107786.

Data availability

The authors do not have permission to share data.

References

Advani, S., 2020. How Commoditization and Cross-Cultural Values Influence the Sustainability of Small-Scale Fisheries in the Andaman and Nicobar Islands. Dissertation, University of British Columbia, India.
ANI Fisheries Policy, 2018. Andaman and Nicobar Islands Fisheries Policy. Department of Fisheries, Andaman and Nicobar Administration, Port Blair, India.
Aufschnaiter, C., 2020. Contested landscapes: mainland and island imaginaries of the Andaman islands. Arch. Orientální 88 (3), 213–240. https://doi.org/10.47979/aror.s.2020.XII.213.
Badola, R., Hussain, S.A., 2005. Valuing the storm protection function of Bhitarkanika mangrove ecosystem, India. Environ. Conserv. 32 (1), 1–8. https://doi.org/10.1017/S0376892905001967.
Bandopadhyay, A., 2010. The colonial legacy of forest policies in India. Soc. Sci. 38, 53–76. https://doi.org/10.2307/25621956.
Bennett, N.J., Roth, R., Klain, S.C., Chan, K., Christie, P., et al., 2017. Conservation social science: understanding and integrating human dimensions to improve conservation. Biol. Conserv. 205, 93–108. https://doi.org/10.1016/j.biocon.2016.10.006.
Bennett, N.J., Satterfield, T., 2018. Environmental governance: a practical framework to guide design, evaluation, and analysis. Conserv. Lett. 11 (6), e12600. https://doi.org/10.1111/conl.12600.
Blaber, S.J.M., 2013. Fishes and fisheries in tropical estuaries: the last 10 years. Estuar. Coast Shelf Sci. 135, 57–65. https://doi.org/10.1016/j.ecss.2012.11.002.
Bluwstein, J., Moyo, F., Kicheleri, R.P., 2016. Austere conservation: understanding conflicts over resource governance in Tanzanian wildlife management areas. Conserv. Soc. 14 (3), 218–231. https://doi.org/10.4103/0972-4923.191156.
Botanical Survey of India, 2020. A Checklist of Plants of Andaman and Nicobar Islands. Botanical Survey of India, Kolkata, India. http://www.bsienvis.nic.in/Database/Checklist-of-Andaman-Nicobar-Islands_24427.aspx. (Accessed 12 June 2024).
Brown, B., Yuniati, W., Ahmad, R., Soulsby, I., 2015. Observations of natural recruitment and human attempts at mangrove rehabilitation after seismic (tsunami and earthquake) events in Simeulue Island and Singkil Lagoon, Aceh, Indonesia. In: Santiago-Fandiño, V., Kontar, Y., Kaneda, Y. (Eds.), Post-tsunami Hazard. Advances in Natural and Technological Hazards Research. Springer, Cham, pp. 311–327. https://doi.org/10.1007/978-3-319-10202-3_19.
Bryman, A., 2016. Social Research Methods. Oxford University Press, Oxford.
Carrasquilla-Henao, M., Ban, N., Rueda, M., Juanes, F., 2019. The mangrove-fishery relationship: a local ecological knowledge perspective. Mar. Policy 108, 103656. https://doi.org/10.1016/j.marpol.2019.103656.
Carter, H.N., Schmidt, S.W., Hirons, A.C., 2015. An international assessment of mangrove management: incorporation in integrated coastal zone management. Diversity 7 (2), 74–104. https://doi.org/10.3390/d7020074.
Census of India, 2011. Office of the Registrar General and Census Commissioner, India. https://censusindia.gov.in/census.website/data/population-finder. (Accessed 20 December 2023).
Cochard, R., Ranamukhaarachchi, S.L., Shivakoti, G.P., Shipin, O.V., Edwards, P.J., et al., 2008. The 2004 tsunami in Aceh and Southern Thailand: a review on coastal ecosystems, wave hazards and vulnerability. Perspect. Plant Ecol. Evol. Syst. 10 (1), 3–40. https://doi.org/10.1016/j.ppees.2007.11.001.
Committee on, 2017. Land Matters in ANI Report. Ministry of Home Affairs, Government of India, New Delhi, India.
Cormier-Salem, M., 2017. Mangrove grabbing: an exploration of changes in mangrove tenure from a political ecology perspective. In: Artaud, H., Surrallés, A. (Eds.), The Sea within: Maritime Tenure and Cosmopolitical Debates. International Work Group for Indigenous Affairs, Copenhagen, pp. 143–162.
Creswell, J.W., Poth, C.N., 2017. Qualitative Inquiry and Research Design: Choosing Among Five Approaches. Sage Publications, Thousand Oaks, pp. 1–423.
Dahdouh-Guebas, F., Hugé, J., Abuchahla, G.M., Cannicci, S., Jayatissa, L.P., et al., 2021. Reconciling nature, people and policy in the mangrove social-ecological system through the adaptive cycle heuristic. Estuar. Coast Shelf Sci., 106942. https://doi.org/10.1016/j.ecss.2020.106942.
Dahdouh-Guebas, F., Koedam, N., 2006. Coastal vegetation and the Asian tsunami. Sci. Technol. Humanit. 311 (5757), 37–38. https://doi.org/10.1126/science.311.5757.37.
Deol, R., 2021. Building an Islandscape: Discourse, Livelihoods, and Development in the Andaman Islands. Dissertation, Ludwig-Maximilians-Universität, India.
Department of Environment and Forests, 2016. Working Plan for the Period from 2016–17 to 2025–26. South Andaman Forest Division, Andaman and Nicobar Island Administration.

Department of Environment and Forests, 2019. Forest Statistics. Department of Environment and Forests, Andaman and Nicobar Island Administration.
Dharanirajan, K., Kasinatha Pandian, P., Gurugnanam, B., Narayanan, R.M., Ramachandran, S., 2007. An integrated study for the assessment of tsunami impacts: a case study of South Andaman Island, India using remote sensing and GIS. Coast. Eng. 49 (3), 229–266. https://doi.org/10.1142/S0578563407001617.
Directorate of Economics and Statistics, 2010. District Statistical Handbook (2010–2011) – Andaman and Nicobar Island (Technical Report). Government of India, New Delhi.
Directorate of Economics and Statistics, 2023. Basic Statistics (2022–2023). Directorate of economics and Statistics. Andaman and Nicobar Island Administration.
Ellison, A.M., Felson, A.J., Friess, D.A., 2020. Mangrove rehabilitation and restoration as experimental adaptive management. Front. Mar. Sci. 7, 327. https://doi.org/10.3389/fmars.2020.00327.
Feagin, R.A., Mukherjee, N., Shanker, K., Baird, A.H., Cinner, J., et al., 2010. Shelter from the storm? Use and misuse of coastal vegetation bioshields for managing natural disasters. Conserv. Lett. 3 (1), 1–11. https://doi.org/10.1111/j.1755-263X.2009.00087.x.
Forest Survey of India, 2023. India State of Forest Report 2023: Volume 1, Ministry of Environment Forest and Climate Change, Dehradun, India. https://fsi.nic.in/forest-report-2023. Accessed December 2023.
Friess, D.A., Adams, J., Andradi-Brown, D.A., Bhargava, R., Carrasco, G., et al., 2024. Mangrove forests: their status, threats, conservation and restoration. In: Baird, D., Elliott, M. (Eds.), Treatise on Estuarine and Coastal Science, second ed. Elsevier, pp. 529–625.
Golebie, E.J., Aczel, M., Bukoski, J.J., Chau, S., Ramirez-Bullon, N., et al., 2021. A qualitative systematic review of governance principles for mangrove conservation. Conserv. Biol. 36 (1), e13850. https://doi.org/10.1111/cobi.13850.
Guha, R., 1983. Forestry in British and Post-British India: a historical analysis. Econ. Polit. Wkly. 18, 1882–1896. https://www.jstor.org/stable/4372653.
IndiaMART, 2024. Mangrove charcoal prices. IndiaMART Limited. https://www.indiamart.com/proddetail/natural-mangrove-charcoal-13510609433.html. (Accessed 8 June 2024).
Kamthonkiat, D., Rodfai, C., Saiwanrungkul, A., Koshimura, S., Matsuoka, M., 2011. Geoinformatics in mangrove monitoring: damage and recovery after the 2004 Indian ocean tsunami in phang nga, Thailand. Nat. Hazards Earth Syst. Sci. 11, 1851–1862. https://doi.org/10.5194/nhess-11-1851-2011.
Khan, A.S., Ali, M.S., 2017. Mangroves living at the edges: a social survey based on environmental issue. J. Hum. Ecol. 25 (2), 75–77. https://doi.org/10.1080/09709274.2009.11906138.
Kodikara, K.A.S., Mukherjee, N., Jayatissa, L.P., Dahdouh-Guebas, F., Koedam, N., 2017. Have mangrove restoration projects worked? An in-depth study in Sri Lanka. Restor. Ecol. 25 (5), 705–716. https://doi.org/10.1111/rec.12492.
Mafaziya Nijamdeen, T.W.G.F., Ratsimbazafy, H.A., Kodikara, K.A.S., Nijamdeen, T.W.G.F.A., Thahira, T., et al., 2023a. Mangrove management in Sri Lanka and stakeholder collaboration: a social network perspective. J. Environ. Manag. 330, 117116. https://doi.org/10.1016/j.jenvman.2022.117116.
Mafaziya Nijamdeen, T.W.G.F., Ephrem, N., Hugé, J., Kodikara, K.A.S., Dahdouh-Guebas, F., 2023b. Understanding the ethnobiological importance of mangroves to coastal communities: a case study from Southern and North-western Sri Lanka. Mar. Policy 147, 105391. https://doi.org/10.1016/j.marpol.2022.105391.
Mafaziya Nijamdeen, T.W.G.F., Peruzzo, S., Kodikara, K.A.S., Ratsimbazafy, H.A., Nijamdeen, T.W.G.F.A., et al., 2024. Stakeholder perceptions in mangrove management in the Jaffna Peninsula, Sri Lanka. For. Policy Econ 164, 103236. https://doi.org/10.1016/j.forpol.2024.103236.
Majumdar, D., Chakraborty, S., Saha, S., Datta, D., 2019. Geospatial analysis of the effects of tsunami on coral and mangrove ecosystems of Mayabunder in Andaman Islands, India. Braz. J. Oceanogr. 67, e19258. https://doi.org/10.1590/S1679-87592019025806715.
Malik, J.N., Murty, C.V.R., Rai, D.C., 2006. Landscape changes in the andaman and nicobar islands (India) after the december 2004 great Sumatra earthquake and Indian ocean tsunami. Earthq. Spectra 22, 43–66. https://doi.org/10.1193/1.2206792.
Meadowcroft, J., 2009. Climate change governance. World Bank Policy Research Working Paper 4941. The World Bank, Washington.
Mittermeier, R.A., Turner, W.R., Larsen, F.W., Brooks, T.M., Gascon, C., 2011. Global biodiversity conservation: the critical role of hotspots. In: Zachos, F., Habel, J. (Eds.), Biodiversity Hotspots. Springer, Berlin, pp. 3–22. https://doi.org/10.1007/978-3-642-20992-5_1.
Mukherjee, N., Dahdouh-Guebas, F., Kapoor, V., Arthur, R., Koedam, N., et al., 2010. From bathymetry to bioshields: a review of post-tsunami ecological research in India and its implications for policy. Environ. Manag. 46, 329–339. https://doi.org/10.1007/s00267-010-9523-1.
Nath, A., Joshi, C., Prabakaran, N., Ghosh, S., Talukdar, G., 2022. Change mapping of aboveground carbon stocks and ecosystem services in the mangrove forest of Andaman Islands: implications for conservation and ecosystem-based adaptation. In: Dasgupta, R., Hashimoto, S., Saito, O. (Eds.), Assessing, Mapping and Modelling of Mangrove Ecosystem Services in the Asia-Pacific Region. Science for Sustainable Societies. Springer, Singapore, pp. 143–166. https://doi.org/10.1007/978-981-19-2738-6_8.
Nehru, P., Balasubramanian, P., 2018. Mangrove species diversity and composition in the successional habitats of Nicobar Islands, India: a post-tsunami and subsidence scenario. For. Ecol. Manag. 427, 70–77. https://doi.org/10.1016/j.foreco.2018.05.063.
Nfotabong-Atheull, A., Din, N., Essomè Koum, L.G., Satyanarayana, B., Koedam, N., et al., 2011. Assessing forest products usage and local residents' perception of environmental changes in peri-urban and rural mangroves of Cameroon, Central Africa. J. Ethnobiol. Ethnomed. 7, 1–13. https://doi.org/10.1186/1746-4269-7-41.
Oommen, M.A., Ramesh, M., 2019. Tides of change in the andaman and nicobar islands. Ecol. Econ. Soc. INSEE J. 2, 145–149.
Porwal, M.C., Padalia, H., Roy, P.S., 2012. Impacts of tsunami on the forest and biodiversity richness in nicobar islands (andaman and nicobar islands), India. Biodivers. Conserv. 21, 1267. https://doi.org/10.1007/s10531-011-0214-x, 128.
Poti, M., Hugé, J., Shanker, K., Koedam, N., Dahdouh-Guebas, F., 2022. Learning from small islands in the Western Indian Ocean (WIO): a systematic review of responses to environmental change. Ocean Coast Manag. 227, 106268. https://doi.org/10.1016/j.ocecoaman.2022.106268.
Prabakaran, N., Bayyana, S., Vetter, K., Reuter, H., 2021. Mangrove recovery in the Nicobar archipelago after the 2004 tsunami and coastal subsidence. Reg. Environ. Change 21, 87. https://doi.org/10.1007/s10113-021-01811-0.
Ragavan, P., Mohan, P.M., Saxena, A., Jayaraj, R.S.C., Ravichandran, K., et al., 2018. Mangrove floristics of the andaman and nicobar islands: critical review and current scenario. Mar. Biodivers. 48, 1291–1311. https://doi.org/10.1007/s12526-016-0581-3.
Rajendran, C.P., Rajendran, K., Anu, R., Earnest, A., Machado, T., et al., 2007. Crustal deformation and seismic history associated with the 2004 Indian Ocean earthquake: a perspective from the Andaman–Nicobar Islands. Bull. Seismol. Soc. Am. 97, S174–S191. https://doi.org/10.1785/0120050630.
Ramachandran, S., Anitha, S., Balamurugan, V., Dharanirajan, K., Vendhan, K.E., et al., 2005. Ecological impact of tsunami on nicobar islands (camorta, katchal, nancowry and trinkat). Curr. Sci. 89, 195–200.
Ramakrishna C., Raghunathan, Sivaperuman, C., 2010. Biodiversity of Andaman and Nicobar Islands: an overview. In: Ramakrishna, Raghunathan, C., Sivaperuman, C. (Eds.), Recent Trends in Biodiversity of Andaman and Nicobar Islands. Zoological Survey of India, Kolkata, pp. 1–42.
Ramakrishnan, R., Gladston, Y., Kumar, N.L., Rajput, P., Murali, R.M., et al., 2020. Impact of 2004 co-seismic coastal uplift on the mangrove cover along the North Andaman Islands. Reg. Environ. Change 20, 1–12. https://doi.org/10.1007/s10113-020-01608-7.
Ray, S.K., Acharyya, A., 2011. Coseismic uplift, slow plant mortality and ecological impact in North Andaman following the December 2004 (Mw > 9.2) earthquake. Curr. Sci. 101 (2), 218–222.
Reis-Filho, J.A., Harvey, E.S., Giarrizzo, T., 2019. Impacts of small-scale fisheries on mangrove fish assemblages. ICES J. Mar. Sci. 76 (1), 153–164. https://doi.org/10.1093/icesjms/fsy110.
Rog, S.M., Cook, C.N., 2017. Strengthening governance for intertidal ecosystems requires a consistent definition of boundaries between land and sea. J. Environ. Manag. 197, 694–705. https://doi.org/10.1016/j.jenvman.2017.04.052.
Rotich, B., Mwangi, E., Lawry, S., 2016. Where Land Meets the Sea: A Global Review of the Governance and Tenure Dimensions of Coastal Mangrove Forests. CIFOR: Bogor; USAID Tenure and Global Climate Change Program, Washington. https://hdl.handle.net/10568/93954.
Roy, S.D., Krishnan, P., 2005. Mangrove stands of Andamans vis-à-vis tsunami. Curr. Sci. 89, 1800–1804.
Saavedra-Díaz, L.M., Rosenberg, A.A., Martín-López, B., 2015. Social perceptions of Colombian small-scale marine fisheries conflicts: insights for management. Mar. Policy 56, 61–70. https://doi.org/10.1016/j.marpol.2014.11.026.
Sankaran, R., Andrews, H., Vaughan, A., 2005. The ground beneath the waves: post-tsunami impact assessment of wildlife and their habitats in India. In: Wildlife Trust of India, pp. 10–103. New Delhi.
Santos, L.C.M., Gasalla, M.A., Dahdouh-Guebas, F., Bitencourt, M.D., 2017. Socioecological assessment for environmental planning in coastal fishery areas: a case study in Brazilian mangroves. Ocean Coast Manag. 138, 60–69. https://doi.org/10.1016/j.ocecoaman.2017.01.009.
Schipper, E.L.F., 2020. Maladaptation: when adaptation to climate change goes very wrong. One Earth 3 (4), 409–414. https://doi.org/10.1016/j.oneear.2020.09.014.
Schoon, M., Cox, M., 2018. Collaboration, adaptation, and scaling: perspectives on environmental governance for sustainability. Sustainability (Basel) 10 (3), 679. https://doi.org/10.3390/su10030679.
ShivaShankar, V., Narshimulu, G., Kaviarasan, T., Narayani, S., Dharanirajan, K., et al., 2020. 2004 Post tsunami resilience and recolonization of mangroves in South Andaman, India. Wetlands (Wilmington, N. C.) 40, 619–635. https://doi.org/10.1007/s13157-019-01211-5.
Simlai, T., 2022. Negotiating the Panoptic Gaze: People, Power and Conservation Surveillance in the Corbett Tiger Reserve. University of Cambridge, Dissertation.
Singh, A.R., Thirumurugan, V., Prabakaran, N., 2024a. Distribution of *Avicennia* spp. in the Andaman and Nicobar Islands with special reference to new distributional reports and post-tsunami colonization patterns. J. Mar. Biol. Assoc. U. K. 104, e43. https://doi.org/10.1017/S0025315424000262.
Singh, A.R., Thirumurugan, V., Bhomia, R.K., Prabakaran, N., 2024b. Mangrove vegetation response to alteration in coastal geomorphology after an earthquake in Andaman Islands, India. Reg. Stud. Mar. Sci., 103583. https://doi.org/10.1016/j.rsma.2024.103583.
Singh, A.R., Thirumurugan, V., Joshi, N., Ramesh, C., Prabakaran, N., 2025. Coastal vegetation response to land uplift inflicted sea level drop in the North Andaman Islands, India. Reg. Stud. Mar. Sci. 85, 104134. https://doi.org/10.1016/j.rsma.2025.104134.
Springate-Baginski, O., Sarin, M., Reddy, M.G., 2013. Resisting rights: forest bureaucracy and the tenure transition in India. Small-scale For 12, 107–124. https://doi.org/10.1007/s11842-012-9219-x.

Taylor, A., 2016. Institutional inertia in a changing climate: climate adaptation planning in Cape Town, South Africa. Int. J. Clim. Change Strategies 8 (2), 194–211. https://doi.org/10.1108/IJCCSM-03-2014-0033.

Temmerman, S., Horstman, E.M., Krauss, K.W., Mullarney, J.C., Pelckmans, I., et al., 2023. Marshes and mangroves as nature-based coastal storm buffers. Annu. Rev. Mar. Sci. 15, 95–118. https://doi.org/10.1146/annurev-marine-040422-092951.

Thirumurugan, V., Singh, A.R., Karattuthodi, S., Gnanasekaran, G., Prabakaran, N., 2024. Impacts of invasive spotted deer (*Axis axis*) herbivory on mangrove vegetation in South Andaman Island, India. J. Wildl. Sci. 1 (1), 3–15. https://doi.org/10.63033/JWLS.BKZC9401.

Tracy, S.J., 2019. Qualitative Research Methods: Collecting Evidence, Crafting Analysis, Communicating Impact. Wiley Blackwell, London, p. 368.

Treviño, M., 2022. The mangrove is like a friend: local perspectives of mangrove cultural ecosystem services among mangrove users in northern Ecuador. Hum. Ecol. 50, 863–878. https://doi.org/10.1007/s10745-022-00358-w.

Vaidik, A., 2010. Imperial Andamans: Colonial Encounter and Island History. Palgrave Macmillan, London.

Velmurugan, A., Swarnam, T.P., Lal, R., 2015. Effect of land shaping on soil properties and crop yield in tsunami inundated coastal soils of Southern Andaman Island. Agric. Ecosyst. Environ. 206, 1–9. https://doi.org/10.1016/j.agee.2015.03.012.

VERBI Software, 2021. MAXQDA 2022 Computer Software. Berlin, Germany. www.maxqda.com.

Wiles, R., 2013. What are qualitative researchers like me to consider as ethical issues in qualitative research? Int. J. Soc. Res. Methodol. 16 (5), 399–413. https://doi.org/10.1080/13645579.2013.802924.

Young, J.C., Rose, D.C., Mumby, H.S., Benitez-Capistros, F., Derrick, C.J., et al., 2018. A methodological guide to using and reporting on interviews in conservation science research. Methods Ecol. Evol. 9 (1), 10–19. https://doi.org/10.1111/2041-210X.12828.

Zehmisch, P., 2012. A Xerox of India? Policies and politics of migration in an overseas colony. In: Working Papers in Social and Cultural Anthropology, vol. 2. Ludwig-Maximilians-Universität, Munich, pp. 1–28.

zu Ermgassen, P.S.E., Mukherjee, N., Worthington, T.A., Acosta, A., da Rocha Araujo, A. R., et al., 2021. Fishers who rely on mangroves: modelling and mapping the global intensity of mangrove-associated fisheries. Estuar. Coast Shelf Sci. 248, 107159. https://doi.org/10.1016/j.ecss.2020.107159.