Chapter

Secondary Ecological Succession of Mangrove in the 2004 Tsunami Created Wetlands of South Andaman, India

V. Shiva Shankar, Neelam Purti, Ravi Pratap Singh and Faiyaz A. Khudsar

Abstract

Andaman and Nicobar Islands (ANI's) being situated in the Tropical zone is the cradle of multi-disasters viz., cyclones, floods, droughts, land degradation, runoff, soil erosion, shallow landslides, epidemics, earthquakes, volcanism, tsunami and storm surges. Mangroves are one of the first visible reciprocators above land and sea surface to cyclonic storms, storm surges, and tsunamis among the coastal wetlands. The Indian Ocean 2004 tsunami was denoted as one of the most catastrophic ever recorded in humankind's recent history. A mega-earthquake of Magnitude (9.3) near Indonesia ruptured the Andaman-Sunda plate triggered this tsunami. Physical fury, subsidence, upliftment, and prolonged water logging resulted in the massive loss of mangrove vegetation. A decade and half years after the 2004 tsunami, a study was initiated to assess the secondary ecological succession of mangrove in Tsunami Created Wetlands (TCWs) of south Andaman using Landsat satellite data products. Since natural ecological succession is a rather slow process and demands isotope techniques to establish a sequence of events succession. However, secondary ecological succession occurs in a short frame of time after any catastrophic event like a tsunami exemplifying nature's resilience. Band-5 (before tsunami, 2003) and Band-6 (after tsunami, 2018) of Landsat 7 and Landsat-8 satellite respectively were harnessed to delineate mangrove patches and TCWs in the focus area using ArcMap 10.5, Geographic Information Systems (GIS) software. From the study, it was understood that *Fimbrisstylis littoralis* is the pioneering key-stone plant followed by *Acrostichum aureum* and *Acanthus ilicifolius* facilitating *Avicennia spp/Rhizophora spp* for ecological succession in the TCWs.

Keywords: natural disasters, Landsat (7 & 8), satellite image, Short Wave Infra-Red, GIS (Geographic Information Systems), fluvial influx, mangrove biodiversity

1. Introduction

A befitting example of the interaction of Sea, land, and air is the 'coastal frontier'. This Coastal frontier comprises of fragile, sensitive, dynamic, and diverse ecosystems like forests, estuaries, coral reefs, tidal mudflats, salt marshes, seagrass, and mangroves [1, 2]. Mangroves are circum-tropical halophytes representing an ecotone between terrestrial and marine habitats which are adapted to wet and saline conditions having a vital ecological and economic relevance at global, regional, and local scales [3]. These mangrove forests comprise of 65 true mangrove species and 6 hybrids [4], housed in one hundred and twenty-three countries between 32°N and 38°S covering an area of 1.5 million sq. Km [5]. The highest concentration (60%) of global mangrove species (44) are reported from southeast Asia [5, 6]. The mangroves of Andaman and Nicobar Islands (ANI's) represent the third-largest cover on the Indian subcontinent next to Gujarat and Sunderbans respectively [5]. ANI's comprise 38 true mangrove species belonging to 19 genera, and 13 families. Thus, ANI's houses 50% of the global mangrove species [7, 8].

Globally mangrove forests are known as among one of the most productive and biologically important ecosystems because they deliver a variety of vital and distinctive ecosystem goods and services to humankind and other coastal marine ecosystems like the mudflats, coral reefs, seagrass, etc [9]. Since time immemorial mangrove is been conventionally used for firewood, charcoal, alcohol, folk-lore therapeutics, roof thatching [10, 11]. They act as nursery and breeding ground for the juveniles of many commercial fish, crustaceans, including avifauna and reptiles [12–15]. Also, they reduce coastal erosion, stabilize the shoreline, provide sediment and nutrient retention, improve water quality, and provide both flood and flow control as well as protection against storms, hurricanes, and tsunamis [16–21]. Carbon sequestration is presently recognized as the most important service of the mangrove owing to the growing appreciation of the efficacy of these habitats in climate regulation through fixing carbon from the atmosphere [22–24].

The mangrove forests of the world are dwindling at a rate of 1–2% annually and if this trend continues the mangrove and its ecosystem shall be erased from the face of the earth by the 21st century [25–27]. The deterioration of mangrove is more alarming than any other ecosystem like the coral reef and marine forests. At this rate of destruction, the world would be deprived of mangrove and its ecosystem services by the end of this century [28]. The loss of mangrove forests can be attributed to anthropogenic and natural factors. Anthropogenic factors such as dumping of wet and solid wastes generated by the urban population, deforestation, conversion for aquaculture, agriculture, industrial discharge, petroleum spills, the combustion of fossil fuels, automobile exhaust are responsible for the loss of mangrove forests [25, 27, 29–33]. Although the mangrove forest act as a bio-shield against natural disasters such as climate change, cyclones, hurricanes, typhoons, storm surges, and tsunamis [3, 16–21]. On the contrary, these natural factors are also partly responsible for the loss of mangrove forests [34]. However, Mangroves demonstrates the ability to be resilient to natural eventualities [18, 35–40] by following the fluvial influx [39, 41].

The resilience of mangrove is naturally ensured by ecological succession. It is rather a slow process of development and adjustment of species compositions of the mangrove communities over time and space. Further, the ecological succession is dependent on the vital driving factors such as growth potential of the mangrove species, dispersal, settlement, competition, and external or biogenic changes in abiotic conditions [42]. The fluvial influx in the landmass subsided zones due to the 2004 tsunami created a conducive environment for mangrove colonization (ecological succession). Hence, the present study aims at understanding the secondary ecological succession of mangrove in Tsunami Created Wetlands (TCWs) of South Andaman so that it would help in initiating anthropogenically induced massive restoration and rehabilitation of it in the future [6, 28, 43–47].

DOI: http://dx.doi.org/10.5772/intechopen.94113

2. Study area

ANI's is a union territory of India in the Bay of Bengal between peninsular India and Myanmar, trending in a north-south direction. Bounded by the coordinates (92° to 94° East and 6° to 14° North), it is an archipelago with > 500 islands/islets, stretching over 700 km [39]. They are closer to the Indonesian landmass than to mainland India (1200 km), with the southernmost island only 150 km from Sumatra and the northernmost landfall, 190 km south of West Myanmar. ANI's being the cradle of multi-disasters like cyclones, storm surges, earthquakes, and tsunami, the mangroves of this region are vulnerable to disaster. However, nature has its own plans for resilience after any disaster. The present study illustrates the ecological succession of mangrove in south Andaman after the 2004 devastating tsunami. Subsidence and Upliftment of landmass were observed in ANI's due to the 2004 tsunami [48]. Subsidence of landmass around the coastal frontiers rendered it to be permanently waterlogged thus creating wetlands that are very conducive for the mangroves to colonize [37–39]. The area under focus is bounded by the coordinates 11°27′00″and 11°45′00"N and 92°30′00″and 92°46′47″E (**Figure 1**) covering a land area of 333.18 km^2 that encountered destruction from the 2004 tsunami and subsidence as well [48, 49].

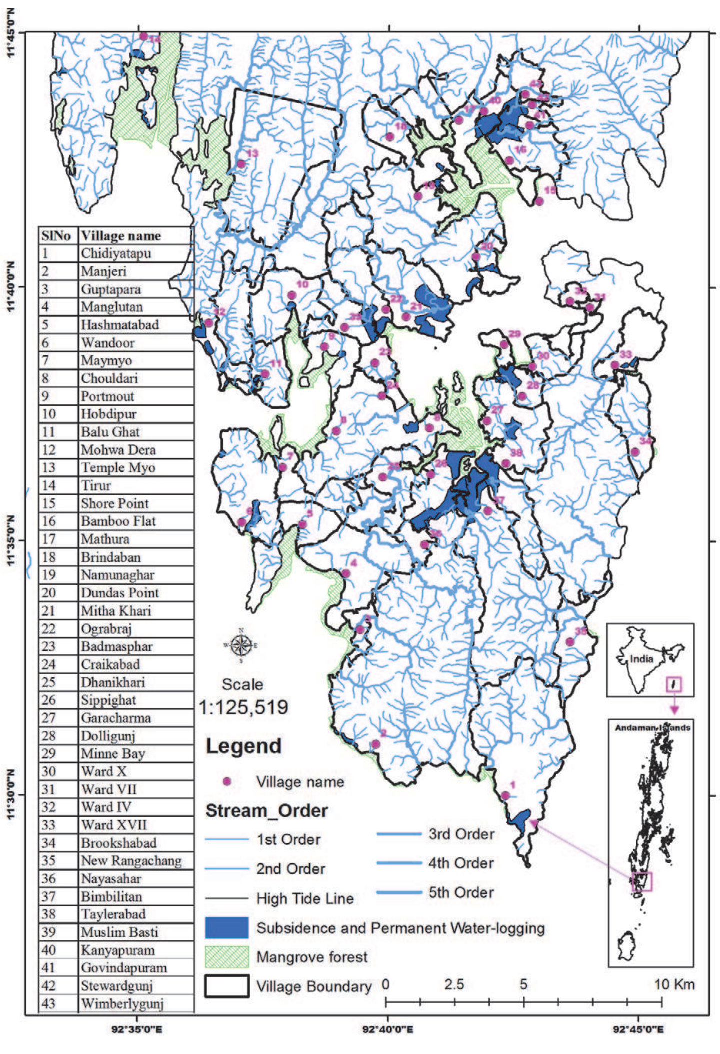

Figure 1.
Study area map showing TCWs with mangrove forest.

2.1 Geology, soils, geomorphology, and drainage

The origin of the Andaman-Nicobar islands is approximately dated as late Pliocene to Pleistocene [50]. The subsidence of landmass is defined by the rock type. Two types of rocks are encountered in the study area viz., (1) Sedimentary rock (Andaman flysch), and (2) Ophiolite suite of volcanic origin [51, 52]. Sedimentary rock comprises of greywacke, siltstone, chalk, limestone are soft and more susceptible to subsidence due to tectonic activity when compared to the Ophiolite suite (**Figure 2a**).

Geomorphogically the study area is dominated by the structural hill, valley trending N-S direction followed by pediments and coastal plains (**Figure 2b**). The coastal plains are dominated by alluvium and colluvium.

The soils of the study area have developed under the dominant influence of vegetation and climate and over diverse parent material. The soil is either present on the hill tops or deposited in the valleys or along the coast as escorted soil. Along the coast, the soil is sandy and contains shingles and old corals, etc. It is extremely porous. In the valley and in the lower slopes of hills, the soil is clayey loam. On the hills, it is rigid clay and dark red loam. There are three orders of soil Entisols, Inceptisols, and Alfisols [53] in six soil texture class viz., Clay, Clay loam, Loamy sand, Sandy, Sandy Clay, Sandy Clay loam. Clay loam is the dominant textural class of soil well distributed throughout the study area followed by clay. Sandy texture was seen along the coastal fringes (**Figure 2c**).

The drainage in the area under investigation exhibits dendritic and trellis patterns a typical structurally controlled drainage pattern of volcanic origin. In general, almost all the drainages are very young and terminate their first or second-order

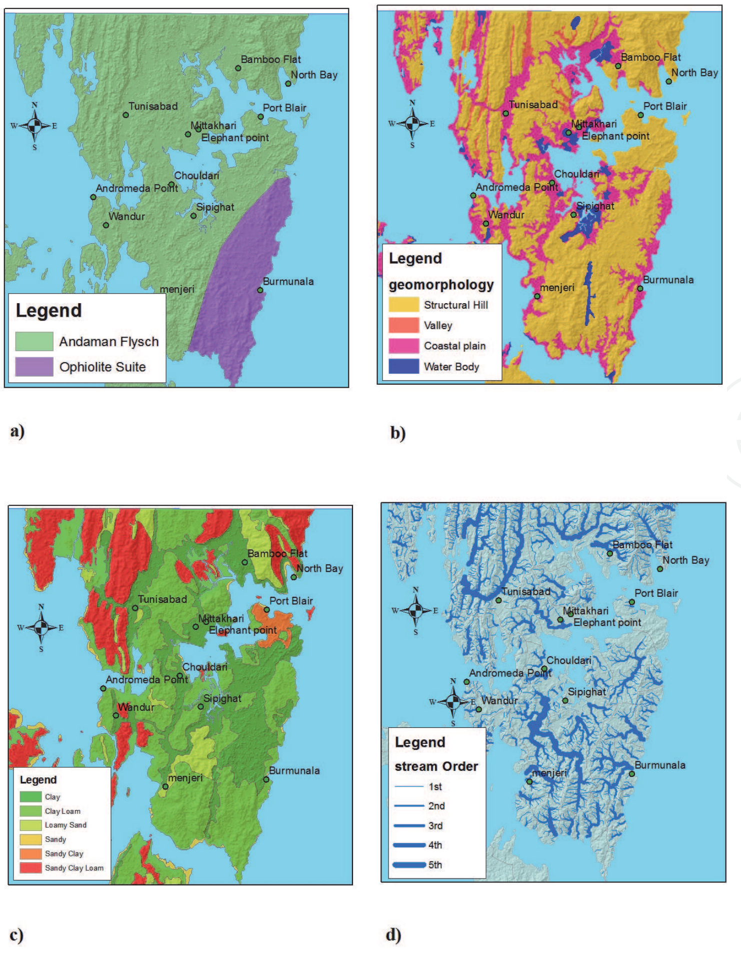

Figure 2.
Maps of (a) Geology, (b) Geomorphology, (c) Soil texture, and (d) Drainage.

stream within a short distance. There are no landlocked watersheds hence all the streams empties into the adjacent sea (**Figure 2d**).

2.2 Meteorology

The study area is situated south of Tropic of Cancer and the region is surrounded by warm seas. The climate of this region is categorized as Warm and Humid. The recorded average temperature ranges from 25°C to 30.5°C. The prevalent temperature along with relatively high humidity gives rise to perceptible and sultry weather. However, this type of weather is moderated with pleasant sea breezes. The relative humidity is high throughout the year reaching > 90 % during the northeast monsoons. The maximum temperature recorded at Port Blair is 32°C. The average annual rainfall is around 3000 to 3500 mm. May to August is the rainiest months and April is the warmest month in this region. It is observed that the South-West monsoon brings in most of the rainfall. During May-June, the onset of the monsoon occurs and in September-October withdrawal of monsoon is observed. The North-East monsoons beginning in November and persists till the end of February. This transitional period is nonetheless disturbed by cyclonic storms which may be accompanied by thundershowers. Most of the storms experienced by the mainland and the area under investigation originate in the Bay of Bengal [54].

3. Conducive environment for mangrove ecosystem

The prevalent geology, soil, geomorphology, drainage system, and climatic conditions in the study area favour the tall and gregarious growth of mangrove flora. The rocks of sedimentary origin are more susceptible to weathering than volcanic rocks. Tropical rains weather the rock material and escort them to the coastal front through the natural drainage system along with abundant freshwater. The climate of any tropical intertidal zone acts as a vital and requisite factor for the natural growth, development, and succession of mangroves. Among these necessary climatic factors are (i) the temperature fluctuation-ranges between 20°C and 30°C [55, 56], (ii) the humidity is of a higher range [57], (iii) the total annual rainfall is above 1000 mm [58], (iv) there is regular wind flow, (v) the area is frost free [59], (vi) radiation and (vii) sedimentation along with upstream water supply plays a very dominant role for the growth and viability of mangrove in a holistic manner [60].

4. Materials and methodology

Landsat (7 & 8) satellite data products before (2003) and after (2018) tsunami respectively, for the study were downloaded from the website (www.earthexplorer.usgs.gov/). The study area is covered by the scene with path (134) and row (52). Mangrove patches and water bodies decipherably picked up very well by band-5 and band-6 by the short-wave infrared (SWIR) sensor of Landsat 7 and 8 satellites respectively from other features like the forest, human settlements, etc. Using ArcGIS Desktop 10.5 software mangrove patches and TCWs were demarcated.

Apart from the demarcation of TCWs, stream networks were delineated from the 1979 Survey of India (SOI) toposheet. An overlay analysis of stream network was comprehended over (1) satellite imageries, (2) geology map, (3) geomorphology map, (4) soil texture map, and (5) village administrative boundary map to understand the source of fluvial Influx dynamics and ecological succession.

Village-wise mangrove stand and TCWs (subsided landmass and permanent waterlogging thereafter) were inferred from before and after tsunami satellite image interpretation. A fishnet grid of 1 km^2 covering mangroves and TCWs was generated with unique ID's and the same was converted into Global Positioning System (GPS) compatible format (*.gpx). These grids were loaded in the handheld Garmin 62CSX, GPS for field investigation. Enumeration of mangrove species was carried out through a 150 m line transect technique [61] with a 50 m interval between each transect within the 1 km^2 grid during the dry season (January-May, 2019 and March-April, 2020). These line transects were laid orthogonal to the coast either ways (land to sea and sea to land). A subplot of 4 m^2 dimension was laid for enumerating individual plants [8]. Mangrove phenology and habitat description were carried out as per Debnath 2004 [62].

5. Results and discussion

Through field survey, a total of twenty-eight mangrove species around existing mangrove and TCWs in forty-three village locations were enumerated and presented in **Table 1**. Also, village-wise pre-tsunami landuse with soil type and the maximum distance from the existing mangrove patch (km) were tabulated in **Table 2**.

Tsunami is rather a rare disaster in the Indian Ocean [63]. A mega-earthquake of magnitude 9.3 on the Richter scale struck near Indonesia On December 26th, 2004 at 07:58:53 local time [64, 65]. The epicenter was located 80km west of the coast of Northern Sumatra (at approximately 95°51' W and 3°25'N). The earthquake advanced thereafter approximately northward rupturing 1200 km to 1300 km (with an average rupture speed of 2.5 to 3 km/s) of the Andaman-Sunda plate in about 8 to 10 minutes [66–68] causing up to ∼6 m of bottom subsidence and ∼10 m of uplift parallel to the rupture and about100-150 km wide across the subduction area [69]. Upliftment and subsidence of landmass [38] were generated as a consequence of earthquake elastic rebound, offshore of Banda Aceh, the northern tip of Sumatra [70]. Rupture of the plate and coseismic activities spontaneously triggered a tsunami catastrophic devastation ever witnessed in the modern history of humankind [70–73]. All the above sequential events just occurred in a short span of few hours resulting in unprecedented destruction and mangroves were one of the first visible responders of the tsunami [3, 74–77].

Voluminous literature speaks about mangrove demonstrating resilience after a disaster like hurricane, cyclone, and tsunami [18, 35–40, 78, 79]. However, very few studies were conducted to understand the dynamics of the ecological succession of mangroves after natural disasters like hurricanes and tsunamis [80]. The mangroves of the study area faced the double impact of mortality due to 26th December 2004 tsunami viz., (1) physical fury, and (2) prolonged submergence due to subsidence of land mass [38–48]. Zones of subsided landmass were waterlogged permanently resulting in (TCWs). Nudation of mangrove (**Figure 3**) occurred due to a catastrophic event [81].

Overlay analysis of geology geomorphology and stream network of pre-post–tsunami satellite imageries suggest that subsidence of landmass (TCWs) has occurred in the regions of sedimentary rock and on the coastal plains. Sedimentary rocks (Andaman flysh) being soft are more susceptible to deformation due to tectonic activity when compared to volcanic rock (Ophiolite suite). Also, the streams once which were emptying itself in the shallow depths of the coastal frontiers started depositing in the TCWs (**Figures 1, 3**, and **4**). Mineral-rich fine sediments and abundant freshwater were deposited into TCWs through the

DOI: http://dx.doi.org/10.5772/intechopen.94113

Species Name	1*	2*	3	4	5	6*	7	8*	9*	10*	11*	12*	13	14*	15	16	17	18	19*	20*	21*	22*
Acanthus ebracteatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Acanthus ilicifolius	* +	* +	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	+	*+
Acrostichum aureum	* +	* +	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	+	*+
Aegiceras corniculatum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Avicennia marina	* +	* +	+	+	+	*+	+	*+	*+	*+	–	–	+	*+	+	+	+	+	*+	*+	*+	*+
Avicennia officinalis	* +	* +	+	+	+	*+	+	*+	*+	*+	–	–	+	*+	+	+	+	+	*+	*+	*+	–
Bruguiera cylindrica	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Bruguiera gymnorhiza	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Bruguiera parviflora	+	–	–	–	–	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	+
Ceriops tagal	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cynometra iripa	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dolichandrone spathacea	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Excoecaria agallocha	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Heritiera littoralis	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Lumnitzera littorea	+	+	+	+	+	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	+	+
Lumnitzera racemosa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Species Name	23	24	25	26*	27*	28*	29	30	31	32	33*	34	35	36**	37**	38**	39**	40**	41**	42**	43**
Acanthus ebracteatus	+	+	+	*+	+	+	+	+	–	–	–	–	–	+	+	+	–	–	–	–	–
Acanthus ilicifolius	+	+	+	*+	*+	+	+	+	–	–	*+	+	+	+	+	+	+	+	+	+	+
Acrostichum aureum	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+
Aegiceras corniculatum	–	–	–	–	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–
Avicennia marina	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	–	+	+	+	+	+	+	+
Avicennia officinalis	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+
Bruguiera cylindrica	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Bruguiera gymnorhiza	+	+	+	+	+	+	+	+	–	–	–	+	+	–	–	–	–	–	–	–	–
Bruguiera parviflora	+	+	+	+	+	+	+	+	–	–	+	–	–	–	–	–	–	–	–	–	–
Ceriops tagal	+	+	+	+	+	+	+	+	–	–	+	–	–	–	–	–	–	–	–	–	–
Cynometra iripa	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Dolichandrone spathacea	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Excoecaria agallocha	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Heritiera littoralis	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Lumnitzera littorea	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lumnitzera racemosa	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–

Species Name	1*	2*	3	4	5	6*	7	8*	9*	10*	11*	12*	13	14*	15	16	17	18	19*	20*	21*	22*	23	24	25	26*	27*	28*	29	30	31	32	33*	34	35	36**	37**	38**	39**	40**	41**	42**	43**
Nypa fruticans	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Pemphis acidula	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Phoenix paludosa	–	–	–	–	–	–	–	–	–	–	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pandanus tectorius	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rhizophora apiculata	* +	* +	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	*+	*+	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+
Rhizophora mucronata	* +	* +	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	*+	*+	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+
Rhizophora stylosa	+	+	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–
Scyphiphora hydrophylacea	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Sonneratia alba	+	+	–	+	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Sonneratia ovata	+	–	–	+	+	+	+	+	+	+	–	–	–	–	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Xylocarpus granatum	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	–	–	–	–	–	–	–	–
Fimbrisstylis littoralis	* +	* +	+	+	+	*+	+	*+	*+	*+	*+	*+	+	*+	+	+	+	+	*+	*+	*+	*+	+	+	+	*+	*+	*+	+	+	+	+	*+	+	+	+	+	+	+	+	+	+	+

"" -Village-wise distribution of Mangroves, "**" -Village-wise distribution of Mangrove in new venues of TCWs, "–" - Indicates absence of Mangrove species, "+" - Indicates presence of Mangrove Species, "*+"- Indicates presence of Mangrove species in TCWs*

Table 1.
Village-wise distribution of mangrove and its associated species.

Sl no	Village name	Soil texture type	Pre-tsunami land use land cover	Max distance from the existing mangrove patch (km)
1*	Chidiyatapu	Clay loam	Agricultural Land & Settlement	1.2
2*	Manjeri	Clay loam	Agricultural Land & Settlement	0.12
3	Guptapara	Clay and loamy sand	—	—
4	Manglutan	Clay loam	—	—
5	Hashmatabad	Sandy clay loam	—	—
6*	Wandoor	Clay	Agricultural Land	1.14
7	Maymyo	Clay	—	—
8*	Chouldari	Loamy sand	Agricultural Land & Settlement	0.55
9*	Portmout	Clay loam	Agricultural Land & Settlement	0.29
10*	Hobdipur	Clay	Agricultural Land & Settlement	0.35
11*	Balu Ghat	Clay loam and sandy clay loam	Open jungle	0.15
12*	Mohwa Dera	Sandy and sandy clay loam	Open jungle	1.5
13	Temple Myo	Clay loam	—	—
14*	Tirur	Clay loam, Loamy sand, clay, sandy clay loam	Agricultural Land & Settlement	0.25
15	Shore Point	Clay loam	—	—
16	Bamboo Flat	Clay loam and clay	—	—
17	Mathura	Clay and clay loam	—	—
18	Brindaban	Clay and clay loam	—	—
19*	Namunaghar	Clay and clay loam	Agricultural Land & Settlement	0.27
20*	Dundas Point	Clay loam	OpenJungle	0.65
21*	Mitha Khari	Clay	Plantation/ Agricultural land	1.5
22*	Ograbraj	Clay and clay loam	Agricultural Land & Settlement	0.22
23	Badmasphar	Clay and clay loam	—	—
24	Craikabad	Sandy and clay loam	—	—
25	Dhanikhari	Clay and clay loam	—	—
26*	Sippighat	Clay and clay loam	Agricultural Land & Settlement	1.01
27*	Garacharma	Clay and clay loam	Agricultural Land & Settlement	0.45
28*	Dolligunj	Clay and clay loam	OpenJungle	1.05
29	Minne Bay	Clay and clay loam	—	—
30	Ward X	Clay loam	—	—

Sl no	Village name	Soil texture type	Pre-tsunami land use land cover	Max distance from the existing mangrove patch (km)
31	Ward VII	Sandy clay	—	—
32	Ward IV	Sandy clay	—	—
33*	Ward XVII	Clay	Agricultural Land	1.01
34	Brookshabad	Clay	—	—
35	New Rangachang	Clay loam	—	—
36**	Nayasahar	Clay and clay loam	Agricultural Land & Settlement	2.5
37**	Bimblitian	Clay and clay loam	Agricultural Land & Settlement	1.2
38**	Taylerabad	Clay and clay loam	Agricultural Land & Settlement	0.87
39**	Muslim Basti	Clay and clay loam	Agricultural Land & Settlement	1.32
40**	Kanyapuram	Clay loam and clay	Agricultural Land & Settlement	0.95
41**	Govindapuram	Clay loam and clay	Agricultural Land & Settlement	1.47
42**	Stewardgunj	Clay loam and clay	Agricultural Land & Settlement	1.91
43**	Wimberlygunj	Clay loam and clay	Agricultural Land	2.02

*Indicates TCWs in the vicinity of pre-existing mangrove.
**Indicates new venues of TCWs.

Table 2.
Village-wise soil texture, pre-tsunami landuse pattern and maximum distance from the existing mangrove patch.

conduits of natural streams network (**Figure 4**). Freshly deposited fine sediments are barren and are called as mud banks.

These mud banks in the TCWs were wet, saline, and poorly aerated proves unfavourable for higher plants [82] so, microbes and algae prepare the mud banks for the utilization of higher plants by aerating them [83, 84]. Also, sediments are counteracted by compaction and consolidation of both mud and peat [82]. Coaction of non-woody key-stone species like *Fimbrisstylis littoralis*, *Acrostichum aureum*, and *Acanthus ilicifolius* subsequently colonized the TCWs (**Figure 5**, **Tables 1–3**). The aforementioned key-stone species were the pioneer plants to colonize the landmass subsided zones thus trapping the sediments and nutrients resulting in the invasion of novel mangrove species [85, 86]. Basically, key-stone species for the initial succession perform the role of nurse plants which start on the bare aerated soil, modifying its conditions like decreasing interstitial salinity and increasing nutrient, enabling the succession of mangroves and can thus be called facilitator species [87, 88]. key-stone species like *Fimbrisstylis littoralis and Acrostichum aureum* were invariably found in all the forty-three sites. Similarly, mangrove species like *Rhizophora* and *Avicennia spp* were also encountered in all the stations. *Pandanus tectorius* and *Pemphis acidula* were found in Mitha Khari and Ward XVII respectively (**Table 1**). Basic soil textures like clay, sand, and loam in different

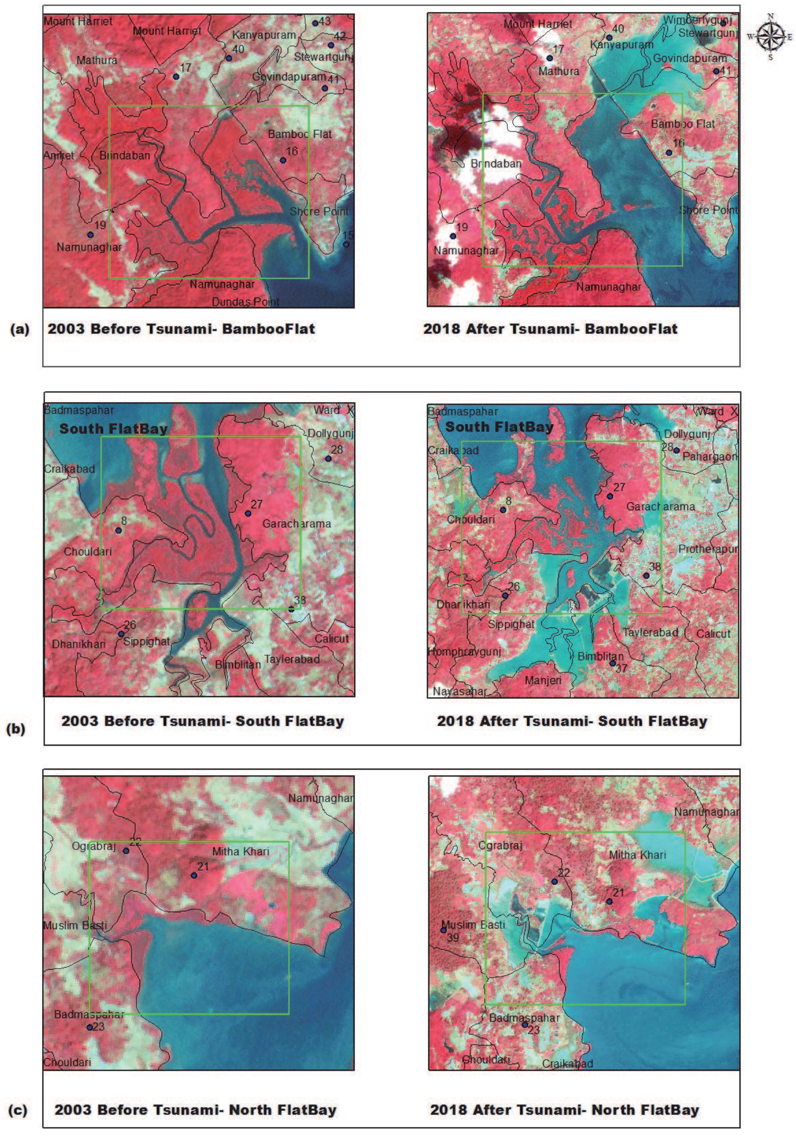

Figure 3.
Satellite image showing before and nudation of mangrove after tsunami (a) Bambooflat, (b) South Flat Bay and (c) North Flat Bay.

combinations were found in the focus area (**Table 2**). The flowering and fruiting phenology along with the habitat descriptions are presented in **Table 3**.

The mangrove seedlings were transported to the TCWs through the tidal influx from pre-existing mangrove (**Tables 1** and **2**) and thus had a stable environment. TCWs being situated in the shallow sheltered bays with low tidal amplitude favours the rooting of propagules [82, 89]. Mangroves follow the existing patterns of fluvial influx and their distribution is determined by the formation of banks, deltas, channels, levees, lagoons, and bays [55, 90–92]. Mangroves respond to geomorphic changes [93, 94] and attain a steady-state system in low energy tropical saline environments [95]. Mangrove succession is a continuous process, where the species recruitment and replacement is systematic and anticipated [96]. It has to be noted here that the likelihood of this phenomenon is of enormous benefit in assessing the evolution towards the climax species complex. The ecological succession from land towards the sea in TCWS in south Andaman is as follows: *Fimbrisstylis littoralis* is the pioneering key-stone plant followed by *Acrostichum aureum* and *Acanthus ilicifolius*. *Avicennia spp/Rhizopara spp* are the prime mangroves to colonize. The ecological succession of mangrove in TCWs are

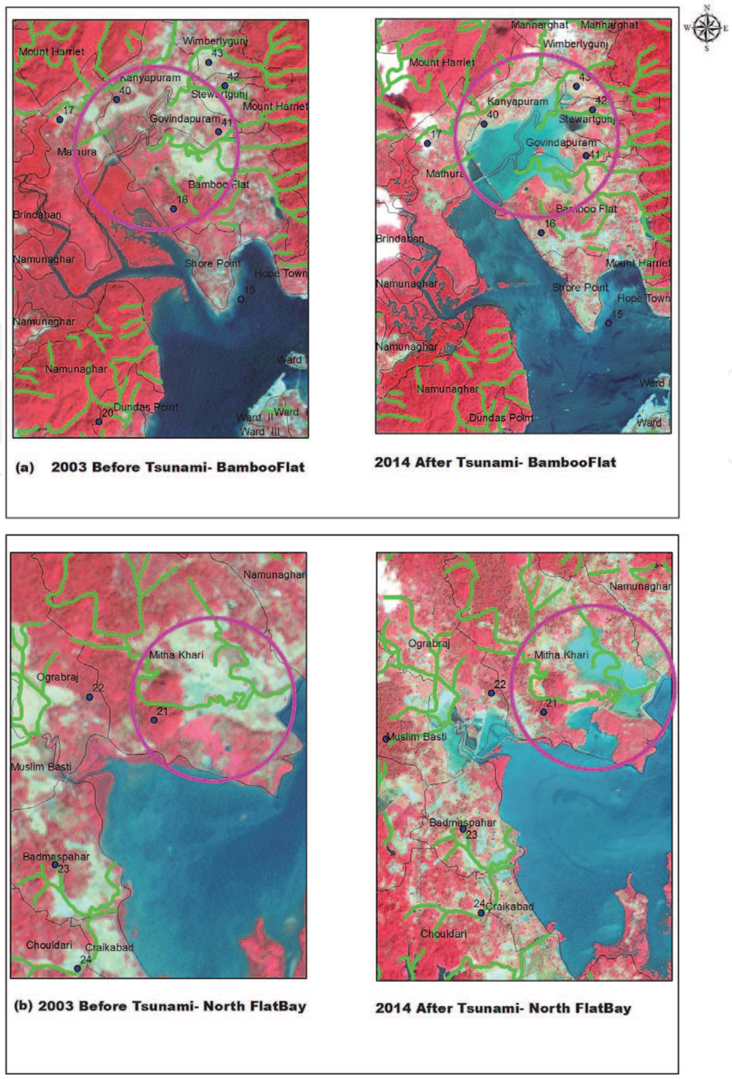

Figure 4.
Siltation and freshwater influx by natural stream network in TCWs.

considered as secondary ecological succession, which is caused by a natural disaster like the tsunami, subsidence of landmass followed by permanent waterlogging. This type of succession was studied worldwide [35, 37, 38, 80].

6. Conclusion

From the present study, it is understood that secondary ecological succession has occurred in Andaman after the catastrophic 2004 tsunami. Key-stone species like *Fimbrisstylis littoralis, Acrostichum aureum* and *Acanthus ilicifolius* acting as a facilitator species were first to colonize the TCWs and followed by mangrove species like *Avicennia spp/Rhizopara spp*. Infact the key-stone species were the pioneer lower plants to colonize the landmass subsided zones of the 2004 tsunami. The nutrient-rich upstream sediments trapped amongst the roots of the key-stone species provides a conducive environment for the mangrove to colonize. The present study provides a window for anthropogenically induced rehabilitation and restoration of mangrove forests. For any rehabilitation and restoration endeavor of mangrove firstly, the area should be seeded with key-stone species after couple of years mangrove species like *Avicennia spp and Rhizopara spp* has to planted. Thereafter it may take 15–20 years for dense patch of mangrove. A broad avenues for future

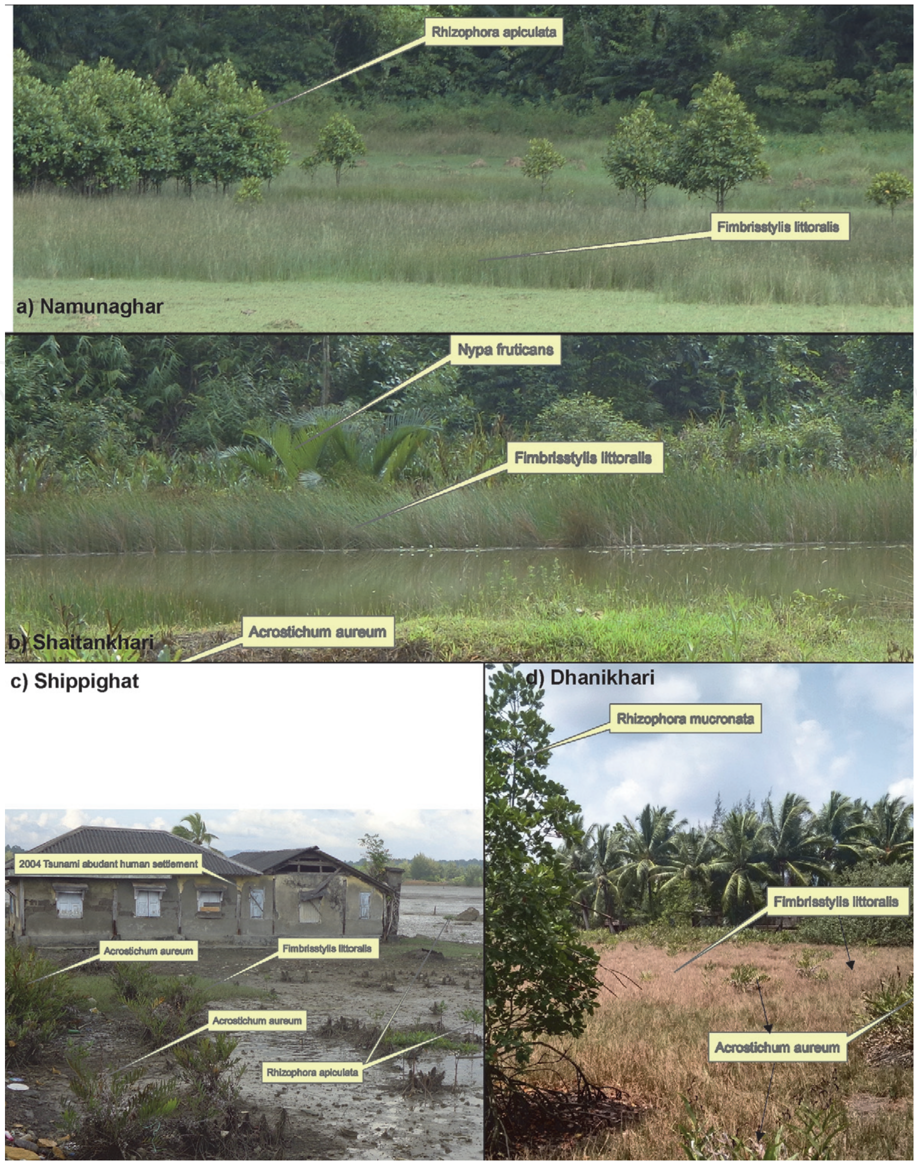

Figure 5.
Field photos of key-stone species and mangroves TCWs.

Sl no	Species name	Phenology		Habitait
		Flowering	**Fruiting**	
1	*Acanthus ebracteatus*	Mar-Jun	Jun-Aug	Common along tidal streams, inland borders of Mangrove swamps under the influence of salt or Brackish water
2	*Acanthus ilicifolius*	Apr-Jun	Jun-Aug	Gregarious in brachish swamps along the seashore and tidal streams
3	*Acrostichum aureum*	NA	NA	Landward side of mangrove, survives in TCWs completely cut off from sea
4	*Aegiceras corniculatum*	Throughout the year		Often found in inner mangroves along with *Bruguiera* spp., *Ceriops* spp., and *Xylocarpus* spp. Also present at landward margin of mangroves inundated during normal high tides and fringing the banks at upstream region.
5	*Avicennia marina*	Apr-Jun	Jun-Aug	Often found in high intertidal and intermediate estuarine position also present in downstream and low intertidal areas. It is a dominant species in highly polluted areas

Sl no	Species name	Phenology		Habitait
		Flowering	Fruiting	
6	*Avicennia officinalis*	Jun-Aug	Aug-Oct	Often found in low and high intertidal position and also occur in mid and upper estuarine position along the banks of the creek.
7	*Bruguiera cylindrica*	Mar-Jun	Jun-Aug	Gregrious on stiff clay behind Avicennia, sometimes in association with Bruguiera gymnorrhiza
8	*Bruguiera gymnorhiza*	Throughout the year		Commonly occur in intertidal zone, along creeks, usually associated with Rhizophora apiculata and R. mucronata
9	*Bruguiera parviflora*	Apr-Jul	Jul-Sep	Occur in intertidal zones of esturaine swamps in association with Bruguriera gymnorrhiza,Rhizophora apiculata and R. mucronata
10	*Ceriops tagal*	Mar-Jul	Jul-Oct	Occur in intertidal banks of mangrove, also in areas nearer to and under esturaine influnce
11	*Cynometra iripa*	Sep-Nov	Dec-Feb	Frequent to back mangrove in the Heritiera littoralis zones
12	*Dolichandrone spathacea*	May-Jun	Jun-Aug	Sporadic occurrence, found around the inner edge ofmangrove swamps in association with Sonneratia caseolaris and Heritiera littoralis
13	*Excoecaria agallocha*	Mar-Jun	Jun-Aug	Occurs in muddy or sandy shores, commonly found in intertidal
14	*Heritiera littoralis*	Mar-Jun	Jun-Aug	Commonly found in intertial zone, frequently extending into muddy or sandy shores
15	*Lumnitzera littorea*	Jan-Apr	Apr-Oct	Occurs in middle zone of mangrove forest, where soulble salts are more
16	*Lumnitzera racemosa*	Jan-Apr	Apr-Jul	Occurs in muddy or sandy elevated zones of esturaine and backwater
17	*Nypa fruticans*	Feb-Jun	Jun-Sep	Sheltered intertidal creeks of mangrove swamps, preferably low saline regions
18	*Pemphis acidula*	Aug-Dec	Dec-Apr	Occur along the edge of mangrove forests
19	*Phoenix paludosa*	Jan-May	May-Aug	Elevated muddy swamps, esturaine banks, can tolerate higher percentage of salt, even found on the sea coast too
20	*Pandanus tectorius*	Sep-Nov	Nov-Marp	Littoral shrub,often found in the tidal forests
21	*Rhizophora apiculata*	May-Jul	Jul-Sep	Occur in intertidal regions of the creek in the in sheltered parts of mangrove
22	*Rhizophora mucronata*	Jul-Sep	Sep-Nov	Occur in intertidal banks of creeks or in estuaries
23	*Rhizophora stylosa*	Jul-Sep	Sep-Nov	Often found in mid to low intertidal and downstream tidal creeks; grows in a variety of habitats and disrupted mangrove areas. One distinctive niche is its ability to grow on edges of small coral islands, establishing on the coral substrate.
24	*Scyphiphora hydrophylacea*	Mar-Aug	Mar-Aug	Along mangrove creeks
25	*Sonneratia alba*	Mar-Jun	Jun-Sep	Occurs along the mouth of tidal creeks, grows on sandy or rocky soil

Sl no	Species name	Phenology		Habitait
		Flowering	Fruiting	
26	*Sonneratia ovata*	Mar-Jun	Jun-Sep	Often occurs on the landward edge of mangrove swamps in brackish water and muddy soil.
27	*Xylocarpus granatum*	Throughout the year		Occur in the sheltered banks in association with Kandelia candel, Rhizophora sp and Sonneratia alba

Pehonology and habitat description is as per Ref. [62].

Table 3.
Phenology of mangrove and it associated species.

research are generated like role of benthic community, avian population, physico-chemical and biological parametric studies, etc., in TCWs.

Acknowledgements

The author would like to acknowledge Dr. G. Narshimulu, guest faculty, Dept. Geography, JNRM, Port Blair, Andaman for the capturing field photos. Also, gratitude's is due to Dr. Manoharan, PG- teacher, Rangat, Middle Andaman for inspiring to write this book chapter.

Field visits and other incidentals were spent from our own coffer and no external funding's were received from either national or international agencies.

Conflict of interest

None.

Author details

V. Shiva Shankar[1]*, Neelam Purti[2], Ravi Pratap Singh[3] and Faiyaz A. Khudsar[4]

1 Department of Coastal Disaster Management, Pondicherry University, Brookashabad Campus, Port Blair, Andaman, India

2 Department of Environment and Forest, Manglutan Range, South Andaman Forest Division, Andaman, India

3 Department of Ocean Studies and Marine Biology, Pondicherry University, Brookashabad Campus, Port Blair, Andaman, India

4 Yamuna Biodiversity Park, CEMDE, University of Delhi, Delhi, India

*Address all correspondence to: shivashankarvj@gmail.com

References

[1] Pereira FRDS, Kampel M, Cunha-Lignon M. Mapping of mangrove forests on the southern coast of São Paulo, Brazil, using synthetic aperture radar data from ALOS/PALSAR. Remote Sensing Letters. 2011;**3**(7):567-576

[2] Gnanappazham L, Selvam V. The dynamics in the distribution of mangrove forests in Pichavaram, South India – perception by user community and remote sensing. Geocarto International. 2011;**26**(6):475-490

[3] Kathiresan K, Rajendran N. Coastal mangrove forests mitigated tsunami. Estuarine, Coastal and Shelf Science. 2006;**65**(3):601-606 https://doi.org/10.1016/j.ecss.2005.06.022

[4] FAO. The world's mangroves 1980-2005. FAO forestry paper. 2007:153

[5] Spalding, M., Kainuma, M., and Collins, F., (2010). World mangrove atlas. Earthscan, London, 319pp. ISBN: 978-1-84407-657-4.

[6] Sharma S, MacKenzie RA, Tieng T, Soben K, Tulyasuwan N, Resanond A, et al. The impacts of degradation, deforestation and restoration on mangrove ecosystem carbon stocks across Cambodia. Science of the Total Environment. 2019. DOI: https://doi.org/10.1016/j.scitotenv.2019.135416

[7] Goutham Bharathi MP, Roy SD, Krishnan P, Kaliyamoorthy M, Immanuel T. Species diversity and distribution of mangroves in Andaman and Nicobar Islands, India. Botanica Marina. 2014;**57**(6):421-432 https://doi.org/10.1515/bot-2014-0033

[8] Ragavan P, Saxena A, Mohan PM, Ravichandran K, Jayaraj RSC, Saravanan S. Diversity, distribution and vegetative structure of mangroves of the Andaman and Nicobar Islands, India. Journal of Coastal Conservation. 2015; **19**(4):417-443 https://doi.org/10.1007/s11852-015-0398-4

[9] Ragavan P, Mohan PM, Saxena A, Jayaraj RSC, Ravichandran K, Saxena M. Mangrove floristics of the Andaman and Nicobar Islands: critical review and current scenario. Marine Biodiversity. 2016 https://doi.org/10.1007/s12526-016-0581-3

[10] Lignon, C.M., Kampel, M., Menghini, R.P., Novelli, S.Y., Cintrón., Guebas, D.F., (2011). Mangrove Forests Submitted to Depositional Processes and Salinity Variation Investigated using satellite images and vegetation structure surveys. Journal of Coastal Research. SI 64, 344-348.

[11] Dodd RS, Ong JE. Future of Mangrove Ecosystems to 2025. In: Polunin NV, editor. Aquatic Ecosystems: Trends and Global Prospects. New York, NY, USA: Cambridge University Press; 2008. pp. 172-287

[12] Robertson AI, Duke NC. Mangroves as nursery sites, comparisons of the abundance of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. Marine. Biology. 1987;**96**(2):193-205 https://doi.org/10.1007/BF00427019

[13] Twilley RR. The exchange of organic carbon in basin mangrove forests in a southwest Florida estuary. Estuarine, Coastal and Shelf Science. 1985;**20**(5): 543-557 https://doi.org/10.1016/0272-7714(85)90106-4

[14] Moran MA, Wicks RJ, Hodson RE. Export of dissolved organic matter from a mangrove swamp ecosystem – evidence from natural fluorescence, dissolved lignin phenols and bacterial secondary production. Marine Ecology Progress Series. 1991;**76**:175-184

[15] Kamal M, Phinn S. Hyper-spectral Data for Mangrove Species Mapping: A Comparison of Pixel-Based and Object-Based Approach. Remote Sensing. 2011; *3*(10):2222-2242 https://doi.org/10.3390/rs3102222

[16] Ewel KC, Twilley RR, Ong JE. Different kinds of mangrove forests provide different goods and services. Global Ecology. Biogeography Letters. 1998;**7**:83-94 https://doi.org/10.1111/j.1466-8238.1998.00275.x

[17] Mumby P, Edwards A, Arlas-Gonzalez J, Lindeman K, Blackwell P, Gall A, et al. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature. 2004;**427**:533-536 https://doi.org/10.1038/nature02286

[18] Alongi DM. Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. Estuarine, Coastal and Shelf Science. 2008;**76**:1-13 https://doi.org/10.1016/j.ecss.2007.08.024

[19] Nagelkerken I, Blaber SJM, Bouillon S, Green P, Haywood M, Kirton LG, et al. The habitat function of mangroves for terrestrial and marine fauna: A review. Aquatic Botany. 2008; **89**(2):155-185 https://doi.org/10.1016/j.aquabot.2007.12.007

[20] Walters BB, Rönnbäck P, Kovacs JM, Crona B, Hussain SA, Badola R, et al. Ethnobiology, socio-economics and management of mangrove forests: A review. *Aquatic* Botany. 2008;**89**(2):220-236 https://doi.org/10.1016/j.aquabot.2008.02.009

[21] Giri C, Zhu Z, Tieszen LL, Singh A, Gillette S, Kelmelis JA. Mangrove forest distributions and dynamics (1975-2005) of the tsunami-affected region of Asia. Journal of Biogeography. 2008;**35**(3): 519-528 https://doi.org/10.1111/j.1365-2699.2007.01806.x

[22] Murray BC, Pendleton L, Jenkins WA, Sifleet S. Green Payments for Blue Carbon Economic Incentives for Protecting Threatened Coastal Habitats. Durham: Duke University; 2011

[23] Pendleton L, Donato DC, Murray BC, Crooks S, Jenkins WA, Sifleet S, et al. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. PloS One. 2012;**7**:e43542 https://doi.org/10.1371/journal.pone.0043542

[24] Cornell, H.A., Susan O. Grose, Pendleton. L., 2018. Mangrove Ecosystem Service Values and Methodological Approaches to Valuation: Where Do We Stand? Frontiers in Marine Sciences https://doi.org/10.3389/fmars.2018.00376.

[25] Valiela I, Bowen JL, York JK. Mangrove forests: One of the world's threatened major tropical environment. Bioscience. 2001;**51**:807-815

[26] Ellison AM. Macroecology of mangroves: Large scale patterns and processes in tropical coastal forests. Trees Struct. Funct. 2002;**16**:181-194

[27] Duke NC, Meynecke J-O, Dittmann S, Ellison AM, Anger AM, Berger U, et al. A world without mangroves. Science. 2007;**317**:41-42

[28] Friess DA, Yando ES, Abuchahla GMO, Adams JB, Cannicci S, Canty SWJ, et al. Mangroves give cause for conservation optimism. *Current Biology*. 2020;***30***(4):R153-R154

[29] IUCN. The impact of climatic change and sea-level rise on ecosystems. London: Report for the Commonwealth Secretariat; 1989

[30] Primavera J. Socio-economic impacts of shrimp culture. Aquaculture Research. 1997;**28**:815-827

[31] Alongi DM. Present state and future of the world's mangrove forests. Environmental Conservation. 2002;**29**: 331-349

[32] Kruitwagen G, Pratap HB, Covaci A, Wendelaar Bonga SE. Status of pollution in mangrove ecosystems along the coast of Tanzania. Marine Pollution Bulletin. 2008;**56**:1022-1031

[33] Cavalcante, M.R., Sousa,W.F., Nascimento, F.R., Nascimento, R.E., Freire, S.S.G., (2009). The impact of urbanization on tropical mangroves (Fortaleza, Brazil): Evidence from PAH distribution in sediments. Journal of Environmental Management 91, 328–335. https://doi.org/10.1016/j.jenvman.2009.08.020.

[34] Gilman E, Ellison J, Duke NC, Field C. Threats to mangroves from climate change and adaptation options: a review. Aquatic Botany. 2008;**89**(2): 237-250

[35] Roth LC. Hurricanes and mangrove regeneration: effects of Hurricane Joan, October 1988, on the vegetation of Isla del Venado, Bluefields, Nicaragua. Biotropica. 1992;**24**:375-384

[36] Sherman RE, Fahey TJ, Battles JJ. Small-scale disturbance and regeneration dynamics in a neo-tropical mangrove forest. Journal of Ecology. 2000;**88**(1):165-178 https://doi.org/10.1046/j.1365-2745.2000.00439.x

[37] Nehru P, Balasubramanian P. Re-colonizing mangrove species in tsunami devastated habitats at Nicobar Islands, India. Check List. 2016; **7**(3):253-256 https://doi.org/10.15560/7.3.253

[38] Nehru P, Balasubramanian P. Mangrove species diversity and composition in the successional habitats of Nicobar Islands, India: A post-tsunami and subsidence scenario. Forest Ecology and Management. 2018; **427**:70-77 https://doi.org/10.1016/j.foreco.2018.05.063

[39] ShivaShankar, V., Narshimulu, G., Kaviarasan, T., Narayani, S., Dharanirajan, K., James, R.A., Singh, R. P., (2019). 2004 Post Tsunami Resilience and Recolonization of Mangroves in South Andaman, India. Wetlands. https://doi.org/10.1007/s13157-019-01211-5.

[40] Sopher MF, MacKenzie RA, Sharma S, Cole TG, Litton CM, Sparks JP. Non-native mangroves support carbon storage, sediment carbon burial, and accretion of coastal ecosystems. In: Global Change Biology. 2019 https://doi.org/10.1111/gcb.14813

[41] Xiao H, Su F, Fu D, Qi W, Huang C. Coastal Mangrove Response to Marine Erosion: Evaluating the Impacts of Spatial Distribution and Vegetation Growth in Bangkok Bay from 1987 to 2017. Remote Sensing. 2020;**12**:220 https://doi.org/10.3390/rs12020220

[42] Berger U, Adams M, Grimm V, Hildenbrandt H. Modeling secondary succession of neotropical mangroves: causes and consequences of growth reduction in pioneer species. Perspectives in Plant Ecology, Evolution and Systematics. 2006;**7**(4):243-252 https://doi.org/10.1016/j.ppees.2005.08.001

[43] Primavera, J.H,, Esteban, J., (2008). A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. Wetlands Ecology and Management 2008; 16: 345-358.

[44] Lewis RR, Milbrandt EC, Brown B, Krauss KW, Rovai AS, Beever JW, et al. Stress in mangrove forests: Early detection and preemptive rehabilitation are essential for future successful worldwide mangrove forest management. Marine Pollution Bulletin. 2016;**09**:764-771

[45] Feller IC, Friess DA, Ken W, Krauss RR, Lewis III. The state of the

world's mangroves in the 21st century under climate change. Hydrobiologia. 2017 https://doi.org/10.1007/s10750-017-3331-z

[46] Onrizal, Ahmad, A.G., Mansor, M., (2017) Assessment of natural regeneration of mangrove species at tsunami affected areas in Indonesia and Malaysia. IOP Conference. Series: Materials Science and Engineering 180 01204. https://doi.org/10.1088/1757-899X/180/1/012045.

[47] Teutli-Hernández C, Herrera-Silveira JA, Comín FA, López MM. Nurse species could facilitate the recruitment of mangrove seedlings after hydrological rehabilitation. Ecological Engineering. 2017;**130**:263-270 https://doi.org/10.1016/j.ecoleng.2017.07.03

[48] Roy SD, Krishnan P. Mangrove stands of Andamans: Vis-à-Vis tsunami. Current Science. 2005;**89**(11):1800-1804 https://www.jstor.org/stable/24111111

[49] Dharanirajan K, Kasinatha Pandian P, Gurugnanam B, Narayanan RM, Ramachandran S. An integrated study for the assessment of tsunami impacts: a case study of South Andaman Island, India using remote sensing and GIS. Coastal Engineering Journal. 2007;**49**(3):229-266 https://doi.org/10.1142/S0578563407001617

[50] Chibber HL. Geology of Burma. London: Macmillan; 1934

[51] Karunakaran, C., Ray, K.K., Saha, S. S., (1964). Geology of South Andaman Island. Proceedings in 22nd International Geological Congress, India. 11, 79-97.

[52] Karunakaran C, Ray KK, Saha SS. Tertiary sedimentation in the Andaman and Nicobar geosyncline. Journal Geological Society of India. 1968;**9**:32-39

[53] Ganeshamurthy AN, Dinesh R, Ravisankar N, Nair AK, Ahlawat SPS. Land resources of Andaman and Nicobar islands. Andaman and Nicobar, India: CARI publication; 2000

[54] Meteorological Statistics of Andaman & Nicobar Islands, 2019. Directorate of economics and statistics Andaman and Nicobar Administration Port Blair.

[55] West RC. Mangrove Swamps of the pacific coast of Columbia. Annals of the Association of American Geographers banner. 1956;**46**(1):98-121 https://doi.org/10.1111/j.1467-8306.1956.tb01498.x

[56] Blasco, F., (1984). Climate factors and the biology of mangrove plants. In: The Mangrove Ecosystem: Research Method. Snedaker SC, Snedaker JG, (Eds) UNESCO. 18-35.

[57] Davis JH. The Ecology and Geologic role of mangroves in Florida. Carnegie Institution of Washington publication. 1940;**517**:303-412

[58] Galloway, R.W., (1982). Distribution and physiographic patterns of Australian mangroves In: Clough BF (ed): Mangrove Ecosystems in Australia: Structure, Function and Management, Canberra B.F. Australian National University Press 31-54.

[59] Clough BF, Andrews TJ, Cowan IR. Physiological process in Mangrove. In: Clough BF, editor. Mangrove Ecosystems in Australia: Structure, Function and Management, Canberra B.F. Australian National University Press; 1982. pp. 193-210

[60] Venkatesan T. The Mangroves of Madras State. Indian Forester. 1966; **92**(1):27-34

[61] Altamirano, J.P., Primavera, J.H., Banaticla, M.R.N., Kurokura, H., (2010). Practical techniques for mapping small patches of mangroves. Wetlands Ecology and Management 18 (6):707–715, https://doi. org/10.1007/s11273-010-9190-2.

[62] Debnath HS. Mangroves of Andaman and Nicobar Islands: Taxonomy and Ecology (A community profile). Bishen singh Mahendra Pal Singh publication, DehraDun, India. 2004;**248001** 81-211-0420-3

[63] O'Neil, T., (2005). Tsunamis: Where Next? With danger waiting in every ocean, detection is key. Geographica, National Geographic. Available online at: www.nationalgeographic.com/ngm/0504/resources_geo.html (accessed 8 Jan 2016).

[64] Stein S, Okal EA. Size and speed of the Sumatra earthquake. Nature. 2005; **434**:581-582 https://doi.org/10.1038/434581a

[65] Micheal, J, G., David, J, D., (2007). Multi-angle Imaging Spectro Radiometer (MISR) time- lapse imagery of tsunami waves from the 26 December 2004 Sumatra-Andaman earthquake. Remote Sensing of Environment. 107, 256-263.

[66] Ammon CJ, Ji C, Thio H-K, Robinson D, Ni S, Hjorleifsdottir V, et al. Rupture process of the 2004 Sumatra-Andaman earthquake. Science. 2005;**308**:1133-1139 https://doi.org/10.1126/science.1112260

[67] Bilham R, Engdahl R, Feldl N, Satyabala SP. Partial and complete rupture of the indo-Andaman plate boundary 1847-2004. Seismological Research Letters. 2005;**76**(3):299-311 https://doi.org/10.1785/gssrl.76.3.299

[68] Lay, T., Kanamori, H., Ammon, C. J., Nettles, M., Ward, S.N., Aster, R.C., Beck, S.L., Bilek, S.L., Brudzinski, M.R., Butler, R., DeShon, H.R., Ekström, G., Satake, K., Sipkin, S., (2005). The great Sumatra-Andaman earthquakeof 26 December 2004. Science 308:1127–1133. https://doi.org/10. 1126/science.1112250.

[69] Ioualalen M, Asavanant J, Kaewbanjak N, Grilli ST, Kirby JT, Watts P. Modeling the 26 December 2004 Indian Ocean tsunami: case study of impact in Thailand. Journal of Geophysical Research, Oceans. 2007;**112** (C7) https://doi.org/10.1029/2006JC003850

[70] Bilham R. A flying start, then a slow slip. Science. 2005;**308**:1126-1127 https://doi.org/10.1126/science.1113363

[71] Nagarajan B, Suresh I, Sundar D, Sharma R, Lal AK, Neetu S, et al. The great tsunami of 26 December 2004: a description based on tide- gauge data from the Indian subcontinent and surrounding areas. Earth, Planets and Space. 2006;**58**:211-215 https://doi.org/10.1186/BF03353380

[72] Subarya C, Chlieh M, Prawirodirdjo L, Avouac JP, Bock Y, Sieh K, et al. Plate boundary deformation associated with the great Sumatra–Andaman earthquake. Nature. 2006;**440**:46-51 https://doi.org/10.1038/nature04522

[73] Piatanesi A, Lorito S. Rupture process of the 2004 Sumatra–Andaman earthquake from tsunami waveform inversion. Bulletin of the Seismological Society of America. 2007;**97**(1A):S223-S231 https://doi.org/10.1785/0120050627

[74] Danielsen, F., Sørensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S/, Hansen, L.B., (2005). The Asian tsunami: a protective role for coastal vegetation. Science310:643. https://doi.org/10.1126/science.1118387.

[75] Dahdouh-Guebas F, Jayatissa LP, Di ND, Bosire JO, Lo SD, Koedam N. How effective were mangroves as a defence against the recent tsunami? Current Biology. 2005a;**15**(12):R443-R447 https://doi.org/10.1016/j.cub.2005.06.008

[76] Dahdouh-Guebas F, Hettiarachchi S, Lo SD, Batelaan O,

Sooriyarachchi S, Jayatissa LP, et al. Transitions in ancient inland freshwater resource management in Sri Lanka Affect Biota and Human Populations in and around coastal lagoons. Current Biology. 2005b;**15**:579-586 https://doi.org/10.1016/j.cub.2005.01.053

[77] Dahdouh-Guebas F, Koedam N, Danielsen F, Sørensen MK, Olwig MF, Selvam V, et al. Coastal vegetation and the Asian tsunami. Science. 2006;**311**: 37-38 https://doi.org/10.1126/science.311.5757.37

[78] Mateo DM, Ruiz Bruce Taylor BR, Rangel-Salazar LJ, Hernández CB. Resilience in a Mexican Pacific Mangrove after Hurricanes: Implications for Conservation-Restoration. Journal of Environmental Protection. 2013;**4**:1383-1391 http://dx.doi.org/10.4236/jep.2013.412159

[79] Das AK, Jha DK, Devi MP, Sahu BK, Vinithkumar NV, Kirubagaran R. Post tsunami mangrove evaluation in coastal vicinity of Andaman Islands, India. Journal of Coastal Conservation. 2014; **18**(3):249-255 https://doi.org/10.1007/s11852-014-0312-5

[80] Ross, M.S., Meeder, J.F., Sah, J.P., Ruiz, P.L., Telesnicki, G.J., (2000) The Southeast Saline Everglades revisited: 50 years of coastal vegetation change. Journal of Vegetation Science 11(1):101–112. https://doi.org/10.2307/3236781.

[81] Bullock EL, Fagherazzi S, Nardin W, Vo-Luong P, Nguyen P, Woodcock CE. Temporal patterns in species zonation in a mangrove forest in the Mekong Delta, Vietnam, using a time series of Landsat imagery. Continental Shelf Research. 2017;**147**: 144-154 https://doi.org/10.1016/j.csr.2017.07.007

[82] Doeke Eisma and Dijkema, K.S., (1997). The influence of salt marsh vegetation on sedimentation. In Doeke Eisma and Dijkema, K. (eds): Intertidal Deposits: River mouths, Tidal flats and Coastal lagoons. 403-435.

[83] Schuster, W.H., (1952). Fish Culture in brackish water ponds of Java. Spec. Publ. Indo Pac Fish Counc., no.1.

[84] Emerit M. Etude granulométrique de la mangrove de Joal, Senegal. Ann. Fac. Sci. University Dakar. 1960;**5**:107-115

[85] Milbrandt EC, Tinsley MN. The role of saltwort (Batis maritime L.) in regeneration of degraded mangrove forests. Hydrobiologia. 2006;**568**(1): 369-377 https://doi.org/10.1007/s10750-006-0203-3

[86] Lewis RR. Successful mangrove Forest restoration informs the process of successful general wetland restoration. National Wetlands News. 2011;**33**:23-25

[87] Lewis, R.R., (1982). Creation and restoration of coastal plant communities. In: Lewis RR (ed) Mangrove forests. CRC Press, Boca Raton, pp 153–172.

[88] Teutli-Hernández C, Herrera-Silveira JA, Comín FA, López MM. Nurse species could facilitate the recruitment of mangrove seedlings after hydrological rehabilitation. Ecological Engineering. 2019;**130**: 263-270 https://doi.org/10.1016/j.ecoleng.2017.07.030

[89] Oliver, J., (1982). The geographic and environmental aspect of mangrove communities: Climate. In: B.F. Clough (ed.). Mangrove Ecosystem of Australia. *Austr. Inst.Mar.Sci.* with A.N.U. Press. 19-30.

[90] Thom BG. Mangrove ecology and deltaic geomorphology: Tabasco, Mexico. J. ecol. 1967;**55**:301-343

[91] Egler F. Southeast Saline Everglades Vegetation, Florida, and its management. Vegetatio. 1950;**3**:213-265

[92] Vann J. Landform-vegetation relationship in the Atrato Delta. Annals of the Association of American Geographer. 1959;**49**:345-360

[93] Odum EP. Fundamentals of ecology, pp xiv, 574. Philadelphia, London, Toronto: W.B. Saunders Company; 1971

[94] Smith, W. G., (1968). Sedimentary Environments and Environmental Change in the Peat forming Area of South Florida. Pennsylvania State University, 254pp.(Ph.D . thesis).

[95] Lugo EA. Mangrove Ecosystem: Successional or Steady State? Biotopica. 1980;**12**(2):65-72

[96] Zedler, J.D., (2000) Handbook of restoring tidal wetlands. CRC, London.