Biodivers Conserv (2012) 21:1267–1287
DOI 10.1007/s10531-011-0214-x

ORIGINAL PAPER

Impact of tsunami on the forest and biodiversity richness in Nicobar Islands (Andaman and Nicobar Islands), India

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Received: 3 May 2011 / Accepted: 21 December 2011 / Published online: 30 December 2011

Abstract Occurrences of extreme events are likely to cause major decline in global biodiversity. In one such event, on December 26, 2004 tsunami caused extensive damage and irreparable losses to the ecology and biodiversity of low-lying areas of the countries located around the Indian Ocean region. Archipelago of Andaman and Nicobar Islands, one of the richest centre of endemism and biodiversity in the Indo-Malayan region, suffered great loss of forests and coastal biodiversity owing to its closeness to the epicenter of tsunami, i.e. just off the coast of Indonesia. There is little insight into the resilience and rate of recovery pattern of tropical coastal habitats consequent to catastrophic impacts of tsunami. It's important to study the impacts of tsunami on the forest and biodiversity in order to suggest mitigation, restoration measures and long-term conservation planning. Here we have assessed the immediate after-effects of December 26, 2004 tsunami on the forests and areas prioritized for biodiversity conservation analyzing pre and post tsunami satellite imageries. The effect of topographic patterns of Island's coastal areas and their distance from the epicenter of tsunami with respect to changes in the forests and different levels of biologically rich areas modeled for prioritization for different groups of Islands in Nicobar has been studied. Great Nicobar accounted for higher proportion of total forest area damaged and submerged in Nicobar, followed by Central Nicobar and Car Nicobar. Mangroves, littoral forest, beach forest and low land swamps and *Syzygium* swamps were most affected. Study brings out spatially explicit scenario of damaged, submerged and lost forest areas and corresponding area statistics, vital for understanding and mitigating medium and long term effects of tsunami an extreme event.

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Keywords Tsunami · Nicobar Islands · Biodiversity · Remote sensing

Introduction

Extreme events and disasters, such as floods, droughts, tsunamis or hurricanes are expected to become more severe and more frequent with changes in climate and tectonics. Depending upon their area of occurrence, they can have enormous direct and indirect human, environmental and economic impacts. December 26, 2004 tsunami in Indian Ocean is one such example when a massive earthquake occurred in the Indian Ocean just off the coast of Indonesia. The earthquake of magnitude of 9.0 rector scale created a series of tsunamis in the known history that caused great destruction and loss in low-lying towns adjoining the coastline of eleven countries, including Indonesia, Thailand, Malaysia, India and Sri Lanka, causing more than 150,000 causalities. The closest Indian landmasses to the epicenter are the Andaman and Nicobar Islands over a narrow arc of about 800 km in the Bay of Bengal. The catastrophic seismic event, tsunami and subsequent tremors have caused irreparable losses in the Nicobar group of Islands particularly to the pristine forests and biodiversity because of their proximity to the epicenter and significantly altered the coastal landscape.

In tropical coastal areas, spatial variation in plant composition, structure and extent is largely determined primarily by tidal flood patterns and intensity (Hupp and Osterkamp 1985; Ferreira and Stohlgren 1999). These areas receive regular pulses of tidal wave that cause predictable changes in the abiotic character of plant habitats. Plant species adapt either developing tolerance to these changes through physiological or morphological traits (e.g. ability to develop adventitious roots), or avoidance via life history traits (e.g. timing of reproduction) (Blom et al. 1990). The enrichment process of complex ecosystem evolved in thousands of years can be significantly altered by any extreme events such as tsunami.

The occurrence of event like tsunami in the tropical regions has special significance as these regions support thick forest cover and high biological diversity. Many of the oceanic Islands in the tropical south-east Asia, show high endemism and rarity in their floral and faunal composition and are devoid of high anthropogenic pressure. Moreover, very often high level of endemism remains concentrated in the small oceanic Islands which are highly vulnerable to extreme events. Since in the recent history, there is no evidence of tsunami for Indian Ocean region, it has not been sufficiently understood what likely impacts the tsunami will have on the Island's biodiversity and ecosystems in immediate, medium and long-term basis. There is little insight into the resilience and rate of recovery pattern of tropical coastal habitats consequent to catastrophic impacts of tsunami. It's important to study the impacts of tsunami on the forest and biodiversity in order to suggest mitigation, restoration measures and long-term conservation planning. Though the immediate impacts of tsunami can be observed and quantified such as reduction in the sizes of the Islands, inundation/submergence of forest floors by the ingress of saline sea water, destruction and loss in the area of forests and other coastal habitats, soil erosion, formation of new beaches and creeks, etc. The medium and long term impacts such changes in the phenology, ecology and ecophysiology of vegetation are difficult to be realized through rapid assessment. However, continued studies for a longer duration can certainly be meaningful to safeguard ecology and biodiversity of the Islands.

The extent and magnitude by which tsunami can destroy any area can be directly linked to its distance from the epicenter, configuration of its coastal topography and vulnerability of its coastal habitats against the powerful waves action. December 26, 2004 tsunami was caused due to the displacement of a large volume of a body of water by undersea earthquake associated with earth crustal deformation. Owing to the immense volumes of water and the high energy generated, tsunamis devastated coastal areas of many countries even those located at a considerably longer distance from the epicenter. Tsunami and tides both produces waves, which moves towards the inland areas but tsunami waves are of far greater strength, thus travel longer inland distance and causes heavy damage. Tsunami waves are often hundreds of kilometer long as compared to normal sea wave. They have small wave height offshore but they attain height when they reach shallower water by a wave shoaling process causing heavy devastation and inundation of coastal areas. The damage is caused by two mechanisms; first, the waves smash the coasts with huge force and the large volume of water brings even more destruction while draining off the land. As tsunami wave travels long distances from its epicenter, the force carried away by the propagating waves is different for areas located at different distances. Theoretically, areas located at closer distance from the epicenter, shall receive heavy damage contrary to those located at the farther distances. Thus, it would be interesting to know, does the magnitude of damage in the Islands depend on the distance from the epicenter of the event? It is further intriguing to understand whether submergence and forest/biodiversity loss has followed the topographic patterns? Since the configuration of topography along the coast have influence on the extent and magnitude of damage caused by the oceanic waves.

Remote sensing technologies are the most sought after tools in case of natural disasters such as tsunami. The unique capability of remote sensing sensors to view any area or phenomenon synoptically, almost in real time and transmitting images with unprecedented details both in space and time has made this technology quiet relevant to study extreme events. The optimal use of remotely sensed imageries of disasters events can be when they are analyzed in conjunction with geo-database containing information on various themes (soil, geology, biodiversity databases, etc.) and legacy information (historical land use and land cover, past occurrences of disasters, etc.).

Oceanic Islands of Nicobar are the part of Indo-Malayan global biodiversity hotspot and represent a major centre of endemism in India (Nayar 1996). The rain forests of Nicobar Islands are pristine and nearly 14% of flora is endemic (Nayar and Shastry 1987). More than 2,100 species of angiosperms have been reported together with Andaman Islands, of which 11% are strictly endemic to the Islands (Balakrishnan and Ellis 1996). The pre-tsunami status of vegetation communities, species diversity and biologically rich areas of Nicobar groups of Islands were studied as part of Biodiversity Characterization Project under Jai Vigyan National Science and Technology Mission project, Department of Science and Technology, Government of India (IIRS 2003). In the present work, the immediate impact of tsunami on the biodiversity of the Nicobar groups of Islands has been studied comparing the pre-tsunami and post-tsunami scenarios interpreted from satellite remote sensing imageries. This is an attempt to study the immediate impacts of tsunami by evaluating the (i) change in the forest cover/spread (ii) changes in prioritized area for biodiversity conservation. Further, the study also attempt to highlight the effect of coastal topography and distance of the Island from the epicenter on extent of damage occurred to different group of Islands during tsunami.

Methods

Study area

The Nicobar groups of Islands are geographically located between 6°45′ to 9°15′N latitude and 92°42′ to 93°56′E longitude (Fig. 1). In Nicobar, three different groups of Islands (Car

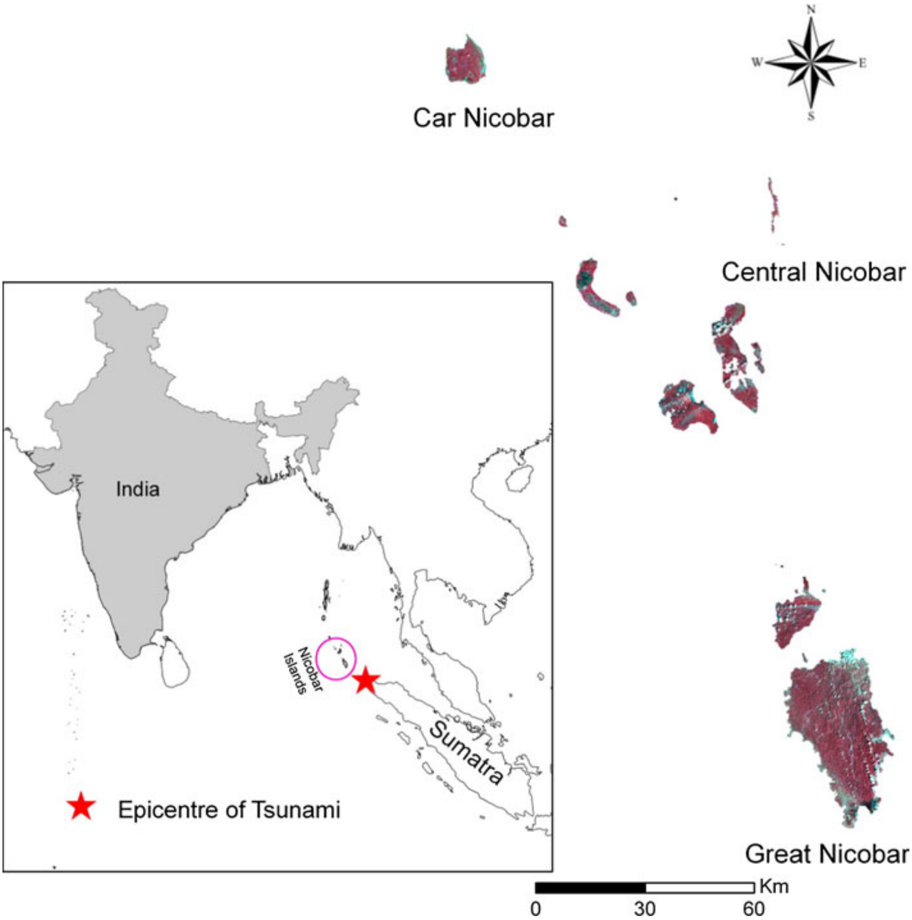

Fig. 1 Location map of Nicobar Islands

Nicobar, Central Nicobar and Great Nicobar) occur and of which Great Nicobar is closest and Car Nicobar is at the farthest distance from the epicenter of tsunami, while Central Nicobar is located at intermediate distance. Topographically, each group of Islands has coastal areas where topography varies from flat to undulating and elevated areas. The Car Nicobar landscape is mostly a flat area with small hillocks at the centre of Island. However, Great Nicobar shows slight complexity in structural makeup.

Demographically, the population of these Islands is made up of Nicobari tribe, relying on coconut plantation for their livelihood, while parts of Islands in the group are uninhabited. In this group of Islands, Car Nicobar, Katchal, Kamorta, Nancowry, Trinket and Great Nicobar are the areas under habitation. The Islands are mostly inhabited by the Nicobarese and settlers from main land India. Amidst the forest are patches of grassland on the hilltops, mostly dominated by *Cymbopogon* sp. and *Carex* sp. The grassy patches form the unique characteristic of these groups of Islands. Great Nicobar and Little Nicobar Islands are very unique in its vegetation. The vegetation of the Nicobar Islands is divided into coastal, mangrove forests, inland evergreen and mixed evergreen forests. The floristic diversity of the Nicobar group of Islands shows good affinity with the neighboring phytogeographical Malaysian and Indonesian taxa. The flora of the Andaman and Nicobar Islands are known to host 42% of Malaysian and south-east Asian elements that do not have natural occurrence in the Indian sub-continent (Mathew 1998). About 48% angiosperm species are not common to both Andaman and Nicobar groups of Islands (Pandey and Diwaker 2008).

The inventory of different categories of vegetation types occurring in Nicobar Islands was carried out during 2002–2004 which provided information on relative ecological importance and species diversity (Table 6). In total 77 plots of 0.1 ha size were laid in different vegetation types to highlights the species diversity, basal area, endemic and rare species information. Evergreen forests are the most luxuriant vegetation types and the largest area under this type occurs in Great Nicobar Island.

The Great Nicobar Island is well known for high endemism and diversity. Gupta et al. (2002) rediscovered *Podocarpus wallichianus*, a rare gymnosperm from the evergreen forests of Great Nicobar Island after the interval of 50 years. Littoral forest zones present in this group of Islands extends from few yards to around a mile dominated by *Barringtonia* and *Pandanus* sp. Thick strands of *Casuarina equisetifolia* with good regeneration status stands along the Casuarina Bay in Great Nicobar Island. Beach forest, also categorized in the same group is common in the Nicobar Isles with the dominant species like *Scaevola frutescens*, *Hibiscus tiliaceus* along with *Clerodendrum inerme* respectively. *Nypa fruticans* occurs gregariously along the muddy banks of the creeks. The luxuriant growth of trees, shrubs and climbers are common in the mixed evergreen formations. *Bruguiera gymnorrhiza* and *Heritiera littoralis* forms the habitat of many orchid's species viz. *Dendrobium*, *Asplenium* and *Bulbophyllum*, etc. Evergreen forests of Great Nicobar, Kamorta, and Katchal are dominated by *Calophyllum soulattri*, *Sideroxylon longipetiolatum*, *Garcinia xanthochymus*, *Pisonia excelsa* and *Mangifera sylvatica.* Evergreen formation generally occurs in the moist valleys and along the river. Tree ferns (*Sphaeropteris nicobarica* and *S. albosetacea*) are a unique occurrence with attaining a height up to 6 meters in dense forest of Great Nicobar Island. The southeast coast of the Great Nicobar Island (Galathea Bay) is the nesting ground for the famous Giant Leather Back turtles. Out of the 270 bird species and sub-species reported from Andaman and Nicobar Islands (Sankaran and Vijayan 1993), 56 were from the Nicobar (Andrews and Sankaran 2002).

Materials

Tsunami impacts in relation to change in forest cover/area prioritized for conservation: For the tsunami inflicted damage assessment, IRS P6 LISS III data of January 4, 2005 was acquired for the Nicobar Islands and compared with the map generated using IRS 1D LISS III data of January 1999. The post-tsunami vegetation type land cover map was derived and compared with the pre-tsunami scenario prepared using IRS 1-D LISS III data of the year 1999 (IIRS 2003). The pre-tsunami map was prepared by using on screen visual interpretation technique at 1:50,000 scale coupled with detailed ground truth and field inventory.

Since forest types and density of the tropical Islands are not expected to change over a period of 5 years, the information derived from the year 1999–2000 satellite imagery holds potential information for comparative assessment of damage due to tsunami. During the field visits to Car Nicobar, Katchal, Kamorta and Great Nicobar in the year 2002–2004, it was observed that human interference to these Islands was not prevalent therefore any change observed in 2005 satellite imagery can be prejudiced to the tsunami-induced change. The tsunami damage assessment for the Nicobar Islands from the satellite data belonging to January 4, 2005 has been carried out following standard visual interpretation technique using image elements and collateral information. The interpretation elements namely tonal variation, association, signature of different classes was considered following convergence of evidence approach. Local enhancements viz., linear stretching, histogram equalization, etc. were performed while interpreting the satellite data. The conversion of the vegetation and the other land cover has been classified into four main categories namely the area which has submerged in deep water, complete loss of vegetation (severely damaged area) and damaged areas (substantial damage to vegetation and landscape) and the no change areas. The classes have been defined based on the degree of inundation which was interpreted on satellite data.

Biological richness is a cumulative property of an ecological habitat and its surrounding environment, which has emerging implications for conservation and planning (Behera et al. 2005). Mapping biological richness area in Andaman and Nicobar Islands was carried out as part of a Nation-wide project on "Biodiversity characterization at landscape level" (Roy et al. 2005). The BCLL model was designed using the GIS interface combining landscape and field-based information (Roy and Tomar 2000). The model is based on landscape principles, primarily simulating the synoptic view of the ecological infrastructure that allows biodiversity to occur, maintain and change within the wider environment. Different biological richness levels were computed by integrating disturbance index with physical (i.e., terrain complexity), ecological (i.e., species diversity), phyto-sociological (i.e., species endemism, rarity and threatened) and economical (i.e., species importance value) using SPLAM (IIRS 1998). Being a distinct bio-geographical regions, biological richness modeling in Andaman and Nicobar Islands was carried out during 1999–2003 (IIRS 2003) and the results obtained were successfully validated (Roy et al. 2005).

Tsunami impacts in relation to distance from epicenter: In Nicobar, three different groups of Islands (Car Nicobar, Central Nicobar and Great Nicobar) occur and of which Great Nicobar is the closest and Car Nicobar is at farthest distance from the epicenter of tsunami while Central Nicobar is located at intermediate distance. The distances from the epicenter were calculated for Car Nicobar, Central Nicobar (Kachal, Kamorta, Nancowry) and Great Nicobar Island. Further, these Islands were compared in terms of % area mapped under the classes namely submerged, loss of vegetation and damaged.

Tsunami impacts in relation to topographic pattern: The topographic patterns, i.e., elevation map of these Islands was derived from the digital elevation model prepared from Shuttle Radar Topographic Mission (SRTM) data. Further, the vector coverage of the classes viz., submerged, loss of vegetation and damaged were integrated with elevation map to assess the role of topography in the tsunami damage pattern.

Results

Major vegetation types mapped using satellite data include tropical evergreen, mixed evergreen, littoral, mangrove, scrub/shrub and grasslands. Semi-evergreen formation is absent in these Islands. However, mixed evergreen forests occur in small patches. The areal extent of major forest classes shows that the tropical evergreen forest is most dominant and evenly distributed in these Islands. Lowland swamp forest and rubber plantations contribute significantly in the Katchal Island. The grasslands are widely distributed in the Tarasa and the Nancowry group of Islands. Because of its unique flora and fauna the major portion of the Great Nicobar Island has been declared as Biosphere reserve, by the Ministry of Environment and Forest, Government of India. Post tsunami assessment of damage has been carried out in Car Nicobar, Central Nicobar (Nancowry group of Islands) and Great Nicobar Islands (Figs. 2, 3, 4). The assessment primarily shows the spatial changes in vegetation/land cover types and biological richness areas due to tsunami activity and the earthquake. It is observed that in Car Nicobar, mangroves, littoral forest and the lowland swamp forest were most affected. Out of the total 80.7 ha under mixed mangroves available prior to tsunami, 89.4% was devastated after tsunami. More than 74% mixed mangrove area was submerged in deep water, 10.4% was lost and 4.8% was damaged. More than one third of the littoral swamp forest was severely damaged. It is also observed that more than 12% of the mixed evergreen forests are either inundated or severely damaged. The details of vegetation and other land cover types having impact of tsunami are given in Table 1.

Central Nicobar Islands were one of the most severely affected areas due to tsunami. The cause can be attributed to massive upheaval on the ocean floor changing the coastal ecosystem. While analyzing the loss in an earlier study, it was observed that a very heavy loss of mangrove has occurred in Katchal Island (94.3%), Trinket Island (51.5%), Kamorta and Nancowry Islands (42.9%) due to submergence (Porwal et al. 2007). Maximum change (>42%) has been observed in the Trinket Island. The change is because of inundation of the mangrove areas. Most of the mangrove in the middle part of Island has been submerged. The situation might have occurred due to tsunami triggered waves penetrating deep inside the Island through streams. Likewise, agricultural land has also been adversely affected in the northern part of the Island. In the Katchal Island, the mangrove has been submerged under water in the southwest region, where the impact of tsunami was the greatest. However, in the Kamorta and Nancowry Islands, the tsunami has affected the mangrove forests along the entire periphery. The coastal areas having coconut plantation, agriculture and settlement were badly affected. Mangroves, littoral and beach forest and *Syzygium* swamps were the most affected. More than 82% of littoral (beach) forest was either submerged or damaged. Out of the total area available under mixed mangrove, 68% was submerged, lost or damaged and 86.2% *Bruguiera* sp. was submerged, lost or damaged. It was also observed that 15% of the very unique vegetation in these Islands, i.e., *Syzygium* swamp was submerged and more than 12% was either lost or severely damaged (Table 2).

The Great Nicobar and Little Nicobar Islands that are considered most important in terms of floral and faunal biodiversity were severely affected by tsunami waves and upheaval. More than 89% of the mixed mangroves and 86.3% of the littoral beach forest are either submerged or severely damaged. A total of 34% of mixed evergreen forest in Great Nicobar Island submerged due to its occurrence on flat areas nearer to the coast. In this Island, 14% of the unique *Syzygium* swamp was also submerged. A detailed analysis of changes in the major vegetation types and other land cover types is given in Table 3.

The effect of distance from the epicenter of tsunami is clearly understandable from Table 4. Great Nicobar Island located near to the epicenter has suffered highest from the impacts (58.28%), out of total area changed due to tsunami in all the groups of the Islands (Car Nicobar, Central Nicobar and Great Nicobar) (Table 4). Central Nicobar, located at intermediate distance, shared 31.81% of the changed area. While Car Nicobar which is located at longest distance from the epicenter accounted for 9.90% of the changed area. Majority of the submerged areas were found in case of Great Nicobar Island (80% of total submerged area). Whereas loss of vegetation (washed away area) was higher for Central Nicobar (67.59%) as compared to Car Nicobar Island (32.41%). The coastal areas of different groups of Islands contribute to different level of biological richness hence are

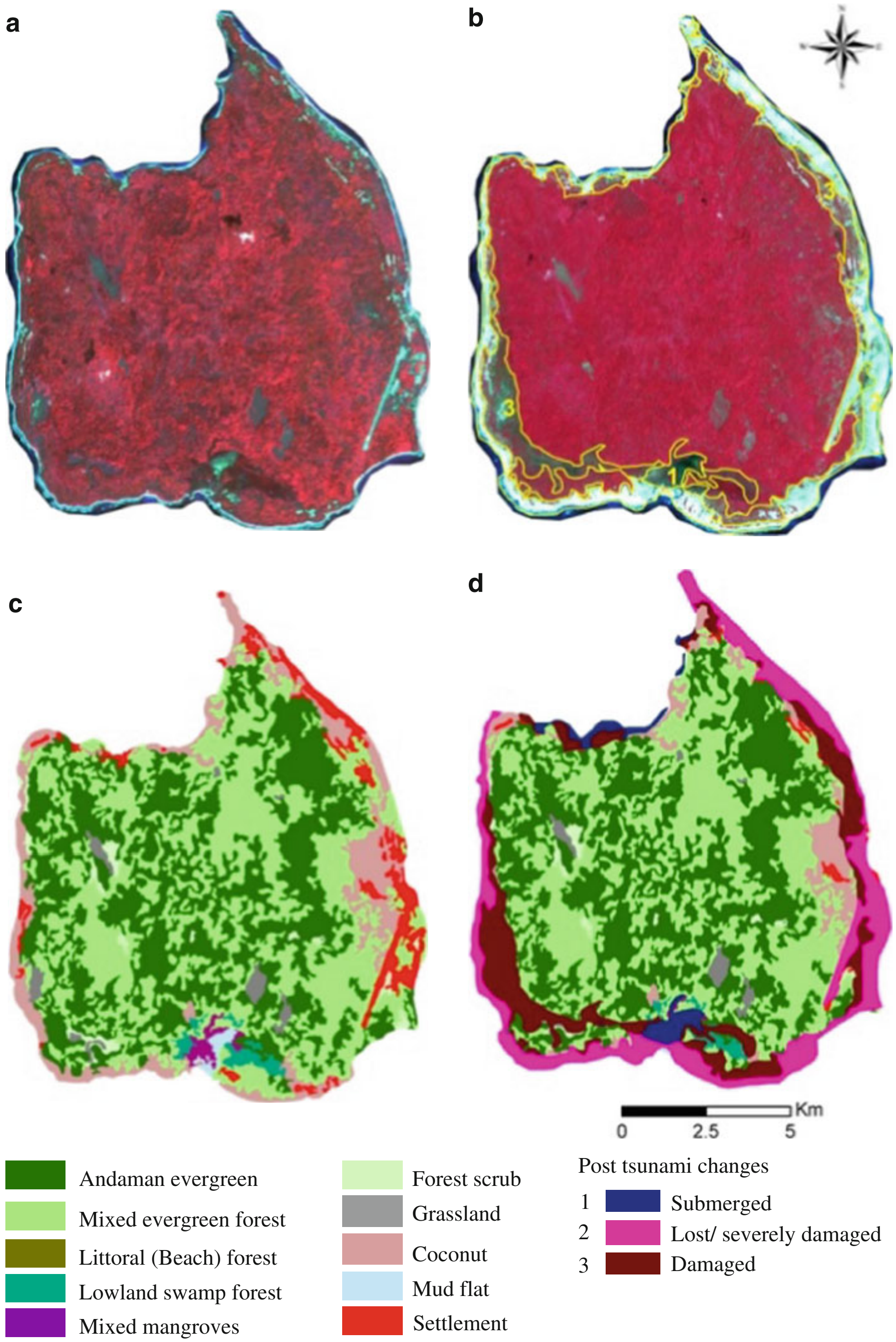

Fig. 2 Car Nicobar Island. **a** Pre tsunami LISS III FCC of year 1999, **b** post tsunami LISS III FCC 2005 of year 2005, **c** vegetation type/land use map of year 1999 and **d** post tsunami status in 2005

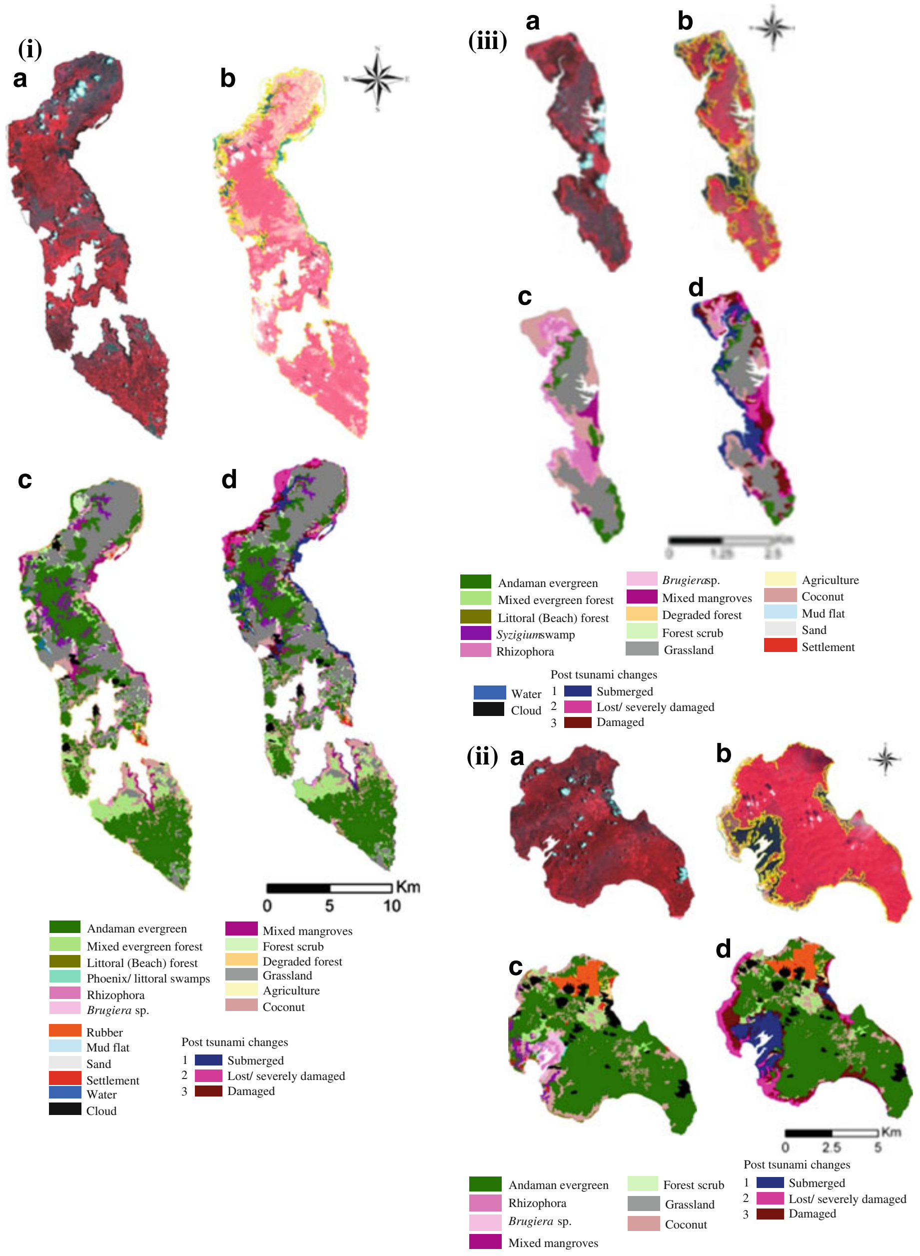

Fig. 3 **i** Kamorta and Nancowry, **ii** Katchal Island and **iii** Trinket Island. (*a*) Pre tsunami LISS III FCC of year 1999, (*b*) post tsunami LISS III FCC of year 2005, (*c*) vegetation type/land use map of year 1999 and (*d*) post tsunami status in 2005

prioritized under low, medium and high biological richness conservation areas. The changes in prioritized categories of low, medium and high biological richness has been different for different Island groups (Figs. 5, 6). This has revealed that 13.6% high

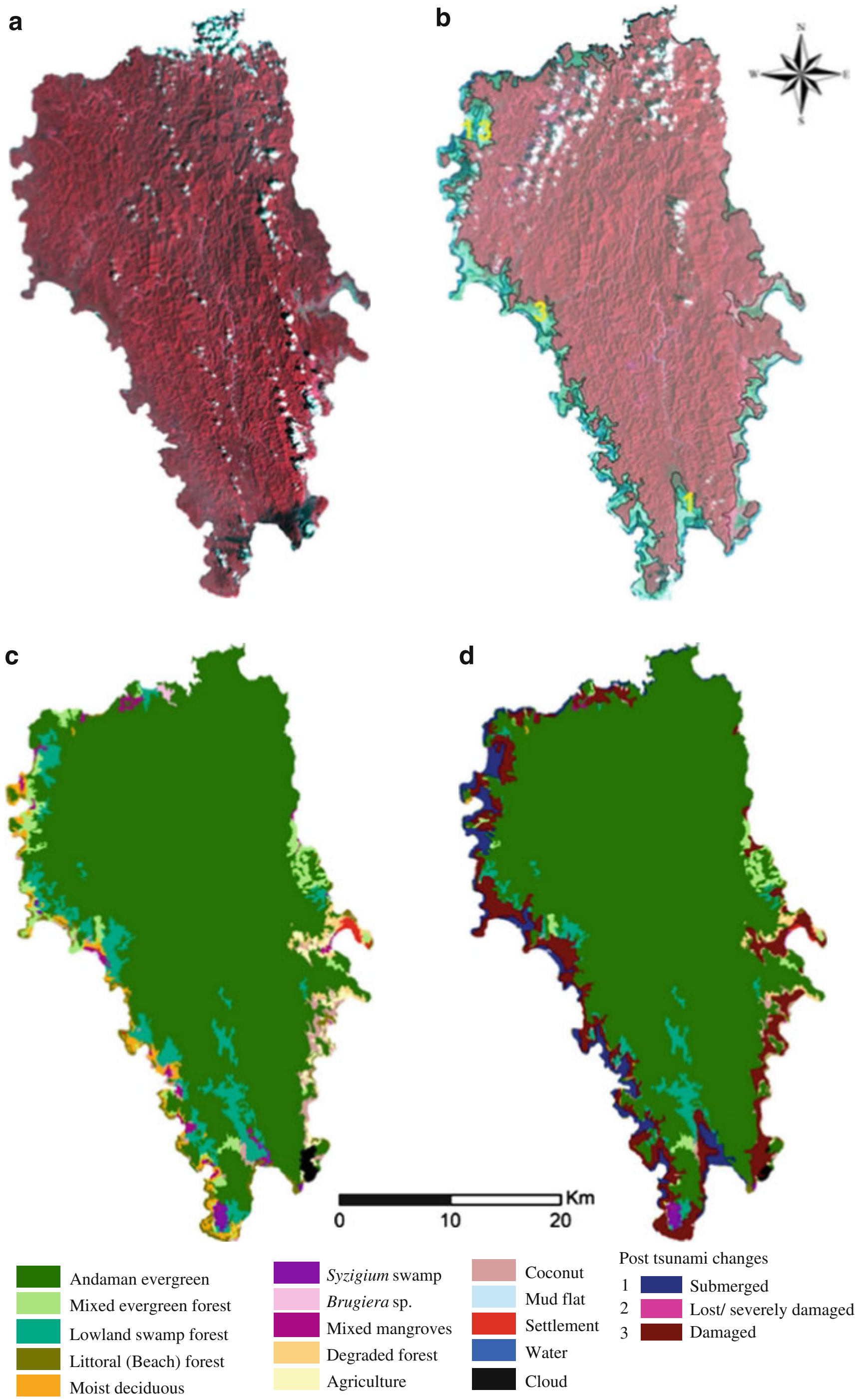

Fig. 4 Great Nicobar Island. **a** Pre tsunami LISS III FCC of year 1999, **b** post tsunami LISS III FCC 2005 of year 2005, **c** vegetation type/land use map of year 1999 and **d** post tsunami status in 2005

Table 1 Impacts of tsunami on major vegetation/land cover types in Car Nicobar Island

Major vegetation/land cover types	Pre tsunami (1999)	No change	Post tsunami change (2005)					
			Submerged		Loss of vegetation		Damaged	
	Area (ha)	Area (ha)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Evergreen	4802.9	4429.9	3.1	0.1	80.5	1.7	289.4	6.0
Mixed evergreen forest	5061.6	4404.0	15.8	0.3	253.5	5.0	388.4	7.7
Lowland swamp forest	140.9	75.5	13.1	9.3	5.5	3.9	46.8	33.2
Littoral (Beach) forest	1.6	0.0	0.0	0.0	0.0	0.0	1.6	100.0
Forest scrub	169.7	104.0	0.0	0.0	22.5	13.3	43.3	25.5
Grasslands	178.1	123.6	0.0	0.0	0.0	0.0	54.5	30.6
Mixed mangroves	80.7	8.6	59.9	74.2	8.4	10.4	3.9	4.8
Mud flat	50.0	0.0	33.9	67.8	12.9	25.7	3.2	6.5
Coconut	1311.3	574.1	12.9	1.0	461.3	35.2	263.0	20.1
Settlement	578.3	71.1	19.4	3.3	346.1	59.8	141.8	24.5

biological richness areas in Central Nicobar Islands (Nancowry group of Islands) and 9.9% of Car Nicobar Islands were either submerged, lost or severely damaged (Table 5).

Figure 7 shows the effect of topography (elevation) on the vegetation area submerged, damaged and lost due to tsunami. Overall, the area under damaged and submergence classes was confined below 45 m elevation but peak damaged and submergence of vegetation occurred below 30 m of elevation. In some of the Islands, loss of vegetation occurred up to 45 m of elevation. High rising tsunami waves damaged and submerged areas up to 75 m elevation. Great Nicobar being closer to epicenter has suffered grater damage in areas where tsunami impacts was received up to 100 m of elevation but majority of damaged vegetation area was confined below 50 m elevation. In Car Nicobar, damage due to vegetation was confined below 30 m elevation. In case of Central Nicobar, vegetation occurring more than 90 m of elevation was damage while majority of damaged occur below 45 m elevation. More than 45 m elevation vegetated areas were submerged in Central and Great Nicobar. However, submergence in Car Nicobar was confined to below 30 m elevation. The area under vegetation loss during tsunami in Car Nicobar was confined below 30 m elevation as compared to Central Nicobar where, vegetation loss has occurred in more than 60 m elevation areas. Great Nicobar (55.77%) accounted for higher proportion of total damaged area in Nicobar, followed by Central Nicobar (27.75%) and Car Nicobar (16.48%) Islands.

The areas submerged/lost or damaged due to tsunami on December 26, 2004 in Nicobar Islands supported large number of species under trees, herbs, shrubs and lianas. Plant species inventory, uniqueness pattern, taxonomic richness, diversity, structural and total importance value patterns of major vegetation types affected by tsunami is given in Table 6. A total of 390 plant species were recorded belonging to 214 genera and 105 families. Evergreen forest accounted for highest number of endemic species (36) and rare (7) species. Mixed evergreen forests are mainly occurring in Car Nicobar and Central Nicobar while low land swamp mainly occurs in Central Nicobar. Mixed evergreen (195) and low land swamp (186) accounted for almost equal number of species. Mangrove forests are rich with 15 tree species. The mean basal area values of evergreen forest was

Table 2 Impacts of tsunami on major vegetation/land cover types in Central Nicobar Islands (Nancowry group of Islands)

Major vegetation/land cover types	Pre tsunami (1999)	No change	Post tsunami change (2005)					
			Loss of vegetation		Submerged		Damaged	
	Area (ha)	Area (ha)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Evergreen	21849.8	19868.9	393.7	1.8	760.8	3.5	826.4	3.8
Mixed evergreen forest	1813.3	1623.7	40.1	2.2	68.1	3.8	81.5	4.5
Littoral (beach) forest	225.7	39.1	20.3	9.0	150.1	66.5	16.3	7.2
Phoenix/littoral swamps	16.0	0.1	12.2	75.8	0.0	0.0	3.8	23.6
Syzygium swamp	999.5	594.5	149.9	15.0	129.2	12.9	125.9	12.6
Degraded forest	186.6	146.6	1.0	0.5	6.4	3.4	32.6	17.5
Forest scrub	685.6	578.3	9.9	1.4	84.3	12.3	13.1	1.9
Padauk plantation	10.7	10.7	0.0	0.0	0.0	0.0	0.0	0.0
Teak plantation	30.6	27.4	0.0	0.0	0.4	1.2	2.9	9.4
Grasslands	10095.8	9674.5	41.7	0.4	120.2	1.2	259.5	2.6
Waste lands	6.3	4.5	0.0	0.0	1.8	28.6	0.0	0.0
Rhizophora sp.	964.9	428.9	496.1	51.4	9.1	0.9	30.8	3.2
Bruguiera sp.	516.6	71.4	412.3	79.8	5.8	1.1	27.2	5.3
Mixed mangroves	845.5	269.6	403.3	47.7	107.5	12.7	65.1	7.7
Agriculture	108.1	95.3	0.0	0.0	3.8	3.5	9.0	8.3
Settlement	279.3	88.8	37.2	13.3	106.0	38.0	47.3	16.9
Coconut	6342.7	4591.0	313.7	4.9	906.6	14.3	531.5	8.4
Rubber	708.3	706.3	0.0	0.0	0.0	0.0	2.0	0.3
Mud flat	27.2	3.4	20.9	76.8	0.3	1.0	2.6	9.6
Sand	9.1	1.6	0.0	0.0	6.6	72.3	0.9	9.9
Water	69.1	17.7	32.0	46.2	16.5	23.8	3.0	4.3
Cloud	1352.5	–	–	–	–	–	–	–

highest (71.59 m^2/ha), followed by mixed evergreen forests (47.14 m^2/ha). Littoral swamp and low land swamps possesses 22 and 14 endemic species, respectively.

Some of the rare plants species occurring in the coastal habitats which have received deleterious impacts of tsunami were: *Barringtonia apendula*, *Bauhinia stipularis*, *Pomatocalpa andamanicum*, *Psychotria platyneura*, *Schefflera longifolia*, *Ixora tenuifolia*, *Cratolari apallida*, *Tinomiscium nicobaricum*, *Tinomiscium petiolare*, *Psilotum nudum*, *Psilotum complanatum*, etc.

Endemic species encountered in the habitats were: *Codiocarpus andamanicus*, *Cyrtandroemia nicobarica*, *Eria andamanica*, *Pandanusleram* var. *andamanensium*, *Semecarpus kurzii*, *Syzygium andamanicum*, *Uvaria nicobarica*, etc.

Discussion

Andaman and Nicobar Islands comprising of 0.03% of the India's land- mass has about 86% of the total geographical area under very fragile tropical rain forest (Rao 1989). About

Table 3 Impacts of tsunami on major vegetation/land cover types in Great Nicobar group of Islands

Major vegetation/ land cover types	Pre tsunami (1999)	No change	Post tsunami change (2005)			
			Submerged		Damaged	
	Area (ha)	Area (ha)	Area (ha)	Area (%)	Area (ha)	Area (%)
Evergreen	93317.1	89321.1	3034.2	3.3	961.8	1.0
Mixed evergreen forest	2644.1	1240.7	897.8	34.0	505.6	19.1
Moist deciduous	1717.1	90.8	1048.8	61.1	577.5	33.6
Lowland swamp forest	6109.8	2933.7	2531.7	41.4	644.4	10.5
Littoral (beach) forest	1820.7	249.4	834.4	45.8	736.9	40.5
Syzygium swamp	297.5	255.8	41.7	14.0	0.0	0.0
Degraded forest	701.4	477.3	224.1	32.0	0.0	0.0
Mixed mangroves	927.1	98.4	297.1	32.0	531.6	57.3
Bruguiera sp.	230.9	45.6	171.4	74.2	14.0	6.0
Mud flat	13.4	0.0	0.0	0.0	13.4	100.0
Agriculture	844.0	142.6	701.5	83.1	0.0	0.0
Coconut	1452.5	525.6	753.7	51.9	173.3	11.9
Settlement	189.5	16.5	168.8	89.1	4.2	2.2
Water	21.0	0.1		0.0	20.9	99.6
Cloud	319.1	–	–	–	–	–

40% of the flora of these Islands is absent in mainland India (Balakrishnanan 1989). Natural disasters, like tsunami cause irreparable loss to the vegetation, biodiversity, agriculture and habitation in the areas where they occur. Even in the most developed nation like Japan more than 25,000 people are feared dead. Present study after the tsunami on December 26, 2004 in Nicobar Islands demonstrates the efficacy of remote sensing and GIS in assessment of damage on one hand and subsequent assessment of forest and biodiversity, which was affected due to such catastrophe. Present study has provided an assessment of the vegetation cover, forest habitats, biodiversity and key sites that have been affected due to submergence, loss of vegetation and damage. The results indicated that lowland forest viz., mangroves, lowland swamps, littoral forest and the mixed evergreen forest, which occur in low land areas and exposed to sea-water were most affected. Some of the lowland areas in these Islands, especially Great Nicobar Island is supporting important species like Tree Fern (*S. nicobarica* and *S. albosetacea*) and the other unique vegetation, i.e., *Syzygium* swamps. Since post tsunami assessment pertain to satellite data belonging to January 4, 2005, this study addresses the immediate impacts of tsunami apparent on satellite remote sensing data. The damage in the coastal habitats/mangroves could easily be interpreted on satellite remote sensing data due to submergence/inundation. Subsequent to this study, regular monitoring of these areas is also considered to be important for long term assessment.

In Nicobar groups of Islands, moist deciduous formations are found only towards the southern parts of Great Nicobar Island, and a large proportion of this forest was lost and severely damaged during tsunami. Even the population of species such as *Terminalia procera*, *Thunbergia fragrans* occurring in the dense forest got affected. The analysis of effect of topography and distance from the epicenter of the tsunami revealed that both

Table 4 Impacts of tsunami to different group of Islands with respect to distance from the epicenter

Islands group	Distance from epicentre (km)	Pre Tsunami (1999)	No change	Post tsunami change (2005)							
				Changed	Changed	Submerged		Loss of vegetation		Damaged	
		Area (ha)	Area (ha)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Car Nicobar	741	12375.1	9790.8	2584.3	9.90	158.1	1.19	1190.7	32.41	1235.9	16.48
Central Nicobar	597	47143.2	38842.3	8300.9	31.81	2384.3	18.00	2483.5	67.59	2081.4	27.75
Great Nicobar	445	110605.2	95397.6	15207.6	58.28	10705.2	80.81	–	–	4183.6	55.77
Total area		170123.5	144030.7	26092.8	100.00	13247.6	100.00	3674.2	100.00	7500.9	100.00

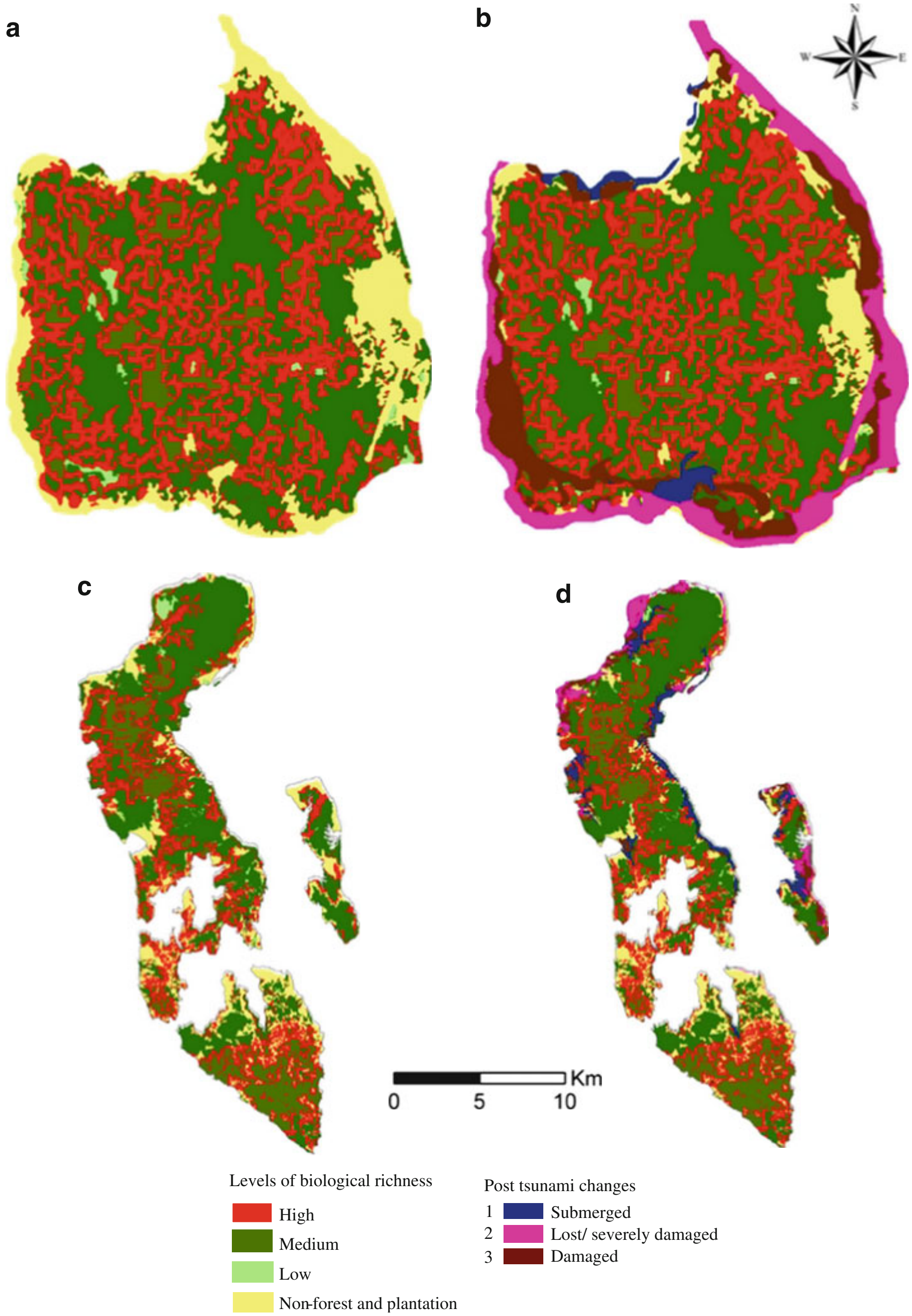

Fig. 5 Car Nicobar, Kamorta, Nancowry, Trinket Islands. **a** Biological richness map of 1999, **b** post tsunami status of biological richness of year 2005

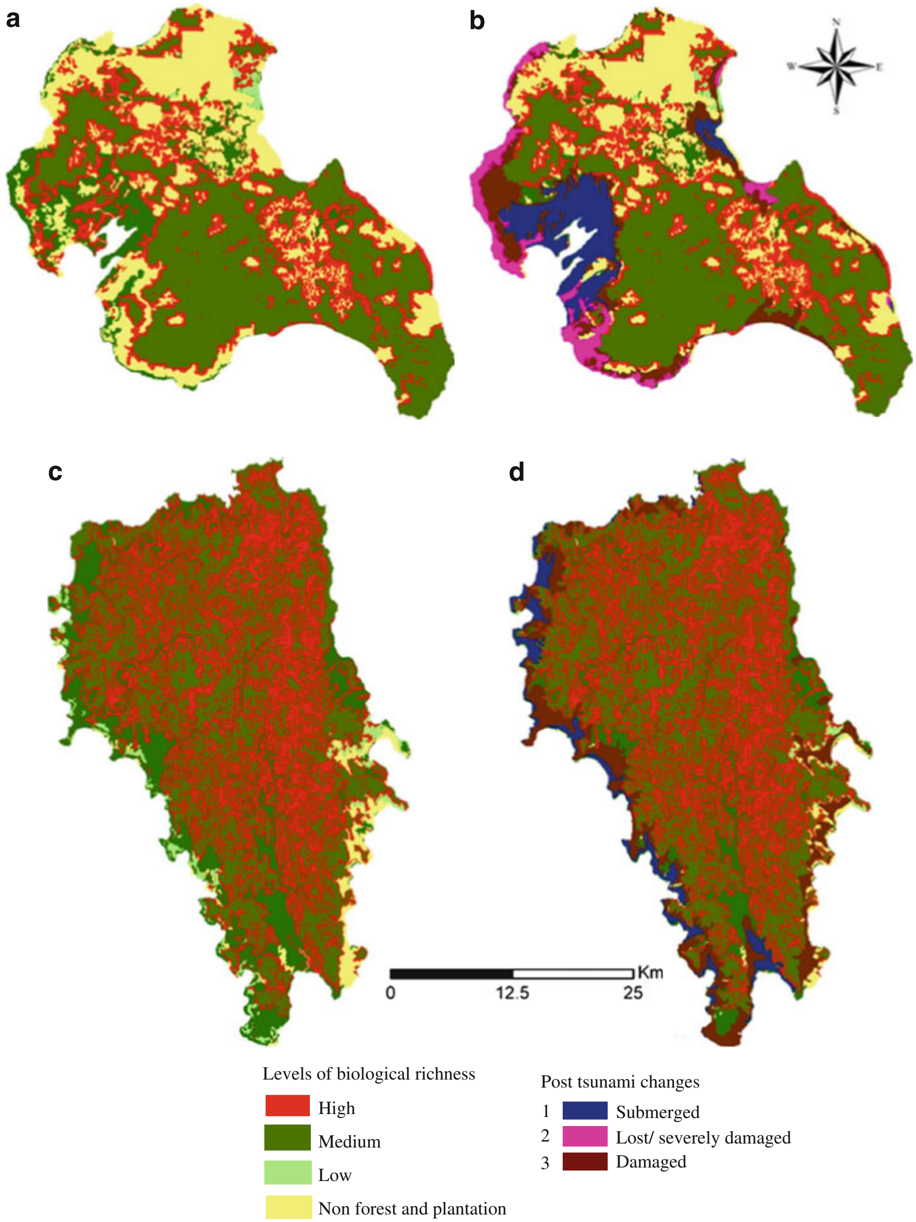

Fig. 6 Kachal and Great Nicobar Island. **a** Biological richness map of 1999, **b** post tsunami status of biological richness of year 2005

these variables has significant influence on the severity of damaged forest cover and areas prioritized for biodiversity conservation in different groups of Islands in Nicobar. Although extent of damage may also differ due to differences in the sizes of different Islands as Great Nicobar being largest in size followed by Central Nicobar and Car Nicobar; yet coastal topography and distance from the epicenter has profound impacts on damage pattern in

Table 5 Biological richness areas affected by tsunami in Nicobar Islands

Biological richness	Pre tsunami (1999)	No change	Area changed	Area changed	Post tsunami change (2005)					
					Submerged		Loss of vegetation		Damaged	
	Area (ha)	Area (ha)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Car Nicobar Island (741 km distance from the epicenter of tsunami)										
Low	1811	692.2	1118.8	4.65	30.7	0.25	615.7	12.12	472.5	7.28
Medium	5902.3	5138.1	764.2	3.18	83.5	0.67	294.8	5.81	385.9	5.94
High	4170.5	3756	414.5	1.72	41.7	0.33	131.1	2.58	241.6	3.72
Central Nicobar Islands (597 km distance from the epicenter of tsunami)										
Low	7677.7	5810.9	1866.8	7.76	616.4	4.94	409.9	8.07	840.6	12.94
Medium	25095.8	22495.3	2600.5	10.81	790.5	6.34	1138.3	22.42	671.6	10.34
High	11238.4	9709	1529.4	6.36	538.8	4.32	584.2	11.50	406.4	6.26
Great Nicobar Islands (445 km distance from the epicenter of tsunami)										
Low	4721.2	1239.3	3481.9	14.48	2412	19.34	564.1	11.11	505.8	7.79
Medium	66129.1	56151.8	9977.3	41.49	6395.8	51.27	1059.1	20.86	2522.5	38.84
High	40254.2	37961	2293.2	9.54	1564.8	12.54	280.9	5.53	447.4	6.89
Total	167000.2	142953.6	24046.6	100	12474.2	100	5078.1	100.0	6494.3	100

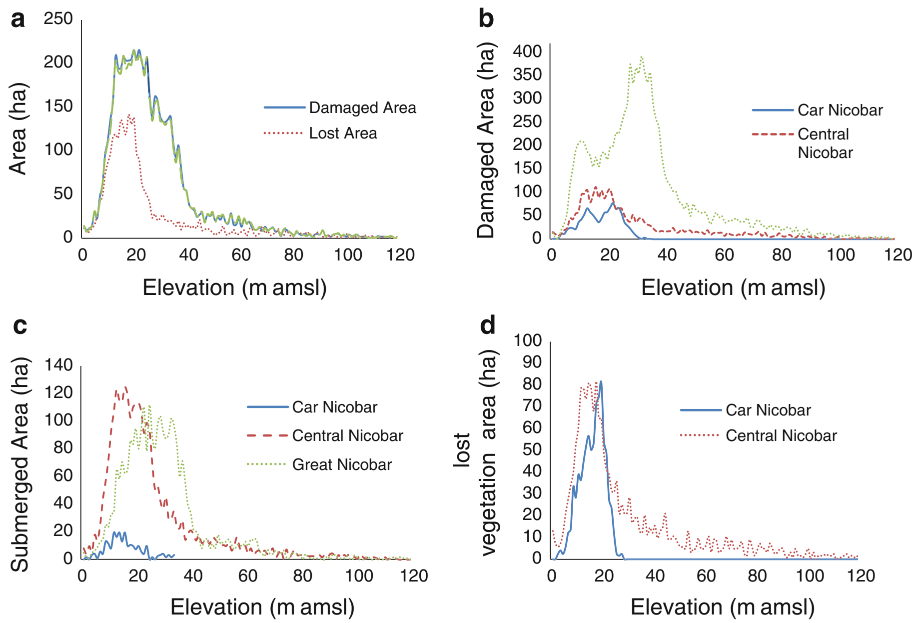

Fig. 7 Effect of coastal topography (elevation) on damage, submergence and loss of vegetation caused by tsunami in Nicobar (**a**) and different groups of Islands (**b**, **c**, **d**)

case of Nicobar groups of Islands. In case of Car Nicobar and Central Nicobar (mainly Trinket and Kachal Islands) topography along the coast are mainly flat. In these areas, vegetation (beach vegetation) was washed away by the tsunami resulted in the formation of larger beaches and were clearly identifiable on the satellite data due to high reflection from the sandy beaches. While in case of Great Nicobar majority of the coasts are elevated therefore loss of vegetation has not occurred to the proportion that it could be mapped using LISS III data.

Tsunami has also induced fragmentation in the forest/vegetation. Most of the vital habitats of rare species such as *P. complanatum* encountered in the littoral forest and endemic species are now likely to be disturbed or damaged by anthropogenic activities. Submergence, inundation and damage to habitats may impact or alter the patterns of vegetation, expose interior species, favor spread of invasive species and expansion of mono species plantation, etc. Mangrove, *Syzygium* and low land swamps and littoral vegetation possesses lower species richness in comparison to inland evergreen and mixed evergreen formations. Rasingam and Parathasarathy (2009) reported ten times lower tree density in the tsunami affected littoral forests as compared to the undisturbed littoral forest in Little Andaman Islands. These effects may be several times greater in Nicobar Islands as these Islands were more severely hit as compared to Andaman Islands. Likely effects of tsunami on the forest structures of Nicobar Islands resembles with the studies in Sri Lanka by Fernando et al. (2006) where they reported effects of tsunami on the vegetation in terms of complete uprooting, partially uprooting, dead, standing but defoliated and broken trees. Low lying habitats of the Nicobar Islands are also associated with a variety of faunal species, particularly the habitats of Crab-eating-Macaque and Nicobar Megapode were either lost or severely damaged due to tsunami. The beaches in Great Nicobar which were the nesting ground of sea turtles were also affected due to submergence. Around 70% of

Table 6 Diversity, structure and economic values patterns of major vegetation types affected by tsunami in Nicobar Islands

Vegetation types	Tree	Shrub	Herb	Climber	Epiphyte	Endemic	Rare	Genera	Families	Species diversity	Mean basal area (m^2/ha)	TIV
Evergreen	127	24	118	72	6	36	7	214	105	6.99	71.59	19.13
Mixed evergreen	87	18	22	41	1	21	5	150	87	6.39	47.14	20.07
Littoral swamp	70	25	24	36	6	22	3	134	75	6.21	38.05	20.62
Syzygium swamp	7	2	4	–	–	–	–	21	16	3.7	30.76	22.33
Lowland swamp	41	9	6	18	2	14	5	75	45	5.39	36.81	25.73
Mangrove	15	8	–	8	2	5	2	33	23	3	27.9	40.94
Grassland	1	3	19	–	–	5	2	46	32	5.31	–	14.56

the population of Nicobar Megapode had disappeared and it is apparent that this was primarily due to the tsunami that washed away their habitat along with nests (Sivakumar 2007). Specific measures should be taken for preservation and conservation of areas which are ecologically more fragile and supporting rare and endangered flora and fauna like Great Nicobar Island (Galathea Bay) which was the nesting ground for the famous Giant Leather Back turtle.

Acknowledgments The authors acknowledge the contribution of Stutee Gupta and Nidhi Chauhan, Biodiversity characterization team members before the tsunami and Dr. P. K. Hajra, Ex Director, Botanical Survey of India for identification of plant species. Authors also acknowledge the support of officials of forest department, Andaman and Nicobar Islands during the field work for sampling in different vegetation types for assessment of biodiversity.

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