NATURAL RECOVERY OF TSUNAMI IMPACTED LITTORAL AND MANGROVE FORESTS IN NICOBAR ISLANDS, INDIA

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DEGREE OF DOCTOR OF PHILOSOPHY

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BOTANY

by

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COIMBATORE – 641 108

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CERTIFICATE

This is to certify that the thesis entitled "**Natural recovery of tsunami impacted littoral and mangrove forests in Nicobar Islands, India**" submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Botany is a record of original research work done by Mr. P. Nehru during the period 2009 – 2012 of his study in the Division of Landscape Ecology at Sálim Ali Centre for Ornithology and Natural History (SACON) under my supervision and guidance and the thesis has not formed the basis for the award of any Degree / Diploma / Associateship /Fellowship or other similar title to any candidate of any University.

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DECLARATION

I Mr. P. Nehru hereby declare that the thesis, entitled "**Natural recovery of tsunami impacted littoral and mangrove forests in Nicobar Islands, India**" submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Botany is a record of original and independent research work done by me during 2009 - 2012 under the supervision and guidance of Dr. P. Balasubramanian, Principal Scientist, Division of Landscape Ecology, Sálim Ali Centre for Ornithology and Natural History (SACON) and it has not formed the basis for the award of any Degree / Diploma / Associate ship / Fellowship or other similar title to any candidate in any University.

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CHAPTER I

INTRODUCTION

1.1. Tropical Islands

The islands in tropical countries are bestowed with high species diversity that contributes enormously to the biodiversity of the world. Most of the tropical islands are included in the world's hot spot of biodiversity by IUCN (Mittermeier et al., 2004) which is a testimonial for the importance of Island biodiversity. About one in six of the world's plant species grows on oceanic islands, while one in three of all known threatened plants are island forms (Groombridge, 1992). In terms of plant biodiversity, the islands make a disproportionate contribution and are also suffering further disproportionate pressure in terms of the maintenance of the biodiversity. Due to the small geographical distribution and isolation from multiple predators, island species are more vulnerable to disturbances and hence the high extinction rates are reported for Island endemics. Humans have influenced the ecology of islands in many ways, but the most profound must surely be the extinction of numerous island races and species (Whittaker, 1998).

1.2. Natural disturbances and tropical forests

Natural calamities of various kinds and scales keep posing threat to the living organisms since the origin of the earth. The major natural disasters such as hurricanes, flood, landslide and drought causes long lasting impacts on the human society and biodiversity. However, these natural processes were accounted for the evolution and shaping of biological communities in an ecosystem (Chazdon, 2003). The process through which an ecosystem respond and recover from such natural disturbances have enthused many ecologists who study the dynamics of tropical ecosystems (Herbert et al., 1999; Vandermeer et al., 2000; Guariguata and Ostertag, 2001; Chazdon, 2003). The island communities are frequently affected by storms and sea erosion. Rare events like tsunami and volcanic eruptions can devastate large extend of coastal environs and cause considerable damage to the coastal biodiversity especially in the Oceanic Islands.

1.3. Tsunami: a natural disaster

The term tsunami is from Japanese, (tsunami= *tsu*-harbour, *nami*-wave) and was coined by fishermen who returned to port to find the harbour devastated, although they had not been aware of any wave in the open water. Tsunamis are generated mainly due to sudden displacement of the sea bottom surface that generates near vertical disruption of the water column. Such a phenomenon can occur usually due to the onset of massive earthquakes under the sea due to tectonic plate movements. Other than the earthquake of high magnitude, volcanic eruptions, displacement of marine sediments, landslides near the coast, manmade nuclear explosions in the sea, and meteor impact from space can also results in a tsunami (Harinarayana and Hirata, 2005). Typically, a tsunami may have a period of over 60 minutes and a wavelength in excess of 100 km, whereas a wind-generated wave may have a period of 10 seconds and a wavelength of 150 m (Kaul and Menon, 2005). A tsunami can cause damage to thousands of kilometres from its origin, so there may be several hours between its creation and impact on a coast, arriving long after the seismic wave generated by the originating event.

The velocity of tsunamis varies and it depends on many parameters such as the bathymetry, height of the originating wave, initial pressure changes in the sea, etc. and can travel with a velocity of more than 1000 km/hour. Since the velocity is proportionate to the depth of the water column at the location, near the shore the velocity reduces to a few tens of kilometers. However, the wave height can reach tens of meters and run up increases to as large as 100 m in extreme cases (Tinti, 1991). A tsunami wave can divide at the shore or break and sometimes appear as flooding with water rushing inside the land more violently with great force towards a river or stream course. When the tsunami wave reaches the shore, the sea shallows and the wave no longer travels as quickly, the water level of the sea may drop significantly as if the sea water is receding to large distance and it comes back more violently with faster speed. These waves may repeat within a gap of minutes or even an hour and sometimes the later events may cause more severe damage (Harinarayana and Hirata, 2005).

1.4. The Indian Ocean tsunami

An earthquake of 9.3 Mw magnitude occurred on 26th December 2004, with its epicenter located at shallow depths of seabed at 3.29°N and 95.94°E off the coast of Sumatra in the Indonesian Archipelago at 06:29 h IST in water depth about 1300 m with its hypocenter located relatively at about 30 km below the ocean floor (Chadha et al., 2005). This earthquake triggered a massive tsunami which traveled in the open ocean with a speed of about 800 km/hour and reached to about 4500 km within 7 hours touching far away countries in African coast.

1.4.1. Global level impact of tsunami

The coastal regions of Asian countries in the Indian Ocean, Bay of Bengal and Arabian Sea have experienced adverse effects of the tsunami. Among the 18 countries affected by tsunami, Indonesia, Sri Lanka, Maldives, India and Thailand were the worst affected nations in terms of loss of human lives, infrastructure and economy. The human death toll was estimated to be over 250,000 and at least 2 million people were displaced (Telford et al., 2006).

Aftermath of tsunami had posted hostile impacts on the coastal areas of India, Sri Lanka and the South East Asian countries. The coastal vegetation including mangroves, coastal dune vegetation and coastal terrestrial forest in the affected regions suffered a considerable damage (Danielsen et al., 2005; Hayasaka et al., 2009; Giri et al., 2008). Maximum damage occurred in regions where heavy human disturbance had either wiped off or significantly reduced the coastal vegetation, mangrove forests and coral reefs (Kathiresan and Rajendran, 2005). However, the mangrove forests have attenuated the Indian Ocean tsunami waves and protected coastal communities in Indonesia, Thailand, India and Sri Lanka (Danielsen et al., 2005; IUCN, 2005; Kathiresan and Rajendran, 2005). Studies from Thailand and Sri Lanka have recorded considerable change in the species diversity of herbaceous beach vegetation after tsunami (Fernando et al., 2006; Hayasaka et al., 2009; Hayasaka et al., 2012).

Immediately after tsunami, the huge pile of washed off material debris got accumulated and sediment on the coastal environs (Hawkes et al., 2007; Yan and Tang, 2009). The suspended sediment concentration in the North East Indian Ocean increased drastically (Yan and Tang, 2009). The waste material sedimentation over the coral reefs and sea grass beds has further depleted these highly affected ecosystems (Sankaran, 2005). Drastic changes in the coastal landscapes such as widened river mouths, formation and disappearance of beaches by sand deposition and sea erosion, increased levels of salinity in coastal fresh water wetlands, loss of agriculture lands due to increased salinity in soil substratum (Sankaran, 2005; Fagherazzi and Du, 2008; Hulugalle et al., 2009).

1.4.2. Effects of Tsunami in India

The entire coastal line of India had been impacted by the tsunami (Kaul and Menon, 2005). The damage levels were high in the eastern coast when compared with the Western coast. Andaman and Nicobar Islands, Tamil Nadu, Andhra Pradesh and Kerala were the worst affected states in India (Kumar et al., 2008). The human death toll was estimated to be over 12,000 and casualties were high in Tamil Nadu and Andaman and Nicobar Islands.

Bio-physical impacts of tsunami on the marine environments were assessed by many researchers immediately after tsunami. The beach profile and coastal line in the eastern coast of mainland India was observed to be dynamic and not reached normalcy even after 2 years from the tsunami (Kumar et al., 2008, Pari et al., 2008). Ranjan et al. (2008) studied the geochemical impact of tsunami on Pichavaram mangroves and observed that a change in mangrove sediment profile and high levels of Nitrogen and Phosphate in the coastal waters. Mascarenhas and Jayakumar (2008) observed that the sand dunes and Casuarina vegetation had significantly reduced the tsunami damage levels when compared with the damage levels at open areas in South east coast of India. Similarly, Kathiresan and Rajendran (2005) recorded that the villages sheltered by mangrove forests had less impacted by tsunami. Narayana et al. (2007) studied the post tsunami sediment characteristics of the west coast of India and demonstrated a significant exchange of materials from the shelf and near shore zones to beach and estuarine environments.

1.5. Tsunami impact in the Nicobar Islands

Andaman and Nicobar Islands situated in the Bay of Bengal was the worst affected state in India. Among these two groups of Islands, Nicobar was the worst affected in terms of human lives and the infrastructure owing to its immediate vicinity to the epicenter of the earthquake. About 10% of the human population in the Nicobar Islands lost their lives and heavy damage had occurred to the infrastructure. In particular, the subduction of Indian plate under the Burma plate during mega earthquake resulted in a tilt in the land, with the southernmost Nicobar Islands having sunk by about 1.75 m and the northernmost Andaman Islands having risen by about 1.2 m relative to the sea-level. This effect had caused sea water incursion in the low lying areas of Nicobar Islands where most of the human settlements were present. Thus, the Nicobar group of Islands was not only affected by the tsunami but also by the land tilt (Ramachandran et al., 2005; Porwal et al., 2012).

The tsunami had significantly damaged all vegetation that existed in the coastal area between the beach and the hill, up to a height of 10–12 m ASL, and at a few places higher still, this depending on the run ups (Sankaran, 2005). The coastline had been altered, promontories destroyed, smaller inundations straightened, and adjacent bays have been joined. Coastlines have receded towards the hills, at places by several hundred meters, often resulting in very little or no land between the hills or high ground and the sea. Several new islets have been formed by breaking off from the main island (Sankaran, 2005; Kumar et al., 2007; Bahuguna et al., 2008). It is to be noted that the Megapode Island in the Great Nicobar group which was largely covered by mangrove vegetation prior to tsunami got totally drowned into the sea after tsunami. Apart from a single scorched tree stump in the middle of the sea, there is no evidence available on the existence of this Island.

1.5.1. Impacts of tsunami on vegetation

The terrestrial vegetation on coastal plains and the mangrove vegetation of the Nicobar Islands were severely damaged by the tsunami and the land tilt resulted sea incursion (Figs. 1.1 and 1.2). The major impacts of tsunami on vegetation were,

i. The tsunami waves had uprooted most of the littoral and mangrove vegetation

ii. High level of salt stress immediately after tsunami resulted in scorching of all the terrestrial vegetation that survived tsunami force

iii. Tectonic submergence resulted in loss of low lying coastal plains, hence the loss of littoral habitats

iv. Perennial submergence of pneumatophores resulted in the scorching of mangrove trees due to the hypoxic condition

1.6. Objectives

The post-tsunami studies describing the impacts of tsunami on the Nicobar vegetation is rather scanty. Ramachandran et al. (2005) and Sridhar et al. (2006) studied the damages sustained by mangrove habitats. Both these studies have explained the loss of about 60–70% of the mangrove forest in Nicobar Islands. Porwal et al. (2007, 2012) studied forest cover changes due to tsunami in the coastal habitats of entire Nicobar Islands. All these studies (Ramachandran et al., 2006, Sridhar et al., 2006; Porwal et al., 2007 and 2012) focused only

Figure 1.1. Impacts of tsunami on littoral forest (a) heavy deposition of uprooted littoral trees at Nyikalang, Kamorta (b) scorched littoral forest at West bay, Katchal.

Figure 1.2. Effect of tsunami on mangrove forest (a) unaffected mangrove forest at Kimios, Car Nicobar (b) deposition of uprooted mangrove trees at Chinlak, Noncowrie (c) Scorched mangrove trees at Safed balu, Trinket.

on satellite remote sensing data. As there was a lack of field based information on the impact of tsunami on the vegetation, the present study was carried out. The objectives are as follows,

i. To study the vegetation recovery and influence of soil substrate on the vegetation succession in tsunami impacted littoral forests

ii. To study the impacts of tsunami on the mangrove forests and asses the natural colonization of mangrove species

1.7. Field work

The study was initiated 5 years after the tsunami in 2009. The field work was carried out in three consecutive years. The first season commenced during 2009 October and extended till May 2010 spanning 8 months. Similarly, the second season started in October 2010 and extended till July 2011 spanning 10 months.

1.8. Organization of thesis

Chapter 1. In the introductory chapter, the impacts of tsunami on the coastal biodiversity of Nicobar Islands have been illustrated. A detailed background and objectives of the study is also given.

Chapter 2. A brief description and the importance of the biodiversity of Nicobar Islands and the study forest types littoral forest and mangrove forest is provided. In addition, detailed description of the study locations distributed over 14 Islands of Nicobars is given with maps.

Chapter 3. Natural recovery of littoral forest after tsunami is discussed in detail. The two types of secondary vegetations namely Sandy Regenerating Vegetation (SRV) and Sand-Loamy Regenerating Vegetation (SLRV) are described and the vegetation recovery is compared with the unaffected forest (UF). In addition, influence of soil substratum on vegetation recovery is illustrated.

Chapter 4. Rate of vegetation change in the two vegetation types during the course of the study is described. The same is compared with UF to predict the recovery of species diversity, stem density and basal area on a long run.

Chapter 5. Impact of tsunami on the mangrove vegetation is described. The natural colonization of various mangrove species in different mangrove zones was illustrated.

Chapter 6. In the final chapter of my thesis, I tried to suggest site specific restoration measures for the habitat restoration of both littoral and mangrove forest. The potential sites for restoration and seed material collection are suggested based on the outcome of the study and my experience with the coastal vegetation of Nicobar Islands.

Chapter 7. A summary of the thesis is provided.

CHAPTER II

STUDY AREA

2. 1. Geography

The Nicobar Islands in the Bay of Bengal are peaks of a submerged mountain range Arakkan Yoma arching from the Andaman Islands in the north to Sumatra in Indonesia in the south, between latitudes 6°45′ and 9°15′ and longitudes 92°42′ and 93°50′ with a total area of 1,841 km^2. Geologically young in age, presumably formed sometimes in upper Mesozoic (*ca* 100 million years ago). Principal nature of the rocks can be said as soft micaceous and sandstone and are younger in origin than the Andaman Islands (Sinha, 1999). This group of island is geographically separated from the close by Andaman group of Islands by the Ten degree channel at its northern boundary. This island group comprises 22 islands of which 11 are inhabited by humans.

The Nicobar group of Islands is broadly classified into three subgroups (Fig. 2.1). The Car Nicobar group is situated at the northern most part and comprised of two islands namely, Car Nicobar and Batti Malve. The Nancowry group in the center of the Nicobar group is situated 88 km south of Car Nicobar group. This group consists of three islands (Kamorta, Katchall and Teressa) larger than 100 km^2, two of 36 (Trinket) and 67 km^2 (Nancowry), three less than 17 km^2 (Tillanchong, Bombuka and Chowra), one islet and a few rocks. Seven islands in this group are inhabited by humans. The Great Nicobar group in the southern boundary of the entire island group is situated 58 km south of the Nancowry group. It consists of two islands, larger than 100 km^2 (Great Nicobar and Little Nicobar), eight islets smaller than 5 km^2 (Kondul, Pilo milo, Menchal, Pigeon, Kobra, Treis, Trak, Mereo), and a few rocks. The Megapode Island in this group was completely drowned in the sea after tsunami. Out of ten islands in this group, three are inhabited by humans. Topographically, each group of Islands has coastal areas where topography varies from flat to undulating and elevated areas. The highest elevation is 670 m ASL at Mount Thullier in Great Nicobar Island.

2.2. Climate and soil

The climate of the Nicobar Islands is humid, tropical coastal climate. Proximity to the equator and the sea ensures a hot, humid, and uniform climate (Saldanha, 1989). These islands receive rainfall from both southwest and northeast monsoons. Maximum precipitation is between May and December, the driest period being January–April. The mean annual rainfall is about 3800 mm (Saldanha,1989). Temperature variations are low from a minimum of 20°C to a maximum of about 32°C (Dagar et al, 1991). The soil shows considerable variation

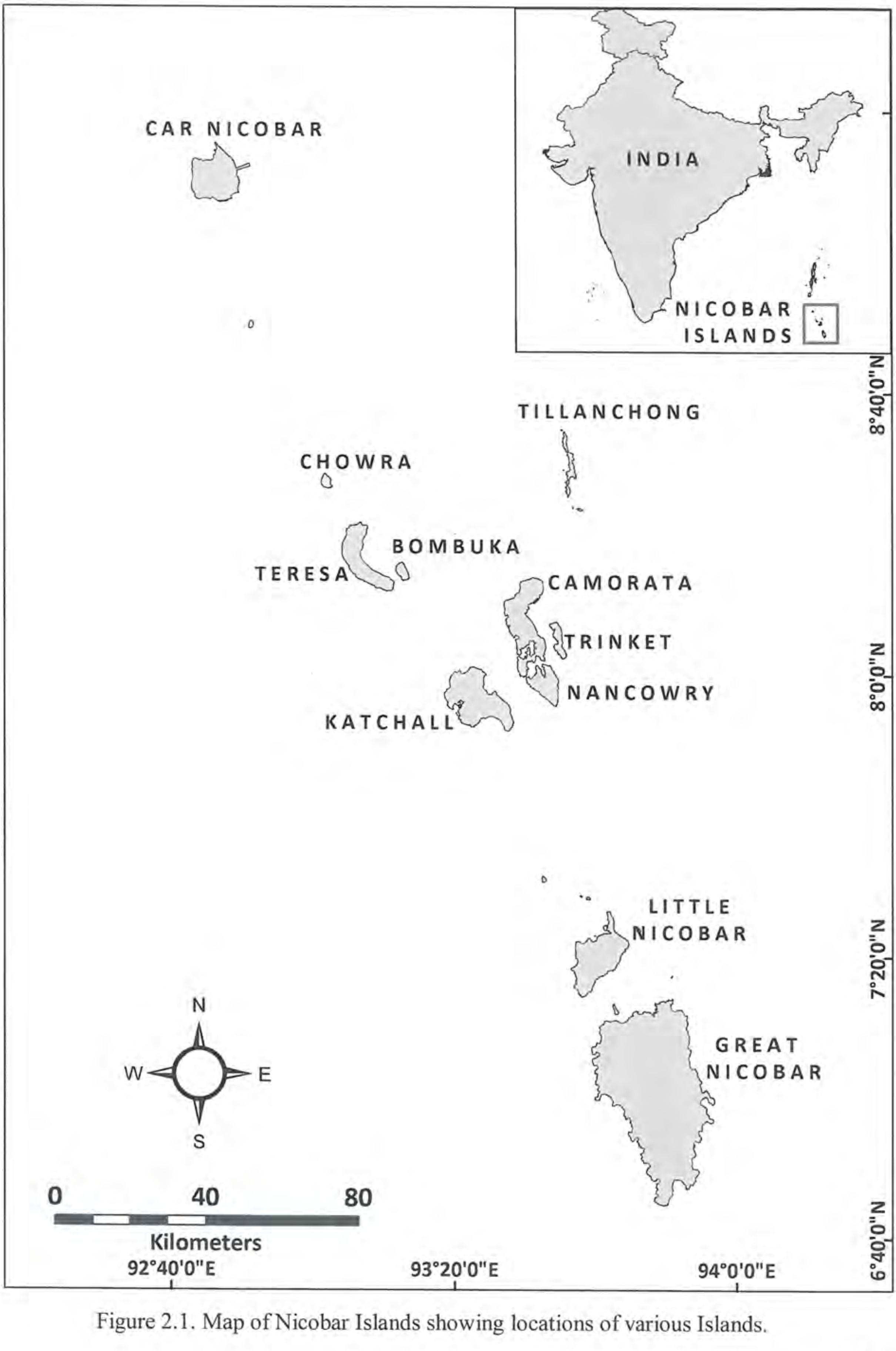


Figure 2.1. Map of Nicobar Islands showing locations of various Islands.

from heavy clay, loams, gravelly loams, sandy loam and sand. The depth of soil depends on the slope, with deep alluvial deposits often found along the lower reaches of the creeks. The soil lacks humus due to continuous leaching by heavy rainfall (Sivakumar, 2007).

2.3. Vegetation

The vegetation of Nicobar Islands has more floristic affinities with the Malaysian and Indonesian flora than with the Andaman Islands or mainland India (Abdulali, 1964; Sinha, 1999). As a result of low human influence, the forest cover in Nicobar Islands is exceptionally high with 93% of the land area is forested. The vegetation of the Nicobar group of Islands is divided into Coastal and Inland. The coastal vegetation is again subdivided into Littoral forest and Mangrove forest. The inland vegetation is subdivided into Low land swamp forest, Tropical evergreen forest, Mixed evergreen forest, Moist deciduous forest and Grass lands. In addition, plantations of cash crops such as Coconut, Rubber and Cashew are also present.

The tropical evergreen forest is the predominant forest type occupying 68% of the forest cover and is dominated by *Terminalia procera, Myristica andamanica, Barringtonia racemosa* and *Goniothalamus malayanus*. The occurrence of vast stretches of grasslands (8.5%) dominated by *Cymbopogon spp.* and *Carex spp.* is typical of Nancowry group of islands with an exception of Katchall and Tillanchong. Other dominant vegetation types such as Mixed evergreen forest (5.6%) and Low land swamp forest (3.6%) were dominated by *Terminalia spp., Syzygium samarangense, Semecarpus kurzii* and *Fragraea racemosa* (IIRS, 2003).

2.4. Fauna

The Nicobar Islands comprises an impoverished Sumatran fauna (Smith, 1930), but Stoliczka (1870) remarked that several species of lizard and snake are common to both Andaman and Nicobar Islands, and the whole fauna generally resembles the Malayan, gradually passing into Burmese fauna. Affinities of mammalian and avian species of these islands seem to be closer to India than Burmese and Malay (Abdulali, 1964). The islands are characterized by the absence of large mammals and the presence of a significant number of endemics among the island's vertebrates (Sivakumar, 2000). Within the Nicobar group of Islands there are notable differences in the faunal profile (Sankaran, 1997). For example, the Nicobar Parakeet

Psittacula caniceps occurs in Great Nicobar, Little Nicobar, Kondul and Menchal but is absent in the Nancowry group. The Nicobar Bulbul *Hypsipetes nicobariensis* is present in the Nancowry group but is absent in the Great Nicobar group. The Nicobar Racket-tailed Drongo *Dicrurus paradiseus nicobariensis* occur on Great Nicobar, Little Nicobar, Katchall, and Car Nicobar but is absent on other islands of the Nancowry group (Sankaran, 1995). The differences are also evident in the herpetofauna; Pit vipers are common on the Nancowry group but are absent in the Great Nicobar group. The Nicobar Long-tailed Macaque *Macaca fascicularis umbrosa* is present in Great Nicobar, Little Nicobar and Katchall. The Nicobar Tree Shrew *Tupaia nicobarica* is present in Great Nicobar and Little Nicobar Islands but is absent in other Nicobar Islands (Tikadar and Das, 1985).

2.5. Biological importance

The insular nature of these islands resulted in a high endemism in terms of flora (13.11%) and fauna (13%) (Sinha, 1999; Rao, 1989). Two uninhabited islands in the Nicobar group, Tillanchong and Batti Malv Island are wildlife sanctuaries. Great Nicobar is a Biosphere Reserve (885 km^2) whose core area consists of two National Parks, the Galathea National Park (110 km^2) and the Campbell Bay National Park (426 km^2). In addition to that, this group of Islands is a part of Sundaland Global hotspots of Biodiversity (Mittermeier et al., 2004).

2.6. People

There are two groups of Indigenous people reside in the Nicobar Islands namely Shompens and Nicobarese. They are considered as two distinct ethnic groups, although they are originated from the common Mongoloid stock of Southeast Asia.

Shompens: This semi-nomadic food gatherers and hunters of Stone Age civilization are only residing in the interior forests of Great Nicobar Island. They entirely depend on the forest resources and a diminutive amount of agriculture for their sustenance. Shompens are a total of not more than 150 people living in a complete isolation from the modern world.

Nicobarese: They are the dominant ethnic tribes of Nicobar islands spread across 11 inhabited islands of the Nicobars Archipelago have adapted well to existing conditions and constitute an expanding population, maintaining contacts with settlers and traders from the mainland India and other Asian countries. The main occupations of Nicobarese are fishing, coconut and areca nut trade. Along with these aboriginal people, there are good numbers of people who are migrants from the mainland India are also present in these Islands.

2.7. Tsunami of December 26, 2004

The Indian Ocean tsunami on 26th December, 2004 made an adverse effect on the people as well as the coastal biodiversity of Nicobar Islands. It was estimated that almost 10% of the Islanders lost their lives during tsunami. As a result of the drastic changes in the coastal landscape especially at human settlements (Malik and Murthy, 2005; Sankaran, 2005), four Islands namely Kondul, Pilo Milo, Trinket and Chowra were abandoned and the people were given shelters in the close by islands. The post-tsunami high main land India influence had brought remarkable changes in the socio-cultural, economical and food habits of Nicobarese community (Chandi *pers. com.*).

2.8. Study forest typs

The present study was carried out in the coastal vegetation namely littoral forest and mangrove forest as they were the worst affected habitats in the Nicobar Islands.

2.8.1. Littoral forest

The coastal vegetation that starts immediately after the shore line and extends usually up to 100 m (rarely up to 1000 m) on coastal plains till the boundary of hill forest is referred as littoral forest (Sankaran, 2005). In the Nicobar group of Islands, according to the pre-tsunami records, littoral forests are spread over 23.7 km^2 occupying 1.3% of the total land cover (IIRS 2003) and are dominated by *Terminalia bialata, Barringtonia asiatica, Pometia pinnata, Syzygium samarangense* and *Calophyllum inophyllum*. Littoral forests are prime habitat for many endemic flora, about 12% of the plants found in this forest type are endemics. *Alstonia kurzii, Semecarpus kurzii, Pandanus leram* var. *andamanensium, Tabernaemontana crispa* and *Bentinckia nicobarica* are some of the endemic plants found primarily in the littoral forest. This coastal vegetation is very crucial for the indigenous communities (Nicobarese and Shompens) as it is the prime habitat for their major food source *Pandanus lerum*, and their hunting ground for Water monitor lizard (*Varanus salvator)* and Wild boar (*Sus sorofa andamanensis*). Some of the endemic and rare fauna of Nicobar Islands namely Nicobar megapode (*Megapodius nicobariensis),* Nicobar Long-tailed Macaque (*Macaca fascicularis umbrosa*) and Robber Crab (*Birgus latro*) mainly inhabit in littoral forests.

2.8.2. Mangrove forest

Mangroves are trees, shrubs, palms or ground ferns exceeding 0.5 m in height and which normally grows above mean sea level in the intertidal zone of tropical coastal or estuarine environment (Duke, 1992). Shorelines of the Nicobar Islands face open seas, are not sheltered, and are relatively deep waters. Hence, Nicobar Islands support comparably less mangrove vegetation than Andaman Islands. Large extend of mangroves existed mainly in the Nancowry group of Islands. The mangrove stands dominated by *Rhizophora mucronata*, *Bruguiera gymnorhiza*, *Heriteria littoralis* and *Nypa fruticans* were present in patches and as thin fringes on Great Nicobar, Little Nicobar and Car Nicobar, and as larger stands on Kamorta, Nancowry, Trinkat and Katchall Islands. According to pre-tsunami studies, Nicobar Islands had a mangrove area of 36.67 km^2 covering 2.14% of its total forest cover (IIRS, 2003). Mangroves were highly utilized by the Nicobarese community for the following reasons (i) *Nypa fruticans* leaves are used for thatching roofs, (ii) *Bruguiera gymnorhiza* and *Xylocarpus granatum* as house construction poles, (iii) major catching ground for marine food resources such as fishes, prawns, turtles, shells, crabs and crocodiles.

2.9. Study sites

2.9.1. Littoral forest

The natural recovery of littoral forests was observed from 48 sites of which a total of 34 sites distributed over ten Islands were chosen for the intensive study. The study locations were chosen by foreseeing the non-possibilities of anthropogenic influence on the sites (Table 2.1), so that, the long-term monitoring of vegetation changes would be assessed (Figs. 2.2–2.4).

2.9.2. Mangrove forest

The natural regeneration of mangrove species was observed at localities where small patches of land remains as inter-tidal zones. In total, 23 locations spreading across seven Islands were identified to have mangrove colonization (Figs. 2.2–2.4). Of which, 12 locations were studied intensively to understand the natural re-colonization patterns of mangrove species (Table 2.1).

Table 2.1. Intensive study sites in Nicobar Islands (*Mangrove sites)

S.No	Island name	Location	Lat	Lon
1	Little Nicobar	Lanaeyi	07°17′14.5″	093°40′78.2″
2		Thavaithav	07°16′29.3″	093°38′04.4″
3		Komath	07°21′48.3″	093°40′29.9″
4		School point	07°23′41.8″	093°43′29.1″
5		Makachua*	07°24′14.7″	093°42′34.0″
6	Great Nicobar	Chingampasthy	06°48′00.2″	093°50′39.8″
7		Pilo bakka	06°50′18.0″	093°47′35.7″
8		Khopen heat	06°58′28.8″	093°44′13.2″
9		Ayoam Bay	07°06′14.3″	093°40′07.4″
10		Pethai	07°13′46.9″	093°48′34.0″
11		Trinket bay	07°12′02.5″	093°52′46.8″
12		Laful*	07°10′20.1″	093°52′37.7″
13		Dungy nallah*	07°02′23.3″	093°54′35.9″
14	Meroe	Meroe	07°31′14.3″	093°32′39.1″
15	Kamorta	Remyok	08°06′35.6″	093°28′16.7″
16		Mohreak*	08°11′43.2″	093°29′22.2″
17		Ol-hin-pun	08°08′28.0″	093°28′04.9″
18		Nyikalang	08°11′49.4″	093°32′49.0″
19	Trinket	Trinket settlement*	08°04′53.3″	093°35′21.3″
20		Eu	08°05′32.4″	093°35′14.6″
21		Lahung	08°02′44.1″	093°35′21.7″
22		Safed balu*	08°06′53.9″	093°33′56.5″
23	Nancowry	Mus	07° 57′03.7″	093°34′49.6″
24		Chinlak*	07°59′37.0″	093°33′05.6″
25	Katchal	West Bay 1	07°55′32.7″	093°21′15.5″
26		West Bay 2	07°54′59.4″	093°21′02.8″
27		Hoi-hi-poh*	07°57′12.2″	093°26′09.7″
28		Jansin	07°58′20.2″	093°19′50.8″
29		Marin Katchal*	07°58′41.9″	093°23′39.8″
30	Teressa	Safed balu	08°14′32.4″	093°09′12.4″
31		Kolaeru	08°12′34.6″	093°12′05.5″
32		Reksal	08°20′55.6″	093°07′10.6″
33		Hinam	08°15′21.0″	093°06′06.1″
34		Chuckmasui	08°13′23.0″	093°11′38.1″
35		Kalasi	08°15′42.3″	093°07′40.4″
36	Bomboka	Atluch	08°15′03.5″	093°14′33.1″
37		Bombuka pasthi	08°15′00.3″	093°13′13.9″
38	Car Nicobar	Kimios*	09°07′37.6″	092°47′06.2″

Figure 2.2. Map showing the study locations in the central group of Island

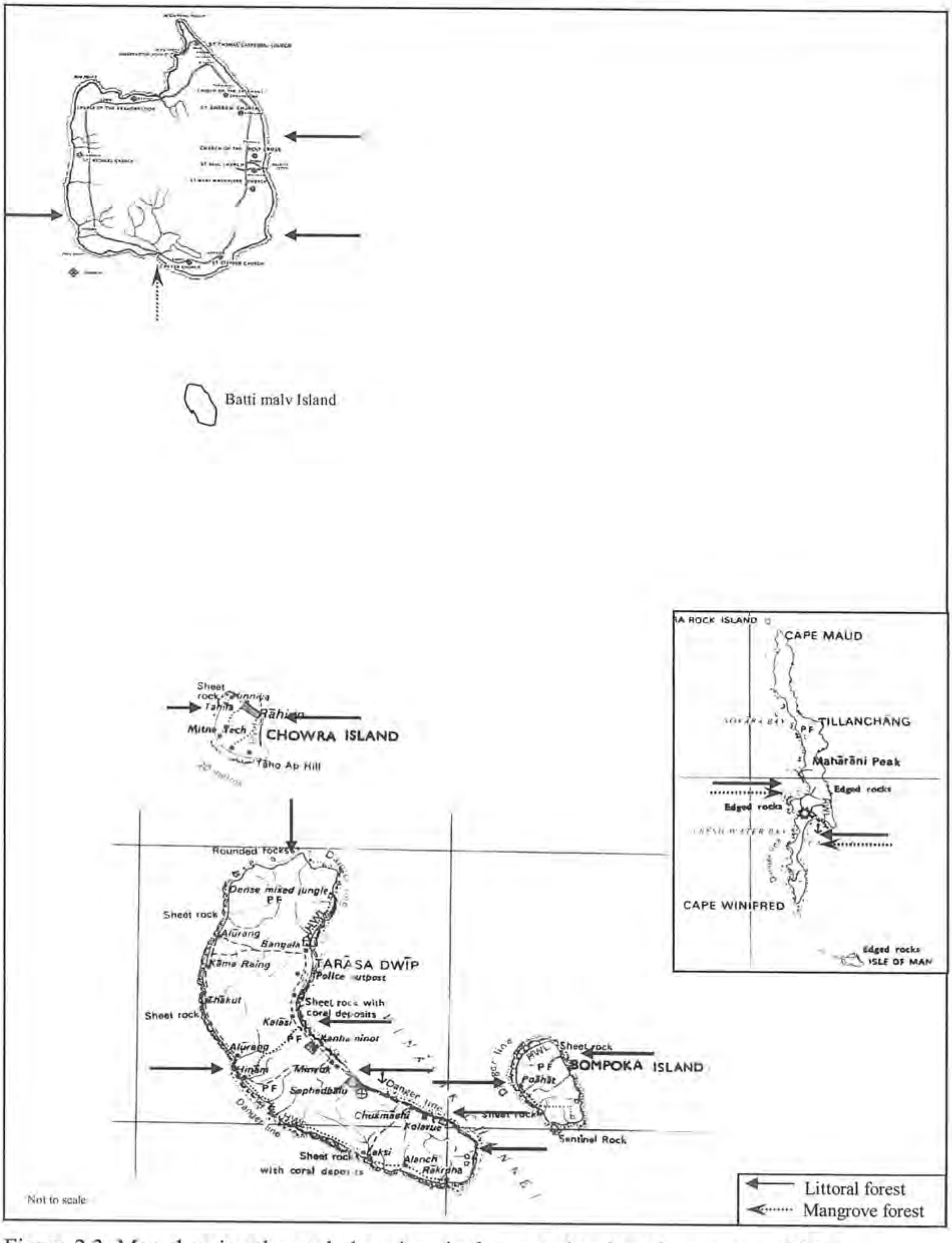


Figure 2.3. Map showing the study locations in the central and northern group of island

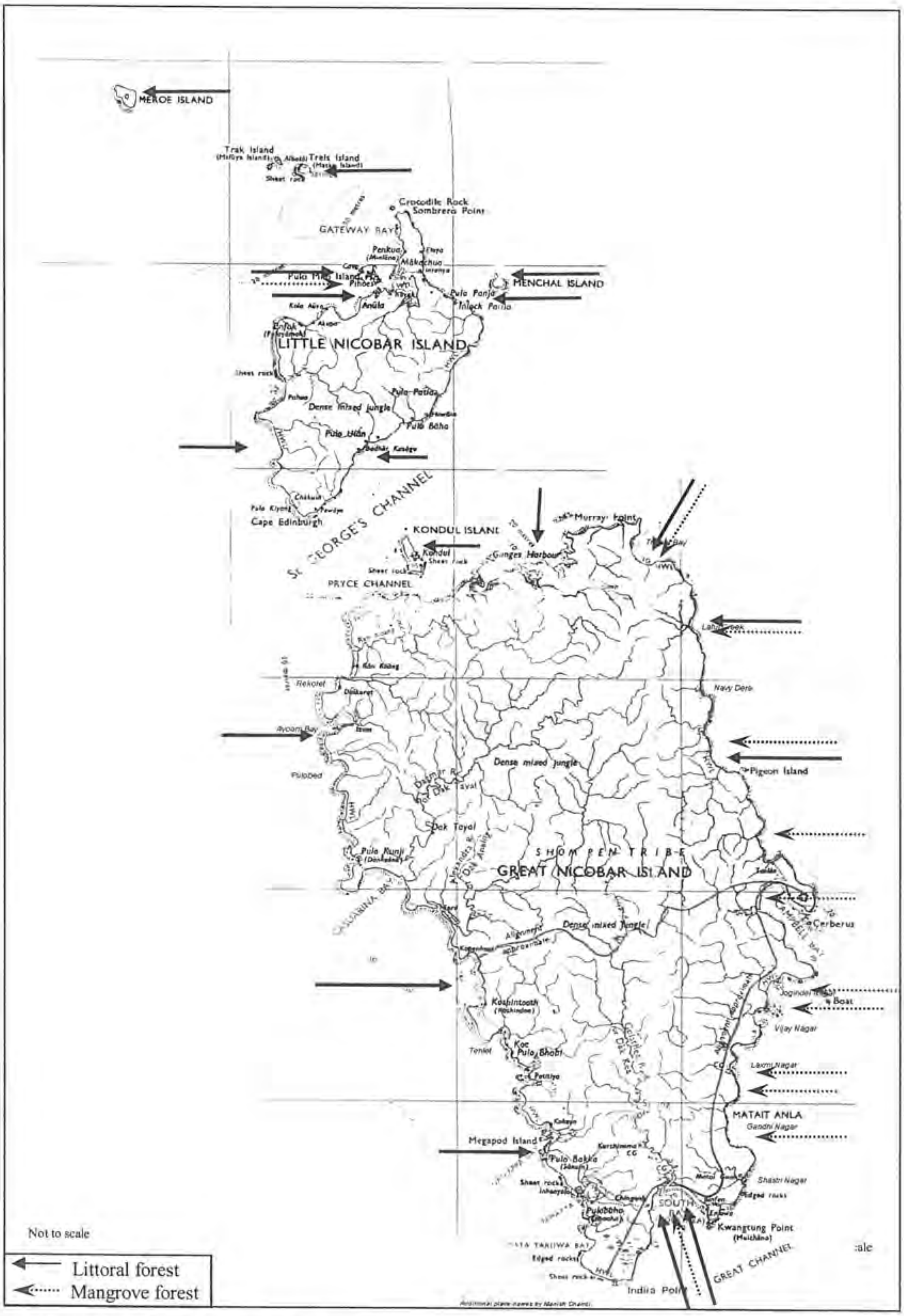


Figure 2.4. Map showing the study locations in the southern group of island

CHAPTER III

NATURAL RECOVERY OF TSUNAMI AFFECTED LITTORAL FOREST

3.1. Introduction

The natural process, through which disturbed forest vegetation, attains the undisturbed or pre-disturbed condition in terms of species diversity, species composition, stem density and biomass can be defined as vegetation succession or vegetation recovery. Various factors like soil, seed bank, remnant vegetation, dispersal agents, rainfall and frequency of disturbance are the main driving forces behind the succession process (Ding et al. 2012).Tropical forest succession has long been intrigued many ecologists enthused in understanding the dynamics and recovery pattern after a disturbance event.

The succession of forest is classified into three phases: (i) first phase is dominated by herbs, shrubs, and climbers that establish soon after disturbance and last for short span until the establishment of light demanding pioneer tree species (ii) the second phase is dominated by pioneer tree species that require more sun light. These species are usually generalists that develop rapidly a closed canopy and dominate the landscape for 10 to 30 years, depending on their life spans (iii) the third and final stage is dominated by long-lived trees, otherwise known as the climax forest community. These species are largely habitat specialists that requires a specific microclimatic condition for their regeneration and establishment and usually tolerant to shade (Peña-Claros 2003).

Structural characteristics such as basal area, above-ground biomass, tree height, and stem density often show rapid, easily measurable changes following disturbance and most directly apply to measures of recovery and ecosystem function (Chazdon 2003). In general, in a successional forest community, the recovery of basal area and aboveground biomass can occur within a few decades while others, such as species diversity and composition occur over centuries (Guariguata and Ostertag 2001). The impacts of human and natural disturbance and the following succession of tropical forest were widely studied throughout the tropics, yet the information on the impacts of tsunami and tectonic movements are rather scanty (Hayasaka et al., 2009 and 2012). Hence the present study was envisaged with the following objectives (i) to study the difference in species diversity, tree density and basal area between successional forest and unaffected forest (ii) rate of vegetation recovery in sites with affected and unaffected soil substrate (iii) influence of soil physicochemical properties on vegetation recovery in littoral forest.

3.2. Methodology

3.2.1. Vegetation monitoring

Sites with higher levels of damage by tsunami were selected based on the preliminary survey that commenced immediately after tsunami for assessing the tsunami impact on the coastal vegetation of Nicobar Group of Islands (Sankaran, 2005). Plots of 50 × 20 m (0.1 ha.) size were established at sites without residual trees where changes due to anthropogenic pressures are not likely to occur in the foreseeable future to enable the long term monitoring of vegetation succession possible. The regenerating vegetation was categorized into two namely Sandy Regenerating Vegetation (SRV) and Sand Loamy Regenerating Vegetation (SLRV) based on the soil substratum. SRV—sites where enormous amount of sand and coral rubble were deposited over the pre-tsunami soil substratum, SLRV—sites where the vegetation was totally damaged but the soil substratum remained without any deposition. Sampling plots were also established in the unaffected/less affected forest (UF) for comparison. Each monitoring plot was divided into five 10 × 20 m subplots for the convenient enumeration of trees. Trees measuring ≥10 cm Circumference at Breast Height (CBH) were marked and counted. Number of sampling plots varied for different habitats based on the availability of sites and logistics: SRV (n=36), SLRV (n=42) and UF (n=21). Specimens for tree species that could not be identified in the field were collected and identified with the help of Floras and compared with the specimens of the Botanical survey of India, Port Blair.

3.2.2. Soil sample collection and analysis

Soil samples were collected at 0–10 cm depth following Álvarez-Yépiz (2008) from five randomly selected sites each in SRV and SLRV. Three soil samples were collected from each site at 20 m distance from each collection point. A total of 30 (SRV=15; SLRV=15) soil samples were collected for physicochemical analyses. Texture was determined using Bouyoucos hydrometer, pH by using Potentio meter ($CaCl_2$), percentage of organic carbon by chromic acid wet oxidation method (Walkley and Black, 1934), bulk density by paraffin method, available N by alkaline permanganate method (Subbiah and Asija, 1956), available P by Olsen's method (Olsen et al., 1954), available K flame photometer (Jackson, 1973), available micronutrients (Fe, Mn, Zn, Cu) by atomic absorption spectrophotometer (Lindsay and Norvell, 1978), Ca and Mg by versenate titration method (Cheng and Bray, 1951).

3.2.3. Data Analysis

Data from the three different habitats SRV, SLRV and UF were used to calculate stem density (individuals/0.1 ha.), species diversity (species/0.1 ha.) and basal area (m^2/ha.). For multi stemmed trees, basal area for each stem was calculated separately and summed. Importance Value Index (IVI) was calculated for all the species in each of the three habitats following Magurran (2004). Diversity indices such as Shannon (*H*) and Simpson's index (*1/D*) was calculated as a measure of diversity. Species accumulation curve was generated (S_{obs}) separately for each habitat and the total species richness was derived from non-parametric estimator Chao 2 with 1000 randomizations in the Estimate S ver. 8.2.0. software programme (Colwell, 2004). Mann-Whitney *U*-test was used to test the variation in the soil macro and micro nutrient composition between SRV and SLRV. Kruskal–Wallis test was used to test the null hypothesis that the species diversity, stem density and basal area among SRV, SLRV and UF are not varies and derived from the same population. Mann–Whitney *U*-test was used to test the variation in the species diversity, stem density and basal area among the following combination of datasets: SRV and SLRV, UF and SLRV, and UF and SRV. Pearson's 2-tailed bivariate correlation analysis was carried out to test the null hypothesis that the increase in number of species as the function of increase in tree individuals. Statistical software's such as SPSS ver. 16, Diversity ver. 2.65 and PAST ver. 2.14. were used in the analyses.

3.3. Results

In the 99 permanent monitoring plots distributed over 10 Islands, a total of 8420 individuals ($\geq$10 cm CBH) belonging to 181 tree species, 116 genera and 52 families were recorded (Appendix 1). Among the plants recorded 152 were identified to species level, 10 were identified to genus level, one was identified to family level and 18 could not be identified. The genera richness was highest in Euphorbiaceae (13 genus), followed by Fabaceae and Malvaceae (8 each). Species richness was highest in Moraceae (16 species) followed by Euphorbiaceae (14 species) and Malvaceae (10 species). Among the families recorded, 45% were represented by a single species. Among the species recorded, 18 were endemic to Andaman & Nicobar Islands and seven were strict endemics of Nicobar Islands (Appendix 1).

3.3.1. Species diversity among different vegetation types

Species diversity was highest in the UF followed by SLRV. Both these vegetation types show almost equal diversity in all the three levels such as family, genus and species. The species diversity significantly varied among UF, SLRV and SRV ($\chi^2 = 59.05$, df=2, $P<0.0001$; Fig. 3.2). SRV had shown three times less species diversity, two times less in genus diversity and single fold less in family diversity when compared to SLRV and UF. Though SLRV and UF shows less variation in the total number of species, the mean species diversity Plot^{-1} shows high variation where SLRV having less diversity than UF with 2:3 ratio variation ($z = -2.59$, $P<0.05$). The mean species diversity observed in SRV was four times lesser than SLRV ($z = -6.8$, $P<0.0001$) and six times lesser than UF ($z = -5.82$, $P<0.0001$) (Table 3.1). The diversity value as the measure of Shannon's (*H*) and Simpson's (*1/D*) diversity indices followed similar trends, where the mean diversity value Plot^{-1} was highest for UF followed by SLRV and less in SRV (Table 3.1).

The estimated species richness value by Non-parametric estimator Chao2 shows highest species richness in UF (191) followed by SLRV (155) and SRV (40). Among the regenerating vegetations, species diversity in SLRV is estimated to be three times higher than SRV. The species accumulation curve plotted for the three habitats did not reach the asymptote. Chao2 had reached the asymptote after 30 sample plots in the SLRV. But in the case of SRV and UF, the species area curve is kept ascending gradually due to the addition of new species throughout the sampling and did not reach the asymptote (Fig. 3.3). The number of rare species (species having less than 10 individuals) present in each vegetation type was nearly the same (72%). The number of singletons (species with one individual) and doubletons (species with two individuals) were less in SRV (33%) and almost equal in SLRV (44%) and UF (45.5%).

3.3.2. Stem density and basal area

The mean stem density plot^{-1} calculated for each of the three vegetation types was significantly different from each other ($\chi^2 = 70.29$, df=2, $P<0.0001$). SLRV showed highest stem density with single fold increase ($z = -3.28$, $P<0.001$) and SRV lowest with 90% decrease ($z = -6.0$, $P>0.0001$) when compared with the UF (Table 3.1). The dominance of species differed among UF, SLRV and SRV. In SRV, *Casuarina equisetifolia* was the predominant species with 89 individuals followed by *Hibiscus tiliaceus* (38) and

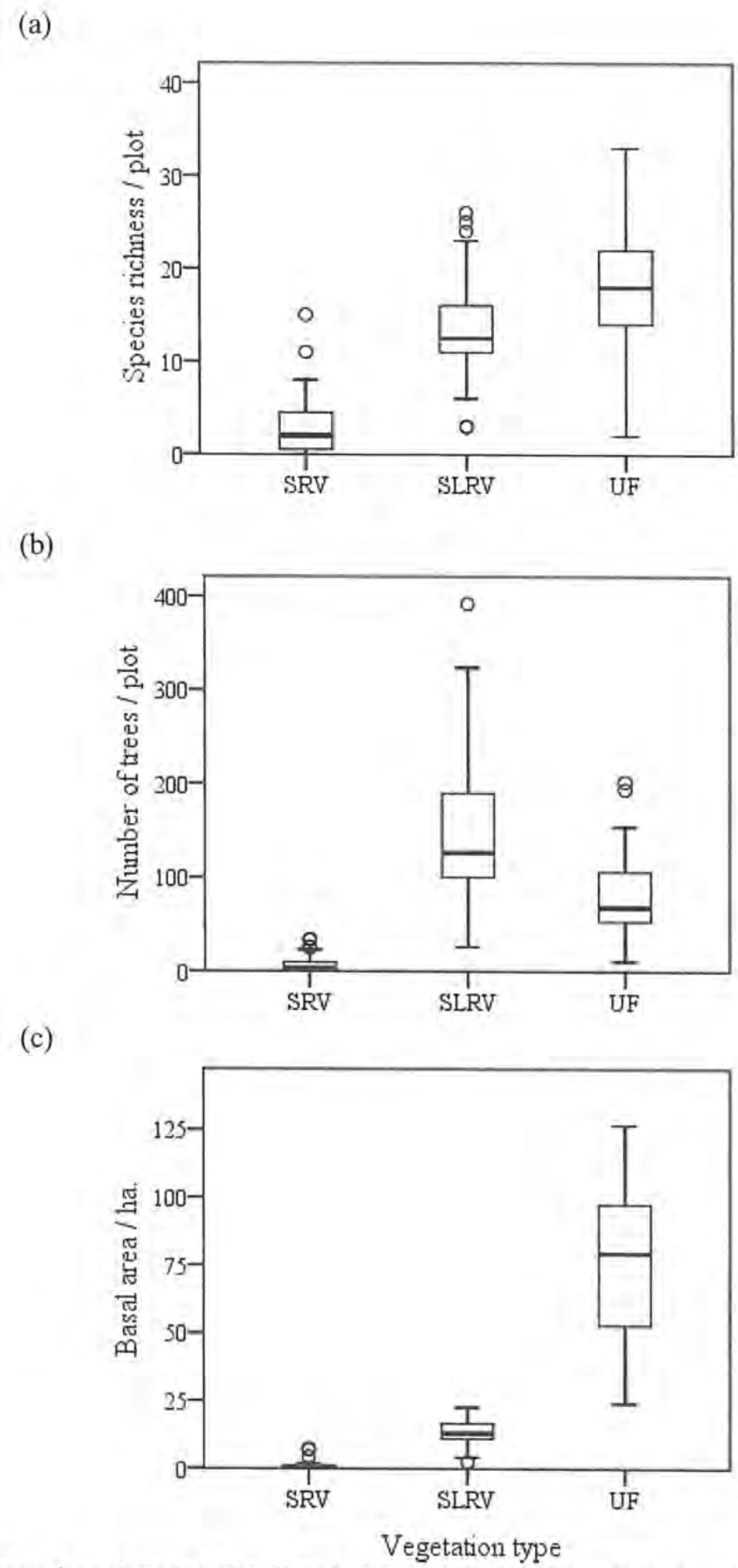


Figure 3.2. Box plots showing the distribution of (a) number of species (b) individuals plot^{-1} and (c) basal area ha.$^{-1}$. Box represents 50% of the data distribution, line inside the box indicates the median value and whisker's indicates 25% of data distribution on both sides of the box.

(a)

(b)

(c)

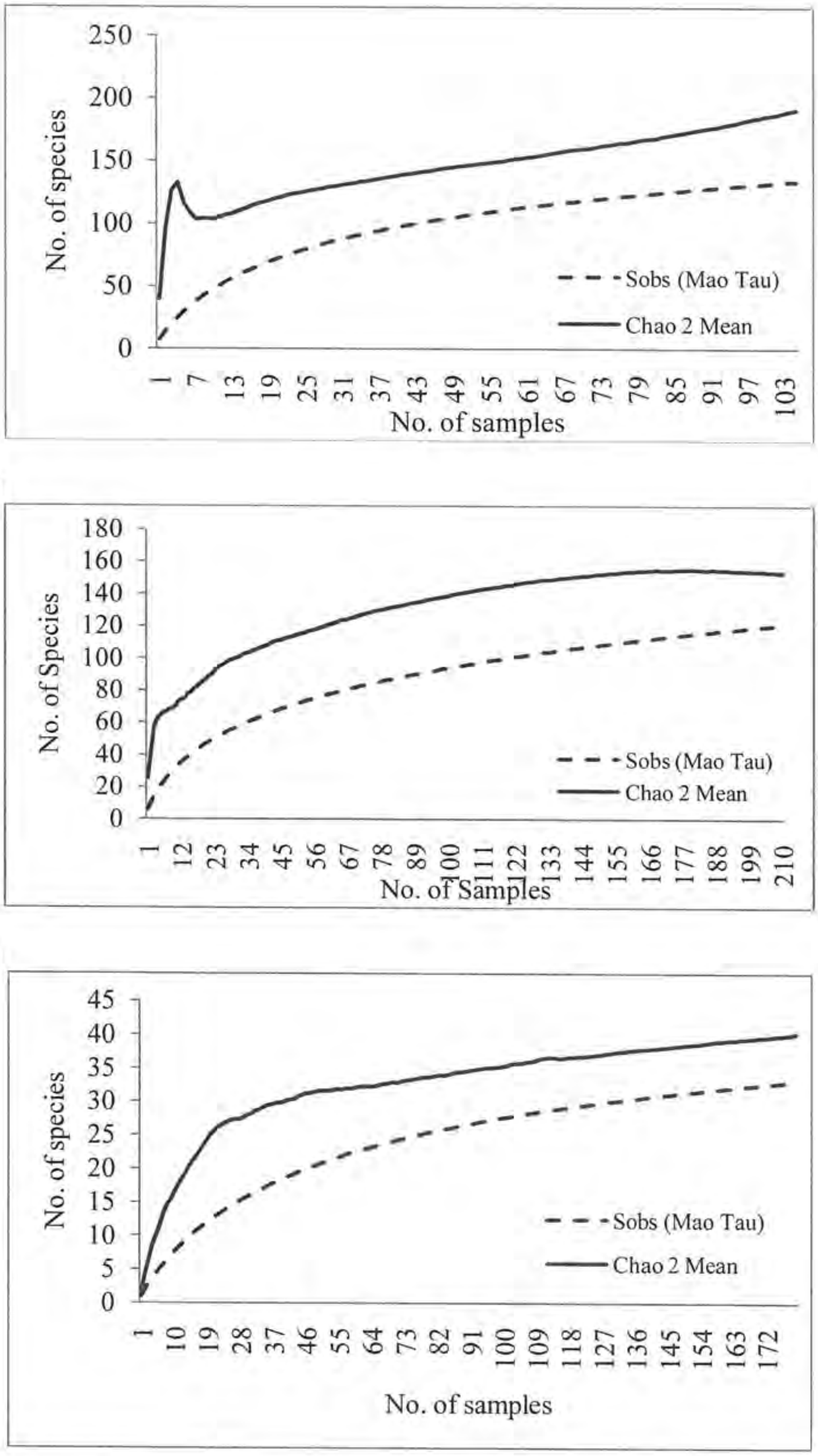


Figure 3.3. Species accumulation curves (a) Unaffected forest (b) Sand-Loamy regenerating vegetation and (c) Sandy regenerating vegetation.

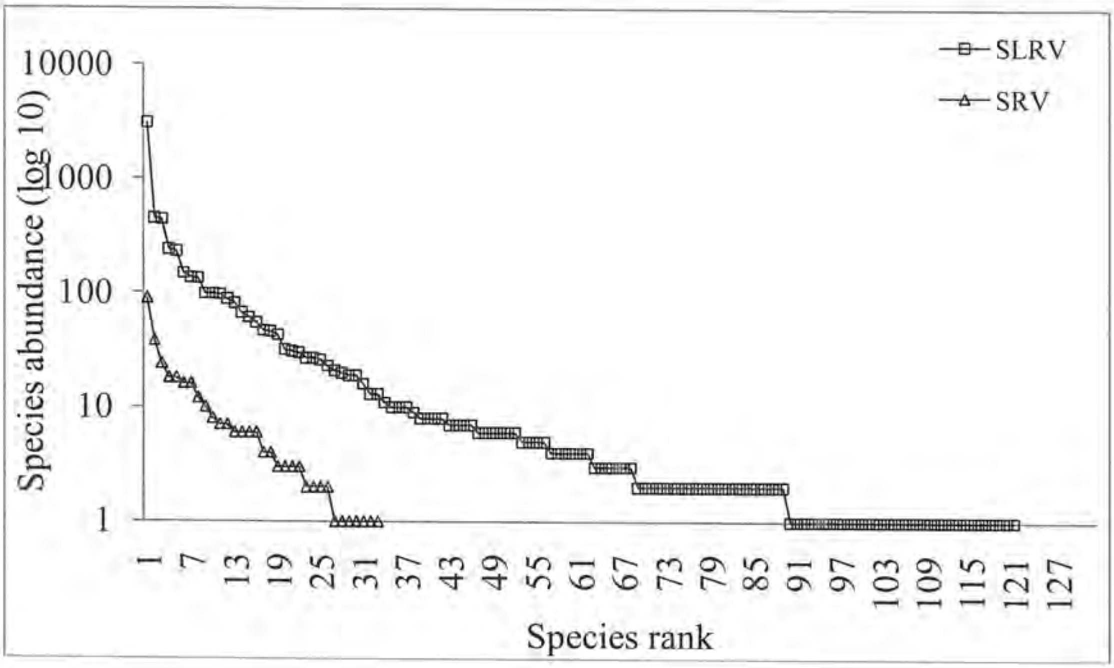
Dendrolobium umbellatum (24). In SLRV, *Macaranga peltata* (3064) was the single most dominant species contributed 50% of the total stem density. *Ficus hispida* (448) and *Boehmeria nivea* (439) were the other dominant species present in SLRV. The first ten species with more number of individuals contributed 47, 82 and 78% of total stem density in UF, SLRV and SRV. In UF, *Macaranga peltata* had maximum stem density of 201 tree individuals, of which, 92% of individuals were recorded from only two plots that were established in the less affected littoral forest in Bombuka Island. The other dominant species having high stem density in UF are *Sterculia rubiginosa* (107) and *Orophea katschallica* (104). The Rank Abundance Curve (RAC) gradually declined for UF, indicating that the species abundances are evenly distributed. Steep decline in the initial part RAC for SLRV and SRV indicates the dominance of a few species and hence the low evenness in these pioneering vegetation types (Fig. 3.4).

The basal area values significantly differed among the three vegetation types ($\chi^2 = 79.11$, df=2, $P<0.0001$) where SLRV had 80% ($Z = -5.56$, $P<0.0001$) and SRV had 98.4% ($Z = -6.26$, $P<0.0001$) lesser basal area values than UF (Table 3.1). The Pearson's correlation shows a positive correlation between the number of stem individuals and species diversity in the all the three vegetation types (UF: $r^2 = 0.751$, $P<0.0001$, SLRV: $r^2 = 0.374$, $P<0.05$, SRV: $r^2 = 0.871$, $P<0.0001$) but the level of correlation was less in SLRV than UF and SRV (Fig. 3.5d). *Terminalia bialata* (19.02 m^2 ha^{-1}) and *Manilkara littoralis* (10.9 m^2 ha^{-1}) had high basal area values in the UF. Likewise, *M. peltata* (7.3 m^2 ha^{-1}) and *Boehmeria nivea* (1.2 m^2 ha^{-1}) in SLRV, *Casuarina equisetifolia* (0.48 m^2 ha^{-1}) and *Pandanus lerum* (0.14 m^2 ha^{-1}) in SRV had high basal area values.

3.3.3. Species dominance across vegetation types

Importance Value Index (IVI) values had shown dominance of different species in different vegetation types. From the IVI values it is seen that *Terminalia bialata* (29.99), *Manilkara littoralis* (18.3) (Fig. 3.6a,b) and *Pterocymbium tinctorium* (14.16) are the dominant species in UF. Likewise, *Macaranga peltata* (98.16), *Ficus hispida* (17.03) and *Boehmeria nivea* (16.83) (Fig 3.6c,d) are dominant in SLRV; *Casuarina equisetifolia* (97.49), *Hibiscus tiliaceus* (26.97) and *Pandanus lerum* (22.93) (Fig. 3.6e,f) are dominant in SRV.

(a)



(b)

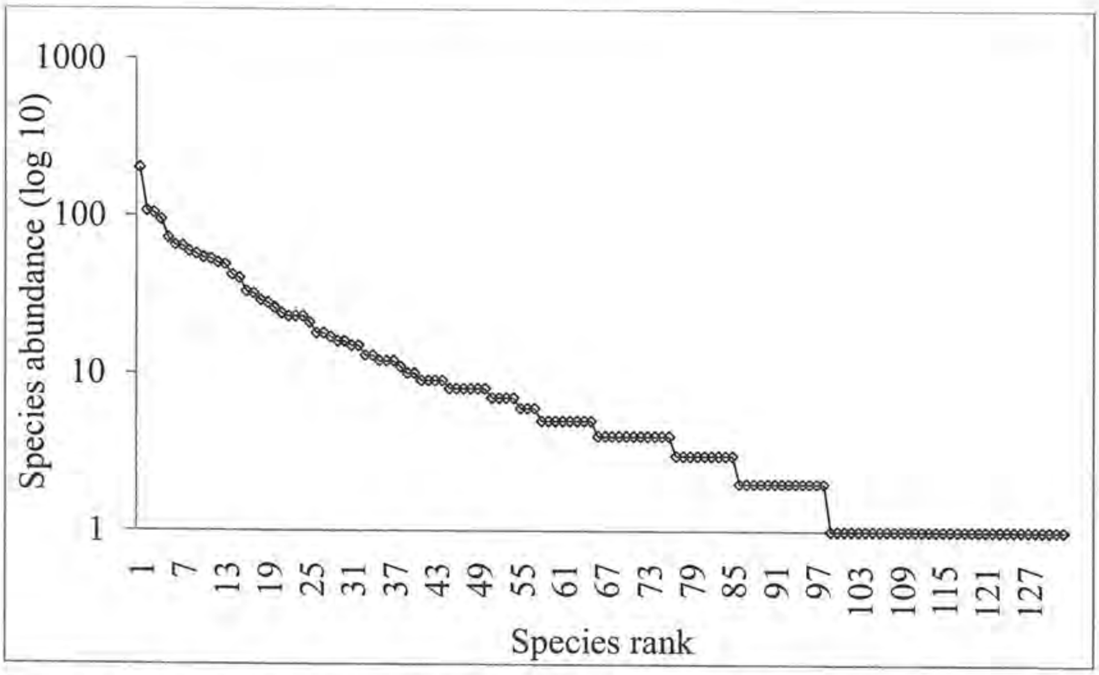


Figure 3.4. Rank abundance curve (a) steep decline in the beginning for SRV and SLRV indicates less evenness (b) gradual slope indicates high evenness for UF

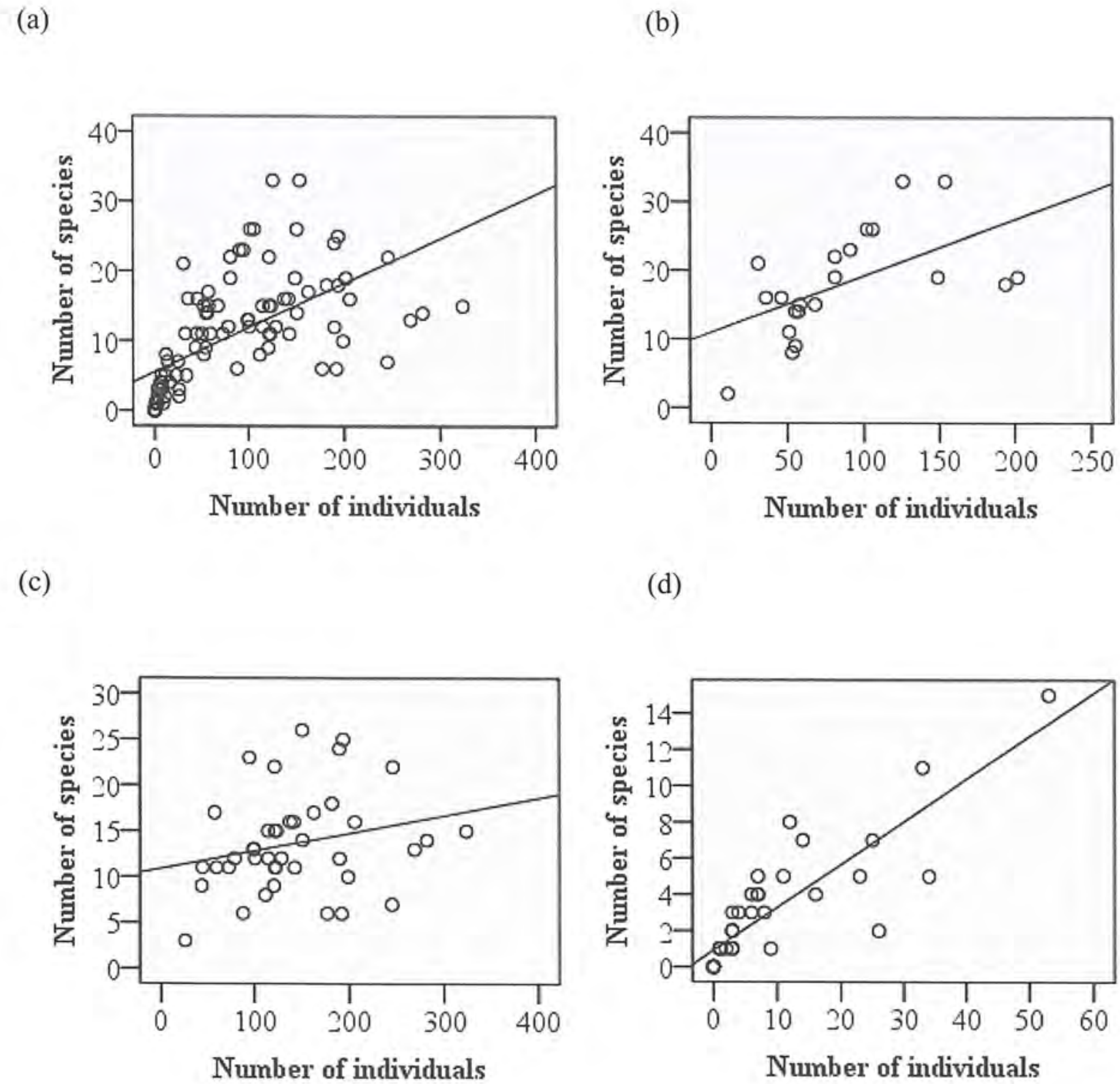


Figure 3.5. Correlation between species diversity and stem individual (a) The overall correlation for all the three habitat is $r^2 = 0.903$; $P<0.0001$.(b) SRV ($r^2 = 0.871$; $P<0.0001$) and (d) UF ($r^2 = 0.751$; $P<0.0001$). (c) SLRV had less correlation ($r^2= 0.374$; $P<0.05$).

3.3.4. Soil micro and macro nutrient composition

All the macro and micro nutrients except calcium has shown higher values in SLRV than SRV. The physicochemical parameters such as PH, bulk density, organic carbon, available nitrogen, available potassium, manganese and iron showed significant difference between SLRV and SRV (PH, bulk density, C, N, Mn, Fe: $P<0.0001$; K, Mg: $P<0.01$). The mean values for phosphorus, calcium, copper and zinc did not vary between SRV and SLRV ($P>0.05$) (Table 3.2).

Table 3.1. Comparison of ecological variables among different vegetation types studied

Variables	SRV	SLRV	UF
Total species richness	33	121	132
Estimated species richness (Chao2)	40	155	191
No. of Families	23	43	46
No. of Genera	30	88	89
Species richness/plot	3.02 (03.37)	13.38 (05.56)	18.04 (07.66)
No. of trees/plot	8.91 (12.15)	148.78 (76.8)	86.04 (52.43)
Basal area m^2/ha.	1.14 (02.49)	14.95 (06.28)	73.87 (28.76)
Shannon Wiener (H)	0.69 (00.74)	01.49 (00.58)	02.21 (00.61)
Simpson (D)	3.08 (03.59)	03.59 (01.88)	08.97 (60.34)

*Numbers inside parenthesis indicates standard deviation.

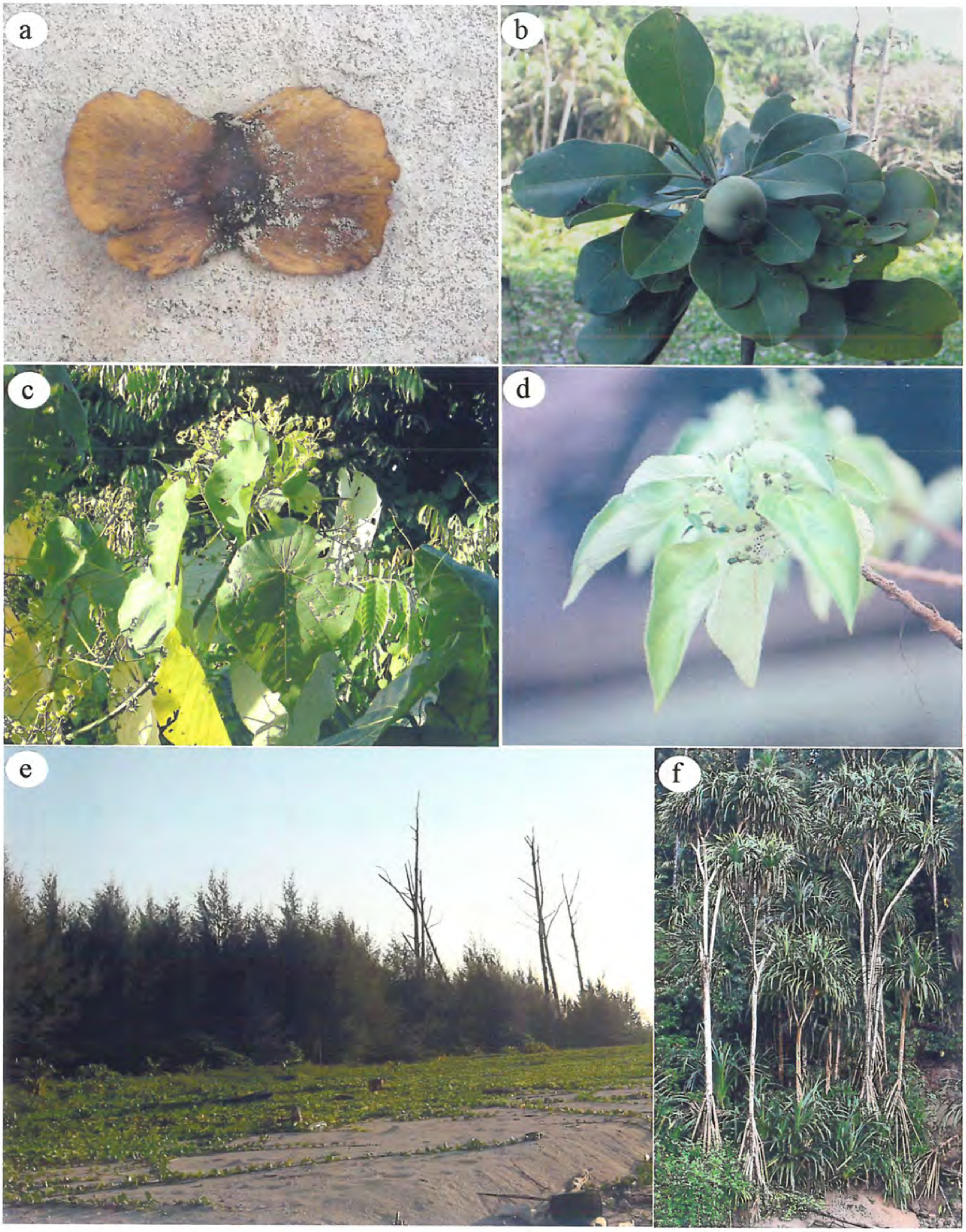


Figure 3.6. The dominant tree species found in the different vegetation types of littoral forest. (a) Seed of *Terminalia bialata*, (b) *Manilkara littoralis* (c) *Macaranga peltata* (d) *Boehmeria nivea* (e) *Casuarina equisetifolia* (f) *Pandanus lerum*

Table 3.2. Variation in physicochemical variables between SRV and SLRV

Parameters	SRV	SLRV	Mann–Whitney *U* test	
			z value	*P* value
pH	07.53 (00.21)	07.16 (00.29)	-3.65	0.000
Bulk density (gm / cc)	01.57 (00.07)	01.26 (00.18)	-4.12	0.000
Organic carbon (%)	00.70 (00.64)	02.11 (00.82)	-3.69	0.000
Available Nitrogen (Kg / ha.)	73.34 (46.59)	182.23 (50.62)	-3.92	0.000
Phosphorus (Kg / ha.)	24.35 (03.72)	26.78 (60.24)	-0.60	0.547
Available Potassium (Kg / ha.)	51.43 (44.97)	86.23 (35.31)	-2.72	0.007
Calcium (Meq / 100 g)	00.73 (00.24)	00.62 (00.19)	-1.52	0.137
Magnesium (Meq / 100 g)	00.04 (00.02)	00.08 (00.05)	-2.70	0.007
Cu (ppm)	00.30 (00.18)	00.85 (00.79)	-1.95	0.061
Zn (ppm)	02.13 (00.74)	02.23 (00.62)	-1.00	0.317
Mn (ppm)	10.87 (07.59)	43.18 (25.42)	-4.21	0.000
Fe (ppm)	04.65 (01.68)	41.28 (33.37)	-4.67	0.000

* Numbers in parenthesis indicates standered diviation

3.4. Discussion

3.4.1 Species diversity

The tropical islands are known to have high levels of species diversity and endemism in a relatively small geographical area (Wilson, 1988). Tree species richness (181 species in 9.9 ha.) in Nicobar Islands recorded during the present study is comparatively higher than the numbers encountered in the tropical forests of the mainland India. In the Western Ghats, 63 species in the 50 ha. plot in Mudumalai (Condit et al., 1996), 103 species in 28 ha. plot in Uppangala (Pascal and Pelissier, 1996) and 148 species in 30 ha. plot at Varagalaiar (Ayyappan and Parthasarathi, 1999) has shown low species diversity than the Nicobar Islands. The observed species plot^{-1} is almost equal to the values recorded by Anitha et al. (2008) in the dry mixed deciduous forest, Anaikatty hills, Western Ghats where it was 15.75 $\pm$ 4.76 for undisturbed and 13.75 $\pm$ 3.54 for disturbed forest. The species level dominance of Moraceae could be due to the high chances of seed dispersal by birds. In particular, a single genus *Ficus* had 11 species. The semi-parasitic nature and seed dissemination by birds explain the high diversity of *Ficus* species in the regenerating vegetation. The dominance of Moraceae, Euphorbiaceae, Meliaceae and Rubiaceae in Nicobar Islands is similar to the adjacent Andaman group of Islands (Rajkumar and Parthasarathy, 2008; Rasingam and Parthasarathy, 2009).

3.4.2. Recovery of vegetation: Species diversity, stem density and Basal area

The vegetation recovery rates in tsunami impacted sites of Nicobar Islands show higher values for SLRV than SRV. In SLRV, 75 % of the mean species richness plot^{-1} and 20% of basal area ha.$^{-1}$ recovered when compared with UF. Interestingly, the mean stem density in SLRV was 72% higher than the UF. Whereas in SRV, mean species richness plot^{-1} (17%), mean basal area ha.$^{-1}$ (1.5%) and mean stem density plot^{-1} (10%) was very low when compare with UF and shown poor recovery rates. The intensity of disturbance could be directly related to the decreased recovery rate of vegetation (Ramirez-Marcial et al., 2001; Sagar et al., 2003). The soil nutrients play an important role in the recovery of vegetation after a disturbance event (Ding et al., 2012).The faster vegetation recovery rates observed in the SLRV could be explained by the presence of nutrient rich soil substratum that can provide suitable habitat and microclimate for the regeneration and establishment of pioneer species immediately after the tsunami. Likewise, the slower recovery rates recorded for SRV can be explained by the drastic change in the top layer of the soil substratum from relatively fine humus rich sandy loamy soil to coarse sand intermixed with coral rubble that completely lack the humus layer and hence the poor micro and macro nutrient composition. The coarse nature of soil substratum that has less water holding capacity intermingled with poor soil nutrients may not be sufficient for the microclimate demands of many of the pioneer species that are showing better colonization tendency in SLRV. Rate of forest recovery is constrained by soil fertility and texture across regions as well as across soil types within a region (Herbert et al., 1999; Guariguata and Ostertag, 2001; Chazdon, 2003). Vandermeer et al. (2000) reported two to three fold increase in species richness over a period of 10 years in the hurricane impacted forest of Caribbean Coast where the soil substratum was not affected. Chinea (2002) documented a strong effect of soil fertility on the recovery of forest structure and species composition in forests along the east coast of Puerto Rico. Based on a global comparison including tropical and temperate secondary forests, Johnson et al. (2000) opined that aboveground biomass accumulation on nutrient-poor sandy soils is lower than on non-sandy soils.

In the past 5 years of vegetation recovery, SLRV had accumulated 56% of the species that are found in UF, whereas SRV had accumulated 16%. Hence, the species composition recovery found to be slower than the species richness recovery. According to Pascarella et al. (2000), after 25–30 years of succession in the abandoned pasture lands, basal area and species richness were similar to those found at old growth forest sites, but species composition remained distinct. Despite a century of opportunities for dispersal and the presence of contiguous mature forest, secondary forest in Singapore contained only 40–60% of the original number of species per plot (Turner et al., 1997). As reported by Chazdon (2003), in many of the tropical forests that are undergoing succession, recovery of species richness, stem density and basal area may occur within a few decades but the species composition recovery may take even a century.

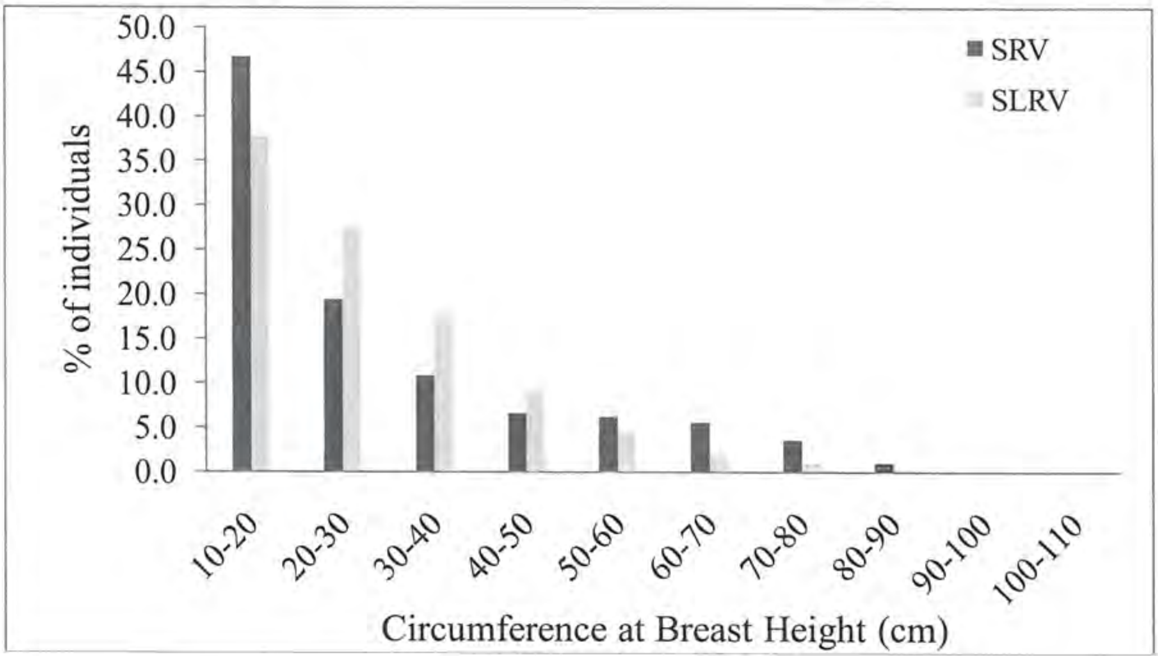
3.4.3. Species dominance, evenness and vegetation structure

The dominance of shade intolerant tree species is characteristic of a pioneering forest community (Peña-Claros, 2003). Usually in a pioneering forest community, the openness in the canopy and high intensity of sunlight will favor the growth of certain pioneer species that have high growth rate with limited resource and hence the low evenness in species distribution (Guariguata et al., 1997; Boucher et al., 2001). In SLRV, about 50% of the trees belong to a single species *Macaranga peltata.* Likewise, *Casuarina equisetifolia* has accounted for 28% of individuals in SRV. The first ten dominant species having high number individuals had accounted for 78, 82 and 47% in SRV, SLRV and UF respectively. The same is illustrated in the Rank abundance curve that the evenness in species distribution is lower for the SRV and SLRV than UF.

The higher proportion of individuals in the 10–20 cm CBH class in SRV than SLRV (Fig. 3.7a) may be either due to the slow vegetation recovery in the early years and the rates started increasing in the recent years as described by Walker and del Moral (2003) or slower growth rate of young individuals in the nutrient poor top soil. Higher number of individuals from 50–80 cm CBH category in SRV is probably due to the high growth rates shown by a single species *Casuarina equisetifolia.* The high percentage of individuals in the 10–40 cm CBH class (Fig. 3.7b) followed by steep decline of older trees in UF is due to the predominance of *Macaranga peltata* at two plots that are established in the less affected forest where the canopy trees have survived but the under canopy (second story) trees have died after tsunami.

The number of individuals and species are highly correlated in tropical forests and it has been well established that the habitats supporting higher number of individuals can support more species than the habitats with less individuals (Chazdon et al., 1999; Vandermeer et al., 2000). The present study shows similar results for UF and SRV, but interestingly, in the SLRV where the stem density has increased 72% more than UF had a less correlation value than SRV and UF (Fig. 3.7). The mean species diversity was high in UF with comparatively a less mean number of individuals than the SLRV. Hence, the increase in species richness as the function of increase in tree individuals as suggested by Chazdon et al. (1999) and Vandermeer et al. (2000) needs further investigation.

(a)



(b)

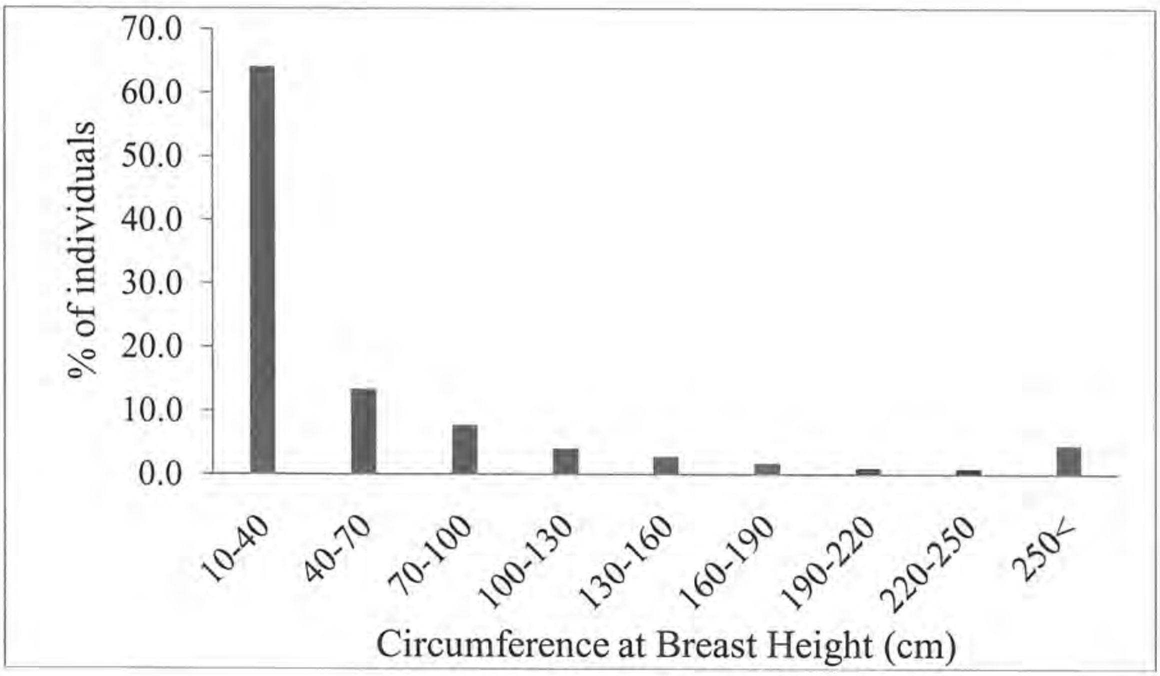


Figure 3.7. CBH classification of trees in vegetation types (a) SRV and SLRV (b) UF

3.5. Conclusion

The results of the present study clearly indicate that the recovery of species diversity, stem density and basal area in tropical forests after a mega disturbance event like tsunami will be rapid if the soil substratum is left undisturbed. In extremely degraded tropical forests after high levels of disturbance, human intervention is required to restore species composition and soil fertility (Chazdon, 2003). In the case of Nicobar Islands, restoration activities are of prima facie importance in the SRV where vegetation recovery rates are slower due to poor soil nutrients. Hence, we suggest scientific intervention to restore the soil fertility that influence the vegetation recovery in sand deposited habitats (SRV).

CHAPTER IV

RATE OF VEGETATION RECOVERY IN THE LITTORAL FOREST

4.1. Introduction

The high species diversity and complexity in its functioning makes tropical forest to be one among the most resilient ecosystems in the world (Mittermeier, 2004). Though vegetation changes in permanent plots intrigued plant ecologists (Vandermeer et al., 2000; Ding at al., 2012), studies on plant succession after a mega natural disturbance events are rare (Vandermeer et al., 2000; Sherman et al., 2001; Hayasaka et al., 2009 and 2012). Information on the impacts and natural recovery of coastal vegetation after tsunami is scanty (Hayasaka et al., 2009; Hayasaka et al., 2012). Hence, the present study was envisaged with the following objectives (i) to study the influence of disturbance in soil substratum on vegetation recovery (ii) to study the rate of change in terms of species richness, stem density and basal area in the secondary vegetation of tsunami impacted sites.

4.2. Methodology

4.2.1. Data collection

Vegetation monitoring plots of 0.1 ha. (50 × 20 m) size that are established in the tsunami impacted sites of Nicobar Islands during 2009–2010 were revisited to collect replicate data. Out of the 78 plots established during the first year sampling, 62 plots distributed over 25 sites of eight Islands were re-sampled to assess the rate of vegetation changes in the tsunami impacted sites. The secondary vegetation formed after tsunami were categorized into two classes based on the soil substratum (i) Sandy Regenerating Vegetation (SRV)—the pre-tsunami soil substratum was buried under enormous amount of sand and coral rubbles that are deposited on the coast as a result of tsunami (ii) Sand-Loamy Regenerating Vegetation (SLRV)—the soil substratum was devoid of any deposits but the entire vegetation was scorched after tsunami due to high salinity in the substratum. The number of plots re-sampled varied for SRV (n=29) and SLRV (n=33) due to logistics. Each sampling plots were divided into five 10 × 20 m grids for the convenient enumeration of tree individuals. All the tree individuals of ≥10 cm Circumference at Breast Height (CBH) found inside the plots were marked and counted. Free man measuring tape was used to measure the CBH of the tree individuals. Specimens were collected for tree species that could not be identified in the field and were brought to the Botanical survey of India, Andaman and Nicobar Islands Circle, Port Blair for confirming the identity.

4.2.2. Data analysis

Stem density (individuals/0.1 ha.), species richness (species/0.1 ha.) and basal area (m^2/ha.) for each of the two vegetation types, SRV and SLRV were calculated separately. For multi-stemmed trees, basal area for each stem was calculated separately and summed. Importance Value Index (IVI) was calculated for all the species following Magurran (2004). Diversity indices such as Shannon index (*H*) and Simpson's index (*1/Y*) was calculated as a measure of diversity. Species accumulation curve was generated (S_{obs}) by plotting the cumulative number of species against the number of grids (10 × 20 m) as they were the smallest sampling units. Species richness was estimated by using non-parametric estimator Chao 2 with 1000 randomizations in the Estimate S ver. 8.2.0. software programme (Cowell, 2004). Chao2 is an incidence based richness estimator that works based on number of uniques (species that are encountered in only one sample) and duplicates (species that are found in only two samples) present in the sampling efforts and was regarded as very effective in estimating species richness for tree communities (Sagar et al., 2003). All the above mentioned analyses and calculations were carried out separately for SRV and SLRV from 2 year datasets (2009–2010, 2010–2011) discretely for comparison. The rate of change in vegetation parameters such as mean stem density (MSD), mean species richness (MSR) and mean basal area (MBA) was calculated by using the following formula,

$$A = ((c-b) / c) * 100$$

A= percentage of change between first and second year values, b and c = first and second year mean value (i.e. Mean of either one of following: stem density, species diversity or basal area).

Non-parametric One-sample Kolmogorov-Smirnov test was carried out to test that normality of the data for stem density, species richness and basal area from all the four data sets SRV1, SRV2, SLRV1 and SLRV2 (number indicates the year). Since, normality was achieved for all variables except basal area of SRV, parametric paired-samples *t*-test was carried out to test the difference in stem density, species diversity and basal area between SRV1 and SRV2 and SLRV 1 and SLRV 2. Non-parametric Kruskal–Wallis test was used to examine the difference in stem density, species richness and basal area among SRV and SLRV.

4.3. Results

A total of 135 tree species belonging to 97 genera and 42 families were recorded during the study (Appendix 2). The diversity varied between the years for both SRV and SLRV. All the vegetation parameters have shown higher values for SLRV2, except the estimated species richness using Chao 2, where the highest value was achieved for SLRV1. SRV1 recorded the lowest values for all the vegetation parameters. The number of stem individuals recorded during the second year (5843 individuals) was higher than the first year (5528 individuals) (Table 4.1). Family level species richness was highest in Euphorbiaceae and Moraceae (13 each) followed by Malvaceae (10). The genus level richness was highest for Ficus (11), Sterculia (4) and Leea (4). Among the species recorded, 12 were endemic to the Andaman and Nicobar Islands and five were strict endemic to the Nicobar Islands (Appendix 2).

Table 4.1. Variation in different vegetation parameters among the vegetation types studied

Variables	SRV1	SRV2	SLRV1	SLRV2
Species observed	31	43	113	120
Estimated species richness Chao 2	36	66	158	143
Genus	28	33	84	90
Families	22	23	43	45
Total stem	294	536	5234	5307
Mean number of species/plot	03.48 (03.58)	05.45 (03.81)	13.54 (05.55)	15.61 (06.95)
Mean number of individuals/plot	10.24 (13.13)	18.48 (17.81)	158.61 (76.38)	160.82 (73.74)
Mean basal area m^2/ha.	01.32 (02.74)	02.07 (02.93)	12.90 (03.52)	14.50 (03.78)
Shannon index (H)	00.79 (00.76)	01.15 (00.78)	01.44 (00.62)	01.57 (00.68)
Simpson's index (D)	04.61 (03.75)	05.23 (05.16)	03.45 (05.16)	03.79 (02.19)

*Numbers inside the parenthesis indicates standared deviation

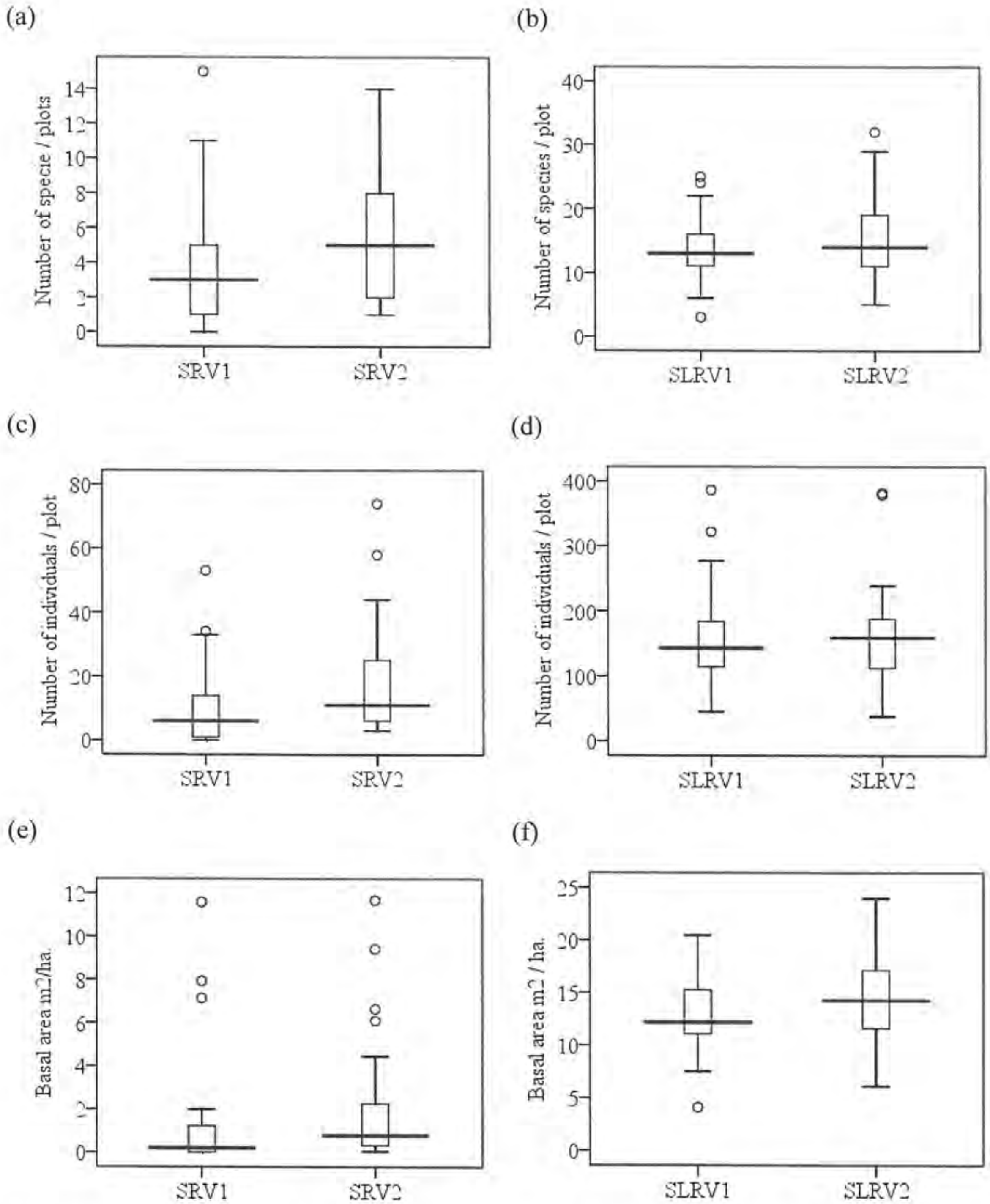


Figure 4.1. Box plot showing the variation in the species richness (a and b), stem density (c and d) and basal area (e and f) among the vegetation types. Box represents 50% of the data distribution, upper and lower percentiles represents 25% of data distribution. Line inside the box represents the median.

4.3.1. Species diversity, stem density and basal area

The mean species richness (MSR) plot^{-1} highly varied among vegetation types and was 75% higher in SLRV1 than SRV1 ($\chi^2 = 35.68$, df=1, $P<0.0001$). Similarly, mean stem density

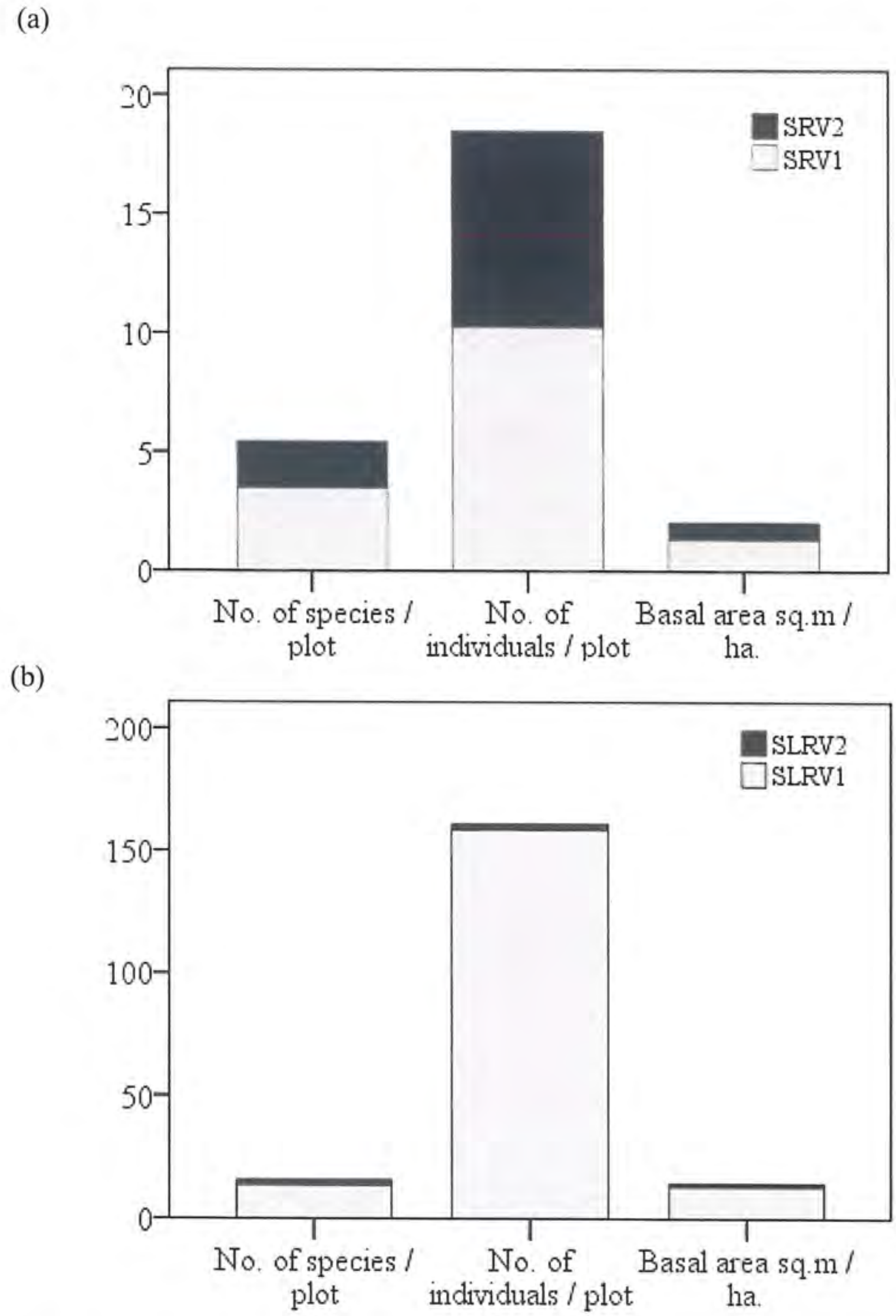


Figure 4.2. Variation in the ecological values of vegetation parameters in SRV1 & SRV2 (a) and SLRV1 & SLRV2 (b).

(MSD) plot^{-1} (93%) and mean basal area (MBA) plot^{-1} (90%) were higher in SLRV1 than SRV1 (χ^2=45.46, P<0.0001; χ^2= 42.64, P<0.0001). The second year data set showed similar trends, where SLRV2 had higher values (MSR=65%; MSD=88% &MBA= 86%) than SRV2 (χ^2=31.89, P<0.0001; χ^2= 44.27, P<0.0001 & χ^2= 43.13, P<0.0001) (Fig. 4.1).

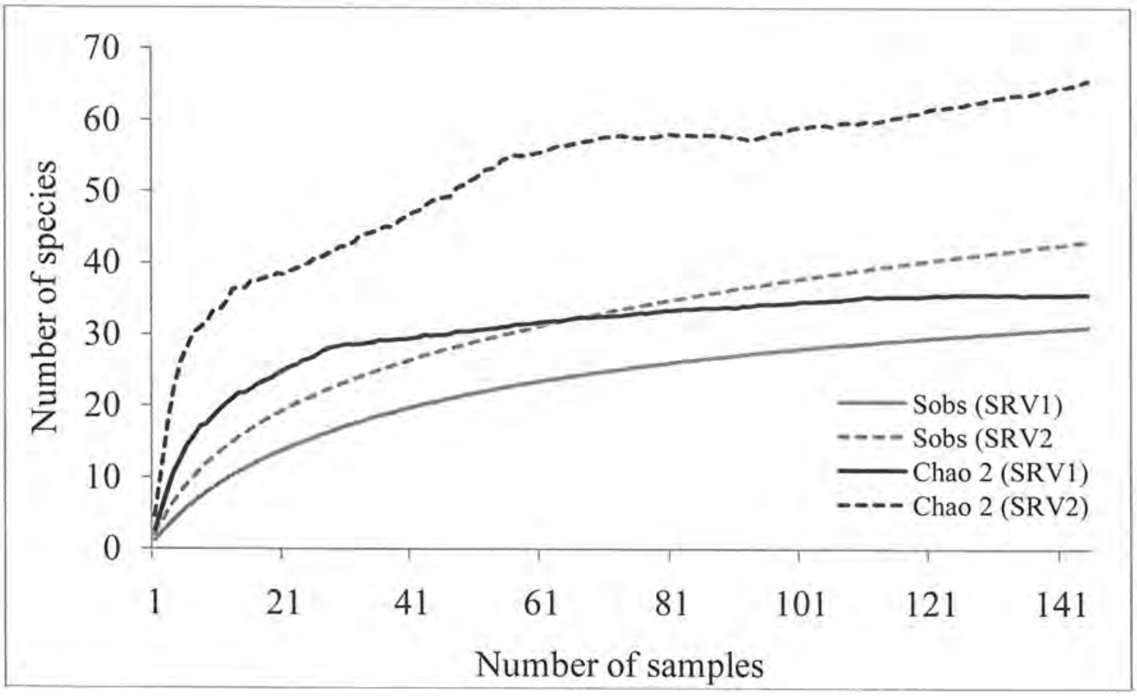
4.3.2. Rate of change

The ecological values for all the vegetation parameters had increased during the re-sampling. In SRV, the values have increased (Fig.4.2a) for MSR (36%), MSD (44.5%) and MBA (36.3%) and shown a significant variation between SRV1 and SRV2 (t=5.75, P<0.0001; t=5.39, P<0.0001; t=3.41, p<0.01). The variation was comparatively low in SLRV, where the values for MSR (13.2%) and MBA (11%) showed significant variation (t=4.42, P<0.001; t=3.71, P<0.01) but the MSD (1.4%) did not vary significantly between SLRV1 and SLRV2 (t=0.44, P>0.05) (Fig.4.2b).

4.3.3. Species dominance

The IVI values for different species varied between the first year and second year in both the vegetation types. In SRV, *Casuarina equisetifolia* was the dominant species (IVI: SRV1=84.57 and SRV2=74.01) with 24 and 18% of the total stem individuals in SRV1 and SRV2 respectively. The co-dominant species were *Hibiscus tiliaceus* (IVI: SRV1=26.71 and SRV2=36.78) and *Pandanus lerum* (IVI: SRV1=25.22 and SRV2=24.45). In SLRV, *Macaranga peltata* (IVI: SLRV1=122.65 and SLRV2=118.52) was the single most dominant species contributing 55% (SLRV1) and 51% (SLRV2) to the total stem individuals. The co-dominant species were *Ficus hispida* (IVI: SLRV1 = 18.95 and SLRV2=17.47) and *Boehmeria nivea* (IVI: SLRV1=16.81 and SLRV2=13.09). The first ten dominant species with higher IVI values have contributed 76, 73, 70 and 68% to the total IVI values in SRV1, SRV2, SLRV1 and SLRV2 respectively (Appendix 1). Similarly, the first ten dominant species accounted for high number of individuals (SRV1=77%, SRV2=75%, SLRV1=85%, SLRV2=82%) in both the vegetation types.

(a)



(b)

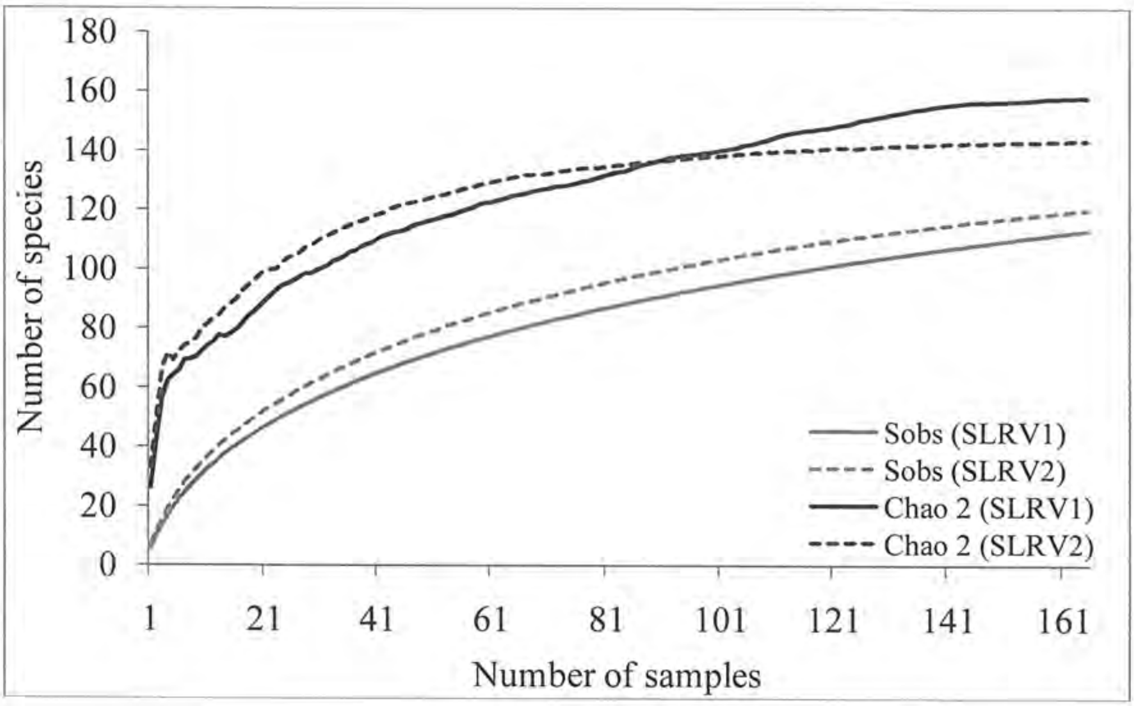


Figure 4.3. Species accumulation curve (a) SRV (b) SLRV

4.3.4. Species accumulation curve

A gradual increase is observed in the species accumulation curve established for the observed number species in all the four datasets (Fig. 4.3). The Chao 2 had reached the asymptotic value in the SRV1 but SRV2 shows high variation and gradual increase (Fig. 4.3a). In contrary, the Chao 2 for SLRV 2 had reached the asymptote and shows lesser value than the estimated species richness of SLRV1 (Fig. 4.3b). The increase of 28% of species was observed in SRV2 resulted in high variation in the Sobs between SRV1 and SRV2. The variation in Sobs between SLRV1 and SLRV2 is comparatively lower (6%) than SRV.

4.3.5. CBH classification

SRV shows a steep decrease between first two CBH classes (Fig. 4.4a). High number of stem individuals were observed in the CBH class 10–20 (SRV1= 49%, SRV2= 47%). In comparison, SLRV with a gradual decrease showed less variation among the adjacent CBH classes (Fig. 4.4b). Highest CBH was recorded for *M.peltata* (105 cm) in SLRV and *C.equisetifoloia* (100 cm) in SRV. The addition of more individuals resulted in exponential increase (44%) of 10–20 cm CBH class in SRV2 in comparison with SRV1. While all the CBH classes in SRV had increased during the second year, in SLRV the number has decreased for 20–30 (11%) and 30–40 (6%) CBH classes (Fig. 4.4c).

4.4. Discussion

4.4.1. Species richness

The dominance of Euphorbiaceae was similar to the adjacent Andaman Islands (Rajkumar and Parthasarathy, 2008; Rasingam and Parthasarathy, 2009), Singapore and Malaysia (Ho et al., 1987; Swan, 1988). The dominance of Moraceae could be due to the high chances of seed dispersal by birds. In particular, a single genus *Ficus* had 11 species. The semi-parasitic nature and a high preference of fruits by birds explain the high diversity of *Ficus* species in the regenerating vegetation. In general, the actual and estimated species richness had increased during the course of the study. Only in SLRV2, the estimated species richness using Chao2 had shown 11% decline due to 21% decrease in uniques (species occur in a single sample) when compared with SLRV1 as Chao2 predicts number of unobserved species by the ratio between unique and duplicates (Chao et al., 2005). SRV1 and SLRV1 together had 120 species and it was increased to 127 species during the second year. Species richness did not vary among the two vegetation types SRV2 (n=13) and SLRV2 (n=14). All the added species in SRV2 were also

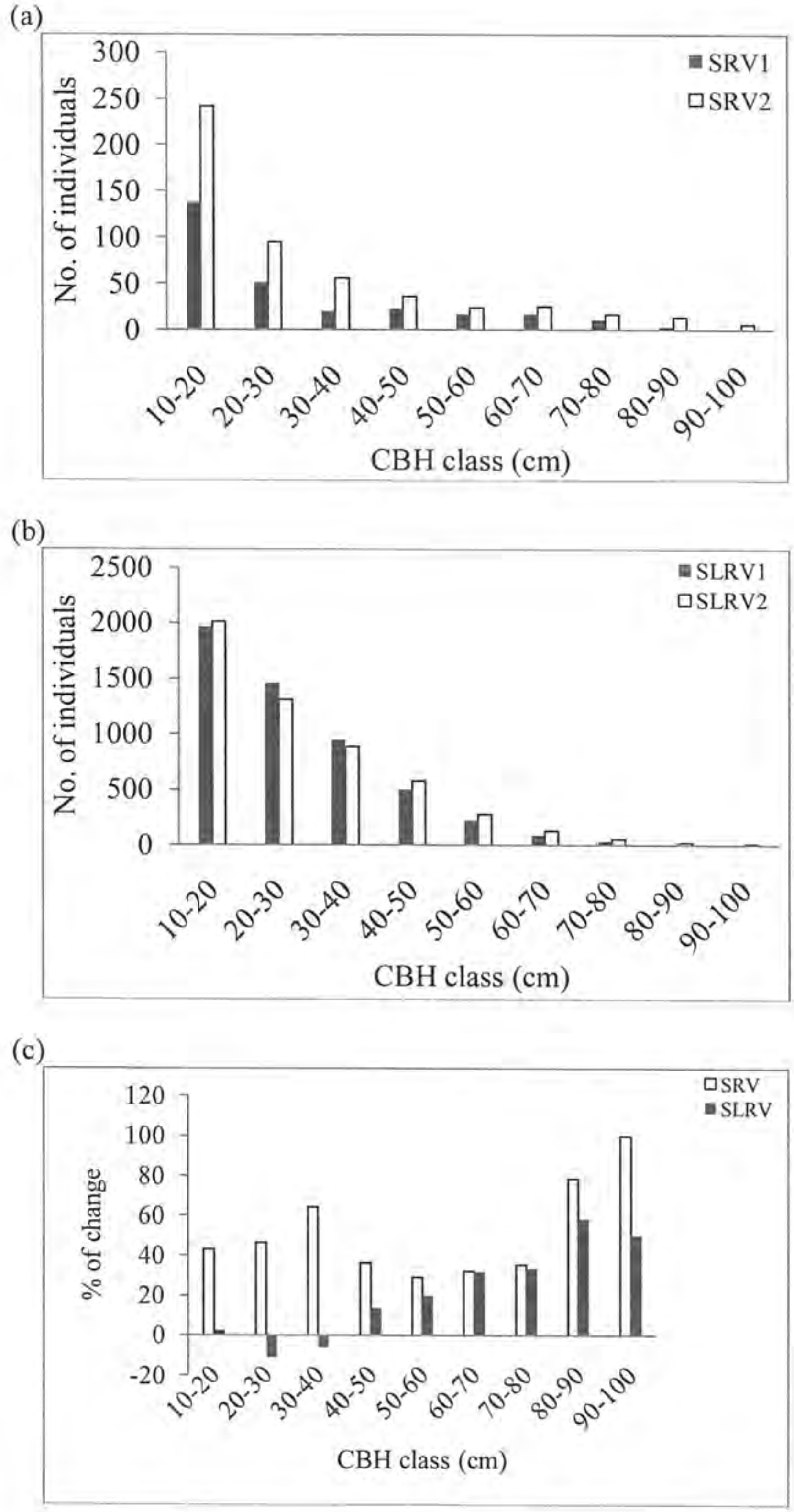


Figure 4.4. Variation in the CBH class distribution in SRV1 & SRV2 (a), SLRV1 & SLRV2 (b). (c) Percentage of change in the CBH class distribution of SRV and SLRV between first and second year sampling.

found in SLRV. Among which, except four species, rest of them are disturbance specialists that prefer open habitats. In contrast, among the 14 added species in SLRV2, four were disturbance specialists, one was exotic tree and nine were unaffected forest species. Interestingly, seven species that are found in SLRV1 was not recorded in SLRV2. These seven species are mostly short-statured trees and shrubby woody plants, which is a characteristic trait of the initial colonizers that has a short life span and disappears as the succession proceeds (Peña-Claros, 2003). It was found that a few species were particular in their habitat preferences. Six species found only in the SRV, of which except *Peltophorum pterocarpum* others were either short statured-trees or shrubby species that prefers open sandy places. Thus, the species richness in the secondary vegetation of tsunami impacted sites did not reach the maximum and may keep accumulating species until it reaches equilibrium. In particular, the species poor SRV may take more years to reach the equilibrium than the SLRV having species richness which is comparable with UF.

4.4.2. Vegetation structure and recovery rate

Variation among factors operating on the early succession such as initial site condition, seed dispersal, germination and predation are accounted for the variation among stands of same age (Kennard, 2002). The high variation in the values of vegetation parameters MSR, MSD and MBA between SRV and SLRV suggest that the vegetation succession and recovery rates can be impeded by the disturbance in the soil substratum and variation in the initial site conditions. However, the levels of difference in vegetation parameters showed slightly decreased values between SRV and SLRV during the second year. The measure of rate of change in MSR, MSD and MBA between the fifth and sixth year (the study period after tsunami 2009–2010 and 2010–2011) suggest that the initial phase of vegetation recovery in SRV was much slower than SLRV and gradually the vegetation recovery in SRV is accelerated as the initial colonizers got established and making the environment suitable for the colonization of other late pioneers that are found in SLRV. The minor variation (1.4%) in the MSD of SLRV suggest that it has almost reached its maximum of stem individuals as it is already close to twice the value of unaffected forest (Table 4.1). Similar pattern was observed by Kennard (2002) and Vandermeer et al. (2000) in a successsional tropical forest community where the stem density had increased twice the number of mature forest in less than a decade. The rate of increase in MSR (13%) and MBA (11%) of SLRV is nearly the same and suggest that the MSR may exceed the unaffected forest value (18.04±7.66) (Table 4.1) in 2 years if it increases at the same rate, while MBA may take decades to reach the unaffected forest values. As reported in other studies, it is found that the species richness and stem density recovery in a disturbed forest takes a few years while basal area may take a few decades (Kennard, 2002; Chazdon, 2003).

4.4.2. Species dominance

The percentage of first ten dominant species IVI values and contribution to the total stem density showed a decrease over the study period. Similarly, the dominant species of SRV (*C.equisetifolia*) and SLRV (*M.peltata)* had shown a decline in IVI and their contribution to the total stem density values. The number of individuals of some dominant species has decreased between the first and second year. In SLRV, number of individuals of *M.peltata* has decreased from 2865 to 2657 and *Boehmeria nivea* decreased from 316 to 219. Early successional stands are known to have a dominance of few pioneer species. The density of these pioneer species decreases with stand age results in increase in species diversity (Saldarriaga et al., 1988; Guariguata and Ostertag, 2001). The pioneering vegetation community in the study area is gradually transforming from less evenness vegetation community showing dominance of a few species to high evenness vegetation community showing dominance of many species. The higher values of Shannon's index and Simpson's index in SRV2 and SLRV2 than SRV1 and SLRV1 also strengthen the above mentioned view.

4.4.3. CBH classification

The girth class frequency for both the vegetation types had decreased exponentially as it approaches the highest CBH from the lowest and exhibiting the reverse 'J' shaped stand structure. The good recruitment rate of young individuals observed for the low circumference classes illustrates the health of the vegetation community (Rasingam and Parthasarathy, 2009). The pioneer species of the early successional stages has high growth rate and are able to surpass other species very rapidly (Swine and Hall, 1983). Due to the high growth rate of *C.equisetifolia* in SRV1, the number of individuals in the CBH classes 30–40, 40–50, 50–60 and 60–70 cm did not vary much. The exponential increase in 10–20 cm CBH class in SRV2 indicates accumulation of individuals is getting accelerated in SRV. The decline in stem individuals of 20–30 and 30–40 cm CBH category in SLRV2 may be due to the mortality of young individuals regarded as the self thinning process (Yoda et al., 1963). In particular, at high stem density plots, the number of individuals had declined where dead trees of *M.*

peltata were commonly found. Hence, further investigation is required to test prevalence of self thinning process in the study area.

4.5. Conclusion

The interplay between disturbance and recovery has several critical implications for ecological studies in tropical rain forests (Chazdon, 2003). The vegetation recovery rates have highly varied between sites with affected and unaffected soil substratum. In unaffected soil substratum (SLRV), the stem density has increased twice the number of mature forest and species richness is expected to reach mature forest value in a couple of years at the current trend. But the basal area recovery, which is comparatively slower, may take a few decades. Whereas in soil substratum affected sites (SRV), the vegetation recovery is much slower at all levels, but it got accelerated in recent years. Accumulation of nutrients in the soil substratum through leaf litter deposition by pioneer species perhaps could be the reason. Mortality of young size class trees observed in some sites suggests the occurrence of self thinning process in the study sites. Further monitoring would provide more information on forest recovery after the natural calamity such as tsunami.

CHAPTER V

IMPACTS OF TSUNAMI AND THE NATURAL RECOVERY PATTERNS IN MANGROVE FOREST

5.1. Introduction

Mangroves are unique ecological communities that are adapted to thrive in margins of tropical coasts where the environmental conditions do not favor the growth of other vegetation communities (Tomlinson 1986). The ecological services of mangroves include breeding ground for fishes and prawn, roosting place for bats and birds, habitat for variety of crabs, crocodile and turtles (Nagelkerken, 2008; Mumby et al., 2004; Walters et al., 2008). Mangroves act as a barrier and minimizes the loss of human lives and properties from natural calamities such as hurricanes, cyclones, coastal erosion and tsunami (Danielson, 2005; Das and Vincent, 2009; Kathiresan and Rajendran, 2005).

Despite all the services rendered, mangroves are disappearing from the world at an alarming rate of 1% per year (FAO, 2007). This critical ecosystem has suffered a global loss of 35% of the total area in the last two decades of twentieth century (Valiela et al., 2001). The main causes of mangrove loss are conversion of mangrove land for various purposes including shrimp cultivation, agriculture, road construction, fuel wood extraction and other developmental activities (Valiela et al., 2001; Polidoro et al., 2010). Other than human induced degradation, mangroves are vulnerable to hurricane, cyclone, climate change and sea-level rise (Gilman et al., 2008). It is predicted that by the end of this century, sea level may rise for about 9–88 cm causing the seaward mangrove to move towards land (Pernetta, 1993; Watson et al, 2001). Tectonic movements can make a large scale disturbance on mangrove by either rise or lower the land level with reference to the sea (Woodroffe, 1988; Blasco et al., 1996). Continued destruction and degradation of many mangrove forests throughout the tropics over the past few decades has decreased the protective capacity of mangrove forest ecosystems and reduced their ability to rebound from natural disasters (Dahdouh-Guebas et al., 2005).

The resilience and dynamics of mangrove forests to human induced disturbances have been studied in many parts of the world (Giri et al., 2008; Ellison and Fransworth, 1996; Putz and Chan, 1986; Sherman et al., 2001), but the quantitative information available on the succession of mangroves after natural disasters are rather scanty (Roth, 1992; Imbert et al., 1996; Sherman et al., 2001; Ross et al., 2006). Large-scale disturbances have been an important driving force behind the mangrove forest evolution (Tomlinson, 1986). However, the processes by which mangrove ecosystems recover from large-scale disturbance events and the rates and patterns of recovery are largely unknown (Sherman et al., 2001) and the species zonation pattern in mangrove forests have been seldom quantified (Ellison and Farnsworth, 2001).

Figure 5.1. Tsunami damage and colonization of mangroves. (a) colonization of mangroves at pre-tsunami coastal evergreen forest, Ok Chu Ka, Trinket Island; (b) mangrove colonization at pre-tsunami coconut grove, Safed balu, Trinket Island; (c) *Rhizophora mucronata* the only colonizing species at the pre-tsunami mono-dominant *Bruguiera gymnorhiza* forest, Safed balu, Trinket Island.

The tilt in the land mass followed by incursion of sea water in the mangrove forests of Nicobar Islands after tsunami resulted in the perennial submergence of pneumatophores, which resulted in scorching of mangrove trees due to the hypoxic condition. In contrast, the same phenomenon has resulted in the formation of new habitats where mangrove species started colonizing at the expense of flat coastal forests (Fig. 5.1) and coconut plantations that existed close to the coast (Nehru and Balasubramanian, 2011).

Studies on the impact of tectonic plate movement (Roy and Krishnan, 2005; Gopal and Chauhan, 2006) and tsunami on mangroves (Giri et al., 2008) are very rare. Similarly, information on recovery of mangrove forests after natural disturbances is scanty (Sherman et al., 2001; Ross et al., 2006). Hence, the present study was planned with the following objectives, (i) vegetation quantification of pre-tsunami and post-tsunami mangrove forest (ii) mangrove species re-colonization in tsunami impacted sites (iii) influence of residual trees and various environmental and ecological factors on the mangrove species re-colonization process.

5.2. Methodology

5.2.1. Field Survey details

The entire coastal line of all the 22 islands present in the Nicobar group of Islands excluding two Islands namely Batti Malve and Isle of Man were circumnavigated by using the small motor boat to find out the existing pre-tsunami and newly formed mangrove habitats. GPS coordinates for each site was recorded by using Garmin 76CSx. The pre-tsunami vegetation maps (IIRS, 2003) were also used to identify the mangrove sites.

5.2.2. Mangrove Diversity

All the species present in the mangrove re-colonizing habitats were collected and identified with the help of local floras and compared with the specimens in the Botanical survey of India, Andaman and Nicobar Islands Circle, Port Blair. A check list of mangrove species of Nicobar Group of Islands was prepared based on the present collections. The pre-tsunami mangrove diversity was compiled from the literature sources (Dagar et al., 1991; Sinha, 1999; Mandal and Naskar, 2008; Yao et al., 2011). The present mangrove diversity was compared with the pre-tsunami species diversity to find out local extinction or additions happened after tsunami.

5.2.3. Structure and diversity of pre-tsunami mangrove forest

The vegetation of pre-tsunami mangrove forest was estimated from the tsunami affected mangrove forest. The scorched mangrove forest was sampled from six sites where inter-tidal zone still exist but the mangroves died out presumably due to high frequency inundation. Mono-dominance of *Bruguirea gymnorhiza* was observed in these sites. A total of 20 sampling plots of 20 × 20 m were established in these six sites for recording the vegetation. The scorched *Rhizophora* stands could not be sampled due to the subduction of the land resulted in permanent inundation for up to 1–2 m depth. To overcome this, sampling was done in the only unaffected mangrove forest present in Car Nicobar Island as a representative for *Rhizophora* stands by using 10 × 10 m quadrates (n=20). All the tree individuals ≥10 cm CBH present in the quadrates were enumerated with their respective CBH. The identification of tree snags in scorched mangrove sites was done using the distinct morphological cues possessed by different species. Species level identification of snags could not be done for certain genera namely, *Rhizophora*, *Bruguiera* and *Sonneratia* since they all had similar kind of pneumatophores (knee roots, cone shaped roots and prop-roots).

5.2.4. Structure and diversity of post-tsunami mangrove forest

The colonization of mangrove species was studied from six sites distributed over four Islands. (Great Nicobar and Trinket – 2 sites each, Katchall and Car Nicobar – 1 site each). The mangrove regenerating sites were grouped under two categories namely, Non-residual and Residual sites, based on the availability of matured trees/residual trees in a particular site to study the influence of availability of seed source on the colonization process. The mangrove colonizing sites have shown more habitat heterogeneity (such as mud flats, puddles, canals and permanent inundations) in a relatively smaller area. Thus, establishing sampling plots of similar size was not possible to cover maximum sampling area. Hence, varying sizes of sampling plots were used to estimate the stem density. (i) In Non-residual sites (n=5), sampling plots of 1000–5000 m^2 were used (ii) In Residual site (n=1), sampling plots of 100 m^2 randomly spacing a minimum of 50 m distance from each other was used to study the stem density and species diversity. All the individuals of stem ≥1 cm CBH were enumerated from the sampling plots.

5.2.5. Zonation

The mangrove sites were classified into four different categories based on the tidal inundation regimes. Van Loon et al. (2007) suggested that the hydrological classification of mangrove zones described by Watson (1928) is not sufficient in mangrove areas with irregular tidal regimes and elevation. We adopted Watson's (1928) classification with slight modification instead of five zones only four zones as described below were considered to analyze its effect on the colonization process.

1- Inundation during every high tide and inundated with sea water for most of the time

2- Inundation during medium high tides. Usually sea water recedes sooner during low tide

3- Inundation during spring tide, devoid of sea water for most of the time

4- Inundation only during high spring tides and equinoctial tide. Rarely gets sea water.

5.2.6. Microhabitat Preference

The micro-habitat preference by different species of mangrove saplings at the colonizing sites was studied from 12 sites over seven Islands (Great Nicobar – 3 sites; Katchall, Kamorta and trinket – 2 sites each; Car Nicobar, Nancowry and Little Nicobar – 1 site each). Point Centre Quarter (PCQ) method was followed for the study. Each PCQ point were spatially 100 m distance from each other and a single sapling ≥ 1 cm CBH nearer to the PCQ point in each of the four quarters were selected for collecting data on different environmental and ecological parameters. Data on ten different variables (adjacent dominant snag species, substrate, drainage, inundation, pre-tsunami habitat status, present habitat status, type of microhabitat, distance from low tide line, status of adjacent mangrove snags and presence and absence of residuals) were collected.

5.2.7. Data analysis

5.2.7.1. Pre and Post tsunami mangrove vegetation

Stem density ha^{-1} was calculated for pre and post tsunami mangrove forest from the quadrate data. Relative frequency, relative density and relative abundance were calculated and Importance Value Index (IVI) was derived following Curtis and McIntosh (1951). Likewise, the stem density for each of the four mangrove zones was calculated separately for both

Residual and Non-residual sites. Chi-square analysis was done to test the null hypothesis that the stem densities of different zones are similar. Both the Residual and Non-residual sites are treated separately to test the hypothesis. We employed cluster analysis to ordinate the species association based on the presence or absence data of a particular species in a particular zone. The paired group algorithm and Jaccard similarity measure were used to measure the distance between species groups.

Stem density for each species present in the colonizing sites was calculated by summing the density of each species observed in the sampling plots and dividing them with the sum of total area sampled to convert the density values in hectares. The calculated stem density values were then used in determining the best fit abundance model for the pioneering mangrove community observed in the study area. Non-parametric Mann–Whitney *U*-test was performed to test the influence of seed source (residual trees) in the colonization process by testing the difference between overall stem density in Residual and Non-residual sites. Statistical software packages SPSS Version 16.0 and PAST version 2.14 were used for the analysis.

5.2.7.2. Habitat preference by mangroves in colonizing sites

Mantel's correlation analysis was performed to find out the correlation between environmental variables and mangrove colonization. As the micro-habitat parameters vary within each of the PCQs (n=57), site of each mangrove sapling ("micro-site") was taken as primary sampling unit (n=228). To compare, the following similarity matrices of micro-sites were constructed: (a) matrix based on mangrove sapling distribution (As the data were presence-absence, Sorenson's similarity measure was computed between micro-sites) (b) matrix based on post-tsunami environmental and ecological parameters. As the data were measured as categorical variables, Hamming similarity index was used to derive this matrix. Since the micro-sites located within a single PCQ were not statistically independent, it was decided to partial out the PCQ id as it would unduly under/over-estimate true relationship through spatial autocorrelation. So a third co-factor matrix was derived on the basis of PCQ id (n=57). Since it is a geographical variable, Euclidean distances were computed to derive this matrix. Then, partial Mantel's correlation analysis was done using 5000 Monte Carlo simulations between mangrove saplings and environmental variables after the PCQ id was partialled out.

Habitat preference by the two most dominant species *Bruguirea gymnorhiza* and *Rhizophora mucronata* was derived from the environmental and ecological parameters collected from the PCQ's. Association analysis was carried out between the micro-sites of *B.gymnorhiza* (n=85) and *R.mucronata* (n=57) with the equal number of randomly selected micro-sites of other species to test the difference between the parameters for dominant and other species. Association analysis was done by using the descriptive statistics Phi and Cramer's V in the cross tab analysis.

5.3. Results

5.3.1. Mangrove diversity of Nicobar Islands

In total, 23 sites distributed over seven Islands were observed to have mangrove colonization after the tsunami. Of the 23 sites, 12 were selected for the intensive study. A total of 17 species of mangroves belonging to 11 genera and 9 families were recorded from the mangrove colonizing sites (Table 5.1). Five species namely *Lumnitzera littorea*, *Ceriops tagal*, *Rhizophora lamarckii*, *Scyphiphora hydrophyllacea* and *Sonneratia alba* were recorded for the first time from the Nicobar Islands (Fig. 5.2). *Sonneratia ovata* a Near Threatened (Polidoro et al., 2010) landward mangrove was recorded for the first time within Indian territory which also forms a new addition to the mangrove flora of India. Five species of mangroves, namely *Acanthus sp.*, *Cynometra ramiflora*, *Bruguiera parviflora*, *Bruguiera sexangula* and *Xylocarpus moluccensis* reported from the Nicobar Islands prior to tsunami (Dagar et al., 1991; Sinha, 1999) were not found during the present study.

5.3.2. Vegetation structure of Pre-tsunami mangrove forest

The Mean Stem Density (MSD) observed for the pre-tsunami mangrove forest is 600 ± 350.18 ha^{-1}. The MSD varied between *Bruguiera* stand (325 ± 121.4 ha^{-1}) and *Rhizophora* stand (875 ± 278.9 ha^{-1}) where the stem density was much higher for *Rhizophora* stand (Fig. 5.3a). However, the Mean Basal Area (MBA) of *Bruguiera* stands (24.6 ± 10.83 m^2 ha^{-1}) was higher than *Rhizophora* stands (14 ± 4.08 m^2 ha^{-1}). *B. gymnorhiza* was the predominant species with greater values of MBA (19.11 ± 9.77 m^2 ha^{-1}), relative frequency (40%), relative density (62%) and relative dominance (62) and thus the highest IVI (163.25) value in the *Bruguiera* stands. Likewise, *R. mucronata* was the single most dominant species with highest

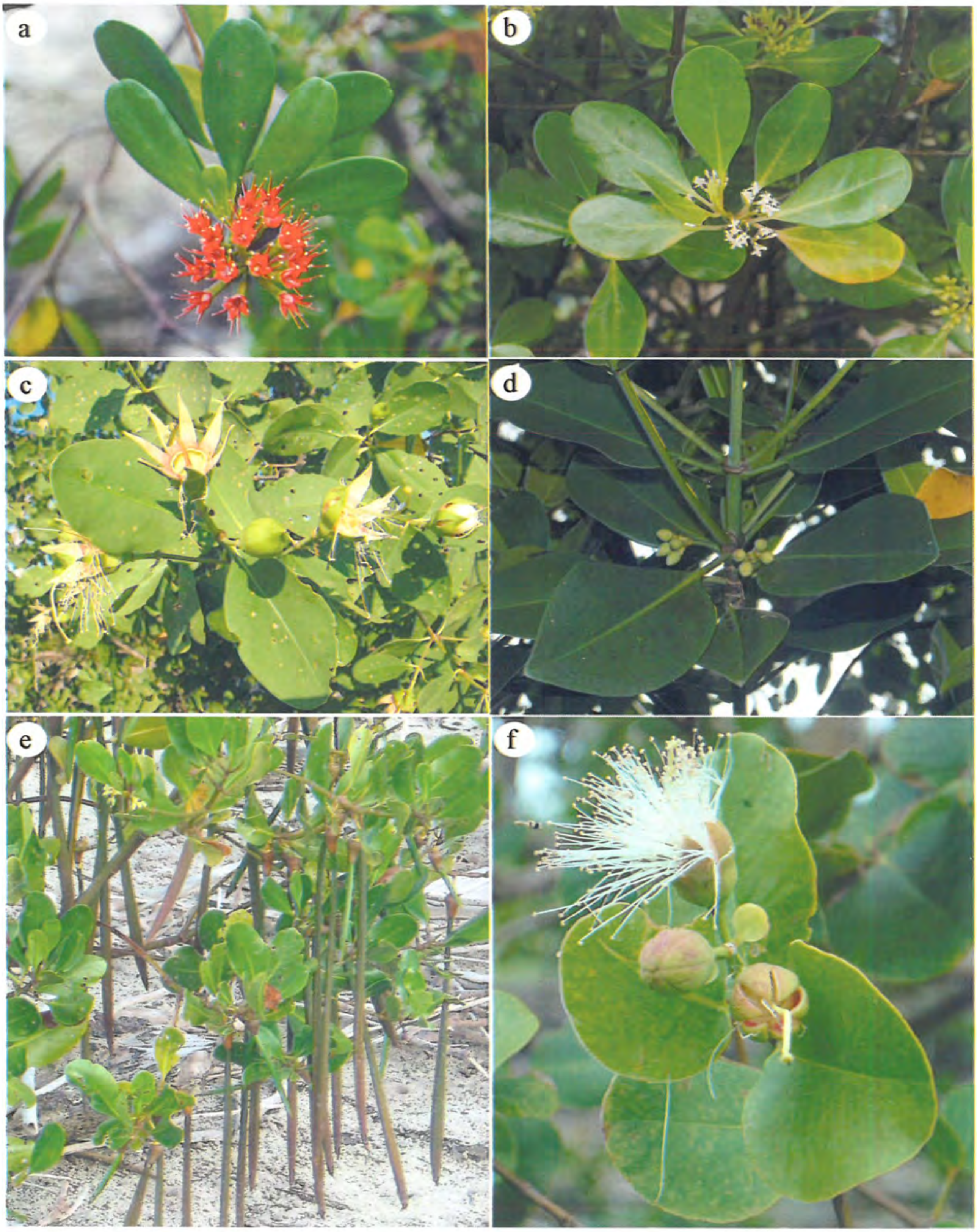


Figure 5.2. The new additions of mangrove species for the Nicobar Islands flora. (a) *Lumnitzera littorea* (b) *Scyphiphora hydrophyllacea* (c) *Sonneratia alba* (d) *Rhizophora lamarckii* (e) *Ceriops tagal* (f) *Sonneratia ovata*

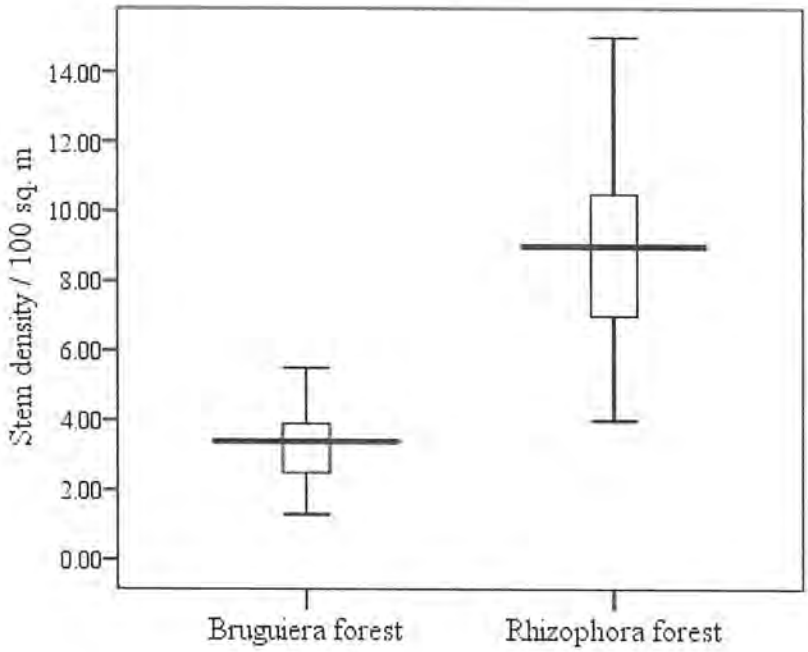
values of MBA (13.49 ± 4.54 m^2 ha^{-1}), relative frequency (79%), relative density (91%), relative dominance (91%) and IVI value (261.45) in the *Rhizophora* stands.

In the case of post-tsunami mangrove colonizing sites, the overall MSD (288 ± 217.5 ha^{-1}) was less than the pre-tsunami mangrove forest. The Whisker plots representing the MSD of residual sites (364.5 ± 205.82 ha^{-1}) and non-residual sites (149.9 ± 166.96 ha^{-1}) are not overlapping and spatially dispersed in a long distance and are significantly different from each other (Mann–Whitney *U*-test, $P<0.001$) (Fig. 5.3b). The overall stem density for each species was calculated from the sum of all the observations of a species divided by the total area sampled (Fig. 5.4). The stem density of *B. gymnorhiza* (59 ha^{-1}) and *R. mucronata* (30 ha^{-1}) recorded highest values. Species such as *X. granatum* and *R. stylosa* were having least number of individuals (1 $ha.^{-1}$). Among the models tested for the community structure of mangrove in the colonizing site, the rank abundance curve shows log series model (P=0.79, χ^2= 3.83) (Fig. 5.5).

3.3. Mangrove zonation in colonizing sites

The zonation patterns in the colonizing areas were distinctly marked with species diversity as well as stem density (Figs. 5.6 – 5.7). Zone 1 was poor in species richness (RS=1 and NRS=2) as well as MSD (RS=290 ± 158.6 $ha.^{-1}$ and NRS=20 ± 5.25 $ha.^{-1}$). Species richness was highest in zone4 of NRS (n=9). However, zone 3 in NRS had the highest mean stem density with relatively higher number of species (n=8). The MSD was high in the zone 3 for both the sites (NRS= 275 ± 218.2 $ha.^{-1}$ and RS= 513 ± 247.5 $ha.^{-1}$). Zone 4 could not be found in the residual site; hence it was not included in the sampling. The stem density in different zones significantly varies from each other in both the sites (RS χ^2= 65.49, df=2, $P<0.001$; NRS χ^2= 224.01, df=3, $P<0.001$) (Fig. 7). *B. gymnorhiza* and *R. mucronata* were found in all the four zones.

(a)



(b)

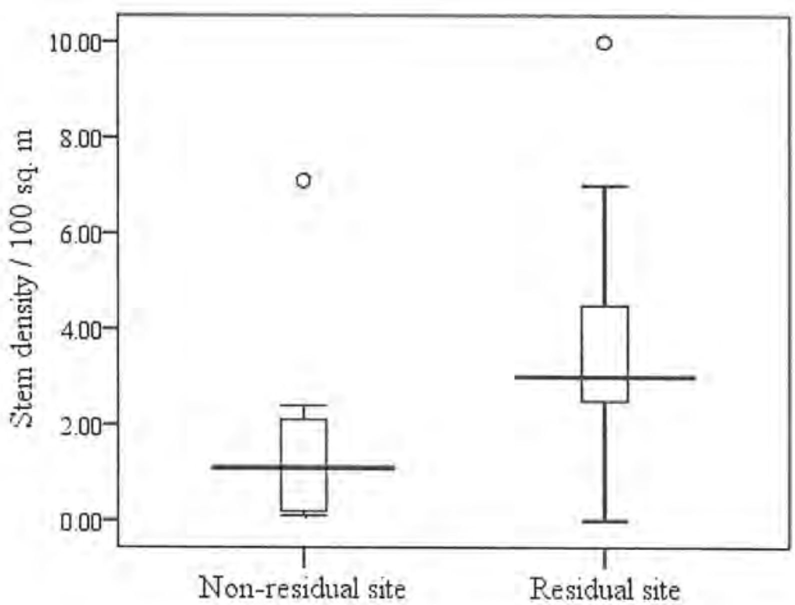


Figure 5.3. (a) The mean stem density of Bruguiera forest and Rhizophora forest (b) Residual site and Non-residual site. The boxes represent parameter values between 25th and 75th percentile and the lower and upper bars refer to minimum and maximum values. The outliers are shown as open dots.

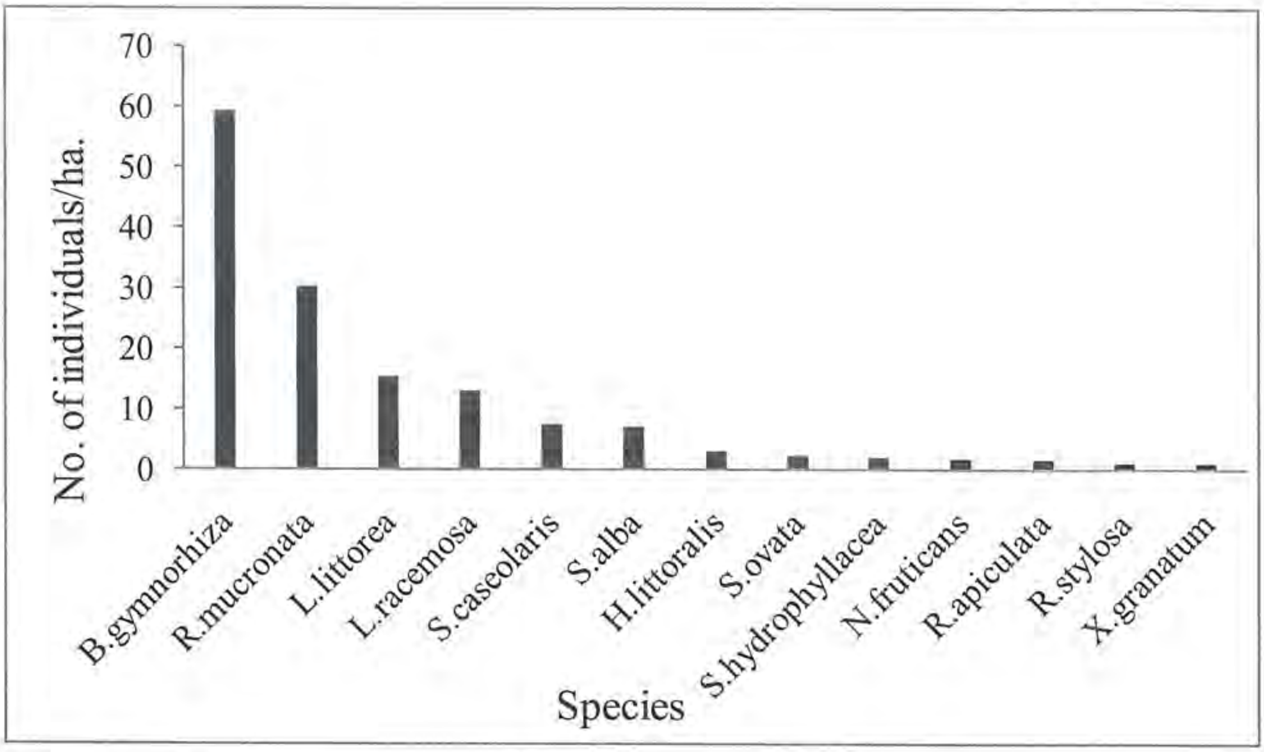


Figure 5.4. Abundance value of different species in the mangrove colonizing sites in Nicobar Islands

5.3.4. Cluster analysis

Classification of species according to their zonal affinity could be drawn from the cluster analysis (Fig. 5.8). The dendrogram constructed using the Jaccard similarity to findout the association between different species present in the colonizing sites had classified the species step wise based on the inundation zone (Cophenetic correlation coefficient = 0.85). Species such as *R.stylosa* and *L.racemosa* present in a single zone formed a distinct clade. Four distinct groups were formed based on the co-occurrence of species in different zones. *R.mucronata* and *B.gymnorhiza* found in all the four zones formed a group. Likewise, *N. fruticans* and *R.apiculata* found in zone 2 and 3, *H.littoralis, S.alba* and *S.ovata* found in zone 3 and 4 formed ditinct groups. Zone 4 had the maximum number of species with 4 species, namely *L.littorea, S.hydrophyllacea, S.caseolaris* and *X.granatum* that are restricted only to this particular zone which constituted a group at the base of the cluster.

Table 5.1. List of mangrove species present in the Nicobar Islands (including historical records)

S.No	Family	Binomial
1	Acanthaceae	**Acanthus sp.*
2	Arecaceae	*Nypa fruticans* Wurmb.
3	Bignoniaceae	*Dolichandrone spathacea* (L.f.) K. Schum.
4	Combretaceae	*Lumnitzera racemosa* Willd.
5	Combretaceae	‡*Lumnitzera littorea* (Jack) Voigt.
6	Euphorbiaceae	*Excoecaria agallocha* L.
7	Fabaceae	*Cynometra ramiflora L.*
8	Meliaceae	*Xylocarpus granatum* Koen.
9	Meliaceae	**Xylocarpus moluccensis (Lamk.) Roem.*
10	Rhizophoraceae	*Rhizophora mucronata* Poir.
11	Rhizophoraceae	‡*Ceriops tagal* (Perr.) Robins
12	Rhizophoraceae	*Rhizophora apiculata* Bl.
13	Rhizophoraceae	‡*Rhizophora lamarckii* Mont.
14	Rhizophoraceae	*Rhizophora stylosa* Griff.
15	Rhizophoraceae	*Bruguiera gymnorhiza* (L.) Savigny
16	Rhizophoraceae	**Bruguiera parviflora* (Roxb.) Wight and Arn.
17	Rhizophoraceae	**Bruguiera sexangula* (Lour.) Poir.
18	Rubiaceae	‡*Scyphiphora hydrophyllacea* Gaert.
19	Sonneratiaceae	*Sonneratia caseolaris* (L.) Engler
20	Sonneratiaceae	‡*Sonneratia alba* Sm.
21	Sonneratiaceae	‡**Sonneratia ovata* Backer
22	Sterculiaceae	*Heritiera littoralis* Dryand.

‡ New record for Nicobar Islands

‡* New record for India

* Species recorded prior to tsunami but could not be found during the present study

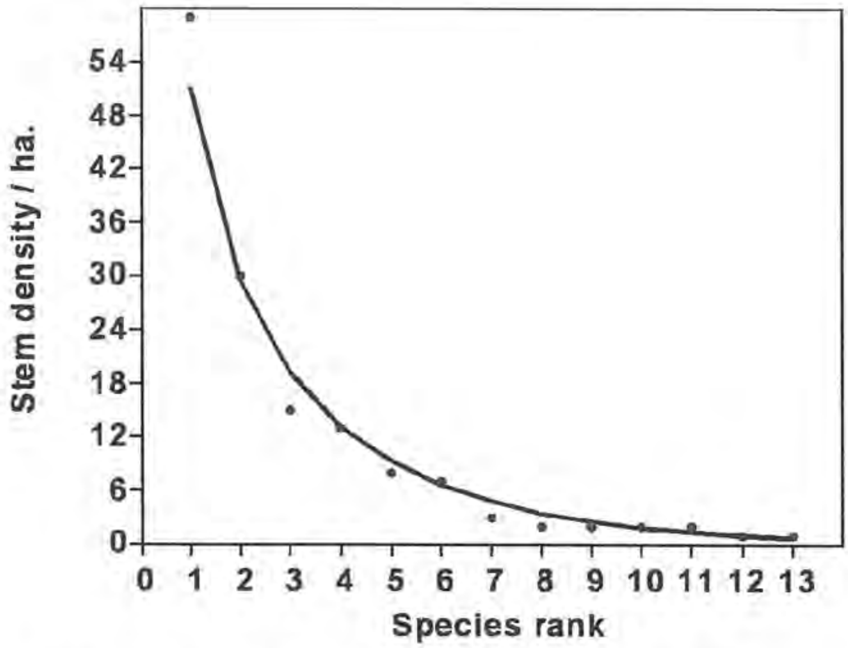


Figure 5.5. Rank abundance curve of mangrove species found in the mangrove colonizing sites of Nicobar Islands.

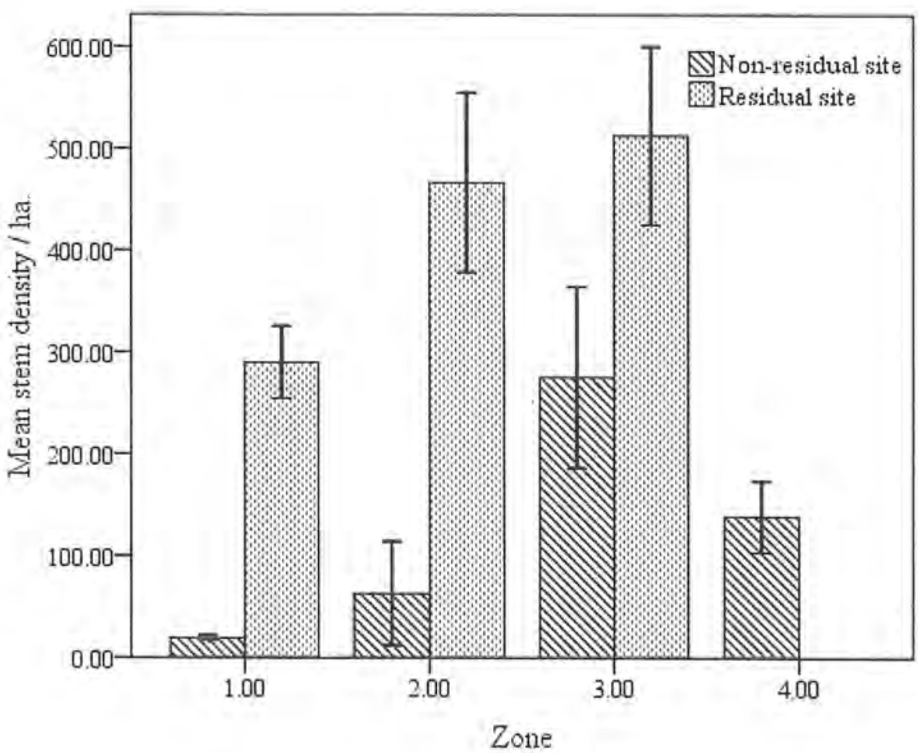


Figure 5.6. Variation in the mean stem density of Residual site and Non-residual sites in different zones

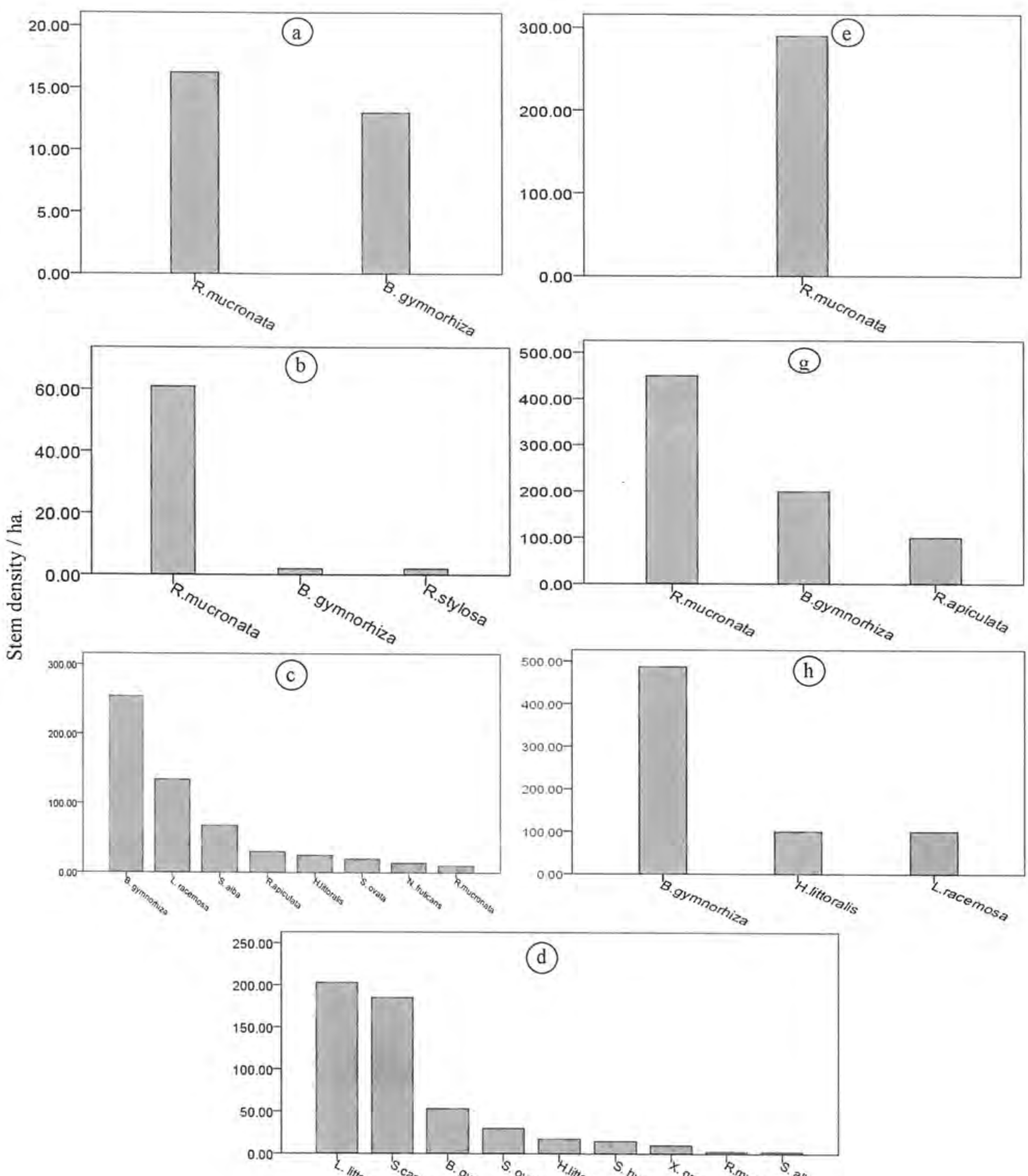


Figure 5.7. Stem densities of different species in various zones of residual and non-residual sites. a,b,c,d represents zone 1,2,3 and 4 of Non-residual site; e,f,g represents zone 1,2 and 3 in Residual site

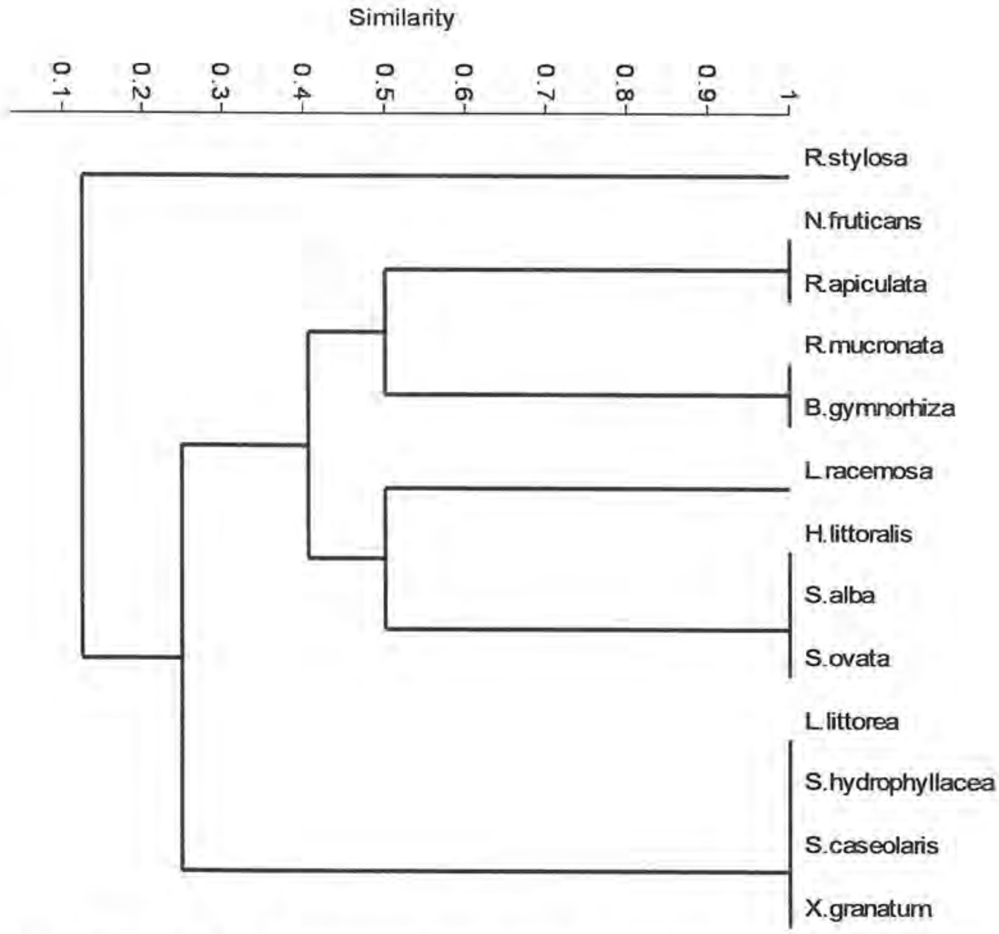


Figure 5.8. Cluster based on the association between species present in the different zones of colonizing sites by using paired group algorithm and Jaccard similarity measure

5.3.5. Preference of Environment and Ecological parameters

Mantel's correlation analysis carried out using 5000 Monte Carlo simulations between mangrove saplings and environmental variables shows a significant correlation between mangrove distribution and environmental factors (Mantel's r = 0.223, $P<0.001$), but the strength of this association was rather weak (being only 0.22 in a scale of 0–1).

The species wise habitat preference analysis carried out for three dominant mangrove species by comparing with the equal number micro-sites of other randomly selected species have shown varying results for different species. Of the ten parameters tested, results for *B. gymnorhiza* had shown a significant difference for six parameters (Table 5.2). However, the association was not very strong except for adjacent dominant snag species (Cramer's V = 4.99). Likewise, *R. mucronata* and *N. fruticans* had shown significant difference for five and one parameter each. The association was strong between inundation versus *R. mucronata* establishment (Cramer's V = 5.14) and *N. fruticans* versus drainage (Cramer's V= 4.81).

Table 5.2. Effect of Environmental and Ecological parameters on the dominant species of mangrove colonization sites

Variables	*B. gymnorhiza* (*n*=85)		*R. mucronata* (*n*=57)		*N. fruticans* (*n*=31)	
	Cramer's V	*P*-value	Cramer's V	*P*-value	Cramer's V	*P*- value
Adjacent dominant						
Snag species	0.499	<0.001	0.315	0.05	0.215	>0.05
Substrate	0.188	>0.05	0.167	>0.05	0.266	>0.05
Drainage	0.193	>0.05	0.282	>0.05	0.481	<0.05
Inundation	0.273	<0.05	0.514	<0.001	0.192	>0.05
Pre-tsunami history	0.317	<0.05	0.33	>0.05	0.335	>0.05
Present status	0.407	<0.001	0.31	<0.05	0.267	>0.05
Micro-habitat	0.366	>0.05	0.458	<0.05	0.61	>0.05
Distance from low-tide line	0.325	<0.01	0.261	>0.05	0.443	>0.05
Adjacent snag destruction	0.315	<0.05	0.457	<0.001	0.11	>0.05
Residuals	0.217	>0.05	0.121	>0.05	0.012	>0.05

5.4. Discussion

5.4.1. Natural disturbances and loss of species

The interplay between disturbance and recovery has several critical implications for ecological studies in tropical forests (Chazdon, 2003). The local extinction of species after a mega disturbance event like tsunami is inevitable. More than the vegetation loss by the force of the tsunami, the mangrove forests of Nicobar Islands suffered largely due to the submergence of land into the sea (Sankaran, 2005; Sivakumar, 2007). The resultant sea level rise had caused habitat loss, which became a major constraint for the colonizing species. The results of the present study show addition and local extinction of species for the mangrove flora of Nicobar Islands. Species that are found to be locally extinct after tsunami were mostly the mangroves that prefer the landward margins and medium inundation zones. The landward mangroves are vulnerable to sea level rise for the reason that their landward movement may not be possible due to high developmental pressure exerted on the mangrove edges (Farnswoth and Ellison, 1997; Polidoro et al., 2010). The occurrence of two locally extinct species namely *B. parviflora* and *C. ramiflora* reported from a single site in Car Nicobar Island is an indication that species with restricted distribution are more prone to disturbance events. Though the other three missing species were reportedly distributed in all the three groups of Islands, but were not common except for *X. mollucensis* (Dagar et al., 1991). Other than the missing species, a few species shown a critical bottle neck in the colonizing sites (e.g., only three individuals of *X. granatum* were observed from two sites and five individuals of *C.tagal* observed from one site). In the case of species that are recorded for the first time in Nicobar Islands, the poor floristic exploration (Sinha, 1999) perhaps could be the reason as it was noticed from the presence of residual trees for *S. alba, R. lamarckii* and *L. littorea*.

The new record for India, *S. ovata* was observed only in Katchall Island at two localities namely Oh hi poh (n=13) and Dhili kadi (n=30) (Nehru and Balasubramanian, 2012). The existence of this species can be explained by either of the two reasons (i) Dagar et al., (1991), has noticed an individual of *Sonneratia* spp. at Katchall Island without any reproductive parts and speculated its identity as *S. grifithii*. If it was a misidentification of *S. ovata*, then possibly that this species must have existed prior to tsunami and was rare, but become common in the colonizing sites by its heliophilic nature (ii) Otherwise, the seeds of *S. ovata* from the nearest sources viz. Indonesia, Malaysia and Singapore must have been carried by the tsunami and established a new population in Katchall Island.

5.4.2. Pre- tsunami Mangrove vegetation

The pre-tsunami mangrove forest of Nicobar Islands was comparably diverse and pristine. The mean basal area derived is almost similar to the values observed (18 m^2 $ha.^{-1}$) by IIRS (2003) in the pre-tsunami Nicobar Mangrove forest. These values are comparable with the values observed for undisturbed *A. germinans* (MBA – 20.4 m^2 $ha.^{-1}$ and MSD – 377 $ha.^{-1}$) stands in Dominican Republic (Sherman et al., 2001). Hence, it can be inferred that the existed mangrove forest of Nicobar Islands was natural and pristine.

5.4.3. Post-tsunami mangrove community structure and colonization

The presence or absence of residuals, defined as individual organisms or their propagules that survive a disturbance event is a key distinction in the recovery process (Turner et al., 1998). Propagule limitation due to non-availability of residuals and factors that are limiting the seed dispersal are the major constraints in the succession of mangrove forest (Lewis, 2005). The close vicinity of remnant vegetation to the disturbed area has a greater chance of high levels of seed dispersal and hence faster the succession rate (Guevara et al., 1986). The mangrove colonizing sites in Nicobar Islands has shown variation in the rate of colonization in terms of MSD where the residual sites had more than two folds MSD than non-residual sites. Our results establish the fact that the recovery process after a large scale disturbance is influenced by the presence/absence of residuals.

Understanding the structure of any plant community is the prerequisite for the classification of vegetation and defining the ecological importance for the habitat. The pioneering plant communities after a large scale disturbance often draw more attention from the ecological point of view to understand the dynamics of tropical forest. The abundance models constructed for the pioneering mangrove community of Nicobar Islands followed a log-series distribution model. It explains that the pioneering mangrove community is in an intermediate level of succession in terms of diversity and abundance. Usually the log-normal explains the undisturbed tropical plant communities and geometric distribution model known to explain the species poor pioneering communities where the pre-dominance of single or few species followed by rare species prevails (Ludwig and Reynolds, 1988). According to Volkov et al., (2007), the landscape level abundance distribution models best fit log-series distribution and the same has been observed in the present study.

5.4.4. Mangrove species colonization

Occurrence of zonation pattern in mangrove forests is observed throughout the world (Chapman, 1970; Aksomkoae, 1975; Sabhasri, 1987; Van Loon et al., 2007). Though many hypotheses have been put forward to explain the zonation pattern, still the generalization could not be derived due to the diversity of various factors determining the mangrove colonization (Smith, 1992). The present study has shown a similar pattern observed by Watson (1928) that the species diversity as well as stem density increasing vertically from proximal zone1 to the intermediate zone 3 in both NRS and RS. Settling down and establishment of propagules to seedling may be difficult in the seaward zone due to disturbance caused by high tidal activity, perhaps the reason for this pattern. Low tidal activity and optimum level of salinity achieved by influx of fresh water has resulted in greater chances of seed settling and seedling establishment possibly explains the species diversity and high stem density in the zone3. Though the landward zone 4 had maximum number of species, the stem density is lower when compared with zone3. The landward margins of mangrove forests are more influenced by fresh water rather than saline water and were too dry for many species (Polidoro et al., 2010) could be the plausible reason for less stem density at zone 4.

Mangrove species having large propagules are more likely to travel longer distances and colonize new areas (Chapman, 1976; McGuinness, 1997). The species with large propagule namely *Bruguiera gymnorhiza* and *Rhizophora mucronata* are dominant and found in all the four zones. However, their densities were kept changing at different zones. *R.mucronata* had higher stem density in the zone 1 and 2 and poorly represented in other zones. Likewise, *B.gymnorhiza* had a high stem density at zone3 and moderately represented in other zones. This phenomenon was explained by Ball (1988) that the mangrove species which survives in wide range of salinity gradients or tidal zones tends to change its relative abundance based on their salinity optima.

5.4.5. Mangrove establishment and environmental parameters

The succession of mangrove forest depends on environmental factors such as salinity, frequency of inundation, time duration of inundation, soil characteristics and seed dispersal (Tomlinson, 1986; Lewis, 2005; Hogarth, 2007). Though a significant correlation was found between the tested environmental variables and mangrove establishment, the strength of association was found to be rather weak. According to Ashton and Macintosh (2002), the interaction between environment and mangrove vegetation exists but the direction is not clear, which means the distribution of mangrove species is probably determined by interaction of different factors; therefore species-wise study may throw more light on this subject.

5.5. *Conclusion*

This study has recorded the initial colonization pattern of mangrove vegetation after a large scale disturbance caused by tsunami. It forms an example for the response of mangroves and Islands vegetation community to sea-level rise caused by seismic movements. It was found that the loss of habitat by the submergence and unavailability of residual trees are the major constraints in mangrove colonization. However, in some of the study sites, the early colonizers have attained their reproductive maturity. Hence, the colonization process presumably will accelerate in the immediate future. Long term monitoring would provide mre information on the succession, dynamics and long term impacts of tsunami on the mangroves of the Nicobar Islands. Restoration efforts are needed to recover at least some functions and diversity of the mangroves. It is suggested that some of the colonizing sites can be kept un-intervened to understand the natural recovery on a long term basis, so that quantitative comparisons can be made to look at what extend the restoration programs are effective in restoring the biodiversity of mangrove forest.

CHAPTER VI

RESTORATION OF TSUNAMI IMPACTED SITES

"Despite evidence of rapid forest recovery following large-scale deforestation, many degraded areas of today's tropics will require human assistance to recover forest structure, species composition, and species interactions typical of mature tropical forests."

Robin Chazdon

6.1. Introduction

The ecological balances in tropical forests are maintained by replacing climax vegetation with pioneer plant species at the time of a disturbance event (Peña-claros, 2003). Studies have established the fact that when a tropical forest ecosystem is disturbed, even though the recovery rates varies both spatially and temporally due to various ecological and environmental factors, it reconciles by itself (Vandermeer et al., 2000; Kennard, 2002; Lawrence, 2004; Ding et al., 2012). However, severe disturbances such as landslides, bulldozing and volcanic eruption that impacts soil as well as canopy will significantly slow down the rate of forest structural recovery and can render long-lasting effects on species composition (Riswan et al., 1985; Guariguata, 1990; Chinea, 2002). Human intervention is needed in such cases for the speedy recovery of species composition and ecosystem functions. In particular, restoration of soil fertility may be a prerequisite for forest recovery on these kinds of severely disturbed habitats (Chazdon, 2003). Knowledge on the structural diversity and pioneer species of the mature forest are important in designing restoration program for the disturbed forests (Lewis and Streever, 2000).

In the case of Nicobar Islands, the impacts that tsunami had created on the coastal vegetation both littoral forest and mangrove forest was so disastrous and hence the natural recovery may take a very long period. The main reasons are (i) habitat loss by permanent inundation of sea water (ii) disruption of soil substrate by sand deposition (iii) non-availability or presence of few residual trees had resulted in insufficient seed source for the establishment of seedlings (iv) human disturbances such as agricultural activities in the littoral habitat. Hence, human intervention is necessary for the speedy recovery of littoral and mangrove vegetation in the Nicobar Islands. This will enhance the quality of the habitat for many endemic flora and fauna that are primarily distributed in the coastal habitats.

6.2. Littoral forest

Rapid recovery of vegetation in all the levels like stem density, species diversity and basal area were observed in locations where the soil substratum remained sand loamy without sand deposition. In contrast, vegetation recovery is slower at locations where the substrate was deposited with sand and coral rubbles.

In some sites, where the substrate was affected with sand deposition, mono-dominant stands of *Casuarina equisetifolia* has saturated vegetation to the canopy level (12–15 m). The heliophilic nature (regeneration requires high intensity of sunlight) and availability of air borne seeds from residual tress must have helped *C.equisetifolia* to establish copious amount of seedlings immediately after tsunami by exploiting the complete canopy openness created in the coastal forests. Adaptive nature of *C.equisetifolia* to the adverse environmental conditions like strong wind and nutrient depleted soil could have played major role in its succession (Goltenboth et al., 2006). Despite the mono-dominance in tree layer, presence of only a few seedlings indicates that *C.equisetifolia* cannot regenerate anymore in these sites because of the low intensity of light in the ground layer (Goltenboth et al., 2006). Likewise *Hibiscus tiliaceus* and *Dendrolobium umbellatum* also showed good adaptation to harsh conditions that prevails in the SRV.

6.2.1. Suggestions for littoral forest restoration

Species that are well adapted to harsh conditions viz., windy environment, intense sunlight, high salinity and less soil nutrition can be given priority in the initial phases of restoration programs. Once these pioneer species are established, they are expected to enhance the habitat status in terms of soil nutrient, soil moisture and light requirements to pave way for the colonization of mature forest species that are less adaptive to harsh conditions. In addition, species such as *Barringtonia asiatica* (Fig. 6.1b), the most dominant tree species in the littoral forests prior to tsunami (IIRS, 2003; Sivakumar, 2006) shows low natural establishment, possibly due to non-availability of seed material, should also be given priority in the planting programs.

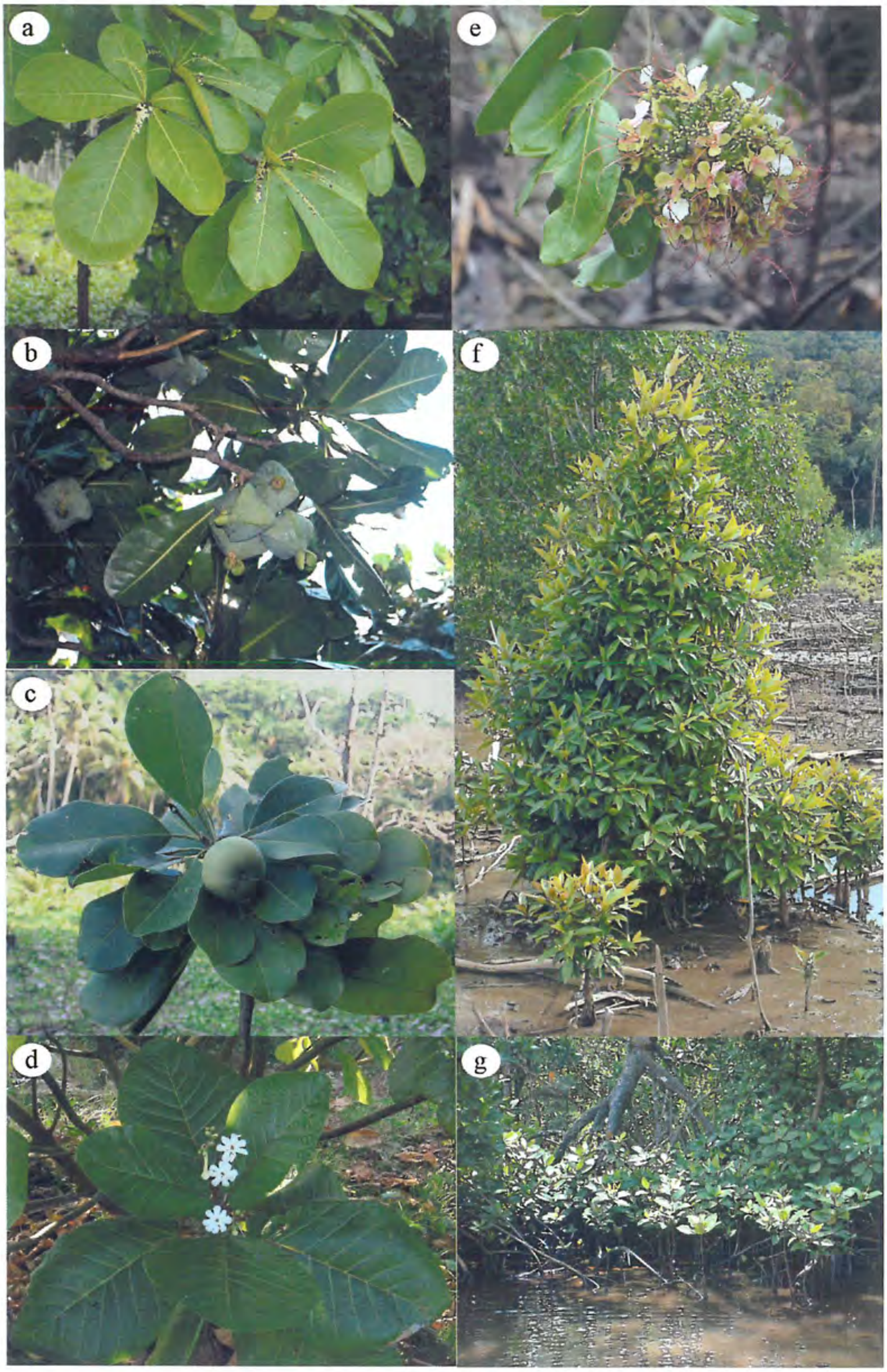


Figure 6.1. Plant species recommended for restoration (a) *Terminalia cattapa* (b) *Barringtonia asiatica* (c) *Manilkara littoralis* (d) *Guettarda speciosa* (e) *Intsia bijuga* (f) *Bruguiera gymnorhiza* seedlings beneath the mother tree (g) *Rhizophora mucronata* seedling found in the unaffected forest at Kimios, Car Nicobar.

Species given in Table 6.1 shows better colonization in the sand deposited places, but the stem density is too less. Hence, planting of these species are recommended. The seed collection sites given in Table 6.1 constitute the neighboring locations of the proposed restoration sites, where the seed collection could be done without much logistic problems. Ecological experiments have proved that mixed plantations are more successful than monocultures for the speedy recovery of damaged ecosystem (Kelty, 2006). Hence the mixed planting with suitable species is recommended (Table 6.1).

Table 6.1. Plant species recommended for restoration of Littoral Forest in Nicobar Islands

S.No	Name of the Species	Fruiting period	Potential seed collection sites
1	*Barringtonia asiatica*	April–May	Manchal Island
2	*Callophyllum inophyllum*	August	Nyikalang-Kamorta
3	*Intsia bijuga*	July–August	APWD beach, Trinket bay and Laful
4	*Manilkara littoralis*	January–March	Kamorta & Nancowry Coastal Hill forest
5	*Syzygium samarangense*	April–May	APWD beach, Trinket bay and Laful
6	*Terminalia cattapa*	May–August	APWD beach, Laxman beach, Laful
7	*Terminalia bialata*	May–August	Laful, APWD beach
8	*Pongamia pinnata*	May–June	Laful, APWD beach
9	*Hernandia peltata*	February–June	Trinket bay, Pilopanja
10	*Guettarda speciosa*	April–August	Laful and Trinket Bay
11	*Lannea coromandelica*	November–December and July-August	Laful, APWD beach
12	*Morinda citrifolia*	Throughout the year	Laful and Trinket Bay
13	*Thespesia populnea*	April–June	Dungy nallah, Trinket Bay
14	*Ochrosia oppositifolia*	April–June	Laful and Trinket Bay
15	*Claoxylon indicum*	Throughout the year	APWD beach, Trinket bay and Laful
16	*Sterculia rubiginosa*	April–June	Teressa Island
17	*Sterculia macrophylla*	April–June	APWD beach, Trinket bay and coastal hill forests of Great Nicobar & Katchal

6.2.2. Site selection for restoration

The site selection for the restoration of littoral forest is complicated in Nicobar Islands. The local Nicobarese community has lost most of their coconut plantation during tsunami by the incursion of sea. As a result, there is a substantial crunch for land to raise new coconut plantations as they mainly subsist on coconut plantations for their livelihood. Many of the regenerating vegetation sites were already planted with saplings of coconut to reclaim the land. So, it is recommended that localities where the local community has not planted coconut can be chosen for the restoration program. Five suitable sites are recommended for the restoration of littoral forests (Table 6.2.).

Table 6.2. Sites recommended for restoration of Littoral forest in the Nicobar Islands

S.No	Island	Locality	Lat (N)	Long (E)
1	Katchall	West Bay	07°55′14.5″	093°21′03.2″
2	Great Nicobar	Galathia river mouth	06°49′19.5″	093°51′49.4″
3		Pilobah	06°48′52.0″	093°49′20.3″
4		Kokeon	06°50′55.1″	093°47′58.8″
5		IyomBay	07°06′14.3‴	093°40′07.4″

6.3. Mangrove forest

Mangrove habitat can self-repair or successfully undergo secondary succession in 15–30 years if normal tidal hydrology and availability of water borne seeds and seedlings are provided (Lewis, 1982; Cintron-Molero, 1992). Studies on the restoration of mangrove forests indicates that planting of mangrove seedling can only be tried when natural recruitment mechanisms were inadequate for reestablishment of mangroves due to lack of propagules or soil condition that prohibit natural establishment (Lewis and Streever, 2000). In the case of Nicobar Islands, most of the mangrove regeneration sites were littoral forests or coconut plantations before tsunami. So, the mangroves are apparently exploring and exploiting new habitats wherever conditions are favorable for them to colonize despite the limitations such as insufficient seed source, altered tidal hydrology and new soil condition. Therefore planting of seedlings or introducing mature propagules in the water ways are much needed to restore the functionality of mangrove ecosystem in the Nicobar Islands.

Mangrove plantations established by the forest department at Marine, Katchall Island and Magar Nallah, Great Nicobar Island shows good plant diversity. Dense thickets of *Rhizophora spp.* have already been established in these places. The natural regeneration of many mangrove species in the tsunami impacted sites is very poor. Even the species which take advantage of the present environmental conditions in their early colonization period shows very less stem density when compared to the natural or undisturbed mangrove forest stem density of 1000 trees $ha.^{-1}$ (Lewis and Streever, 2000). Non-availability of residual trees for the seed source could be the reason for the lesser stem density in the regenerating habitats.

Residual trees of mangroves were observed only at four sites (Nyikalang, Safed Balu, Castlebay and Kimios) for the whole Nicobar Islands. At Nyikalang, Kamorta Island, 80–90 residual trees of *Bruguiera gymnorhiza* (Fig. 6.1f) were observed. One individual of *Lumnitzera littorea* and two individuals of *Sonneratia alba* was observed in Safed Balu, Trinket Island. Thirty individulas of *Sonneratia alba*, 13 *Heritiera littoralis* and two *Rhizophora stylosa* were recorded in Castle bay, Tillanchong Island. Unaffected/least affected mangrove forest showing mono-dominance of *Rhizophora spp.* was observed only at Kimios, Car Nicobar Islands (Fig. 6.1g). Changes in the hydrology of mangrove habitat and permanent inundation of sea water are the other major constraints for the colonizing species (Nehru and Balasubramanian, 2011).

6.3.1. Suggestions for mangrove forest restoration

Careful attention need to be paid to avoid introduction of species that were not present in the habitats prior to the tsunami. Zonation patterns according to the salt and fresh water influx varies among different species. Hence, it is important to understand the autecology of each species in terms of their preferences to soil substrate and salt water influx before the initiation of planting. If species are planted in their preferred zones, the likelihood of sapling survival will be high (Lewis and Streever 2000). An illustrative diagram explaining the zonal preferences of mangrove species in the Nicobar Islands is shown in Fig. 6.2 and the same can be followed for planting various species in different zones.

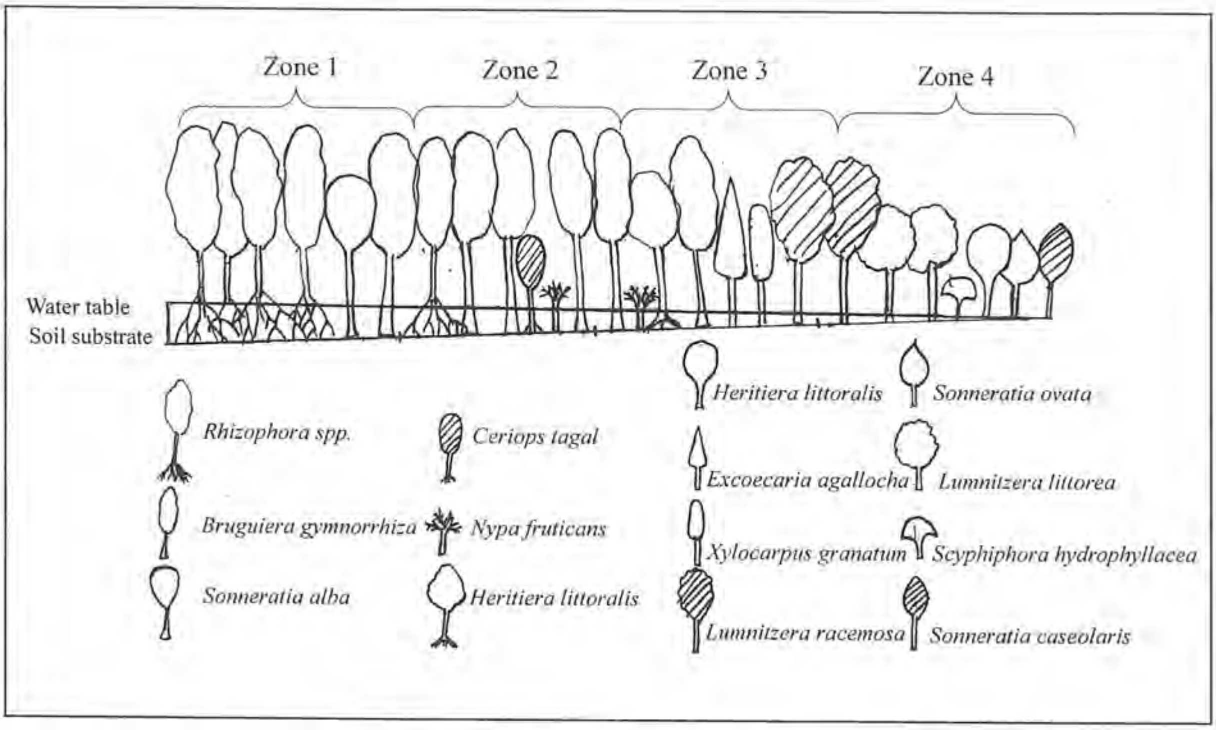


Figure 6.2. Mangrove species zonation pattern in the re-colonizing sites of the Nicobar Islands

6.3.2. Seed and propagule harvesting

Seedlings and propagules can be collected from the already established mangrove trees found in the regenerating sites. The dominant species in the regenerating sites *Bruguiera gymnorhiza* was observed to have nearly 30–60 seedlings beneath each adult plant at most of the regenerating sites. These seedlings can be collected and exploited in the restoration sites. Likewise, *Rhizophora spp., Ceriops tagal, Sonneratia spp.* and *Nypa fruticans* have also attained reproductive maturity in the regenerating sites. So the propagules and seed materials can be harvested for these species readily from the site itself. The unaffected mangrove stands of *Rhizophora spp.* present in Kimios at Car Nicobar Island constitute the most potential site for harvesting *Rhizophora* propagules (Fig. 1.2a). The propagules harvested from Kimios can be transported to other islands of the Nicobar by inter-island ship services without much delay and logistical problems. Potential sites identified for harvesting seed material are given in Table 6.3.

Table 6.3. Potential sites identified for collection of mangrove seed material

S.No	Island	Place	Plant species
1	Car Nicobar	Kimios	*Rhizophora spp.* and *Bruguiera gymnorhiza*
2	Trinket	Safed balu	*Rhizophora spp., Bruguiera gymnorhiza, Ceriops tagal* and *Lumnitzera littorea*
3		Ok chu ka	*Lumnitzera racemosa* and *Sonneratia alba*
4	Kamorta	Dering	*Rhizophora spp., Bruguiera gymnorhiza* and *Nypa fruticans*
5	Nancowry	Chinlak	*Rhizophora spp., Bruguiera gymnorhiza* and *Nypa fruticans*
6	Katchal	Oh hi poh	*Bruguiera gymnorhiza, Sonneratia caseolaris, S.ovata, Heritiera littoralis* and *Dolichandrone spathacea*
7		Marine	*Rhizophora spp., Bruguiera gymnorhiza, Ceriops tagal* and *Dolichandrone spathacea*
8		Dhili Kadi	*Rhizophora spp., Bruguiera gymnorhiza, Sonneratia ovata* and *Dolichandrone spathacea*
9	Great Nicobar	Dungi nallah	*Bruguiera gymnorhiza and Nypa fruticans*
10		Laxman beach	*Rhizophora murcronata, Bruguiera gymnorhiza, Sonneratia caseolaris, Nypa fruticans* and *Dolichandrone spathacea*
11		Javu nallah	*Rhizophora murcronata* and *Bruguiera gymnorhiza*
12		Laful	*Bruguiera gymnorhiza and Nypa fruticans*

6.3.3. Planting in mangrove areas

As a general rule, the mangrove seedlings should be planted on 1 m × 1 m space. This methodology has been followed in several mangrove restoration projects implemented in various parts of the world (Lewis and Streever, 2000; Lewis, 2009). Different techniques need to be employed for planting different species of mangroves. Placement of ripen propagules of *Rhizophora spp.* and *Ceriops spp.* directly into the substrate is effective in establishment of seedling. For other species such *as Bruguiera spp., Sonneratia spp.* and *Nypa fruticans,* root has to be developed and cotyledons need to be exposed before planting (Table 6.4.). High mortality of seedlings is expected in the initial stages of establishment and approximately 50% of seedling survival is considered as successful (Lewis and Streever, 2000).

Table 6.4. Mangrove species distribution in the re-colonization sites of Nicobar Islands with the mode of plantation (GNG – Great Nicobar Group, CNG- Central Nicobar Group, Car – Car Nicobar).

S.No	Family	Binomial	GNG	CNG	Car	Mode of Plantation
1	Arecaceae	*Nypa fruticans* Wurmb.	+	+	+	Seedling
2	Bignoniaceae	*Dolichandrone spathacea* (L.f.) K. Schum.	+	+	+	Seedling
3	Combretaceae	*Lumnitzera littorea* (Jack) Voigt.*	+	+	-	Seedling
4	Combretaceae	*Lumnitzera racemosa* Willd.	+	+	+	Seedling
5	Euphorbiaceae	*Excoecaria agallocha* L.	+	+	+	Seedling
6	Meliaceae	*Xylocarpus granatum* Koen.	+	+	-	Seedling
7	Rhizophoraceae	*Bruguiera gymnorhiza* (L.) Savigny	+	+	+	Propagule
8	Rhizophoraceae	*Ceriops tagal* (Perr.) Robins*	-	+	-	Propagule
9	Rhizophoraceae	*Rhizophora apiculata* Bl.	+	+	+	Propagule
10	Rhizophoraceae	*Rhizophora lamarckii* Mont.*	-	-	+	Propagule
11	Rhizophoraceae	*Rhizophora mucronata* Poir.	+	+	+	Propagule
12	Rhizophoraceae	*Rhizophora stylosa* Griff.	+	+	+	Propagule
13	Rubiaceae	*Scyphiphora hydrophyllacea* Gaert.*	+	+	+	Seedling
14	Sonneratiaceae	*Sonneratia alba* Sm.	+	+	-	Seedling
15	Sonneratiaceae	*Sonneratia caseolaris* (L.) Engler	+	+	+	Seedling
16	Sonneratiaceae	*Sonneratia ovata* Backer*	-	+	-	Seedling
17	Sterculiaceae	*Heritiera littoralis* Dryand.	+	+	+	Seedling

+ and – indicates the presence and absence of the species respectively

6.4. Conclusions and future research needs

The tsunami impacted coastal vegetation of Nicobar Islands, undoubtedly require scientific intervention to ameliorate the present condition for restoring its functionality, which will directly influence the conservation of many flora and fauna that are exclusively present in the coastal habitat. The dynamics and succession of mangrove and littoral forests can be understood only if long-term studies are conducted. At the same time, some of the regenerating sites can be kept un-intervened to understand the natural recovery on a long term basis, so that quantitative comparisons can be made to look at what extend the restoration programs are effective in restoring the biodiversity of both mangrove and littoral forest. Monitoring of biodiversity including various faunal components of coastal vegetation in these tsunami affected habitats would give a holistic understanding on the effects of natural disturbances on this pristine island ecosystem.

CHAPTER VII

SUMMARY

Tropical forests are one among the species rich biome on earth. The high species diversity and complexity in its functionality makes this forest type as the most resilient ecosystem. The ever increasing anthropogenic pressures and natural calamities are placing tropical forest at a high risk in the recent time. Due to high levels of disturbance, most of the tropical forests of today are in various stages of succession. Natural disturbances such as flood, forest fire, land slide and hurricane are known to cause long lasting impacts on a large scale in tropical forests. Tsunami perhaps could be the new addition to the above list. The natural recovery of vegetation after large scale disturbances are influenced by many ecological and environmental factors. Hence, understanding the vegetation recovery pattern and the influencing factors are important in planning and implementing habitat restoration programme.

Island ecosystems are rich in biodiversity and more prone to natural and anthropogenic disturbances. The mega earthquake of 9.3 *Mw* magnitude and subsequent tsunami on December 26, 2004 had disastrous impacts on people and biodiversity of south-east Asia. The close vicinity to the epicenter of the earth quake attributed to the maximum damage levels in Nicobar Islands located in the Bay of Bengal of India in terms of human lives and coastal biodiversity. The tsunami had completely destroyed or significantly damaged all vegetation that existed in the coastal area between the beach and the hill. The mega earth quake had resulted in a tilt in the land with southernmost Nicobar Islands having sunk by about 1.75 m while the Northern most Andaman Islands have been elevated by about 1.2 m relative to sea-level. Coastlines have receded towards the hills, at places by several hundred meters, often resulting in very little or no land between the hills and coast.

The coastal vegetation of Nicobar Islands, littoral forest and mangrove forest, carries enormous importance in terms of biodiversity and the livelihood of the Islanders. Due to the close vicinity to the coast, littoral forest and mangrove forest have suffered a maximum damage. The impacts of tsunami on coastal ecosystems are: (1) physical uprooting of coastal forests and mangroves by the tsunami, (2) scorching of littoral vegetation due to salt stress from sea water inundation, (3) dying out of mangroves due to perennial submergence of the pneumatophores, (4) sea water inundation of inland freshwater bodies, destruction of marshes and creeks, and (5) physical destruction of coral reefs by the tsunami waters.

Although a few studies were made for assessing the vegetation damage by tsunami through satellite remote sensing, there was no field based assessment. Hence, there was a need for an extensive field based study to assess the impacts of tsunami and natural recovery of coastal vegetation in Nicobar Islands. The objectives of the present study are follows,

iii. To study the vegetation recovery and influence of soil substrate on the vegetation succession in tsunami impacted littoral forests

iv. To study the impacts of tsunami on the mangrove forests and asses the natural colonization of mangrove species

The study was initiated five years after the tsunami in 2009. The field work was carried out in two seasons during 2009-2011. The first season commenced during 2009 October and extended till May 2010 spanning eight months. Similarly, the second season started in October 2010 and extended till July 2011 spanning 10 months.

Sampling plots of 50 x 20 m size (0.1 ha.) were established to assess and monitor the colonization of plant species in the predetermined sites of tsunami affected littoral forests. Each plot was divided into five 10 x 20 m grids for convenience. All the woody plants $\geq$ 10 cm CBH were enumerated from the sampling plots. The regenerating vegetation was categorized into two types namely, Sandy Regenerating Vegetation (SRV) and Sand Loamy Regenerating Vegetation (SLRV) based on the soil substratum. SRV - regenerating sites where enormous amount of sand and coral rubble were deposited over the pre-tsunami soil substratum, SLRV - regenerating sites where vegetation was completely damaged but the soil substratum remained without any deposition. Sampling plots were also established in the unaffected/less affected forest (UF) for comparison. Soil samples were collected at 0 - 10 cm depth from five randomly selected sites each in SRV and SLRV and three soil samples were collected from each site for physicochemical analyses.

Natural recovery of littoral forest was assessed from 99 permanent monitoring plots (SRV=36; SLRV=42; UF=21) distributed over 10 Islands. A total of 8420 tree individuals ($\geq$ 10 cm CBH) belonging to 181 species, 116 genera and 56 families were recorded during first year survey. The mean species richness (MSR), Stem Density (MSD) and Basal Area (MBA) Plot^{-1} shows high variation among vegetation types. UF shows high values for MSR (18.04±7.66) and MBA (73.87±28.76 m^{2}. ha.$^{-1}$). High MSD was observed in SLRV

(148.78±76.8). SRV shows poor value for all the three parameters MSR (3.02±3.37), MSD (8.91±12.15) and MBA (1.14±2.04). SLRV shows 74% MSR, 22% MBA recovery when compare with UF. SRV shows 17% MSR, 10% MSD and 1.5% MBA recovery when compare with UF. The species dominance also varied among vegetation types. Importance Value Index values indicates that *Terminalia bialata* (29.99), *Manilkara littoralis* (18.3) and *Pterocymbium tinctorium* (14.16) were dominant in the UF. Likewise, *Macaranga peltata* (98.16), *Ficus hispida* (17.03) and *Boehmeria nivea* (16.83) in SLRV and *Casuarina equisetifolia* (97.49), *Hibiscus tiliaceus* (26.97) and *Pandanus lerum* (22.93) in SRV are the dominant species. All the macro and micro nutrients tested except for calcium has shown higher values in SLRV than SRV. The influence of soil nutrients on the vegetation recovery was noticed in the study sites.

Out of the 78 plots established in the secondary vegetation during the initial survey, 62 plots distributed over 25 sites of eight Islands were re-sampled to assess the recovery rates in SRV (n=29) and SLRV (n=33). A total of 135 tree species belonging to 97 genera and 45 families were recorded from studied plots. The number of stem individuals recorded during the second year (5843 individuals) was higher than the first year (5528 individuals). The values for all the vegetation parameters increased during the study period. In SRV, the values for MSR (36%), MSD (44.5%) and MBA (36.3%) have increased in the second year when compared with first year data. The variation was comparatively low in SLRV, where the values for MSR (13.2%) and MBA (11%) showed significant variation but the MSD (1.4%) did not vary much.

Entire coastal line of Nicobar Islands was surveyed to assess the impacts of tsunami on the mangrove forest and to study the natural colonization of mangrove species. Plots of 400 m^2 and 100 m^2 were used for studying the pre-tsunami mangrove vegetation and all the stems $\geq$ 10 cm CBH were counted. The post-tsunami mangrove colonizing sites were classified as two types namely, Residual Site (RS) and Non-Residual Site (NRS). Varying sizes of sampling plots were used in NRS (1000 - 5000 m^2) and RS (100 m^2) and stems $\geq$ 1cm GBH were enumerated from the plots. Data on ten different environmental and ecological variables influencing the mangrove establishment (adjacent dominant snag species, substrate, drainage, inundation, pre-tsunami habitat status, present habitat status, type of microhabitat, distance from low tide line, status of adjacent mangrove snags and presence and absence of residuals) were also collected.

In total, 23 sites distributed over seven Islands showed mangrove colonization after the tsunami. Of the 23 sites, 12 were selected for the intensive study. A total of 17 species of mangroves were recorded of which five species namely *Lumnitzera littorea*, *Ceriops tagal*, *Rhizophora lamarckii*, *Scyphiphora hydrophyllacea* and *Sonneratia alba* were new distributional records for the Nicobar Islands and one species (*Sonneratia ovata*) form a new record for India. Five species recorded in the previous studies namely *Acanthus sp.*, *Cynometra ramiflora*, *Bruguiera parviflora*, *Bruguiera sexangula* and *Xylocarpus moluccensis* were not found during the present study and perhaps gone locally extinct.

Stem density was significantly different between pre-tsunami (600 ± 350 ha^{-1}) and post-tsunami (288 ± 218 ha^{-1}) mangrove forest. Similarly, the stem density between Residual (364.5 ± 205.82 ha^{-1}) and Non-residual (149.9 ± 166.96 ha^{-1}) sites also varied and proven the influence of availability of seed source on the natural recovery. A typical zonation pattern was found in the mangrove colonizing sites where the species diversity and stem density has increased from seaward to landward zone. The environmental factors tested have shown a significant correlation with mangrove seedling establishment.

The high species diversity in tropical forests makes it more resilience to any disturbance event. The succession and dynamics of tropical forest after large scale natural disturbances are rarely understood. Hence, a continuous monitoring of vegetation in the tsunami impacted sites of Nicobar Islands is required to understand different aspects of vegetation recovery in littoral and mangrove forest. Very often, studies have established the fact that when a forest ecosystem is disturbed, it reconciles by itself. However, disturbances that affect the soil quality of the habitat will result in long-lasting effects on species composition. Based on the present study, restoration measures were suggested for both mangrove and littoral habitats of the Nicobar Islands.

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APPENDICES

Appendix I. Species diversity and vegetation composition among different vegetation types of littoral forest (SRV- Sandy Regenerating Vegetation, SLRV- Sand-Loamy Regenerating Vegetation, UF- Unaffected/least affected forest, R.den – Relative density, R.frq – Relative frequency and IVI – Importance Value Index)

		SRV			SLRV			UF		
S. No.	Family and Species	R.den	R.frq	IVI	R.den	R.frq	IVI	R.den	R.frq	IVI
	Achariaceae									
1	***Ryparosa javanica*** (Blume) Kurz ex Koord. & Valeton	-	-	-	0.03	0.18	0.23	-	-	-
	Actinidiaceae									
2	***Saurauia sp.***	-	-	-	0.02	0.18	0.23	0.16	0.26	0.44
	Anacardiaceae									
3	***Lannea coromandelica*** (Houtt.) Merr.	0.93	0.93	13.65	0.13	1.26	2.87	0.43	1.06	2.21
4	***Mangifera camptosperma*** Pierre.	-	-	-	-	-	-	0.05	0.26	0.32
5	***#Mangifera nicobarica*** Kosterm.	-	-	-	-	-	-	0.85	0.79	3.40
6	***Mangifera sp.***	-	-	-	-	-	-	0.27	0.53	0.82
7	***Semecarpus prainii*** King	-	-	-	0.11	0.54	0.74	2.66	1.85	5.41
8	***Spondias cytherea*** Sonn.	-	-	-	0.34	1.98	2.69	0.21	0.79	1.12
	Annonaceae									
9	***Annona muricata*** L.	-	-	-	0.32	1.62	3.25	0.37	1.32	1.91
10	****Miliusa mukerjeeana*** Debika Mitra & Chakr.	-	-	-	-	-	-	0.80	1.06	1.87
11	***#Orophea katschallica*** Kurz	-	-	-	0.02	0.18	0.21	5.53	1.85	7.57
12	***Polyalthia lateriflora*** King	-	-	-	-	-	-	0.27	0.53	0.80
13	****Polyalthia parkinsonii*** Hutch.	-	-	-	-	-	-	0.16	0.53	0.73
14	***Polyalthia sp.***	-	-	-	0.05	0.36	0.42	-	-	-
	Apocynaceae									
15	****Alstonia kurzii*** Hook. f.	-	-	-	0.69	0.90	1.80	-	-	-
16	***Alstonia macrophylla*** Wall. ex G. Don	-	-	-	0.51	0.72	1.55	0.27	0.79	1.30
17	***Cerbera odollam*** Gaertn.	-	-	-	0.02	0.18	0.20	-	-	-
18	***Ochrosia oppositifolia*** K. Schum.	-	-	-	0.11	0.72	0.85	0.48	1.32	1.95
19	****Tabernaemontana crispa*** Roxb.	-	-	-	0.02	0.18	0.20	3.45	1.58	5.16
	Araliaceae									
20	***Arthrophyllum diversifolium*** Blume	-	-	-	-	-	-	0.11	0.53	0.65
	Arecaceae									
21	***Areca catechu*** L.	-	-	-	0.02	0.18	0.20	0,05	0.26	0.32
22	***#Bentinckia nicobarica*** (Kurz) Becc.	-	-	-	0.03	0.36	0.63	0.05	0.26	0.32
23	****Calamus andamanicus*** Kurz	-	-	-	0.13	0.18	0.31	0.16	0.53	0.69
24	***Cocos nucifera*** L.	3.73	3.73	7.45	0.21	0.90	2.57	0.11	0.53	0.67
25	****Pinanga manii*** Becc.	-	-	-	0.03	0.18	0.27	0.05	0.26	0.34
26	***#Rhopaloblaste augustata*** (kurz) Moore	-	-	-	0.06	0.54	0.91	0.21	1.06	1.34
	Asparagaceae									
27	****Dracaena brachyphylla*** Kurz	-	-	-	0.02	0.18	0.20	1.54	1.32	2.96
	Bignoniaceae									
28	***Dolichandrone spathacea*** (L.f.) K. Schum	2.17	2.17	5.63	0.02	0.18	0.21	-	-	-

S. No.	Family and Species	SRV R.den	SRV R.frq	SRV IVI	SLRV R.den	SLRV R.frq	SLRV IVI	UF R.den	UF R.frq	UF IVI
	Boraginaceae									
29	***Argusia argentea*** (L.f.) Heine	1.24	1.24	3.35	0.10	0.54	0.77	-	-	-
30	***Cordia dichotoma*** G. Forster	-	-	-	0.31	1.08	2.09	0.27	0.53	1.04
31	***Cordia subcordata*** Lam.	0.93	0.93	1.97	0.16	1.08	1.32	0.48	0.26	0.76
32	***Cordia grandis*** Roxb.	-	-	-	0.10	0.72	1.24	-	-	-
	Burseraceae									
33	***Canarium euphyllum*** Kurz	-	-	-	0.05	0.54	0.61	0.69	1.32	2.80
34	***Dacryodes rugosa*** H.J. Lam	-	-	-	0.03	0.36	0.51	0.27	0.53	1.33
	Calophyllaceae									
35	***Calophyllum inophyllum*** L.	0.31	0.31	0.68	0.03	0.36	0.41	-	-	-
	Cannabaceae									
36	***Trema orientalis*** (L.) Blume	5.59	5.59	12.81	2.15	1.62	6.05	-	-	-
	Caricaceae									
37	***Carica papaya*** L.	-	-	-	0.10	0.72	0.95	-	-	-
	Casuarinaceae									
38	***Casuarina equisetifolia*** L.	27.64	27.64	97.49	0.74	0.90	4.74	-	-	-
	Celastraceae									
39	***Euonymus javanicus*** Bl.	-	-	-	-	-	-	0.11	0.26	0.38
40	****Glyptopetalum calocarpus*** (Kurz) Prain	-	-	-	-	-	-	0.05	0.26	0.32
	Clusiaceae									
41	***Garcinia nervosa*** Miq.	-	-	-	0.06	0.18	0.33	-	-	-
42	***Garcinia speciosa*** Wall.	0.31	0.31	2.60	-	-	-	-	-	-
	Combretaceae									
43	***Terminalia bialata*** Steud.	-	-	-	1.58	2.52	4.78	2.13	2.11	29.99
44	***Terminalia catappa*** L.	5.59	5.59	13.23	2.38	3.06	7.33	3.03	2.11	6.83
45	***Terminalia procera*** Roxb.	-	-	-	0.37	0.36	0.86	0.69	0.53	3.28
	Cycadaceae									
46	***Cycas rumphii*** Miq.	-	-	-	0.02	0.18	0.24	0.21	0.79	1.07
	Dilleniaceae									
47	****Dillenia andamanica*** Parkinson	-	-	-	0.03	0.36	0.47	0.11	0.53	0.72
	Ebenaceaea									
48	***Diospyros kurzii*** Hiern	-	-	-	-	-	-	0.48	0.53	1.07
49	***Diospyros undulata*** Wall. ex G.Don	-	-	-	-	-	-	0.21	0.79	1.01
	Elaeocarpaceae									
50	***Elaeocarpus rugosus*** Roxb. & G.Don	-	-	-	-	-	-	0.16	0.26	0.57
	Euphorbiaceae									
51	***Alchornea rugosa*** (Lour.) Muell.-Arg.	-	-	-	-	-	-	0.11	0.26	0.37
52	***Antidesma diandrum*** Spreng.	-	-	-	0.10	0.36	0.47	1.49	0.53	2.07
53	***Breynia recemosa*** (Bl.) Muell.- Arg.	-	-	-	0.03	0.36	0.40	-	-	-
54	***Claoxylon indicum*** (Reinw. Ex Bl.) Hassk.	-	-	-	3.84	3.24	8.93	1.22	1.85	3.12
55	***Croton argyratus*** Bl.	-	-	-	0.02	0.18	0.20	0.05	0.26	0.32
56	***Drypetes longifolia*** (Blume) Pax & Hoffm.	-	-	-	0.02	0.18	0.20	0.11	0.26	0.39
57	***Flueggea virosa*** (Willd) Baill.	-	-	-	0.14	0.54	0.71	-	-	-
58	****Glochidion calocarpum*** Kurz	-	-	-	0.43	2.52	3.06	0.43	1.32	1.76

S. No.	Family and Species	SRV			SLRV			UF		
		R.den	R.frq	IVI	R.den	R.frq	IVI	R.den	R.frq	IVI
59	***#Macaranga nicobarica*** Balakr. & P. Chakrab	-	-	-	0.21	0.90	1.15	0.11	0.53	0.64
60	***Macaranga peltata*** (Roxb.) Muell.-Arg.	4.97	4.97	11.43	49.27	7.19	105.51	10.68	1.85	13.43
61	***Mallotus floribundus*** Müll.Arg.	-	-	-	-	-	-	0.21	0.26	0.49
62	***Phyllanthus reticulatus*** Poir.	-	-	-	0.02	0.18	0.20	-	-	-
63	***Suregada multiflora*** Baill.	-	-	-	0.03	0.36	0.39	0.21	1.06	1.29
64	***Unidentified 1***	-	-	-	0.05	0.18	0.26	-	-	-
	Fabaceae									
65	***Adenanthera pavonina*** L.	-	-	-	0.03	0.18	0.33	-	-	-
66	***Albizia procera*** (Roxb.) Benth.	-	-	-	0.02	0.18	0.20	-	-	-
67	***Albizia saman*** (Jacq.) F.v. Muell.	-	-	-	0.02	0.18	0.22	-	-	-
68	***Archidendron bigeminum*** (L.) Nielsen	-	-	-	-	-	-	0.05	0.26	0.33
69	***Dendrolobium umbellatum*** (L.) Benth.	7.45	7.45	18.82	3.71	2.52	8.70	1.75	0.79	2.64
70	***Erythina fusca*** Lour.	0.31	0.31	0.90	-	-	-	-	-	-
71	***Erythrina variegata*** L.	0.31	0.31	0.68	0.02	0.18	0.50	-	-	-
72	***Intsia bijuga*** (Colebr.) O.Kunze	-	-	-	0.03	0.18	0.23	0.21	0.26	0.88
73	***Peltophorum pterocarpum*** (DC.)	0.93	0.93	2.36	0.02	0.18	0.20	-	-	-
74	***Pongamia pinnata*** (L.) Pierre	3.11	3.11	7.61	0.31	0.90	1.43	1.12	1.85	3.33
	Gentianaceae									
75	***Fagraea racemosa*** Jack	-	-	-	-	-	-	0.05	0.26	0.35
	Gnetaceae									
76	****Gnetum gnemon*** L.	-	-	-	-	-	-	0.96	1.58	2.67
	Goodeniaceae									
77	***Scaevola sericea*** Vahl	2.48	2.48	5.29	0.26	1.26	1.64	-	-	-
	Hernandiaceae									
78	***Gyrocarpus americanus*** Jacq.	-	-	-	-	-	-	0.05	0.26	0.40
79	***Hernandia nymphaeifolia*** (Presl.) Kubitzki.	1.86	1.86	4.33	0.43	2.70	4.13	0.27	1.06	1.57
	Lamiaceae									
80	***Clerodendrum paniculatum*** L.	-	-	-	0.03	0.36	0.40	-	-	-
81	***Premna pyramidata*** Wall.	-	-	-	-	-	-	0.05	0.26	0.36
82	***Vitex trifolia*** L.	0.31	0.31	0.85	0.03	0.18	0.22	0.11	0.26	0.38
	Lauraceae									
83	***Actinodaphne procera*** (Blume) Nees	-	-	-	-	-	-	0.53	1.32	1.98
	Lecythidaceae									
84	***Barringtonia asiatica*** (L.) Kurz.	1.86	1.86	4.30	0.13	1.08	1.28	0.27	1.06	1.33
85	***Barringtonia racemosa*** (L.) Spreng.	-	-	-	0.18	0.54	0.89	-	-	-
86	***Chydenanthus excelsus*** (Blume) Miers	-	-	-	0.05	0.36	2.59	-	-	-
	Lythraceae									
87	***Lagerstroemia ovalifolia*** Teijsm. & Bim.	-	-	-	0.02	0.18	0.21	-	-	-
	Malvaceae									
88	***Ceiba pentandra*** (L.) Gaertn.	-	-	-	0.02	0.18	0.21	-	-	-
89	***Grewia calophylla*** Kurz ex Mast.	-	-	-	-	-	-	0.16	0.26	0.53
90	***Heritiera littoralis*** Aiton	-	-	-	0.02	0.18	0.20	-	-	-
91	***Hibiscus tiliaceus*** L.	11.80	11.80	26.97	1.58	3.42	6.11	1.70	1.32	3.26

S. No.	Family and Species	SRV			SLRV			UF		
		R.den	R.frq	IVI	R.den	R.frq	IVI	R.den	R.frq	IVI
92	***Melochia umbellata*** (Houtt.) Stapf.	-	-	-	1.56	1.26	4.29	-	-	-
93	***Pterocymbium tinctorium*** Merri.	0.31	0.31	4.31	2.19	2.52	7.75	4.99	2.37	14.16
94	***Sterculia cordata*** Bl.	-	-	-	0.08	0.36	0.46	0.05	0.26	0.35
95	***Sterculia macrophylla*** Vent.	-	-	-	0.08	0.18	0.28	0.27	0.53	0.83
96	***Sterculia parviflora*** Roxb.	-	-	-	0.08	0.36	0.48	0.32	0.79	1.22
97	***Sterculia rubiginosa*** Vent.	-	-	-	1.30	1.26	4.46	5.69	2.64	13.37
98	***Thespesia populnea*** (L.) Soland ex Correa	0.62	0.62	1.67	0.05	0.36	0.42	0.05	0.26	0.32
	Melastomataceae									
99	****Memecylon andamanicum*** King	-	-	-	-	-	-	0.05	0.26	0.32
	Meliaceae									
100	***Aglaia argentea*** Blume	-	-	-	-	-	-	0.43	0.53	0.98
101	***Aglaia sp.***	-	-	-	0.02	0.18	0.20	-	-	-
102	***Aglaia sp.***	-	-	-	0.50	0.54	1.78	0.90	1.06	4.33
103	***Aglaia sp.***	-	-	-	-	-	-	0.05	0.26	0.32
104	***Aglaia sylvestris*** (M. Roem.) Merr.	-	-	-	-	-	-	0.21	0.26	0.72
105	***Aphanamixis polystachya*** (Wall.) R. Parker	-	-	-	-	-	-	0.05	0.26	0.37
106	***#Chisocheton nicobarianus*** Debnath & Sreek.	-	-	-	0.02	0.18	0.20	-	-	-
107	***Disoxylum*** sp.	-	-	-	-	-	-	0.43	0.53	1.97
108	***Sandoricum koetjape*** (Burm. f.) Merr.	-	-	-	-	-	-	1.38	0.79	2.90
	Moraceae									
109	***Artocarpus chama*** Buch.-Ham.	-	-	-	-	-	-	0.11	0.26	0.59
110	***Artocarpus gomezianus*** Wall. ex Trec.	0.62	0.62	1.40	0.13	0.36	1.06	0.37	0.79	1.55
111	***Artocarpus peduncularis*** Kurz	-	-	-	-	-	-	0.37	1.06	2.17
112	***Ficus altissima*** Bl.	-	-	-	0.02	0.18	0.20	-	-	-
113	***Ficus callosa*** Willd.	-	-	-	0.16	1.26	1.58	0.05	0.26	0.47
114	***Ficus fistulosa*** Reinw. ex Blume	-	-	-	0.06	0.18	0.27	-	-	-
115	***Ficus hispida*** L.f.	-	-	-	7.20	6.47	17.69	0.85	1.58	2.45
116	***Ficus microcarpa*** L.f.	1.86	1.86	3.98	0.88	3.06	4.31	0.11	0.53	0.64
117	***Ficus nervosa*** Heyne ex Roth	-	-	-	0.03	0.36	0.40	0.16	0.79	0.96
118	***Ficus rumphii*** Bl.	1.24	1.24	4.04	0.16	0.90	1.38	0.21	0.53	0.77
119	***Ficus sp.***	-	-	-	0.03	0.18	0.22	-	-	-
120	***Ficus sp.***	-	-	-	0.02	0.18	0.20	-	-	-
121	***Ficus sp.***	-	-	-	0.02	0.18	0.20	-	-	-
122	***Ficus variegata*** Blume	-	-	-	0.10	0.90	1.02	-	-	-
123	***Sloetia sideroxylon*** Teijsm. & Binn.	-	-	-	0.11	0.36	0.79	3.13	0.79	12.20
124	***Streblus asper*** Lour.	-	-	-	0.03	0.36	0.95	0.64	0.79	1.54
	Myristicaceae									
125	***Horsfieldia glabra*** (Reinw. ex Blume) Warb.	-	-	-	-	-	-	0.16	0.53	1.08
126	***Horsfieldia irya*** (Gaertn.) Warb.	-	-	-	0.02	0.18	0.21	0.58	0.79	1.90
127	****Myristica andamanica*** Hook.f.	-	-	-	0.06	0.18	0.50	3.83	1.58	7.28
128	***Myristica elliptica*** Wall. ex Hook.f. & Thomson	-	-	-	-	-	-	0.16	0.26	1.37
	Myrtaceae									
129	***Syzygium cumingianum*** (Vidal) Gibbs	-	-	-	-	-	-	0.11	0.26	0.38

S. No.	Family and Species	SRV R.den	SRV R.frq	SRV IVI	SLRV R.den	SLRV R.frq	SLRV IVI	UF R.den	UF R.frq	UF IVI
130	***Syzygium samarangense*** (Bl.) Merr. & Perry	0.31	0.31	3.37	0.48	1.44	2.20	2.60	3.17	13.13
	Nyctaginaceae									
131	***Pisonia umbellifera*** (J.R. & G. Forst.) Semm.	-	-	-	0.03	0.18	0.22	0.48	0.53	4.30
	Opiliaceae									
132	***Champereia manillana*** (Bl.) Merr.	-	-	-	0.08	0.36	0.59	0.05	0.26	0.42
	Pandanaceae									
133	****Pandanus leram*** var. ***andamanensium*** (Kurz) ined.	4.97	4.97	22.93	0.06	0.36	0.74	2.82	2.11	6.74
134	***Pandanus odoratissimus*** L.f.	-	-	-	0.03	0.18	0.28	-	-	-
135	***Pandanus tectorius*** Parkinson	0.62	0.62	2.38	-	-	-	0.43	0.26	0.77
	Pentaphylacaceae									
136	***Ternstroemia penangiana*** Choisy	-	-	-	-	-	-	0.11	0.26	0.41
	Primulaceae									
137	***Ardisia solanacea*** Roxb.	-	-	-	-	-	-	0.21	0.79	1.02
	Rhamnaceae									
138	***Ziziphus glabrata*** B. Heyne ex Roth	-	-	-	-	-	-	0.05	0.26	0.70
139	***Ziziphus rugosa*** Lam.	-	-	-	-	-	-	0.05	0.26	0.65
	Rhizophoraceae									
140	***Carallia brachiata*** (Lour.) Merr.	-	-	-	0.03	0.36	0.40	1.22	1.06	2.92
	Rubiaceae									
141	***Guettarda speciosa*** L.	2.17	2.17	5.03	0.42	1.80	2.49	2.87	1.58	4.70
142	****Ixora brunnescens*** Kurz	-	-	-	0.02	0.18	0.20	0.64	0.53	1.20
143	****Ixora grandifolia*** Zall & Mor.	-	-	-	0.02	0.18	0.20	0.16	0.79	0.96
144	***Morinda citrifolia*** L.	1.86	1.86	4.24	1.08	3.42	5.15	0.96	2.11	3.15
145	***Mussanda macrophylla*** Wall.	-	-	-	0.02	0.18	0.20	-	-	-
146	***Neolamarckia cadamba*** (Roxb.) Bosser	-	-	-	0.98	1.80	3.47	0.05	0.26	0.32
147	***Neonauclea excelsa*** Merr.	-	-	-	0.05	0.36	0.42	-	-	-
148	***Petunga racemosa*** (Roxb.) K.Schum.	-	-	-	0.03	0.18	0.23	0.05	0.26	0.32
	Salicaceae									
149	***Atalantia monophylla*** DC.	-	-	-	-	-	-	1.22	0.79	2.11
150	****Glycosmis mauritiana*** (Lam.) Tanaka var. ***insularis*** (Kurz) Tanaka	-	-	-	-	-	-	3.40	1.85	5.33
151	***Casearia fuliginosa*** Blanco	-	-	-	0.02	0.18	0.20	-	-	-
152	***Casearia grewiaefolia*** var. ***gelonoides*** (Blume) Slender	-	-	-	-	-	-	0.37	0.53	0.91
	Sapindaceae									
153	***Dodonaea viscosa*** Jacq.	0.93	0.93	1.95	1.42	0.36	2.19	-	-	-
154	***Lepisanthes rubiginosa*** (Roxb.) Leenh.	-	-	-	0.06	0.54	0.66	1.28	1.58	2.96
155	***Lepisanthes senegalensis*** (Juss. ex Poir.) Leenh.	-	-	-	0.11	0.90	1.07	0.80	1.06	1.94
156	***Pometia pinnata*** J.R. Forst. & G. Forst.	-	-	-	-	-	-	0.05	0.26	0.46
	Sapotaceae									
157	***Manilkara littoralis*** (Kurz) Dub.	-	-	-	-	-	-	2.23	1.32	18.30
158	***Planchonella obovata*** (R.Br.) Pierre	-	-	-	0.02	0.18	0.20	0.53	1.06	1.68

S. No.	Family and Species	SRV			SLRV			UF		
		R.den	R.frq	IVI	R.den	R.frq	IVI	R.den	R.frq	IVI
	Urticaceae									
159	***Boehmeria nivea*** (L.) Gaudich.	0.62	0.62	2.29	7.06	3.06	18.03	-	-	-
	Vitaceae									
160	***Leea angulata*** Korth ex Miq.	-	-	-	0.03	0.36	0.40	-	-	-
161	***Leea asiatica*** (L.) Ridsdale	-	-	-	-	-	-	0.05	0.26	0.32
162	***#Leea grandifolia*** Kurz	-	-	-	0.10	0.54	0.67	0.32	0.53	0.85
163	***Leea indica*** (Burm. F.) Merr.	-	-	-	0.76	2.34	3.29	0.43	1.32	1.76
164	Unidentified 2	-	-	-	-	-	-	0.05	0.26	0.32
165	Unidentified 3	-	-	-	-	-	-	0.05	0.26	0.32
166	Unidentified 4	-	-	-	-	-	-	0.05	0.26	0.32
167	Unidentified 5	-	-	-	-	-	-	0.21	0.26	0.53
168	Unidentified 6	-	-	-	-	-	-	0.05	0.26	0.32
169	Unidentified 7	-	-	-	-	-	-	0.05	0.26	0.38
170	Unidentified 8	-	-	-	0.02	0.18	0.21	-	-	-
171	Unidentified 9	-	-	-	-	-	-	0.64	0.26	0.99
172	Unidentified 10	-	-	-	-	-	-	0.05	0.26	0.32
173	Unidentified 11	-	-	-	-	-	-	0.05	0.26	0.34
174	Unidentified 12	-	-	-	-	-	-	0.05	0.26	0.32
175	Unidentified 13	-	-	-	0.02	0.18	0.20	-	-	-
176	Unidentified 14	-	-	-	0.03	0.18	0.22	0.05	0.26	0.32
177	Unidentified 15	-	-	-	-	-	-	0.11	0.26	0.38
178	Unidentified 16	-	-	-	-	-	-	0.05	0.26	0.38
179	Unidentified 17	-	-	-	0.02	0.18	0.21	-	-	-
180	Unidentified 18	-	-	-	-	-	-	0.05	0.26	0.34
181	Unidentified 19	-	-	-	-	-	-	0.32	0.53	1.19

*Endemic to Andaman and Nicobar Islands
#Endemic to Nicobar Islands

Appendix 2. Importance Value Index (IVI) and Relative Frequency (R. frq) of tree species recorded from SRV1, SRV2, SLRV1 and SLRV1.

		SRV1		SRV2		SLRV1		SLRV2	
S.No	Family and Species	R.frq	IVI	R.frq	IVI	R.frq	IVI	R.frq	IVI
	Achariaceae								
1	***Ryparosa javanica*** (Blume) Kurz ex Koord. & Valeton					0.04	0.29	0.04	0.25
	Actinidiaceae								
2	***Saurauia sp.***					0.02	0.29	0.02	0.26
	Anacardiaceae								
3	***Buchanania splendens*** Miq.							0.02	0.22
4	***Lannea coromandelica*** (Houtt.) Merr.			0.19	0.85	0.11	1.32	0.11	0.78
5	***Semecarpus prainii*** King					0.13	0.83	0.11	0.72
6	***Spondias cytherea*** Sonn.					0.23	2.42	0.28	2.38
	Annonaceae								
7	***Annona muricata*** L.			0.56	1.90	0.34	2.13	0.55	2.49
8	***#Orophea katschallica*** Kurz					0.02	0.26	0.04	0.46
9	***Polyalthia sp.***					0.06	0.53	0.09	0.52
	Apocynaceae								
10	****Alstonia kurzii*** Hook. f.					0.82	2.26	1.30	3.16
11	***Alstonia macrophylla*** Wall. ex G. Don					0.59	1.37	0.58	1.66
12	***Cerbera odollam*** Gaertn.					0.02	0.25		
13	***Ochrosia oppositifolia*** K. Schum.					0.11	0.81	0.04	0.43
14	****Tabernaemontana crispa*** Roxb.					0.02	0.25	0.15	0.95
	Arecaceae								
15	***Areca catechu*** L.					0.02	0.25	0.06	0.48
16	****Calamus andamanicus*** Kurz					0.15	0.38	0.15	0.34
17	***Cocos nucifera*** L.	2.06	6.16	3.92	5.18	0.02	0.24	0.06	0.25
18	****Pinanga manii*** Becc.					0.04	0.34	0.04	0.31
19	***#Rhopaloblaste augustata*** (kurz) Moore					0.04	0.34	0.02	0.28
	Asparagaceae								
20	****Dracaena brachyphylla*** Kurz					0.02	0.25	0.26	0.70
	Bignoniaceae								
21	***Dolichandrone spathacea*** (L.f.) K. Schum	2.12	6.20	2.43	4.45	0.02	0.26	0.04	0.28
	Boraginaceae								
22	***Argusia argentea*** (L.f.) Heine	1.03	3.58	0.75	2.86	0.04	0.40	0.04	0.35
23	***Cordia dichotoma*** G. Forster					0.36	2.75	0.43	2.98
24	***Cordia subcordata*** Lam.	3.09	4.26	0.37	1.77	0.15	1.38	0.15	1.05
25	***Cordia grandis*** Roxb.					0.10	0.80	0.08	0.69
	Burseraceae								
26	***Canarium euphyllum*** Kurz					0.06	0.76	0.11	1.12
27	***Dacryodes rugosa*** H.J. Lam					0.02	0.25		
	Calophyllaceae								
28	***Calophyllum inophyllum*** L.	1.03	1.45	0.56	2.21	0.04	0.51	0.04	0.45

S.No	Family and Species	SRV1		SRV2		SLRV1		SLRV2	
		R. frq.	IVI	R. frq.	IVI	R. frq.	IVI	R. frq.	IVI
	Cannabaceae								
29	***Celtis timorensis*** Span.							0.02	0.22
30	***Trema orientalis*** (L.) Blume	7.22	15.60	3.54	8.49	0.82	3.34	0.30	1.30
	Caricaceae								
31	***Carica papaya*** L.					0.11	1.20	0.02	0.24
	Casuarinaceae								
32	***Casuarina equisetifolia*** L.	11.30	84.80	17.91	74.01	0.15	1.50	0.13	1.52
	Clusiaceae								
33	***Garcinia nervosa*** Miq.					0.08	0.42	0.09	0.39
34	***Garcinia speciosa*** Wall.							0.02	0.22
	Combretaceae								
35	***Terminalia bialata*** Steud.					0.53	2.69	0.73	3.17
36	***Terminalia catappa*** L.	11.30	19.80	3.92	12.89	2.62	8.47	2.37	8.94
37	***Terminalia procera*** Roxb.			0.37	1.31	0.44	1.08	0.45	1.37
	Cycadaceae								
38	***Cycas rumphii*** Miq.					0.02	0.31	0.02	0.27
	Dilleniaceae								
39	****Dillenia andamanica*** Parkinson					0.04	0.49	0.02	0.23
	Euphorbiaceae								
40	***Alchornea rugosa*** (Lour.) Muell.-Arg.							0.02	0.22
41	***Antidesma diandrum*** Spreng.					0.11	0.58	0.13	0.35
42	***Breynia recemosa*** (Bl.) Muell.- Arg.					0.02	0.25	0.02	0.22
43	***Claoxylon indicum*** (Reinw. Ex Bl.) Hassk.					4.47	10.70	4.35	9.94
44	***Croton argyratus*** Bl.					0.02	0.25	0.02	0.22
45	***Drypetes longifolia*** (Blume) Pax & Hoffm.					0.02	0.25	0.06	0.45
46	***Flueggea virosa*** (Willd) Baill.					0.17	0.89	0.21	1.23
47	****Glochidion calocarpum*** Kurz			0.19	0.83	0.50	3.56	0.81	3.74
48	***#Macaranga nicobarica*** Balakr. & P. Chakrab			0.19	0.83	0.25	1.42	0.43	1.73
49	***Macaranga peltata*** (Roxb.) Muell.-Arg.	4.12	11.60	6.16	12.62	54.74	122.65	50.63	118.52
50	***Macaranga tanarius*** (L.) Müll. Arg.							0.02	0.22
51	***Phyllanthus reticulatus*** Poir.					0.02	0.25		
52	***Suregada multiflora*** Baill.					0.04	0.49	0.04	0.43
53	***Unidentified 1***			0.19	0.83	0.06	0.33	0.09	0.54
	Fabaceae								
54	***Peltophorum pterocarpum*** (DC.)	2.06	3.72	0.75	3.02				
55	***Adenanthera pavonina*** L.					0.04	0.43	0.04	0.43
56	***Albizia procera*** (Roxb.) Benth.					0.02	0.25	0.02	0.23
57	***Albizia saman*** (Jacq.) F.v. Muell.					0.02	0.28	0.02	0.25
58	***Dendrolobium umbellatum*** (L.) Benth.	5.15	18.70	9.33	21.90	3.90	9.74	5.13	11.76
59	***Erythina fusca*** Lour.	1.03	1.75	0.19	1.07				
60	***Erythrina variegata*** L.	1.03	1.46	0.19	1.68				
61	***Flemingia strobilifera*** (L.) R. Brown							0.02	0.2

S.No	Family and Species	SRV1		SRV2		SLRV1		SLRV2	
		R. frq.	IVI	R. frq.	IVI	R. frq.	IVI	R. frq.	IVI
62	***Intsia bijuga*** (Colebr.) O.Kunze					0.04	0.28	0.04	0.27
63	***Pongamia pinnata*** (L.) Pierre	4.12	9.45	2.43	6.88	0.10	0.97	0.11	0.84
	Goodeniaceae								
64	***Scaevola sericea*** Vahl	5.15	7.98	3.92	9.24	0.11	0.84	0.04	0.50
	Hernandiaceae								
65	***Hernandia nymphaeifolia*** (Presl.) Kubitzki.	1.03	3.91	0.93	3.22	0.27	2.65	0.32	2.52
	Lamiaceae								
66	***Clerodendrum paniculatum*** L.					0.04	0.49	0.08	0.67
67	***Premna corymbosa*** (Burm. f.) Rottler & Willd.			0.19	0.84				
68	***Vitex trifola*** L.	1.03	1.69	0.19	0.95				
	Lauraceae								
69	***Actinodaphne procera*** (Blume) Nees							0.02	0.21
	Lecythidaceae								
70	***Barringtonia asiatica*** (L.) Kurz.	3.09	5.92	2.99	7.96	0.10	1.03	0.11	0.74
71	***Barringtonia racemosa*** (L.) Spreng.					0.21	1.14	0.26	1.09
72	***Chydenanthus excelsus*** (Blume) Miers					0.02	0.25	0.08	0.68
	Leeaceae								
73	***Leea angulata*** Korth ex Miq.					0.04	0.50		
	Lythraceae								
74	***Lagerstroemia ovalifolia*** Teijsm. & Bim.					0.02	0.26	0.02	0.24
	Malvaceae								
75	***Ceiba pentandra*** (L.) Gaertn.					0.02	0.26	0.02	0.23
76	***Heritiera littoralis*** Aiton					0.02	0.25	0.06	0.26
77	***Hibiscus tiliaceus*** L.	9.29	26.90	16.98	36.78	1.34	6.27	1.56	6.76
78	***Melochia umbellata*** (Houtt.) Stapf.					1.80	4.96	1.68	4.39
79	***Pterocymbium tinctorium*** Merri.					2.14	6.81	2.94	7.95
80	****Sterculia cordata*** Bl.					0.04	0.27	0.02	0.22
81	***Sterculia macrophylla*** Vent.			0.75	2.15	0.10	0.34	0.11	0.33
82	***Sterculia parviflora*** Roxb.					0.10	0.61	0.09	0.74
83	***Sterculia rubiginosa*** Vent.					1.38	4.16	1.34	3.65
84	***Thespesia populnea*** (L.) Soland ex Correa	2.06	3.33	0.56	3.03	0.06	0.52	0.08	0.68
	Meliaceae								
85	***Aglaia sp.***					0.02	0.26		
86	***Aglaia sp.***					0.55	1.41	0.68	1.45
87	***Aglaia sylvestris*** (M. Roem.) Merr.							0.08	0.69
88	***Aphanamixis polystachya*** (Wall.) R. Parker							0.04	0.43
89	***#Chisocheton nicobarianus*** Debnath & Sreek.					0.02	0.24	0.04	0.24
	Moraceae								
90	***Artocarpus gomezianus*** Wall. ex Trec.	1.03	1.93	0.56	1.37	0.10	0.63	0.15	1.03
91	***Ficus altissima*** Bl.			0.19	0.83	0.02	0.25		
92	***Ficus callosa*** Willd.			0.19	0.86	0.17	1.74	0.17	1.39

S.No	Family and Species	SRV1		SRV2		SLRV1		SLRV2	
		R. frq.	IVI	R. frq.	IVI	R. frq.	IVI	R. frq.	IVI
93	***Ficus fistulosa*** Reinw. ex Blume					0.08	0.33	0.08	0.29
94	***Ficus hispida*** L.f.			0.19	0.85	6.92	18.95	7.25	17.47
95	***Ficus microcarpa*** L.f.	3.09	5.48	2.43	7.84	0.63	3.93	0.85	3.80
96	***Ficus nervosa*** Heyne ex Roth					0.04	0.49	0.04	0.43
97	***Ficus rumphii*** Bl.	2.06	3.70	0.37	2.68	0.10	0.91	0.19	0.94
98	***Ficus sp.***					0.02	0.24	0.09	0.33
99	***Ficus sp.***							0.04	0.24
100	***Ficus tinctoria*** G. Forst.							0.02	0.23
101	***Ficus variegata*** Blume					0.06	0.74	0.26	1.75
102	***Sloetia sideroxylon*** Teijsm. & Binn.					0.11	0.58	0.08	0.48
103	***Streblus asper*** Lour.					0.02	0.25	0.09	1.09
	Myristicaceae								
104	***Horsfieldia irya*** (Gaertn.) Warb.					0.02	0.26	0.04	0.26
105	****Knema andamanica*** (Warb.) W.J.de Wilde							0.02	0.22
106	****Myristica andamanica*** Hook. f.					0.06	0.34	0.02	0.24
	Myrtaceae								
107	***Syzygium samarangense*** (Bl.) Merr. & Perry	1.03	1.46	0.19	0.91	0.55	2.52	0.64	2.72
	Nyctaginaceae								
108	***Pisonia umbellifera*** (J.R. & G. Forst.) Semm.					0.04	0.28	0.08	0.67
	Opiliaceae								
109	***Champereia manillana*** (Bl.) Merr.					0.10	0.77	0.08	0.65
	Oxalidaceae								
110	***Averrhoa bilimbi*** L.							0.02	0.22
	Pandanaceae								
111	****Pandanus leram*** var. ***andamanensium*** (Kurz) ined.	2.06	25.30	5.78	24.45	0.08	0.99	0.09	1.17
112	***Pandanus odoratissimus*** L.f.			0.19	2.39	0.04	0.36	0.04	0.35
113	***Pandanus tectorius*** Parkinson	1.03	3.21	0.37	1.69				
	Rhizophoraceae								
114	***Carallia brachiata*** (Lour.) Merr.					0.04	0.49	0.06	0.65
	Rubiaceae								
115	***Guettarda speciosa*** L.	4.18	7.44	2.61	7.59	0.34	1.79	0.43	2.11
116	****Ixora brunnescens*** Kurz					0.02	0.25	0.02	0.22
117	***Morinda citrifolia*** L.	4.12	6.87	3.54	11.97	1.18	5.83	1.51	6.33
118	***Mussanda macrophylla*** Wall.					0.02	0.25	0.02	0.22
119	***Neolamarckia cadamba*** (Roxb.) Bosser					0.76	3.14	0.72	3.01
120	***Neonauclea excelsa*** Merr.			0.75	2.09	0.06	0.52	0.09	0.72
121	***Petunga racemosa*** (Roxb.) K.Schum.					0.04	0.28	0.04	0.26
	Salicaceae								
122	***Casearia fuliginosa*** Blanco					0.02	0.25	0.02	0.22
	Sapindaceae								
123	***Dodonea viscosa*** Jacq.	2.06	3.20	0.93	1.75				
124	***Lepisanthes rubiginosa*** (Roxb.) Leenh.					0.08	0.84	0.13	1.38

S.No	Family and Species	SRV1		SRV2		SLRV1		SLRV2	
		R. frq.	IVI	R. frq.	IVI	R. frq.	IVI	R. frq.	IVI
125	***Lepisanthes senegalensis*** (Juss. ex Poir.) Leenh.					0.13	1.34	0.24	1.32
	Sapotaceae								
126	***Planchonella obovata*** (R.Br.) Pierre					0.02	0.24	0.04	0.24
	Urticaceae								
127	***Boehmeria nivea*** (L.) Gaudich.	1.03	3.15	1.12	2.97	6.04	16.81	4.13	13.09
	Vitaceae								
128	***#Leea grandifolia*** Kurz					0.08	0.55	0.26	1.29
129	***Leea indica*** (Burm. F.) Merr.					0.65	3.34	0.98	3.96
130	***Leea macrophylla*** Roxb. ex Hornem.							0.08	0.49
131	Unidentified 2					0.04	0.27	0.04	0.24
132	Unidentified 3					0.02	0.27	0.02	0.25
133	Unidentified 4							0.02	0.22
134	Unidentified 5					0.02	0.24		
135	Unidentified 6					0.02	0.26		

*Endemic to Andaman and Nicobar Islands
#Endemic to Nicobar Islands

Appendix 3: Publications

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Check List

LISTS OF SPECIES

Re-colonizing Mangrove species in tsunami devastated habitats at Nicobar Islands, India

Prabakaran Nehru and Paramasivam Balasubramanian*

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Abstract: Mangrove habitats are crucial for maintaining the biodiversity of coastal ecosystem. Climatic change, sea level rise and anthropogenic pressures are the major threats to mangrove forests. The Nicobar Islands comprised one of the pristine mangrove stands in India. The mega earthquake of >9 M and subsequent tsunami during 2004 caused destruction of over 70% of mangrove vegetation in Nicobar Islands. The present study was carried out in the Central Nicobar Group of Islands (Camorta, Nancowry, Katchall and Trinkat), where tsunami has entirely wiped out the mangrove vegetation. Re-colonization started on its own course. We enumerated nine species of mangrove plants and 30 species of mangrove associates from the surveyed locations. *Lumnitzera racemosa* has been recorded for the first time from the study area. *Rhizophora mucronata* and *Bruguiera gymnorrhiza* were the common pioneer mangrove species. Long-term monitoring of re-colonization process will help us in understanding succession of mangrove forests.

Introduction

Mangrove habitats in the tropical coasts confined between latitudes 25° N and 30° S represent a unique ecosystem, which is vital for the maintenance of marine biodiversity (Valiela *et al.* 2001). Inhabiting the interface between land and sea at low latitudes, mangroves occupy a harsh environment, being subjected to daily tidal changes, temperature, salt exposure and varying degrees of anoxia. Therefore mangroves exhibit a high degree of ecological stability in the water-logged saline zone between sea and terrestrial environment (Tomlinson 1986; Alongi 2008; Giri *et al.* 2008). Mangrove habitat supports the survival of plant species that are adapted to live in the high salinity conditions.

Mangrove forests occupy 14,650,000 ha of coastline around the globe (Wilkie and Fortuna 2003). Bountiful information is available on the status of mangrove habitats, their extent and biodiversity (Sidhu 1963; Chapman 1976; Dagar *et al.* 1991; Duke 1992; Saenger and Bellan 1995; Li and Lee 1997; Spalding *et al.* 1997; Valiela *et al.* 2001; Jayatissa *et al.* 2002; Wilkie and Fortuna 2003). These tidal forests are often important nursery grounds and breeding sites for birds, mammals, fish, crustaceans, shellfish and reptiles; a renewable resource of wood; and sites for accumulation of sediment, nutrients, and contaminants (Sasekumar *et al.* 1992; Kathiresan and Bingham 2001). Mangrove forests protect land from hurricanes and tsunamis by acting as a physical barrier along the coast (Barbier 2006; Chang *et al.* 2006).

However, the mangrove forests have been declining at an alarming rate–perhaps even more rapidly than inland tropical forests and much of what remains is in degraded condition (Valiela *et al.* 2001; Wilkie *et al.* 2003). The remaining mangrove forests are under immense pressure from felling, encroachment, hydrological alterations, chemical spills, farm land conversion, storms and climate change (Menesveta 1997; Blasco *et al.* 2001; Valiela *et al.* 2001; McKee 2005; Giri *et al.* 2008).

The mega earth quake and the subsequent tsunami in the Indian Ocean during December 2004 had an adverse effect on the mangrove forests of Asian countries such as India, Sri Lanka, Thailand, and Indonesia. Mangrove forests suffered severe damage during tsunami by breaking and uprooting (UNEP 2005; IUCN 2005; Sankaran 2005; Giri *et al.* 2008). The Nicobar Islands of India situated very close to the epicenter of the earthquake suffered a major loss in terms of human lives and biodiversity. The mangrove forests of Nicobar Islands considered to be one of the pristine forests in India had been badly ravaged during tsunami. It was variously estimated that 62 – 70% of mangrove forests of Nicobar Islands were destroyed (Ramachandran *et al.* 2005; Roy and Krishnan 2005; Sankaran 2005; Sridhar *et al.* 2006).

The resilience and dynamics of mangrove forests to human induced disturbances have been studied in many parts of the world (Ball 1980; Sherman *et al.* 2000; Giri *et al.* 2008), but the information available on the succession of mangroves after natural disasters like hurricane and tsunami are scanty (Roth 1992; Ross *et al.* 2000). The present study describes the species richness of mangrove re-colonizing habitats in the Central Nicobar group of Islands, which were completely destroyed by the tsunami, 2004.

Materials and Methods

Study site

Nicobar group of Islands consists of 24 Islands situated in the Bay of Bengal between Latitude 06°45' – 9°15' N and Longitude 92°42' – 93°50' E. Of the 24 islands, 12 are inhabited by the humans. The temperature ranges from 22°C – 32°C and annual rainfall from 3,000 mm – 3,800 mm (Sinha 1999).

The study was carried out in the Central Nicobar group of Islands (Figure 1). Tsunami ravaged mangrove forests of four islands namely Camorta, Nancowry, Katchall and Trinkat were studied for species diversity in the mangrove re-colonizing habitats during January- May 2010. The latitudes and longitudes of the four Islands are as follows: Camorta 07°59'12"–8°14'43" N, 93°25'49"– 93°34'36" E, Katchall 07°51'50"– 08°01'56" N, 93°17'41"– 93°28'47" E, Nancowry 07°55'04" – 08°01'57" N, 93°29'23" – 93°35'01" E, and Trinkat 08°01'45" - 08°08'48" N, 93°37'04" - 93°37'30" E (Ramachandran *et al.*, 2005).

Data Collection

The entire coastal lines of the above-mentioned islands were surveyed. Mangrove re-colonizing sites were selected for detailed study. Plant specimens were collected whenever identification was not possible in the field. The collected specimens were identified with the help of the publications on the Flora of Andaman & Nicobar Islands (Dagar *et al.* 1991; Hajra *et al.* 1999; Sinha 1999). Nomenclatures of the identified species were checked with the International Plant Naming Index (IPNI).

Results and Discussion

A total of nine species of mangroves belonging to six families and 30 species of mangrove associates belonging to 21 families were enumerated (Table 1). The most common mangrove species in the re-colonizing vegetation are *Rhizophora mucronata* (Figure 2) and *Bruguiera gymnorrhiza* (Figure 3B). The common mangrove associates include *Wedelia biflora, Dolichandrone spathacea, Cyperus javanicus, Ischaemum muticum* and

Table 1. List of Mangroves and Mangrove associates observed from the re-colonizing mangrove habitats of Central Nicobar Islands (Ca- Camorta, Ka- Katchall, Na- Nancowry and T- Trinkat).

FAMILY	SPECIES	HABIT	ISLAND
	Mangroves		
Sterculiaceae	*Heritiera littoralis* Dryand.	Tree	Ka
	Bruguiera gymnorrhiza (L.) Savigny	Tree	Na, Ca, Ka, T
Rhizophoraceae	*Rhizophora mucronata* Poir.	Tree	Na, Ca, Ka, T
	Ceriops tagal (Perr.) Robins	Tree	T
Combretaceae	*Lumnitzera racemosa* Willd.	Tree	T
	Lumnitzera littorea (Jack) Voigt.	Tree	Ca, Ka, T
Sonneratiaceae	*Sonneratia caseolaris* (L.) Engler	Tree	Na, Ca, Ka, T
Euphorbiaceae	*Excoecaria agallocha* L.	Tree	Ca, T
Arecaceae	*Nypa fruticans* Wurmb.	Shrub	N, Ca, Ka, T
	Mangrove Associates		
Malvaceae	*Hibiscus tiliaceus* L.	Tree	N, Ca, Ka, T
	Thespesia populnea (L.) Soland ex Correa	Tree	T
Celastraceae	*Salacia chinensis* L.	Shrub	Ca
Anacardiaceae	*Lannea coromandelica* (Houtt.) Merr.	Tree	Ca, T
Fabaceae	*Derris scandens* Benth.	Liana	Ka
	Pongamia pinnata (L.) Pierre	Tree	Ca, Ka
	Derris trifoliata Lour.	Liana	Ka
	Vigna marina (Burm.f.) Merr.	Climber	N, Ca, Ka, T
Caesalpiniaceae	*Caesalpinia bonduc* (L.) Roxb.	Straggler	N, Ca, Ka, T
	Intsia bijuga (Colebr.) O.Kunze	Tree	N, Ca, Ka
Combretaceae	*Terminalia catappa* L.	Tree	N, Ca, Ka, T
Myrtaceae	*Syzygium samarangense* (Bl.) Merr. & Perry	Tree	N, Ca, Ka, T
Barringtoniaceae	*Barringtonia racemosa* Bl.	Tree	Ka
Rubiaceae	*Guettarda speciosa* L.	Tree	N, Ca, Ka, T
	Morinda citrifolia L.	Tree	N, Ca, Ka, T
Asteraceae	*Wedelia biflora* DC.	Herb	N, Ca, Ka, T
Goodeniaceae	*Scaevola sericea* Vahl	Shrub	N, Ca, Ka, T
Myrsinaceae	*Ardisia solanacea* Roxb.	Shrub	Ca
Sapotaceae	*Planchonella obovata* (R.Br.) Pierre	Tree	Ca
Boraginaceae	*Cordia subcordata* Lam.	Tree	N, Ca, Ka, T
Bignoniaceae	*Dolichandrone spathacea* (L.f.) K.Schum.	Tree	N, Ca, Ka, T
Verbenaceae	*Clerodendrum inerme* (L.) Gaertn.	Shrub	Ca, Ka
	Premna corymbosa (Burm.f.) Rottb. & Willd.	Shrub	T
Hernandiaceae	*Hernandia nymphaeifolia* (Presl.) Kubitzki.	Tree	Ka, T
Casuarinaceae	*Casuarina equisetifolia* L.	Tree	Ca, T
Flagellariaceae	*Flagellaria indica* L.	Straggler	N, Ca, Ka
Cyperaceae	*Fimbristylis dichotoma* (L.) Vahl	Sedge	T
	Cyperus javanicus Houtt.	Sedge	N, Ca, Ka, T
	Scirpus littoralis Schrad.	Sedge	N, Ca, Ka, T
Poaceae	*Ischaemum muticum* L.	Grass	N, Ca, Ka, T

Caesalpinia bonduc which were found in all the four Islands. *Lumnitzera racemosa* (Figure 3E) was recorded for the first time from the Central Nicobar Islands. The species richness of mangroves and mangrove associates are more or less similar among the three islands namely Camorta (6, 23), Katchall (6, 22) and Trinkat (8, 20). Lesser species richness was observed in Nancowry (4, 16). The lesser species richness could be due to the highest damage occurred in this island as reported by Ramachandran *et al.* (2005).

The observed species richness for the Central Nicobar Islands is lower than the earlier record of 17 and 85 for the mangrove and mangrove associates respectively (Dagar *et al.* 1991). Loss of mangrove habitats by the perennial submergence of the Nicobar Islands into the sea for about 1m due to the earth quake formed a major constraint for the re-colonizing species (Figure 4). However, the present study gives the first hand information on the plant diversity of re-colonizing mangrove habitats, which will eventually help in the long term monitoring of mangrove species in the Islands.

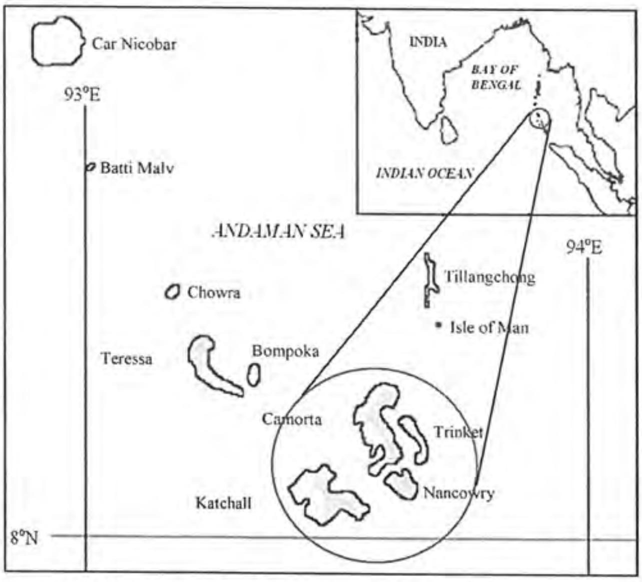

FIGURE 1. Map showing the Central Nicobar Group of Islands.

FIGURE 2. Saplings of *Rhizophora mucronata* observed in the regenerating habitat at Trinkat Island (Photo by P Nehru).

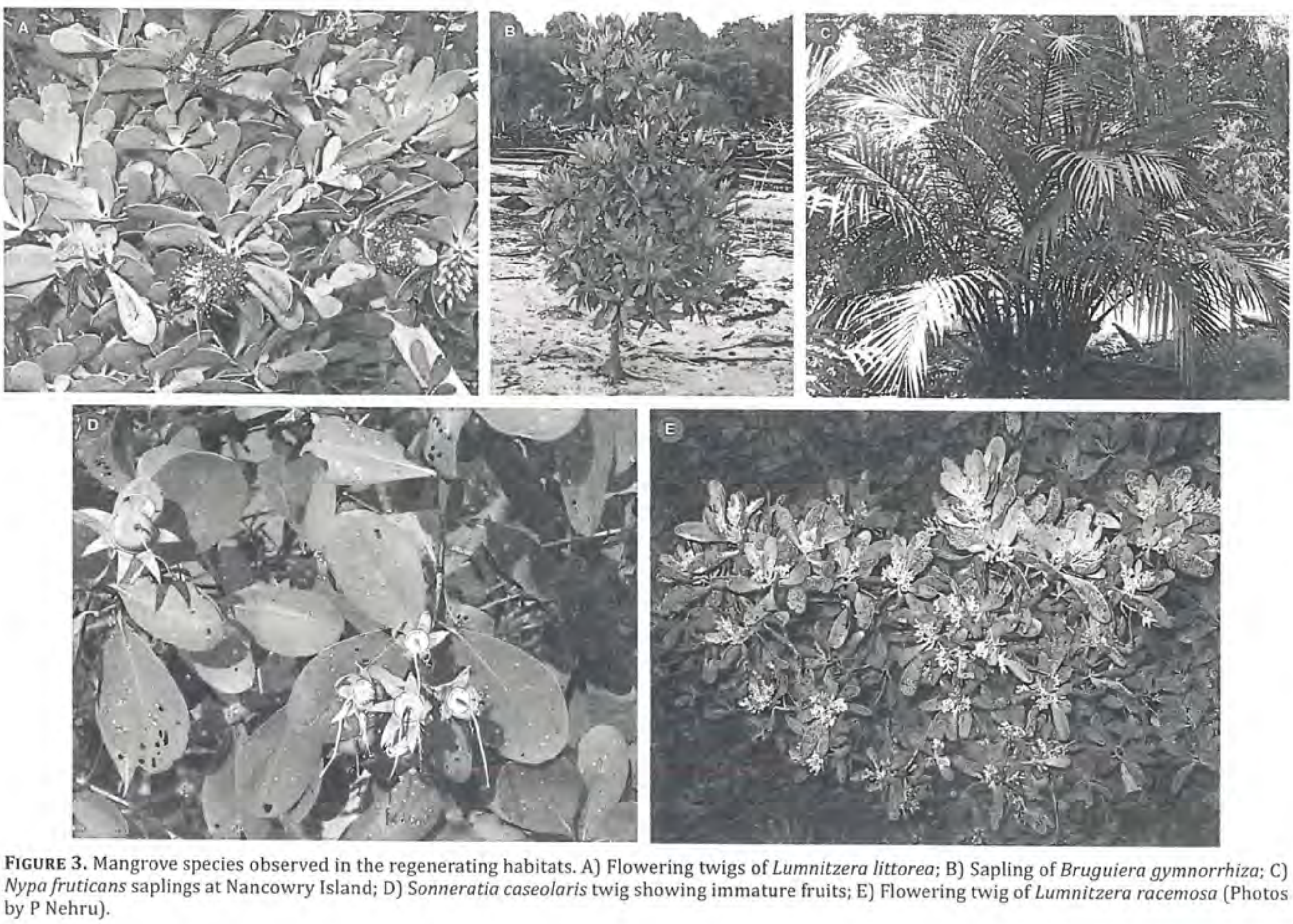

FIGURE 3. Mangrove species observed in the regenerating habitats. A) Flowering twigs of *Lumnitzera littorea*; B) Sapling of *Bruguiera gymnorrhiza*; C) *Nypa fruticans* saplings at Nancowry Island; D) *Sonneratia caseolaris* twig showing immature fruits; E) Flowering twig of *Lumnitzera racemosa* (Photos by P Nehru).

Figure 4. A vast stretch of Mangrove snags near Dering village, Camorta Island (Photo by P Nehru).

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Sonneratia ovata Backer (Lythraceae): status and distribution of a Near Threatened mangrove species in tsunami impacted mangrove habitats of Nicobar Islands, India

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Abstract: The world's most productive ecosystem, the mangrove forest, is under immense pressure due to natural and human induced disturbances. The Indian Ocean tsunami on 26 December 2004 had an adverse effect on these habitats by breaking and uprooting the mangrove trees. The mangrove vegetation and the coastal forest of Nicobar Islands, India, were severally damaged by the force of the tsunami and the loss of habitat due to the sudden rise in sea level. We studied the re-colonization of mangroves species that began after the tsunami over 19 Islands and 25 locations present in the Nicobar group. *Sonneratia ovata* (Lythraceae), a Near Threatened landward mangrove species, is reported for the first time from India. A total of 43 individuals of *S. ovata* was recorded from two sites, namely, Oh Hi Poh and Dhili Kadi, on Katchall Island. All the individuals of mangrove species ≥ 1cm girth at breast height were counted from both sites. The relative density for *Bruguiera gymnorhiza* (77%) and *Sonneratia caseolaris* (77%) are high at Oh Hi Poh and Dhili Kadi, respectively. Global distribution, occurrence in India, threats and conservation of *S. ovata* are discussed in detail. The influence of the tsunami in the dispersal of *S. ovata* from the nearest known sources Thailand, Malaysia or Indonesia is not very clear. Hence, molecular based study is required for the confirmation of the possible seed source location.

Keywords: Habitat destruction, Indian Ocean tsunami, mangrove, recolonization, *Sonneratia ovata*.

Mangrove forests are the most productive ecosystem adapted to thrive in the coastal margins of the tropics (Ellison & Fransworth 2001). The ecosystem service provided by mangroves includes breeding grounds for many marine organisms, a carbon sink and is also the main source of economy for coastal dwelling human communities (Kathiresan & Bingham 2001). Mangrove ecosystems play a major role in protecting coastal regions from natural calamities such as storms, hurricanes and tsunamis. Regardless of the services provided, mangrove forests are disappearing from the world at an alarming rate of 1% per year and almost 35% of the mangroves have disappeared in the last two decades of the 20th century (Valiela et al. 2001). The remaining mangrove forests are under immense anthropogenic pressure from felling, encroachment, shrimp cultivation, hydrological alterations, chemical spills, and land conversion (McKee 2005; Giri et al. 2008). Natural disturbances such as storms, hurricanes, tsunamis, land elevation or submergence due to tectonic movements, climate change and sea level rise are also threatening this biologically important ecosystem.

The mega earthquake of 9.15 magnitude and the following tsunami on 26 December 2004 had a serious impact on the human population and on the biodiversity of the coastal regions in the Asian countries such as India, Sri Lanka, Indonesia, Burma, Thailand, Singapore and Malaysia. The close vicinity of the Nicobar Islands to the epicenter of the earthquake resulted in a heavy impact on the mangroves and

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littoral forests. It was variously estimated that the tsunami wiped off 60–70 % of the mangrove forests in the Nicobar Islands (Ramachandran et al. 2005; Sridhar et al. 2006). More importantly, subduction of the Indian plate with the Burma plate during this mega earthquake caused the Nicobar Islands to sink into the sea by about 1m, this resulted in a rise in the sea level in the coastal areas where mangroves and littoral evergreen vegetation were prevalent (Sankaran 2005; Sivakumar 2007). Perennial submergence of pneumatophores resulted in the scorching of mangrove trees due to the hypoxic condition. This submergence also resulted in the formation of new inter tidal areas at the expense of flat coastal forests (littoral forest) and coconut plantations that existed adjacent to the coast (Nehru & Balasubramanian 2011) and mangroves started colonizing in these newly formed habitats (NFH).

The post tsunami research work in the Nicobar Islands on mangroves are almost all based only on remote sensing and GIS (Ramachandran et al. 2005; Sridhar et al. 2006; Porwal et al. 2012). A single field based study that described the mangrove plant species diversity in the NFH of Central Nicobar Group of Islands was by Nehru & Balasubramanian (2011).

The current study describes the population, distribution and microhabitat preference of the Near Threatened mangrove species *Sonneratia ovata* Backer (Lythraceae) from the NFH after the tsunami impact.

Materials and Methods

We surveyed the Nicobar Islands from October 2010 to July 2011 for assessing the colonization of mangrove species in the NFH. Excluding Batti Malv, Isle of Man and Megapode Island, the entire coastal line of all the other 19 islands, viz., Car Nicobar, Chowra, Bombuka, Teresa, Tillanchong, Kamorta, Trinket, Nancowrie, Katchall, Great Nicobar, Little Nicobar, Kondul, Kobra, Manchal, Pigeon, Pilomilo, Tris, Trak, and Meroe of the Nicobar group were surveyed (Fig. 1).

It is to be noted that the Megapode Island which was largely covered by mangrove vegetation prior to the tsunami was totally submerged into the sea after the tsunami (Sankaran 2005). Apart from a single scorched tree stump in the middle of the sea, no evidence was found during the present study confirming the existence of this island.

Qualitative data on inundation levels, substratum, freshwater influx, pre tsunami history of the habitat, adjacent forest type, tsunami destruction level, number of colonizing mangroves and mangrove associates were noted for each NFH by direct observation. Geographic coordinates were taken using the Garmin 76C SX at all the localities and the area was calculated using the GE-path software package (ver. 1.4.6).

All the individuals ≥1cm girth at breast height (GBH) of mangroves species present in the NFH were enumerated. The whole population of *S. ovata* was enumerated and each individual was tagged. Samples of all the mangrove species were collected for herbarium purpose. Relative density was calculated for mangrove species studied in Katchall Island.

Results

In total, 25 localities distributed over eight islands were observed to have NFH. *S. ovata* was observed only on Katchall Island (7^{0}51'–8^{0}01'N & 93^{0}17'–93^{0}28'E) at two localities namely Oh Hi Poh and Dhili Kadi where vast stretch of littoral forest existed prior to tsunami, but are presently colonized by mangroves (Fig. 1). The total area of NFH at these two locations was 23.9 and 4.64 ha, respectively. The littoral forest existing in these two locations experienced different modes of destruction during the tsunami leading to the transformation into mangrove forests. At Oh Hi Poh, the littoral forest that existed prior to the tsunami was uprooted and resulted in the deposition of copious amount of logs in the substratum (Image 1a). At Dhili Kadi, the entire stretch of littoral vegetation was scorched due to salt stress and hypoxia created by the rise of sea level leaving a vast stretch of snags (Image 1b). A total of 43 live individuals of *S. ovata* were recorded (13 at Oh Hi Poh and 30 at Dhili Kadi) along the edges of the NFH abutting the evergreen hill forest. The relative density was high for *Bruguiera gymnorhiza* (77%) and *Sonneratia caseolaris* (77%) at the NFH studied at Dhili Kadi (n=114) and Oh Hi Poh (n=237), respectively (Figs. 2&b).

S. ovata was always found intermixed with the associated species (viz. *B. gymnorhiza, S. caseolaris, Barringtonia racemosa* and *Crataeva religiosa*), whereas its conspecific *S. caseolaris* was mostly found as mono-dominat patches with out any associated species. The substratum in both these sites was muddy clay towards the sea and firm clay inland. *S. ovata* is

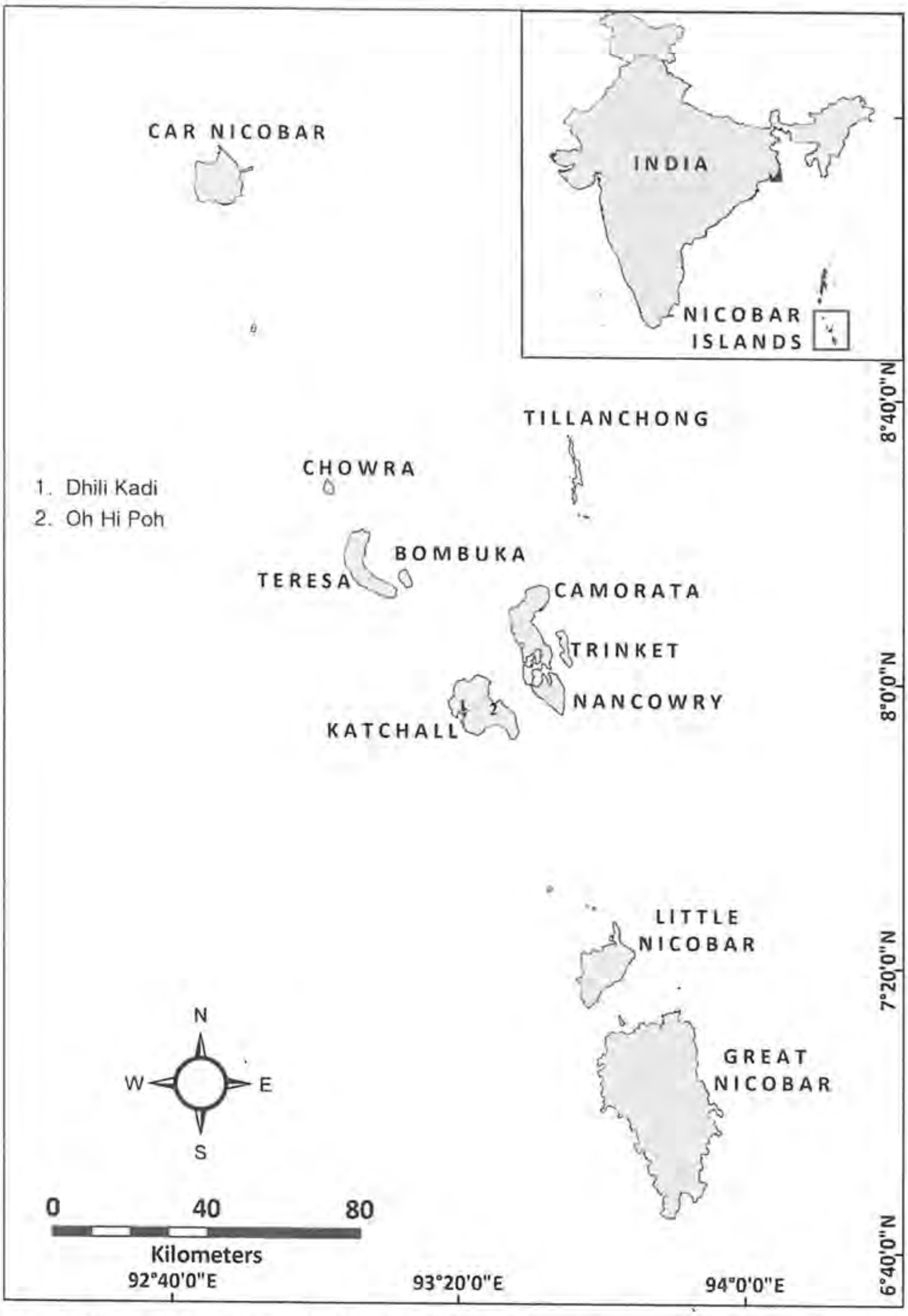

Figure 1. Nicobar Islands, India, showing the study localities, on Katchall Island, where *Sonneratia ovata* was observed: 1 - Dhili Kadi; 2 - Oh Hi Poh.

found in the firm clay substratum towards the landward mangrove forest edge where constant seepage of freshwater from the hill forest was observed.

S. ovata is distinguished from other species of the genus *Sonneratia* by (i) having verrucose texture on the outer surface of the calyx, (ii) fruits are enclosed by persistent calyx, and the calyx are either reflexed or flat in the other species (iii) and suborbicular coriaceous leaves without a mucronate apex. *S. ovata* normally grows in the landward mangrove habitats where sea water enters only during full moon and spring tides. A detailed description and the nomenclature of the

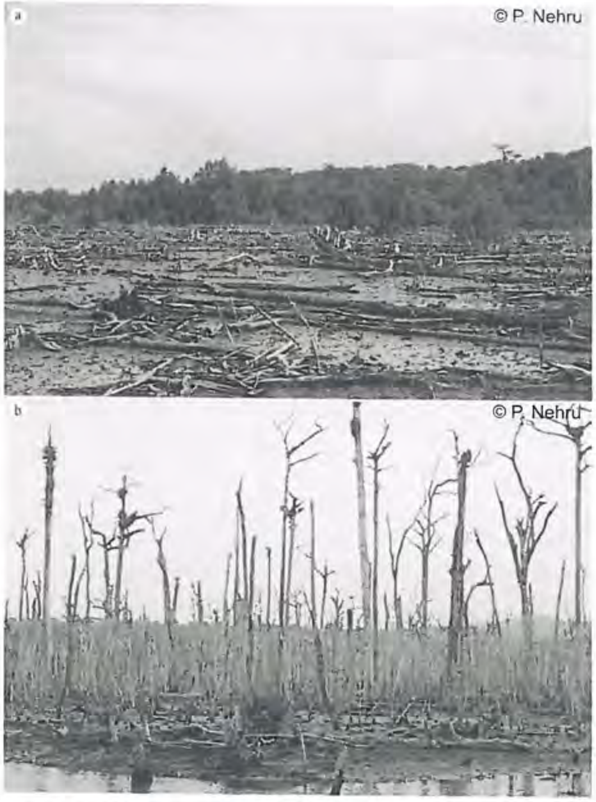

Image 1. a - A view of Oh Hi Poh NFH showing deposition of logs in the substratum by uprooted trees (23.xi.2010);
b - A view of Dhili Kadi NFH showing vast stretch of snags (28.iv.2011)

species are given below.

Sonneratia ovata Backer, Bull. Jard. Bot. Buitenzorg Ser. 3, 2: 329. 1920; Qin & al. in Wu & Raven, Fl. China 13: 287. 2007.

Trees up to 8m high; bark lenticellate; pneumatophores ca. 20cm high, thin, pointed. Leaves opposite, sub-orbicular to ovate-elliptic, 5.5–9 x 4–8 cm, attenuate to cuneate at base, entire to undulate at margins, obtuse at apex, coriaceous; petioles 0.8–1.5 cm long. Flowers 1–3, terminal, ca. 3 cm across, white. Bracts orbicular, ca. 0.5 cm, cauducous. Pedicels 1.5–2 cm long. Sepals 6, coriaceous, verrucose outside, smooth, pinkish at base inside. Petals 6, linear, 1.5–2 x 0.1–0.2 cm, white. Stamens numerous; filaments 2–3 cm long; anthers basifixed. Style 1.8–2.5 cm long; stigma capitate. Berry sub-globose, 2.5–3 x 3–4 cm, ca. 1/3 of the fruit enclosed within persistent calyx; seeds numerous.

Flowering and fruiting: Throughout the year with peaks during February–March and July–August (Images 2 a&b).

Specimen examined: 28.vi.2011, Andaman and Nicobar Islands, Nicobar District, Katchall Island, Dhili Kadi, P. Nehru (189). The voucher specimen is deposited in SACON Herbarium.

Discussion and Conclusions

The genus *Sonneratia* has six species distributed in the tropical mangrove forests from East Africa to Australia (Mabberley 2005). In India, it is represented by four species namely *S. alba, S. apetala, S. caseolaris* and *S. grifithii* (Banerjee et al. 2002). Occurrence of *S. ovata* within the Indian territory has not been reported

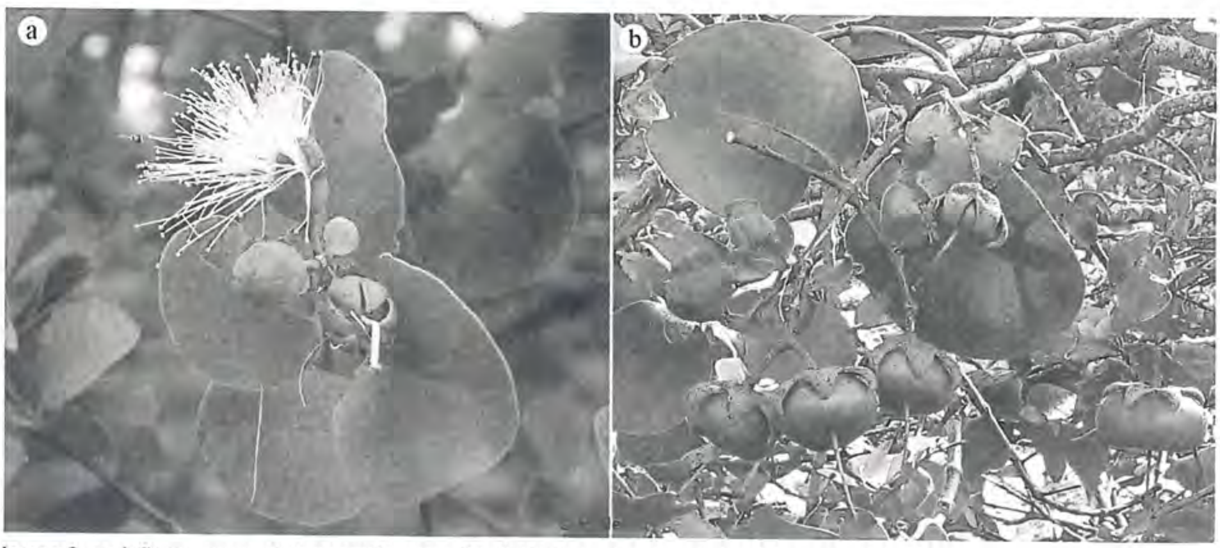

Image 2. a - Inflorescence of *Sonneratia ovata* (23.xi.2010); b - Fruiting twig of *S.ovata* (28.iv.2011)

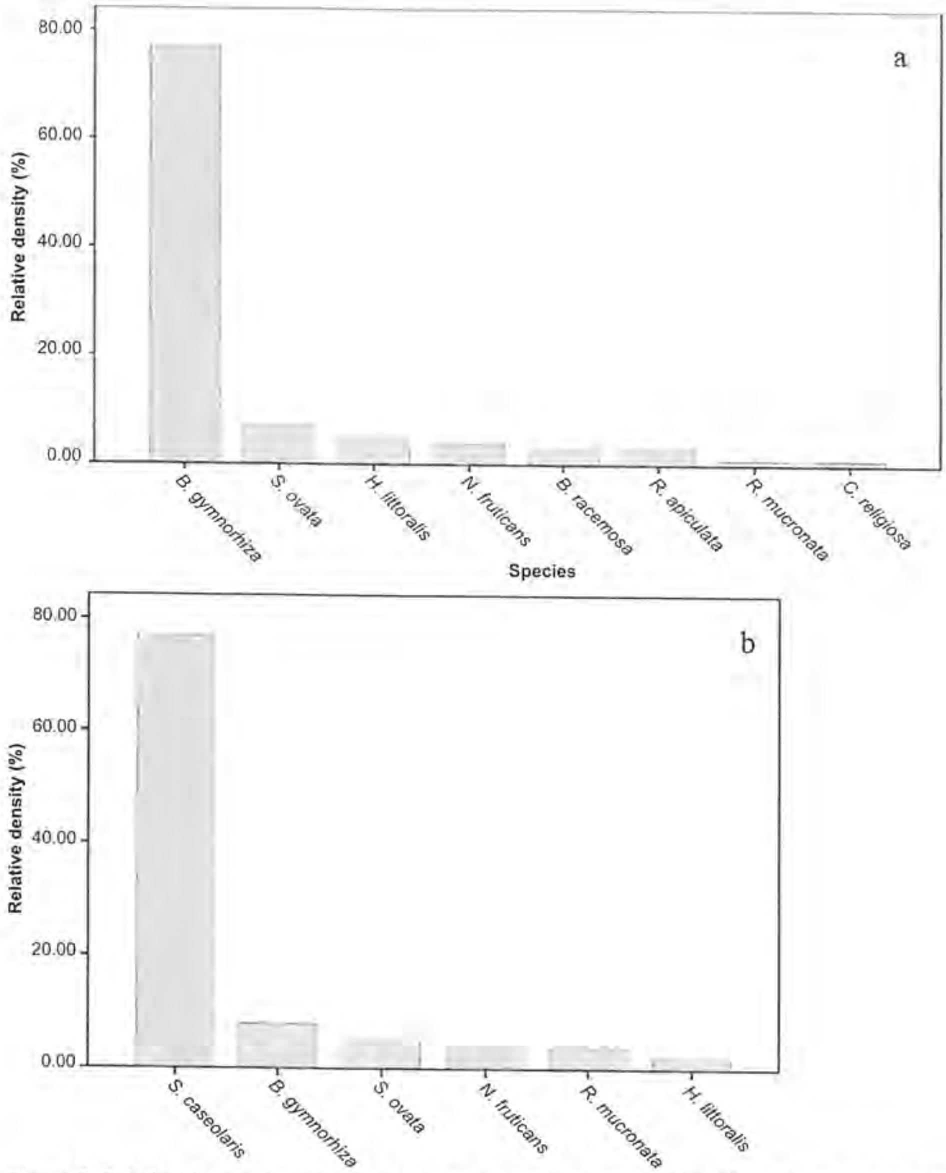

Figure 2. Relative density of mangrove species at Dhili Kadi (a) and Oh Hi Poh (b) on Katchall Island

(Banerjee et al. 1989; Dagar et al. 1991; Banerjee et al. 2002; Mandal & Naskar 2008; Yi-feng et al. 2011). Thus the present report is a new record for the flora of India. This species is distributed in East and Southeast Asian countries such as China, Malaysia, Singapore, Thailand, Indonesia, New Guinea and Vietnam (Haining et al. 2007) and categorized as Near-Threatened by IUCN due to severe habitat loss throughout its distributional range (Polidoro et al. 2010).

There are two probable reasons for the occurrence of *S.ovata* on Nicobar Islands. Dagar et al. (1991) has noticed an individual of *Sonneratia* spp. at Katchall Island without any reproductive parts and speculated its identity as *S. grifithii*. If it was a misidentification of *S. ovata*, then possibly this species must have existed very rarely prior to the tsunami, and later became common in the NFH of Katchall Island. Or, the seeds of *S. ovata* from the nearest sources viz. Indonesia, Malaysia and Singapore must have been carried by the tsunami and established a new population on Katchall Island.

Sonneratia spp. along with *Avicennia* are usually considered pioneers of mangrove swamps and seeds of *Sonneratia* spp. are intolerant to shade, germinating on bare or near bare mud banks (Duke & Jakes

1987). Hence, the scorching of littoral forests due to salt stress has resulted in the formation of open area and the heliophilic nature of *S. ovata* has eventually ameliorated the species to colonize the NFH. The occurrence of *S. ovata* in the NFH abutting the evergreen hill forests confirms the landward movement of mangroves when subjected to sea level rise, as proposed by Ellison (2005). Landward mangroves are vulnerable to sea-level rise, since there may not be any habitat to re-establish because mangrove edges are highly influenced by human developmental activities (Polidoro et al. 2010).

It is strongly recommended to include landward mangrove species such as *Sonneratia* spp. in the mangrove restoration programs as many of the current programs give emphasis mainly to seaward mangroves such as *Rhizophora* spp., and *Avicennia* spp. (Ellison 2000). Further research based on molecular tools can provide more information on the occurrence of *S.ovata* on Katchall Island.

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Mangrove forest regeneration in tsunami impacted sites of Nicobar Islands, India

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Abstract

Anthropogenic disturbances on the mangrove ecosystem are well documented and it has been reported that the mangrove forests are disappearing around the globe at an alarming rate of 1% per year. Natural disturbance like tsunami coupled with the man-made disturbances can drive the mangrove forests to an unrecoverable condition. The paper presents the post tsunami scenario of mangrove forest regeneration in the Nicobar Islands, India. In total, 25 locations over eight Islands were identified and surveyed for recording the re-colonization of mangrove species. The regeneration of mangrove species was quantified by laying plots of varying sizes ($100m^2$ to $5000m^2$) and saplings of $\geq 1.3m$ were enumerated. To find out the pre-tsunami status of mangrove species distribution, plots were established in the scorched mangrove habitats and the snags were enumerated. In total, 17 species of mangroves were recorded from the re-colonization sites of which five were recorded for the first time from these Islands. Thirty per cent of the mangrove species recorded prior to tsunami could not be found during the present survey. The abundance of various species in the tsunami impacted sites was much lesser than the pre-tsunami situation. Definite pattern has been observed in the re-colonization of mangrove species. *Rhizophora* spp. dominating the proximal zone, a combination of *Rhizophora* spp. and *Bruguiera gymnorrhiza* dominating the middle zone and, *B. gymnorrhiza*, *Lumnitzera* spp., *Sonneratia* spp. were dominating the back mangrove zone. We suggest a continuous monitoring programme for these sites which could provide a better perspective on the re-colonization pattern of mangrove species.

Keywords
tsunami, Nicobar Islands, regeneration, habitat loss

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communities. Both case studies utilize a new interdisciplinary modeling approach to conservation management, integrating high- and moderate-resolution remote sensing imagery, multi-temporal GIS data, biological inventories, local natural history, and expert narratives to produce a comprehensive view of human-natural system dynamics at multiple scales over time.

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NATURAL RECOVERY OF TSUNAMI AFFECTED LITTORAL FORESTS IN NICOBAR ISLANDS, INDIA

Indian Ocean tsunami (2004) has severely damaged the littoral habitats that are critical for the survival of many endemic flora and fauna of Nicobar Islands, India. We studied the recovery of littoral forest tree community after the tsunami to develop restoration strategies. The study was carried out in six Islands of the Central Nicobar group of Islands during 2010-2011, where tsunami had wiped-out all the vegetation. Two kinds of regenerating sites were identified namely 1) Sandy regenerating sites (SRS) where substrate was affected by enormous deposition of sand and coral rubbles 2) Sand loamy regenerating sites (SLRS) where the substrate was remained as sand-loamy but the vegetation was destroyed completely. Since 2010, we annually monitored tree vegetation (stems ≥ 10 cm GBH) from six plots (50 x 20 m) each in SRS and SLRS. Six control plots from unaffected forest (UF) were also studied during 2011. The mean number of species, individuals and basal area varied significantly between SRS, SLRS and UF ($p<0.01$). The tree diversity (19.67±9.07/plot) and basal area (73.17±22.42 m2/ha.) were high in UF and stem density (186.67±99.6/plot) was high in SLRS. Among the regeneration sites, mean number of species, individuals, basal area and species accumulation rate were very high in SLRS than SRS. It is inferred that, changes in substrate level can inhibit the colonization rate of plant species. Hence, we recommend that the restoration programs should concentrate on improving the soil condition that could promote the natural colonization of other pioneer and pristine forest species.

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ADAPTIVE GENETIC VARIABILITY IN THE MARBLED MURRELET: IMPLICATIONS FOR CONSERVATION

Maintaining adaptive genetic diversity is essential for conserving the ability of species to adapt to