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Recovery rate of vegetation in the tsunami impacted littoral forest of Nicobar Islands, India

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ABSTRACT

The interplay between disturbance and recovery has implications in understanding the dynamics of tropical forests. The high magnitude earthquake of 9.3 *Mw* and the subsequent tsunami in Indian Ocean had severe impacts on the coastal biodiversity of Southeast Asia. Close vicinity of the Nicobar Islands to the earthquake epicenter has been attributed to the maximum damage levels in terms of coastal biodiversity as well as human lives. Littoral forests that are important for the survival of many endemic flora and fauna of Nicobar Islands were badly affected. We studied the recovery of littoral forest tree community from 25 sites on eight islands in Nicobar group during 2009–2011 where the tsunami had wiped out all the vegetation. Changes in woody plants $\geqslant$ 3.2 cm Diameter at breast height (DBH) were monitored for 62 plots of 50 $\times$ 20 m (0.1 ha.) for two consecutive years, 2009–2010 and 2010–2011. Two kinds of regenerating vegetation were identified namely, Rubble-affected Vegetation (RV) where substrate was found deposited with sand and coral rubbles during tsunami and Loamy Vegetation (LV) where the substrate remained as sand-loamy without any deposition. A total of 5528 tree individuals of 120 species and a total of 5843 tree individuals of 127 species were recorded during the first and the second year, respectively. Species diversity was high in the second year for both the vegetation types, where LV with 120 species had higher species diversity than RV (43 species). The species composition differed among vegetation types. *Macaranga peltata* and *Ficus hispida* were dominant in LV, and *Casuarina equisetifolia* and *Hibiscus tiliaceus* were dominant in RV. Mean species richness, stem density and basal area plot^{-1} varied significantly between RV and LV ($P < 0.0001$). LV showed higher values for variables than RV. The values for all the variables increased during the second year, except for stem density in LV and show significant differences between the years for RV and LV ($P < 0.01$). Species richness plot^{-1} in LV may reach the mature forest value in two years if the species accumulation proceeds at the observed rate. We inferred that the natural recovery of vegetation was higher in the soil substratum unaffected LV than the debris deposited RV. Hence, the restoration of soil at RV sites is important for promoting the natural colonization of pioneer and old-growth forest species. Continuous monitoring of these plots may provide useful information on the long lasting impacts and recovery of littoral forest after tsunami.

1. Introduction

The high species diversity and system complexity make tropical forests one of the most resilient ecosystems in the world (Condit et al., 2002; Chazdon, 2003; Mittermeier et al., 2004; Loreau and Mazancourt, 2013). Anthropogenic influences coupled with natural disturbances have degraded tropical forests worldwide. Hence, most of tropical forests today are actually in various stages of succession (Whitmore and Burslem, 1998; Chazdon, 2003). Natural disturbances such as hurricanes, fires, landslides, floods and tsunamis can cause long lasting impacts on the vegetation (Vandermeer et al., 2000; Chazdon, 2003; Peña-claros, 2003; Imbert and Portecop, 2008; Hayasaka et al., 2009). Recovery of vegetation after such natural disasters is influenced by various ecological and environmental factors. Distance from remnant vegetation, presence/absence of seed dispersal agents, soil seed bank, soil nutrients, rainfall, temperature, light intensity and frequency of disturbance are some of the factors that can affect rates of vegetation recovery (Ding et al., 2012). Understanding the direct and indirect effects of these factors on the dynamics of disturbed forests is essential for the restoration and conservation of tropical forests (Chazdon, 2008; Ding et al., 2012).

Recent studies have provided different perspectives on the recovery of tropical forest (Peña-Claros, 2003; Kalacska et al., 2004; Imbert and Portecop 2008; Letcher and Chazdon, 2009;

Abbreviations: RV, Rubble-affected Vegetation; LV, Loamy Vegetation; MSR, mean species richness; MSD, mean stem density; MBA, mean basal area.

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Ding et al., 2012). Forest structural characteristics such as basal area, above-ground biomass, tree height, stem density and species richness often show rapid change in relatively small span of time and have been used to measure the rate of recovery and ecosystem function after a disturbance (Chazdon, 2003). According to Guariguata and Ostertag (2001), species composition recovery takes longer than the recovery of species richness, basal area and aboveground biomass. Although the natural recovery of tropical forests has been studied in many parts of the world (Hawthorne, 1990; Vandermeer et al., 2000; Ghazoul and McLeish, 2001; Molino and Sabatier, 2001; Lévesque et al., 2011), the majority of them were based on chronosequences rather than long-term monitoring (Kennard, 2002; Kalacska et al., 2004; Pascarella et al., 2004; Chazdon et al., 2007; Colon and Lugo, 2006). Information based on long-term monitoring of vegetation following a major natural disturbance might aid in the comprehensive understanding of the succession and dynamics in tropical forests.

The Indian Ocean earthquake of 26th December 2004 with 9.3 *Mv* and the subsequent tsunami had adverse impacts on the coastal biodiversity of Asian countries such as India, Sri Lanka, Thailand, Malaysia and Indonesia (Dahdouh-Guebas et al., 2005; IUCN, 2005; Alongi, 2008). The Nicobar Islands of India, which were situated only 100 km from the epicenter of the earthquake, suffered major losses in terms of human lives and biodiversity. The subduction of Indian plate under the Burma plate during the earthquake resulted in a tilt in the land with the southernmost Nicobar Islands sinking about 1.75 m and the northernmost Andaman Islands having rising about 1.2 m (Sankaran, 2005; Thakkar and Goyal, 2006). At some places in the Nicobars, tsunami waves reached more than a kilometer inland and destroyed all vegetation between the coast and the hill (Sankaran, 2005). The littoral forests that are situated immediately inland from the coast were the prime victim of tsunami. The littoral forest decreased from 22 km^2 to 10 km^2 due to the earthquake and tsunami, with 50% of the land area submerged below sea level. Porwal et al. (2012) estimate that only 10% of the littoral forest was unaffected by tsunami.

Tropical forest dynamics have been studied from permanent plots established at various parts of the world (Phillips et al., 1994; Bakker et al., 1996; Sheil et al., 2000; Vandermeer et al., 2000; Ding et al., 2012). However, studies on plant succession after major natural disturbances on vegetation are rare (Tagawa et al., 1985; Vandermeer et al., 2000; Sherman et al., 2001; Chazdon et al., 2007; Hayasaka et al., 2009; Hayasaka et al., 2012a, 2012b). In particular, information on the impacts and natural recovery of coastal vegetation after tsunamis is scarce (Hayasaka et al., 2009, 2012a, 2012b). 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 vegetation of tsunami impacted sites.

2. Material and methods

2.1. Study area

The Nicobar Islands in the Bay of Bengal are peaks of a submerged mountain range stretching from the Andaman Islands in the north to Sumatra in the south between latitudes 6°45′ and 9°15′ and longitudes 92°42′ and 93°50′. This island group comprises 22 islands (12 inhabited) with an area of 1841 km^2 (Fig. 1). The biological importance of Nicobar Islands has been recognized by four Wildlife Sanctuaries, two National Parks and one Biosphere Reserve within its boundaries. The Nicobar islands are also a part of the Sundaland Global hotspot of Biodiversity (Mittermeier et al., 2004).

The Nicobar Island's proximity to the equator and the ocean ensures a hot, humid, uniform climate (Saldanha, 1989). The islands receive rainfall from both the southwest and northeast monsoons. Maximum precipitation is between May and December and the driest period is between January and April. Mean annual rainfall is about 3800 mm (Saldanha, 1989). Temperature ranges from 20 °C to about 32 °C (Dagar et al., 1991).

In Nicobar (Fig. 1) there are three different groups of Islands viz. Car Nicobar group in the north comprising two islands, Nancowry group in the center comprising 10 islands, and Great Nicobar group in the south also comprising 10 island. Great Nicobar was the closest to the earthquake epicenter and Car Nicobar was the farthest (Porwal et al., 2012). Topographically, the islands are composed of flat, undulating and hilly areas. The highest point is Mount Thullier, Great Nicobar with an altitude of 670 m. The Islands are inhabited by mainland Indian settlers and two indigenous tribes, the Nicobarese and Shomphens. The Nicobarese are a mostly coastal dwelling community found in all the 12 inhabited islands, and Shomphens are a forest dwelling community found only in the interior forest of Great Nicobar Island. Major vegetation types in the Nicobar Islands include littoral forest, mangrove forest, evergreen hill forest, low land swamp forest and grass lands. Other than the natural vegetation, coconut plantations are common throughout the Islands, and rubber plantations are predominant in Katchall Island. The floristic diversity of the Nicobar group of Islands has close similarities with the neighboring phytogeographical Malaysian and Indonesian taxa (Sinha, 1999).

2.2. Data collection

Vegetation monitoring plots of 0.1 ha (50 × 20 m) were established in the tsunami impacted littoral forest sites of the Nicobar Islands where entire vegetation was wiped out by tsunami. Data were collected for two consecutive years during 2009–2010 and 2010–2011 from 62 plots distributed over 25 sites on eight Islands (Fig. 1). Based on the soil substratum, the secondary vegetation that formed after the tsunami was categorized into two classes: (i) Rubble-affected Vegetation and (ii) Loamy Vegetation. In Rubble-affected Vegetation (RV) the pre-tsunami soil was buried under enormous amount of sand and coral rubbles that were brought to the coast by the tsunami waves (Fig. 2a). In Loamy Vegetation (LV) the soil was devoid of any such deposits but the entire vegetation was scorched due to the sudden increase in soil salinity caused by the stagnant tsunami waters (Fig. 2b). The number of plots varied between RV ($n = 29$) and LV ($n = 33$). Each plot was divided into five 10 × 20 m grids for the convenient enumeration of tree individuals. All the tree individuals of ⩾3.2 cm (10 cm circumference) Diameter at breast height (DBH) found inside the plots were marked during enumeration to avoid recounting. Specimens were collected for the 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 identification. Voucher specimens are deposited in the herbarium at Salim Ali Centre for Ornithology and Natural History herbarium (SACON), Coimbatore.

2.3. Data analysis

Stem density (individuals/0.1 ha.), species richness (species/0.1 ha.) and basal area (m^2/ha.) were calculated for each of the two vegetation types, RV and LV. For multi-stemmed trees, basal area for each stem was calculated separately and summed. Importance Value Indices (IVI) were calculated for all the species following Magurran (2004). Diversity indices such as the Shannon