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Disturbance and recovery of mangrove forests and macrobenthic communities in Andaman Sea, Thailand following the Indian Ocean Tsunami

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Abstract. On December 26, 2004, the impact of tsunami waves caused by an undersea earthquake off Sumatra Island generated severe damage to coastal communities throughout the Indian Ocean. One year before the Indian Ocean Tsunami (IOT), we established permanent survey plots in characteristic mangrove forests on the coast of Ranong, Thailand. Since then, we have continued to survey mangrove stands and macrobenthic communities. Damage caused by the IOT included immediate damage and gradual indirect mortality, but the damage to mangrove ecosystem was limited and habitat specific with 6% to 16 % of mangrove stands showing damage one year after the tsunami. Although population density and biomass of macrobenthic organisms were not affected by the tsunami, diversity decreased in some areas. The community structure of macrobenthic organisms in mangrove swamps was affected: endobenthic organisms decreased due to an increase in the abundance of coastal sand in the sediments; epibenthic organisms initially decreased but recovered gradually; and terrestrial epibenthic organisms increased on dried sandy substratum.

Key words: natural disaster, Thailand, tsunami, macrobenthos, Andaman Sea, mangrove forests

Introduction

Mangroves play important roles in coastal ecosystems of the tropics and sub-tropics producing of a lot of litter which provides food and energy to the aquatic flora and fauna. Mangroves also provide fundamental ecological services to local inhabitants (Aksornkoae 1993; Hogarth 1999; Barbier and Sathirathai 2004). Many studies have been done on mangrove distribution and productivity, both in forest stands and aquatic systems, however, there is insufficient knowledge on the disturbance of mangrove ecosystems by large natural disasters such as the tsunami which is different from usual ocean waves and on the process of recovery from such catastrophic damage.

On December 26th, 2004, the impact of tsunami waves caused by an undersea earthquake off Sumatra Island generated severe damage to artificial constructions and some natural ecosystems on coastal area along the Andaman Sea (MNRE 2005; UNEP 2005; Stoddart 2007). Mangrove stands suffered unprecedented damage by both direct impact from the waves and floating material and also more gradual indirect symptoms caused by root damage due to piles of thick sand brought by the tsunami (Matsumoto et al. 2006). The tsunami also disturbed fish and benthic communities which play a very important role in mangrove ecosystems.

One year before the tsunami disaster, we established permanent survey plots in some characteristic mangrove forests on the coast of Ranong area facing the Andaman Sea, Thailand. Since then, we monitored regularly the dynamics of mangrove forests and macrobenthic communities which utilize them as habitat and potential food sources. These areas suffered severe damage from the tsunami on human lives, infrastructure and mangrove ecosystems, and therefore, we could obtain comparable data to show disturbance patterns and to evaluate the recovery process in mangrove ecosystems. In this study, we demonstrate the initial process of recovery from damage over a few years on mangrove forests and macrobenthic communities.

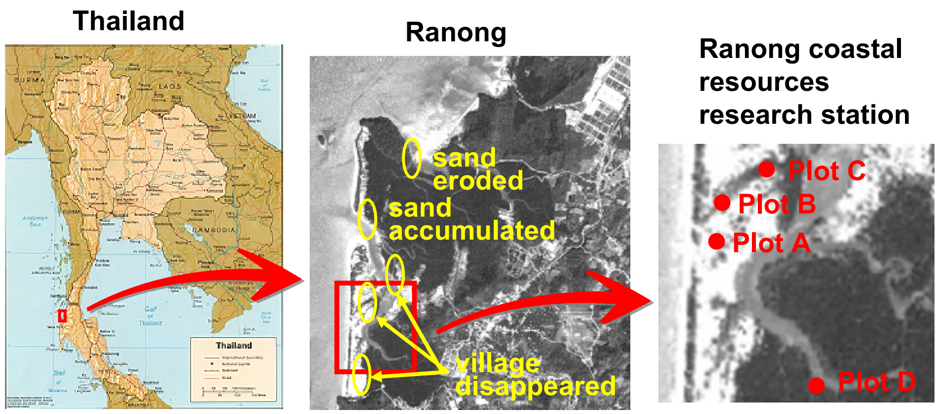

Figure 1: Map of Ranong, southern Thailand, showing the study sites in Ranong coastal resources research station, Kasetsart University

Material and Methods

Four study plots (Plots A-D) of mangrove forests were established in the vicinity of Ranong coastal resources research station (RCRRS) (9°23'N 98°24'E), Kasetsart University, situated on the Andaman coast of Suksamran sub-district, Ranong province, southern Thailand (Fig. 1). Plot A was *Avicennia alba* Blume forest located at the interior tidal inlet branched from main river. Plot B was a complex forest of *A. alba* and *Rhizophora mucronata* Lamarck located at the mouth of a tidal inlet branching off the main river. Plot C was *R. mucronata* forest on the bank of the main river. Plot D was also *R. mucronata* forest in an interior mangrove estuary outside the station. These mangrove stands were harvested and regenerated about 15-20 years previous to the begin of our study in 2003.

All mangrove trees within 500-1,000 m^2 areas were continuously monitored in every plot before and after the tsunami. Diameters above the neck of the highest root were measured. Damage to mangrove stands was estimated from loss of trees by comparing data before and the after the tsunami.

Soil and sediment at each study site was collected from the surface to a depth of 20 cm using an acrylic core with a 44 mm diameter, and grain size composition was analyzed by a series of phi-scaled mesh sieves. Taxonomic composition, density and biomass of epibenthic organisms were investigated quantitatively using a 50 cm x 50 cm quadrat set at random on the ground. Five replicate samples of sediments were collected from the surface to the depth of 10 cm at every site. The collected soils were sieved using a 500 µm mesh sieve and preserved with 10% neutralized formalin. Macrobenthic specimens were identified to the lowest taxonomic category possible. The total weight of each species was measured using an electric balance after being picked out from the residue under a dissecting stereo microscope. The survey was conducted before the tsunami on September 26, 2003 and after the tsunami on March 15, 2005 and November 23, 2006.

Population density and biomass were calculated as the number of individuals (n/m^2) and the wet weight (g/m^2) per square meter, respectively, for every species/taxa. Species richness and diversity index

Figure 2: Serious tsunami damages in the survey areas just after the tsunami (March 2005).

1. *Rhizophora* forest was destroyed by 10 m width along river (near Plot C).
2. *Rhizophora* - *Xylocarpus* stands were mown down and buried by sea sand more than 1 m thick (river mouth).
3. Concrete boardwalk for mangrove observation on *Avicennia* forest was broken by direct wave impact (Plot A)
4. Sands were carried by waves from the beach onto the floor of *Rhizophora* forest (Plot B).

were calculated for every plot. Species diversity was calculated using the Shannon-Weaver Index $H' = -\Sigma(n/N)\log(n/N)$, using logarithmic base 2, where ‘n’ is the number of individuals for each species/taxa, and ‘N’ is the total number of individuals.

Results and Discussion

The tsunami damaged many human lives and much property in coastal areas as well as natural ecosystems (MNRE 2005; UNEP 2005; Stoddart 2007). Examples of tsunami damages in the survey areas are presented in Fig. 2. The damage by the tsunami was caused by immediate direct impacts of floating materials as well as extremely strong wave action and backwash. Some mangrove forests suffered decline/death after being buried by sand.

In Plots A, B and C, 6.5-16.1% of mangrove stands were damaged (Fig. 3). Smaller trees suffered more damage than the larger ones, especially in Plot A (Fig. 3).

It was assumed that the damage to mangrove stands in the survey areas was due to direct and indirect causes. Gradual indirect lethal symptoms seemed to be caused by: 1) root damage due to strong shaking or disturbance of root respiration by accumulated sand carried by the tsunami; and 2) damage by sea water abnormally accumulated in the forests and the surrounding soil (Matsumoto et al. 2006).

Composition of sediment grain size of four survey plots and the neighboring beach were compared (Fig. 4). Mean particle size of sediment was the largest and well sorted in Plot C, followed in Plots A and B, and the smallest in Plot D. A considerable amount of accumulated sand (mainly 125 - 250 µm) of which the tsunami brought from the sub-tidal parts of the neighboring coast were included in the sediments of Plots A, B and C.

When we surveyed three months after the tsunami in March 2005, we found that approximately 5-10 cm of sand had accumulated on the substratum in Plots A, B and C. (observations in March 2005; Fig. 2.4). Sediment conditions recovered gradually in the two years after the tsunami. Situated in a tidal inlet the bottom substrate was exchanged frequently by routine tidal flow and by bioturbation by benthic organisms such as crabs, *Uca* spp., horn snails, *Cerithidea cingulata*, and some polychaetes.

Mollusca (36 taxa) constituteed the most dominant and diverse taxa, followed by Arthropoda (21 taxa) and Annelida (9 taxa). Dominant in the survey areas were: *Nerita violacea*, *Cerithium coralium*, *Cerithidea cingulata*, *C. quadrata*, *C. obtusa*, *Telescopium telescopium*, *Littoraria pallescens*, *L. strigata*, *Assiminea brevicula*, *Stenothyra ovalis*, *Cassidula nucleus*, *Ellobium aurisjudae* (gastropods), *Saccostrea forskali*, *Gelonia erosa* (bivalves), *Perinereis* spp. and Capitellidae (polychaetes), *Parasesarma pictum*, *Episesarma* spp., *Uca annulipes*, *U. vocans*, *Thalassina anomala* (crustaceans) and some insects.

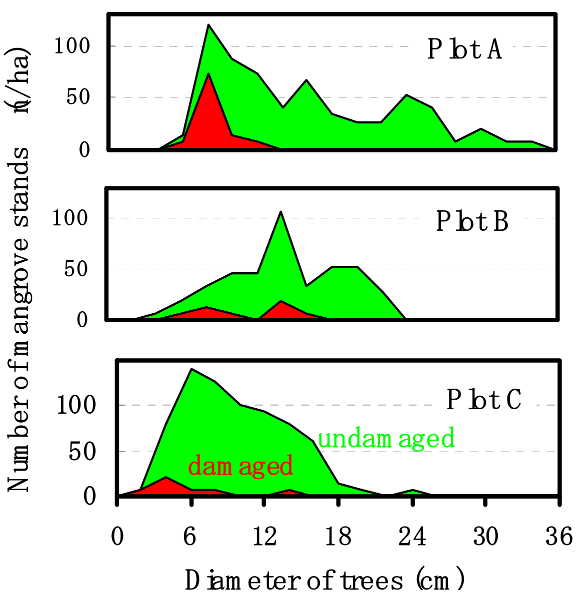

Figure 3: Damage to mangrove stands seen one year after the tsunami (until November 2005). Red: Damaged tree, Green: Undamaged tree.

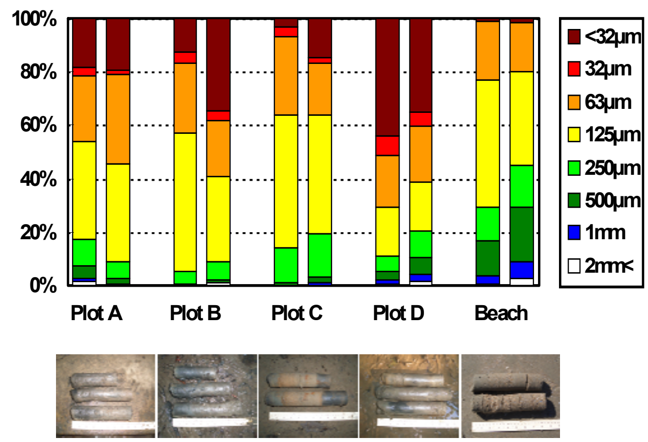

Figure 4: Composition of sediment grain size two years after the tsunami (November 2006) on four survey plots and the neighboring beach. Left bar: 0-10 cm deep, right bar: 10-20 cm deep. Photos below every plot represent the core samples in which left side of every photo is the surface layer of the substratum.

When we surveyed three months after the tsunami in March 2005, we found that almost all macrobenthic organisms, except for a few epibenthic gastropods inhabiting stem and root of mangrove trees, were buried in sand transported from nearby shallow ocean waters or the neighboring beach (Fig. 2.4). Population density (number of individuals), biomass (wet weight), and diversity (number of species/taxa and diversity indices) of macrobenthic organisms were compared before and two years after the tsunami (Fig. 5). The population density and the biomass measures were very high in Plot A in which the maximum density and biomass of horn snails, *Cerithidea cingulata*, exceeded 1,000 individuals/m^2 and 200 g/m^2, respectively, including many juveniles. In Plot D, the population density was the highest but the biomass was not large because a large number of small polychaetes and nematodes were included. Number of species/taxa decreased significantly after the tsunami in Plots B and C (t-test: $t = 3.89$ $p < 0.05$, $t = 14.6$ $p < 0.01$, respectively). In Plot B, the total number of species/taxa decreased 77% and the diversity index based on the number decreased 86% after the tsunami.

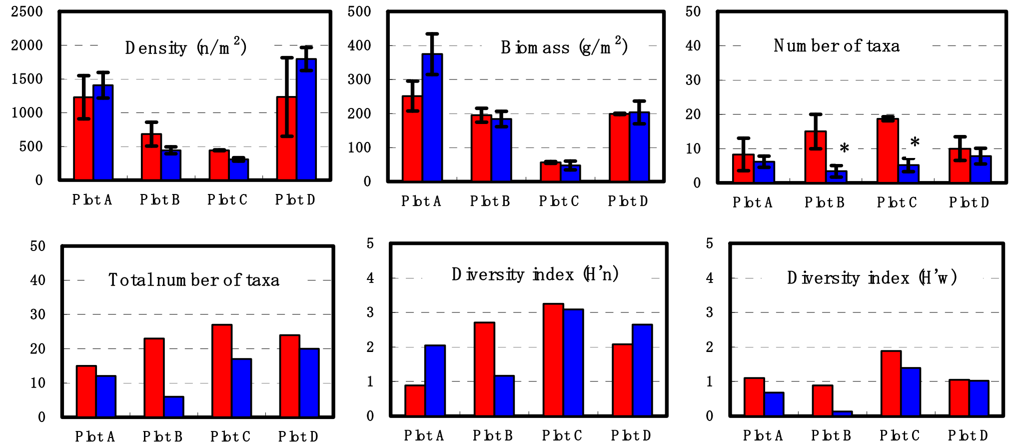

Figure 5: Community structure of macrobenthic organisms in four mangrove plots.
Red bar: before the tsunami, blue bar: after the tsunami. *mark: significant difference p<0.05.

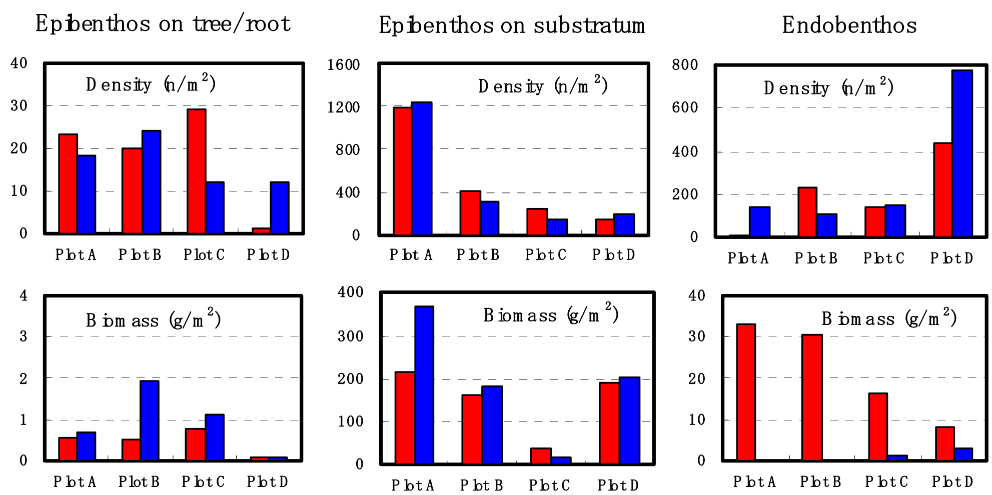

Figure 6: Population density and biomass of benthic organisms based on differences in habitat preference. Red bar: before the tsunami, blue bar: after the tsunami.

Population density and biomass of the following macrobenthic organisms were compared before and two years after the tsunami (Fig. 6): epibenthic organisms inhabiting stem and root of mangrove trees; epibenthic organisms inhabiting the forest floor; and endobenthic organisms living in the substratum. Although there was no distinct difference in the density and the biomass of epibenthic organisms before and after the tsunami, the taxonomic composition changed substantially. Epibenthic organisms such as gastropods and crustaceans decreased initially (observations in March 2005) but recovered gradually. Terrestrial epibenthic organisms increased on dried sandy substratum due to immigration from neighboring forests and beaches by insects such as ants and chironomids. Biomass of endobenthic organisms decreased drastically because bivalves such as *Gelonia erosa* and polychaetes died due to the increased sedimentation by coastal sand on the floor of the mangrove forests.

The tsunami damaged many human lives and much property in coastal areas as well as natural ecosystems (MNRE 2005; UNEP 2005; Stoddart 2007), mainly in fishing villages and beach resorts facing the Andaman Sea (Matsumoto et al. 2006). These areas were characterized by shallow sub-tidal beaches and/or closed-off section of bays and low, flat land. Around our survey plots, the tsunami waves reached approximately 6 m in maximum height above ground (information from RCRRS staffs) leading to damage of mangrove ecosystems. Damage to mangrove forests and macrobenthic communities was limited and habitat specific. Although benthic organisms decreased temporarily just after the tsunami (Plots A and B), the community recovered quickly.In highly disturbed areas (Plot C) where thick sand accumulated on the bottom of the mangrove forest, recovery appears to be difficult due to altered sediment composition and depth.

Tsunami-related damage to the mangrove ecosystem was not only direct physical damage, but also subsequent decline/death/change due to salt stress, drying stress, etc., as has been discussed in some reports (MNRE 2005; UNEP 2005; Matsumoto *et al* 2006; Stoddart 2007). It is important to continue monitoring to evaluate the recovery process of mangrove forests and macrobenthic communities from the catastrophic damage.

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