Recovery status of mangroves along western coast of Aceh until 7 years after the 2004 Tsunami

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Abstract. The recovery status of mangroves at west coast of Aceh until 7 years post the Indian Ocean tsunami (IOT) was examined. The field researches were conducted during January 2005 to December 2011 in more than 20 km (1) to record flora species that were resistant to the paroxysm of tsunami swells, and (2) to record and observe the appearance of several existing and new plant species caused by tsunami. The main result shows that (1) mangrove beaches may not recover at all to their original state because the topography has changed greatly and the hydrological and sediment condition differ from their previous conditions, (2) most of mangrove trees dead due to change in habitat environments, (3) some mangrove species in land subsidence coasts were found migrating landward through seed recruitment, naturally, (4) several species of mangroves appear to flourish in the natural stands with mother trees survived against tsunami, (5) new species, for example, Typha angustifolia greatly colonize along the intertidal areas, and (6) Acrostichum aureum (mangrove fern) population occupies an bare lands left by mangrove vegetation communities or abandoned brackish pond. Because mangroves provide bio-shields or natural belts, more lives can possibly be survived during the natural hazard, including tsunami. Unluckily, due to high market of brackish pond products, severe damage to mangroves was not managed. Therefore, degraded mangroves must be restored and preserved very well in the future.

1. Introduction
Aceh in northern Sumatra, Indonesia is most affected area due to earthquake and tsunami on 26th December 2004 (Figure 1). An earthquake measuring is about 9.3 in magnitudes happened along the Subduction Region of Sunda up to 150 km of the Northern Sumatra of Indonesia [1–4]. The premier energy generated by the earthquake was approximated to be around 25 Hiroshima bombs [5]. This large earthquake triggered mega tsunami, which is a combination of the destructive effects of an earthquake and a very large tsunami on the coastline and its inhabitants lining the Indian Ocean.

The natural disaster has caused considerable damage to human and the seashore environment, containing the forfeit of many human lives, damage to ecosystems and coastal communities, and the destruction of infrastructure and facilities. In Aceh alone, a total of 476,808 people were displaced, 120,663 killed, 116,126 lost and 714,517 affected [6]. The natural event caused severely damaged of brackish ponds, estuarine fisheries, agriculture and tourism sectors as well as threatened the food supplies and livelihoods. The total damage is estimated up to US $ 4,450 million (more than 96% of GDP of Aceh) and economy in the affected area is estimated to reduce by around 14%, including US $
1,000 million in lost productivity [7]. Nearly 900 km$^2$ of Aceh’s coastal plain was largely destroyed and flooded [8].

The tsunami run up heights varied which the West Coast was impacted by the highest wave height, occasionally more than 30 m until 51 m, the North Coast with a height circa 10 m [9-14], but the plain lowland allowed those tsunamis to pierce far inland, and the East Coast by heights of about 5 m [13].

The most destroy on coastland was surrounding Aceh that nasty and extensive affected areas found in north and west coast of Aceh. According to Liew et al. [15], the tsunami eliminated the all set of sedimentary beached forms of seashores, wetlands and small sand dunes, and eroded the coast back by around 0.5 km. Another finding [2] measured that nearly 90% of mangroves of Aceh were damage by the tsunami. These different swell heights that could have implications on the impacts and recovery of multiform coastal types [13] in Aceh coast after the giant earthquake and tsunami. This paper examined the impact and recovery of mangroves at west coast of Aceh from the giant tsunami on 26 December 2004 on the various coastal types.

2. Study Site and Method

This research sites focused on the western tips of Aceh coast about 20 km. This area stretches north to Lhok Nga and south to Ujung Pulot about 20 km (Figure 1). Aceh beach has various geomorphological setting [16]. Subsequently, wave properties very varied on the Aceh beach which is affected by semi-diurnal tides with a tidal gyration of rather more than 100 cm [17].

Figure 1. Study area that shows main beach types on the west coast of Aceh before the tsunami. Source: Wong [13]

The west beach of Aceh is very relieved and be composed large Paleozoic limestone on the headland and alluvium in estuaries and bays [16]. The west coast landform is controlled by waves; marked by the position of a coast ridge on the shoreline of hills and sea verandas. Desolated tidal bogs generally form on the back of a coast at a river mouth (Figure 2) [18] or behind a beach on a river bank. The west beach is highly open because it is facing to the waves of the Indian Ocean with swell heights of 1-2 m and moreover than the prominent southwest [17]. Prior to the tsunami, mangrove forests on the west coast were restricted and scattered in limited areas on the banks of rivers and cramped to estuaries and back of barriers forming dunes that were overgrown by coastal vegetation communities (such as coconut, fir beach (*Casuarina*) and other woody plants and bushes) or bare land.
The seven field researches were conducted during January to February 2005, September 2005 and every December of 2006, 2007, 2009, 2010 and 2011 to (1) record plant species that are resistant to tsunami wave up to 50-meter high, and (2) record and observe the emersion of various being flora species nor new flora species induced by tsunami.

Due to lack accessibility, not all locations were covered in 2005, 2006 and 2007 surveys, but field survey could determine how the tsunami affected and the mangroves recovered. This study extends the locations and duration of other filed surveys not covered in the previous survey to get a better idea of mangrove forest restoration. To know the mangrove condition before tsunami, the Google earth image is used. Some surviving people was interviewed of some of surviving as soon as possible is to know the mangrove plant species and utilization before tsunami.

3. Result and Discussion

Before tsunami, mangrove forests were restricted and limited to deltas and or river mouth and back of the fences in Aceh’s west coast. In the Ujung Pulot coast, mangroves were converted to tambak (brackish pond). The sand dune width as barrier of tambak from the sea is measured less than 25 m (Figure 3). Mangroves were distributed in a narrow area on riverbanks behind the barriers with covered by littoral trees (Figure 4) or without vegetation (Figure 5) and behind the beaches were converted to urban garden and settlement area (Figure 6).

All fragmented and small mangroves in the areas were destroyed (Figure 7 and 8) by giant tsunami with swell height, occasionally outstripping 30 m to a peak of 51 m [9-14]. The images also show that tsunami eliminated almost the entire set of sedimentary beach forms, wetlands and low sand dunes, and eroded the beach.

The surviving of local people in western coast of Aceh stated that before tsunami; the mangroves trees were cut for firewood and cleared-cut for conversion to tambak (brackish pond). Various mangrove tree species, such as Avicennia, Rhizophora, Sonneratia, and mangrove Nypa fruticans palm were usual growing in the intertidal areas.
Figure 3. Tidal area with mangroves were converted to tambaks in Ujung Pulot before the tsunami

Figure 4. Mangroves were distributed in limited area in riverbanks and behind the beaches in Leupung before the tsunami

Figure 5. Mangroves with narrow width on riverbanks (less than 10 m width) in Namplan, Leupung before tsunami
The western coast of Aceh experienced the maximum devastation because it was dealing directly with the tsunami wave direction and was not shielded by imminent islands. The Leupung and Lhok Nga edge reefs could not stop giant tsunami swells [13] (Figure 7). The others studies noted advanced subsidence and erosion with a beach backtrack until 60-100 m hinterland in Lhok Nga and broad sand layers reaching 5 km hinterland [19] (Figure 8). The erosion impacts counted beach retreat, vertical erosion, cliffs and rivers erosion, and large rock sediments [20]. At one location, continuous reached 50 m hinterland from the seacoast [21].

The mangrove recovery status is varied up to 7 years post the tsunami. True mangrove trees are not found in Ujung Pulot which mangroves were changed to brackish pond prior to tsunami. The areas are also buried by tsunami deposit, mainly died coral reef (Figure 9). The associate mangrove plants, such as Acrostichum aureum (fern), and Plucea indica (shrub) are colonizing the unmanaged tambak in the area.
Figure 8. The condition of west coast of Aceh in Lhok Nga at January 2005. Several big trees of Casuarina survived against the giant tsunami.

Figure 9. Unmanaged tambaks are colonizing by *A. aureum* and *P. indica* (above); the largest boulder with fresh (milky) marks that show it was legibly force out and proceed to the tidal area by the tsunami swells (below; left), and seed of *Nypa fruticans* is dying on the died coral reef (below; right) in Ujung Pulot, Dec 26, 2009.
The trees of *Sonneratia caseolaris* as true mangroves are dominated the riverbanks in Leupung which are growing well, reached about 16 cm in DBH at 7 years after tsunami (Figure 10). Others plants were found in the area, i.e. *Nypa fruticans* (palm), *Acanthus ilicifolius* (shrub) and *Acrostichum aureum* (fern). All mangrove plants in the area are natural regeneration. This situation showed that the mangrove seeds survived and can grow very well after the tsunami disaster.

The new species, named *Typha angustifolia* is dominated the tidal area on Namplan riverbanks, especially the flood-deep is less than 30 cm. Mangrove trees are not found in Namplan riverbanks until 7 years after the 2004 tsunami (Figure 11).

According to Gilman et al. [22], if sea level rises relative to the surface height of mangrove deposits, the sea boundary and the edge of the mangrove retreat towards the land because mangrove species maintain their preferred hydro period. Subsequently, mangroves can extend laterally to areas with higher elevations. Environmental requirements for the recruitment and formation of mangrove plant species in new areas ready with relative sea level rise including hydrology and appropriate deposit compositions, rivalry with non-mangrove species and presence of seaborne seedlings [23].

The seaward mangroves migrate ashore from dieback of mangrove tree due to pressures induced by sea level rises, for example, abrasion which results in the weakening of the root structure and tree fall, increased salinity, and too high frequency, duration, and inundation depth [24-26]. Mangroves migrate ashore through recruitment of seeds and vegetative reproduction when new habitats become ready on land through inundation, erosion and salinity changes that occurs together [27]. In this study, mangrove tree species, such as *Sonneratia caseolaris* and *Rhizophora apiculata* and mangrove palm *Nypa fruticans* were found to migrate ashore through recruitment of seeds, naturally.

![Figure 10](image)

**Figure 10.** The natural recovery of mangroves in riverbanks of Leupung until 5 years (a) and 7 years (b) after the 2004 tsunami
Figure 11. The recovery of tidal area in Namplan riverbanks at December 2009 (above; left) and December 2011 (above right) and coastal setting based on Google map on March 2, 2011. The white circle mark in the map indicates the wreckage of bridge which collapse due to tsunami wave.

4. Conclusion and Recommendation
An important factor in structuring ecological communities is disturbance, that provides its affect via changes in trajectory of the succession process and physical environment [28]. Disruptions could caused substantial changes in vegetation communities that depend on the nature, extent, intensity, seasonality, frequency, and the resilience attributes of the constituent species [29, 30]. Ecological and biological changes are frequently the output of community or population features such as tolerance to physicochemical factors, the capability to contend for restricting resources, and functional processes. All of these changes happen in an environment of natural disruption to the ecological balance or equilibrium [31]. Therefore, mangroves should be restored and preserved in the future very well.

5. References
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